AEROSPACE REPORT NO
ATR-78(7674)-1, VOL II

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(NASA-CR-157301) PRELIMINARY DEFINITION AND EVALUATION OF ADVANCED SPACE CONCEPTS. VOLUME 2: ANALYSES AND RESULTS (Aerospace Corp., El Segundo, Calif.) 409 p HC A18/MF A01 CSCL 22A G3/12
N78-28107
Unclas
15272

Preliminary Definition and Evaluation of Advanced Space Concepts

Volume II: Analyses and Results

Prepared by

I. Bekey
Advanced Orbital Systems Division

30 June 1978

Prepared for
OFFICE OF SPACE TRANSPORTATION SYSTEMS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington,D.C.

Contract No. NASW3030

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Volume II: Analyses and Results

Prepared

I. Bekey, Director
Advanced Space System Studies

Approved

Samuel M. Tennant
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Advanced Orbital Systems Division

FOREWORD

This report documents the results of a study performed under NASA Contract NASW-3030 during FY77-78 by The Aerospace Corporation. Mr. Ivan Bekey was the Study Director and Principal Investigator. The study was performed under the technical direction of Mr. Donald Saxton, Advanced Programs, NASA Marshall Space Flight Center. Mr. J. vonPuttkamer, NASA Headquarters, Office of Space Transportation Systems, was the overall Program Manager.

The report is issued in two volumes. Volume I contains the Executive Summary. Volume II contains the full analyses and results of the study as well as appendixes and ancillary data.

A number of inputs were obtained during the study from people in various agencies and institutions, and some members of industry. Even though an attempt was made to reflect those inputs, the assumptions, numbers, views, and conclusions of the study are solely those of the Study Director.

The characteristics, performance, and cost numbers derived in this study represent a "first cut," and were generated without any attempt at optimization. They should be viewed as very preliminary, and will undoubtedly change with further analysis.

ACKNOWLEDGEMENTS

This report is the product of many minds. Their contributions are hereby gratefully acknowledged.

Satellite/Transponder Analysis and System Analysis — S. Lewinter

Wrist Radio Set Analysis — R. J. Meyer

Onboard Switch Analysis and Design — D Theiss, L. Katzin

Antenna Analysis and Design — C. Coulbourn, J. Murphy, L. Cantafio

Satellite Design — D. Cooley, G. Yee, and F. K. Hawkins

Intermodulation Analysis — D. Martin

Propulsion Analysis and Definition — J. Russi

Control System Analysis — G. Iwanaga

Graphics Coordination — R. Johnson

Acknowledgement is also made of the help of Mr. C. Tiffany, Mr. R. Guest, and Mr. J. McQuilland of AT&T Long - Lines and Government Operations who kindly provided data on the likely configuration and user charges of the telephone networks in the 1990 time period, which were used in costing and analyzing terrestrial alternatives to the space concepts.

In addition, a special thanks is extended to Mrs. J. Antrim for her invaluable support throughout the project, in preparation of many of the graphics, and in typing and shepherding the presentation and this report. It would not have been possible without her.

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INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND

This study is the third in a sequence of investigations into advanced space system concepts performed by The Aerospace Corporation under contract to the NASA Office of Space Transportation Systems begun in 1975. The first in the series of studies was the identification of a large number of concepts (over 100) which appeared to have high potential for utility, depended on advanced technology and the availability and use of the Space Shuttle, and might be fielded in the 1980-2000 time period (Ref. 1). This set of initiative concepts - together with those identified by the NASA Outlook for Space Study - both performed in parallel in 1976, constituted a rich set of options for constructing an advanced space plan for the next two decades.

The second in the series of studies identified a set of development plans for groups of these initiatives to obtain a better understanding of possible program evolution as follow-on to the then-just-issued NASA 5-year plans, as well as, to identify needed growth in the Space Transportation and Orbital Support Systems in that time period (Ref. 2).

This study represents the third step in which a few of the most promising initiatives identified initially, and grouped into development plans in the second study, are analyzed in more depth First, to derive more confident numbers on their potential performance and characteristics; and second, to compare their performance and cost against leading terrestrial alternatives designed for the same requirements in order to evaluate their potential merits and utility.

Most of the more attractive initiatives identified in these past works took advantage of the complexity inversion phenomenon, in which the ability to service larger numbers of users with smaller and less expensive user equipment and deliver lower priced services, is made possible by deliberately making the satellites larger, more complex, heavier, and therefore more costly. The operation of these satellites in synchronous orbit, however, enables a single satellite (or at most a few) to provide services directly to thousands or millions of users. Thus, the total system costs usually favor increasing the size of the satellite inasmuch as the differential cost savings thereby made possible in the terminals greatly exceeds the increased cost of the satellite. Furthermore, a number of services are thus made possible which simply cannot be provided with smaller satellites.

Examples of these include (as an extreme) - the provision of personal and emergency communications to very large numbers of citizens wearing wrist-sized terminals, electronic mail distribution to home terminals, distribution of TV programs directly to homes or schools, mass library and data bank exchange by small users, small business teleconferencing as a means to save travel expenses and time, readout of very large numbers of small and inexpensive ground sensors for applications as diverse as freight tracking and prevention of undetected hijacking of nuclear powerplant fuel shipments. A number of optical applications also exist - such as detecting forest fires by large optical heat detection systems in synchronous orbit, coastal zone monitoring for fishing violations, and the observation of creep along large numbers of points along fault zones for earthquake prediction. The latter is another example of complexity inversion in which the satellite would have a complex laser, however the ground units would consist of simple corner reflectors, proliferated at very low cost.

It is examples such as the above that aroused an enthusiasm among both lay and technical audiences over the past two years, since the first study on advanced concepts was made public. As a result of the report, numerous presentations on its contents, and presentations by other people on results of similar studies and analyses, an atmosphere is being created in which advanced technology satellites designed for earth-oriented applications are viewed with increasing favor by the Congress and many people as as representing fruitful expenditures of public funds. Simultaneously, a number of social and institutional questions have been triggered, which are beginning to be asked in public forums. This is a very healthy sign, inasmuch as technologists can at best hope to stimulate debate on the desirability of new applications while removing from such debates uncertainties about cost, availability, and performance of the potential systems. Thus, the motivation behind this study was to perform a definitive first analysis that contributes such data.

1.2 PURPOSE

The purpose of this study was to develop the characteristics, cost, and performance of a few of the more attractive application concepts, and to compare them against leading terrestrial alternatives, in order to determine their potential, identify those deserving further NASA attention and possible inclusion into the formal development planning sequence, and serve to initiate a dialogue with the using community and agencies.

1.3 APPROACH

The approach followed in this study was to select a maximum of three initiative concepts for detailed analysis from the hundreds identified previously; to specify a set of requirements against which the initiative design could proceed based on an interpretation of the needs of the using community; to perform preliminary designs of the initiatives using the desired set of requirements, iterating the requirements as necessary to keep the evolving systems feasible yet challenging; to identify leading terrestrial alternatives to each of the space initiatives which are capable of performing the same functions and meet the same requirements; to perform a one-to-one cost comparison of the space and ground concepts, and thus to draw conclusions on the advantages and disadvantages of the alternative space and ground solutions of the same problems.

At the outset, it was decided that only objective measures such as cost and performance would be quantitatively compared, and not the more subjective areas of benefits, social risks, institutional impact, regulatory agency attitudes, or the general desirability or appeal of the potential concepts. Although these more subjective measures clearly represent key issues that must be addressed prior to any commitment to proceed into serious design and development of such system concepts, it was felt such subjective analyses were beyond the resources of this study. Thus, this study was geared solely to provide technological and cost inputs that could be then supplied to those addressing the more subjective issues.

Both the space and user equipment segments were defined in the performance of this study, and a development plan was developed for each initiative. The general flow of the study is described by Figure 1-1.

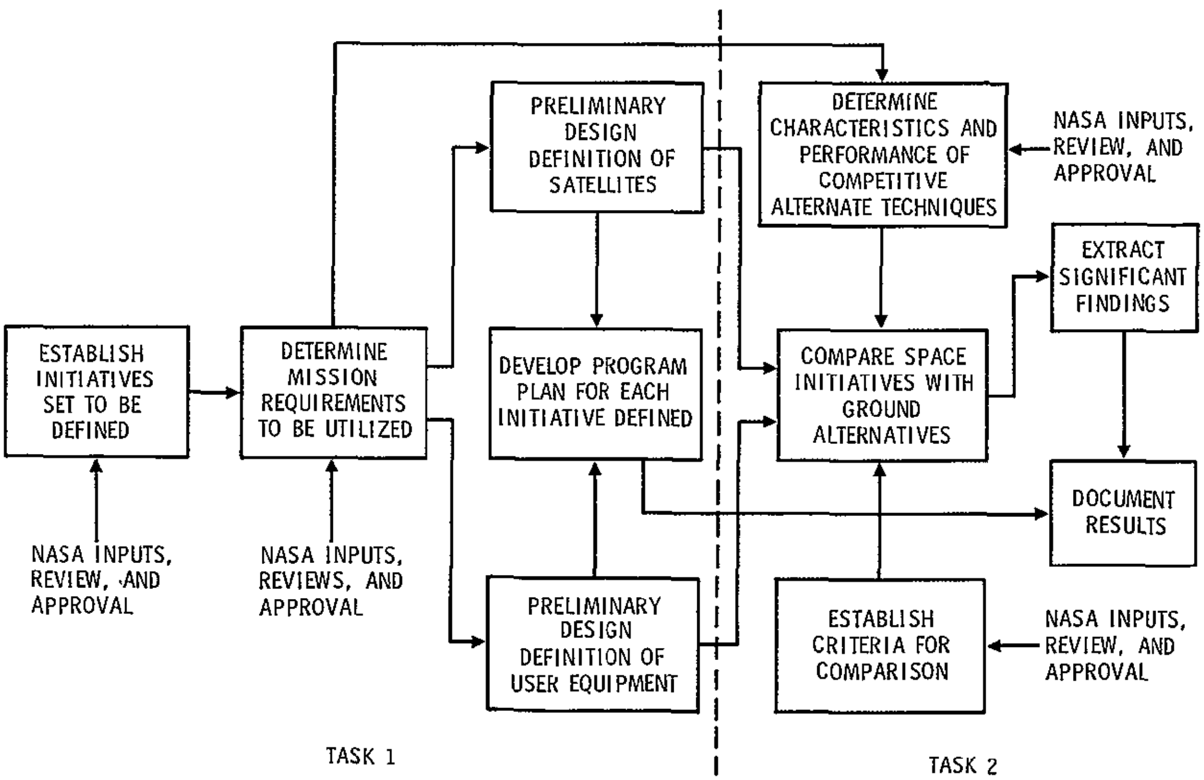

Figure 1-1. Functional Study Description

1.4 CONTACTS/DOCUMENTS

After the initial set of initiatives to be defined were selected, a number of data-gathering trips and telephone contacts were made. Discussions were held with various agency and organization personnel in order to ascertain what might be a reasonable set of requirements against which to design the initiative systems and general alternatives. People who furnished inputs and thoughts regarding useful functions and probable needs of the using community included the following:

U.S. Postal Service	Mr. Ralph Marcotte
Public Broadcasting System	Mr. Dan Wells
Corporation for Public Broadcasting	Mr. Brian Brightly
National Institute of Education	Dr. Richard Otte
Appalachian Regional Commission	Mr. Robert Shuman
Joint Council on Educational Television	Mr. Frank Norwood
Public Service Satellite Consortium	Mr. John Witherspoon and Dr. James Potter

In addition, discussions and numbers regarding the telephone networks in the 1990 time period were contributed by:

American Telephone and Telegraph Co.	Messrs. Curran Tiffany, Jim McQuillan, and Robert Guest

In addition, a document search was performed using many sources that resulted in the accumulation of over 270 documents and represented the working library of source material for this study. The list of documents utilized is included in this report as Appendix C.

1.5 REPORT ORGANIZATION

Section 2 of this report deals briefly with the process of selection of the initiatives to be analyzed, with the bulk of the process described in Appendix B.

Sections 3, 4, and 5 of this report are independent and complete, each discussing all aspects of one initiative. Each initiative section thus includes derivation of the requirements, definition of the concept for the satellite and the user terminals, extraction of the development plan, derivation of the costs, definition of the alternative terrestrial concept and derivation of its costs, and comparison of the space concept with the ground concept on a technical, cost, and operational basis. In Section 6 all three system concepts are compared and evaluated in an overall context.

The Electronic Mail and Educational TV concept sections appear much smaller and less detailed than the Personal Communications section, even though the analysis depth is equivalent, because the applicable analyses are included in those sections by reference to the similar portions in the Personal Communications initiative. Section 7 presents the summary conclusions and recommendations reached in this study.

2. SELECTION OF INITIATIVES

The process of selection of the initiatives to be defined proceeded in two major thrusts. The first was a decision to make a point design for as many initiatives as possible, limited only by the available funding, in order to penetrate the initiatives with good depth and thus make the cost and performance numbers as credible as possible. The other major options available, which were rejected, were the definition of a spectrum of point designs for a single application and the definition of a nominal and one growth capability for one to two initiatives. The reason was to gain insight into the maximum number of initiatives possible and to protect against the possibility that a single initiative otherwise selected might prove to be the wrong choice, being noncompetitive with terrestrial alternatives. The second major thrust was a definition of the criteria for initiative selection.

The selection process, with full description of the steps used for narrowing from the large initial number of choices to the final selections, is reported in Appendix B, not because it is not important but because it was felt that it might distract the reader from the main task of this report, which is to furnish information on the selected initiatives themselves. Among the criteria used for selection of the initiatives the most prominent were (1) the initiatives should perform functions that appear marketable with obvious potential benefits and apparent popular appeal, (2) the identification of organizations that in principle at least could advocate such a system, (3) the existence of readily and credible definable terrestrial alternatives, (4) the existence of a data bank or technology to support its definition; its availability in the 1985-1990 time frame, (5) its utilization of large structures, large power, or other elements associated with other project thrusts within NASA for compatibility and mutual support.

The major candidate systems surviving the preselection process included a number of other initiative concepts with potentially great public appeal. That list of initiatives is shown in Table 2-1. The purpose of including this table here is to point out that it appeared to the team that performed the selection, which included representatives of NASA and Aerospace, that many, if not most, of these major options deserve the same study attention that the funds only would allow to be spent on three. Studies such as the one reported in this report should therefore be considered with high priority for most, if not all, of the items on Table 2-1.

Table 2-1. Major Candidate Initiatives

MOBILE COMMUNICATIONS

- PERSONAL/EMERGENCY COMMUNICATIONS
- PACKAGE/VEHICLE LOCATOR
- AIR TRAFFIC CONTROL

FIXED COMMUNICATIONS

- ELECTRONIC MAIL (HOME-HOME)
- VIDEO TELECONFERENCING
- RURAL EDUCATIONAL TV

REMOTE SENSING

- FOREST FIRE DETECTION
- 200-MILE LIMIT MONITORING
- EARTHQUAKE FAULT MOVEMENT

The initiatives selected by the process found in Appendix B were an Electronic Mail Delivery system, an Educational Television Distribution system, and a Personal/Emergency Communications system. The functions and general orientations of the initiatives selected for further definition are illustrated in Table 2-2. Note that a fourth initiative was selected to be analyzed if time and resources permitted, which was the provision of telephone service to rural areas via communications satellite. Unfortunately, time did not permit the addressing of this initiative.

Table 2-2. Selected Initiatives

INITIATIVE	FUNCTION
• Personal Communications	– Interconnection of Wrist Radio Personal Terminals – Pleasure, Business, Mobile Uses – Emergency Channels For. Panic Search/Rescue Disasters
• Educational TV	– Program Dissemination and Interchange Within All School Systems In CONUS – Open University Learning Center Program Distribution/Interaction – Public TV Interconnect?
• Electronic Mail	– Interconnection of Business and Government Buildings Directly
• Rural Telephones	– To Be Defined If Time Permits

Thus, the rest of this study report treats only the three initiatives that have been selected. The Personal Communications Initiative is treated first in Section 3, inasmuch as its analysis was the most demanding of the three, and many of the subsystems, techniques, and tradeoffs defined for it are applicable to the other systems as well. The function of the Personal Communications Initiative is the interconnection of wrist-sized personal radiotelephone terminals for pleasure, business, and emergency use. In Section 4, the Educational TV Initiative is analyzed. Its function is the dissemination and interchange of educational programs within all the school systems and schools in the United States, or similar functions for open university learning centers as well as other educational opportunities. In Section 5, the Electronic Mail Initiative is analyzed and reported. Its functions are limited to interchange of the business and government sectors of the mail stream, and not penetration of the home mail sector.

Sections 3, 4, and 5 of this report are independent and complete, each discussing all aspects of one initiative. Each initiative section thus includes derivation of the requirements, definition of the concept for the satellite and the user terminals, extraction of the development plan, derivation of the costs, definition of the alternative terrestrial concept and derivation of its costs, and comparison of the space concept with the ground concept on a technical, cost, and operational basis. In Section 6 all three system concepts are compared and evaluated in an overall context.

The Electronic Mail and Educational TV concept sections appear much smaller and less detailed than the Personal Communications section, even though the analysis depth was equivalent, because the applicable analyses are included in those sections by reference to the similar portions in the Personal Communications initiative.

3. PERSONAL COMMUNICATIONS INITIATIVE

This section examines the characteristics, requirements, performance, and costs of an initiative concept to provide personal communications to a large number of citizen users via wrist-mounted user radiotelephones. At the outset, this initiative concept is seen as an extension of rather than a replacement of the telephone networks. This philosophy was adopted not only to maximize the use of the current investment in the telephone networks, but rather to augment them in providing services that such networks find difficult. This includes mobile services and provision of services to very thinly populated or wilderness and nature areas where it has not proven profitable to provide telephone service in the past.

As a set of initial guidelines and a number of assumptions were made that would guide the definition of the requirements and the development of the concept in the following pages. These assumptions and guidelines are identified in Table 3-1. Of these, perhaps the most important is that the satellite should act as the sole node between users rather than as a relay point between the usér and fixed ground locations. The reason for that was

Table 3-1. Assumptions and Guidelines, Personal Communications Initiative

- NO INTERMEDIATE NODES
- WRIST RADIO, NOT LARGER THAN POCKET RADIO USER SET
- MASS ACCESS - TRY FOR AT LEAST 10 PERCENT OF POPULATION
- NO MICROWAVE RADIATION SAFETY PROBLEM
- IMMEDIATE ACCESS TO CHANNELS FOR EMERGENCY USES
- RIGID DISCIPLINE BUILT INTO SYSTEM - AVOID "CB CHAOS"
- COVER AT LEAST CONUS - HAWAII AND ALASKA DESIRABLE BUT OPTIONAL
- IOC ≈ 1990 OR SOONER

an expectancy that in order to prove competitive such a system would have to be freed from toll and service charges otherwise inescapable if a ground network is used for even part of the user-to-user transmission path.

A second and most important assumption was a fierce determination to resist making the user package much larger than a wrist radio or a tiny pocket radio set. The temptation to increase the size is great inasmuch as it alleviates a number of system problems. The rationale for keeping the package small is simply that it maximizes convenience and availability of the set to large numbers of people and minimizes the user cost, inasmuch as modern microelectronics appear to be priced by the pound. Third, the system must operate with rigid and enforced radio discipline to avoid the kind of self interference that mass access radio systems otherwise usually exhibit. The best example is the chaos that now exists in citizen's band (CB) radio; people pay several hundred dollars for a user set that gives them the privilege of interferring with each other's transmissions. This characteristic has limited the growth of the CB industry inasmuch as people find that many times they cannot even use the sets for emergencies, let alone for pleasure or business purposes. Thus the need for a discipline in which channel access is controlled by the system, and prevents exploitation of the spectrum space was felt to be an absolutely indispensible feature of the system to be designed.

Last, it was felt that the intuitive appeal of a "Dick Tracy" wrist radio system would create a very large market in which something approaching 10 percent of the total expected U.S. 1990 population might be considered as the user model. At the prices of current wrist-mounted digital electronic devices (such as a digital watch, which retails for under $10.00) such mass access is to be expected rather than hoped for.

3.1 REQUIREMENTS

A geographic and demographic study of the United States was performed, utilizing reference library sources, to determine the coverage requirements for the Personal Communications system. The first and most important portion of this determination involved the determination of the minimum coverage area for each satellite beam footprint. This had two parts: the first was the definition of the beam footprint to cover the urban and suburban areas, and the second was the number of beams of that size required to cover all of rural areas of the United States. Inasmuch as the former determines the number of the latter, a study was made of the number of cities, towns, and urbanized areas in the U.S. that could be covered as a function of the size of the beam footprint. The results of this study are summarized in Figure 3-1, which shows that for cities of less than one million population the nominal coverage footprint can be as small as 20 mi in diameter and still cover virtually all of the cities. However, if the largest cities in the U.S. are included, the beam footprint must be in the order of 50 or 60 mi in diameter for 100 percent coverage. For 90 percent

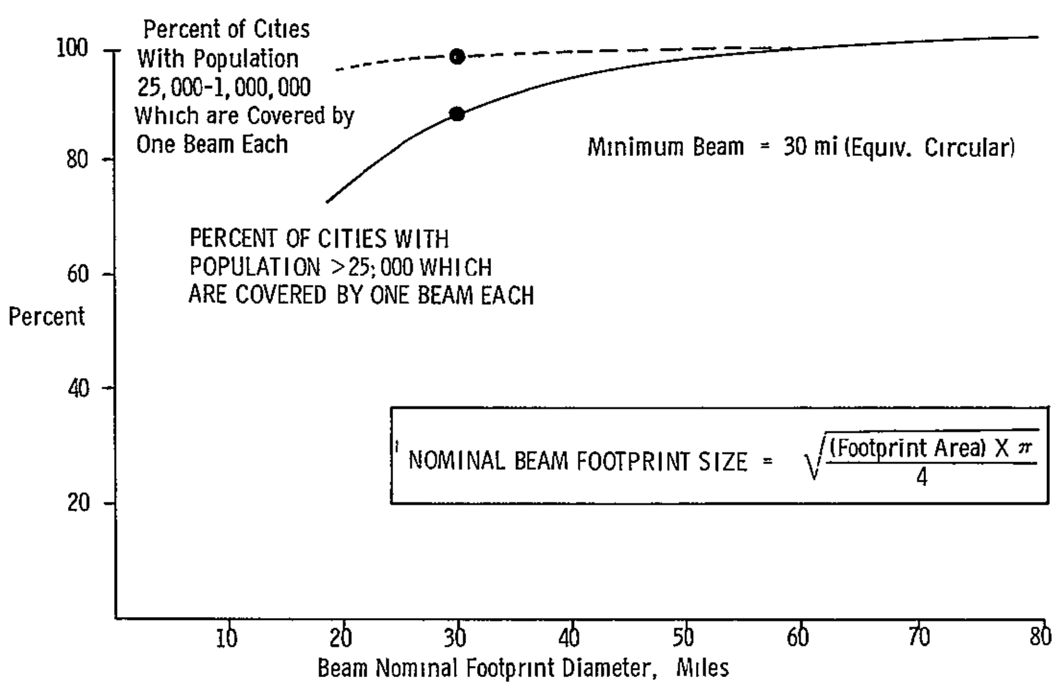

Figure 3-1. Determination of Minimum Beam Footprint

coverage, the beam footprint diameter can be as small as 30 mi. This is alleviated somewhat by the expectation that the footprint will not be circular (indeed it cannot be from a synchronous equatorial satellite) and more than likely will be elliptical with major to minor axis ratio of about 1.5 to 2 for the northern-most extremes of latitude and longitude. This size beam is expected to cover not only the central city area but the major suburban regions associated with each city as well. A number of examples are shown for Chicago, Boston, Philadelphia, Los Angeles, Washington, Baltimore, Seattle, St. Paul, Minneapolis, Kansas City, and St. Louis as being representatives of larger cities in the U.S. In every case, a beam diameter of 30 mi by 60 mi served well to cover most of the populated regions associated with the urbanized area. The exception is Los Angeles, which requires three overlapping beams for full coverage. These examples are shown in Figures 3-2 through 3-7. The total number of urbanized areas with population exceeding 25,000 was determined to be 846. Thus, coverage of the urbanized regions was set to require 846 beams each with a 30-mi footprint along the minor axis. This determination was made from consideration of the distribution of the city sizes and numbers. A determination was then made of the total number of users to be expected in each beam and the total number of users for all urban beams. The results of this analysis are illustrated in Table 3-2 in which the number of users was determined based on the number of beams required to cover the various size cities in the U.S. The number of users was based on the assumption that up to 10 percent of the expected 1990 population will be a potential market for a personal communications set. The actual urban population reached was doubled to allow for the suburban population statistics that were not readily available in the reference data at hand and to allow for beam spillover inasmuch as the 3-dB beam contours were plotted while the system margin was expected to allow for a service area larger than the 30-mi footprint being specified. The result was that 17,850,000 users are expected in the urban and suburban areas, distributed along 846 beams as in Table 3-2 and represent 6.3 percent of the expected 1990 population.

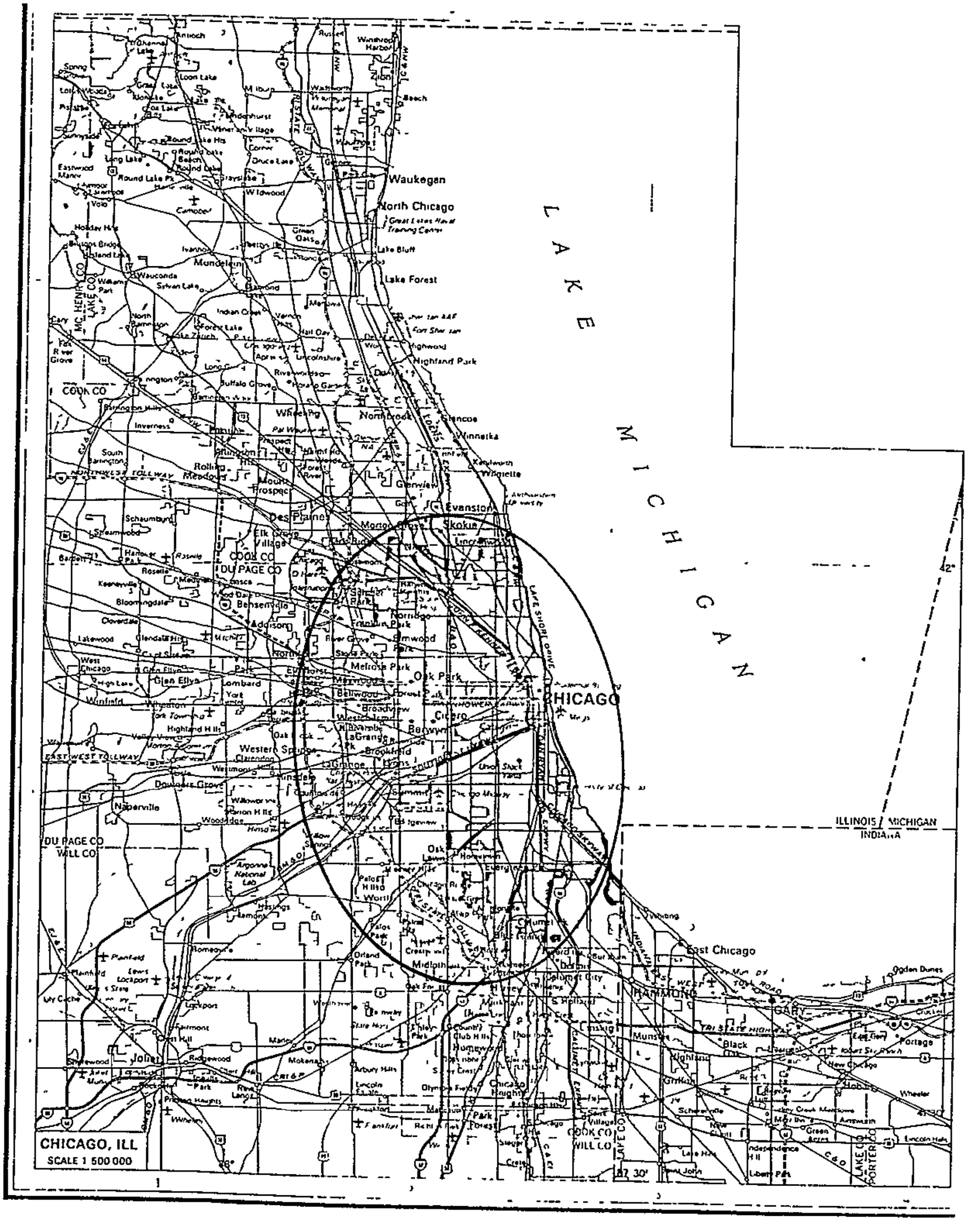

Figure 3-2. Beam Coverage of Urban Areas Footprint Elipse 20 by 30 miles

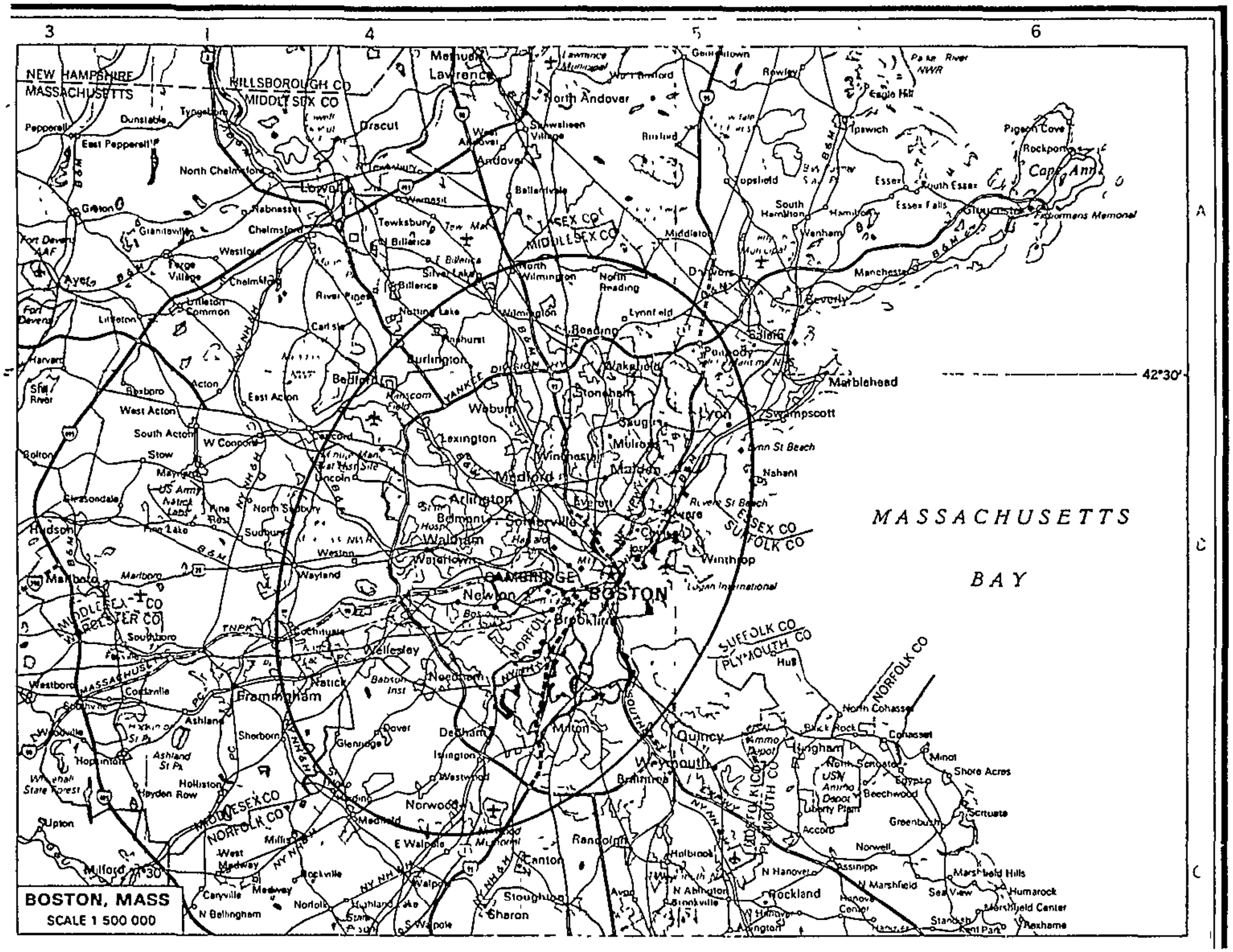

Figure 3-3. Beam Coverage of Urban Areas Footprint Elipse 20 by 30 miles

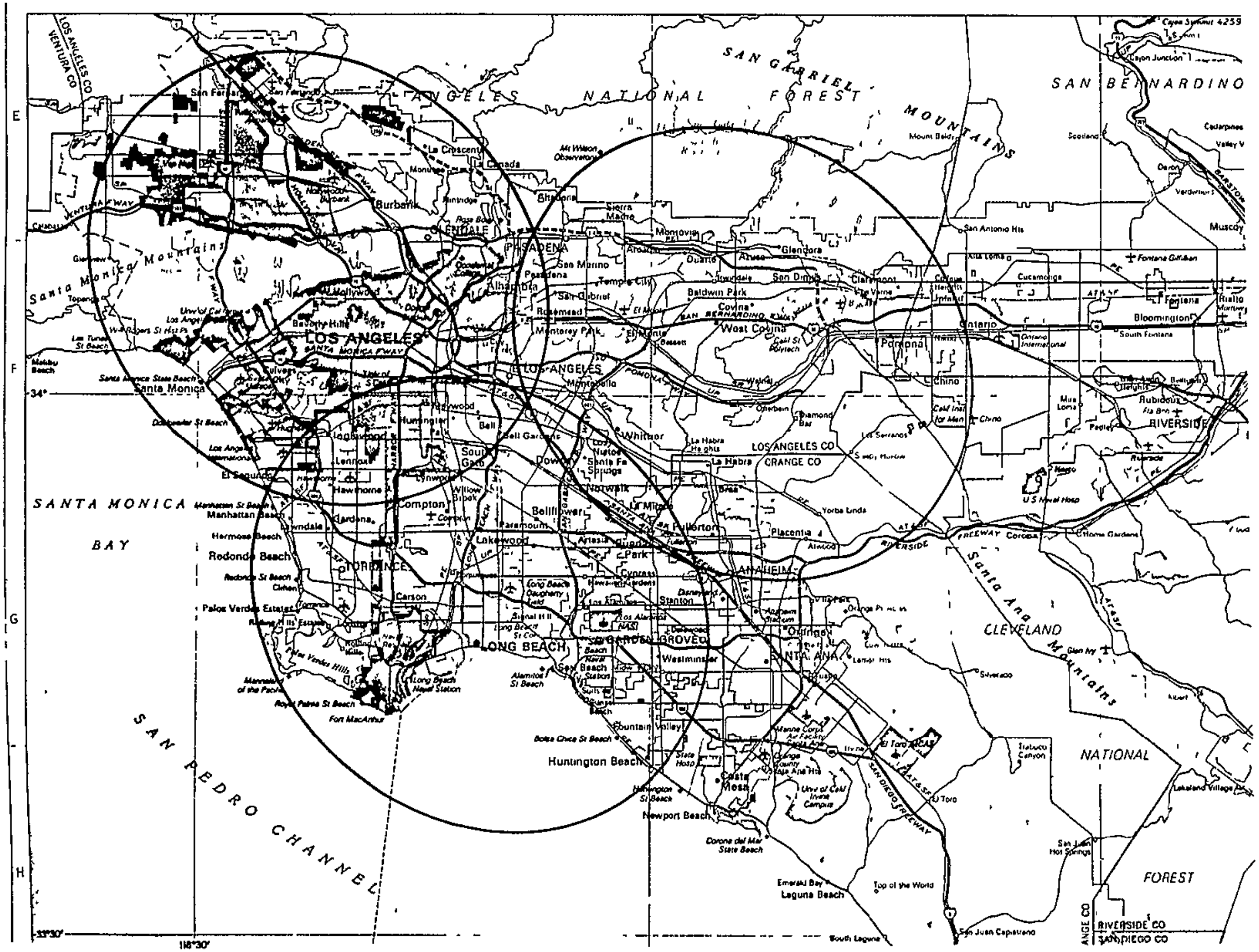

Figure 3-4. Beam Coverage of Urban Areas Footprint Ellipse 25 by 30 miles

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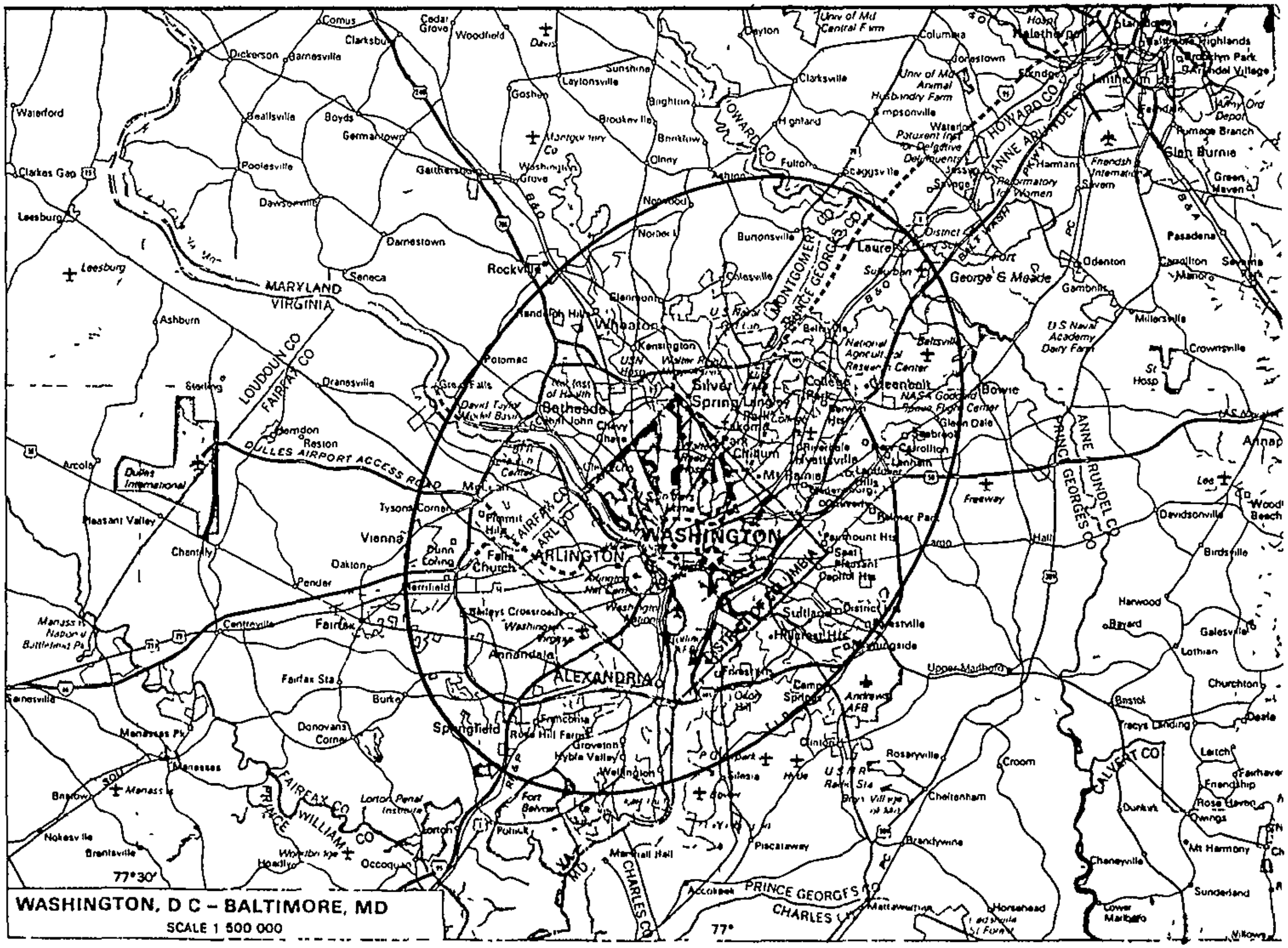


Figure 3-5. Beam Coverage of Urban Areas Footprint Ellipse 20 by 30 miles

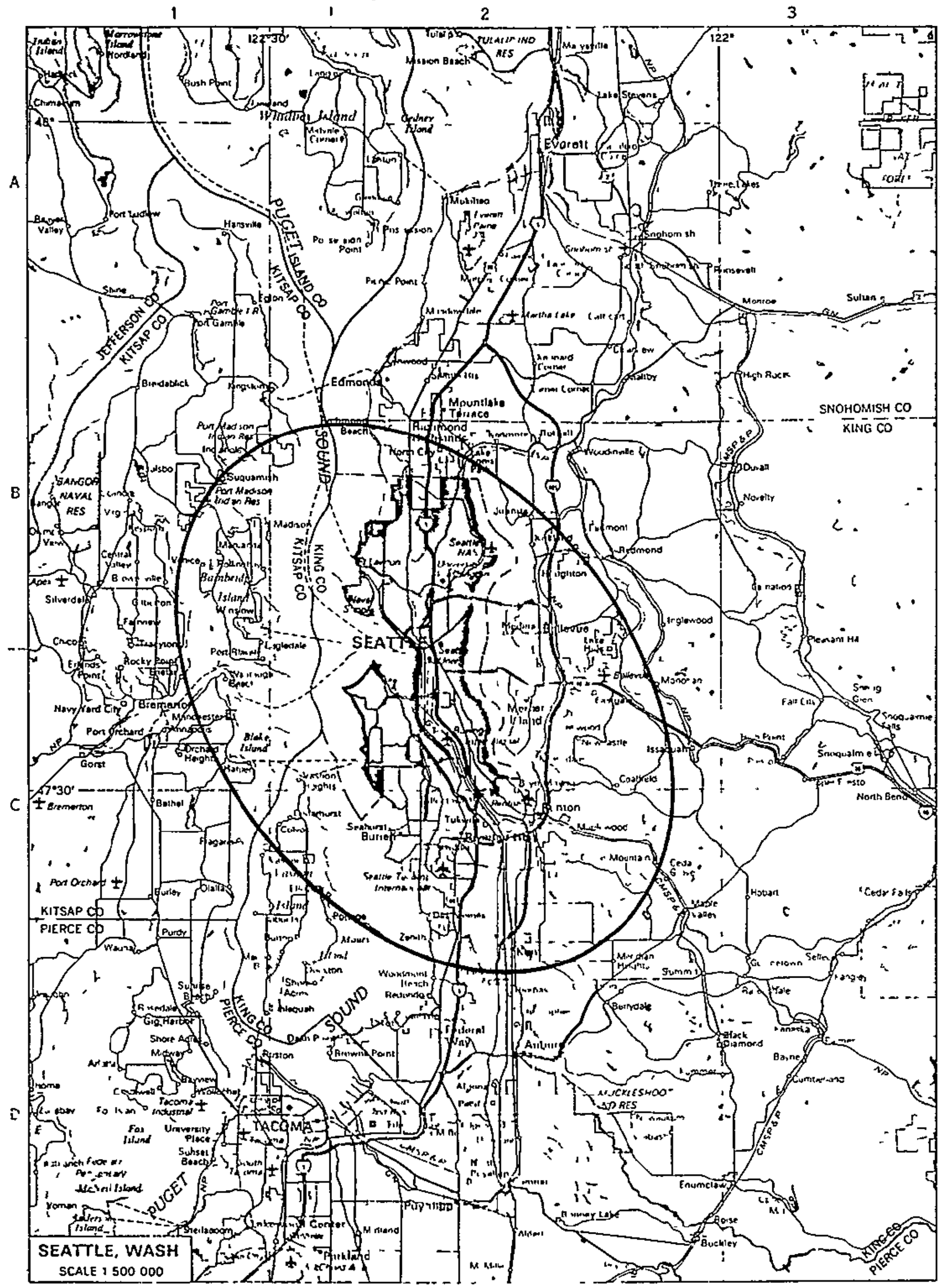


Figure 3-6. Beam Coverage of Urban Areas Footprint Elipse 20 by 30 miles

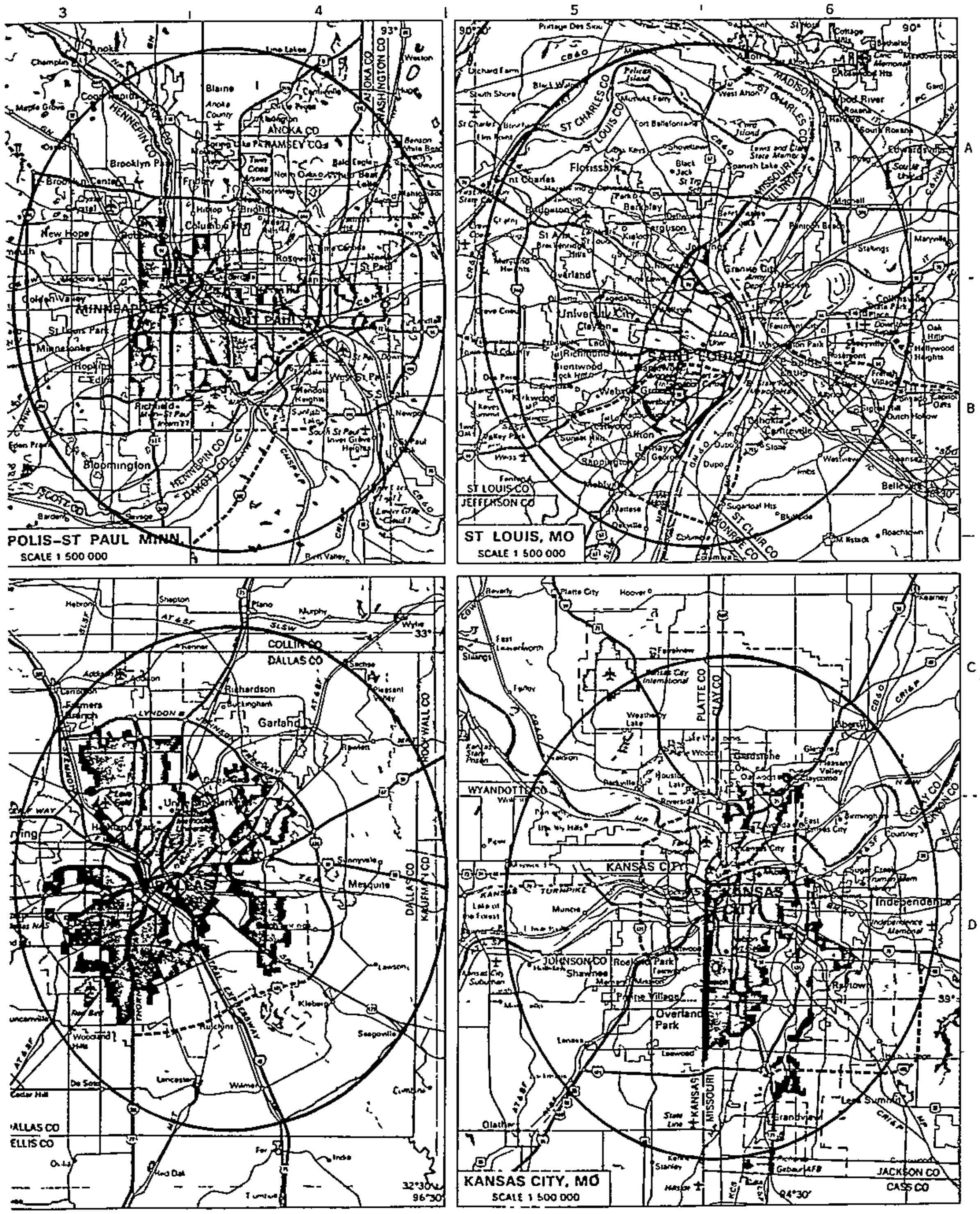


Figure 3-7. Beam Coverage of Urban Areas Footprint Ellipse 25 by 30 miles

Table 3-2. Urban and Suburban Beam Needs Summary

CITY SIZE (1970)	NUMBER OF CITIES	10% of 1990 POPULATION	NUMBER OF BEAMS/CITY	NUMBER OF BEAMS	USERS/ BEAM
> 1,000,000	6	150,000	2	12	75,000
500,000 - 1,000,000	20	75,000+	1	20	75,000
250,000 - 500,000	30	37,500+	1	30	37,500
100,000 - 250,000	97	15,000+	1	97	15,000
50,000 - 100,000	232	7,500+	1	232	7,500
25,000 - 50,000	455	3,750+	1	455	3,750

SUBURBAN· The same beams will cover about twice the population, into suburban areas This is because of beam spill-over and elliptical footprints.

Total Number of Beams	846
Total Number of Urban Users	8,426,000
Total Number of Suburban Users	8,426,000
Total Users	16,850,000
Percent of 1990 vs. Population	6.3%

·The second major portion of the beam and coverage determination involved the rural areas of the country. In this case the total area of the United States was assumed covered with contiguous 30-mi minimal axis beams with a 35 percent area overlap between adjacent beams to ensure that no user would fall outside of the 3-dB contour of any beam. This assumes a hexagonal tessellation to cover the United States. The number of rural beams, and the expected number of users per beam were determined for each state under the previous guidelines. These rural beam needs by state are shown in Tables 3-3 through 3-5 and summarized in Table 3-6. Referring to Table 3-6, it is seen that the total number of beams of 30-mi minor axis required to cover the U.S. is over 7268 and 6084 if Alaska and Hawaii are excluded. The total number of users served is about 8,440,000 representing 3.3 percent of the expected 1990 U.S. population.

Table 3-3. Rural Beam Needs by State

STATE	AREA	NUMBER OF RURAL BEAMS*	RURAL (1970) POPULATION	USERS/BEAM **	USERS/BEAM ***
Alaska	586,000	1,184	185,000	14	21
Texas	267,000	540	2,653,000	441	661
California	158,000	319	1,406,000	395	592
Montana	147,000	297	553,000	167	250
New Mexico	121,000	244	683,000	265	397
Arizona	114,000	230	476,000	186	279
Nevada	110,000	222	99,000	40	60
Colorado	104,000	210	456,000	195	292
Wyoming	98,000	198	350,000	158	238
Oregon	97,000	196	855,000	391	586
Utah	85,000	171	227,000	119	179
Minnesota	84,000	169	1,465,000	776	1,164
Idaho	83,000	167	634,000	339	509
Kansas	82,000	165	1,342,000	726	1,090
Nebraska	77,000	155	895,000	517	776
South Dakota	77,000	155	573,000	331	497
North Dakota	70,000	141	602,000	383	574

* At 30 mi/beam, 35 percent overlap area
** At 10 percent of population, 1970
*** At 10 percent of population, 1990 (at 2 5 percent/year growth)

Table 3-4. Rural Beam Needs by State

STATE	AREA	NUMBER OF RURAL BEAMS*	RURAL (1970) POPULATION	USERS/BEAM **	USERS/BEAM ***
Oklahoma	70,000	141	1,211,000	770	1,155
Missouri	70,000	141	1,726,000	1,097	1,646
Washington	68,000	137	972,000	635	953
Georgia	59,000	119	2,103,000	1,582	2,373
Florida	58,000	116	1,139,000	878	1,317
Michigan	58,000	116	1,612,000	1,242	1,863
Illinois	56,000	112	2,170 000	1,728	2,592
Iowa	56,000	112	1,890 000	1,505	2,258
Wisconsin	56,000	112	1,819,000	1,449	2,174
Arkansas	53,000	107	1,254,000	1,052	1,578
North Carolina	52,000	105	2,953,000	2,521	3,782
Alabama	51,000	102	1,388,000	1,218	1,827
New York	50,000	100	2,058,000	1,840	2,760
Louisiana	48,000	96	1,458,000	1,354	2,032
Mississippi	48,000	96	1,766,000	1,641	2,461
Pennsylvania	45,000	91	2,341,000	2,311	3,467
Tennessee	42,000	84	1,507,000	1,605	2,408

* At 30 mi/beam, 35 percent overlap area
** At 10 percent of population, 1970
*** At 10 percent of population, 1990 (at 2.5 percent/year growth)

Table 3-5. Rural Beam Needs by State

STATE	AREA	NUMBER OF RURAL BEAMS*	RURAL (1970) POPULATION	USERS/BEAM **	USERS/BEAM ***
Ohio	41,000	82	2,174 000	2,368	3,553
Virginia	41,000	82	1,671,000	1,820	2,731
Kentucky	40,000	80	1,804,000	2,011	3,017
Indiana	36,000	73	1,859,000	2,288	3,432
Maine	33,000	66	723 000	980	1,470
South Carolina	31,000	62	1,442,000	2,071	3,106
West Virginia	24,000	48	1,139,000	2,117	3,175
Maryland	11,000	22	598,000	2,465	3,697
Vermont	10,000	19	469,000	2,119	3,178
New Hampshire	9,000	18	395.000	1,973	2,960
Massachusetts	8,000	16	175,000	976	1,464
New Jersey	8,000	16	437,000	2,441	3,661
Hawaii	6,000	12	146 000	1,158	1,737
Connecticut	5,000	10	241,000	2,290	3,435
Delaware	2,000	4	170,000	4,050	6,075
Rhode Island	1,000	2	99,000	4,700	7,050

* At 30 mi/beam, 35 percent overlap area
** At 10 percent of population, 1970
*** At 10 percent of population, 1990 (at 2.5 percent/year growth)

Table 3-6. Rural Beam Needs Summary

COVERAGE	TOTAL NUMBER OF BEAMS	TOTAL USERS SERVED*	PERCENT OF U. S. POPULATION
All U. S. A. (Not Alaska or Hawaii)	6084	8,414,000	3.3
All U. S. A.	7268	8,440,000	3.3

* @ 10 Percent of 1990 Population

The total coverage and beam requirements were then collected and are shown in summary form in Table 3-7. In this table the assumption is made for the rural beams that Hawaii and Alaska are excluded from coverage. Although this need not be the case in a real design, the decision for this was based on some preliminary antenna design work that hinted difficulties in antenna design for the large numbers of beams of such small diameter subtending angles at the satellite representing longitude deviations from the satellite nadir of more than about 3 deg. Thus, coverage for the continental and contiguous United States appeared feasible but the 6-deg requirement to also cover Alaska and Hawaii appeared to be marginal. In later analyses this turned out to be probably over-pessimistic and it now appears as though coverage of all 50 states may well be possible from a single satellite. However, the assumptions of Table 3-7 were used for the rest of the analysis. The total number of beams for the U. S. is then 6,930 serving 25,244,000 people, representing almost 10 percent of the U. S. population expected to exist in 1990.

A further set of considerations to define the system requirements specification was made in which it was set that the user must have total mobility anywhere in the U. S. with communications limitations only inside tunnels and shielded buildings. Communications was desired using

Table 3-7. Coverage Requirements Summary, Personal Communications

COVERAGE	NUMBER OF BEAMS*	USERS SERVED**	PERCENT OF 1990 POPULATION
URBAN AND SUBURBAN	846	16,830,000	6.7
RURAL***	6084	8,414,000	3.3
TOTAL FOR U. S. A ***	6930	25,244 000	9.3

* Beam Footprint = 30-Mile Circular Equivalent
** @ 10 Percent of 1990 Population
*** Not including Hawaii and Alaska

3 kHz normal voice rather than by morse code or a small teletypewriter. The antenna for the wrist unit should be self-contained, however an extendible structure might be permitted for use in fringe reception or transmission areas, although it was considered undesirable as an initial specification. The access time for the user in obtaining a channel upon demand was considered to be acceptable if it did not exceed 1 min during nonpeak hours and 10 min during peak hours provided that emergency channels would essentially be available instantaneously on demand. The use time of the system was felt to be at least a minimum of 1 min and probably not very much longer, inasmuch as most messages can be conveyed with ease in a 1-min time period by they personal or emergency. It is felt the system should be capable of responding to requests of users for longer channel usage time when channel loading permits and perhaps respond with a charge structure escalating with time. The short messages, however, would ensure freedom from "chewing the fat" or channel-hogging and assure maximum number of users access to radio channels. It was desirable that the user access be nonblocking, i.e., when a user requests a channel, except for the normal waiting time for channel assignment, no extra waiting time would accrue due to equipment limitations.

The life of the wrist radio was felt to be reasonable if it would allow several conversations during any one 24-hr day allowing an 8-hr overnight recharge period for the batteries in the wrist unit. Preferably the equipment should be capable of being turned on for 1-hr continuously to handle expected emergencies. It was felt to be undesirable for the wrist terminal consumer price to retail for more than $100 in order to penetrate the maximum population market, as has been assumed in the previous tables. A further consideration of the microwave radiation danger was felt to be necessary to gain consumer acceptance in view of possible environmental opposition, and thus the criteria for radiation safety was taken to be not the 10^{-2} w/sqcm of the current U.S. standard for permissible long-term, whole-body microwave radiation absorption, but rather 10^{-4} W/sqcm at 10 cm distance, exceeding by an order of magnitude the Russian standard and by two orders of magnitude the U.S. standard for radiation safety. These requirements or specifications, as well as others applying to the system, are shown in Table 3-8. With respect to the systems requirements, the satellite longitude would obviously be over the U. S., the desirable operational time should begin about 1990, and the satellite to be serviceable for at least a 10-yr period whether designed for long life or maintained on-orbit. Billing for the services was assumed to occur through the U. S. mail or telephone bills to be handled by a central operations control center located somewhere in the U. S., which would double to all operations of the satellite system.

Table 3-8. System Requirements Specification - Personal Communications

USERS

- NUMBER - 25,000,000
- LOCATION - All Contiguous 48 States
- MOBILITY - Total
- INFORMATION RATE - 3 kHz Voice
- USER AGGREGATION - Dispersed as Population
- ANTENNA SIZE LIMIT - Wrist Package (Could Have Extendible Structure for Weak Areas)
- ACCESS TIME - < 1 min - Non Peak Hours; <10 min - Peak Hours
- USE TIME - >1 min Minimum
- TERMINAL LIFE - > 1 hr Continuous; 24 hr Intermittent
- PREFERRED OR MAXIMUM TERMINAL COST - < $100
- SAFETY CONSIDERATIONS - Power Density Less Than 10^{-4} W/cm^2 at 10 cm Distance

SYSTEM

- FREQUENCIES/LIMITS - 4.7 - 4.9 GHz
- SATELLITE LOCATIONS - Over USA
- FLUX DENSITY LIMITS - N/A
- OPERATIONAL TIME - 1990
- LIFE/SERVICING CONCEPTS - 10-yr minimum (Unmanned or Manned)
- INTERFACES WITH OTHER NETWORKS/SERVICES -

  Telephone Service Drops - Common Carriers
  Billing for Services Through US Mail
  Central Operational Control Center, One Anywhere in USA

3.2 CONCEPT DEFINITION

Definition of the Personal Communications Cencept must of necessity begin with considerations relating to the limiting elements of the link — in this case the wristuser set itself. Because it is so limited in power and antenna size, consequent demands will be placed on the satellite receiving antenna and the uplink will be the dominant limiting factor in the communications link. A system concept is shown in Figure 3-8, which illustrates the personal and emergency uses of such a concept. The definition of this concept will be discussed in terms of the selection of the best frequency at which to operate, the link calculations that size the communications system, the methods required for obtaining multiple access for the very large number of users while maintaining system discipline, the definition of the satellite design itself, the design of the wrist radio user set, and the derivation of the costs of both.

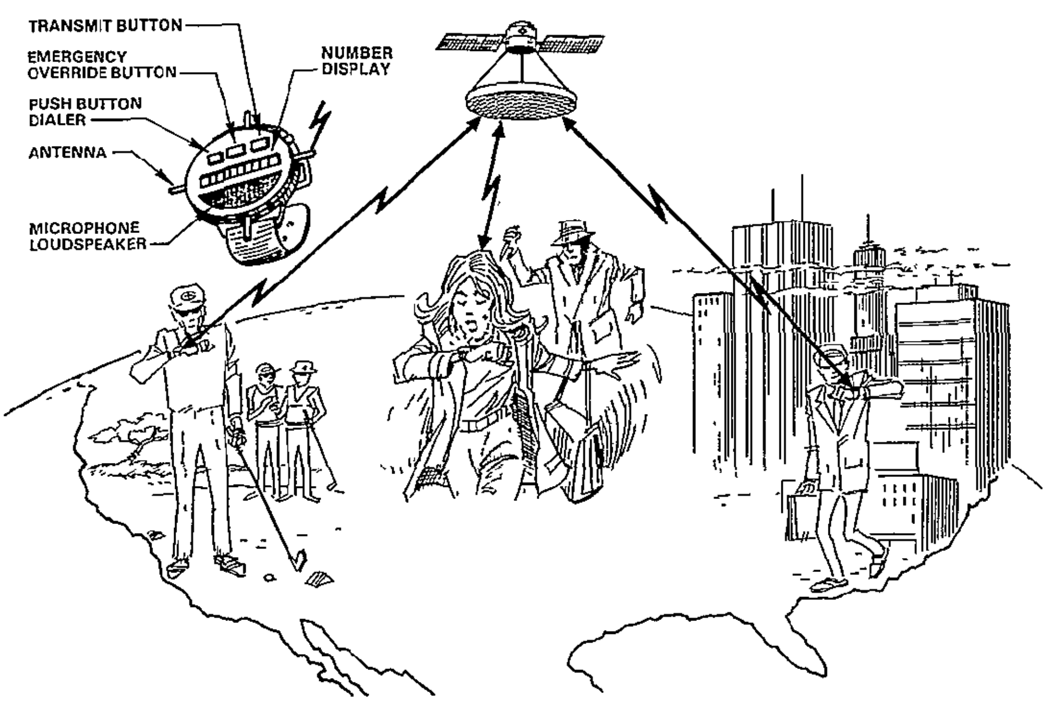


Figure 3-8. Personal Communications

3.2.1 Frequency Selection

A number of factors strongly influence the preferred frequency selection for the Personal Communications System. One of the foremost is that the system must operate at a high enough frequency that the self-contained, physically small antenna in the wrist unit have a reasonably high radiation efficiency when operating in the transmitter mode. Referring to Figure 3-9, this implies that the frequency of operations should be in the middle microwave region of several gigahertz or higher, since the efficiency loss begins to be severe due to losses in the loading coils necessary to resonate the antenna at lower frequencies. The problem of finding allocations at the middle microwave frequencies or higher is difficult, however, due to the allocations currently existing and about to be imposed as the result of the world administrative conference to occur in 1979 (GWARC-79). From

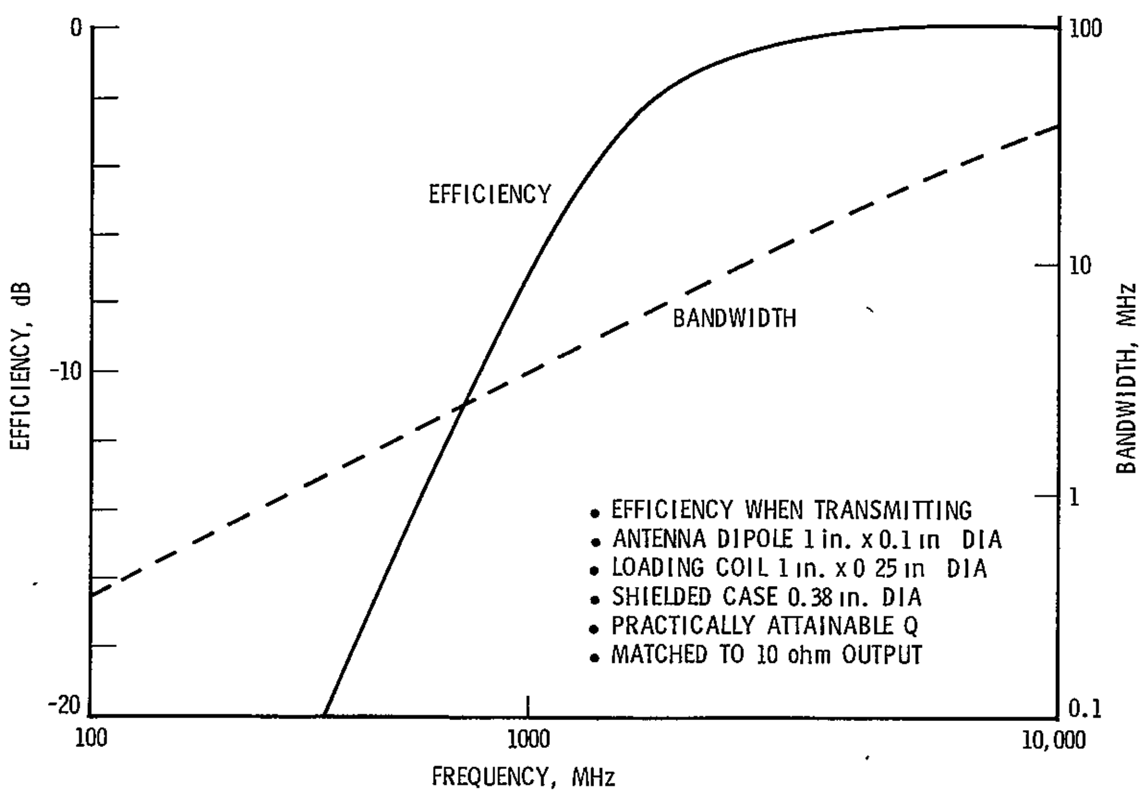


Figure 3-9. Attainable Efficiency and Bandwidth of Wrist Radio Antenna

the standpoint of availability of frequencies, the easiest solution would be to go into the 20- and 30-GHz regions in which large bandwidths and easy allocations are virtually a certainty, since there is almost no service from satellites in this band at this time. However, the problems with operating at those wavelengths are not only the excess margin for attenuation due to rain that one has to build into the links (which will probably be very marginal to begin with), but the requirement to provide an extremely large number of simultaneous beams to obtain a given coverage. This point will be discussed in much more detail presently.

The existing frequency allocations from 1.4 to 31 GHz are shown in Tables 3-9 through 3-12. In addition to these specific tables, there are probable allocations for satellite mobile applications in the 620 to 890 MHz region and possibly in the 1 to 2.5 GHz region for limited applications. These lower regions are severely congested and the possibility of interference with ground-based systems is very high. A review of Tables 3-9 through 3-12 indicates that a number of frequency bands might be available for mobile satellite communications systems as allocated by the international agreements, which the U.S. has further constrained relegating them to fixed service only. Mobile satellite services are currently permitted or under serious consideration at 800 MHz, 6.875 to 7.125 MHz, 17.7 to 19.7 GHz, 27.5 to 29.5 GHz, and a number of other areas. In particular the 4.4 to 4.9 GHz region is allocated for satellite and mobile service internationally, and is apparently fairly lightly loaded as reported by a Public Service Satellite Consortium report (Ref. 3). These bands appear to be properly located between the two extremes applicable to personal communications as discussed above, and should be considered seriously for a Personal Communications Concept, even though they might require a variance from current FCC rules. For the purposes of this study, these bands were assumed for a preliminary design with the understanding that feasible designs are probably possible for many other frequency bands with some sacrifice in system performance or increased requirements in transmitter power, antenna size, satellite beamwidths, or all of the above.

Table 3-9. L-Band Satellite Frequency Allocations

FREQUENCY MHz	BANDWIDTH MHz	UP/DOWN	SERVICE
1427 TO 1429	2	UP	SPACE OPERATION (Telecommand) FIXED, MOBILE (except Aero)
1525 TO 1535	10	DOWN	SPACE OPERATIONS (Telemetering) FIXED, MOBILE, EARTH EXPLORATION SATELLITE
1535 TO 1542.5	7.5	DOWN	MARITIME MOBILE-SATELLITE
1542.5 TO 1543.5	1	DOWN	AERONAUTICAL MOBILE-SATELLITE MARITIME MOBILE-SATELLITE
1543.5 TO 1558.5	15	DOWN	AERONAUTICAL MOBILE-SATELLITE
1636.5 TO 1644	7.5	UP	MARITIME MOBILE-SATELLITE
1644 TO 1645	1	UP	AERONAUTICAL MOBILE-SATELLITE MARITIME MOBILE-SATELLITE
1645 TO 1660	15	UP	AERONAUTICAL MOBILE-SATELLITE
1670 TO 1690	20	DOWN	METEOROLOGICAL-SATELLITE FIXED, MET AIDS
1690 TO 1700	10	DOWN	METEOROLOGICAL-SATELLITE MET AIDS

Table 3-10. Frequency Allocations - I

	SERVICE	
FREQUENCY (MHz)	ITU REGION 2	USA
2500-2535	F, FS Down, M, BS	BS Down F, FS
2535-2580	F, M, BS	BS Down, F
2550-2655	F, M, BS	BS Down F
2655-2690	F, RSUP, M, BS	BS Down, F, GS Up
3400-3500	FS Down, RL	G and NG (Amateur, RL)
3500-3700	F, FS Down, M, RL	G and NG (RL)
3700-4200	F, FS Down, M	F, FS Down
4400-4700	F, FS Up, M	G } Under Consideration
4700-4900	F, M	G } ASNG, FS Down
5925-6425	F, FS Up, M	F, FS Up
6625-6875	F, M	F, FS Down
6425-6925	F, M	Under Consideration as NG, FS Up

NOTE:

G = Government		B = Broadcast	
NG = Non-Government		RN = Radio Navigation	
F = Fixed		RL = Radio Location	
M = Mobile		ME = Meteorological	
S = Satellite		EE = Earth Exploratory	
		A = Aeronautical	

Table 3-11. Frequency Allocations - II

FREQUENCY (MHz)	SERVICE	
	ITU REGION 2	USA
6875-7125	F, M	F, FS Down, M, NG
7250-7300	FS Down	G
7300-7450	F, FS Down, M	G
7450-7550	F, FS Down, METS, M	G
7556-7750	F, FS Down, M	G
7900-7975	F, FS Up, M	G
7975-8025	FS Up	G
8025-8175	EES Down, F, FS Up, M	G
8175-8215	EES Down, F, FS Up, MES, M	G
8215-8400	EES Down, F, FS Up, M	G
8400-8500	F, M Space Research	G and NG, Space Research

NOTE:

G	=	Government	B	=	Broadcast
NG	=	Non-Government	RN	=	Radio Navigation
F	=	Fixed	RL	=	Radio Location
M	=	Mobile	ME	=	Meteorological
S	=	Satellite	EE	=	Earth Exploratory
			A	=	Aeronautical

Table 3-12. Frequency Allocations - III

FREQUENCY (MHz)	SERVICE	
	ITU REGION 2	USA
10.95-11.2	F, FS Down, M	F, FS Down
11 45-11 7	F, FS Down, M	F, FS Down
11 7-12.2	FS Down, M, B, BS	BS, FS Down
12.5-12 75	F, FS Up, M	F, FS Up
14.0-14.3	FS Up, RN	G and NG, FS Up, RN
14.3-14.4	FS Up, RNS	G and NG, FS Up, RNS
14.4-14.5	F, FS Up, M	G and NG, FS Up
17 7-19.7	F, FS Down, M	F, FS Down, M
19 7-20.2	FS Down	FS Down, G
20 2-21 2	FS Down	G
27.5-29 5	F, FS Up, M	F, FS Up, M
29.5-30 0	FS Up	FS Up
30.0-31.0	FS Up	G

NOTE

G	=	Government	B	=	Broadcast
NG	=	Non-Government	RN	=	Radio Navigation
F	=	Fixed	RL	=	Radio Location
M	=	Mobile	ME	=	Meteorological
S	=	Satellite	EE	=	Earth Exploratory
			A	=	Aeronautical

The number of beams required from the satellite antenna in order to completely cover the United States from border to border and coast to coast, excluding Hawaii and Alaska, are shown in Figure 3-10 as a function of the frequency and the satellite antenna diameter. If, as expected, the satellite antenna diameter will have to be large (in the range of 50 to 60 meters or more), it is seen that operating the system at 20 and 30 GHz, where frequency allocations are expected to be available, results in hundreds of thousands of simultaneous beams having to be generated. This since the beamwidth of each beam is only in the order of 10 miles or less at intercept with the earth. This seemed impracticable. On the other hand, operation at 1 or 2 GHz or less, which would seem ideal from the standpoint of number of beams that has to be generated, is difficult due to the loss in efficiency

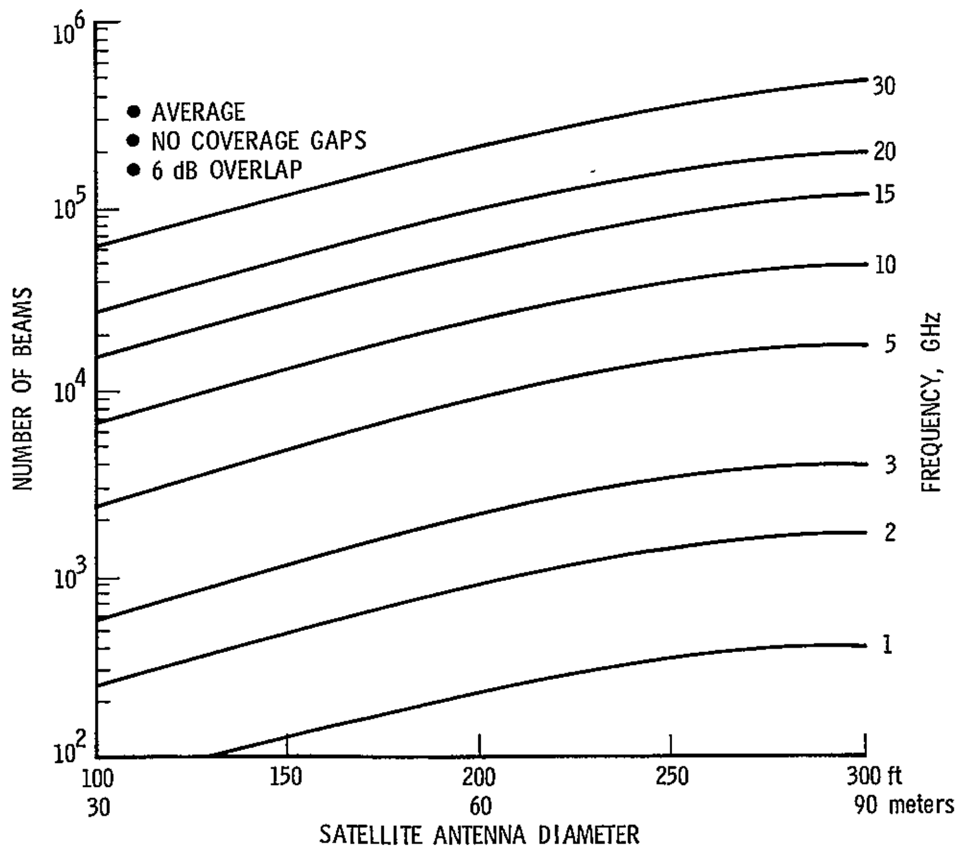


Figure 3-10. Number of Beams Required to Cover the USA

of the very tiny mobile antenna required, is shown by Figure 3-9 thus suggesting that the optimum frequency lies somewhere in the middle microwave region from 3 to 10 GHz.

There is another factor that must be taken into consideration in selecting the frequency for the system and that is the requirements for the power and antenna size of the terminals and the satellite as a function of frequency.

Consider the following: Given a diffraction-limited antenna beam produced by a spacecraft aperture of fixed dimensions, and given an earth terminal antenna of fixed angular coverage (such as hemispherical coverage), how does the net transmission loss vary with frequency? It is easy to show that the net transmission loss is independent of frequency, except for the effect of factors such as rain loss and hardware degradations (which are frequency dependent). The proof follows. First, observe that the principle of reciprocity applies, so that the proposition need only be proven for a single direction of transmission. For convenience, consider a downlink.

Let

P_t be the satellite transmitter power at the antenna feed terminals

ℓ a characteristic linear measure of the satellite antenna (for a circular antenna, ℓ is usually taken as the diameter).

λ the wave length

r the distance between the satellite and the earth terminal

Ω the solid angle subtended by the earth terminal antenna beam

The gain of the satellite antenna is

$$G_t = k\left(\frac{\ell}{\lambda}\right)^2 \qquad (1)$$

where k is a constant that is determined by the type of antenna design, but is independent of frequency.

The flux density on the ground is

$$\phi_r = \frac{P_t G_t}{4\pi r^2} \tag{2}$$

The received power is equal to the flux density times the effective area of the earth terminal antenna, A_r, where $A_r = \lambda^2/\Omega$.

$$P_r = \frac{P_t G_t A_r}{4\pi r^2} = \frac{P_t k \ell^2}{4\pi r^2 \Omega}$$

Hence

$$\frac{P_t}{P_r} = \frac{4\pi r^2 \Omega}{k\ell^2} \tag{3}$$

Eq. (3) is independent of frequency, thus proving the proposition. For the case where the earth terminal provides hemispheric coverage, $\Omega = 2\pi$ and Eq. (3) becomes

$$\frac{8\pi^2 r^2}{k\ell^2} = \frac{P_t}{P_r} \tag{4}$$

The fact that the transmission loss is constant with frequency, except for hardware and weather effects, provides an interesting degree of freedom in design. For example, one may wish to size the spot beams provided by the spacecraft antenna so that each beam tends to provide service to the same number of subscribers. Since the density of subscribers is much greater in urban areas than in rural areas, one would then require narrow beams for cities and wider beams for the countryside. If this were done by using a fixed frequency in conjunction with adjustable beam spoiling techniques in the satellite, the inevitable result would be higher transmission loss due to beam spoiling. However, the desired result could be achieved by use of a higher frequency in city areas relative to rural areas without (to a first order) a loss penalty.

Nevertheless, discussed previously, the use of higher frequencies entails penalties because of higher rain losses and higher hardware losses.

3.2.2 Link Calculations

A link calculation was performed for the uplink because it was felt that the uplink was probably the limiting one in the communications chain due to the very limited user power and antenna size. A typical uplink budge is shown in Table 3-13. A number of assumptions are made that require explanation. First, the user transmitter power of 250 mW was selected and a satellite antenna of 220-ft dia was chosen. These numbers are not accidental but the result of careful thought that will be elaborated below after the discussion of the budget itself. A third assumption was a receiver noise temperature of 430°K in the satellite, which is the result of projecting uncooled field effect transistor (FET) preamplifiers to the 1987 state of the art. A number of other assumptions are as follows. The user terminal is assumed to have a zero dB gain antenna and be truly omnidirectional. The receiver bandwidth was chosen at about 14 kHz to support a voice channel, which was selected to operate with a variable-slope delta-modulation digital channel for reasons that will also be explained below. Under these conditions, it is seen that a signal-to-noise ratio of 8 dB is the minimum that would be expected in the link. This will be shown to be just adequate for a required minimum level of intelligibility of the digital voice, with a margin of 10 dB to take into account degradations, nulls in antenna patterns, fades, etc.

Table 3-13. Typical Uplink Budget

ITEM	QUANTITY	GAIN (dB)	LOSS (dB)
USER TRANSMIT POWER	250 MW		6 dBW
FEED LOSS	-		0.2
TRANSMIT ANTENNA GAIN	OMNI-DIRECTIONAL	0	0
FREE SPACE "LOSS"	-		198.7
RAIN ATTENUATION	-		0.3
POLARIZATION LOSS	-		3
EDGE OF CONTOUR LOSS	-		3
SATELLITE ANTENNA GAIN	220 ft DIA η = 55%, σ/λ = 32	68	
RECEIVED CARRIER LEVEL	W	-144.4 dBW	
RECEIVER NOISE TEMPERATURE	430 °K		26.3
RECEIVER BANDWIDTH	13.5 kHz		41.3
RECEIVER THERMAL NOISE	W/°kHz	228 8	
RECEIVER TOTAL NOISE	W	-161.1 dBW	
S/N	-	8 dB	
MARGIN (Voice channel)	-	10 dB	
MARGIN FOR ORDER WIRE (30 Hz bandwidth)		35 dB	

The link calculations were then repeated for a number of frequencies, keeping the size of the satellite antenna and the rest of the parameters constant, to ascertain the effect of rain attenuation at 10 mm/hr rate as well as equipment performance variations with frequency. A tabular listing of this calculation is shown in Table 3-14, which is plotted on Figure 3-11 as the carrier-to-noise power density in dBHz as a function of frequency.

The major assumptions involved in developing the link budgets are highlighted, as they are treated separately.

1. An uplink transmitter power of 250 mW is available.
2. Uplink thermal noise is the predominant noise source. A 1.0-dB degradation margin has been allowed for intermodulation noise.

Table 3-14. Uplink Budget

		Frequency, GHz					
		1 0	2 0	5 0	10	15 5	NOTES
TRANSMIT POWER	dBW	-6 0	-6 0	-6 0	-6 0	-6 0	250 mW
FEED LOSS	dB	0 1	0 1	0 2	0 4	0 6	
TRANSMIT ANTENNA GAIN	dB	0	0	0	0	0	
EIRP	dBW	-6 1	-6 1	-6 2	-6 4	-6 6	
FREE SPACE LOSS	dB	184 7	190 8	198 7	204 7	208 5	AT 5° ELEVATION
RAIN LOSS	dB	0	0	0 3	3 0	9 0	10 mm/hr
POLARIZATION LOSS	dB	3 0	3 0	3 0	3 0	3 0	
EDGE OF CONTOUR LOSS	dB	3 0	3 0	3 0	3 0	3 0	
UPLINK DEGRADATION MARGIN	dB	1 0	1 0	1 0.	1 0	1 0	
Σ UPLINK LOSSES	dB	191 7	197 8	206 0	214 7	224 5	
ANTENNA GAIN, SATELLITE	dB	53 8	59 8	67 8	73 8	77 6	220 ft dia, η = 55% σ/λ = 1/32
SATELLITE RECEIVING SYSTEM NOISE TEMP	°K	400	410	430	500	600	REFERRED TO ANTENNA FEED
$(C/N_0)_\mu$ = EIRP LOSSES + $(G/T)_{sat}$ -10 LOG k	dBHz	58 6	58 4	57 9	54 3	47 3	
$(C/N_0)_t$ = $(C/N_0)_\mu$ -1 0	dBHz	57 6	57 4	56 9	53 3	46 3	1 0 dB DEGRADATION DUE TO INTER-MODULATION

3. A 200-ft dia antenna is used in the spacecraft. Efficiency is 55 percent and surface accuracy is 1/32 wavelength rms.
4. The earth terminal antenna has zero dB gain.
5. A rain loss corresponding to 10 mm/hr rain rate is included.
6. Satellite receivers use projected 1990 state of the art FET preamplifiers (an uncooled paramp would be a fall-back position).

Figure 3-11 shows a horizontal line corresponding to a requirement for a 49.3-dBHz carrier-to-noise density ratio for a voice channel of acceptable quality. For the given assumptions it may be observed that any frequency up to 12.5 GHz will provide service that equals or exceeds the minimum requirement. However, the extra margin provided by the lower frequencies will be of great benefit. The multipath and blockage environment

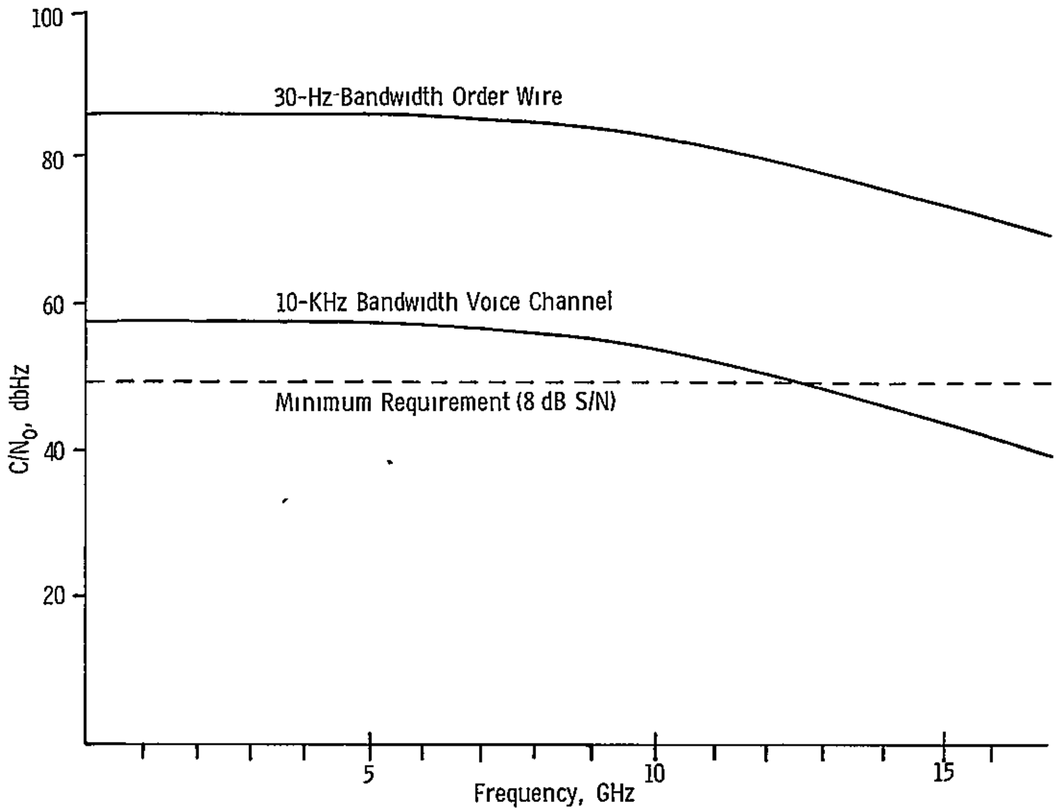


Figure 3-11. Link Performance vs. Frequency

in the vicinity of each user will cause the local fields to vary widely with small displacements of the wrist radio antenna. Worse yet, at any one position rapidly fluctuating fades may be encountered as a result of moving vehicles, aircraft, etc. Fade depths of as much as 20 dB may not be uncommon. The lack of any significant directivity in the wrist radio antenna will aggravate these multipath effects. The margin provided by the lower frequencies will reduce the percentage of outage time due to signal dropouts.

Should it be necessary to operate in the 15.5 GHz band, an additional 4 dB would be required to meet the minimum standard for an acceptable voice channel. To equal the performance attainable at 5 GHz, an additional 10.6 dB would be required. In theory, this increment can be obtained by means of higher transmitter power in the wrist radio and/or a larger satellite antenna. In practice, both of these avenues may be foreclosed by serious technical problems. The operation of the system at frequencies below 10 GHz is thus demonstrated to be desirable.

The determination of 220-ft or 67-m antenna size being required at the satellite was made on the following basis. The link budget can be interpreted in terms of a sliding scale relationship between the required satellite antenna diameter and the user transmitter power. Such a relationship is illustrated in Figure 3-12, and shows that to have a very small antenna in the satellite requires a very large transmitter power considering the size of the wrist radio package desired. Conversely, for powers in the order of 10 mW, the antenna diameter is in the order of 300 m. A calculation is shown in Section 3.2.6 in the ground segment definition that shows that if the user transmitter power is less than about 250 mW, the size of batteries that the package must contain will not be unreasonable for a wrist-mounted package — and yet will be able to sustain 4 min of continuous transmission per day without requiring recharging overnight. For these reasons, which are elaborated in Section 3.2 6, a design point was chosen at 67 m (220 ft) satellite antenna and 0.25 W user transmitted power into an omnidirectional antenna.

Due to the close coupling between the antenna, the power, and the resultant coverage as a function of frequency, the trades between these are shown plotted in Figure 3-13. In this figure, the number of beams required to contiguously cover the U.S. is shown as a function of the antenna diameter and the frequency of operation. Superimposed is the information from the last figure, the required user transmitter power as a function of antenna diameter. It is seen that operating with very small satellite antennas, say 3 m or so, that the beamwidth would be large enough that the number of beams required to cover the U.S., even at frequencies of 20 and 30 GHz, would only be several hundred - certainly a practical number — and much less at lower frequencies. However, the user transmitter power required would be about 100 W, an impractical number not only for transmitter reasons

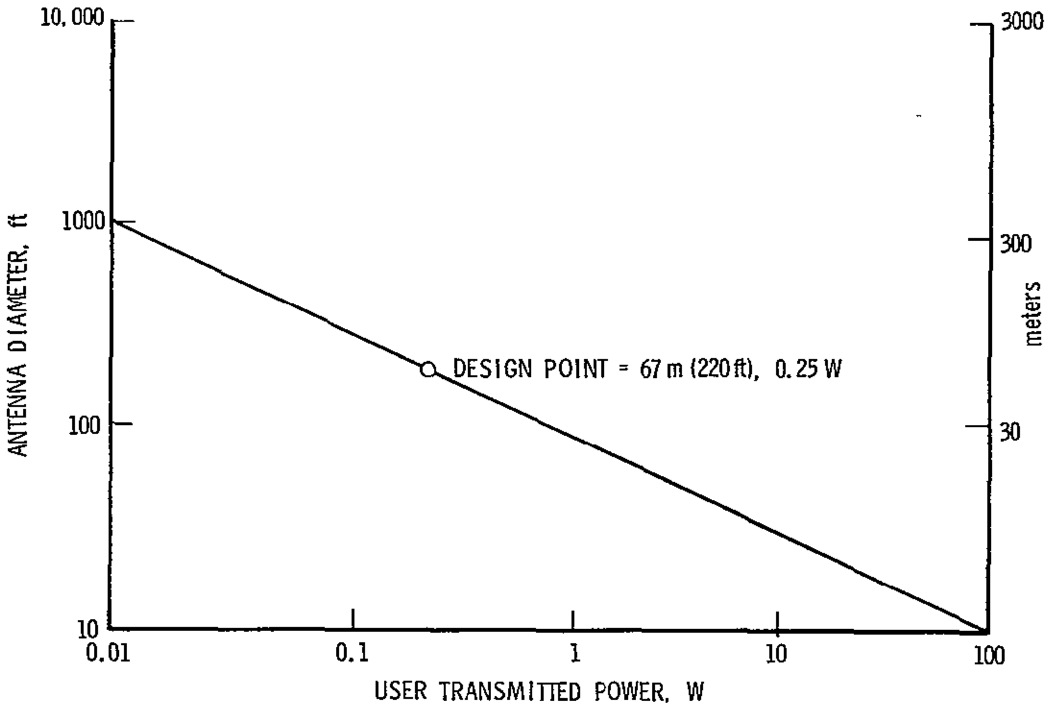


Figure 3-12. Required Satellite Antenna Size

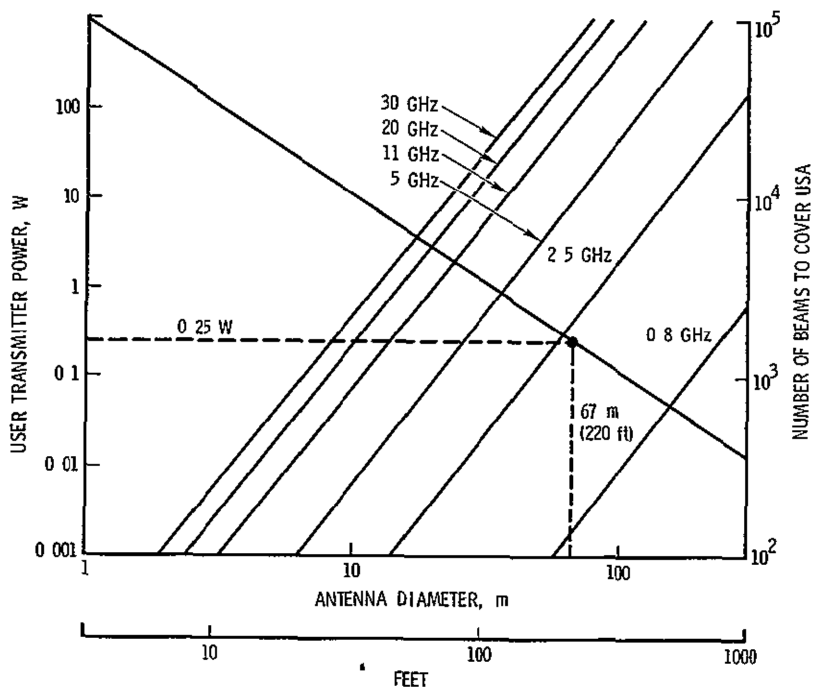


Figure 3-13. Antenna/Coverage/Power Trades

but particularly for battery reasons. On the other end of the scale, choosing an antenna diameter of over 100 m for the satellite, while resulting in a user transmitter power of less than 100 mW which is certainly desirable, results in a reasonable number of beams (a few thousand) only for frequencies less than about 2.5 GHz; while operation at the more desirable frequencies of 11 to 30 GHz results in a need for hundreds of thousands simultaneous beams and a tremendous proliferation of satellite equipment, which is certainly undesirable. For these reasons as well as those elaborated in Section 3.2.1 (Frequency Selection), a design point was chosen at 0.25 W and 67 m. This antenna, when operating at frequencies close to 5 GHz, would require approximately 6000 to 7000 simultaneous beams. While this is a large number, it is probably attainable in the time period.

Another major factor that was subjected to trade-off analysis was a selection of analog versus digital modulation of the voice signal. In order to make this selection, both theoretical and actual listening tests were analyzed. Quality comparisons were made between single sideband suppressed carrier (SSB) transmissions and variable slope delta modulation (VSDM). The SSB simulation was actually performed at baseband, since the process of high level carrier reinsertion and synchronous detection results in a linear translation of the SSB signal and noise from RF to baseband. Audio tapes using male and female voices were generated, corresponding to various signal-to-noise ratios in a band-limited channel (300 to 3000 Hz). Listeners were then asked to judge the quality of the recordings at various signal-to-noise ratios (SNR).

The VSDM comparisons were based on recordings previously made using two slightly different algorithms for varying the slope. These recordings were available at a variety of bit rates from 9.6 to 38.4 kbps. Unfortunately, these recordings were made in a system that provided error free transmission. Hence, only those distortions produced by quantizing effects could be heard, whereas one would have liked to also program various bit error rates (corresponding to different channel carrier-to-noise density $[C/N_0]$ ratios) into the results. Upon further consideration, this omission was found to not be as serious as first thought. From previous work, there is a great deal of information concerning the effect on intelligibility of bit error rates in VSDM systems having various bit rates. While the voice quality criterion used here is much more demanding than simple intelligibility score, the intelligibility results were quite instructive. It was shown that bit error rates as high as 5 percent produced no loss in intelligibility in VSDM. These data are reproduced here as Figure 3-14 and were obtained from Reference 4.

It appeared reasonable that if the error rate were one order of magnitude less than 5 percent, the quality impairment due to bit errors would be quite small. This assumption was found to be conservative if extrapolated to the SSB tests. There it was observed that an SNR of 10 dB sufficed to produce intelligible speech, while a 20-dB SNR gave more than adequate voice quality. Since the baseband noise power produced by bit errors is directly proportional to bit error rate, a 10-dB change in baseband SNR is roughly equivalent to an order of magnitude change in bit error rate (BER). Admittedly, the comparison is not exact because of the different nature of the two types of noise.

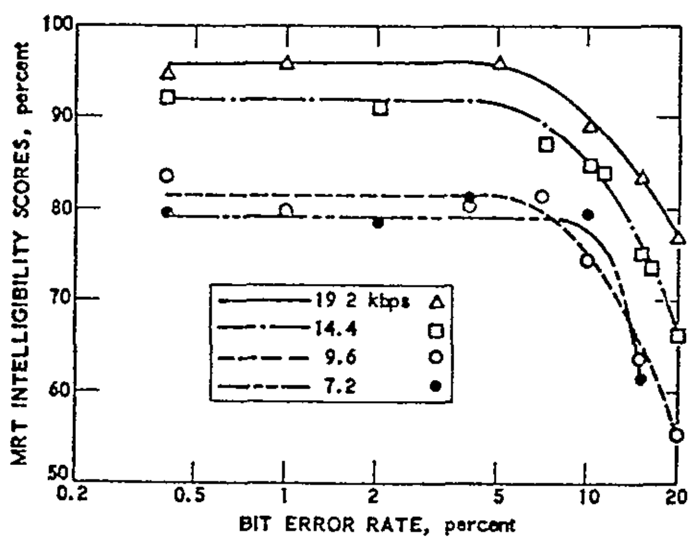


Figure 3-14. Intelligibility vs Bit Error Rate

If one assumes, tentatively, a maximum BER of 0.5 percent $= 5 \times 10^{-3}$ for a VSDM system offering reasonable voice quality, it is easy to show that the theoretical bit energy to noise density ratio (E_b/N_o) requirement is $E_b/N_o = 5.3$ dB. The important point is that the rate of change of BER with E_b/N_o is very rapid, due to the nature of the complementary error function. Hence, if the estimate of required BET turns out to be off by a factor of, say, 2 (3 dB in baseband noise power) the error in the required E_b/N_o is only about 0.8 dB, well within the hardware implementation margins generally allocated to digital modems. Hence, our working hypothesis will be toward a theoretical E_b/N_o requirement of 5.3 dB, to which an implementation margin of 2.5 dB will be added, for a net requirement of $E_b/N_o = 7.8$ dB.

We are now in a position to make a direct comparison of SSB and VSDM, assuming the same channel C/N_o. In an actual test, listeners found that SSB at an SNR of 10 dB was intelligible, while an SNR of 20 dB produced more than adequate voice quality while much noisier than a usual telephone line. It was the general consensus that an SNR of 15 dB would be taken as the minimum acceptable quality standard for an SSB channel. Since the channel under test was band-limited from 300 to 3000 Hz, the channel C/N_o corresponding to an SNR of 15 dB would be 49.3 dBHz. If one assumes the availability of a channel having a $C/N_o = 49.3$ dBHz, it is then possible to employ bit rates of up to 14.1 kbps, consistent with the assumption of an E_b/N_o requirement of 7.8 dB.

The closest comparison VSDM tapes were at bit rates of 9.6 and 14.4 kbps. While the 9.6 kbps rate provided intelligible speech, the quality was quite deficient. In comparison, a tape made at 19.2 kbps sounded almost as good as a tape made at 38.4 kbps. The latter was essentially "high-fidelity", with no noticeable quantizing noise. The 14.4-kbps tape sounded somewhere in-between the nearly unimpaired 19.2 kbps rate and the substandard 9.6 kbps rate. Hence, roughly, the 14.4 kbps tape provided that elusive minimum quality standard for VSDM that we were seeking to establish.

The requirement for 14.4 kbps VSDM compares with a capacity of 14.1 kbps on a channel having a C/N_o adequate to support an acceptable SSB channel. This difference is not significant, particularly if one considers the subjective nature of the evaluations. Moreover, VSDM is still in a technology growth area (as compared with SSB). There is reason to believe that the allocated modem implementation margin (2.5 dB) can be reduced, and improved algorithms for slope control may be found, so that within 10 to 15 years VSDM is likely to be less demanding than SSB with respect to channel C/N_o requirements. For the purposes of this study the C/N_o requirements of both systems will be taken as 49.3 dBHz.

The comparison between SSB and VSDM is not complete without mentioning channel bandwidth requirements. In this respect VSDM is more demanding. Telephone company practice is to allocate a 4.0-kHz slot per voice channel. The excess bandwidth beyond the usable voice frequency response is provided to permit economical voice band filtering, and to accommodate out of band signaling, in some instances. Assuming that doppler shift and frequency instability do not force use of wider bandwidths in the COMSAT application (this implies that the carrier frequency will be regenerated by a phase-locked system synchronized at both ends of the link), the 4.0-kHz bandwidth requirement can be accepted for the proposed system, if an SSB implementation is chosen.

The bandwidth for the VSDM system would ideally be matched to the pulse spectrum. However, as receiver predetection filters tend to approximate a rectangular shape, a commonly used rule of thumb is that the bandwidth should equal 1.2 times the symbol rate. For quaternary phase shift keying (QPSK), there are two bits per symbol and therefore the required bandwidth is 0.6 times the bit rate. For a bit rate of 14.4 kbps, the required bandwidth is therefore 8.64 kHz, or somewhat greater than twice the voice bandwidth. To simplify the filtering requirement, the bandwidth of VSDM/QPSK will be taken as 10 kHz.

As a result of the foregoing and the fact that use of digital transmission alleviates needs for linearity in all components and allows higher power to be used without fear of intermodulation distortion, it was decided that variable slope delta modulation would be adopted as the baseline modulation scheme on this study.

An additional feature shown on the link budgets is the margin for an order wire which is explained as follows. It will be recognized that a system containing a very large number of users requires some form of command order wire to request and allocate assignment of channel and time space as well as ringing to alert users being called. Not only need these channels not be voice bandwidth, but the fact that they can be narrow-band channels may be used to advantage in increasing their signal-to-noise ratio, which will be shown to be indispensible in system operation. An order wire was assumed at 30 Hz bandwidth - a bandwidth that would probably be attained by phase-locking a local oscillator in the user set to a beacon frequency in the satellite. The signal-to-noise ratio available for such an order wire was then calculated at a minimum of 35 dB plus 10 dB of margin. Whereas this seems extremely comfortable, it will be seen in Section 3.2.6 on Ground Segment that attenuation of the human body is very significant at these frequencies, and deep nulls may well exist due to the interference patterns caused by buildings or other obstructions. Thus the very high margin and signal-to-noise ratio combination of 45 dB is actually necessary in order to assure that the caller and callee may make their intentions of communicating known to a high probability regardless of location. Then the user orientation and location may be changed on a trial and error basis to get out of deep nulls until the voice bandwidth link can be satisfactorily closed. The operation of the order wire will be discussed in more depth in Section 3.2.4 under User Access, Discipline, and Operation.

3.2.3 Satellite Payload Block Diagram

A simplified block diagram of the spacecraft communications payload is shown in Figure 3-15. For convenience, separate transmit and receive multibeam antennas (MBAs) are shown. However, should it be feasible to cope with the passive intermodulation problems encountered with a common transmit/receive MBA, diplexers at each beam port would serve to separate the transmit and receive bands.

The use of multiple independent antenna beams permits potentially unlimited reuse of three frequency bands in a noninterfering manner. That is, no pair of adjacent beams need share the same frequency band if as few as three frequency bands are used. These are designated as f_1, f_2, and f_3 on the downlink and f_1', f_2', and f_3' on the uplink. The uplink and downlink frequency generators supply these frequencies to their respective distribution units.

All spacecraft frequency generators synthesize their required output frequencies using a reference derived from the master oscillator. In addition, each downlink beam will include as a vestigial carrier a frequency at either f_1, f_2, or f_3. These carriers are used at each ground terminal to

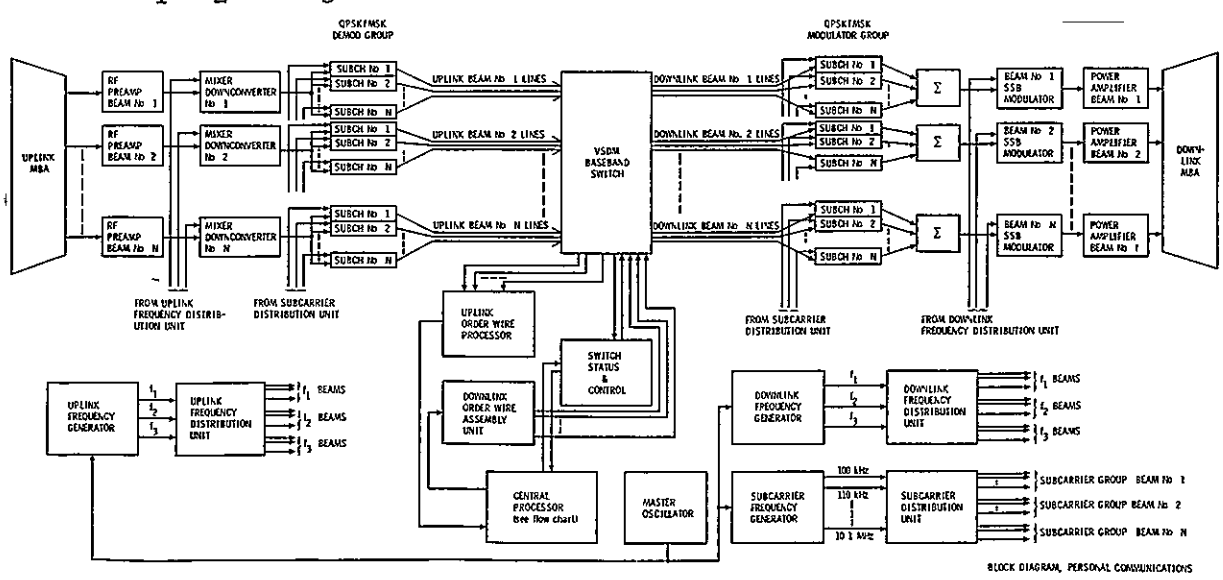


Figure 3-15. Personal Communications Wrist Radio System, Block Diagram

phase lock an oscillator that controls the local frequency synthesizer. Thus, all frequencies required in the spacecraft and the ground terminals are derived from a single frequency source.

Frequency division multiple access (FDMA) is used for uplinks and downlinks. Up to as many as 1000 uplink and 1000 downlink subchannels per beam (the number depending upon the user population within each beam footprint) can be employed. The subchannel frequencies are separated by increments of 10 kHz, from 100 kHz to 10.1 MHz. The subchannels appear as single sidebands of the respective uplink and downlink carrier frequencies.

Each baseband voice channel is encoded on the ground by a variable slope delta modulator (VSDM) at a 14.4 kbps rate. The resultant bit stream is modulated as a QPSK, or possibly some related from, such as minimum shift keying (MSK), on its respective subcarrier frequency. Since there are two bits per symbol, the resultant symbol rate of 7.2 kilosymbols per second is readily accommodated within its assigned 10 kHz subchannel.

Referring to the uplink multibeam antenna, each beam drives its own low noise RF preamplifier, which is tuned to its 10 MHz band (sufficient to encompass up to 1000 modulated subcarriers near either f_1', f_2', or f_3', as appropriate). The signals are downconverted, and the resultant groups of modulated subcarriers are amplified at IF. (Actually, the IF amplifiers more nearly resemble video amplifiers, in that their passbands extend from somewhat below 100 kHz to somewhat above 10.1 MHz). Each modulated subcarrier must be separated from the composite IF signal and demodulated to a baseband VSDM signal. While ordinarily a group of frequency selective filters tuned to individual subcarrier frequencies would be necessary to effect subchannel separation, the presence of a set of phase coherent references from the subcarrier distribution unit permits simplification of the predetection filtering requirement. A low pass filter following each demodulator eliminates the baseband components produced by the unwanted subcarriers.

The outputs of the demodulator group consist of a set of up to 1000 uplink VSDM baseband signals per beam. The total number of beams has been sized as 6930. The average number of baseband subchannels per beam is about 33, so that the number of baseband subchannel pairs is 230,000. (A subchannel pair consists of one uplink and one downlink subchannel, i.e., one half-duplex circuit, if the users are in the same beam. Hence, 230,000 such conversations can be carried on at one time. This represents 1 percent of the users served). The 230,000 uplink signals grouped within 6930 beams, must be switched into baseband VSDM lines that are assigned to downlink subchannels grouped around the appropriate 6930 downlink beams.

The uplink baseband lines are switched to downlink baseband lines in a 230,000 by 230,000 port switch to be described in Section 3.2.5.3. The output lines from the switch are terminated in individual QPSK or MSK modulators. Modulated subcarriers grouped by downlink beams are then summed on a common FDM bus per beam. Each FDM group is then frequency shifted to the desired output frequency by a single sideband vestigial carrier modulator. The carrier frequency appropriate to each downlink beam (either f_1, f_2, or f_3) is obtained from the downlink frequency distribution unit. One power amplifier per beam boosts the composite signal to the required EIRP level, delivering its output to the appropriate input port of the multibeam antenna. Power amplifiers in various module sizes are used, since the number of downlink channels per beam will depend on the user population within its footprint.

The transmitter power in the satellite is 0.5 W per channel. This power is selected so that the uplink will be the dominant noise contributor, however, if it were desired to regenerate the digital data stream it could be readily accomplished and the power reduced to 0.25 W per channel. It is not clear at this point whether the transmitters should all be 0.5 W with one output per channel adding at RF in the waveguide leading to the diplexer and feedhorns, or whether one power amplifier should be used per beam with the various amplifier powers then being selected to match the number of channels per beam. The largest power output required in the latter mode would be just short of 400 W, but there would be less than 7000 total amplifiers as contrasted with 230,000 amplifiers of 0.5 W each. Further study will be required to choose among these two choices.

3.2.4 User Access/Discipline/Operation

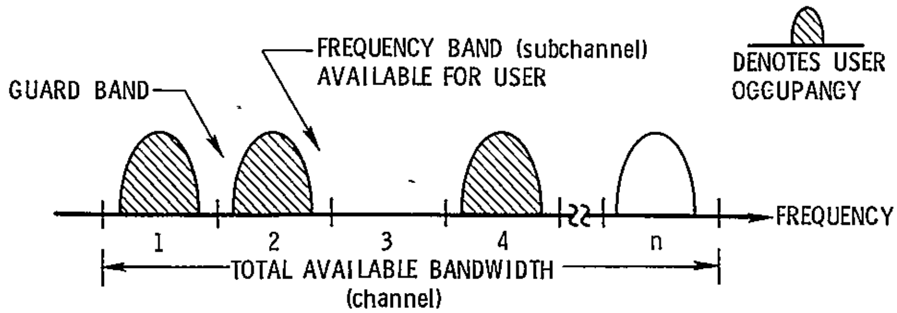
The Personal Communication System is to operate with a very large number of users, larger than any yet considered for a satellite multiple access communications network. A number of thoughts are offered for the choices and recommendations for user access and discipline in the network. Then a preferred technique is selected, and the overall operation of the concept is described.

3.2.4.1 Access Techniques

A number of multiple access techniques exist to provide a means to accommodate a number of transmissions in a common meeting. A basic requirement to allow separation and recovery of the various users' signals is signal orthogonality. Potential techniques include frequency division (FDMA) in which unique frequency band assignments are made, time division (TDMA) in which unique time slot assignments are made, code division (CDMA) in which unique signal structure assignments are made, or combinations of any or all of the above. The basic characteristics of FDMA, TDMA, and CDMA are illustrated in Figures 3-16, 3-17, and 3-18.

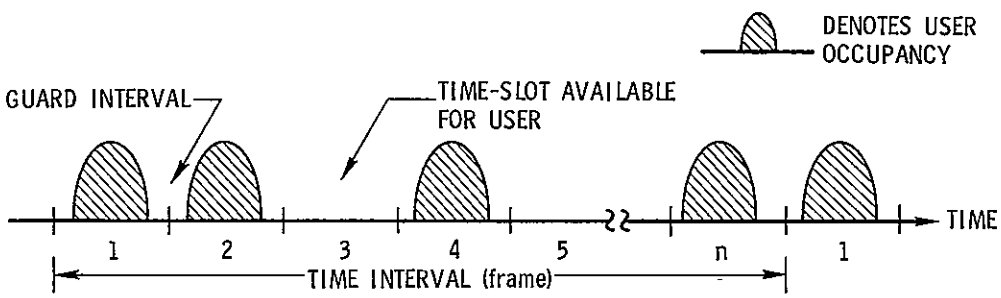
Examples of combination systems are very common. For instance, citizens band radio is fixed FDMA and random TDMA, amateur radio is random FDMA and random TDMA, the INTELSAT IV is FDM/FM/FDMA, whereas the FLTSATCOM is preassigned FDMA and TDMA.

A number of system operation considerations are now considered that vary for the different kinds of access techniques. These considerations are listed in Table 3-15. It is seen that code division multiple access is very powerful in that no cooperation of any sort is needed in operation of the system. However, the hardware and synchronization difficulties can be large. A number of user considerations need also be



- UP TO n USERS MAY OCCUPY THE CHANNEL SIMULTANEOUSLY
- SIGNAL STRUCTURES IN DIFFERENT SUBCHANNELS MAY BE DISSIMILAR
- SEPARATION AND RECOVERY EFFECTED BY ELECTRONIC FILTERING
- GUARD BANDS AND MUTUAL INTERFERENCE MINIMIZED BY ACCURATE FREQUENCY CONTROL

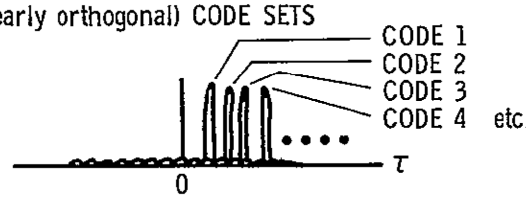
Figure 3-16. FDMA



- ONLY ONE USER MAY OCCUPY THE CHANNEL AT ANY TIME
- SIGNAL STRUCTURES IN DIFFERENT TIME-SLOTS MAY BE DISSIMILAR
- SEPARATION AND RECOVERY EFFECTED BY TIME-GATING
- GUARD INTERVALS AND INTERFERENCE MINIMIZED BY ACCURATE TIME CONTROL

Figure 3-17. TDMA

- SIGNALS ARE DISTINGUISHABLE BY THEIR INTRINSIC STRUCTURE (code)
- EXAMPLES OF ORTHOGONAL (or nearly orthogonal) CODE SETS
  - PSEUDORANDOM CODES
  - BIORTHOGONAL CODES
  - GOLD CODES



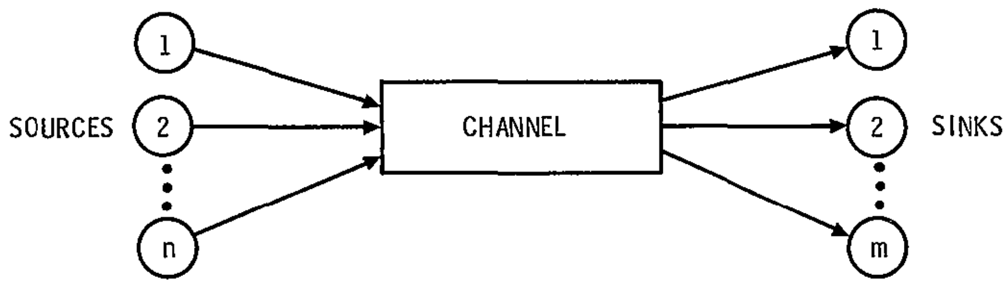
- ANY NUMBER OF USERS MAY OCCUPY THE ENTIRE CHANNEL AT ANY TIME
- SEPARATION AND RECOVERY EFFECTED BY CROSS-CORRELATION WITH A RECEIVER-GENERATED REPLICA OF THE DESIRED CODE
- A DEGREE OF MUTUAL INTERFERENCE WILL EXIST, INCREASING WITH THE NUMBER OF SIMULTANEOUS USERS, IF
  - THE CODE SET IS NOT PURELY (mathematically) ORTHOGONAL
  - PRACTICAL CONSTRAINTS PREVENT CORRELATION OVER THE ENTIRE ORTHOGONALITY INTERVAL
- EXAMPLES - GLOBAL POSITIONING SYSTEM (gold codes)
  - PULSE ADDRESS MULTIPLE ACCESS (low duty-cycle time-hopping using pseudorandom codes)

Figure 3-18. CDMA

Table 3-15. System Considerations

	NETWORK DISCIPLINE	RECEIVER ADDRESSING
FDMA/TDMA	USERS MUST ADHERE TO TIME/FREQUENCY ASSIGNMENTS OR RESPECT OTHER USERS' PREEMPTION OF TIME/FREQUENCY SLOTS	TYPICALLY BY PREASSIGNED TIME/FREQUENCY SLOT "RECEIVER BUSY" CONDITION IS USUALLY APPARENT
CDMA	NO INHERENT COOPERATION REQUIRED	PREASSIGNED CODE TRANSMITTER/RECEIVER CODE SYNCHRONIZATION CAN BE DIFFICULT AND TIME-CONSUMING "RECEIVER BUSY" CONDITION CAN BE DIFFICULT TO DETERMINE

discussed and these are illustrated in Figure 3-19 where it is seen that the way in which the sources are to be connected to the sinks may be varied and will greatly influence the choice of access technique. This access can be controlled or uncontrolled but in either case, for the Personal Communication System it must be dynamic rather than predetermined and fixed. If the uncontrolled access technique, users access the channel with little or no regard for other transmissions. Under these characteristics, FDMA and TDMA systems degrade rapidly beyond the saturation level due to extensive mutual interference, whereas CDMA systems degrade gracefully and exhibit no clear-cut saturation level, i.e., provided that the code set or distinguishable code phases are not exhausted. In practice this can be met.



- COMBINATIONS
  - ONE-TO-ONE
  - ONE-TO-MANY (broadcasting)
  - MANY-TO-ONE (reporting)
  - MANY-TO-MANY (conferencing)
- CHARACTERISTICS
  - MESSAGE LENGTH - SHORT, INTERMEDIATE, LONG
  - MESSAGE INITIATION - REGULAR (periodic), PRESCHEDULED, RANDOM
- NUMBER OF USERS (n + m) VERSUS NUMBER OF AVAILABLE ACCESSES
  - NUMBER OF USERS ≤ ACCESSES → (semi-) PERMANENT TIME/FREQUENCY/CODE ASSIGNMENTS
  - NUMBER OF USERS > ACCESSES → DYNAMIC ASSIGNMENTS

Figure 3-19. User Considerations

Controlled modes recognize that some authority will assign the access to the time and frequency space. This is often termed "demand assignment" and capitalizes on the random nature of access requests. Three features are key in its capitalization. First, the channel capacity should exceed the average number; second, the peak demand may exceed the capacity; and third, this implies access refusals, delays, and/or queues at times of peak activity that must be tolerable in system operation. Optimum design thus depends on trade-offs between economic factors and user satisfaction. For example, channel quality, message delays, minimum length, message time slots, etc. The design decisions for controlled access are generally based on subjective evaluations and intuition as analytic techniques are still very primitive.

A number of dynamic assignment techniques are known and have been analyzed, simulated, and operated in the past.. These are shown in Table 3-16. In considering which of these is best applied to the Wrist Radio Personal Communications System, the characteristics of such a system have to be summarized. This is shown in Table 3-17. The two main choices appear to be DCMA with pure ALOHA and FDMA/TDMA. Implementation of CDMA with a pure ALOHA access is attractive in that the spaceborne equipment can be very simple and the need for network control is minimal. However, the code generators and correlation receivers seriously complicate the user equipment particularly due to the small space available. The transmitter receiver synchronication would be difficult, time consuming, and extend the apparent channel occupancy and there is no satisfactory method to signal a receiver busy condition. For these reasons the configuration selected is a combination of FDMA/TDMA with demand access via a reservation ALOHA system.

The combination of FDMA and TDMA makes best utilization of a wideband channel by many narrowband, low duty cycle users. The frequency and time synchronization is readily obtained via a satellite beacon broadcast, and the user hardware is very simple. The demand access via

Table 3-16. Dynamic Assignment Alternatives

- ALOHA (uncontrolled)
  - USERS TRANSMIT WHENEVER THEY DESIRE
  - LISTEN FOR RECEIVER ACKNOWLEDGEMENT
  - IF ACKNOWLEDGED, RETRANSMIT AFTER RANDOM DELAY
- SLOTTED ALOHA
  - SAME AS PURE ALOHA, EXCEPT THAT ONLY DISCRETE TIME/FREQUENCY SLOTS ARE PERMITTED
- RESERVATION ALOHA
  - CERTAIN TIME/FREQUENCY SLOTS ARE RESERVED FOR ACCESS REQUESTS, USUALLY ON A PURE ALOHA BASIS
  - WHEN AN ACCESS REQUEST IS GRANTED, DISCRETE TIME/FREQUENCY SLOTS ARE ASSIGNED EXCLUSIVELY TO THIS USER
  - ASSIGNMENTS MAY BE DISCRETE OR RANDOM (but usually with a limited duration)
- POLLING
  - USERS ARE QUERIED IN FIXED, SEQUENTIAL ORDER FOR ACCESS REQUESTS
  - REQUESTS ARE ASSIGNED TIME/FREQUENCY SLOTS (like Reservation ALOHA)
- ROUND-ROBIN
  - CHANNEL CAPACITY IS DIVIDED INTO OWNED AND OPEN SLOTS
  - AT LEAST ONE OWNED SLOT IS ASSIGNED TO EVERY USER
  - USERS REQUIRING MORE CAPACITY THAN THEY OWN MAY REQUEST ADDITIONAL SLOTS VIA A PORTION OF THEIR OWNED-SLOT MESSAGE(s)
  - ADDITIONAL SLOT ASSIGNMENTS FROM EITHER THE OPEN POOL OR FROM SLOTS OWNED BY INACTIVE USERS WILL BE MADE IN A SEQUENTIAL (Round-Robin) MANNER, UNTIL ALL REQUESTING USERS OBTAIN ONE ADDITIONAL SLOT
  - IF AVAILABLE, SECOND, THIRD, etc., SLOTS MAY BE ASSIGNED IN THE SAME MANNER
  - CONFLICTS OVER SLOTS OWNED BY PREVIOUSLY INACTIVE USERS ARE ALWAYS RESOLVED IN FAVOR OF THE OWNERS

Table 3-17. Wrist Radio System

- CHARACTERISTICS
  - EXTREMELY LARGE NUMBER OF USERS VASTLY EXCEEDING THE REALIZABLE CHANNEL CAPACITY
  - MESSAGES TEND TO BE OF SHORT DURATION, RANDOMLY INITIATED, AND INFREQUENT (low duty-cycle)
  - USER EQUIPMENT MUST BE SIMPLE, COMPACT, AND AS INEXPENSIVE AS POSSIBLE
  - NETWORK MUST BE IMPERVIOUS TO INTERFERENCE OR SUBJECT TO ABSOLUTE CONTROL; OTHERWISE, CHAOS (e.g., CB radio)

a reservation ALOHA system employs discrete frequency and random time slot assignments that are of fixed term duration. This minimizes channel utilization by any user and makes for a maximum of the number of users satisfied. The transmitter and receiver connections should be straightforward, utilizing satellite equipment for signal routing and switching. Access request messages could be expected to be extremely short and so the use of an order wire channel operated in the contention mode should be tolerable with very little mutual interference on requiests for channel at the same time be expected. The delay in making connections from caller to callee should approach that of a commercial long distance telephone, except possibly at peak traffic periods, depending on the number of channels available per number of users. This will be discussed in more depth in Section 3.2.6. And last, a busy signal is possible and relatively easy to implement via the order wire channels. For all of these reasons, a system of this type was chosen to be implemented in the design of this study.

3.2.4.2 Overall System Operation

In order to explain the operation of a system using FDMA/TDMA and a content ion order wire system, a flow chart was established to illustrate the logical sequence in which calls are handled by such a system. This chart is illustrated in Figure 3-20.

Entry into the flow chart is via the box labelled "caller sends request message." The final element in the flow chart is the box labelled "subchannels are restored to available status".

The system functions in one of two modes. Mode 1 is similar to normal commercial telephone practice. The caller "dials" the number of the called party. The system attempts to find an idle circuit (i.e. available uplink and downlink subchannels in the respective beams), and if the facilities are available, it completes the call by ringing through to the called party. If the facilities to complete the call are not available, the

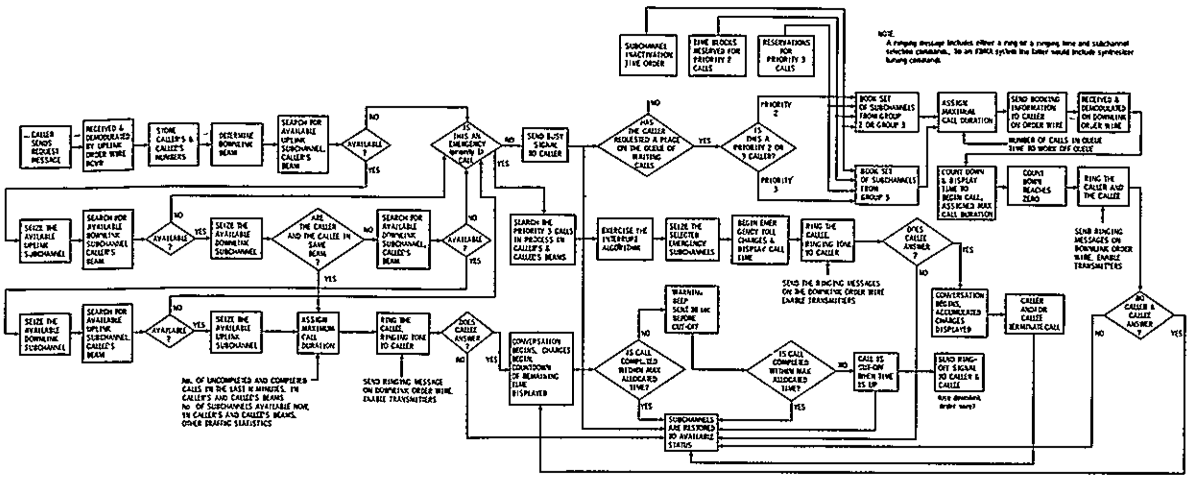


Figure 3-20. Personal Communications Wrist Radio System Flow Chart

system returns a busy signal to the caller*. In mode 1 the caller must call again at a later time, and repeat this process until he reaches his party. An exception occurs if the caller pushes the "emergency" (priority 1) button. In that event, the system searches the calls in progress in the caller's and callee's beam(s) and interrupts a call, diverting the subchannels thus seized to service the emergency call. The decision as to which call to interrupt is made through an interrupt algorithm stored in the satellite computer.

Every user can initiate an emergency call. However, the practice is discouraged by placing a sufficiently high surcharge on each emergency call, to minimize frivolous use and abuse of the system. The surcharge begins from the moment a call is interrupted, whether or not the callee responds to the emergency call.

Mode 2 does not require redialing any call (emergency or otherwise) in the event of a busy signal. Associated with each user is a priority classification. Most subscribers are designated as priority 3. A

*In this system a subscriber busy signal is never sent. For non-emergency calls a busy subscriber is treated as a subscriber who does not answer For emergency calls, the interrupt algorithm gives first choice to the subchannels occupied by the called party.

few subscribers are designated as priority 2. (It must be emphasized that priority 1, emergency service, is available to <u>any</u> user. However, <u>all</u> users are designated as either priority 2 or priority 3 subscribers. No user is a priority 1 subscriber). Any subscriber can place a mode 2 call. If he does and if the circuits are busy, his call goes into a queue at the same time he receives the busy signal. A mode 2 call placed by a priority 2 subscriber goes into a priority 2 queue. A mode 2 call placed by a priority 3 subscriber goes into a priority 3 queue. No calls will be placed from the priority 3 queue while there are competing calls waiting in the priority 2 queue. (A competing call is defined as one which requires the same facilities, i.e. beams, subchannels and switch connections for its completion). The order in which completing calls entered their respective priority 2 and 3 queues is not considered in this decision process. For example, the next call to be completed from the priority 3 queue may have been waiting one hour to get a circuit. If a competing call in priority 2 comes in one moment before the priority 3 call is placed, the priority 2 call goes to the head of the line. However, if the priority 3 call has already been placed, the priority 2 call will not interrupt it. It is obvious that is such a multi-priority queuing system is to work, the preponderance of users must be designated as priority 3. Otherwise, the priority 3 queue may never be served.

To place a call the caller inserts the number of the called party. He selects either mode 1, mode 2, or emergency, and presses the call button. This initiates a request message. The number of the called party includes the familiar area code plus seven digit number, the only difference being that the area code may not include four digits instead of the present-day three. The use of four digits permits a unique identification of up to 9999 beams within the area code -- enough to include all the beams required to provide service for the entire U.S.A. As an alternative the present system of three digit area codes may be retained. However, this would require a locator file to be stored aboard the satellite listing the correct beam number associated with each 10-digit subscriber number.

To store this locator file in binary decimal form for 25 million subscribers would require 1.4×10^9 bits of information. Should a subscriber move outside of his normal beam, he would have to initiate a temporary or permanent change in his locator file.

The request message will also automatically include the full identifying number of the caller. It is estimated that the complete request message will require the transmission of about 100 bits. It is transmitted to the satellite on an uplink order wire. Each beam can include up to 1000 uplink and 1000 downlink FDM subchannels, frequency shifted to the designated frequency band for that beam by a vestigial carrier. The subchannels that are in closest proximity to the vestigial uplink and downlink carriers are reserved as order wires. The request messages consist of unsynchronized burst transmissions in a contention mode. The bit rate is the same as the rate employed for the VSDM speech channels, 14.4 kbps. Hence the transmission of a complete 100 bit request message requires 6.94 msec. Assuming a worst case of a beam with 1000 subchannels and 100 subscribers per subchannel, with all subscribers originating one request message per hour, the probability that no more than one message is being transmitted at one time can be determined from a Poisson distribution to be 0.826. Since an appreciable percentage of request messages would in this case interfere with each other and not be received correctly, it may be anticipated that callers will redial, thus causing additional loading of the order wire, which could lead to a breakdown of service. Hence, it appears that more than one order wire will be required for beams servicing densely populated urban regions. This is not of itself a serious problem, since the order wire channels can be derived from the pool of communications channels, requiring less than 1 percent of them for this purpose.

As shown in the flow chart, the process of completing a call involves searching for available uplink and downlink subchannels in the caller's and callee's beams. If both parties are in the same beam, they can share the same uplink and downlink subchannels, since communication is provided on a half duplex basis.

Except for emergency calls, every call placed in the system has a maximum time assigned for its completion. This time is displayed on the wrist radio of each party, and is counted down toward zero during the time the circuit remains active. The maximum call duration assignment is the basic traffic management tool of the system. During off-peak hours the maximum call duration assigned would be generous -- perhaps as much as 10 min. As traffic builds up, the time assignment becomes shorter. Since most calls, to be useful, require some minimum time, the system will be programmed so as to never assign less than the predesignated minimum time (perhaps one min).

To establish the maximum call duration permitted at any time, the system looks at a window of recent traffic, perhaps the 10 or 15 most recent minutes of activity, in each area (beam group) served by the system. The system calculates and continuously updates basic traffic statistics during this time window. For example, the number of completed and uncompleted calls in each goegraphic area, the number (if any) of presently available subchannels in each area, and the trend (first derivative) of these parameters. These statistics are provided as input variables to an algorithm from which the maximum call duration assignment is calculated. The development of this algorithm will require the exercise of various traffic scenarios in a simulation model.

By virtue of the fact that a maximum call duration has been assigned for every call (except emergency calls) there is information residing within the system concerning the latest time at which every subchannel assignment is to be vacated. It is therefore possible for the satellite computer to organize the queue of waiting calls. Disregarding the priority 2 callers for the moment, calls are placed in queue in the order in which they are received. The system selects the first subchannels in the respective beams to become free (on the assumption that calls will last their maximum assigned duration) and reserves them for the first call in queue. As additional calls are added to the queue, subchannels are booked in the order in which they are expected to become free. The booking includes the telephone numbers of the caller and callee and the numbers of the reserved subchannels. A predetermination of the maximum allowed call duration for the booked call is made at this time. The time at which the call will be placed and the assigned maximum call duration is relayed to the caller on a downlink order wire and displayed on his wrist radio.

The existence of priority 2 callers forces some revision in the queuing procedure just described. The system will reserve a certain number of subchannels in each beam for allocation to priority 2 callers, in advance of such calls being placed. These reserved subchannels are selected from the first group of presently busy subchannels expected to become free. Priority 3 callers are not booked on this pool of subchannels. As priority 2 calls come in they are placed in queue to receive service from the block of subchannels reserved specially for them. As such reservations are made, the allocated number of priority 2 subchannels is replenished by looking ahead and picking the earliest subchannels to become free that have not yet been reserved. If subchannels allocated to priority 2 calls have not been requested at the time they become free, they are used to service real time (mode 1) incoming calls. Thus, available channel time is never wasted during the busy hour.

3.2.5 Satellite Segment Definition

In this section the satellite will be defined including the transponders, the antenna, the switch and processor, the power and propulsion systems, and the attitude control subsystem. The weights will be derived and a design described. A number of pertinent factors were considered, and studies performed to define what appeared to be the most reasonable way of satisfying the system requirements. In no case, however, was a true optimum or best trade solution suggested. Such trade studies and optimization investigations should be performed in the next serious iteration of system study.

3.2.5.1 Multibeam Antenna

The multibeam antenna is perhaps the single most unique and significant feature of the satellite, which together with the onboard switching device is absolutely essential for system operation. The reason for its existence is the fact that a large satellite antenna is required due to the low user transmitter power, the large antenna, and the high frequency combination making for a very small footprint. The small footprint of the antenna must then be replicated a large number of times to attain a reasonable coverage without losing the advantage of the large antenna itself. This replication, however, enables a great deal of frequency reuse to be otbained and works to the advantage of the system in general. The major requirements for the satellite antenna are to provide a number of simultaneous beams of the proper diameter on the earth with sufficient isolation between beams to allow frequency reuse and with the simplest possible structure to allow the maximum antenna gain and the minimum construction difficulty. The highlights of an analysis that was performed to these ends is discussed in this section with the details being shown in Appendix A.

The link calculations performed in Section 3.2.2 indicated the requirement for an antenna diameter of about 67 m, operating at a frequency of about 5 GHz. The footprint of this antenna, operated from synchronous equatorial orbit, was determined to be somewhat larger than 20 nmi diameter at the subsatellite point, as shown in Figure 3-21. In actuality, however, the satellite antenna aim point must be offset from the nadir depending on the latitude and longitude of the area to be covered. The latitude for the furthest north aim point is about 48 deg and the longitude difference between the subsatellite point and furthest aim point is about 6 deg if the satellite is positioned over one of the coasts, or about 3 deg if the satellite is positioned over the middle of the U.S. The actual beam footprint was calculated at the -3 dB contour points and is shown in Figures 3-22 through 3-25 for various geometries, with the satellite positioned over Los Angeles aiming at Dallas or Los Angeles, and with the satellite positioned

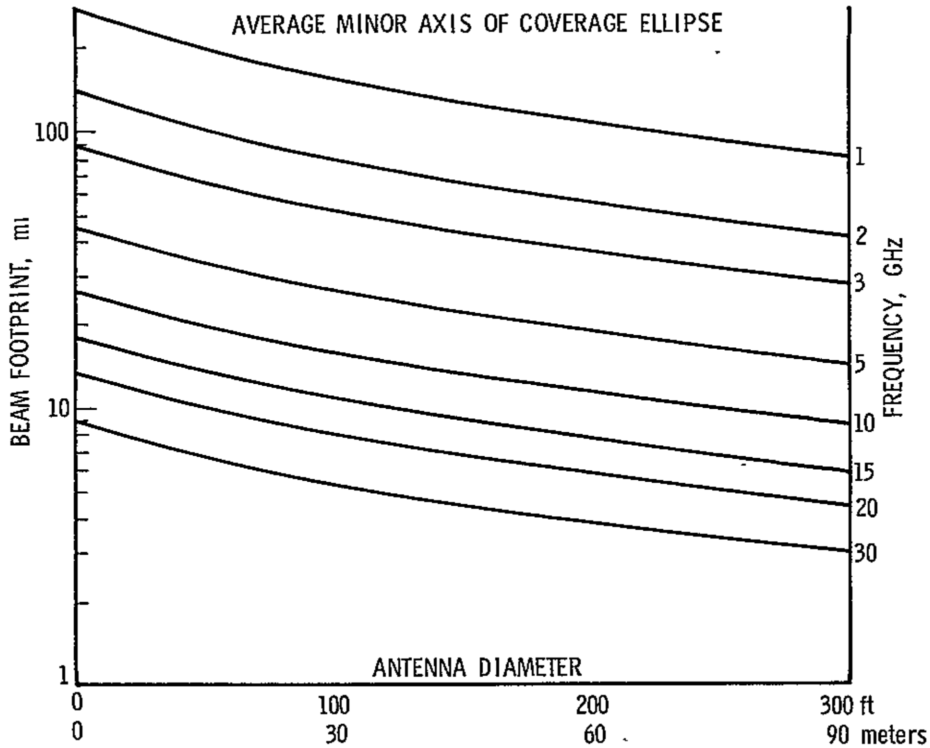


Figure 3-21. Beam Footprint on the USA from Synchronous Equatorial Orbit

over Dallas aiming at Boston. A further geometry was analyzed with the satellite positioned over Los Angeles and aiming at Seatlle. These figures indicate that the satellite footprint will vary from almost a circle to an elipse with a major-to-minor axis ratio of 1.5 to 2.5 depending on the geometry. The average area encompassed in these elipses is approximately equal to that of a 30-mi circular area and so that latter number was used in the remainder of the calculations.

In use, a multibeam antenna will allow frequency reuse due to the fact that nonadjacent beams can nominally operate on the same frequency providing that the sidelobe levels do not interfere. In principle,

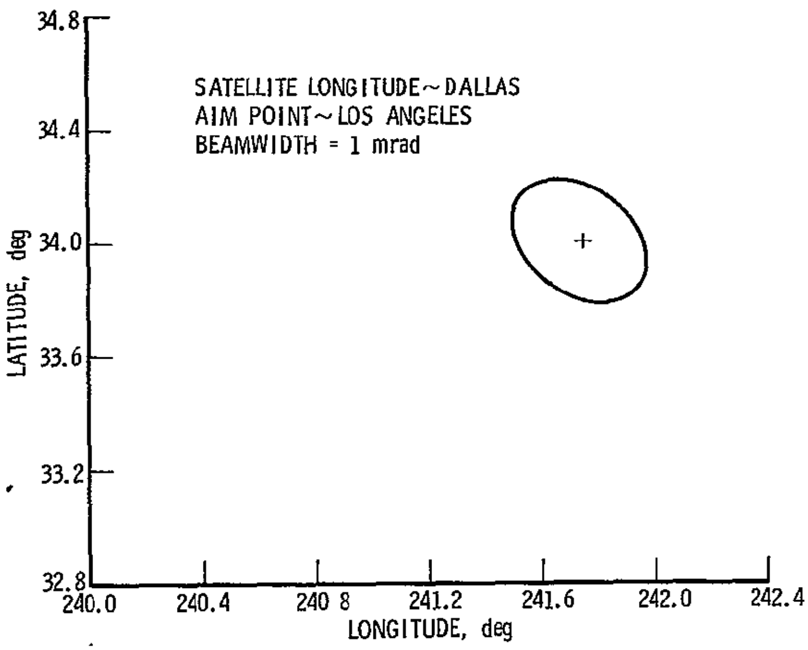


Figure 3-22. Instantaneous Power Contours

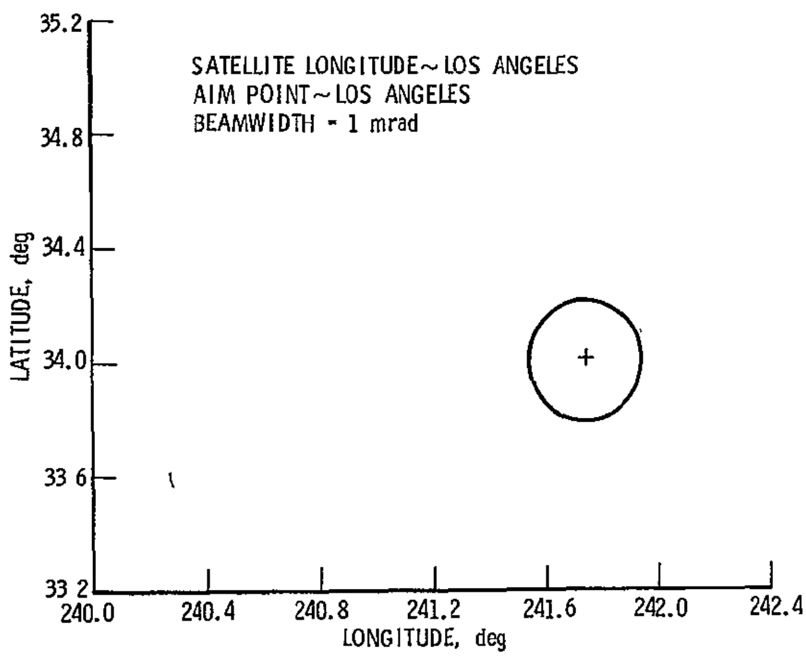


Figure 3-23. Instantaneous Power Contours

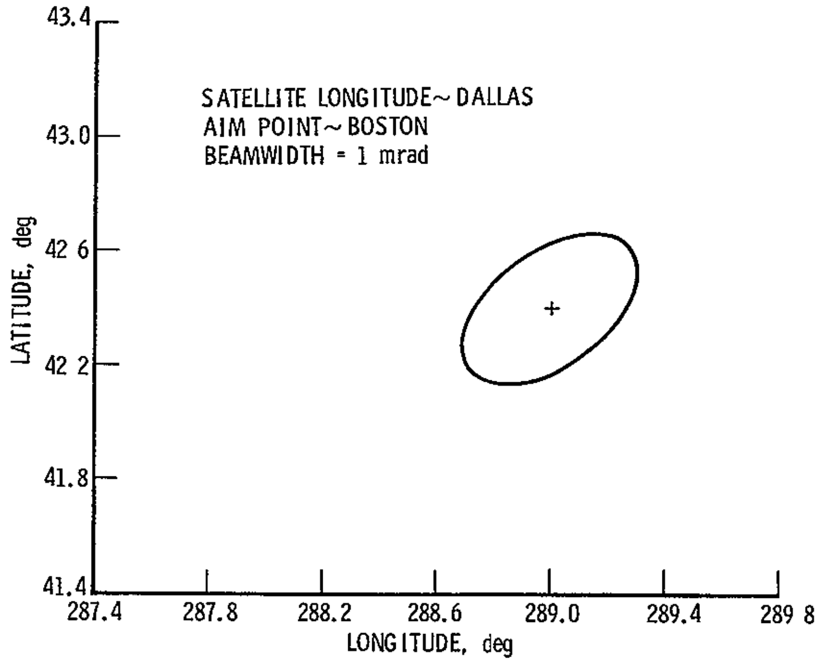


Figure 3-24. Instantaneous Power Contours

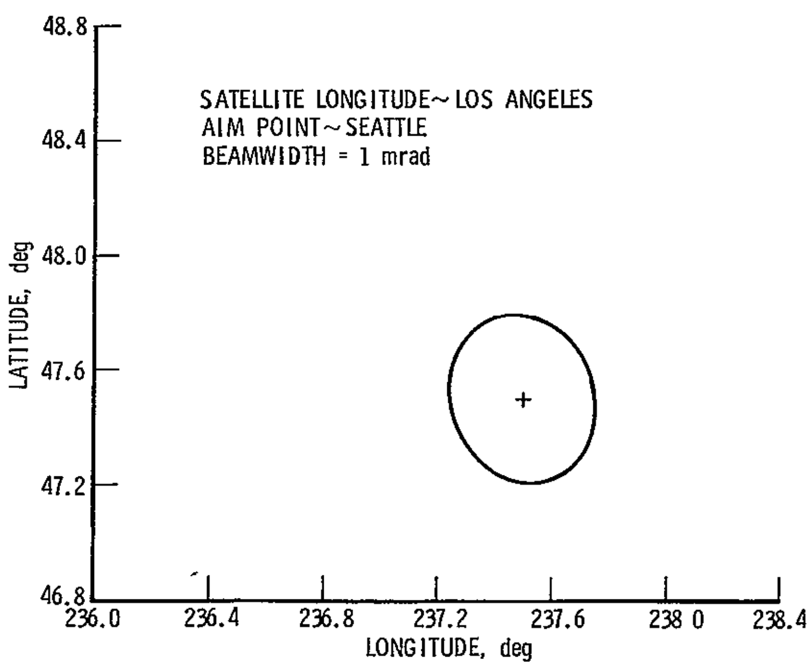
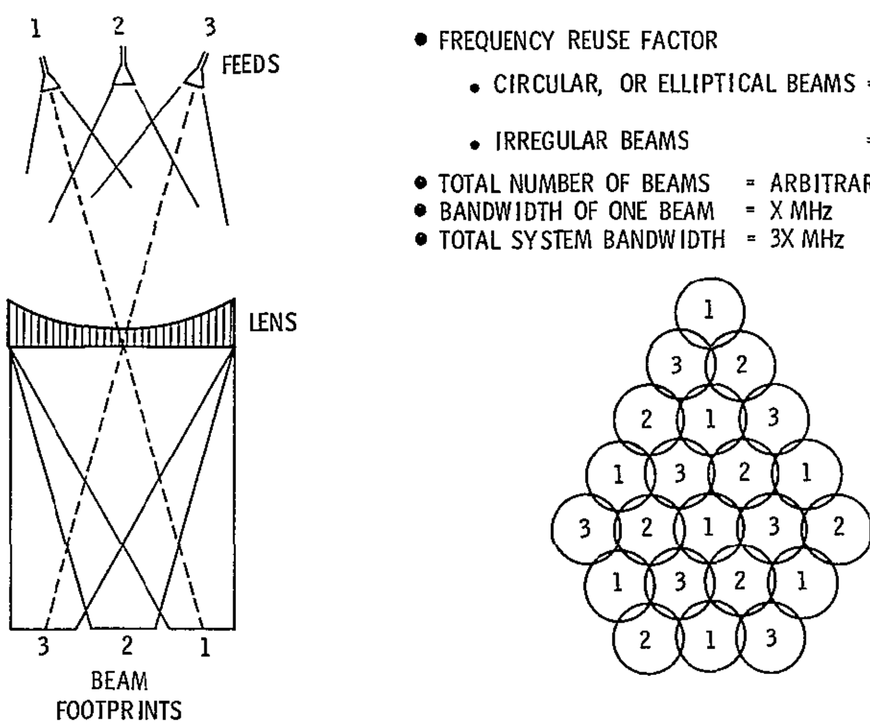


Figure 3-25. Instantaneous Power Contours

this is shown in Figure 3-26 where the illustrated antenna is a lens although a relfector antenna would be equivalent. In this case, it is seen that if a circular array of beam footprints is formed, three frequencies (one per beam) are adequate to cover an infinite of spots. This can also be extended to eliptical beams by analogy with the four color map problem - irregular shaped beams would require four frequencies. Thus, the total bandwidth occupancy of a set of eliptical beams is expected to be, as a minimum, three times the bandwidth occupancy of a single beam. In practice, multibeam antennas that have been analyzed and/or constructed have shown a frequency reuse ability approaching this number, the degree of closeness of approach being dependent on the sidelobe levels and the tolerable interference from neighbor beams.

The allowable level of the sidelobes is a function of how much tolerance there is for interference from all of the sidelobes of all of the other beams in the pattern. A worst case calculation was made in lieu of



- FREQUENCY REUSE FACTOR
  - CIRCULAR, OR ELLIPTICAL BEAMS = $\frac{\text{No. BEAMS}}{3}$
  - IRREGULAR BEAMS = $\frac{\text{No. BEAMS}}{4}$
- TOTAL NUMBER OF BEAMS = ARBITRARY
- BANDWIDTH OF ONE BEAM = X MHz
- TOTAL SYSTEM BANDWIDTH = 3X MHz

Figure 3-26. Multibeam Antenna and Frequency Reuse an antenna trade-off study, in which the total allowable sidelobe level from all the sidelobes of the antenna was plotted versus the first sidelobe level attained for two different interference level criteria. This plot is shown Figure 3-27. It is a set of contours with a given interference level (say 10 dB) that can be tolerated as a parameter. The average level of all the sidelobes permissible rises with a decrease in the energy from the first sidelobe level and vice versa. The conditions under which this was calculated were for a plus or minus 3 deg off-axis coverage, over 7000 beams, an allowance of 3 dB for duplex operation, and 3 dB for the peak-to-average levels of the sidelobes. The interference level was calculated as one first sidelobe plus 7265 divided by 3 to account for the number of beams on the same frequency and multiplied by the two factors of 3 dB.

The interference level that is considered tolerable is of course dependent on the signal-to-noise ratio available in the system. As seen by the link calculations in Section 3.2.2, the system normally operates with very low signal-to-noise ratios. It is thus expected that interference ratios

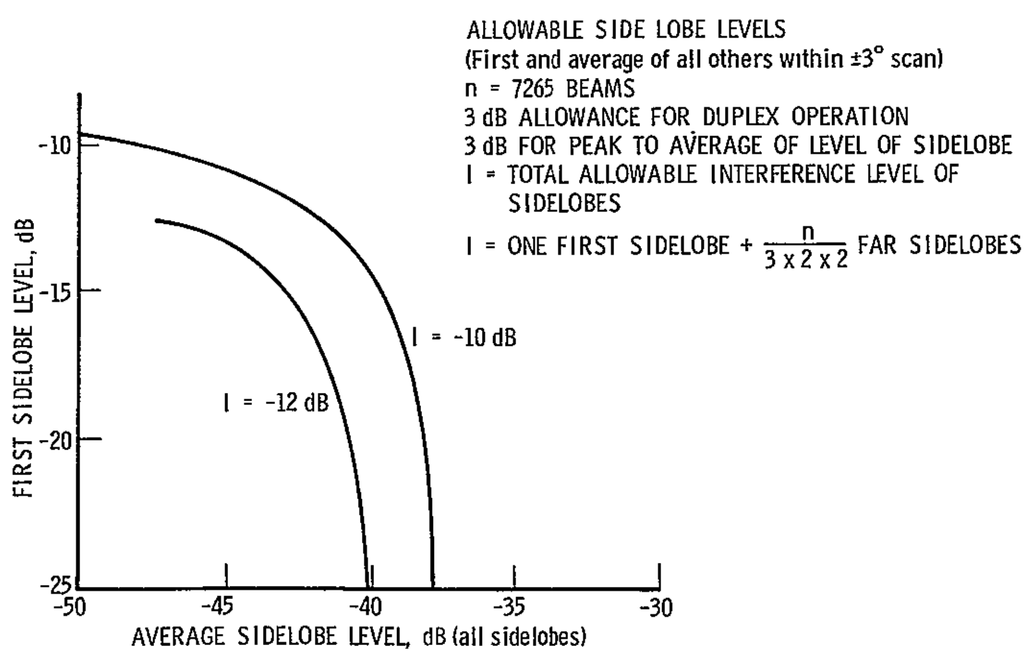


Figure 3-27. Allowable Sidelobe Levels

equally low will be tolerable, particularly since a digital stream is used. In fact, since the signal-to-noise ratio at the design point is 8 dB, Figure 3-27 is plotted for interference levels varying from 10 to 12 dB below the expected level of the signal or the main beam. This worst case calculation then indicates that in order for an interference level of 10 dB to not be exceeded, the average sidelobe level must be at least in the order of 40 dB down if the first sidelobe level of the antenna pattern is 13 dB down from the main beam. As will be seen from antenna patterns to follow, this is not such a tough requirement and can probably be met. Conversely, should the average sidelobe level rise above -37 dB, the first sidelobe level must not exceed -25 dB in order for the total interference to be tolerable.

The expected radiation pattern of the multibeam antenna was calculated, and appears in full in Appendix A. A portion of that material deals with the average and peak sidelobe levels expected for various types of antennas. As a prerequisite, the total scan angle or angel off the axis of the antenna was determined in a simplified manner for the CONUS, Alaska, and Hawaii and is shown in Figure 3-28. It is shown that a coverage of ±3 deg is the most that is required for coverage of the CONUS with a satellite longitude approximately over Dallas, and a latitude offset of about

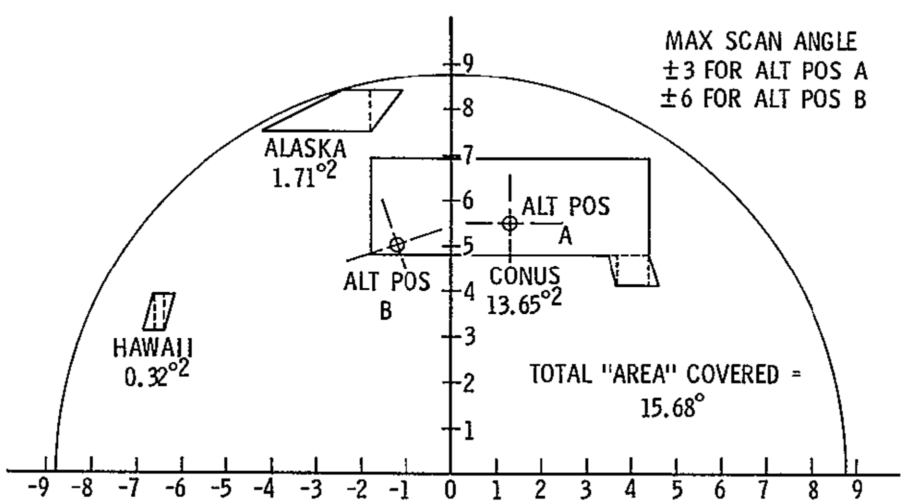


Figure 3-28. Angular Coverage Requirement of MBA

5.5 deg. Should coverage of Hawaii and Alaska also be desired, the satellite would be positioned over California with a latitude offset of about 5 deg; however, a ±6-deg scan angle would then be required. The beam pattern of an antenna of 1016 wavelengths diameter (approximately 200 ft at 5 GHz) was then computed for f/D ratios of 1 and 2 and two tapers of illumination -10 and -30 dB. The resultant antenna pattern plots are shown in Figures 3-29 through 3-32. Reviewing these figures it is seen that the comalobes come up very rapidly as the beam is steered off axis, with the peak of the first sidelobe being reached at an angle of about 2 deg in all cases in which the f/D is 1. For an f/D of 2, however, the peak is reached for the furthest off-axis scan.

The calculation for the average sidelobe level beyond the first two sidelobes was carried out for the f/D of 2 with taper of 30 dB case for the pattern 4 deg off axis. The average far sidelobe level for this pattern was calculated to be 48.4 dB below the mainlobe, thus exceeding the criteria shown in Figure 3-27.

There is a gain loss in scanning far off axis for the different configurations just considered, and these gain losses are shown as a function of scan angle in Figures 3-33 through 3-36. In these figures it is seen that a gain loss of at least 3 dB is incurred at angles of 3 deg or more off axis for both tapers with a f/D of 1; however, with antennas with f/D of 2 the gain loss is less than 1 dB at 3 deg off axis. This implies that in order to have high efficiency the antenna should be operated with an f/D ratio of at least 2.

The previous sets of curves have been assembled and summarized in tabular form in Tables 3-18 through 3-21 inclusive. Referring to these tables, it is seen that very good scanning performance and on-axis efficiency is obtained for antennas with f/D of 2 and particularly with an illumination taper of at least -10 dB and preferably -30 dB. At 3 deg off axis, a loss of less than 0.5 dB with a sidelobe or comalobe maximum of -15 dB should be realizable in this type of antenna. Also for performance

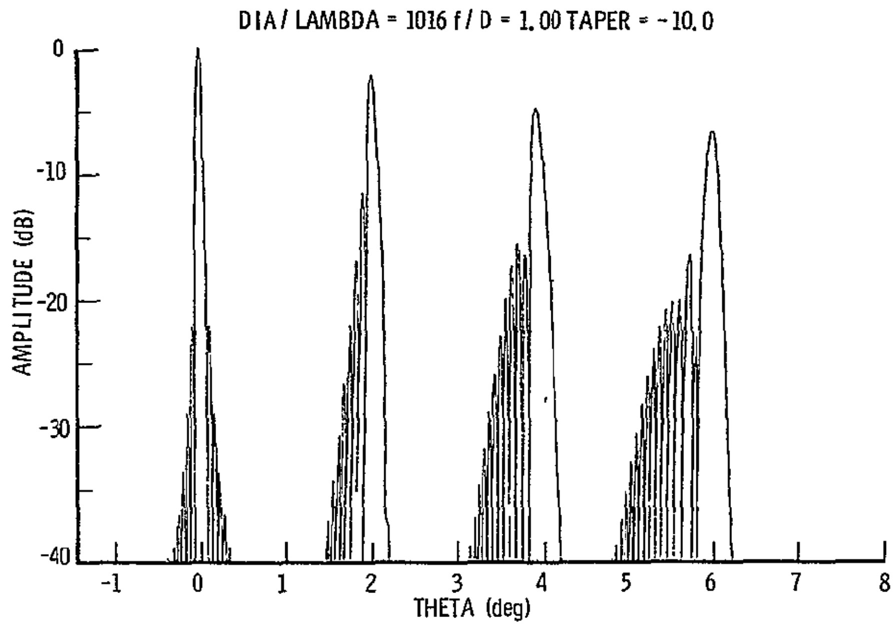


Figure 3-29. Radiation Pattern of a Paraboloid

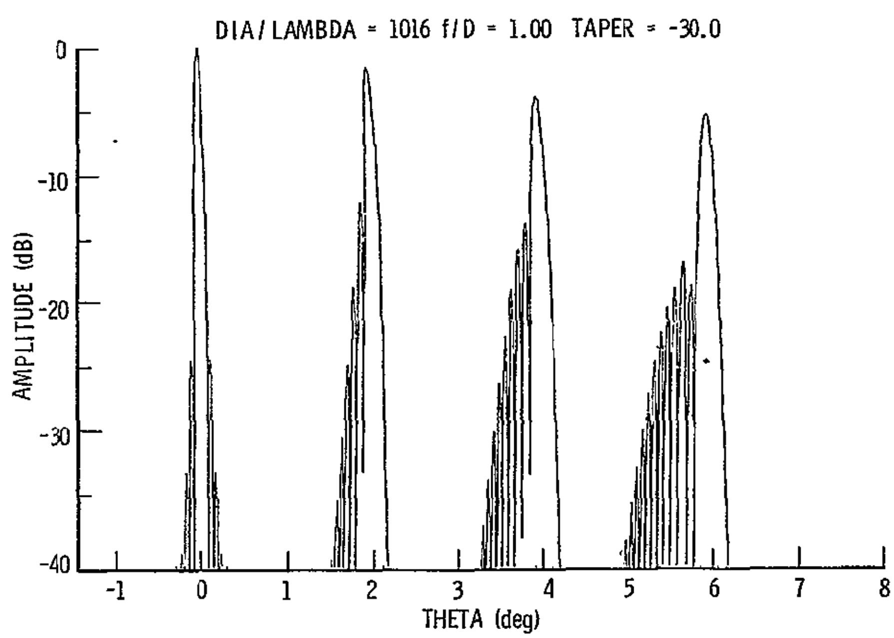


Figure 3-30. Radiation Pattern of a Paraboloid

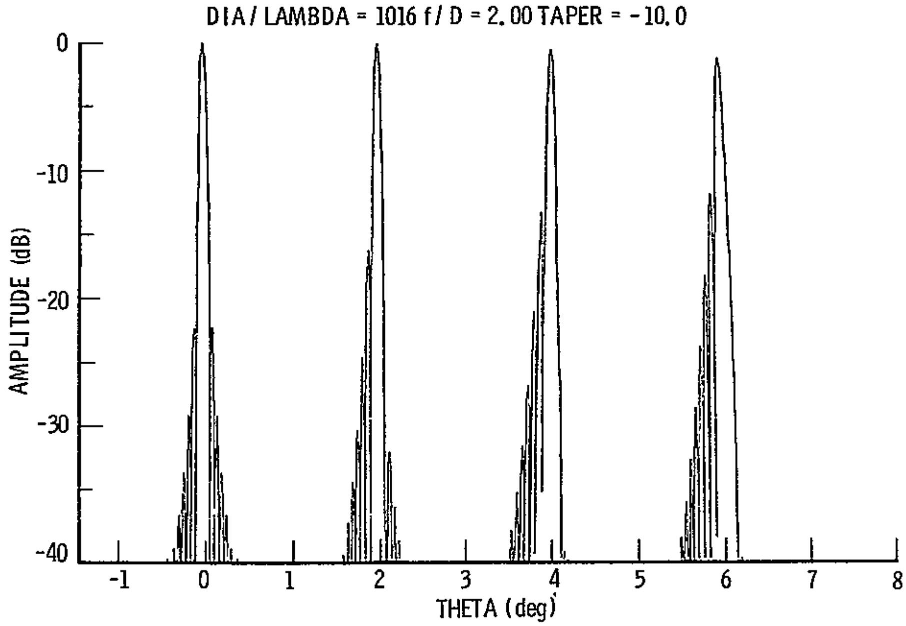


Figure 3-31. Radiation Pattern of a Paraboloid

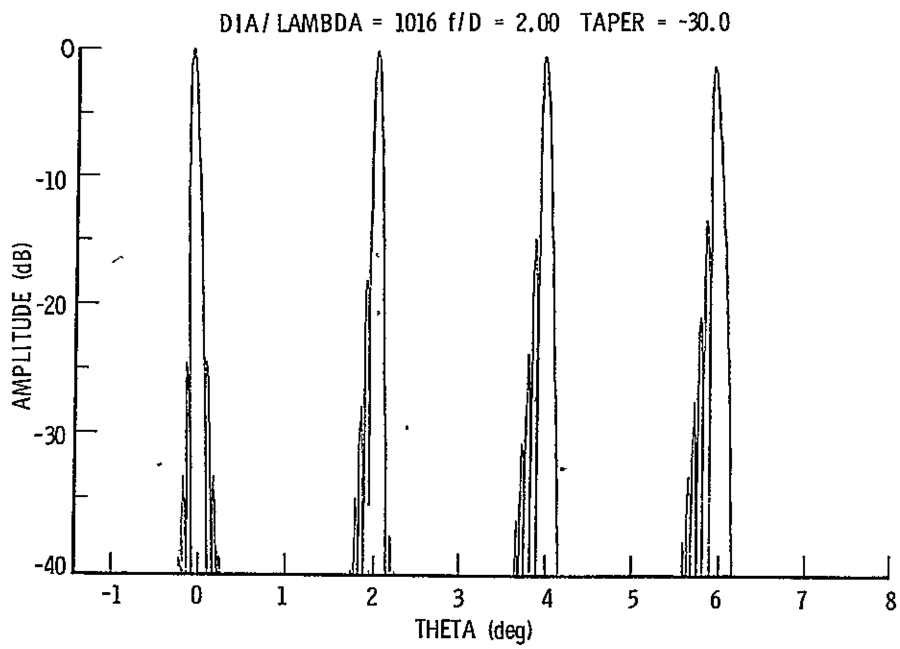


Figure 3-32. Radiation Pattern of a Paraboloid

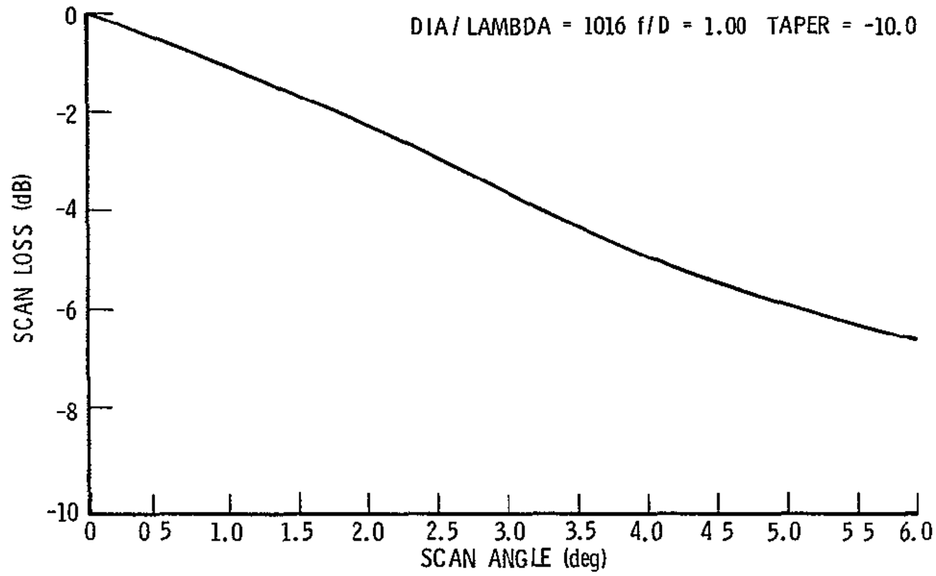


Figure 3-33. Gain Loss Curve

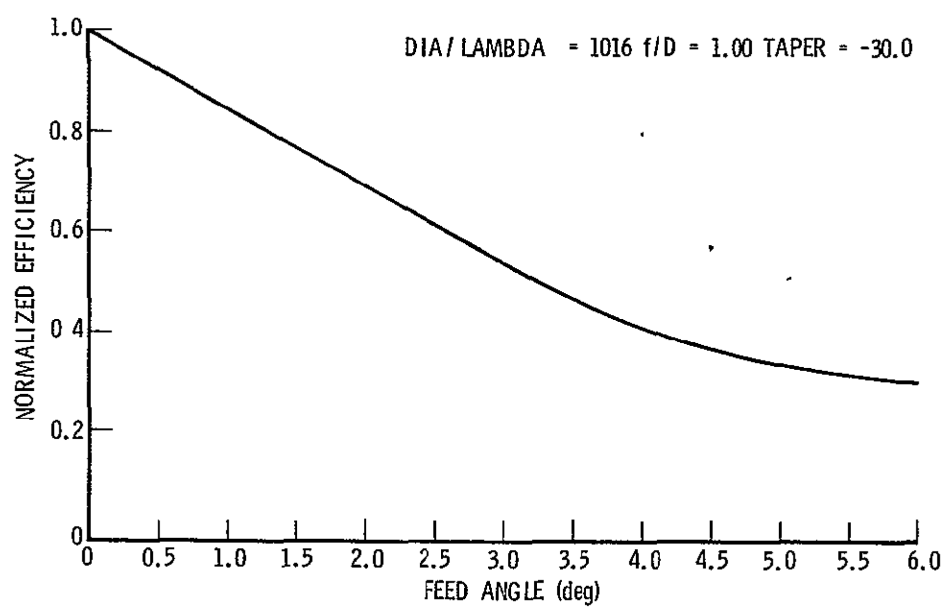


Figure 3-34. Gain Loss Curve

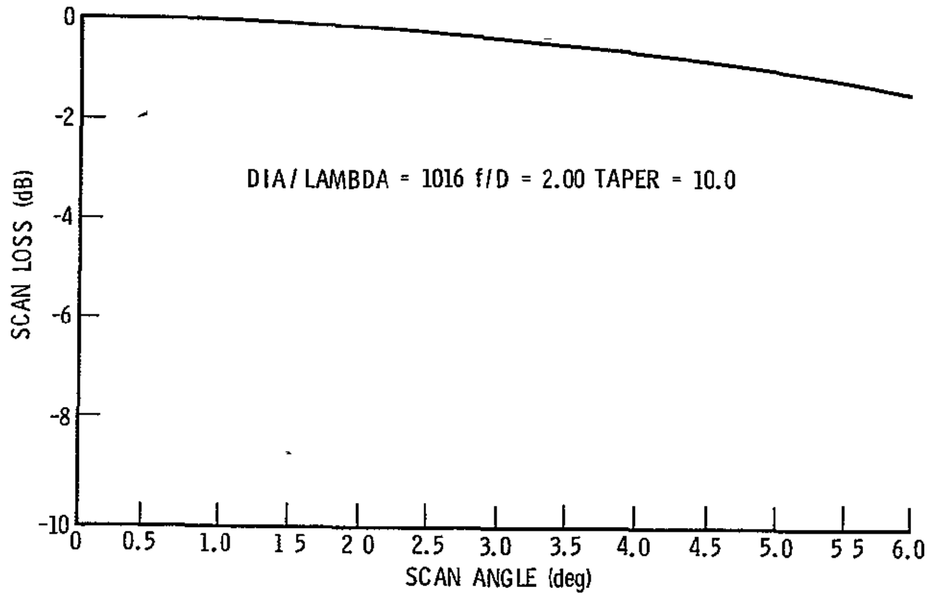


Figure 3-35. Gain Loss Curve

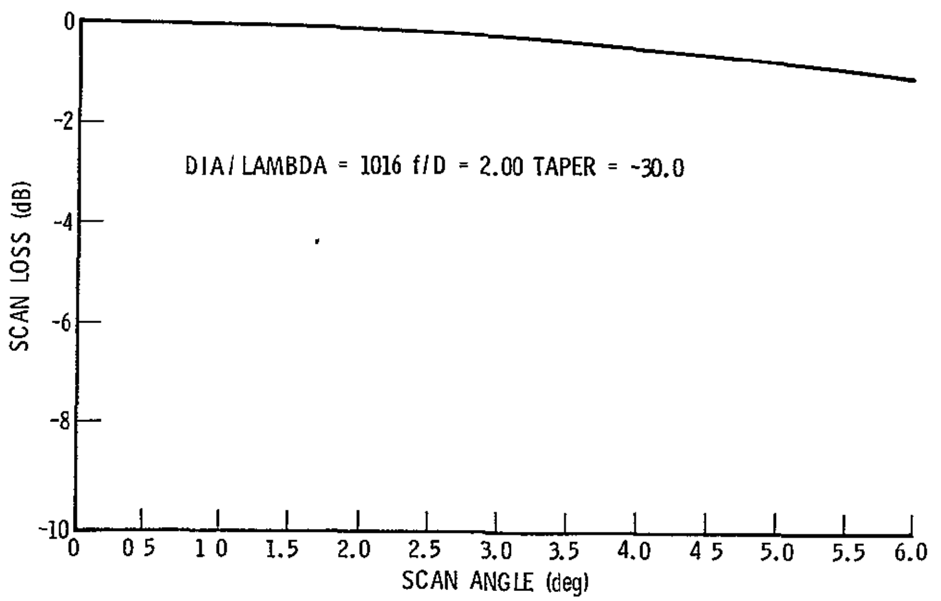


Figure 3-36. Gain Loss Curve

Table 3-18. Performance Summary of Paraboloidal Designs

CASE I

(a) GENERAL DESCRIPTION

REFLECTOR DIAMETER	200 ft (1016λ at 5.0 GHz)
f/D RATIO	1.0
APERTURE ILLUMINATION TAPER	-10 dB

(b) ON-AXIS PERFORMANCE

APERTURE GAIN (maximum)	70.1 dB
ON-AXIS DIRECTIVITY	69 7 dB
ILLUMINATION EFFICIENCY	91.3%
HALF POWER BEAM WIDTH	0.065°

(c) SCANNING PERFORMANCE

FEED ANGLE	0°	2°	4°	6°
BEAM ANGLE	0°	1.93°	3.92°	5 93°
BEAM DEVIATION FACTOR	-	0.97	0.98	0.99
SCANNING LOSS (dB)	-	-2.21	0.98	-6 65
SIDE LOBE/COMMA LOBE (dB)	-22 20	-9.30	-10 90	-9 90

Table 3-19. Performance Summary of Paraboloidal Designs

CASE II

(a) GENERAL DESCRIPTION

REFLECTOR DIAMETER	200 ft (1016λ at 5.0 GHz)
f/D RATIO	1.0
APERTURE ILLUMINATION TAPER	-30 dB

(b) ON-AXIS PERFORMANCE

APERTURE GAIN (maximum)	70.1 dB
ON-AXIS DIRECTIVITY	69.0 dB
ILLUMINATION EFFICIENCY	77%
HALF POWER BEAM WIDTH	0.071°

(c) SCANNING PERFORMANCE

FEED ANGLE	0°	2°	4°	6°
BEAM ANGLE	0°	1.94°	3.92°	5.93°
BEAM DEVIATION FACTOR	-	0 97	0.98	0 99
SCANNING LOSS (dB)	-	-1.59	-3.88	-5.22
SIDE LOBE/COMMA LOBE (dB)	25.50 dB	-11.60	-10.10	-11.80

Table 3-20. Performance Summary of Paraboloidal Designs

	CASE III				
(a)	GENERAL DESCRIPTION				
	REFLECTOR DIAMETER	200 ft (1016λ at 5 0 GHz)			
	f/D RATIO	2.0			
	APERTURE ILLUMINATION TAPER	-10 dB			
(b)	ON-AXIS PERFORMANCE				
	APERTURE GAIN (maximum)	70 1 dB			
	ON-AXIS DIRECTIVITY	69.7 dB			
	ILLUMINATION EFFICIENCY	91 3%			
	HALF POWER BEAM WIDTH	0 065°			
(c)	SCANNING PERFORMANCE				
	FEED ANGLE	0°	2°	4°	6°
	BEAM ANGLE	0°	1 98°	3.97°	5.98°
	BEAM DEVIATION FACTOR	-	0.99	0.99	0.99
	SCANNING LOSS (dB)	-	-0 18	-0.66	-1 46
	SIDE LOBE/COMMA LOBE (dB)	-22.10	-16.10	-12 70	-10 70

Table 3-21. Performance Summary of Paraboloidal Designs

	CASE IV				
(a)	GENERAL DESCRIPTION				
	REFLECTOR DIAMETER	200 ft (1016λ at 5.0 GHz)			
	f/D RATIO	2.0			
	APERTURE ILLUMINATION TAPER	-30 dB			
(b)	ON-AXIS PERFORMANCE				
	APERTURE GAIN (maximum)	70 1 dB			
	ON-AXIS DIRECTIVITY	69.0 dB			
	ILLUMINATION EFFICIENCY	77.2%			
	HALF POWER BEAM WIDTH	0.071°			
(c)	SCANNING PERFORMANCE				
	FEED ANGLE	0°	2°	4°	6°
	BEAM ANGLE	0°	1.98°	3.98°	5.98°
	BEAM DEVIATION FACTOR	-	0.99	0.99	0 99
	SCANNING LOSS (dB)	-	- 0.13	0.48	-1 08
	SIDE LOBE/COMMA LOBE (dB)	-25.00	-18.00	-14.30	-12.00

 6-2

at 6 deg off axis, required for coverage of Alaska and Hawaii, a scanning loss of 1 dB with a sidelobe or comalobe level of -12 dB (worst case) should be attainable.

The previous analysis was carried out for ideal paraboloidal reflectors. It is not clear, however, that such antennas represent the best compromise inasmuch as the tolerances for the mechanical positioning of the feeds and the curvature shaping and positioning of the reflector are all very critical. Furthermore, since the beamwidth of the antenna is nominally quite small (about 1 mrad) either the spacecraft must be pointed to an accuracy of about 100 mrad and all motions at the antenna reduced to that level or smaller, or there must be some form of decoupling of the antenna from the spacecraft — or electronic beam steering.

A trade study was therefore performed between horn-fed parabola reflectors, array-fed parabola reflectors, lenses, lens-fed arrays, and Butler-fed arrays representing the spectrum of choices for multibeam antenna for a satellite of this type. The details of the trade study are contained in Appendix A and the results are summarized in Table 3-22. Referring to this table, the different characteristics or attributes of the antenna types just mentioned were compared. It was found that due to the large number of corporate-fed or Butler-fed matrix points required, that such arrays exhibited very low efficiency compared to all other types. The array-fed parabolas, which allowed for electronic beam storing with variable power dividers, showed in-between efficiency. Lenses and horn-fed parabolas should be capable of very high efficiency as demonstrated by the last set of figures.

A second parameter evaluated was one that allowed shaping of the beam for sidelobe control, including the option to refocus the antenna as a function of scan angle to maintain optimum sidelobe levels. In this characteristic the arrays showed the highest degree of flexibility, with a horn-fed parabola showing the least. An array-fed parabola showed in-between flexibility as did lenses. A third attribute was the frequency

Table 3-22. Antenna Choice Considerations

PARAMETER	ANTENNA TYPES: Butler-Fed Arrays	Lens-Fed Arrays	Horn-Fed Parabolas	Array-Fed Parabolas	Lenses
Efficiency	Low	Low	High	Moderate	High
Sidelobe Control For Scanned Beams	High	High	Low	Moderate - High	Moderate
Frequency Independence of Scan Angle	Low	High	High	Probably Low	High
Electronic Steering of Ensemble of Beams	High	High	Moderate	Moderate	High
Weight (67 m)	High 20,000 lb	High 20,000 lb	Low 4,500 lb	Moderate 5,800 lb	Moderate 5,400 lb

independence of the scan angle. In this case, what is important is that the scan angle far off the axis not change for the transmit and receive frequencies to be used. Since this analysis was performed to be applicable to 20 and 30 GHz antenna systems as well as to 5 GHz systems, the scan angle could vary as much as 50 percent for transmit and receive frequencies for a linearly frequency-dependent system. For this reason, antennas that contain frequency-dependent components were downgraded. This includes Butler-fed arrays and probably array-fed parabolas, with all other antennas being fairly frequency-independent, containing only time delays in the RF paths.

A fourth attribute was the ability to perform electronic steering of the total ensemble of beams in order to alleviate the beam pointing requirements of the satellite itself, in anticipation of the antenna being a very large structure not easily pointed by the entire satellite or not readily decoupled by the satellite proper. In this case, the arrays exhibited high flexibility as did a lens with active time delay or phase control of the lens elements. The parabolas represented a moderate capability inasmuch as electronic steering is much more difficult to incorporate in an offset-fed parabola since the radiation center of the feed must be moved. A last and very telling attribute from the analysis of Appendix A is the weight of the 67-m dia antenna with an estimated 7000 feeds. In this case, it was found that the arrays were extremely heavy compared to all other antenna types, with the horn-fed parabolas being the lightest and array-fed parabola lenses being comparable and also very low in weight. The weights shown in Table 3-22 include all elements of the antenna including structure, feeds, reflector, lens, and supports.

As a summary of the antenna trade study, it appeared that lenses and parabolas each had attributes that made them desirable candidates for the spacecraft antenna. The arrays suffered from low efficiency and high weight and were rejected for this study. The choice between parabolas and lenses could not be made well in the time and with the resources available. Therefore the choice was made based on the availability of design data for electronically steered antennas. Since a great deal of work was done by Grumman Aerospace Corporation on large space lens antennas capable of being self-deployed, electronically steered, and in sizes larger even than needed, lenses were adopted as the baseline for the study with the understanding that follow-on studies would have to make detailed trades between parabolas and lenses.

The antenna design for the baseline system is presented below. The requirements for the antenna are summarized in Table 3-23 and the spaceborne antenna characteristics summarized in Table 3-24. An illustration of the antenna is shown in Figure 3-37. The antenna is seen to be a series of three thin films, 67 m in diameter, which are stretched within compression beams and form a ground plane, input plane, and output plane for a bootlace lens. The elements of the bootlace lens are printed on the input and output films and active phase shifter or time delay shifter networks

Table 3-23. Personal Communications System Requirements

ANTENNA DIAMETER	67 m
NUMBER OF BEAMS	ENOUGH TO COVER CONUS WITH 35% OVERLAP
OVERLAP POINT	3 dB
SOLID ANGLE OF CLUSTER	CONUS-0.0064 sterad
FIELD OF VIEW	0.0974 rad EW x 0.0652 rad NS
BEAM SIZE	COMPATIBLE WITH REQUIRED GAIN
DIRECTIVE GAIN	70.73 dB AT λ = 0.0612 m
WAVELENGTH	0.068 m $\geq \lambda \geq$ 0.0666 m UPLINK 0.0625 m $\geq \lambda \geq$ 0.0612 m DOWNLINK
FREQUENCY	4.4 - 4.5 GHz UPLINK 4.8 - 4.9 GHz DOWNLINK
POWER (max)	500 W PER BEAM IN 30 BEAMS
SIDELOBES	-15 dB AT MAX ANGLE OFFSET
MODULATION	DIGITAL QPSK
ORBIT ALTITUDE	35,871 km
ORBIT LATITUDE	0 deg
ORBIT LONGITUDE	100 deg W
POLARIZATION	2 ORTHOGONAL LINEAR
BANDWIDTH	10 MHz PER BEAM
COVERAGE	CONUS
RECEIVER NOISE TEMPERATURE	
ANTENNA SYSTEM NOISE TEMPERATURE	
BEAM STEERING	10 milrad

printed on a stretched ground plane film and connected by printed lines to the input and output elements. The lens is contained within a compression structure supported from a deployable mast with guy wires. The compression structure is supported to the feed horn cluster by space-extendable or space-fabricated beams to form an antenna whose length is approximately twice its diameter. The support masts were designed to be outside of the main beam of the feed horns in order to avoid generating intermodulation products. This subject will be treated in much more depth in Section 3.2.5.2.

Table 3-24. Personal Communications System Spaceborne Antenna Characteristics

TYPE	MULTIHORN FEED AND BOOTLACE LENS f/D = 2
FREQUENCIES	4.4 - 4.56 GHz UPLINK 4.8 - 4.9 GHz DOWNLINK
DIAMETER OF LENS	67 m
BEAMWIDTH	$1.114\ (10)^{-3}$ rad PER BEAM (0.064 deg)
NUMBER OF BEAMS	6084
COVERAGE	CONUS WITH 35% OVERLAP
DIRECTIVE GAIN	70.7 dB AT $\lambda = 0.0613$ m
RF POWER	0.5 W PER CHANNEL (250,000 channels) 125 kW maximum
FEED	
TYPE	FLARED CIRCULAR HORNS, CIRCULAR WAVEGUIDE
DIMENSIONS·	
FEED DIAMETER	11.95 m (max)
HORN DIAMETER	15.4 cm
FEED DEPTH	60 cm
WAVEGUIDE DIAMETER	4 cm
MATERIAL	GRAPHIC ALUMINUM COMPOSITE
NUMBER OF HORNS	6000
POLARIZATION	2 ORTHOGONAL LINEAR
WEIGHT	2598 kg INCLUDING LENS, FEED, SUPPORT STRUCTURE

The weight of this antenna was calculated utilizing the weight methods pioneered by Grumman, and the weight is summarized in Table 3-25. It is seen that the entire antenna is expected to weight less than 2600 kg representing a weight of about 0.7 kg/m^2. The tolerances for the various components of this antenna were calculated by the following procedure:

The geometry of a lens antenna with a diameter D, is defined by a feed located at a distance f from the plane of the lens. The geometry is shown in Figure 3-38. The angle α is defined by

$$\tan \alpha = \frac{D}{2f} \tag{5}$$

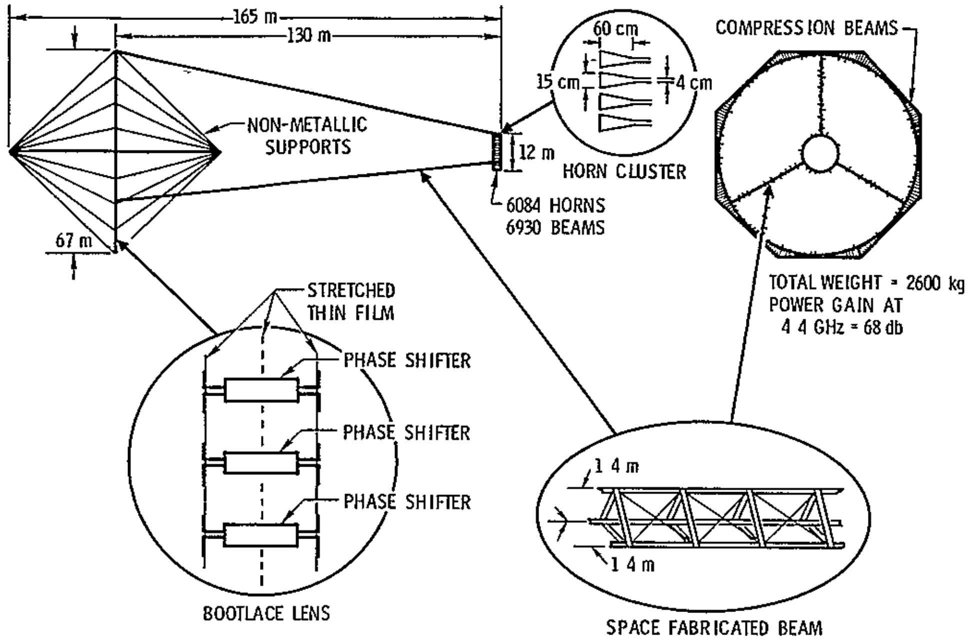


Figure 3-37. Multibeam Antenna for Personal Communications

Table 3-25. Weight Breakdown, Personal Communications Antenna

FEED HORN ASSEMBLY	1112 kg
- HORNS	
- SUPPORTS	
- WAVEGUIDES	
LENS ASSEMBLY	800 kg
- ELEMENTS	
- FILMS	
- SHIFTERS	
- COMPRESSION STRUTS	
- STAYS	
- MAST	
SUPPORT STRUTS	586 kg
- LENS/FEED SUPPORTS	
- 4 STRUTS (SPACE FABRICATED BEAMS)	
CONTINGENCY	100 kg
TOTAL	2600 kg

Assume that the surface of the lens is distorted so that the edge of the lens defined by the point 2 is moved to the point 2'. The ray path to the point 2 is given by

$$PL = \frac{f}{\cos \alpha} \tag{6}$$

For the distorted position of the surface of the lens, there is an increase in the ray path length, Δ and a decrease in the path length to the point 2' which is given by $\frac{\Delta}{\cos \alpha}$. The net change in path length is therefire ϵ defined by

$$\epsilon = \Delta \left(\frac{1}{\cos \alpha} - 1 \right) \tag{7}$$

If the allowed path length change is $\frac{\lambda}{16}$, then

$$\epsilon = \frac{\lambda}{16} = \Delta \left(\frac{1}{\cos \alpha} - 1 \right) \tag{8}$$

and the allowable surface distortion is

$$\Delta = \frac{\lambda}{16} \left(\frac{1}{\cos \alpha} - 1 \right)^{-1} \tag{9}$$

For example, if the f/D ratio is 2.5, then from Eq. (5), $\alpha = 11.31°$, and $\cos \alpha = 0.98$. Then from Eq. (9) the allowable surface distortion is 3.16 Figure 3-38 shows the relationship between f/D ratio and tolerance for an allowable phase error (path length change) of $\lambda/8$ and $\lambda/16$. Typical values of maximum allowable irregularity in the wavefronts or equiphase surfaces formed by lens are $\lambda/8$ and $\lambda/16$. The smaller the allowed phase error the lower the sidelobes, and the less the gain loss. Actual values depend upon the particular antenna design, since the factors to be considered include f/D, scan angle, illumination function, sub-array design, etc.

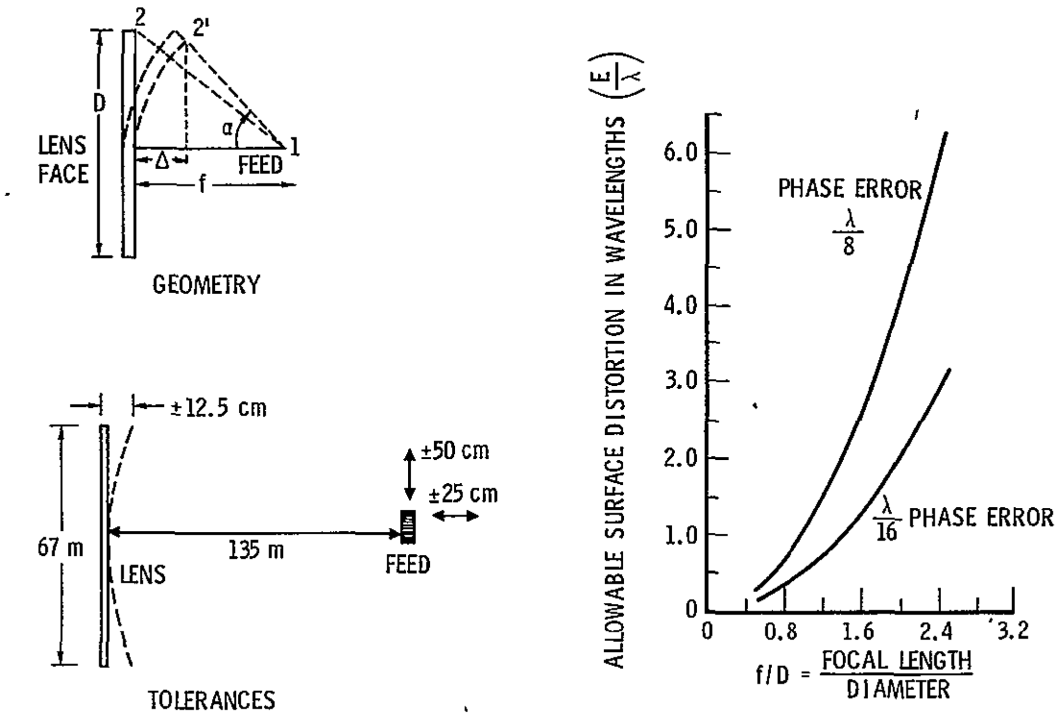


Figure 3-38. Geometry of a Lens Antenna

The resultant deformation allowances are very generous at 5 GHz for the satellite antenna, amounting to 12 to 50 cm as also shown in Figure 3-38. This represents less than a factor of 1 in 1000 length control or tolerance control as opposed to requirements for parabolic antenna system of about an order of magnitude more difficult.

3.2.5.2 Intermodulation Products

One of the more serious potential problems that may be present in an advanced design of this type is the problem of nonlinear intermodulation product generation, which could cause self-interference of a satellite operating in both the transmit and receive modes. Such generation has been observed in every advanced satellite that has been designed and, in fact, was very crucial in a design problem affecting the very feasibility of the FLTSATCOM satellite.

A simplified analysis was performed of the excess intermodulation product generation problem. The mechanism is one in which two frequencies or more impinge on a nonlinear element such as a rivet, bolt, discontinuity between two conductors, probe, the end of a horn, or any other device with nonlinear characteristics, which causes sum and difference products to be generated — some of which may be within the passband of one or more of the receivers of the system. The following simplified analysis was used to determine the magnitude of the effects for the Personal Communications Satellite.

Intermodulation products (IMPs) are formed by a combination of signals. The IMP frequency and bandwidth are related to those of the signals (or fundamentals) by

$$f_{IMP} = \sum_{n=1}^{N} a_n f_n$$

$$b_{IMP} = \sum_{n=1}^{N} |a_n| \, b_n$$

where a_n are integers (positive or negative). The order of the IMP is

$$\text{order} = \sum_{n=1}^{N} |a_n|$$

In this study only IMPs near the signal frequencies are of interest, which is expressed by

$$1 = \sum_{n=1}^{N} a_n.$$

This condition is satisfied only by odd order IMPs. A few examples of such IMPs are $f_1 + f_2 - f_3$ (3rd order); $2f_1 + f_2 - f_3 - f_4$ (5th order); $10f_1 - 9f_2$ (19th order).

Active IMPs are formed in active components such as amplifiers, and can be as strong as 10 dB below the power of the fundamentals. Passive IMPs are formed in "passive" components, which are usually assumed to be linear, such as filters, waveguide, and connectors. Their level is typically quite low (e.g., 50 to 200 dB below the fundamentals' power), because of the very small nonlinearities of the components in which they are formed. These low power IMPs, generated in the satellite, may interfere with the uplink signals in the satellite's receivers.

The satellite will operate in the 4.4 to 4.9 GHz band. It will be assumed that the uplinks are at the lower end of the band and the downlinks at the higher end. (However, reversing this assumption will not change the analysis.) The satellite will have three uplink and three downlink frequencies. Associated with each is a 15-MHz band, in order to accomodate up to 1000 digitized voice signals.

No matter what frequencies are assigned for transmission, they they may be defined as being within the limits $f_T \pm \Delta$. The highest IMP frequency that can be generated, for order m, is

$$f_{IMP} = \overline{m}(f_T + \Delta) - \underline{m}(f_T - \Delta)$$

$$= f_T + m\Delta$$

where

$$\overline{m} = (m + 1)/2$$

$$\underline{m} = (m - 1)/2$$

and

$$\overline{m} - \underline{m} = 1$$

$$\overline{m} + \underline{m} = m$$

If the lowest receive frequency is f_R, the condition for potential IMP interference is

$$f_T + m\Delta > f_R$$

$$m > \frac{f_R - f_T}{\Delta}$$

Since the power in the IMPs decreases with increasing order, it is desirable to maximize the right side of this equation. Two factors contribute to this maximization. First, separate the transmit and receive frequencies as much as possible. Second, minimize the transmission band. Using these two principles, and allowing some small guardbands between the three channels, the following frequency plan is recommended.

Transmission	4410 - 4425 MHz
	4435 - 4450
	4460 - 4475

Reception	4825 - 4840
	4840 - 4865
	4875 - 4890

There are two types of IMP interferences. The three 15-MHz transmit channels may combine with each other to form IMPs. These are interchannel IMPs. In this case f_T is 4442.5 MHz and Δ is 32.5 MHz. Since f_R is 4825 MHz, there is a possibility of interference for

$$m > \frac{4825 - 4442.5}{32.5} = 11.8$$

Since m must be an odd integer, thirteenth order IMPs are the first that could cause a problem.

A second type of IMP is that generated by the various signals within one 15-MHz transmission channel. This is intrachannel IMP interference. In this case the channel nearest to the receive band is most critical. Thus $f_T = 4467.5$ MHz and $\Delta = 7.5$ MHz, so

$$m > \frac{4825 - 4467.5}{7.5} = 47.7$$

Thus IMPs of orders 49 and above may cause interference.

A baseline for IMP power levels is often a third order product generated by three signals. In the final FLTSATCOM qualification tests this level was always below -165 dBW and usually below -170 dBW. These levels include about 50 dB isolation between the transmit and receive antennas. Therefore, the actual third order IMP level was below -115 dBW.

Test results from a number of systems show that the IMP power level typically drops about 10 dB per odd order. Rarely is the drop as small as 5 dB per odd order, but in some cases it can be 20 dB per odd order. Furthermore, for any order IMP, the power level usually increases with the number of signals involved in its generation. Thus, a five-signal fifth order IMP is expected to be slightly stronger than a two-signal fifth order IMP in the same system. No general quantitative rules have been formulated for this relationship.

The IMP power level also depends on the power levels of the original signals. For a third order IMP

$$f_{IMP} = \sum_{1}^{3} a_n f_n$$

the power relationship is

$$\frac{\Delta P\ (f_{IMP})}{\Delta P\ (f_n)} = |a_n|$$

There is less evidence to support a relationship between the power in higher order IMPs (even 5th order) and the power of the original signals. In some experiments the slope of fifth order power versus signal power was the same as the slope for third order This relationship will be assumed here. Therefore, IMP power levels will be computed by the following steps:

1. The reference level is <-115 dBW for a third order generated by three +15 dBW signals
2. Adjust third order level for actual signal level
3. Decrease level 10 dB per odd order for higher order IMPs.

The satellite transmitter power per voice channel is expected to be 0.5 W (-3 dBW). Each beam will handle a maximum of 1000 voice channels. However, it is well known that, on the average, a voice channel is active only 40 percent of the duration of a telephone call. Thus, we expect a maximum of 400 active voice channels per beam. Assuming that individual voice channel amplifiers are on only when the channel is active (or that a single high power amplifier for the entire beam is sized according to voice statistics), the maximum instantaneous power per beam is 200 W.

The required IMP power level may now be calculated. Remembering that all signals in this system are modulated, and that the bandwidth of an IMP is

$$b_{IMP} = \sum_{1}^{N} |a_n| b_n$$

it is clear that the IMP is broadband. Also, there are a large number of potential IMPs of each order, so that any interference will be a combination of several IMPs. For these reasons, IMP interference is considered to have the characteristics of white gaussian noise.

The satellite receiver noise temperature is estimated to be about 400 deg corresponding to a noise power density of about -202 dBW/Hz. This is equivalent to -130 dBW in a 15-MHz bandwidth. The IMP interference should be well below the thermal noise so as to be a minor contributor to the total noise. At most the IMP level should be 10 dB below thermal noise, so that IMPs increase the total noise by no more than 0.4 dB. It is better to allow some margin, so we will specify that the total IMP power in any band be 15 dB below thermal noise.* Thus, the acceptable IMP power level is -217 dBW/Hz or -145 dBW/15 MHz.

Interchannel IMPs are formed by combinations of signals from either two or three of the transmission bands used by the satellite. For this analysis we consider each band to have a constant amplitude over the entire

*The FLTSATCOM specification is 20 dB below thermal noise.

15 MHz and no power outside the band. The signals* are separate until they are radiated from the antenna feed horns. Then, they can interact at three locations: the mouths of the horns, the structure connecting the horns to the lens, and the lens (see Figure 3-39).

First, consider IMPs formed at the horns. If three full power (23 dBW) signals interact, a third order IMP will be <-91 dBW, because each signal is 8 dB stronger than the reference level. If the drop per odd order

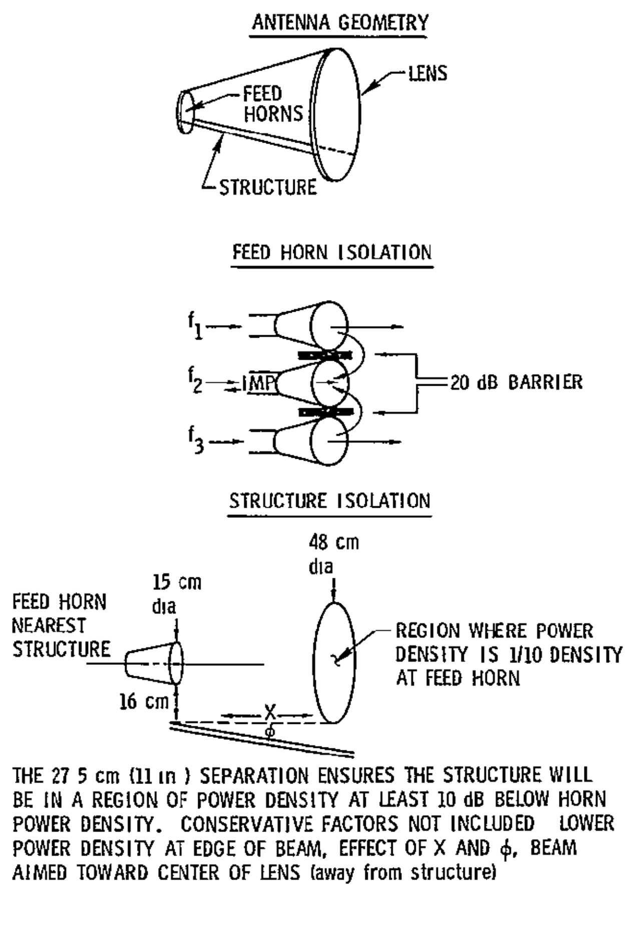


Figure 3-39. Antenna Geometry

*Each "signal" is a 15-MHz band.

is 10 dB, then a thirteenth order IMP (the lowest order which can interfere) will be <-141 dBW. The bandwidth of such an IMP is 13 times 15 MHz, so only 1/13th of the power can be in a receive band. Thus, the interference level will be <-152 dBW. Since the required level is <-145 dBW, a combination of up to five such IMPs can be tolerated. This condition may be considered marginally acceptable. However, it should be possible to provide 20 dB isolation between the honrs (see Figure 3-39). This would reduce the IMP leve l 20 or 40 dB, depending on which signals are involved in the generation of the IMP. This additional margin should be sufficient, since only IMPs generated near a particular horn will be a problem, the others being attenuated as they radiate from their source to the horn.

Next, consider IMPs formed on the structure. If all signals interact at full power, the IMP level will be -152 dBW, as before. However, if the signals interact in a region where they are each 10 dB below peak strength, the IMP will be reduced another 30 dB. This condition is easy to ensure, as depicted in Figure 3-39.

Finally, consider IMPs formed at the lens. The signal power density here is reduced from that at the horns by the square of the ratio of horn diameter (~1 ft) to lens diameter (200 ft). This reduction is 46 dB per signal, with the result that the IMP level will be insignificant.

Based on this analysis, it is believed that 13th order interchannel IMPs can be controlled sufficiently to prevent interference. Fifteenth order IMPs will be about 10 dB weaker and therefore neither they nor higher orders should be a problem.

Intrachannel IMPs are formed by combinations of the signals within one 15-MHz band. The worst case is the highest frequency transmission band interfering with the lowest frequency receiver. The receive band is 4825 to 4840 MHz, and 49th order IMPs exist up to 4835 MHz. These, and higher order IMPs, combine to produce the potential interference to the receiver.

Consider a fully loaded band, used for 1000 voice signals, with 400 on at any one instant. The 49-signal 49th order IMPs have the form

$$f_{IMP} = \sum_{j=1}^{25} f_j - \sum_{k=1}^{24} f_k$$

and their number is $N = C^{400}_{25} \quad C^{375}_{24} = \frac{4001}{251\ 241\ 3511}$ which is about 1.4×10^{126}. The number of 48-signal IMPs is about 4×10^{126}, but the number of IMPs with fewer signals decreases significantly, so the total number of 49th order IMPs is about 10^{127}.

In this case each signal has a level of -3 dB, 18 dB below the FLTSATCOM test level. Thus, the third order IMP should be 54 dB below the reference IMP, or <-169 dBW. If the level drops 10 dB per odd order, a 49th order IMP would be below -399 dBW. If the drop were 20 dB per odd order, the level would be below -529 dBW. However, in either case the total power in all the 49th order IMPs would be greater than the power in the 400 signals which generated the IMPs.

This "result" is to illustrate the fact that techniques that work for a few signals (e.g., 2 to 12) and low orders (e.g., 3 to 13) do not apply directly to cases with very high IMP orders and very large numbers of signals. It is highly probable that the physical mechanism, involved in the IMP generation, changes significantly and thus cannot be described by the general rules discussed earlier. Since no one has done any tests with many signals and high orders, there are no results from which rules can be derived. Intuitively, it seems reasonable that 49th order IMPs for 1/2 W signals would not be a problem, but only an experimental program can give a firm answer to the question.

The conclusion is therefore reached that even though a definitive answer for the intrachannel intermodulation products requires further analysis, both intuition and the results of the interchannel analysis indicate a reasonable probability that a design can be achieved that will not cause excessive self-interference in its operation. The requirements on the rest of the system design are straightforward, being a light separation between the outermost feed horns and the support beams for the lens, as shown by Figure 3-39. The placing of 20-dB barriers between adjacent feed horns or ensuring that the feedthrough coupling is subjected to at least a 20-dB attenuation, and assuring that otherwise no structure is seen by the illuminating beams until well along the separation distance between the feed horns and the lens are requirements that are easily met and have been applied in the satellite deisgn.

It must be mentioned that even if serious difficulty had been uncovered in this area, a straightforward solution still would have existed, requiring but two antennas separated by several antenna diameters - one being used solely for transmission and the other solely for reception, being interconnected via a floating cable or a very short range microwave or laser link. Because of the problems of coordinated tracking and pointing as well as the increased expense and weight, such a solution is undesirable, however, it is eminently feasible and could be adopted if needed The baseline design, however, has proceeded with a single antenna structure for both transmit and receiver for all frequencies and channels.

3.2.5.3 Switch and Processor

By far the most complex component of the entire satellite is the device that is to accept the 230,000 channels in the receivers demodulate them to baseband, and switch them to 230,000 output lines to be modulated and transmitted back to the earth in the downlinks. As we have seen, the requirement to demodulate to baseband exists for two reasons. The first requirement is to be able to recognize the addressor and addressee for proper switching of callee to caller and thus to perform the functions of a telephone switchboard in the sky. The second requirement stems from the fact that the very low EIRP in the wrist radio, even when received by the

67-meter satellite antenna, results in a signal-to-noise ratio in the RF bandwidth that is very clearly negative, and thus the passband must be narrowed to baseband to detect the signal at all. Both of these factors require a matrix interconnection switch at baseband for satellite operation. A first simplified consideration on the configuration of such a switch was performed using crosspoint interconnection switch, as an example the following design for a digital time division switch is presented.

A simple nonblocking square array with N inlets and N outlets requires N^2 crosspoint contacts. For N = 250,000, the number of crosspoint contacts would be 6.25×10^{10}, which is evidently an impractical result. A three-stage nonblocking network having the most favorable configuration of input and output switches would require approximately 7.1×10^8 crosspoint contacts. Ref (5). While this is an improvement of nearly 100 to 1 with respect to a square array, the resultant number of crosspoint contacts is nevertheless discouragingly high. For increasingly large values of N, five-stage, seven-stage, and higher numbers of stages provide further reductions in the number of required crosspoint contacts. Formulas for the general nonblocking multistage switching network are available. An extrapolation of known results suggests that the minimum number of required crosspoint contacts for the optimum nonblocking multistage switching network for N = 25,000 input and output lines is about 2.0×10^8 contacts. It appears that seven or possible nine stages would be required to approximate this result, with a rather involved stage control algorithm being required to thread each connection through successive stages.

In present day commercial telephone systems, the use of nonblocking switching networks is rare. This is due in part to the large number of crosspoints required. The major reason a nonblocking switch would be preferred in this system is that a queuing option has been includedl in the design. In the normal telephone system, callers either ring through to the called party or they get a busy signal. The busy signal can either represent a busy subscriber line or a "trunk busy" (which can include a blocked connection in an exchange even though idle lines are available). Normal telephone practice is to supply a grade of service such that a call offered to a group of trunks or circuits will nearly always find an idle circuit at the first attempt, during the busy hour. As a result, the percentage of busy channels (i.e. circuits) in a multichannel telephone system is normally of the order of 10 percent, even during the busy hour. Hence, switching systems with a moderate level of blocking is tolerable, since blocking refers to the inability to interconnect two idle lines in a network because all possible paths between them are already in use. With a busy hour loading of the order of 10 percent, blocking rarely occurs because most paths are unoccupied most of the time.

The situation changes with a queuing system. A queue can be formed whenever a call cannot be completed because either the subscriber is busy or the required system facilities are busy. The latter can include busy channels or a blocked switch. While some subscribers may be habitually busy, the more troublesome busy condition is the case where the system facilities become overloaded. In this system, a call goes into queue only after an attempt to find a sufficient set of subchannels to complete a desired connection fails (and then only if a mode 2 call has been requested). Therefore, the existence of a significant level of queuing simultaneously throughout the system is symptomatic of a condition wherein the facilities are fully utilized. This will be a fairly frequent occurrence in the Personal Communications System, since the number of users, estimated to be 10 percent of the 1990 population of the USA, is too large to be accommodated without a high degree of sharing of channels. Hence, it will often be found that calls are in queue and almost all subchannels in beams experiencing peak traffic are busy. The significance of blocking in the satellite switch now becomes clear. Because of the extensive sharing of channel facilities, the grade of service will not be comparable to the commercial telephone plant. Trunk busy signals (the only kind of busy signals returned on this system) will be common and a certain percentage of the subchannels will not be usable because block becomes more probable in a heavily loaded system. (This assumes that a nonblocking switch is not used). These difficulties become aggravated with the addition of the queuing system because now nearly all available channels are busy, particularly during peak hours, and those channels that are not busy are not usable mainly because of blocked switch paths.

The conclusions of this preliminary thought are that more than likely the proper solution lies in a digital switch in which all of the queuing sequences and flexible operating subroutines can be incorporated.

A workable approach that was selected for defining a switch for this satellite system was to scale the largest of the ground-based electronic switching systems (ESS) engineered and now being installed by the Bell System. This is the No. 4ESS, which is now being installed at the rate of one a month in the United States. This system switches 100,000 telephone channels and possesses a time division switching system controlled by a flexible processor. Two problems are faced when examining this system. First the system represents fairly old technology by today's standards. That is, it contains chips of medium scale integration and 4K RAMs. Second, it is not designed for space use with little attempt at weight reduction. Therefore, as a first project an attempt was made to break down the type and quantity of components used in the No. 4ESS, increase their number by a factor of 2.3 to accomodate 230,000 trunk lines, project the technology to that which can be expected to exist for 1988 for delivery to a 1990 system, and then estimate the power, size, and weight for the resultant system.

The No. 4ESS is amply described in the literature. A view of the technology is shown in Figure 3-40 showing a veiw of the installed equipment and a back view of the equipment cards in the racks.

Since two No. 4ESS equipment complements have a capacity of approximately 230,000 trunks, that was used as a basline for establishing present technology from which to project 1990 technology. The projections are broken into two five-year segments so a reassessment can be made to

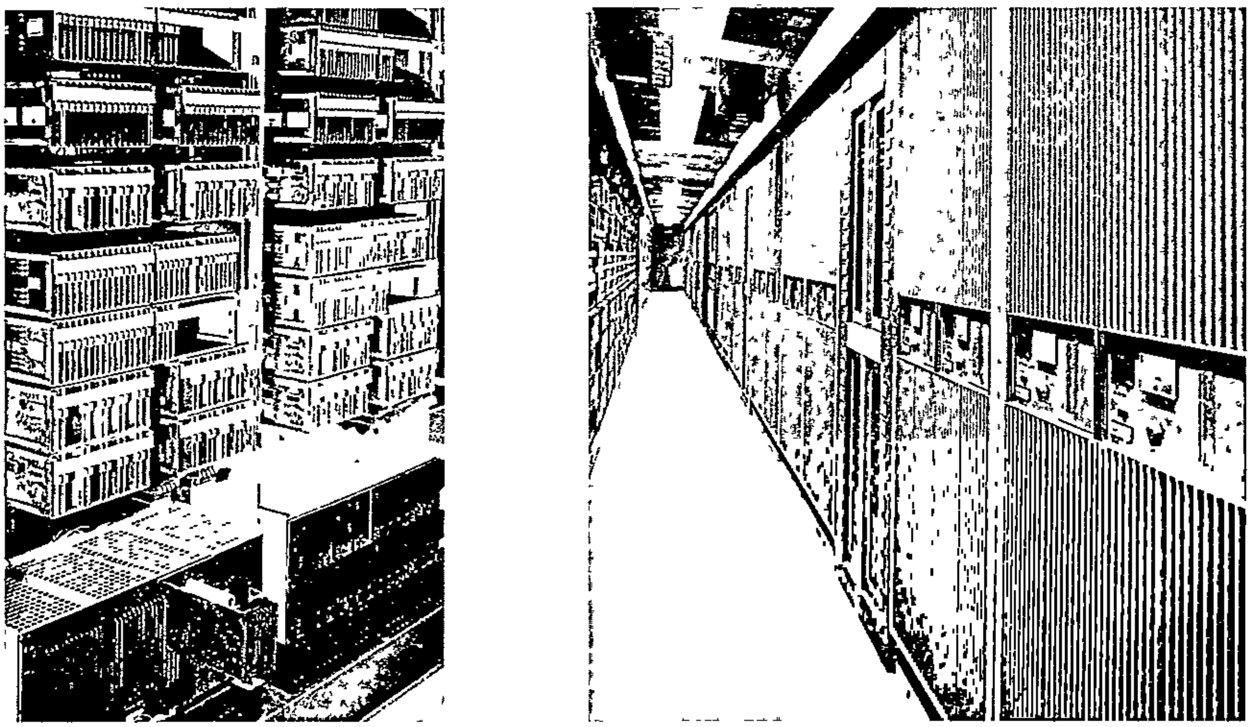


Figure 3-40. Number 4ESS

ascertain the accuracy of the projections at the five-year point for instance. All the frames of the No. 4ESS equipment are comprised of digital circuits with no analog circuits except the power supplies. There are ten basic types of frames that make up the No. 4ESS equipment and these are itemized in Table 3-26 under the appropriate heading. The projected reduction in number of frames for 1983 and 1988 are shown in the next two columns with the rationale for reduction discussed in succeeding paragraphs.

The use of large scale integrated (LSI) technology for ESS equipment is limited by the number of connections and interconnections possible off these small quarter-inch chips. The other key is the built-in redundancy to provide the high reliability that is needed for this application Significant reductions from present technology, however, can be made and these are shown in Tables 3-27 and 3-28 in which it is assumed that the

Table 3-26. Double No. 4ESS Circuit Power Pack Technology Projections

	NUMBER OF CIRCUIT/POWER PACKS PER SUBSYSTEM		
	1978	1983 (Projected)	1988 (Projected)
NETWORK SWITCH			
TSI	140,800/6,144	42,666/1,862	14,080/614
TMS	11,520/ 640	3,491/ 194	1,152/ 64
1A PROCESSOR			
CC	2,560/ 256	776/ 78	256/ 26
H/T DISKS		8/ 2	2/ 1
CCT MT		500/ 4	100/ 2
CONTROL STORES	1,008/ 168	252/ 24	63/ 6
PROGRAM STORES	720/ 120	180/ 30	45/ 8
PPI	840/ 96	420/ 48	120/ 24
I/O	1,056/ 96	526/ 48	263/ 24
SIGNAL PROCESSOR II	35,280/1,904	10,690/ 577	3,528/190
DIGROUP TERMINAL	134,400/9,856	40,727/2,987	13,440/986
CCIS TERMINAL	56,160/3,456	17,018/1,047	5,616/346
TOTAL	384,344/22,736	117,254/6,901	38,665/2,291

Table 3-27. Double No. 4ESS Power Consumption and Projections for 1988

	1978		1983	1988
	SINGLE No. 4ESS (kW)	DOUBLE No. 4ESS (kW)	(W)	(W)
NETWORK SWITCH				
TSI	170	340	103,030	34,000
TMS	11.6	23.2	7,030	2,300
1A PROCESSOR				
CC	15	30	9,090	3,000
H/T	--	--	720	360
CCT	--	--	8,000	800
CS	1	2	500	125
PS	1	2	500	125
PPI	2.7	5.4	2,700	1,350
I/O	1	2	1,000	500
SIGNAL PROCESSOR II	45.7	91.4	27,697	9,140
DIGROUP TERMINAL	176	352	106,666	35,200
CCIS TERMINAL	1	2	606	200
TOTAL	425	850	267,539	87,100

Table 3-28. Memory Technology Projections

	1978			1983			1988		
TYPE OF MEMORY	CHIP bit CAPACITY	POWER PER bit	CENTS PER bit	CHIP bit CAPACITY	POWER PER bit	CENTS PER bit	CHIP bit CAPACITY	POWER PER bit	CENTS PER bit
RAMs (~ System not device)	16K	38 μW	0.1	64K	10 μW	0.05	256K	2.5 μW	0.02
CCDs	64K	12.5 μW	0.05	256K	3 μW	0.02	1M	1.5 μW	0.01
BUBBLES	100K	6.25 μW	0.02	1M	1 μW	0.01	5M	0.1 μW	0.001

pack costs and power remain the same and only the number of frames (i.e., number of packs) are reduced by improved technology.

The following assumptions in technology growth are applicable:

DIGITAL LOGIC SWITCHES (All Frames Except 1A Processor)

1978 Medium scale integrated (MSI) digital logic is the technology used throughout the No. 4ESS frames of equipment. The individual chips are not mounted in dual-in-line packages (DIPs) but on aluminum hybrid circuit packs for much higher density.

1983 There will be a threefold density improvement with both industry standard devices or with custom chip parts. The power per circuit pack is the same assuming similar speeds.

1988 There will be a threefold reduction due to industry standard devices or with custom chip parts. The power per circuit pack is the same assuming similar speeds.

CONTROL/PROGRAM STORES (Using RAM Chip Technology)

1978 No. 4ESS uses 4kb RAMs for all the control stores and program stores. Each board (4 in. by 6 in.) holds 8kb of storage using 20 W. The control stores capacity is 64kb and the program stores is 64kb. Table 3-28 shows projected RAM memory technology trends.

1983 There will be 64K RAM chips in volumne production in 1982. This is a reduction of 4:1 in circuit packs for both control stores and program stores, which results in 432 circuit packs and 54 power packs assuming similar speeds.

1988 There will be 256K RAM chips in production in 1988. This is again a reduction of 4:1 resulting in 108 circuit packs and 14 power packs assuming similar speeds.

HEAD PER TRACK DATA (Replacement with CCD Technology)

1978 Equivalent head per track (H/T) disk unit using 64kb CCD chips are off-the-shelf today (1978). One million bytes on a board (14 in. by 15 in.) with 100 W per board. Table 3-28 shows projected CCD technology characteristics.

No. 4ESS has four Burrough's H/T disks with a total capacity of 10M 24-bit words (i.e., 30Mb). Today this would be 30 boards with an average access time of 500 μsec compared to the disk access time of 17 msec. Thirty CCD boards with chassis and power supplies costs approximately $120K.

1983 There will be 256kb CCD chips. The 4:1 reduction means eight boards with the same power assuming similar speeds

1988 There will be 1Mb CCD chips. The 4:1 reduction means two boards with the same power assuming similar speeds.

COMPUTER COMPATIBLE TAPE (Replacement with Bubble Technology)

1978 Two manufacturers offer storage units using 100kb Bubble chips off-the-shelf today. Each board (6 in. by 6 in.) holds 20kb using one Watt. Table 3-28 shows projected bubble characteristics.

No. 4ESS has eight Conrac nine track, 1600 bbi, 75 ips computer compatible tape units with a capacity of 125Mb (i.e., 4kb record size) per tape or 1000Mb total (i.e., 8×10^9 bits). The equivalent in bubble chips (i.e., 1×10^5 bits) today is 80K bubble chips which is obviously impractical (sizewise and costwise - $1.6M).

1983 There will be 1Mb Bubble chips. The 10:1 reduction means 8K bubble chips or 500 small boards with the same power assuming similar speeds.

1988 There will be 5Mb Bubble chips. The 5:1 reduction means 1,600 bubble chips or 100 small boards with the same power assuming similar speeds.

This technology assessment was a difficult task for several reasons and reflecting on them may help understand the results presented herein:

1. Technology is not only changing very fast but there are so many different approaches one cannot afford to study them all. Whichever inductry standard logic and memory components evolve would be by far the lowest cost; whereas developing a whole family of custom LSI chips for this one system in space would be costly.

2. Packaging and interconnecting all the components to the 230,000 trunk lines is a major equipment task in this whole effort. From an electronics packaging design view, two promising approaches that should be investigated in detail are hybrid packaging and wafer-scale integration. Hybrids are used now and wafer-scale research is just getting underway in 1978. It would achieve much'higher densities by not dicing up the wafer into chips but having the chip interconnect on the wafer. Then with programmability/selection around bad chips, the overall yield would be increased significantly.

3. The last but very important distinction that is not treated here but needs investigation is the deletion of No. 4ESS functions not necessary for this 1990 space application and the addition of specialized functions to this No. 4ESS baseline to meet the 1990 space application requirements. Also, as studies such as this evolve, more requirements and services will be called for, which will have to be accomodated by the computer and equipment

A preliminary design for the spaceborne switch-processor was performed within. The above discussed caveats. Table 3-26 shows the projected number of circuit/power packs in 1988 projected technology to implement the required 230,000 trunk ESS configuration. These estimates are then used to determine the overall size and weight for spacecraft payload equipment without chassis, mounting, or interconnects. Table 3-27 presents the power consumption estimates for that same required ESS configuration using todays No. 4ESS as a baseline from which to make 1988 projections, and is seen to be 87.1K watts compared to the 425 kW in the 1978 design. If the size is estimated using the standard militarized ATR Computer/Electronics package which is one cubic foot per 45 pounds without case and connectors, and the analysis assumes one pound per circuit pack (4 in. by 6 in.) and four pounds per power pack (4 in. by 12 in.), a weight of approximately 48,000 lb results, and translates into approximately 2,000 ft^3 (10 by 10 by 20 ft) payload. This is clearly excessive and a repackaging was performed consistent with the other space hardwares of the late 1980's.

A new concept for this packing was undertaken based on the wafer scale integration of the electronics. Based on the required 384,344 circuit packs, the 22,736 power packs and a power consumption of 87 1 KW, an attempt was made at packaging the system in such a way as to minimize the weight. To do this the volume had to be reduced from the present 280,000 cubic foot facility to the evolved concept that occupies 560 ft^3, or a 500 to 1 reduction in volume.

It must be understood that the evolved design concept is limited by the amount of information and time that were available, and that if ever to be implemented, the concept would require a considerable amount of development work on materials, processes, and parts. It should also be understood that this presentation is oversimplified and that many special required functions would probably not be translatable into the proposed format. It is however, a reasonable concept from which to start, and does reflect a technology that is attainable within the next 10 years.

The concept is described with reference to the figures. A large scale integration (LSI) wafer representing a single circuit pack

(4 in. by 6 in. hybrid printed circuit board) is shown in Figure 3-41. The LSI would be preprobed for good circuits and then interconnected with a conventional multilayer-glassivation network. The wafer would contain a large number of space circuits that could be switched in after the built-in testing isolates a failure. A ceramic toroidal spacer will be associated with each LSI. Both the LSI and the spacer will have a coin edge (straight knurl) with teeth on 0.005-in. centers. These will be used for future interconnecting (628 per wafer).

Two hundred forty wafers and their associated spacers are stacked into a rod (1 in. dia by 6 in. long), as shown in Figure 3-42. The entire assembly is glass bonded into a single hermetically sealed rod. The rod is then plated with copper along the entire cylinder wall. By taking a grinding cut on the cylinder diameter, the teeth of the knurl will be removed leaving 628 parallel axial lines interconnecting all of the 240 wafers. With a computer-programmed laser trimmer, each of the interconnecting lines can be segmented to the required interconnection pattern. There are 1600 rods required.

A power converter module is added to each interconnected rod (this might be better done when first building the rod), as shown in Figure 3-43. A special connector-header is wired and hermetically attached to each rod. The connector, like the rod, will have 628 contacts. A mating connector with three flat flexible cables permanently attached and hermetically sealed will provide the next interface. The mating connectors are also to be "hermetically" (gasket) engaged. The rod assembly with its attached power converter and connector header are coated with parylene.

A heat pipe (various lengths) made of 1/8-in. magnesium with a highly reflective exterior is provided for every 16 rods, as shown in Figure 3-44. The heat pipe is 12 in. in diameter and contains a center "junction box" connector from which the 16 flexible cable assemblies emerge. The connector, which is located in the center of the heat pipe, is attached to a structural spider that will also be used to fasten the 16 rods into the pipe.

- Equivalent to 4x6 Inch Hybrid Printed Circuit Board
- Includes Operating Spare Circuits
- 1-Inch Diameter
- 304,344 Wafers Required

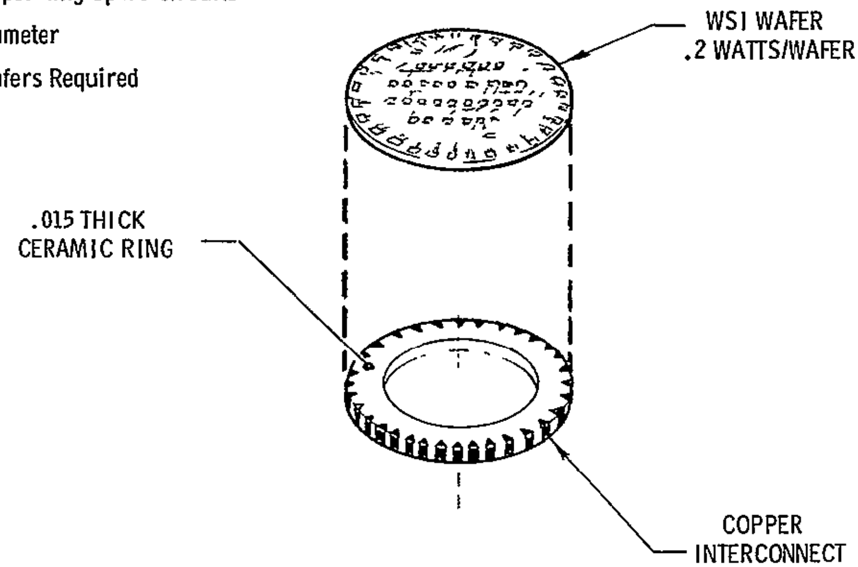
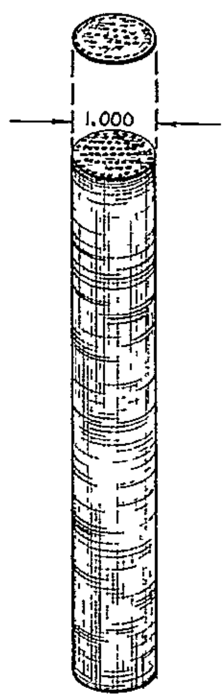


Figure 3-41. Wafer Scale Integrated Assembly



- Bonded into 6-inch Rod
- 628 Input/Output Lines
- 50 Watt/Rod
- 1600 Rods Required

Figure 3-42. Two Hundred Forty Wafer Assemblies

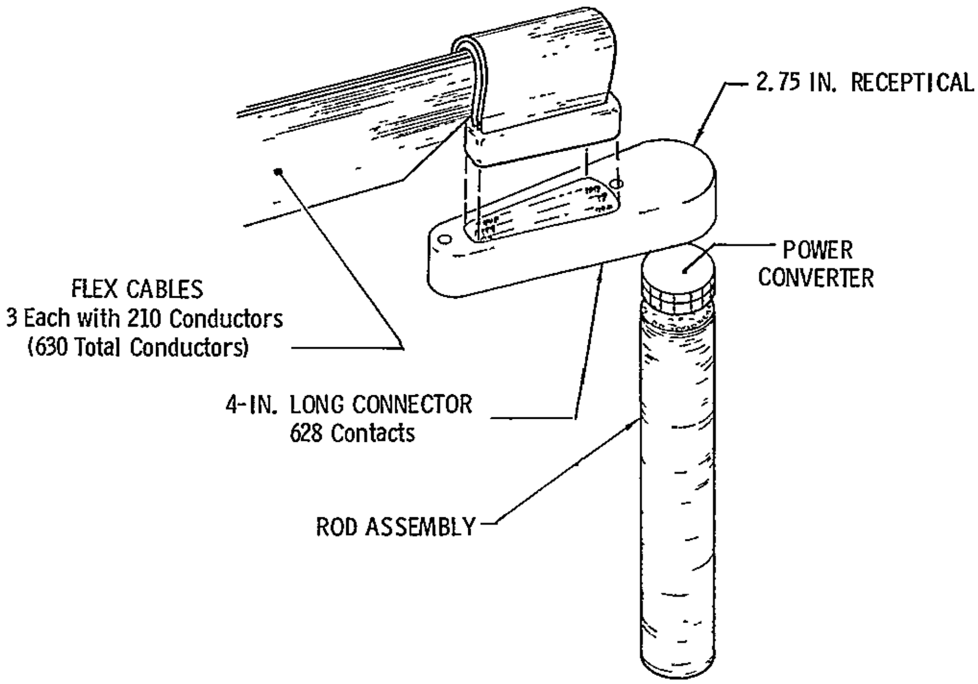


Figure 3-43. Cable Interconnect Assembly

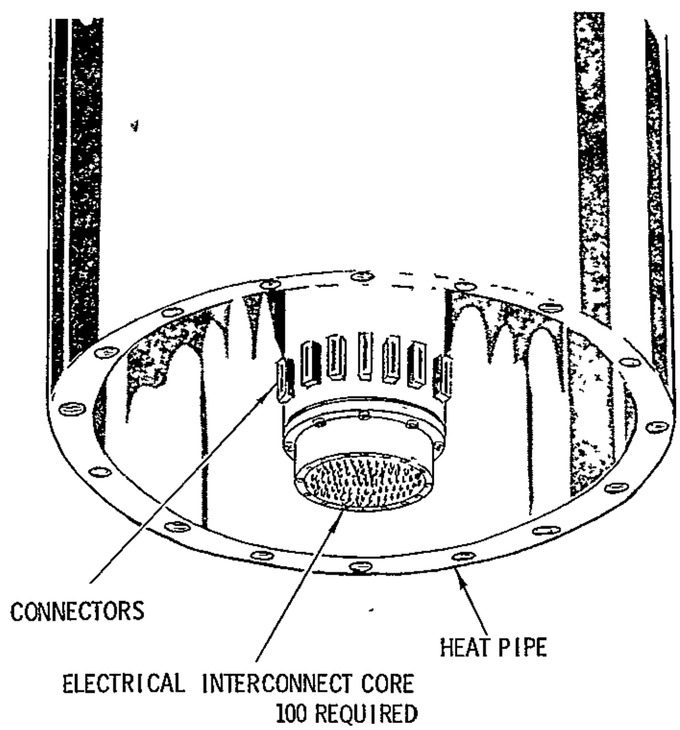


Figure 3-44. Heat Exchanger

The 16 rods, when tied into the heat pipe, will all be located in the bottom 6 in., circumferencially, as shown in Figure 3-45. The 16 radial flexible cables are connected to their respective rod connectors and the assembly is given a functional test, as shown in Figure 3-46. Each heat pipe (shown in Figure 3-47) is charged with its heat transfer liquid. Different boiling point liquids may be used to compensate for differences in generated heat. The center junction box connector (approx. 4 in. dia) extends through the bottom cover for subsequent interconnections. Ninety six such heat pipes are required, each dissipating approximately 800 W.

By varying the lengths of the heat pipes, a conical structure is produced (shown in Figure 3-48). The cone is 8 ft. high and has a base diameter of 14 ft. Since the cone assembly will be done in space, the pipes are sequencially assembled, starting with the inner (longest) pipes. Light strapping is used to tie the pipes to each other in rings and to tie the concentric rings to each other. Four bolts should be enough for each pipe. The individual pipes are readily replaceable in space, but the replacement of a rod would probably be better done at depot or factory level.

Three hundred eighty eight double (folded) printed circuit cards, each single card measuring 12 in. by 12 in. will be required to accommodate the 22,736 power packs. These cards will form radial fins at the base of the heat pipe cone, at spacings of 1.4 in. at the 14-ft dia and 1.55 in. at the major diameter. They are shown in Figure 3-49. For each two-card assembly there will be one connector that will be interconnected to the power source and to the respective heat pipe center connectors.

The weight estimates based on the described concept and the baseline assumptions are shown in Table 3-29.

This first cut at a packaging concept is a starting point. The conceptual effort was many orders of magnitude easier to evolve than will be its implementation. Several other approaches to this packaging problem should be developed and compared to each other and to this approach,

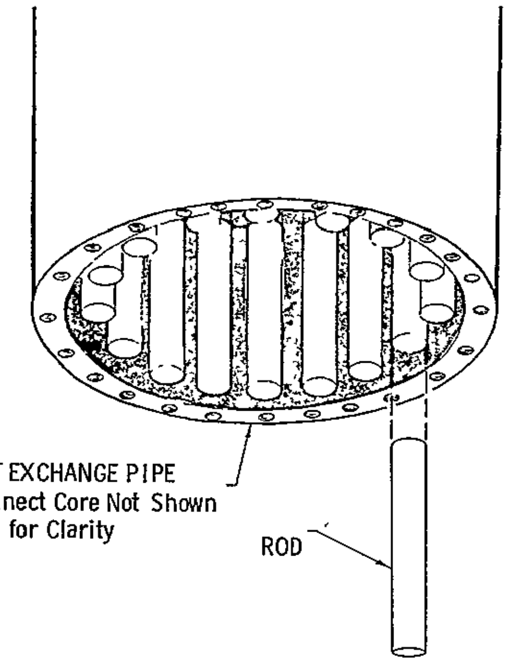


Figure 3-45. Sixteen Rods per Heat Exchanger

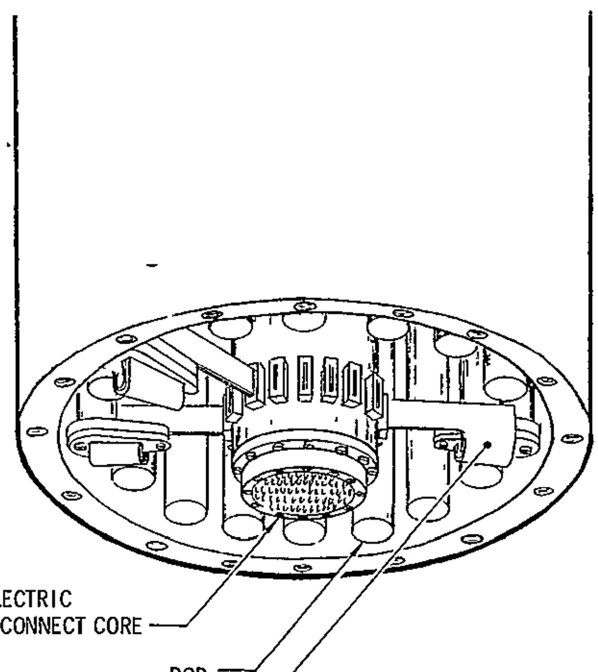


Figure 3-46. Electrical Interconnect

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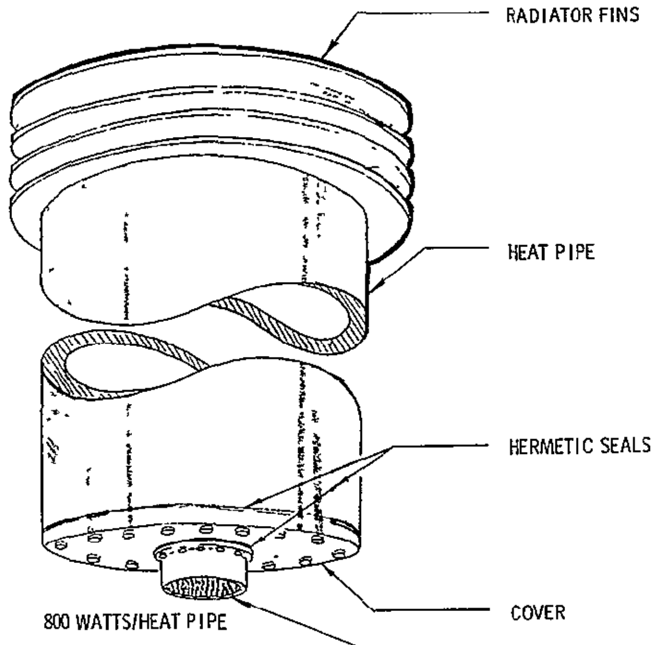


Figure 3-47. Heat Exchanger Pipe Assembly

96 HEAT PIPE ASSEMBLIES
8-FT HIGH PYRAMID
APPROX. 15-FT IN DIAMETER

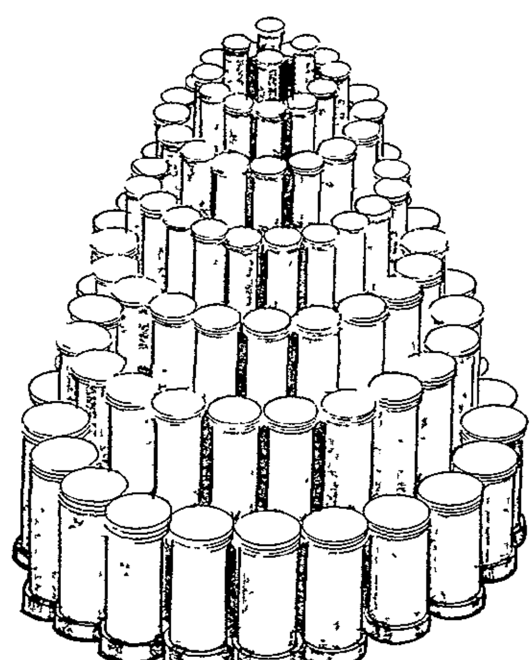
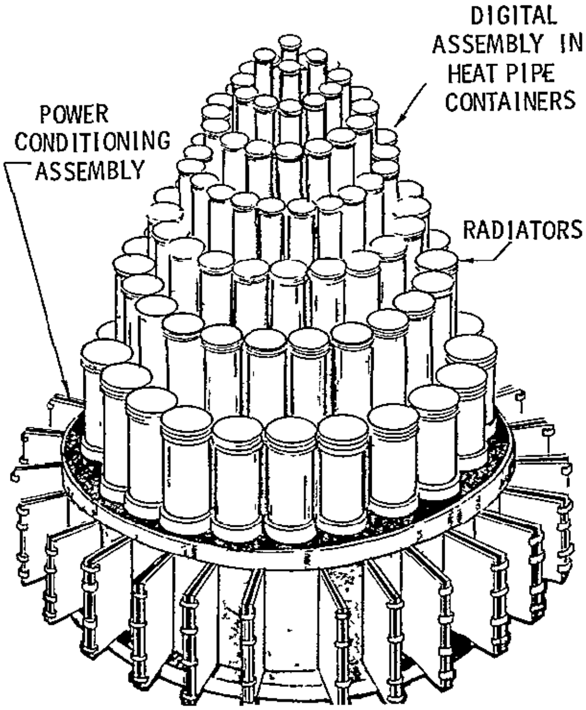


Figure 3-48. Digital System Assembly



DESIGN

- Scaled No. 4 ESS
- 1987 Projected Technology
- Uses Wafer-Scale Integration
- Integral Thermal Control System
- All Modular Space - Plug-in Assemblies

FUNCTIONS PERFORMED

- 230,000 x 230,000 Voice Line Exchange Switching
- Master Processor for Order Wires and System Discipline
- Controller for Switch
- System Health Monitor
- User Charge Processor

CHARACTERISTICS

- Weight = 8000 lb
- Size = 15-ft Dia x 8-ft High
- Power = 50 kW

Figure 3-49. Complete Processor - Switch

Table 3-29. Weight Estimates for Satellite Switch

PERSONAL COMMUNICATIONS
1990
230,000 TRUNKS
NONBLOCKING
REMOTE DYNAMIC RECONFIGURATION

1600 SILICONE RODS 6 in. LONG X 1 1/4 in. dia (SILICONE 0.08 lb/cu in.)	950 lb
96 HEAT PIPES & COVERS AV LENGTH 4.3 ft, 12 in. dia 1/8 SKIN, MAG. (0.065 lb/cu in.)	1,532
1600 ROD CONNECTORS @0.5	800
96 HEAT PIPE CONNECTORS ASSEMBLIES @4 lb	384
1.2 X 10^6 ft # 30 WIRE	360
STRUCTURE TIES, RINGS (2) & BOLTS	400
LIQUID IN HEAT PIPES 10% OF VOLUME @50 lb/cu ft	1,610
388 POWER PACK CONNECTORS PAIRS @0.5 LB	194
388 DOUBLE POWER PACK CARDS CARDS 174 lb, PARTS 1552 lb	1,726
TOTAL	7,956 lb

however, the preceding analyses and designs havé demonstrated that a switch of approximately the right weight and size can probably be built in the time period with novel packaging techniques, lots of time, devotion, and probably healthy amounts of R&D funds.

3.2.5.4 Propulsion

A simplified analysis was made of the attitude control system needs as well as of the propulsion needs to transfer the satellite from low to geostationary orbit. A design concept of assembly in low altitude orbit was selected because the satellite is so complex that it was felt that the presence of man in the space shuttle for its assembly and checkout was desirable, if not indispensable. Then followed an analysis of the major options for orbit transfer of the assembled satellite to its final destination. A comparison study was made of four types of transfer techniques utilizing different orbit transfer vehicles. Analysis was performed for the initial estimate of what the total satellite would weigh, namely 25,000 lb. The summary data are shown in Table 3-30. In this table it is seen that use of the IUS or a new low thrust chemically fueled OTV is approximately four times heavier and probably more costlier than use of solar electric propulsion. It was recognized that a large power source would be required for the solar electric system, however, that similar power would be required for the operation of the satellite itself once it reached destination. Since the power is not needed by the payload during transfer orbit it could be made available to power the electric propuslation thrusters. The analysis on on Table 3-30 indicates that an electric propulsion system utilizing either the current SEPS ion thrusters operated at an ISP of 3000, or a smaller number of the same thrusters operated at higher power in attaining an ISP of 9000 are the most attractive. In either case the large number of thrusters would ensure a reliability factor compatible with the value of the spacecraft and ensure that the satellite would reach synchronous altitude even if one or two thrusters gave out. An additional option would be to develop a new

Table 3-30. Orbit Transfer Options - 25,000 lb Platform

OTV DESCRIPTION	POWER INPUT (kW)	THRUST (N)	No. OF THRUSTERS	Isp (sec)	TRANSFER TIME (days)	STAGE MASS WET (kg)	TOTAL MASS (kg) PWR + STAGE	TOTAL MASS (kg) INCL. PAYLOAD
DUAL LOW THRUST CRYOGENIC ΔV = 4500 m/s 0.1 g MAX ACCELERATION	-	9 k	2	444	0.3	50,000	50,000	60,000
DUAL PUMP FED STORABLE ΔV = 4800 m/s 0.05 g MAX ACCELERATION	-	31 k	2	320	0.3	58,000	58,000	68,000
SOLAR/ELECTRIC HI-POWER 30 cm THRUSTERS MERCURY PROPELLANT ΔV = 6000 m/s	100	2.2	40	3000	340	2300	8,300	18,300
MULTIPLE IUS Equivalent 4.25, 2-Stage IUS's 2.9 g MAXIMUM	-	285 k/ 110 k	5	290	0.2	72,000	72,000	82,000

chemically fueled OTV with high thrust, and probably hydrogen oxygen fueled. The disadvantage of such a OTV is similar to that of the use of the IUS, which is that a fairly high acceleration is reached during transfer. In the case of the IUS this peaks at 2.3Gs, which is really excessive the density of the deployable antenna design of Section 3.2.5.1, which can probably not withstand an acceleration exceeding 0.1 G without incurring serious weight penalties.

The calculations that resulted in Table 3-30 were performed for an initial estimate of a 25,000-lb platform. Some of those calculations were repeated for the case of a 50,000-lb platform, which is closer to the final vehicle weight. These calculations are shown in Table 3-31, from which it is seen that the conclusions are the same - namely, that a solar electric orbit transfer system is by far the most efficient, particularly since the power system can power the satellite on-orbit after orbit transfer

Table 3-31. Comparison of Transfer Propulsion Systems for Personal Communications Initiative

PROPULSION SYSTEM	POWER INPUT, kW	THRUST LEVEL, lb	NO OF THRUSTERS	THRUST TIME DAYS	ISP sec	PROPELLANT WEIGHT, lb	SYSTEM WEIGHT DRY, lb	TOTAL WEIGHT lb	STAGE PLUS POWER SYSTEM(5) WEIGHT, lb
CURRENT 30 cm Hz ION THRUSTER - ΔV = 19730 ft/sec	212	2.56	80	154	3000	11350	1770(1)	13120	28960
HI POWER 30 cm Hz ION THRUSTER, ΔV = 19730	210	1.09	13	337	9000	3520	375(2)	3895	19735
ADVANCED 60 cm ARGON ION THRUSTER, ΔV = 19730	200	0 96	1	382	8770	3620	198(3)	3818	19658
ADVANCED HI CURRENT 30 cm Hz ION THRUSTER, ΔV = 19730	210	3 21	20	123	3000	11350	870(4)	12222	28062
TWO-STAGE LOW THRUST CHEMICAL*, ΔV = 14,900+	-								
STAGE 1		~16000	1	64 min	313	193772	34196	227970	-
STAGE 2		~ 6000	1	51 min	300	63222	11156	74380	-
TOTAL						256994	45352	302350	313438

- 50,000 lb VEHICLE WEIGHT, FINAL
+ 1st STAGE ΔV = 8050, 2nd STAGE ΔV = 6850 (INCLUDES LOW THRUST LOSSES)
* MAX ACCELERATION ≈0 1 g
(1) 1200 lb THRUSTERS, 570 lb TANKAGE AND LINES
(2) 195 lb THRUSTERS, 180 lb TANKAGE AND LINES
(3) 18 lb THRUSTERS, 180 lb TANKAGE AND LINES
(4) 300 lb THRUSTERS, 510 lb TANKAGE AND LINES
(5) POWER SYSTEM @ 33 W/kg

An additional analysis was made of the possibility of dual use of the ion thrusters used for orbit transfer as the attitude control thrusters in three axis and translation control along three axes, once a satellite reaches orbit. The analysis showed that the 30-cm ion thrusters were entirely adequate when gimballed to the proper directions after reaching orbit. They can maintain stability as well as offset gravity gradient, tidal, and solar pressure forces for stationkeeping and attitude control. It was thus decided that the most efficient design was one in which the ion thrusters and the power system provided dual duty as discussed above. This, then, represents the baseline configuration for the baseline design.

3.2.5.5 Power Subsystem

The power subsystem for the Personal Communications Satellite requires 210 kW at the end of life (EOL) in synchronous altitude. This requirement stems from the total budget that is shown in Table 3-32. From this table it is seen that the transmitters require 114 kW of power during the peak periods. This power demand results from the operation of all 230,000 voice channels

Table 3-32. Power Budget - Personal Communications

TRANSMITTERS*	102 kW
SWITCH/PROCESSOR**	79 kW
ATTITUDE/TRANSLATION THRUSTERS	9 kW
MISCELLANEOUS	1 kW
REQUIRED TOTAL IN GEO (EOL)	191 kW
REQUIRED TOTAL IN GEO (BOL)	212 kW
REQUIRED TOTAL IN LEO	273 kW

* 230,000 channels at 0 5 W/channel, 0 4 efficiency, 0 4 average/peak factor due to voice activity, 95% channel loading

** At 95% channel loading

transmitting at 1/2 W per channel, with a factor of 0.4 to account for the average-to-peak power ratios typically encountered in voice transmission and another factor of 0.4 for the DC/RF efficiency of the solid-state transmitters. The switch and processor draws 87 kW as determined in the analysis of Section 3.2.5.3. Since at most 95 percent of the channels are in use at any one time and the transmitters and processor draw roughly equal power, a 10-percent reduction in the required power would be possible. However, this 10 percent will be used to accommodate the expected degradation of the array in 5 to 10 yr on-orbit, thus resulting in power needs appropriate for the beginning of life (BOL) Another 9 kW is budgeted for the ion thrusters utilized in on-orbit attitude and translation control. A miscellaneous 1-kilowatt is added to account for conditioning and other inefficiencies in the system. The total requirement is thus for 191 kW (EOL) or 212 kW (BOL) in geostationary orbit. The total required at the beginning of life in low earth orbit is greater to account for the degradation to be expected during the long passage through the radiation belts and on-orbit operation in geostationary altitude. The total degradation is estimated to be 33 percent and thus a beginning of life power in low altitude orbit of 272 kW is used as the requirement for the power system.

A solar cell/battery system was chosen without any trade studies simply because the power level required appeared reasonable for solar cell power supplies in the time period; solar arrays are a well-developed and understood art; the size of such a system appeared to be in keeping with the size of the satellite; and because the technology improvements currently being developed could be readily projected to the time period to form a practical solar cell system. Using estimates for the technology available in the 1985-87 time period, a design similar to that for the Grumman Space Construction Base power subsystem study was adopted with a total efficiency of 33 W/kg. For such a system a total array size required is 40 by 40 meters, in each of two paddles. These would have to be one-axis gimballed and sun oriented, and require a lightweight support structure to be either space-fabricated or space deployable. The total weight of the space power subsystem is 8548 kg or 18,800 lb, as derived in Table 3-33. In this table the rest of the assumptions are also included and the conclusion is reached that a solar cell battery system is practical for the satellite for this time period.

Table 3-33. Power Subsystem for Personal Communications

- POWER = 273-kW OUTPUT @ BOL IN LEO· 210 kW IN GEO
- LIFE = 10 YR PRIOR TO REFURBISHMENT
- SOLAR/PHOTOVOLTAIC SELECTED
  - SIZE COMPATIBLE WITH SATELLITE DIMENSIONS
  - WELL DEVELOPED ART
  - TECHNOLOGY READILY PROJECTED
- 1985-1987 TECHNOLOGY ESTIMATES USED
- DESIGN SIMILAR TO GRUMMAN SCB POWER SUBSYSTEM
  - TOTAL ARRAY SIZE: 40 x 40 m (x2)
  - 1 AXIS GIMBAL - SUN-ORIENTED
  - SPACE FABRICATED SUPPORT STRUCTURE
  - WEIGHT, kG
    - ARRAY (273 kW) = 2400
    - DIST/COND (210 kW) = 1227
    - BATTERY (210 kW) = 2890
    - STRUCTURE (273 kW) = 2031

8548 kG (18,800 lb)

3.2.5.6 Design

A preliminary design for the Personal Communications satellite was based on the previous analyses and definition of the subsystems. A further definition of the electronics packages was required in order to complete the design and was performed on the basis of individual weights, volumes, and power requirements of the components of the transponders. A breakout of the type, description, and number of the various components is shown in Table 3-34. The assumptions that underlie the per-unit volumes, weights, and power requirements are that all of the diplexer, receiver, demodulator, modulator, transmitter, frequency generator, and master oscillator units would consist of large scale or wafer-scale integrated chips, where applicable integrated on plated microstrip transmission wave-guides. These are positioned strategically with respect to the feed horns to form space-servicable modular packages. A further assumption is

Table 3-34. Physical Descriptions — Personal Communications

ITEM	QTY	DESCRIPTION	PER UNIT in^3	PER UNIT lb	PER UNIT W	TOTAL ft^3	TOTAL lb	TOTAL kW
ANTENNA	1	INCLUDES LENS SUPPORTS 6084 HORNS	-	-	-	-	5 700	-
DIPLEXER/HYBRID	6 930	INCLUDES 6084 DIPLEXERS, 846 HYBRIDS AND SUBSTRATE	0 1	0 01	-	0 4	69	-
RECEIVER	6,930	INCLUDES PREAMP MIXER/DOWNCONVERTER IF/VIDEO AMPLIFIER, AND SUBSTRATE	0 2	0 02	0.1	0 8	138	0 7
DEMODULATOR	230 000	QPSK DEMODULATOR TO BASEBAND AND STRUCTURE	0 02	0 002	0.005	2.6	460	1 1
SWITCH & CONTROL	1	SWITCHES 230 000 TRUNKS IN REAL-TIME, VOICE-BANDWIDTH DATA. PROCESSES & CONTROLS SYSTEM OPERATION INCL STRUCTURE	-	-	-	560 0	8 000	87 0
MODULATOR	230,000	QPSK MODULATORS TO SUBCARRIERS - INCLUDES SUMMER AND SSB TRANSLATOR AND STRUCTURE	0 04	0 004	0.01	5 3	920	2.3
TRANSMITTER	6,930 TOTAL	INCLUDES POWER AMPLIFIER AND FILTERS AND SUBSTRATE	-	-	-	35 0	2,075	125 0
	30	500 Watt LINEAR AMPLIFIER° INCL STRUCTURE	1,000 0	30 0	600 0	17 0	900	18 0
	30	200 Watt LINEAR AMPLIFIER°, INCL STRUCTURE	400 0	10 0	240 0	7 0	360	7 2
	100	75 Watt LINEAR AMPLIFIER° INCL STRUCTURE	80 0	1 3	90 0	4 6	200	9 0
	200	40 Watt LINEAR AMPLIFIER°, INCL STRUCTURE	10.0	0 3	48 0	1 2	100	9 6
	1 700	20 Watt LINEAR AMPLIFIER°, INCL STRUCTURE	3 0	0 1	24 0	3 0	170	41 0
	1 200	10 Watt LINEAR AMPLIFIER° INCL STRUCTURE	1 0	0 1	12.0	0 7	120	14 0
	4 500	5 Watt LINEAR AMPLIFIER° INCL STRUCTURE	0 5	0 05	6 0	1 3	225	27 0
FREQUENCY GENERATORS	2	GENERATES 12 CW CARRIERS DISTRIBUTES TO 13,860 TRANSMITTERS AND RECEIVERS, INCL CASE	500 0	50 0	250 0	0 6	100	0 5
MASTER OSCILLATOR + DISTRIBUTION UNIT	1	GENERATES 1400 SUBCARRIERS, DISTRIBUTES TO 460 000 QPSK MODS/DEMODS INCLUDES STABLE SOURCE INCL CASE	500 0	50 0	250 0	0 3	50	0 25
		GRAND TOTAL				605 0	17 500	216 0

°Average power computed on basis of 40% voice activity and 33% average efficiency made that the total number of beams needed (6930) would be formed from the 6084 feed horns by hybrid combiners to form beams for the urban areas, the combinatorial technique being shown by example in Figure 3-50.

All of the other components were weighed including the weight of their substrate in a design that avoided separate ATR boxes for every major subsystem or component group in order to save weight. There are thus 6930 major electronic assemblies, each associated with a feed horn or a combinatorial assembly of four feed horns. The output of each of the electronic assemblies is a cable containing up to 700 voice channel wires together, which form the input to the switch processor. Each of these electronic packages was estimated to occupy a maximum volume of 18 in. long x 1-1/2 in. diameter, and to include a receiver, a transmitter, and up to 700 modulators and demodulators, the exact number varying for each beam. These packages are shown as the cylinders coupled to the backs

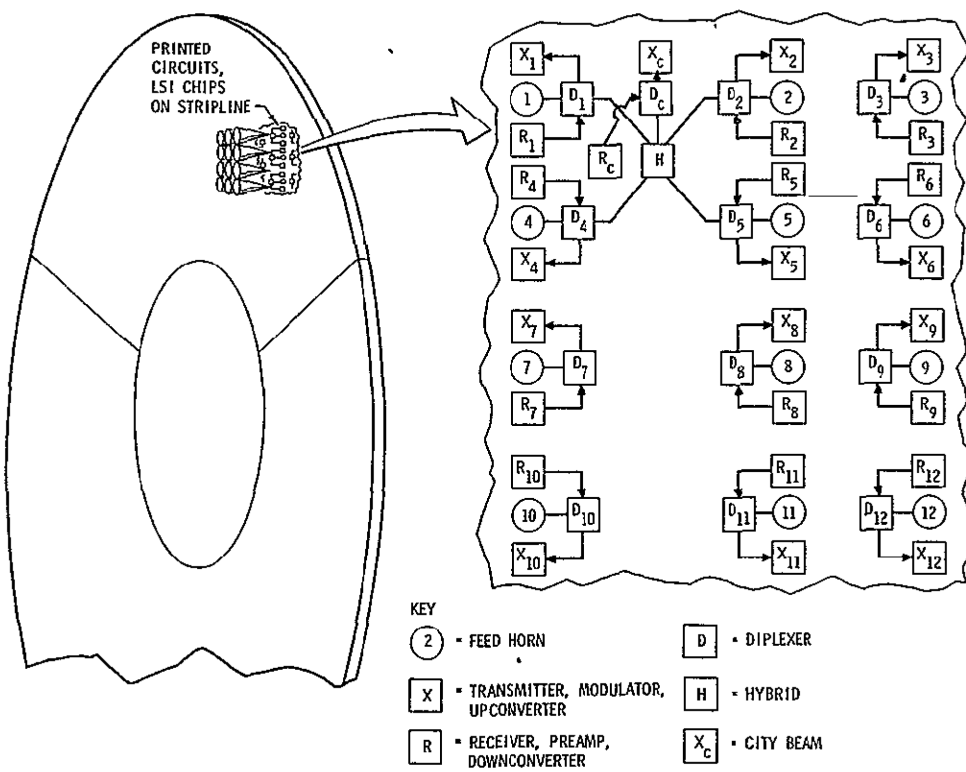


Figure 3-50. Details of Focal Plane Design (LSI Techniques)

of the feed horns shown in Figure 3-51. The basic module size for space assembly and servicing was designed as a package of 91 horns and their associated electronics. The package was designed as a plug-in unit accessible from the front of the support structure.

All of the electronics would be connected through a series of contacts contained on a contact ring. The horn assembly, whose outline is a 57.7-in. hexagon shown in Figure 3-51, would be plugged in using a teleoperator or EVA technique to a latch structure, and a drive-motor would then rotate the contact assembly ring to make a wiping contact with the connectors to complete the circuits, there being an average of 300 contacts per ring. Thus high contact forces are avoided in the process assembling or servicing the module elements.

Should any of the electronics require servicing or replacement during life, the module package of 91 horns and electronics would have

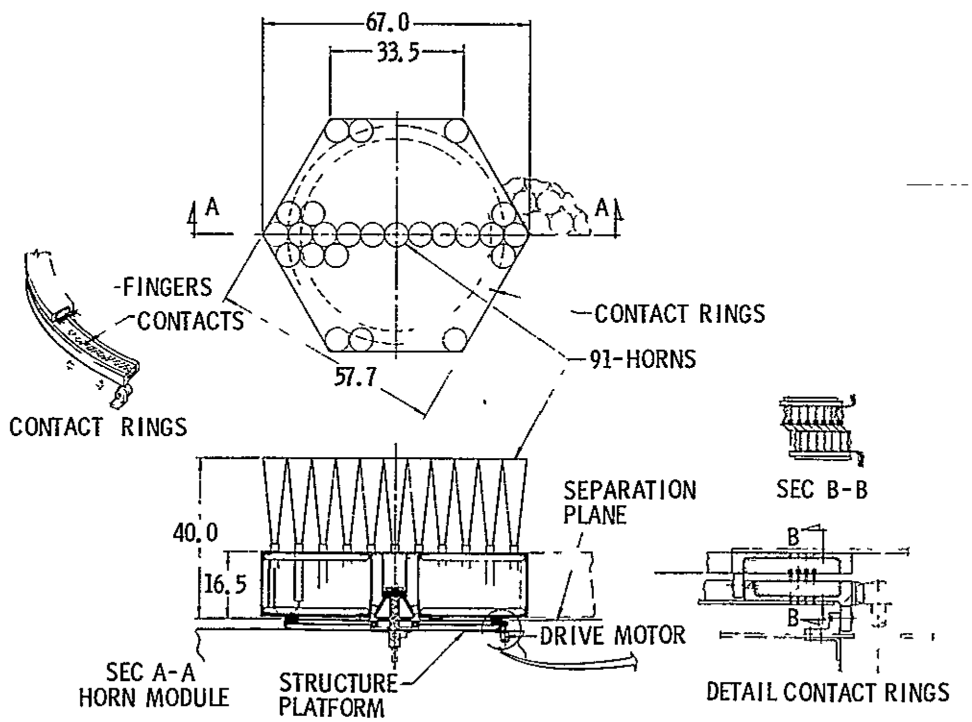


Figure 3-51. Feed Horn Module - Personal Communications Satellite

to be exchanged. A certain amount of redundancy would probably be built into the electronics package itself to assure continued operation until a replacement flight became economically practical. The servicing concept for this satellite assumed one servicing flight every year to synchronous altitude.

The maximum power output of any one set of transmitters for any horn is given by the maximum number of channels per beam, which is about 700. However, the average thermal output for an assembly of horns is given by the average number of channels per beam times the number of beams. This is 33 channels per beam and since the thermal output of a transmitter is 1-1/2 W, a total dissipation capability of an average of 50 W per beam or per horn is required. A simple analysis showed that this heat could be radiated by the horns themselves, thus removing the necessity of providing a separate radiator and thermal path for cooling the transmitters. The packaging of all of the components is illustrated in Figure 3-52. In this

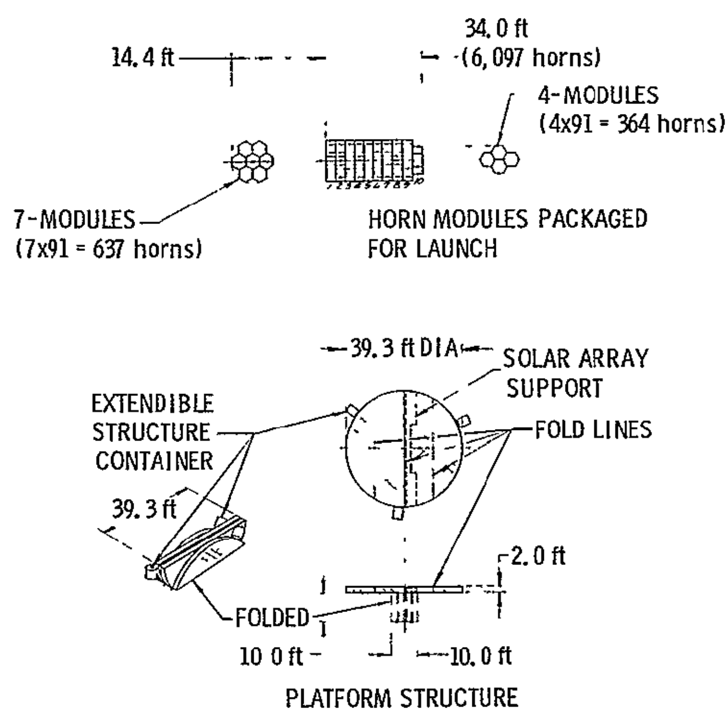


Figure 3-52. Component Packaging Personal Communications Satellite

In this figure the main support assembly is shown as a 39.3 ft dia disc, which is folded for carrying in the space shuttle payload bay. The structure contains a member extending through it for carrying the loads for adapting the solar arrays and supports to which will be attached the trusses for holding the lens of the antenna.

The modules of horns and electronics each containing 91 horn and electronic pieces are shown in this figure to be assembled into clusters and tiers forming a package 14.4 ft in diameter and 34 ft long for carrying in the space shuttle. The modules would be removed one at a time upon reaching low altitude orbit and plugged into the support structure receiving latches and ring assemblies of contacts.

The main lens assembly is deployed from a compact stowed article by a technique identical to the one proposed by Grumman and illustrated in Figure 3-53. The gores in the picture refer to the panels of the lens structure that include the three films: the ground plane, the input plane, and output plane, which contain all of the antenna elements and commandable time delay shifters required for system operation. The deployment is

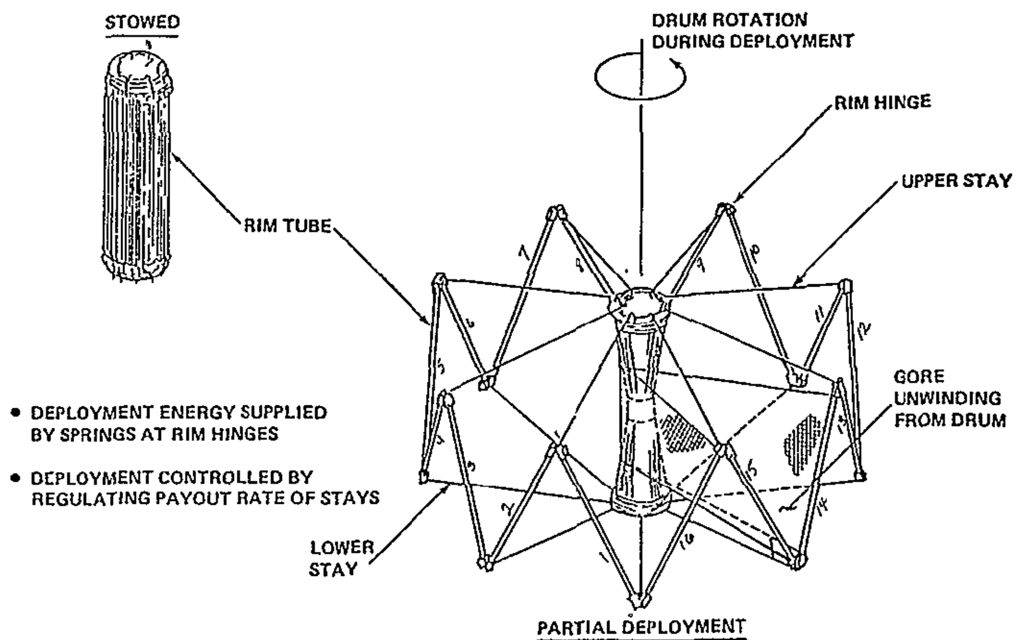


Figure 3-53. Wire Wheel Schematic — Deployment

powered by spring energy at the hinges of the rim compression structure and is stabilized by support wires. The entire satellite is shown in a scale drawing in Figure 3-54. In this figure it is seen that the main electronic support structure is connected to the lens assembly by three extendable truss structures of the Astromast variety. An alternate structural technique would be to use space-fabricated beams. No position is taken at this point as to which is prefereable but the design baseline assumed a wholly extendable and deployable satellite device. The extendable trusses are attached to the platform support structure at points removed from the horn clusters in order to avoid the generation of intermodulation products as discussed in Section 3.2.5.2. The solar arrays are attached to the main truss by extendable struss structures and are in themselves extendable and modular. They are extended from the central electronics support structure in order to avoid the blockage that would occur otherwise by the lens structure itself at some angles approaching, but short of, actual eclipse by the Earth. The back of the main support structure holds the power, electronics, and guidance equipment including the digital switch/processor assembly as shown

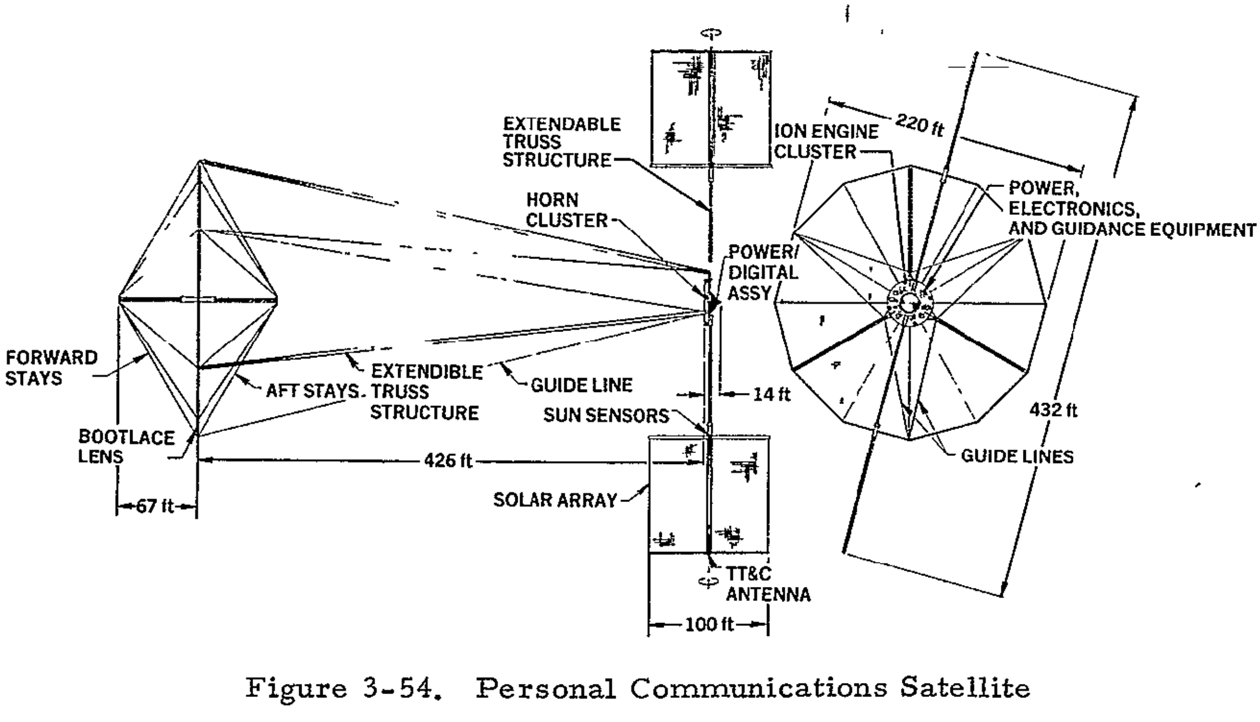


Figure 3-54. Personal Communications Satellite

in Figure 3-54, whereas the front of the structure holds the horn structures facing the lens assembly. The scale of the satellite can best be appreciated by the oblique drawing of Figure 3-55 in which the space shuttle is shown in scale performing adjustment operations. In this figure the mirror image of the USA is apparent in the horn cluster assembly.

The total weight of the satellite is 54,100 lb or 24,600 kg. The weight breakdown is shown in Table 3-35. Approximately one-third of the satellite weight is the electrical power system with the antenna and electronics accounting for another third. A large contingency is included to account for the large uncertainties of this very complicated satellite, keeping in mind that this design is very preliminary and will undoubtedly change with more design attention.

The packaging of all of the components of the satellite is illustrated in Figure 3-56 in which it is seen that three orbiter flights are probably required to take all the components into low-altitude orbit. It may well be possible to perform this with two flights upon more careful packaging consideration, since the entire satellite weight could be borne

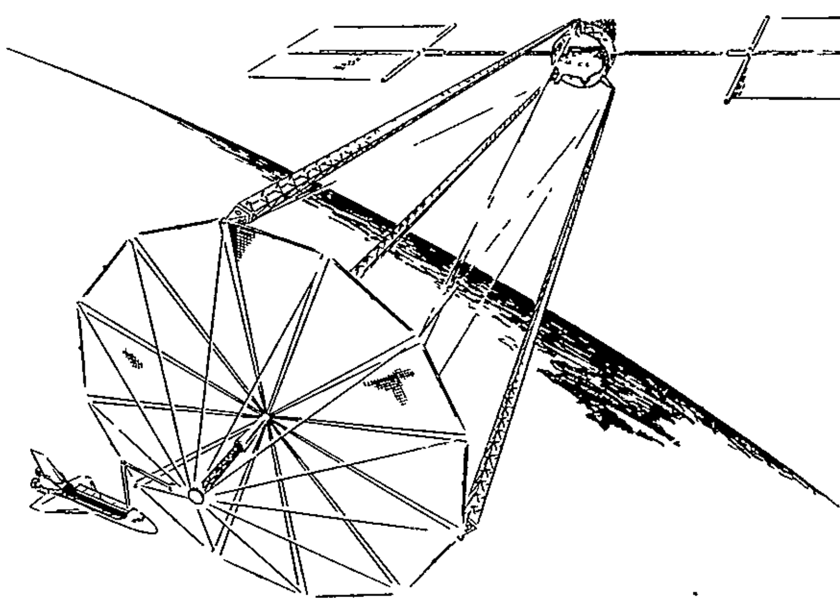


Figure 3-55. Personal Communications Satellite

Table 3-35. Weight Summary Personal Communications Satellite

ITEM	WEIGHT - POUNDS	
STRUCTURE AND THERMAL CONTROL		5 725
ATTITUDE CONTROL (Excludes Reaction Control System)		35
ELECTRICAL POWER AND DISTRIBUTION		18,800
Arrays (273 kW)	5,280	
Array Structure (Including Orientation and Deployment Mech)	4 470	
Distribution and Conditioning } 210 kW B O L	2,700	
Batteries	6,350	
ANTENNA		5,565
Feed Horn Assembly	2 450	
Lens Assembly	1,765	
Support Struts	1,290	
Guide Lines	60	
COMPUTER (Including Heat Pipes)		7 955
ELECTRONICS		3,815
Diplexer/Hybrids	70	
Receivers	140	
Demodulators	460	
Modulators	920	
Transmitters	2,075	
Frequency Generators	100	
Master Oscillator and Distribution Unit	50	
PROPULSION AND REACTION CONTROL		4,610
Propulsion and Reaction Control System (dry)	440	
Propellants	4,170	
WIRING		575
CONTINGENCY (20 PERCENT)		7 020
SATELLITE GROSS WEIGHT		54 100

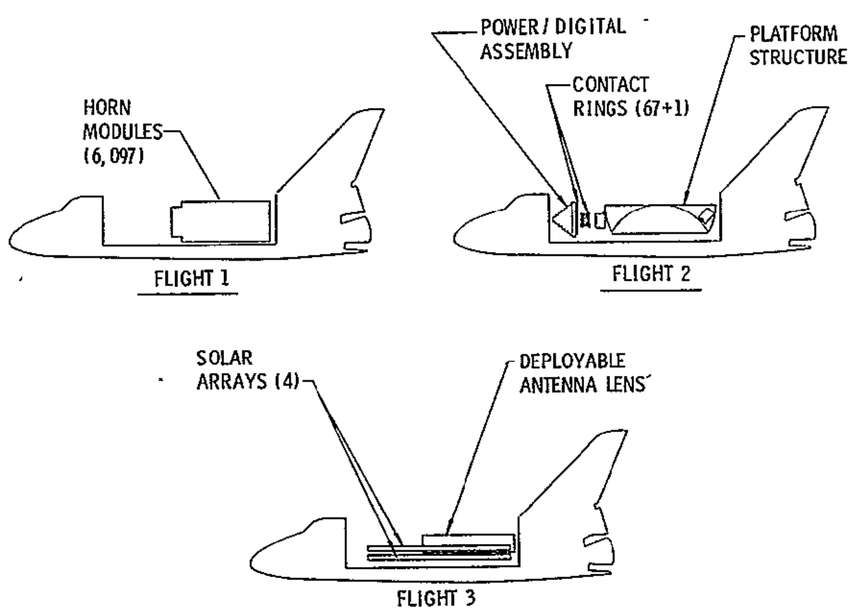


Figure 3-56. Orbiter Flights for Personal Communications Initiative

by a single orbital flight and very little thought was given to optimum packaging. Furthermore, in the development plan that will be discussed in Section 3.3, it is assumed that the final antenna (only a small percentage of the electronics and power) will be deployed in the first flight, with a follow-on flight or flights being required to bring all the rest of the assembly of the computer, the horn modules, and the solar arrays. This entire question of optimum flight packaging then requires further thought and design, however, three flights will be used for the purposes of this design study.

3.2.6 Ground Segment Definition

The ground segment of the satellite system consists of the user sets - namely the wrist radio-telephone instruments and a ground station required to operate, command, and read-out information from the satellite.

3.2.6.1 User Radio-Telephones

In the concept definition the link calculations performed in Section 3.2.2 showed that variable slope delta modulation was assumed for the information stream, an omnidirectional user antenna was assumed, a frequency close to 5 GHz was chosen in which to operate, a transmitter output level of 250 mW was selected, and a 30-Hz bandwidth order wire channel was configured for command to and from the user set. In this section the user set will be further defined and some of those numbers substantiated. One of the major factors determining the allowable power level was consideration of safety.

Since the personal radio will be held close to the face when the set is transmitting, the potential of electromagnetic radiation damage must be evaluated. The radiation limit is 10 mW/cm^2 in the USA. This level sets the maximum allowable transmitter power. The radiating element is assumed to be an omni antenna. The effective area of an omni is $\lambda^2/4\pi$, and with 50 percent efficiency the physical area is $2\lambda^2/4\pi$. This configuration is the radiation equivalent to a point source at a distance of R_e from the surface of the antenna. The area of a sphere of radius R_e, $4\pi R_e^2$, must be equal to that of the antenna, i.e., $4\pi R_e^2 = 2\lambda^2/4\pi$. Then R_e is 0.1125λ. The radiation incident upon a surface R cm from the antenna is then (from Table 3-36)

$$\frac{\hat{P}_t}{4\pi (R + R_e)^2}$$

Since the operation is half duplex, the average transmitter power will be half of the transmission power P and the radiation level is

$$\frac{\hat{P}_t}{8\pi (R + \lambda)^2} = \frac{\hat{P}_t}{8\pi (R + 0.1125\lambda)^2}$$

Table 3-36. Incident Power

EFFECTIVE AREA OF AN OMNI ANTENNA = $\lambda^2/4\pi$

PHYSICAL AREA = $2\lambda^2/4\pi$

RADIATION EQUIVALENT IS A POINT SOURCE RADIATOR AT A DISTANCE R_e

$$4\pi R_e^2 = \frac{2\lambda^2}{4\pi}$$

$R_e = 0\ 1125\lambda$

$= 4.22$ cm AT 0.8 GHz

$= 0.6752$ cm AT 5 GHz

$= 0.241$ cm AT 14 GHz

$$\text{INCIDENT POWER} = \frac{\bar{P}_T}{4\pi(R + R_e)^2} = \frac{\hat{P}_T}{8\pi(R + R_e)^2}$$

R = DISTANCE FROM ANTENNA TO POINT OF INTEREST

$\hat{P}_T = 2\bar{P}_T$ (Two Way Push to Talk Link)

The radiation level increases with frequency, and the level as a function of distance is given for three frequencies, 800 MHz, 5 GHz, and 14 GHz in Figures 3-57, 3-58, and 3-59. For a transmitter power of 250 mW, the radiation level is below the stated limit even for operation at 14 GHz at a distance of 1 cm.

It is seen further, by reference to Figure 3-58 that at 5 GHz the radiation from a 250-mW transmitter is in order ot magnitude less than that allowed by the U.S. Standard and more in conformance with the Russian standard at a distance of 2-1/2 cm (or 1 in.) from the transmitter; thus it is concluded that safety is not a problem even when long-term operation of a wrist-mounted set is assumed, at least at the frequencies and powers contemplated.

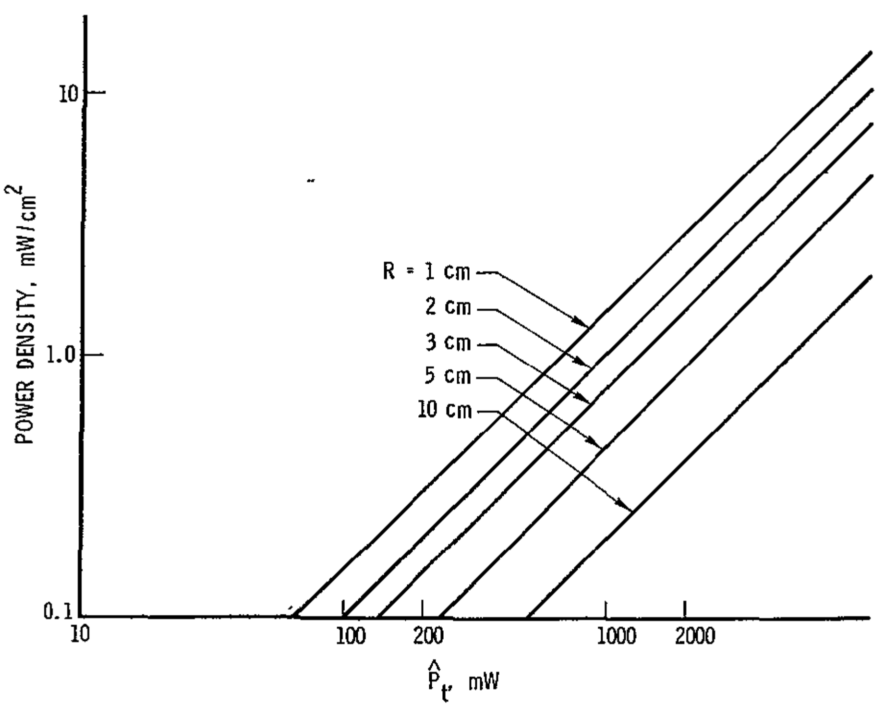


Figure 3-57. Electromagnetic Radiation Incident Power Density as a Function of Distance at a Frequency of 800 MHz

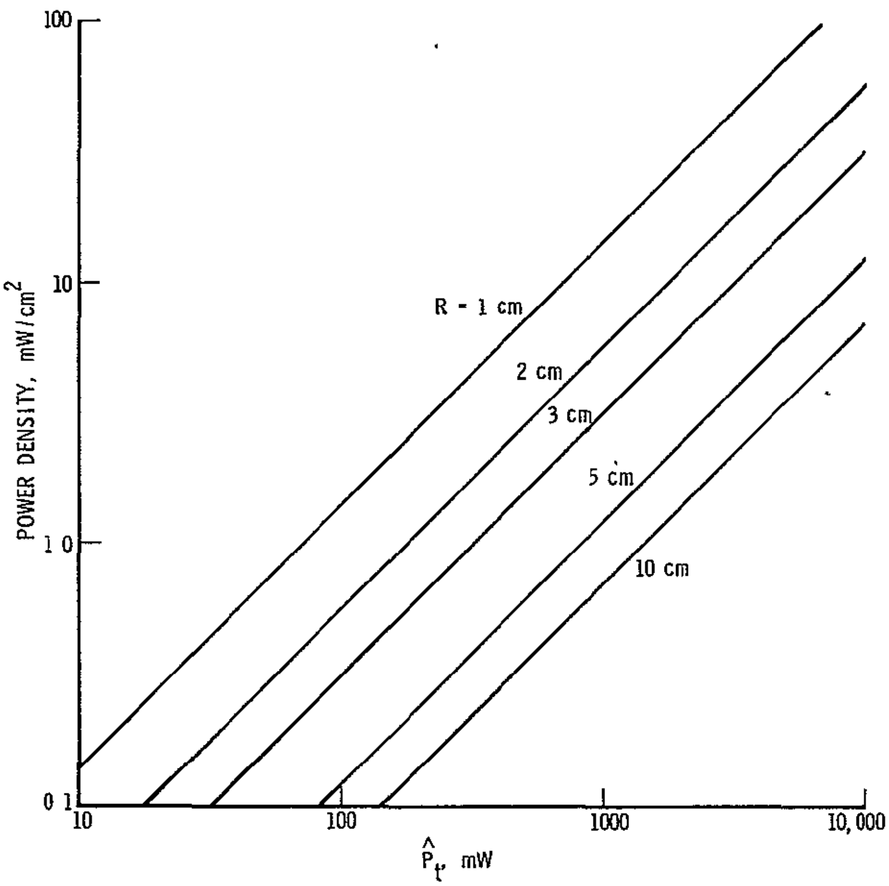


Figure 3-58. Electromagnetic Radiation Incident Power Density as a Function of Distance at a Frequency of 5 GHz

The next item concerns the need for sizing the battery to determine whether indeed a package can be built having the required small size and yet have enough capacity to support the required number of transmissions per day.

It is assumed that the user would keep his receiver on alert for 16 hr per day, allowing 8 hr for recharging the battery. It is also assumed that the traffic during the busy hour is 10 percent of the daily traffic, for an average use of 5 1-min calls per day. With push to talk

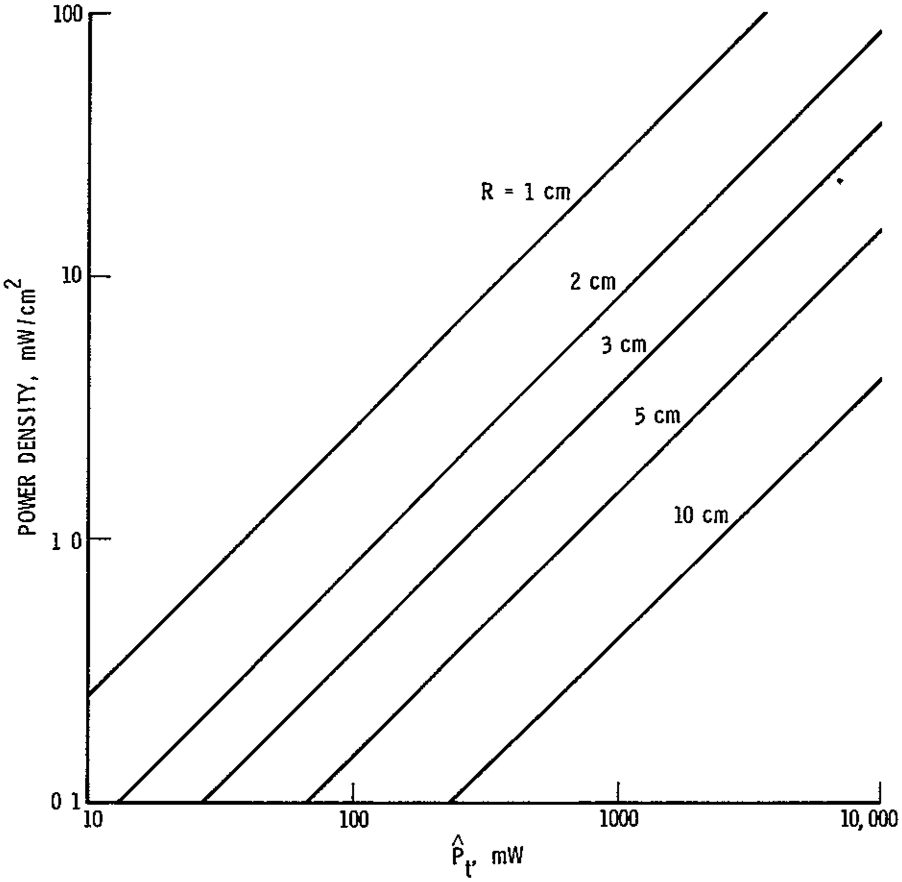


Figure 3-59. Electromagnetic Radiation Incident Power Density as a Function of Distance at a Frequency of 14 GHz

operation, the transmitter would be on 2.5 min per day, as shown in Table 3-37, assuming a receiver idle drain of 100 μA by analogy with the HP01 wrist computer gives a required battery capacity of 2 mW hr. For a transmitter power of 0.25 W, and an efficiency of 25 percent, the battery capacity required is 83.3 mW hr per day. AgCd or AgZn batteries appear to have satisfactory characteristics for this use. From Table 3-37 it is seen that a typical battery such as silver zinc would only be a 0.2-in. cube even assuming a very conservative 50 percent depth of discharge for the battery. It is thus concluded that the battery is practical for five (5) one-min contacts per day. It is also clear, however, that the battery is the

Table 3-37. Battery

ASSUMPTIONS		
OPERATING PERIOD	-	16 HR/DAY
AVERAGE USE	-	5 - 1-MIN CALLS/DAY
TRANSMITTER ON	-	2.5 MIN/DAY (PUSH TO TALK OPERATION)
RECEIVER ON ALERT	-	16 HR/DAY
RECEIVER		
- 100 μA IDLE		
2 mW hr CAPACITY FOR ONE DAY		
TRANSMITTER		
POWER	=	1/4 W
PRIME POWER	=	1 W
CAPACITY	=	2 W X $\frac{2.5}{60}$ HR/DAY = 83 3 mW HR/DAY
TOTAL REQUIREMENTS	=	0.085 W-HR/DAY

TYPE	WT OZ/W-HR	VOL CU IN./W-HR
NiCd	3 5	0.15
AgCd	0.96	0 05
AgZn	1.04	0 055
TYPICAL		
FOR AgZn, ASSUMING 50% DEPTH OF DISCHARGE, = 0.18 OZ; 0.009 CU IN. (0 2 IN. CUBE)		

limiting factor for a wrist-sized package in terms of a larger number of calls or call minutes per day or a larger output power or both.

The next item that was analyzed is the matter of channel loading to determine the feasibility of time-shared operation among a large number of users per channel. This analysis was referred to in the discussion X of Section 3.2.4, User Access and Operation. In this analysis, Figures 3-60 and 3-61, are used to determine the number of channels. The total traffic load impressed on the satellite in $N\lambda t$ erlangs, where N is the number of users, λ is the average call rate per user, or calls per user in the busy hour, and t is the average call duration in hours. The value of assumed here is 1/2 call per busy hour, with a call duration of 1 min or 1/60 hr, for a demand of 0.00833 erlangs. If ρ is defined as the ratio of call arrival rate to call service rate, then for N user and M channels (see Figure 3-60) $\rho = N\lambda t/M$, and $M = N\lambda t/\rho$.

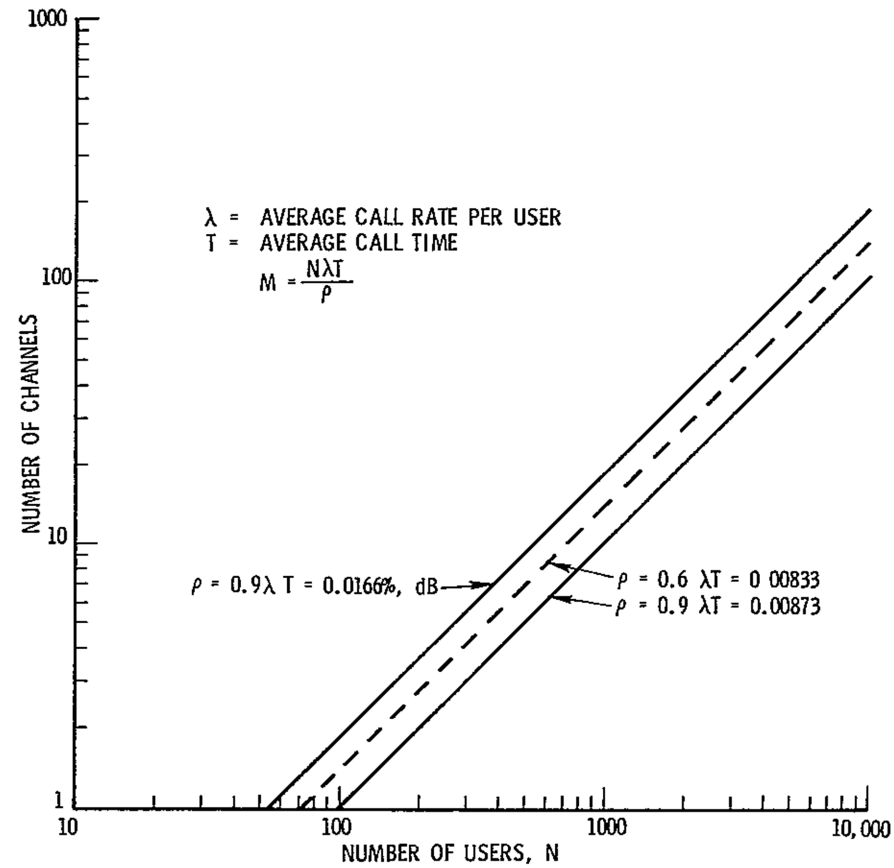


Figure 3-60. Required Number of Channels

Obviously ρ should be as large as possible to minimize the number of channels, but must be less than 1. Figure 3-61 shows that as ρ approaches 1, the length of the queue becomes unbounded, and also that as M increases, ρ may be made to approach closer to 1. The value of selected was 0. 9 so that M = 0. 0092N. Applying this relation to the beam and user data provided indicates that 108 users can share a channel during the peak of the busy hour with a lower loading required at all other times. With a queue length of only three or four even during the busiest time of the day. The resultant capacity of the system is summarized in Table 3-38 in which the required number of channels is determined to be about one percent of the total population in the number of users per beam and

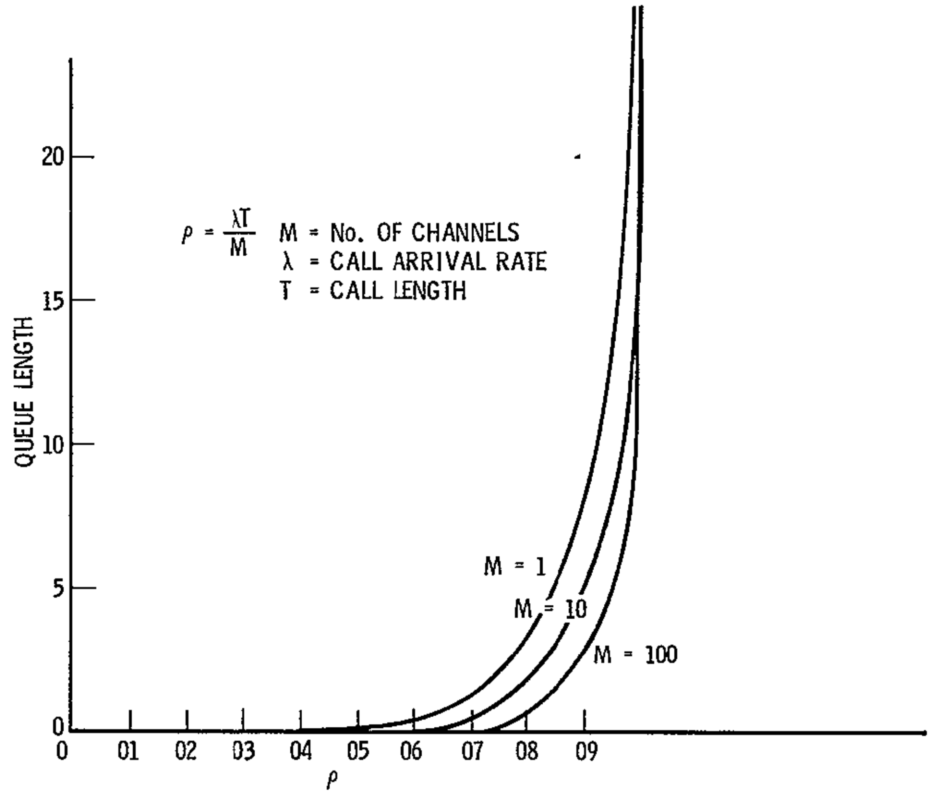


Figure 3-61. Queue Length versus ρ and M

channels per beam derived, utilizing the 108 users sharing a channel derived in this section.

The last topic to be treated in defining the user set is to determine the operation of the system in view of the expected attenuation due to the body, nulls in the antenna pattern, and the presence of residential buildings. All of which will combine to increase the link attenuation in the worst case to the point where a link analysis carried out as in Section 3.2.2 would result in hopelessly large powers for the voice bandwidth transmitters. Data on the attenuation to be expected from residential buildings was obtained from References 6 and 7 and is illustrated in Figure 3-62, from which it is seen that if a user is located inside his home or another building the expected attenuation is in the order of 10 dB or less, provided that the building is

Table 3-38. Coverage Capacity Summary

COVERAGE*	NUMBER OF BEAMS**	NUMBER OF USERS	% OF 1990 US POPULATION	NUMBER OF VOICE CHANNELS ***	NUMBER OF USERS/BEAM	NUMBER OF CHANNELS/BEAM
URBAN AND SUBURBAN	846	16,830,000	6.7	156,000	MAX 75,000 AVG 19 900 MIN 3,750	MAX 694 AVG 175 MIN 34.7
RURAL	6084	8,414,000	3.3	75,000	MAX 7,050 AVG 1,232 MIN 60	MAX 65 AVG 11 MIN 1
TOTAL	6930	25,244,000	9 3	230 000		

*Not including Hawaii and Alaska

**30 mile footprint 3 dB overlap

***108 users share each channel

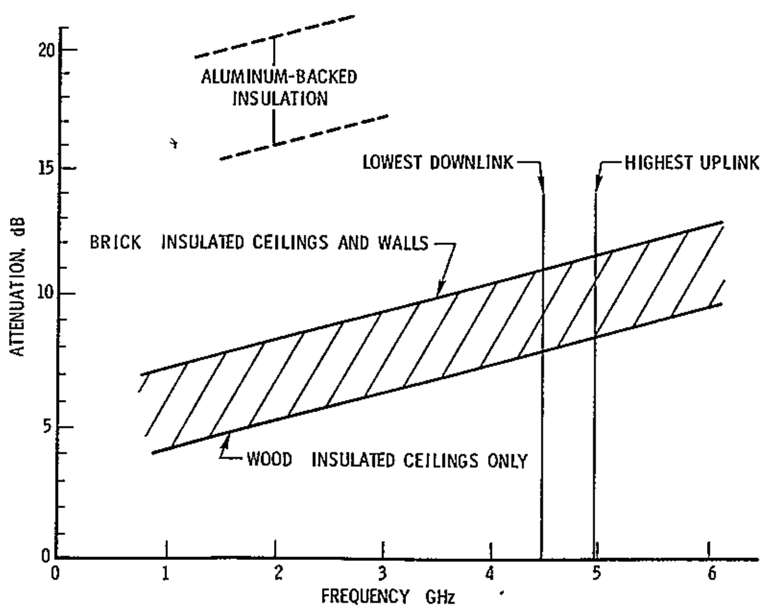


Figure 3-62. Attenuation in Residential Buildings

not totally shielded by aluminum-backed insulation in the ceiling or by a total sheetmetal construction or aluminum siding. It was therefore concluded that the value of 10 dB would be used in considering extra attenuation for a link and that user contact would probably not be possible in the worst case with users inside totally shielded buildings. A second factor comes about the realization that a omnidirectional antenna pattern is almost impossible to achieve, and that in practice there will be nulls in the antenna pattern achieved by any practical system. These nulls may be fairly deep but on the average would not be expected to exceed 10 dB below isotropic. A third factor must come with the realization that the body is a lossy medium and that a wave passsing through different parts of the body will suffer varying attenuations. From measurement and studies performed (Refs 8 and 9) it was determined that the body attenuation would vary from zero, if a clear line of sight existed between the user set and the satellite, to as much as 20 to 30 dB if heavy muscle were interposed in the line of sight and if diffraction of the wave around the body was ignored. In the worst case then, the addition of the three previous factors combine to yield 40 to 50 dB of excess attenuation not accounted for in the link calculations performed previously. In the best case, however, with a clear line of sight outside of a building with the satellite not located along an antenna pattern null, at most a few dB of access attenuation might be expected.

The conclusion was reached that in the latter case, a satisfactory link would be closed due to the margin that exists in the link calculations. In the worst case, such closure is clearly impossible and so an operating procedure was devised to get around the problem. Since the order wire link margin is almost 50 dB even in the worst case the satellite would be able to signal a buzzer in the wrist radio to indicate that a call was coming through. In other words, the excess margin available in the order wire over the voice channel would enable a link to be closed between the user and the satellite and vice-versa at all times. The outfitting of the user set with a digital read-out light, which is when the received signal strength from the satellite beacon is satisfactory, would enable the user to determine whether his line of sight was free enough of attenuation to communicate with the satellite by voice.

The implementation of such an order wire is very simple, requiring but tracking of a CW beacon by the satellite with a phase-locked loop in the user set. Such will be shown to be required anyway for setting the frequency of the local oscillator. Thus in operation a user who wished to transmit would first check his "link OK" light to determine whether his location and orientation was such that his voice transmitter could reach the satellite. Should this not be the case he would have to move out of the building, reorient his wrist, reorient his body, or all three until the light went on indicating that the excess loss was removed. This way a user system has been defined that does not have to incorporate enough power and antenna gain to operate inside shielded buildings, in spite of antenna pattern nulls, or through heavy attenuating layers of body tissue and yet is self-contained in a small package.

This procedure has assumed the availability of an order wire channel with a 30-Hz bandwidth, allowing a 30-bit digital call to be received in 1 sec. This seems like a reasonable time in which a user can be alerted that a call is coming in for him, and yet is narrow enough that the link margin attained is so high as to enable signal reception from the satellite beacon in the worst case.

The resultant block diagram of the user set is shown in Figure 3-63. It is seen to be a straight forward, half duplex transmitter/receiver chain consisting of: an IMPATT diode power amplifier with 1/4-W output, an FET front end; low noise amplifier, a digital variable slope delta modulator and demodulator; a frequency synthesizer locked by a phase-locked loop to a beacon in the satellite that eliminates the drift of the local oscillator and enables narrow channels to be used; a microphone loudspeaker and display unit and an atenna.

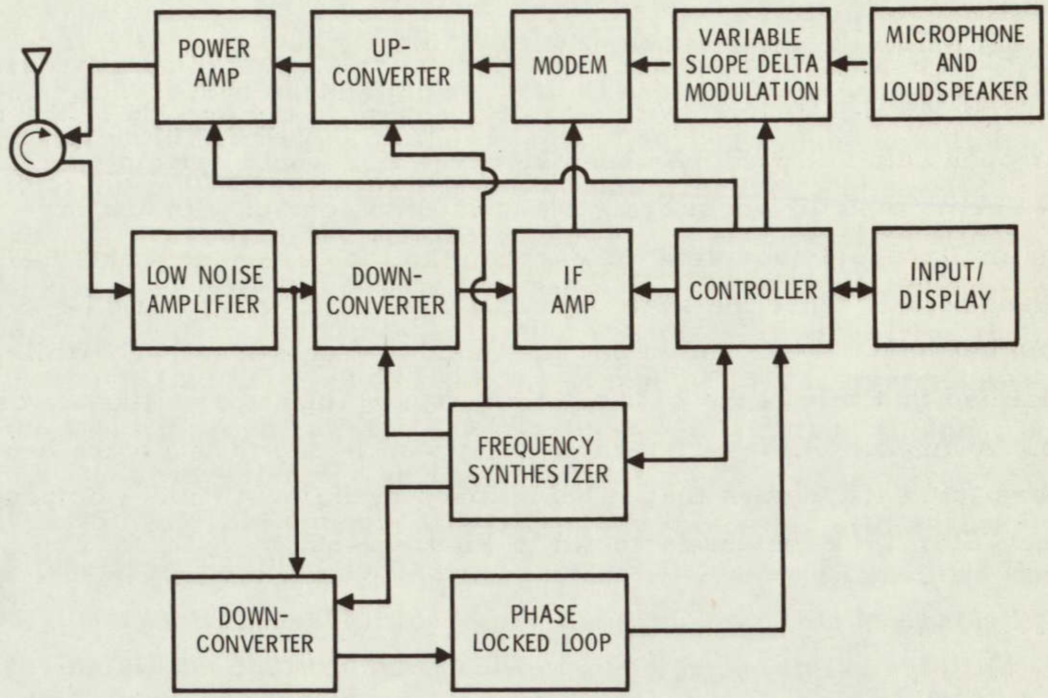


Figure 3-63. Simplified User Set Block Diagram

As mentioned previously the antenna could be a loop, a cavity-backed slot, a series of crossed dipoles, or any combination of the above for attaining essentially an omnidirectional pattern. If desired an extendable structure such as a coil spring helix could be built into the package to provide 10 dB more gain in very adverse locations, in which the user could grossly point his antenna to various portions of the sky until the signal light on his set was energized. This antenna would probably enable conversations from inside buildings with foil-lined insulation in the ceilings.

It is envisioned that the microphone would be a built-in, small condenser microphone, and the entire package would be held up a few inches from the mouth in order to speak. The loudspeaker presents a different problem in that severe battery drain will occur if the sound is made loud enough to overcome ambient noise in noisy locations. A solution is to incorporate a small earphone of the type normally supplied by transistor radios for personal listening, with a cavity opening to the outside of the radio. The user upon being alerted by a beep signal (which would certainly be audible at arms' length) would bring his wrist into contact with his ear thereby simultaneously coupling the earphone to the ear channel and shading out ambient noise. Since the system is half duplex the wrist could be alternated between the ear and facing the mouth for conversation. While it is not claimed that this is the best solution, it certainly seems like a workable one. A mockup of the wrist-radio-telephone is shown in Figure 3-64 and a more futuristic design that is being made by Bulova Watch Company for the new Star Trek movies is shown in Figure 3-65.

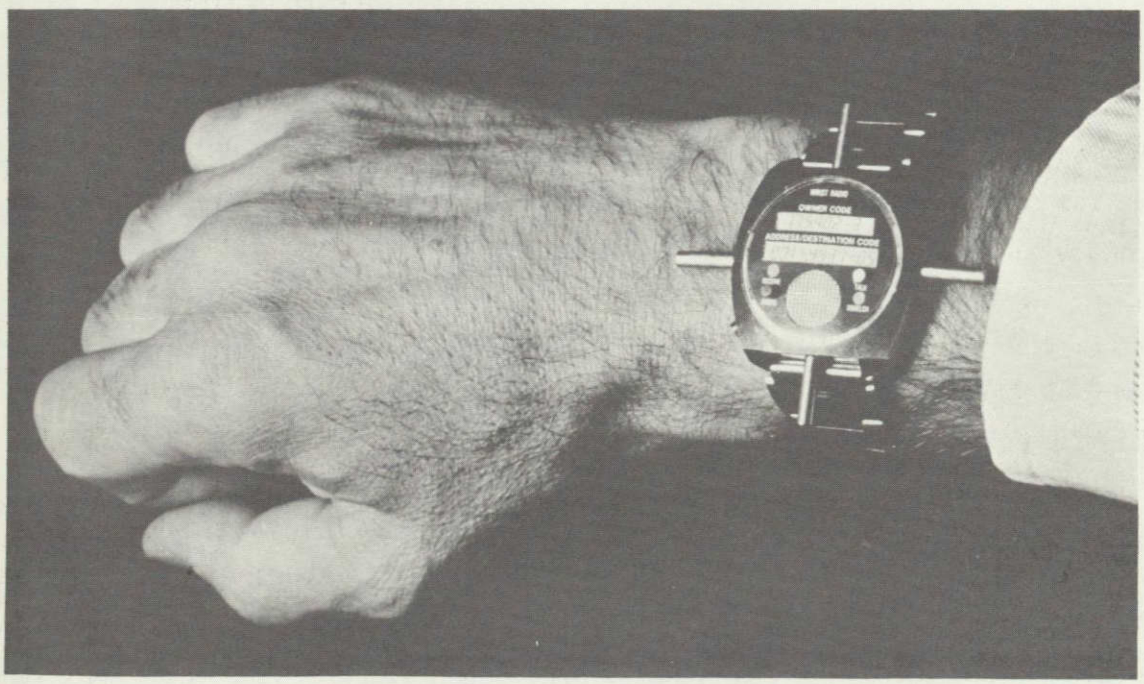


Figure 3-64. Wrist Radio-Telephone

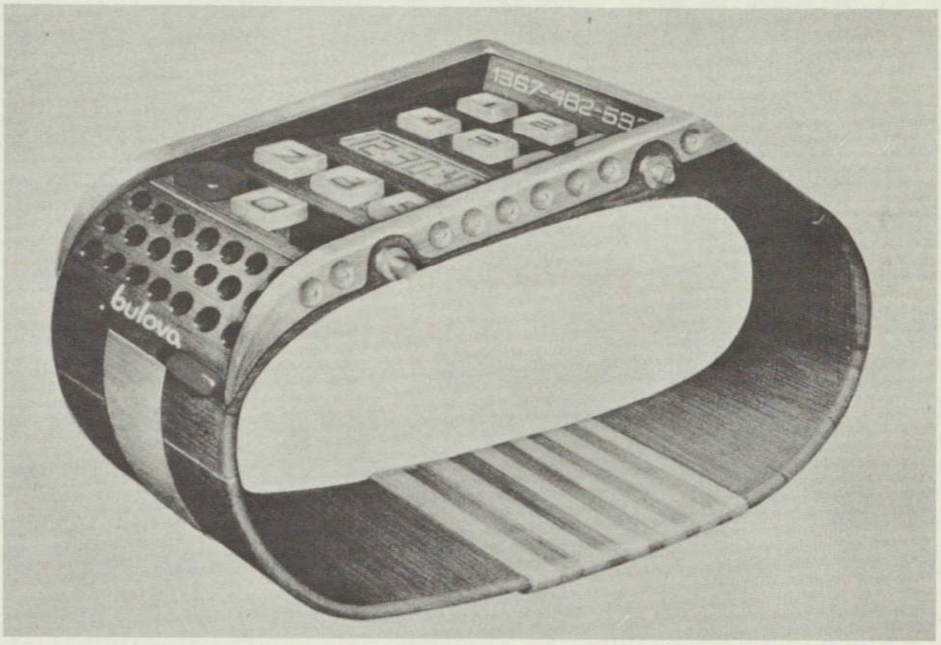


Figure 3-65. New Design Wrist Radio for Star Trek

3.2.6.2 Ground Control Station

The ground control station will be needed in order to maintain a health status on the satellite, determine required servicing, command the satellite for switching and backup functions, overriding onboard computer functions, maintaining an ephemeris, commanding translation functions, and receiving telemetry from the satellite. The latter would contain user charge information based on user identifying codes and measured times of satellite usage that would be converted by the ground station into billing information, and sent to the customers' mailing address on a monthly basis. It is not envisioned that the ground system perform any operational functions involving reception, transmission, or switching of user signals as that will be performed wholly in the satellite by the onboard digital switch.

The link carrying the user charge information is straightforward, requiring about 100 bits of information per use. Thus less than 300,000 bps suffice in the data link — a trivial design requiring only a 10-ft dia ground antenna and a 3-ft satellite antenna with a 10-W transmitter.

An alternate configuration of the entire system, in which the satellite acts as a bent pipe channeling all uplinks from the 230,000 channels to the ground station for switching to the outgoing 230,000 ground downlinks, is also possible, thereby eliminating the complicated, heavy, and power hungry switching processor in the satellite. However, such function allocation would require 4.6 Gbits of bandwidth at about 46 GHz for both up and down transmission links to and from the ground station. Furthermore, the link required to send that data to and from the ground station is horrendous. Even assuming a 20-m ground station antenna and a 3-m satellite antenna, which is almost 1000 wave-lengths across (about the same size in wave-lengths as the 67-m satellite antenna at 5 GHz), a MW of transmitter power would be required from both the ground and the satellite in order to close the link. This is clearly unreasonable; therefore the ground station has been configured leaving all the operational tasks to be performed in the satellite.

3.2.7 Cost Estimates -- Personal Communications System

The purpose of this section is to set forth cost estimates for the Personal Communications System satellite and to explain how they were derived. Historically, much cost estimating for satellites has been done on the basis of subsystem or total spacecraft weight information. However, during the past few years a cost-estimating model has been developed at the Aerospace Corporation that is based on components and major assemblies of satellites. The advantage of such a model is twofold -- it provides a more accurate description of a given subsystem (as opposed to an amorphous subtotal weight) and it takes into consideration the developmental status of each particular component. For example, if a transmitter, which had been developed previously, were to be used in a particular communications subsystem design, the subsystem development (and production) cost estimate could be altered (reduced) to reflect such occurences. The disadvantage of such a model is that it cannot be applied to certain advanced concept satellites where insufficient information exists concerning the components that make up each subsystem. Accordingly, this study makes use of the new cost model where possible and uses subsystem cost-estimating relationships (derived from cost model estimates) in those cases where component information is lacking.

The next section provides a brief description of the Spacecraft Cost Model (SCM) and contains examples of the application of the SCM to Personal Communications System demonstration satellites. A description is also given of how the SCM-derived subsystem estimating relationships were developed and applied to the Personal Communications System satellite. A later section deals with other segments of total life-cycle cost such as on-orbit maintenance, mission operations control, user ground equipment (wrist radios), and their maintenance.

3.2.7.1 Spacecraft Cost Model

As mentioned previously, over the past several years a cost model has been developed at The Aerospace Corporation that relies on component rather than subsystem-based inputs. Figure 3-66 contains a schematic comparison of the conventional (current) method, i.e., building

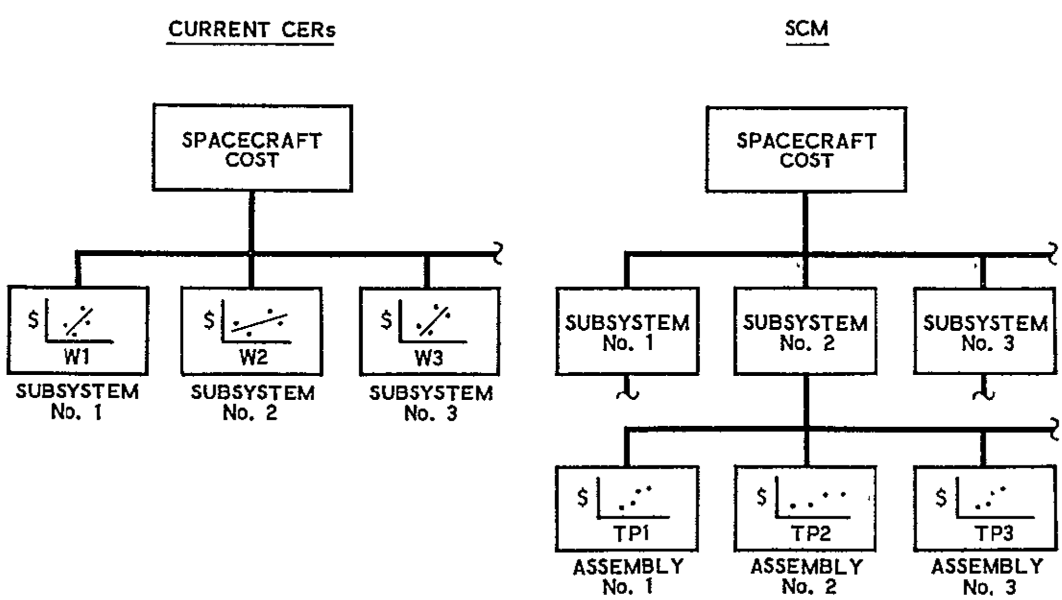


Figure 3-66. Cost Model Comparison

up spacecraft cost by applying cost-estimating relationships (CERs) to subsystem weights, versus the SCM procedure, which is based on applying CERs to each component (assembly) within a subsystem. The SCM provides for (1) a more thorough description of each subsystem, and (2) an appraisal of the developmental status of components within a satellite. Because of the subsystem descriptive detail required by the model, a better estimate of the effect of changes in reliability (through redundant components) can also be made. Technical performance characteristics can often be used in addition to or in lieu of weight as cost drivers for CERs; thus, certain cost estimates reflect performance directly rather than by using componet weight as a surrogate.

The program operates on a CDC 7600 computer and requires as inputs the items listed in Table 3-39. The inputs of primary importance for each component are its quantity (per satellite) and a design, development, text, and engineering (DDT&E) factor. The DDT&E factor describes the status of development on the component in question. A factor of 1.0 denotes that the component is new and, thus, will require complete design, development, and testing including qualification. A factor close to 0.0 announces that the component has previously been developed and that no modification or redesign is anticipated for its use in the satellite design. Values between 0.0 and 1.0 signify that modifications or redesigns, and possibly requalification, will be required; for example, a redesign including qualification testing would be associated with a DDT&E factor of approximately 0.75.

An example of the output of the SCM is provided in Table 3-40 where detailed cost and related technical information are provided for each component for each subsystem of the Personal Communications System Concept Demonstration Satellite. Table 3-41 includes similar information concerning assemblies such as structure, thermal, solar array, and propellant feed system, which are not generally considered to be components. Cost information shown includes design engineering (D.E.) and test and evaluation (R.E.) costs -- two elements

Table 3-39. Spacecraft Cost Model Inputs

General Inputs

- Satellite name
- Quantity of flight and qual units
- Year of constant $, e.g., 1977

Subsystem Oriented Inputs

- Type of configuration for each subsystem
- Subsystem weights
- Mission equipment weight and cost (throughput)
- Orbital data, apogee

Component Oriented Inputs

- Quantity of each component
- DDT&E factor for each component
- Thrust of attitude control and translational thrusters
- Wiring harness weight
- Power control weight
- Weight of power converters
- Solar array area, weight, and BOL power
- Battery system capacity

that make up design and development cost. Also shown are production (vehicle production cost) and sustaining or production engineering (vehicle engineering cost) -- the two elements that make up unit production cost. Such cost information is augmented by the addition of system engineering and integration, program management, and quality control costs and is summarized by subsystems in Table 3-42. In addition, qualification satellites (if needed), GSE, launch site satellite checkout and support, and prime contractor fee are incorporated in the cost estimate and appropriate totals are provided.

Table 3-40. Example of SCM Output

NC3-1-18 PC DEMO

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
1303	REACTION WHEEL	2	5.1	.3	1.00	111435.	68611.	46538.	44526.
1601	VALVE DRIVER ASSY	3	1.6	1.0	1.00	67552.	72567.	54408.	47539.
1815	EARTH SENSOR	2	15.4	15.6	1.00	1304769.	503376.	672052.	521367.
2203	CONTROL ELECTRNCS	3	7.1	62.0	1.00	1271747.	1058460.	715079.	394982.

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
818	THRUSTER	18	.4	0.0	.10	14248.	70110.	109787.	116814.
834	THRUSTER	8	.7	.1	.10	13754.	45762.	77273.	76092.

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	DIGITAL TELEMETRY	2	8.9	3.0	1.00	2468796.	139061.	319646.	986496.
403	CDU	2	12.3	7.5	1.00	6576660.	47819.	109917.	2627940.

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
106	BASEBND ASSY UNIT	3	2.0	0.0	1.00	54662.	38681.	91544.	38468.
202	ANTENNA	1	8.4	0.0	1.00	349517.	137063.	75778.	0.
327	TRANSMITTER	2	4.7	18.0	1.00	272957.	90576.	227794.	109070.
401	RECEIVER	2	3.9	6.3	1.00	85947.	42118.	71951.	34343.
503	COMMAND SIG COND	4	1.5	.9	1.00	24229.	56157.	74952.	23232.
605	DIPLEXER	2	.7	.3	1.00	13337.	5661.	9185.	5329.
640	ANTENNA,70 FT	1	1800.0	0.0	1.00	23976000.	4662000.	10205784.	0.
641	XPONDERS + SWITCH	1	750.0	*****	1.00	19980000.	2331000.	5953374.	0.

Table 3-41. Example of SCM Output

NC3-1-18 PC DEMO

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
269	BATTERY	4	102.5	0.0	.10	212838.	105376.	389604.	429509.

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	202.5	1.00	1261916.	313137.	799840.	0.
WIRING HARNESS	140.4	1.00	543492.	319727.	432508.	0.
THERMAL CONTROL	99.7	1.00	4432034.	248324.	228546.	0.
POWER CONVERTERS	0.0	0.00	0.	0.	0.	0.
PROPULSION FEED SYS	147.7	1.00	1380189.	905430.	770907.	0.
STRUCTURE	307.5	1.00	5094206.	1415192.	903699.	0.
POWER CONTROL UNITS	162.0	1.00	1652515.	502868.	642232.	0.
SOLAR ARRAY DRIVE	17.3	1.00	690177.	330536.	422140.	0.
SATELLITE ADAPTER	110.4	1.00	209132.	160400.	61930.	0.

PROPELLANT WEIGHT 704.0

MISSION EQUIP WEIGHT 0.0

TOTAL SATELLITE WEIGHT 5000.0

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OF POOR QUALITY

Table 3-42. Example of SCM Summary Output

SPACECRAFT COST MODEL

MC3-1-18 PC DEMO

(MILLIONS OF 1977 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL DDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	10.2	2.6	12.8	0.0	2.0	2.0
THERMAL CONTROL	7.5	.3	7.9	0.0	.3	.3
ELECTRICAL POWER	6.2	1.7	8.0	.7	3.2	3.9
COMMUNICATIONS	76.1	10.2	86.2	.4	23.7	24.1
DATA HANDLING	15.4	.3	15.6	6.1	.6	6.8
STABILITY AND CONTROL	4.7	2.4	7.0	2.6	2.1	4.7
AUXILIARY PROPULSION	2.4	1.4	3.8	.3	1.4	1.7
SPACECRAFT	122.5	18.9	141.4	10.1	33.3	43.4
MISSION EQUIPMENT			0.0			0.0
SATELLITE			141.4			43.4
QUALIFICATION UNIT(S)			0.0			
GSE (ACE)			6.9			
LAUNCH SITE SUPPORT						1.2
CONTRACTOR FEE			10.4			3.1
TOTAL SATELLITE			158.7			47.7
AVERAGE UNIT COST (1 SATELLITES)						47.7
TOTAL SATELLITE DDT+E AND RECURRING COST						206.4

3.2.7.2 Subsystem Cost-Estimating Relationships

When insufficient component information exists to permit use of the SCM, subsystem CERs must be relied upon. For this study such CERs were derived from the output of a large number of satellite estimates generated by the SCM for a NASA study (Ref. 10). For each subsystem, data similar to that shown in Table 3-42, were extracted and plotted against its weight. An example of such a plot is given in Figure 3-67 where electrical power subsystem design engineering cost is displayed against subsystem weight for twenty representative satellites. Similar

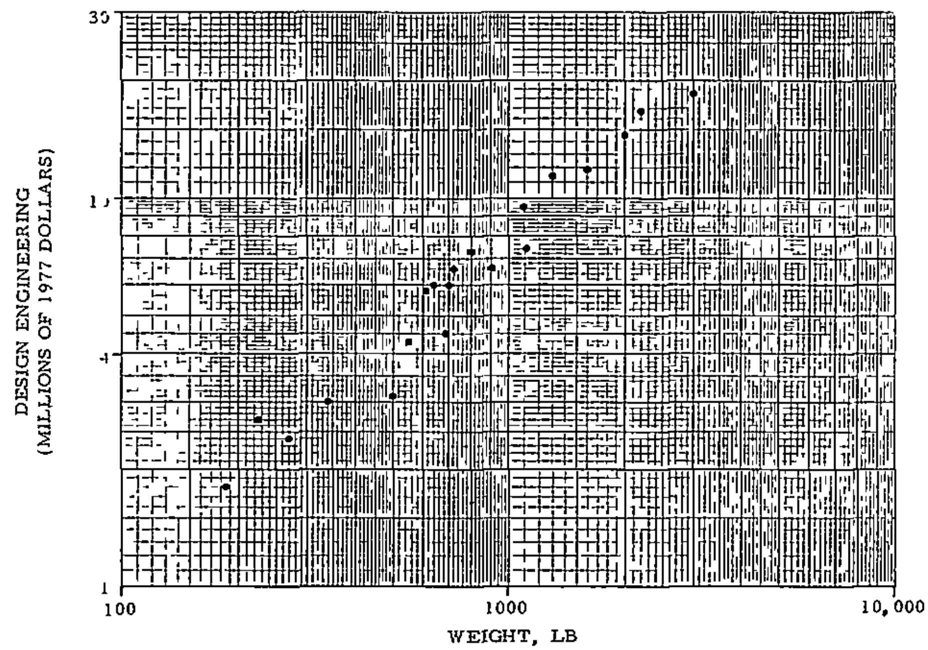

Figure 3-67. Electrical Power Subsystem Design Engineering Cost vs. Weight

aphical representations were developed for test and evaluation cost and for production cost for each subsystem -- structure, thermal, electrical power, communications (including data processing), stability and control, and auxiliary propulsion.

3.2.7.3 Application of CERs to the Personal Communications System Satellites

The subsystem CERs described above and selected component CERs were used to make estimates of the nonrecurring (DDT&E) and recurring (production) cost of three satellites included in the Personal Communications System. The first of these, the Personal Communications System Principle Demonstration Satellite, weighs 1000 lb and is designed to be tested in geosynchronous orbit. Cost estimates and accompanying technical information are presented in Tables 3-43 and 3-44. The satellite is the first in a progression that is planned to demonstrate the technical

Table 3-43. Principle Demonstration Satellite Weight Breakdown

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	5.9	1.00	165834.	15851.	25085.	0.
303	SUN SENSOR	1	.3	.0	1.00	116150.	14519.	18541.	0.
403	NUTATION DAMPER	1	2.8	0.0	1.00	77256.	15984.	17010.	0.
603	CONTROL ELECTRNCS	1	7.4	3.5	1.00	1071594.	447818.	290184.	0.
806	EARTH SENSOR ASSY	2	4.1	1.0	1.00	397432.	153300.	216465.	158306.
1413	POWER CONVERTER	1	15.9	0.0	1.00	0.	0.	0.	0.

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
834	THRUSTER	8	.7	.1	.10	13754.	45762.	77273.	76092.

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	DIGITAL TELEMETRY	1	6.9	3.0	1.00	416809.	139061.	177581.	0.
403	CDU	1	12.3	7.5	1.00	1461546.	47819.	61065.	0.

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.5	1.00	44622.	16117.	36060.	0.
202	ANTENNA	1	8.4	0.0	1.00	349517.	137063.	75778.	0.
306	TRANSMITTER	2	2.1	10.9	1.00	152260.	47779.	139615.	60841.
401	RECEIVER	1	3.9	6.3	1.00	77256.	24775.	39973.	0.
502	COMMAND SIG COND	2	1.5	.9	1.00	20153.	30796.	41640.	8053.
603	DIPLEXER	1	3.1	1.0	1.00	57409.	15451.	21942.	0.
630	ANTENNA,6 FT	1	100.0	0.0	1.00	2797200.	666000.	1180469.	0.
631	SWITCH UNIT	1	65.0	100.0	1.00	2464200.	1332000.	2551446.	0.

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
221	BATTERY	2	25.3	0.0	.10	27169.	23363.	86379.	54827.

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	61.0	1.00	776801.	103086.	263311.	0.
WIRING HARNESS	43.5	1.00	201217.	118373.	160127.	0.
THERMAL CONTROL	32.1	1.00	758002.	115163.	117772.	0.
POWER CONVERTERS	15.9	1.00	590016.	367568.	234718.	0.
PROPULSION FEED SYS	68.3	1.00	881623.	501892.	427324.	0.
STRUCTURE	248.3	1.00	1437792.	1179987.	753504.	0.
POWER CONTROL UNITS	66.6	1.00	630969.	298965.	381820.	0.
SATELLITE ADAPTER	42.4	1.00	61811.	34638.	35410.	0.

PROPELLANT WEIGHT 140.2

MISSION EQUIP WEIGHT 0.0

TOTAL SATELLITE WEIGHT 999.9

feasibility of the Personal Communications System prior to committing the substantial resources required for full-scale development. The second in the plan, the Personal Communications System Concept Demonstration Satellite, weighs 5000 lb and is first tested at low orbit, then transferred to geosynchronous for continued evaluation. Cost estimates and accompanying descriptive information are given in Tables 3-41 and 3-42, previously shown.

The full-scale Personal Communications System satellite cost estimate is based on the subsystem and selected component weight

Table 3-44. Principle Demonstration Satellite Cost Estimate

(MILLIONS OF 1977 DOLLARS)

SUBSYSTEM COST	DDT+E: DESIGN ENGINEERING	DDT+E: TEST AND EVALUATION	DDT+E: TOTAL DDT+E	RECURRING: PRODUCTION ENGINEERING	RECURRING: FAB AND ASSEMBLY	RECURRING: TOTAL RECURRING
STRUCTURE	2.5	1.7	4.2	0.0	1.1	1.1
THERMAL CONTROL	1.3	.2	1.4	0.0	.2	.2
ELECTRICAL POWER	3.8	1.3	5.0	.1	1.6	1.7
COMMUNICATIONS	10.1	3.1	13.3	.1	5.8	5.9
DATA HANDLING	3.2	.3	3.5	0.0	.3	.3
STABILITY AND CONTROL	3.1	.9	4.0	.3	.8	1.1
AUXILIARY PROPULSION	1.5	.8	2.3	.1	.7	.8
SPACECRAFT	25.6	8.1	33.7	.6	10.6	11.2
MISSION EQUIPMENT			0.0			0.0
SATELLITE			33.7			11.2
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			2.2			
LAUNCH SITE SUPPORT						.5
CONTRACTOR FEE			2.5			.8
TOTAL SATELLITE			38.4			12.5
AVERAGE UNIT COST (1 SATELLITES)						12.5
TOTAL SATELLITE DDT+E AND RECURRING COST						50.9

breakdown contained in Table 3-45. The cost estimate is given in Table 3-46. Note that the cost estimate for the total satellite is shown. Later, however, the estimate is broken into two segments; one reflecting the requirement to develop key modules and sections of the satellite to be tested in low orbit, the other dealing with the balance of the satellite to be launched to low orbit where it will be assembled, tested, and the whole satellite transferred to geosynchronous orbit.

3.2.7.4 Ground-Segment Cost Estimates

In the space-based Personal Communications System, the only nonsatellite ground equipment required is the wrist radio used for receiving and sending voice messages. Cost estimates needed are (1) RDT&E required to develop the radio, (2) the unit cost based on large production quantities, and (3) maintenance of the radios over the required period of operation. Based on its similarity with digital timepieces, it is estimated that unit cost would be $10 based on a total quantity of 25 million radios. Development cost is estimated to be $5 million dollars based on the experience of

Table 3-45. Personal Communications Satellite Weight Breakdown

	WEIGHTS (lb)	
	BASIC	WITH CONTINGENCY
STRUCTURE	9,345	10,158
BASIC STRUCTURE	(4,875)	
SOLAR ARRAY ORIENTATION	(4,470)	
THERMAL	840	1,000
ELECTRICAL POWER	14,905	17,140
ARRAYS	(5,280)	
BATTERIES	(6,350)	
POWER CONTROL	(2,700)	
WIRING	(575)	
ATTITUDE CONTROL	35	75
PROPULSION		
ION THRUST SYSTEM	440	500
PROPELLANT	4,170	4,800
MISSION EQUIPMENT		
COMPUTER	7,955	9,547
TRANSPONDERS	3,665	4,160
FREQUENCY GENERATORS	100	150
MASTER OSCILLATOR	50	75
ANTENNA	3,115	3,580
ANTENNA FEED	2,450	2,815
TOTAL SATELLITE		54,000

Table 3-46. Personal Communications Satellite Cost Estimate (Thousands of 1977 Dollars)

	DDT&E	UNIT
STRUCTURE	87,250	30,393
THERMAL	11,034	1,456
ELECTRICAL POWER	107,900	63,212
ATTITUDE CONTROL	7,900	2,056
ION SYSTEM	7,058	7,814
MISSION EQUIPMENT		
COMPUTER	57,116	92,456
TRANSPONDERS	31,436	59,171
FREQ GENERATORS	10,124	7,566
MASTER OSCILLATOR	7,442	3,140
ANTENNA	52,641	10,265
ANTENNA FEED	9,529	51,555
SUBTOTAL	389,430	329,084
TOTAL (Including GSE, Launch Operations Support, and Fee)	440,056	361,992

a major developer and producer of electronic calculators. Finally, maintenance cost is estimated to be ten percent per year of total production cost.

3.2.7.5 Life-Cycle Cost

After completing individual space and ground segment system cost estimates, the next step is to prepare life-cycle cost estimates by synthesizing a plan of operations over a period of time during which the system is expected to perform; ten years of operation is often selected and that assumption is also made for this study. The basic idea behind life-cycle cost estimates is to show not only the major intital costs connected with implementing a system (such as development and production), but also to show the resources required to maintain and operate the system over either its useful lifetime or over a period of time sufficiently long to assess the total cost of the system. Secondary benefits of such an analysis are that time-phasing of total costs can be readily extracted, thus facilitating economic benefit analyses. In order to deal with all of the individual items of cost; to time-phase their development, production, and operation; to accumulate yearly funding expenditures; and to provide for changes to any item within a total life-cycle cost plan, a computer program named MISSCM (for Mission Cost Model) has been used. A description of the model and its application to this study follows.

3.2.7.5.1 Mission Cost Model

The objective of the MISSCM is to relate satellites, launch vehicles, applicable ground segments, and other mission-oriented equipment or tasks so that both total cost and time-phased cost may be calculated. The procedure for accomplishing this is to apply to each major element of cost a schedule and a funding distribution algorithm. The MISSCM computer program keeps each item in memory in terms of both total and time-phased costs and can provide output by individual cost item, by groupings, by subtotals, or by program total.

Examples of MISSCM output are provided in Tables 3-47 and 3-48. Table 3-47 contains data relating to the Personal Communications System Concept Demonstration Satellite. Note that for convenience the weight of 5000 lb is broken down by subsystem, and that basic RDT&E and average unit costs are shown, also by subsystem. The schedule of satellite launches, in this case only one in 1985, is given with its effect on fiscal year funding requirements shown for RDT&E and investment, as well as for the total satellite. Table 3-48 carries forward the schedule and fiscal cost data for the satellite; however, it adds the launch vehicle schedule, description, and fiscal funding requirements to reflect total satellite and launch vehicle cost by fiscal year and by program total. By summing each element within a program, total program cost is calculated. Static totals or total fiscal year amounts are also generated. Finally, the MISSCM can produce either current (inflated) dollars or discounted dollars by fiscal year. This latter step is required for net present value calculations typically made as part of cost/benefit analyses.

Table 3-47. Payload Program Cost (Millions of 1977 Dollars)

SUBSYSTEM	WEIGHTS OPY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	535	535	TYPE,	EIDO	1 000	1 000	23	3		23	3		26
ELECTRICAL POWER	9.5	9.5	WATTS,	2500	1 000	1 000	9	4		9	4		13
TRACKING COMMAND	2671	2531	ALT,	SYNC	1 000	1 000	114	34		114	34		148
STABILITY CONTROL	67	67	TYPE,	3-AXIS	1 000	1 000	8	5		8	5		13
PROPULSION	148	852	TOT IMP(L)0		1 000	1 000	5	2		5	2		7
SPACECRAFT	4296	5000					159	48		159	48		207
MISSION EQUIPMENT	0	0	COMPLXTY, LOW		1 000	1 000							
SATELLITE	4296	5000					159	48		159	48		207
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										159	48		207

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT				1.00																
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)				1																1

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE						40	87	32																
INVESTMENT						12	26	10																
OPERATIONS																								
LOSSES																								
TOTAL						52	113	42																

Table 3-48. Individual Program Cost Breakdown Through 2000 (Millions of 1977 Dollars)

FCS (CONCEPT DEMO)
LAUNCHED FROM ETR

FISCAL YEAR	PAYLOAD TRAFFIC N	R	M	D	LAUNCH VEHICLE TRAFFIC A IUS	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																	6			6	6
1983												40	12			52	8			8	60
1984												87	26			113	9			9	122
1985	1				1 0	1 0						32	10			42	2			2	44
1986																					
1987																					
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1				1 0	1 0						159	48			207	25			25	232

Inputs for the MISSCM are as follows:

- Launch Vehicle Dictionary -- contains name and unit launch cost
- Satellite Schedule -- including weights, RDT&E, and unit cost
- Launch Vehicle Schedule -- including vehicle name and upper stages.

All cost figure output is in terms of constant 1977 dollars (unless discounted or inflated). All cost figures include fee or profit on the part of the prime contractors and their subcontractors.

3.2.7.5.2 Life-Cycle Cost Elements

In addition to the satellites and their launch vehicles, which appear as single line items of cost in the MISSCM Program summaries, other line items such as on-orbit maintenance, mission control, user ground equipment (wrist radio) and ground equipment maintenance must be added to produce the total program life-cycle cost shown in Tables 3-49 and 3-50. On-orbit maintenance is applicable only to the full-scale Personal Communications System satellite and it is assumed that one flight per year would be needed. Each flight requires one shuttle-IUS combination that carries satellite plug-in replacement hardware plus a manipulator. The per flight satellite replacement hardware is estimated to cost approximately five percent of total satellite recurring cost. The development and procurement of a manipulator is assumed to have been previously funded and, therefore, is not included in any of the on-orbit maintenance cost estimates. Tables 3-51 and 3-52 contain MISSCM output for the on-orbit maintenance line item.

Table 3-49. Satellite Traffic and Cost Summary Through 2000 (Millions of 1977 Dollars)

SATELLITE NAME	PAYLOAD TRAFFIC	LAUNCH VEHICLE TRAFFIC 1ST STAGES	IUS	TUG	PROGRAM COSTS RDTE	PAYLOAD COSTS INV	OPS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
SATELLITE-BASED INITIATIVES													
PERSONAL COMMUNICATIONS SYSTEM													
PCS (PRINCPL DEMO)	1	1 0	1 0		38	13		51	25			25	76
PCS (CONCEPT DEMO)	1	1 0	1 0		159	48		207	25			25	232
PCS (TECHNCL DEMO)	1	2 0			310	102		412	38			38	450
PERSONAL COMM SAT	1	2.0			130	259		389	38			38	427
PCS ON-ORBIT MAINT	10	10 0	10 0			169		169	251			251	420
PCS MISSION CONTRL	13				75		130	205					205
PCS WRIST RADIO	25				5	250		255					255
PCS WRIST RAD MAIN	9						225	225					225
SUBTOTAL	61	16 0	12 0		717	841	355	1913	377			377	2290

Table 3-50. Total Program Costs by Fiscal Year Through 2000 (Millions of 1977 Dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVE																							
PERSONAL COMMUNICATIONS SYSTEM																							
PCS (PRINCPL DEMO)			6	21	38	11																	
PCS (CONCEPT DEMO)					6	60	122	44															
PCS (TECHNCL DEMO)								37	175	183	55												
PERSONAL COMM SAT										80	227	120											
PCS ON-ORBIT MAINT											6	18	37	42	42	43	42	42	41	42	36	24	5
PCS MISSION CONTRL								19	41	15	10	10	10	10	10	10	10	10	10	10	10	10	10
PCS WRIST RADIO										1	3	51	125	75									
PCS WRIST RAD MAIN															25	25	25	25	25	25	25	25	25
SUBTOTAL			6	21	44	71	122	100	216	279	301	199	172	127	77	78	77	77	76	77	71	59	40

Table 3-51. Personal Communications System On-Orbit Maintenance Payload Program Cost (Millions of 1977 Dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR FPCD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1.000	1 000		17			169		169
SATELLITE	0	0						17			169		169
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL.											169		169

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)										1	1	1	1	1	1	1	1	1	1	10

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE																								
INVESTMENT												4	14	17	17	17	17	17	16	17	17	13	3	
OPERATIONS																								
LOSSES																								
TOTAL												4	14	17	17	17	17	17	16	17	17	13	3	

Table 3-52. Individual Program Cost Breakdown Through 2000 (Millions of 1977 Dollars)

FISCAL YEAR	PAYLOAD TRAFFIC N P M D	LAUNCH VEHICLE TRAFFIC A IUS	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																		
1979																		
1980																		
1981																		
1982																		
1983																		
1984																		
1985																		
1986																		
1987																		
1988															6			6	6
1989										4			4	14			14	18
1990										14			14	23			23	37
1991	1	1 0	1 0							17			17	25			25	42
1992	1	1 0	1 0							17			17	25			25	42
1993	1	1 0	1 0							17			17	26			26	43
1994	1	1 0	1 0							17			17	25			25	42
1995	1	1 0	1 0							17			17	25			25	42
1996	1	1 0	1 0							16			16	25			25	41
1997	1	1 0	1 0							17			17	25			25	42
1998	1	1 0	1 0							17			17	19			19	36
1999	1	1 0	1 0							13			13	11			11	24
2000	1	1 0	1 0							3			3	2			2	5
TOTAL	10	10 0	10 0							169			169	251			251	420

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Mission control of the full-scale Personal Communications System satellite is judged to be needed because of its size, complexity, and its on-orbit maintenance flight requirements. A control center must be established that houses equipment and the personnel required to maintain flight control, display flight data, schedule on-orbit repairs, and supply billing and other data needed to operate the project. Initial facilities and equipment are estimated to be $75 million -- the cost of personnel and equipment needed to operate and maintain the control center is estimated to be $10 million per year. Thirteen years of operation are shown in Table 3-53, rather than ten, because launch and on-orbit testing must take place before commercial operations can commence.

User ground equipment for the Personal Communications System covers the wrist radios, which were previously discussed in Section 3.2.7.4 and are shown in Tables 3-54 and 3-55 of the MISSCM output. The total of the above line items constitute the Personal Communications System cost estimate as shown in Table 3-49 (total cost) and in Table 3-50 (fiscal year cost).

Table 3-53. Personal Communications System Mission Control Payload Program Cost (Millions of 1977 Dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	75			75			75
SATELLITE	0	0					75			75			75
AGE					0 000								
LAUNCH SUPPORT						0.000		10	10			130	130
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										75		130	205

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT						1 00														
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)							1	1	1	1	1	1	1	1	1	1	1	1	1	13

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE								19	41	15														
INVESTMENT																								
OPERATIONS											10	10	10	10	10	10	10	10	10	10	10	10	10	
LOSSES																								
TOTAL								19	41	15	10	10	10	10	10	10	10	10	10	10	10	10	10	

Table 3-54. Personal Communications System Wrist Radio Payload Program Cost (Millions of 1977 Dollars)

PAYLOAD PROGRAM

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	5	10		5	250		255
SATELLITE	0	0					5	10		5	250		255
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										5	250		255

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT								1 00												
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)									10	15										25

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE										1	3	1												
INVESTMENT												50	125	75										
OPERATIONS																								
LOSSES																								
TOTAL										1	3	51	125	75										

Table 3-55. Personal Communications System Wrist Radio Maintenance Payload Program Cost (Millions of 1977 Dollars)

PAYLOAD PROGRAM

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000							
SATELLITE	0	0											
AGE					0 000								
LAUNCH SUPPORT						0.000		25	25			225	225
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL												225	225

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)											1	1	1	1	1	1	1	1	1	o

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE																								
INVESTMENT																								
OPERATIONS															25	25	25	25	25	25	25	25	25	
LOSSES																								
TOTAL															25	25	25	25	25	25	25	25	25	

3.3 DEVELOPMENT PLAN

The Personal Communications System satellite represents a satellite of unprecedented complexity. Therefore a development plan bridging the gap between today's technology and that of the final Personal Communications System is discussed in this section. The intent is to provide a step by step development and concept proof leading from the present in credible steps and thus to determine the time in which the personal system might be made operational.

3.3.1 Rationale

In order to be credible a development plan must have several features. First, the steps must be of increasing complexity each proving/ demonstrating or developing hardware that is a significant and meaningful step above and beyond the previous step yet not represent such a giant leap as to be inordinately risky, time consuming, or not credible. This was one of the guiding principles behind the rationale for the development plan generation. A further rationale, which was self-imposed but is felt to be realistic, is that all the developmental hardware utilized for space tests be useful in an operational mode, that is to say, that there should be no dead-ended hardware development. Many previous programs that have had the capability to be used in an operational mode such as the ATS-6 have found that they have been extremely useful and have more than earned the money invested in them by the provision of interim services. In some cases these services have been invaluable. A further ground rule is that it is unlikely that any development could begin until the year 1980, if then, due to the realities of the lead time in budget preparation. A step-by-step demonstration and development plan approach is outlined in Table 3-56, in which four steps are described leading to the final system concept.

The first step would be one in which the principle of direct-switched communications from user-to-user through a satellite would be demonstrated. It would use a small antenna, a small number of beams

Table 3-56. Development Plan Approach

1. STEPS OF INCREASING COMPLEXITY
2. ALL DEVELOPMENTAL HARDWARE USEFUL
3. START IN CY 1980
4. STEP COMPLEMENT

STEP 1: DEMONSTRATION OF PRINCIPLE

SMALL ANTENNA, 2-4 BEAMS AND TRANSPONDERS. SWITCHING AT BASEBAND. A FEW LABORATORY-TYPE TERMINALS. PLACE INTO GEO, TEST IN GEO, USE OPERATIONALLY.

STEP 2· DEMONSTRATION OF CONCEPT

SCALE ANTENNA. FINAL FREQUENCY BAND. 1 PERCENT OF BEAMS, TRANSPONDERS, AND SWITCH. A FEW LABORATORY-TYPE TERMINALS, FINAL SIGNAL STRUCTURE PLACE IN GEO, TEST IN GEO, USE OPERATIONALLY

STEP 3· DEMONSTRATION OF TECHNOLOGY

FULL SIZE ANTENNA. 10 PERCENT OF BEAMS, TRANSPONDERS, SWITCH AND POWER, IN FINAL MODULAR PACKAGES. 1-10 PERCENT OF TERMINALS IN PROTOTYPE FORM. ASSEMBLE IN LEO, TEST IN LEO, USE WHILE IN TEST, PROCEED TO STEP 4.

STEP 4· DEMONSTRATION OF SYSTEM

ADD REST OF BEAMS, TRANSPONDERS, SWITCH AND POWER, MODULES. PRODUCTION USER SETS. ASSEMBLE IN LEO, TEST, TRANSFER TO GEO, TEST-DECLARE OPERATIONAL.

and transponders but it would have switching at baseband. It would use a few laboratory type hand-held terminals and would be operated in geostationary orbit. The second step would be a scale model of the final antenna operating in the final frequency band. It would have about one percent of the number of beams, and transponders, and an onboard switch. It would try to simulate the final signal structure to understand the intermodulation effects. It would also operate in geostationary orbit in conjunction with a few laboratory type terminals.

The third step would demonstrate the technology by orbiting the final system's full size antenna, which is structurally the most critical item in the satellite, but it would only incorporate about 10 percent of the feeds, beams, transponders switch complexity, and onboard power. These components would however be in the form of the final modular packages. This would then represent the final hardware without requiring the full complexity on orbit in one step. One-tenth to 10 percent of the wrist radio telephone terminals would be procured in prototype form. The satellite would be assembled and tested in low orbit, and when its technology is fully demonstrated the final step would be undertaken. This step, which is a demonstration of the entire system, would assemble the rest of the modular components to form all the beams, transponders, switch, and power modules. Thus the entire satellite will have been assembled in two distinct steps. The satellite would be fully assembled in low orbit to make use of the space shuttle. Following test it would self-transfer to geostationary orbit, and after retest there would be declared operational. The production user sets would be used at this point for communication through the satellite.

This development plan is not unique and in fact it can be argued that the first two steps could be combined depending on the timing. There is a clear purpose in each step however, and the concept of splitting the launch and assembly of the final satellite into two operations yields it great strength.

The development plan itself appears in Figure 3-68 plotted as a function of time and showing the time lines as well as the steps themselves, in which the estimated time periods for design, fabrication, test, assembly, launch, and operations are shown in the top half and the steps themselves, with some detail on their characteristics, on the bottom half. Referring to that figure it is seen that the first step could be launched about three years from start (about 1983 assuming a start in calendar 1980) and would be operational from 1983 through at least 1986 to cover the gap until the next step could be made operational. The second step of concept demonstration could be launched in 1985 and replace or augment the first operational satellite. Following concept demonstration it would remain operational through the 1990 or 1991 time period. During this period it would furnish operational capability while the final satellite is being assembled and tested in two steps. The third step, which has the final antenna but only

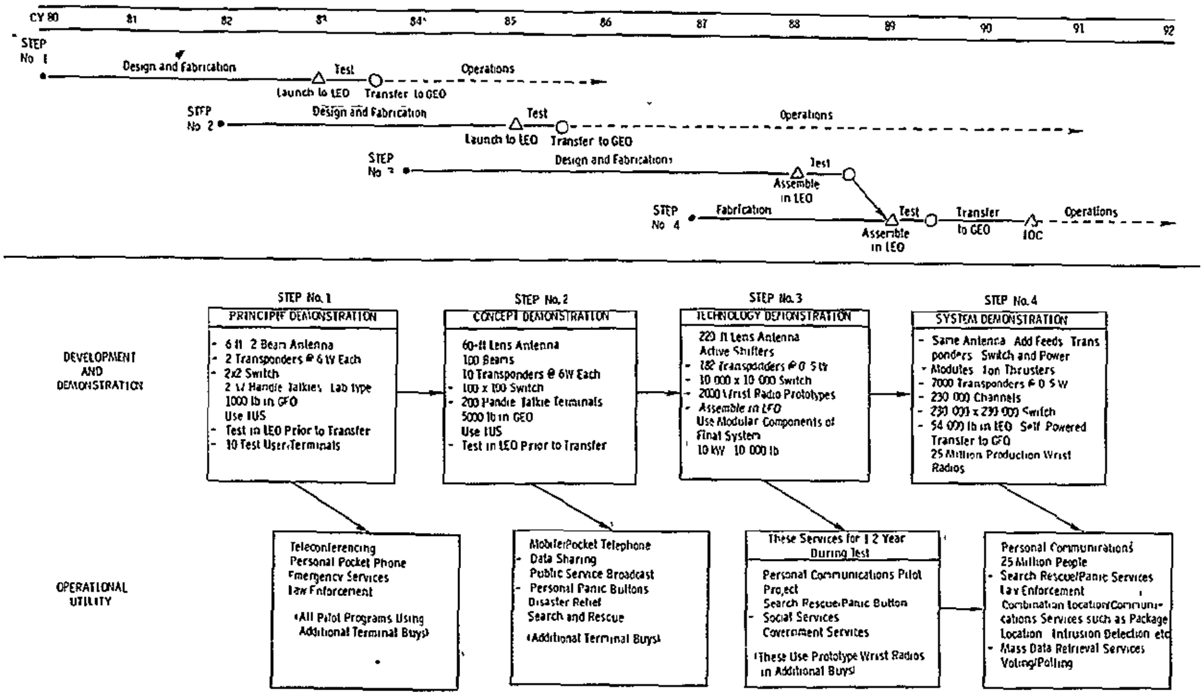

Figure 3-68. Development Plan for Personal/Emergency Communications Initiative

about 10 percent of the electronics, could be assembled and tested in the 1988 time period and wholly assembled with 100 percent of its components in 1989. After test it would take six months to perhaps as much as a year to transfer it to geostationary orbit and, could be operational between 1990 and 1991. Its capability would completely dwarf the operational capability of the first and second steps, however, those steps could be kept operating until their useful life was over.

The operational utility of each step is clearly shown in Figure 3-68. The services of the third step -- the technology demonstration step -- would only be available for about six months and would serve as a test or pilot project with the satellite in low orbit. Thus limited communications times would be available, however, the power of the satellite from that altitude would be enormous and a number of the services listed might benefit even from limited-time services. The rest of the operational utility

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services are all from synchronous altitude, and assume terminal buys in addition to those required in the development/demonstration steps alone.

The development satellite weight steps from 1000 to 5000 to 10,000 to 54,000 lb; with steps of antenna size going from 6 to 60 to 220 ft. The switch complexity goes from a 2 by 2 to 100 by 100 to 10,000 by 10,000 to the final 230,000 by 230,000. The number of transponders goes from 2 to 10 to 182 to almost 7000. The first two steps would utilize the IUS as the orbit transfer vehicle to place the satellite in final orbit. The third step remains in low orbit, and when it becomes the final concept by the addition of the step four components, it transfers itself to geosynchronous altitude using its own ion engines and power service.

More detail on the goals, characteristics, operational use, and features of the satellite and terminals for each of the four steps are shown in Table 3-57. It is seen that this development plan allows utility of the space shuttle in low altitude orbit to check out, assemble, initialize, and prove the concepts prior to their final transfer out of the reach of the space shuttle itself. The servicing concept would utilize replacement components flown to synchronous altitude using the IUS as the orbit transfer vehicle or other more powerful orbit transfer vehicles should they become available. Automated or teleoperator services could be used, or even manned vehicles with EVA, though it is not clear that the physical presence of man is needed. This topic will need much more analysis.

Table 3-57. Development Plan for Personal/Emergency Communications

	CY	82 83 84	85 86	87 88 89	90 91
STEP No 1 DEMONSTRATE PRINCIPLE STEP No 2 DEMONSTRATE CONCEPT STEP No 3 DEMONSTRATE TECHNOLOGY STEP No 4 DEMONSTRATE SYSTEM		TEST - - - USE - - -	TEST - - - USE - - -	ASSEMBLY IN LEO TEST	COMPLETE ASSEMBLY IN LEO ASSEMBLE TRANSFER TO GEO IOC
GOALS		• DEMONSTRATE BASEBAND SWITCHING ON COMMAND • TEST IN LEO, RETEST IN GEO	• DEMONSTRATE MULTIPLE SPOT BEAMS BASEBAND SWITCHING MUX/DEMUX ORBITAL SERVICING • TEST IN LEO TRANSFER TO GEO	• DEMONSTRATE FULL SIZE ANTENNA DIGITAL SWITCHING WRIST TERMINALS MODULAR ASSEMBLY/SERVICING • ASSEMBLE IN LEO TEST IN LEO	• DEMONSTRATE FULL SIZE CASSETTE SYSTEM • TRANFER TO GEO • PLACE INTO OPERATION
OVERALL CHARACTERISTICS		WEIGHT 1000 lb • GEO	• WEIGHT 5000 lb • LEO/GEO	• WEIGHT 10,000 lb • LEO ONLY	• WEIGHT - 54 000 lb • TRANSFER PREVIOUS STEP TO GEO
OPERATIONAL USE		• TELECONFERENCING REMOTE HEALTHCARE DELIVERY AND OTHER PUBLIC SERVICE FUNCTIONS • EMERGENCY/OFFICIAL SERVICES	• AS STEP 1 BUT ADD • MOBILE TELEPROXY ELECTRONIC MAIL POLICE C&L PUBLIC SERVICE BROADCAST EDUCATION etc	• AS IN STEP 2 BUT ADD • EMERGENCY SEARCH/RESCUE TEST BED FOR TECHNIQUES HANDS-ON HEALTHCARE SOCIAL SERVICES PERSONAL SERVICES AND TEST BASIS	• PERSONAL COMMUNICATIONS • SEARCH/RESCUE/PANIC BUTTON • COMBINATION LOCATION/COMMUNICATIONS INITIATIVES • MASS SERVICES
SATELLITE	DESIGN/CONSTRUCTION	• LABORATORY/EXPERIMENTAL • BRASSBOARD • FIXED	• PROTOTYPE • DEPLOYABLE	• FINAL DESIGN • MODULAR/ADD ON • DEPLOYABLE/ASSEMBLED	• ADD ALL MODULES OF FINAL DESIGN
SATELLITE	ANTENNA	• RIGID REFLECTOR • 4 6 ft DIA 2 FEEDS/BEAMS	• BOOTLACE LENS FIXED SHIFTERS • DEPLOYABLE • 60-70 ft DIA • 100 FEEDS/102 BEAMS	• BOOTLACE LENS • VARIABLE PHASE SHIFTERS • ASSEMBLED/DEPLOYED IN ORBIT • 220 ft DIA • 91 FEEDS/103 BEAMS	• SAME AS LAST STEP • ADD 66 MORE MODULES TO MAKE UP FULL 6084 FEEDS/6930 BEAMS
SATELLITE	TRANSPONDERS	• 2 AT 6 WATTS • DEMODULATE/REMODULATE AT BASEBAND • 2 CHANNELS EACH	10 AT 6 WATTS EACH • DEMODULATE/REMODULATE AT BASEBAND • 10 CHANNELS EACH • MODULAR/SERVICING	• 182 AT 5 WATTS EACH • QPSK DEMOD/REMOD BASEBAND • 100 CHANNELS EACH • MODULAR - 2 MODULES	• ADD 6928 MORE MODULES - TO MAKE UP FULL COMPLEMENT OF 6930 TRANSPONDERS
SATELLITE	SWITCH	• 2 x 2 PORTS • CROSSPOINT • RELAY CONTACTS • COMMANDABLE	• 100 x 100 PORTS • CROSSPOINT CONTACTS • MAGNETIC DRIVE • COMMANDABLE	• 10 000 x 10 000 PORTS • DIGITAL • PROGRAMABLE, PASSIVE COOLED • MODULAR - 1 MODULE	• 230 000 x 230 000 PORTS • ADD 1509 MODULES TO MAKE UP FULL SWITCH
SATELLITE	POWER	• 500 WATTS • SOLAR ARRAY • FIXED	• 2500 WATTS • SOLAR ARRAY • FIXED	• 10 KW • SOLAR ARRAY • DEPLOYABLE MODULAR	• 273 KW • ADD MODULES TO MAKE UP FULL POWER
SATELLITE	PROPULSION/STABILIZATION	• CHEMICAL ACS • IUS	• CHEMICAL ACS • IUS	• 16 ION THRUSTERS FOR ACS STATIONKEEPING	• SAME • USE 13 THRUSTERS FOR ORBIT TRANSFER
TERMINALS	CHARACTERISTICS	• LABORATORY TYPE • HANDIE TALKIE OR BRIEFCASE SIZE • 2 WATTS	• LABORATORY TYPE • HANDIE TALKIE • 2 WATTS	• PROTOTYPE • WRIST UNIT • 0 25 WATTS	• PRODUCTION TYPE • WRIST UNIT • 0 25 WATTS
TERMINALS	NUMBER	• 10 FIXED • 10 PORTABLE	• 200 • PORTABLE	• 2000 • WEARABLE	• 25 MILLION • WEARABLE

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3.4 ALTERNATIVE CONCEPTS

The second part of this section deals with the definition of an alternative concept to that of using satellites in order that a cost comparison be performed for systems using the same capacity or having the same performance.

3.4.1 Alternative Concept Selection

A number of major options exist for the configuration of alternate paths from wrist telephone user to wrist telephone user anywhere in the country. These options are illustrated in Figure 3-69. From a standpoint of system considerations there are only two major alternatives to the new initiative comsat directly linking the wrist radiotelephone users. The first of these options links the users via fixed radio relay towers on the ground, the towers being interconnected via any number of possible routes that will be discussed further in a moment. The second major option links the users to balloons or aerostats that are then interconnected via ground radio relay towers if the telephone networks switch plant is to be utilized, or directly if airborne switching is to be a part of the alternate concept.

The first alternate, that of using ground radio relay towers, in a switched telephone network plant is attractive in that the current investment and capability in the ground telephone networks is truly enormous and could probably be used as is. The radio relay towers could be linked by simple telephone lines to local telephone exchanges that are then interconnected via the normal long haul techniques (which include coax cable, microwave relay, and even commercial comsats). The disadvantage of this major option is that the range from the towers to the wrist radio-telephone users would be very small due to the very low power and small antenna size in the wrist equipment, and thus the number of radio relay towers required will be very large. This in itself does not present a problem but the cost will undoubtedly be quite large. Additionally, use of the fixed telephone plant will involve user charges as levied by the telephone companies, which

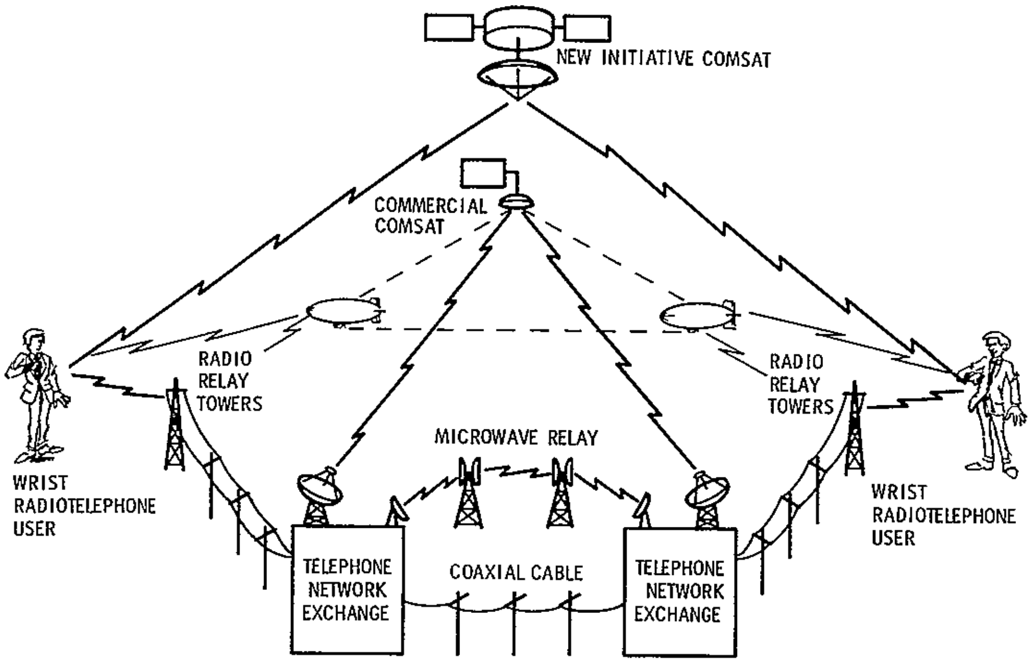

Figure 3-69. Major System Options - Personal/Emergency Communications

could be avoided in a direct user-to-user switched system that bypasses the telephone networks. Perhaps the most serious disadvantage, however, is that it is unlikely that radio relay towers can be positioned so as to have the same coverage as a satellite system, in the wilderness and very thinly populated areas without vastly increasing the number of towers. In addition, new telephone lines not now existing or planned would have to be run to precisely those very remote locations where lines do not now exist because it is economically unattractive to put them there.

The second major alternative utilizes some form of airborne relay platform, in this case a high altitude balloon system. It is attractive in the sense that the added altitude of the relay increases the range obtainable from the wrist radiotelephone users, since it avoids excess link losses (Ref. 11) to the point where the number of relay towers is greatly reduced -- and furthermore obtains coverage in areas where it is uneconomical to install telephone lines and radio relay towers. The disadvantage of the balloon system however, is that is still must operate through the fixed telephone switched plant just as the first option. This could be avoided by relay from balloon-to-balloon, and incorporating a switched airborne capability equivalent to the switch in the new initiative comsat satellite. Should that be the case, communications could then flow directly from user to balloon to balloon to user, or even from user to balloon to a commercial COMSAT to balloon to user. In this option dependence on ground relay radio towers and the user charges of a switched ground network would be eliminated at the cost and complexity of replacing that capability with an equivalent airborne one.

Both of these major options have advantages and disadvantages. The first option was selected for further study for two major reasons. First it was desired to obtain a comparison of the new initiative comsat with utilization of the existing or planned telephone networks since such comparison is a most obvious one and most often mentioned by critics of space systems. Second, insufficient resources and time existed in this study to allow the preliminary design of a new balloon network, including an airborne switched plant. For these reasons a system of ground radio relay towers interconnected by the telephone networks was selected as the alternate concept to the new initiative comsat to be analyzed in this study, even though it would be desirable to analyze both.

3.4.2 Alternative Concept Definition

The most important single factor in defining the selected alternative configuration is to settle on the number of radio relay towers required. In principle the system is very much like the cellular mobile radio-telephone systems being installed by Motorola and the Bell System in Washington, Chicago, and other places on a pilot basis, with the major difference being that the mobile radiotelephones for car operations have output powers in the tens of watts and the networks are designed for high-capacity urban use (it being the most profitable sector to service). The alternative concept, however, was defined to have the same coverage as the satellite system that produces 30-mi dia contiguous coverage areas over the entire United States, superimposed with 846 30-mi areas for higher capacity coverage of the urbanized areas. As a first approximation, then, the alternate concept has to perform within such coverage areas.

Based on information (Refs 11 and 12), and current practice in commercial mobile radiotelephone systems operating with handy talkies, about 5 W of output power into an omnidirectional antenna are required in a handheld unit to reach a 400-ft tower 30 mi away. This number, of course will vary greatly with the kind of terrain, with the frequency of operation, and indeed with the number of obstructions such as tall buildings along the line of path. Based on scaling equations (Ref. 11) if the tower height is reduced to 150 ft as something more economically practical, and the transmitter power is reduced to 250 mW, the average transmission range will be reduced to about 5 mi. Clearly, in the urban areas it could be considerably less than that. Utilizing such a number however, each 30-mi dia area would require an average of nine radio relay towers with 5-mi radius of tranmission. This number is of course highly dependent on the local geography and obstructions. It is estimated that of the total amount of towers required, which in this case is nine towers per area times 6930 areas or 62,370 towers, perhaps 75 percent will be needed in suburban, rural areas, or wild areas in which there are no towers at all, whereas perhaps 25 percent can be colocated with silos, mountain tops, or urban buildings. This distribution was chosen even though it is recognized that there are no telephone lines to many of these areas now.

Since there are 846 urban areas and 6084 rural areas at nine towers each on the average, this implies the need for 7600 urban and suburban radio relay towers in 54,700 rural relays. In order to calculate the required number of channels and transmitter power for each relay equipment, the total population percentage that could be expected to be concentrated within the reach of any one of the nine towers in each area at any one time has to be estimated. This estimate was placed at about 10 percent, worst case. The total number of channels in each 30 mi dia area provided by the satellite system has to be matched, and this number for the urban areas is 34.7 minimum, 175 average, and 694 maximum. For the rural areas the minimum is 1, the average is 11, and the maximum 65. Due to the possible concentration factor (since the users are mobile within the area) 10 percent of the above channel numbers would have to be provided to each and every radio relay tower unit. Such a concentration factor, by the way, is absent in the satellite system which is insensitive to user distribution within a beam footprint. The total number of channels required for the relay units therefore, in urban areas are a minimum of 4, average of 18, and a maximum of 17. In the rural areas is 1, the average is 1.1, and the maximum is 7.

The power required in the relay tower transmitter is computed on the basis of 2.5 W per channel in order to make the link from the wrist radio unit highly dominant in the link noise addition calculations. Under these conditions the urban towers require a minimum of 10, an average of 45, and a maximum of 175 W of output power whereas the rural towers require a minimum of 2.5, an average of 3, and a maximum of 17.5 W each. The exact numbers of channels and output power for any one relay tower, of course, is dependent on its precise location and service requirements in the country. The characteristics and requirements for the alternative concept equipment on the towers is illustrated in Figure 3-70.

A number of other assumptions need to be made to define the system concept to the point where a cost analysis can be performed. These radio relay towers must be interlinked with voice lines of adequate capacity to handle the numbers derived above and they need to be interconnected by switching capacity adequate to handle the expected load of 230,000 channels. Furthermore, the telephone lines to interconnect

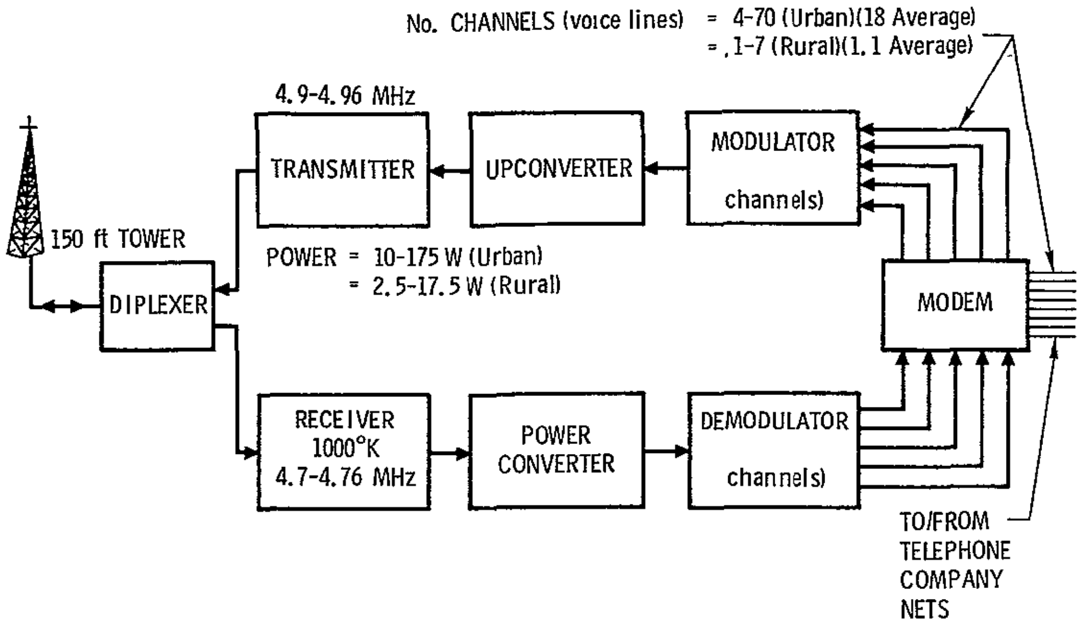

Figure 3-70. Alternative Concept - Personal Communications

these towers must exist wherever these towers must be placed. In many cases it will be possible to place the towers near existing telephone lines, and provide coverage by sheer numbers of relay points. In other cases, however, the towers should be placed on top of mountains or other areas that may not have telephone service. In discussions with AT&T on the best way to implement such a system, it was decided that no new telephone lines would be run to specific tower locations, recognizing that most of the thinly populated areas in the country in 1990 could be covered by putting multiple relay towers along existing or projected telephone line runs. By such a scheme the number of towers could be expected to be roughly equal to that required in a uniform coverage network, however, it is clear that service would not be provided to all wild areas where no telephone lines are projected to exist. Thus some additional lines or high altitude relays may be needed , or the coverage would not be equivalent to that of the satellite.

A further assumption was made that one new telephone line would be installed for each tower installed, however, this simply means either doubling the channel capacity by proper conditioning of existing telephone lines, or running an additional twisted pair along already existing telephone lines, which is fairly inexpensive.

An additional assumption was made after consideration of the switching load that this system would impose on the ground network expected to exist in 1990. This was that the switching required in the rural areas could be provided by local exchanges with the capacity they are expected to have in 1987, however, that the major urban areas would see such a large load that augmentation of their switched plant with a No. 1 ESS switch/processor in each of approximately 20 major areas would be necessary.

This last assumption, as well as one on which the user charge schedule must be based, is dependent on an assumption that most of the calls originated stay within what is known as the local exchange zone. This would certainly be the case for most of the wrist radio users, and thus an assumption was made that 90 percent of calls originated in any 30-mi area will stay within that area. Use of the telephone networks would then be charged by the telephone companies at a flat monthly rate regardless of the number of phone calls. Ten percent of the calls were assumed to be directed outside of the local exchange and thus subject to long distance toll rates. The costing of the alternate configuration is very much dependent on this assumption due to the high cost of long distance toll rates that the telephone companies must charge, as fixed by the regulatory agencies.

The alternative concept is described in summary form in Table 3-58. Total telephone company services required to be provided between the ground relay points are shown in Table 3-59 and are seen to be 197,000 voice channels, whether provided by that number of lines or multiplexed on a smaller number. This number is different from the 230,000 voice channels provided by the satellite system only because average numbers were used in determining the number of towers and the number of channels per tower. Exact calculations would result in identical numbers of channels. However, even with these approximate numbers,

Table 3-58. Alternative Concept Description

- USES SAME USER WRIST RADIOTELEPHONES AS SPACE SYSTEM
- ESTABLISHES MANY RADIO RELAY TOWERS TO PROVIDE ESSENTIALLY THE SAME COVERAGE AS SPACE ALTERNATIVE
- EXPECTED AVERAGE RANGE TO TOWERS IS 5 MILES
- INTERCONNECTS THE TOWERS VIA THE TELEPHONE NETWORKS
    - ALL SWITCHING PROVIDED BY THE TELEPHONE PLANT
    - 75% OF TOWERS 150-FT HIGH, 25% ON BUILDINGS
    - 7600 URBAN/SUBURBAN RELAYS
        - 18 CHANNELS EACH (AVERAGE)
        - 50 WATTS EACH (AVERAGE)
    - 54,700 RURAL RELAYS
        - 1.1 CHANNELS EACH (AVERAGE)
        - 12 WATTS EACH (AVERAGE)
    - TELEPHONE LINES ASSUMED TO EXIST WHERE NEEDED IN 1990. MAY NOT HOLD FOR WILD AREAS
    - A NEW LINE PER TOWER INSTALLED
    - 20 MAJOR URBAN AREAS AUGMENTED WITH No. 1 ESS SWITCH/PROCESSORS; REST OF SWITCHING PROVIDED BY LOCAL EXCHANGES
- 90% OF CALLS STAY WITHIN LOCAL EXCHANGE ZONE - CHARGED AT FLAT RATE
- 10% OF CALLS GO OUTSIDE LOCAL EXCHANGE - SUBJECT TO TOLL RATES

Table 3-59. Telephone Company Services Required

AREA	TERMINALS	VOICE CHANNELS PER TERMINAL	TOTAL VOICE CHANNELS (OR EQUIVALENT)
URBAN AND SUBURBAN	7,600	4 Minimum 18 Average 70 Maximum	136,800
RURAL	54,700	1 Minimum 1.1 Average 7 Maximum	60,200

the alternative system has essentially the same capacity as the satellite system, enabling a one-to-one cost comparison to be made.

3.4.3 Alternative Concept Cost Estimates

The purpose of this section is to describe the procedures for deriving cost estimates of the ground-based alternative, and to present the results of the application of such procedures to the ground alternative system described in Section 3.4.2.

Table 3-60 contains a summary of the major items of equipment required for the alternative concept, and the basis for estimating their costs. In addition it contains estimates of yearly operating costs attributable to such equipment. The procedure used in estimating the cost of this ground-based alternative required four steps: each item of equipment

Table 3-60. Ground Equipment Cost Estimate (Ground-Based Alternative)

ITEM-EQUIPMENT	QTY	UNIT COST	TOTAL ($ 000's)	BASIS OF ESTIMATE
SITE ACQUISITION-GFE	14870	-	-	FARMLAND $500/ACRE, URBAN-RURAL $10000/ACRE, AVG COST = $1500
(INCL FENCING) - PURCHASED	10000	6500	65000	AVG SIZE = 1/3 ACRE, 600 ft FENCE @ $10/ft = 6000 + 500 FOR LAUD
TOWERS - 150 ft EACH	43670	8000	349360	REC'D ESTIMATES FROM LOCAL RADIO SHOPS
- LOW	18700	1000	18700	ESTIMATE OF HARDWARE AND INSTALLATION
TRANSCEIVERS - 1.1 CHANNEL EA	54756	35200	1927411	SCALED SCIENTIFIC-ATLANTA DATA BY CHANNEL, $32000/CHANNEL
- 18 CHANNEL EA	7614	67500	513945	SCALED SCIENTIFIC-ATLANTA DATA BY CHANNEL, $3750/CHANNEL
TOTAL EQUIPMENT			2874416	
OPERATIONS & MAINT /yr	**BASE**	**UNIT OR %**	**YEARLY AMOUNT ($ 000's)**	
LEASED SITES	37500	$2400/yr	90000	EXISTING BROADCAST SITES AT $200 PER MONTH
POWER	197284 chnl	$1 10/yr	217	10 W PER CHANNEL 25% OF TIME = 21.9 kW/CHANNEL/yr
TOWERS	368060	5%	18403	
TRANSCEIVERS	2441356	7%	170895	
TAXES	2809416	2%	56188	
G & A	245703	10%	24570	
TOTAL EQUIP OPS & MAINT/yr			360273	

Table 3-61. Costs of Alternative Concept for Personal Communications

ITEM	RDT&E	INVESTMENT	OPERATIONS	TOTAL
TOWERS, RELAY EQUIPMENT, ANTENNAS, CONNECTION LINES, POWER, OPS CONTROL (62,000 TOWERS)	2874	-	3603	6744
WRIST RADIOTELEPHONES (25,000,000)	5	250	-	255
MAINTENANCE FOR WRIST RADIO TELEPHONES	-	-	225	225
TELEPHONE NETWORK AUGMENTATION AND USER CHARGES	70	-	13800	13870
TOTAL	2949	250	17628	20827

was identified, the quantity required was established, the unit cost including installation was derived by securing estimates from local suppliers or consulting pertinent documents, and a basis for estimating the yearly operating cost of such equipment was established.

The costs of the ground alternative system were then computed, and are shown in Table 3-61. These costs are seen to be dominated by the service charges of the telephone network. The bases of these cost estimates were an average channel loading of 32 percent — arrived at by assuming a loading of 95 percent for 3 hr/day, 50 percent for 10 hr/day, and 10 percent during 11 hr of nighttime; a mix of local to long distance calls of ten to one; flat rate charges of $10/month for local lines; 34 cents/min for long distance toll calls; 197,000 channels; and 10 yr of operation.

3.5 SPACE/GROUND ALTERNATIVES COMPARISON

The analysis, definition, and costing of both space and ground alternatives performed in the above sections allows a comparison of the major alternates to be performed at this point. This comparison is performed for technical, cost, and operational aspects.

3.5.1 Technical Comparison

The space and ground systems were designed to have essentially equivalent performance attaining 230,000 voice channels nationwide Both alternatives utilized the same access technique allowing 100 users to timeshare a channel, resulting in 25 million users served by each system. There are some major differences however, and perhaps the biggest of them is the ability to service wild, highly mountainous, remote and essentially unpopulated territory. The space system has coverage of 100 percent of the land mass of the contiguous 48 states. By proper satellite antenna design, coverage of Hawaii and Alaska could be obtained and interconnected to the other states. In the ground system however, it was assumed for costing purposes that the number of radio relay towers used is that average number required to provide the same coverage. However, there are no telephone lines in many of the remote regions nor are there plans to install them and the cost of running new telephone lines from the nearest termination to these wild areas was not priced. One could therefore argue that the number of radio relay towers should be reduced to those within reach of existing or planned telephone lines in order to make a fair comparison -- and thus reduce the cost of the ground alternative. If that were done, however, then the coverage would not be the same as that of the space system, and one could not make a one-to-one comparison. Since one of the most attractive features of a wrist radio system is that the wearer never loses contact -- even if he goes hiking in the remote high Sierra regions or in the middle of the desert, it would seem that the feature of providing 100 percent coverage is an important one. But to provide such services, new telephone line runs would be needed and the cost of the system as computed would be greatly increased. It is likely therefore that a ground alternative system will not be able to compete with a satellite system in providing coverage of the thinly populated or "backwoods" regions in both cost and coverage.

Another comparison area in which the ground and space alternatives vary is the frequency at which the sets must operate. It is desirable to keep the frequency in the high microwave region in order to make the user set transmitter antenna efficient and yet small. It would not be feasible to use frequencies much above X-Band in the space system, because the large satellite antenna diameter required would result in an extremely narrow beamwidth, and therefore a much larger number of beams to cover the 48 states. Such is not the case in a ground short-range point-to-point link however, and a great freedom of choices exists for the actual frequency to be used. Furthermore, the allocations picture is far more favorable ground-to-ground mobile that it is ground-to-space or space-to-ground mobile there being many more frequencies available within current allocations to support such services and even more within reasonable allocation variances. Thus the ground system has an advantage in that it will be easier to find frequencies for operation. However, once found there would seem to be little advantage in either, they being very comparable.

Another important difference between the ground and space systems will make itself apparent in urban area communications. The high frequencies used virtually ensure that the communications are basically line-of-sight and thus nulls , voids, and shadows in the coverage can be expected due to buildings and other obstructions in urbanized areas. Using a geostationary satellite system, due to the elevation of the satellite above the horizon in the U.S., (which varies from 32 to 45 deg due to the latitude of the U.S.) the angle of arrival of the waves at the earth is fairly steep and therefore the shadows produced by buildings are fairly short, and very predictable in direction and location. If a user cannot succeed in communicating with the satellite due to building shadows he just has to walk out of the shadow to successfully communicate. Furthermore since there is only one satellite, there is only one direction to the shadow. With the ground system, however, the longest range coverage is obtained at grazing incidence of the wave at the user and at the radio relay tower. Shadows of buildings will therefore be extremely long, and in fact, might be so long (and in extensively built up areas so common in occurance) as to render city services not very useful. It is for this reason that mobile vehicular cellular systems were conceived, such as the Bell System's Chicago experiment or Motorla's system which is about to be tested in the Washington/Baltimore area. These systems include multiple antennas and relay points with a spacing as short as 1/2 mile and diversity receivers so that a clear communications path usually exists by virtue of the diversity of the available paths from the user wherever he is. In order for the ground alternative system analyzed in this study to compete in the big cities, it might need a greatly increased number of radio relay towers, increasing its cost.

A further difference between the space and ground alternatives arising from the angle of radiation at the user is that for the ground system there will be much more pronounced excess losses and fading due to interference between the direct wave and the wave reflected from the ground, buildings, and other obstructions; and the depth of those fades is expected to be much larger for the ground than for the space system (Ref. 11) To avoid this fading, or at least minimize its effects, the frequency of operation of the system must be reduced to the low VHF region (Ref. 12), however, that cannot be done and yet obtain an efficient transmitting antenna simultaneously as shown in Section 3.2. Thus the propagation and antenna effects favor a high radiation angle which specifies away from a ground system.

All of the above arguments work against a system consisting of ground relay points. An alternative system utilizing balloons for relays could be very workable, however, maintaining many of the advantages attributed to space systems in the above arguments. It was not analyzed in this study due to the needs either for extensive airborne switching, or incurring telephone network user charges, neither of which would tend to make it competitive with a space system.

3.5.2 Cost Comparison

The overall cost comparison of the space and ground alternatives is now presented. The reader is cautioned that the above considerations should be kept firmly in mind when assessing the relative costs. The overall costs of the two systems were shown separately in Sections 3.2.7 and 3.4.3. The total costs of the space and ground systems extended over approximately a 20-yr period are shown in Table 3-62. The 20-yr costs shown include the costs of research development, test, and evaluation of each of the four steps in the development plan discussed in Section 3.3. It also includes operations and maintenance of the final satellite system and ground system for a 10-yr period, which includes one space shuttle flight and IUS flight per year for the purposes of servicing the satellite on orbit. These costs also include the cost of operating the "precursor" or demonstration/test satellites through the 1991 time period. The costs also include the RDT&E for the user wrist radio set, as well as the wholesale price of 25 million user sets. It was thus assumed that a single agency or entity would assume all of the costs including ground and space system. This was done so that the total cost of operating the system could be weighed against expected income. The costs would not change if a different institutional arrangement were used for testing and operating the system.

The total costs for the space system are 2.29 billion dollars. The costs of the ground alternative system computed in the same way are 20.76 billion dollars. It must be pointed out again, however, that the coverage is not quite the same for both, or that the costs are low for the ground system. By way of comparison the costs charged by the current telephone network for the same number of channels and mix of local/long distance calls is 13.8 billion dollars for the same 10 years of operation. This number is shown to indicate that more than half of the cost of the ground alternative arises from telephone network service charges.

The second column in Table 3-62 shows the call costs to the user. These costs were computed by dividing the total 20-yr costs by the

Table 3-62. Cost Comparison - Personal/Emergency Communications

SYSTEM ALTERNATIVE	COVERAGE	TOTAL 20-YR COSTS (BILLIONS)**	CALL COSTS*** (CENTS/MINUTE)	NET ANNUAL PROFIT/LOSS FROM OPERATIONS CHARGED AT 13.3 CENTS/MINUTE
SPACE	Complete All USA*	2.29	0.7	Profit of $4.8 Billion
GROUND	Incomplete In Rural/Wild Areas, Underpriced, or Both	20.76	20	Loss of $2 6 Billion
CURRENT TELEPHONES (Not Mobile or Portable)	Fixed Point Coverage Only	13 8 (Service Only)	13 3	0

* Not Including Hawaii and Alaska
** 10-Yr RDT&E; 10-Yr Operations and Maintenance, All User Equipment
*** Assumes 37 Percent Average Channel Loading

number of minutes during the 10-yr period that the system is expected to be operating, reduced by a factor to account for the average loading expected in the system channels. This loading was assumed as follows. It was assumed that the channels would be 95 percent loaded during the peak 3 hr a day. The system was assumed 50 percent loaded during 10 hr per day to account for off-peak hour daytime use. The system was assumed to be only 10 percent loaded the rest of the 11 hours of the day to account for very infrequent use expected during night-time hours.

The average channel loading given the above number is 37 percent or 8.8 hr a day on an average basis. It was further assumed that this loading would be seen every day for seven days a week during the 10-yr operational period. Using these assumptions, the total investment and operation costs for the space system can be recouped in a 10-yr period by charging the user only 0.7 cents per min of conversation. The equivalent number for the ground system is 20 cents per min. A number appears in the Table for the approximate average costs of making telephone calls for the current telephone network, under the same assumptions of ratio of local to long range use, which is 13.3 cents per min. This number should be used with care as it is an "apples and oranges" comparison, since the service is neither mobile nor portable, nor as extensive in coverage as either the ground or space system, but of higher quality and without time limits.

These costs to the user represent the breakeven charges with which the entire RDT&E and 10 yr of operation and maintenance are paid off at the end of the 10-yr period. No profit is assumed and no cost of money is included in these numbers. Inasmuch as the space system appears to be so inexpensive to operate, perhaps a better measure of how attractive it might be to private industry would be to calculate the profit (or loss) available if the users were charged at a rate competitive with today's telephone system. Consequently, a column is included in Table 3-62 in which the annual net profit or loss is indicated after paying off the total system 20-yr costs, under the assumption that the users are charged 13.3 cents per min of conversation. In this case the ground system would show a loss of 2.6 billion dollars a year, while the space system would generate a profit of 4.8 billion dollars a year (net). The total income in the 10-yr operations period would thus be 48 billion dollars for the space system, and represents a return of 210 percent the first year of operation and for every year thereafter (or 2100 percent in 10 yr). This is truly a fantastic opportunity that industry is unlikely to pass up.

4. EDUCATIONAL TELEVISION INITIATIVE

This section addresses the requirements, definition, costing, and evaluation of an initiative to provide for the dissemination of educational services via communications satellite. It was selected as representing a promising application of space whose value has been demonstrated by projects such as the Appalachian Educational Satellite Project and other projects utilizing the ATS6 and CTS satellites.

4.1 REQUIREMENTS

The requirements against which the system will be designed were obtained following discussions with people involved in the dissemination of educational television and a review of documentation, references to which were provided by these contacts. A document search was also made. People consulted were representatives of the Appalachian Educational Satellite Project, The National Institute of Education, Corporation for Public Broadcasting System, National Council for Educational Television, and the Public Service Satellite Consortiate.

4.1.1 Ground Rules and Assumptions

A series of ground rules, assumptions, and requirements was adopted for the purposes of this study. Neither the ground rules nor requirements have been reviewed or approved by the people with whom discussions were held. They represent the author's best judgement on a realistic set of assumptions based on the references and the discussions. It must be added that none of the people with whom discussions were held admitted to having a good feeling for the proper set of requirements to use for a large scale services system in the 1990's. Thus the requirements that will be discussed in this section, and the system concept derived from them, represent something much more ambitious than heretofore tackled.

The most important ground rule adopted is that all communications should be direct from program originator to program user through the satellite. The use of ground redistribution nodes is to be avoided, with program switching to be performed on command by the satellite. All applicable learning institutions in the USA (excluding Hawaii and Alaska for the purposes of this study) are to be covered and the time period of initial operation be the late 1980's to the 1990's. The information is to consist primarily of color television with a TASO grade one picture quality or better. This picture quality is rated as "good" by 90 percent of the viewers and is only exceeded by studio quality transmission.

As in the Personal Communication System, the requirements were used to synthesize both ground and space systems and their total system costs for comparison of space vs. alternate ground systems. Both systems would have to be operable in the presence of 10mm/hr rainfall. A cumulative outage of less than 10 hr/yr was assumed to be a requirement to assure that not too many classes would be cancelled on account of rain. Inasmuch as each user would be outfitted with a separate terminal and antenna, it is desirable that both be minimized in size and cost.

4.1.2 Definition of Requirements

The most important classes of services to be provided were extracted from the documentation catalog shown in Appendix C. These are listed in Table 4-1 and include general instructional services to schools, interconnection of local stations for open universities, a number of public TV functions, and other educational dissemination classed under special services. Table 4-1 includes a listing of the major functions for these types of services. The information in Table 4-1 was expanded to derive the requirements of each major class of service in terms of number of sources,

Table 4-1. Educational Services

TYPE	FUNCTION
SERVICES TO SCHOOLS	- Instructional Aids - Teacher Education/Development - Professional Development - Information Storage/Retrieval - Public Information - Program Development
OPEN UNIVERSITIES	- Interconnection of Local Stations - Direct-to-Home Services - Local Learning Centers
PUBLIC TV	- Broadcasters Intertie - Program Distribution - Direct-to-Home Services
SPECIAL SERVICES	- Medical Services - Vocational Services - Services to the Handicapped - Migrant Education

number of sinks of information, from where to where the information is to be transferred, the function that it will fill, the type of information and its bandwidth, the estimated traffic volume, and the number of channels involved, per area and total. This information is found in Table 4-2 for

Table 4-2. Educational Services to Schools

FUNCTION	FROM	TO	NUMBER OF SOURCES	NUMBER OF SINKS	NEED	INFORMATION	BANDWIDTH/ CHANNEL	TRAFFIC VOLUME/ SCHOOL	NUMBER OF CHANNELS PER SCHOOL/DISTRICT	NUMBER OF CHANNELS TOTAL
SERVICES TO SCHOOLS										
1 INSTRUCTIONAL AID	ALL DISTRICTS	ALL SCHOOLS	15 000	65 000	• REMOTE TEACHER ACCESS • COMPUTER AIDED INSTRUCTION • ACCESS TO DATA SOURCES • REMOTE SPECIALISTS ACCESS • INSTRUCTIONAL PROGRAM	• 2 WAY VOICE • INTERACTIVE TERMINAL • FACSIMILE/DISPLAY • ELECTRONIC BLACKBOARD • ONE WAY TV	20 kHz 100 Hz 200 kHz 1 kHz 5 MHz	7 hr/day 7 hr/day 7 hr/day 7 hr/day 7 hr/day	10 25 10 25 0 02*	160,000 400 000 160,000 400,000 320
2 TEACHER EDUCATION AND PROFESSIONAL DEVELOPMENT	ALL DISTRICTS	ALL SCHOOLS	16 000	65 000 SCHOOLS	• TELECONFERENCING • IN SERVICE COURSES • INTER-ASSOCIATION	• 2 WAY VOICE • ONE WAY TV • FACSIMILE/DISPLAY	20 kHz 5 MHz 200 kHz	2 hr/day 1 hr/day 30/day	0 03 (1/1000 teachers) 0 03 (1/1000 teachers) 1	500 500 16,000
3 INFORMATION STORAGE/RETRIEVAL	ALL SCHOOLS	CENTRAL FILES	65 000	16,000	• STUDENT DATA • OBJECTIVES • RESOURCES • DIAGNOSTICS • MANAGEMENT DATA	• FACSIMILE • INTERACTIVE TERMINAL • DATA DISPLAY	200 kHz 100 Hz 20 kHz	2 hr/day 2 hr/day 2 hr/day	1 1 1	65 000 65 000 65 000
4 PUBLIC INFORMATION	ALL SCHOOLS	HOMES IN DISTRICT	65 000	12,000,000 HOMES	• TELECONFERENCING	• 2 WAY VOICE • 1 WAY FACSIMILE	20 kHz 20 kHz	1 hr/day 1 hr/day	1 10 (K 9), SHARED 1 hr/wk	65 000 13,000
5 PROGRAM DEVELOPMENT	ALL DISTRICTS	ALL SCHOOLS AND 1% OF HOMES IN DISTRICT	16 000	65 000 SCHOOLS 120 000 HOMES	• USER INVOLVEMENT • INTER ASSOCIATION • TEST AIRING	• 2 WAY VOICE • SLOW SCAN TV • SLOW SCAN TV	20 kHz 20 kHz 20 kHz	0 1 - 1 hr/day 0 1 - 1 hr/day 0 1 - 1 hr/day	1 1 1	16,000 16,000 16,000

*Video recorder used 24 hr/day program sharing by 100 schools

Services to Schools, in Table 4-3 for Open University TV services, in Table 4-4 for Public TV services, and in Table 4-5 for Special services.

Table 4-3. Educational Instructional Services

FUNCTION	FROM	TO	NUMBER OF SOURCES	NUMBER OF SINKS	USER LOCATION	PRIMARY USE/ ADVANTAGE	INFORMATION	NUMBER OF CHANNELS
INSTRUCTIONAL TV 1 INTERCONNECTIONS OF LOCAL STATIONS	COLLEGES + UNIVERSITIES + CENTERS	COLLEGES + UNIVERSITIES + CENTERS	10 000	10 000	URBAN CENTERS + SUBURBAN LOCATIONS	• PROGRAM SHARING • POLICY MAKING • ADMINISTRATION INTERTIE • REGIONAL ACCESS TO BROAD AREA	• 2 WAY VOICE • 2 WAY TV	10% OF STATIONS 1000 CHANNELS - (Time shared)
2 DIRECT TO LOCAL LEARNING CENTERS (Open university)	COLLEGES AND UNIVERSITIES	LEARNING CENTERS	4,000	250,000 (1/1000 people)	DEMOGRAPHICALLY DISTRIBUTED	• CONTINUING EDUCATION • RECERTIFICATION OF PROFESSIONALS • BUSINESS SUPPORT	• 2 WAY VOICE • COMPUTURIZED TERMINALS • FACSIMILE 2 WAY • 2-WAY TV	250,000 250 000 250 000 4000 x 10 CHANNELS WITH 400 REGIONS SHARING CHANNELS 400 CHANNELS
3 DIRECT TO HOMES	COLLEGES UNIVERSITIES AND CENTERS	HOMES	10 000	10 000,000 (10% of homes)	DEMOGRAPHICALLY DISTRIBUTED	• RECERTIFICATION OF PROFESSIONALS • CONTINUING EDUCATION	• 2-WAY VOICE • COMPUTER AID TERMINALS • FACSIMILE 2 WAY • ONE-WAY TV	10 000 10 000 10 000 100 (at 100/sharing) OF SOURCES

Table 4-4. Educational Public TV Services

FUNCTION	FROM	TO	NUMBER OF SOURCES 1990*	NUMBER OF SINKS 1990	USER LOCATION	PRIMARY USE/ ADVANTAGE	INFORMATION	NUMBER OF CHANNELS	NUMBER OF CHANNELS/ REGION
PUBLIC TV 1 BROADCASTERS ETV INTERSTATE/ DISTRIBUTION	STATION	STATION	500	500	URBAN CENTERS POP > 100K	• PROGRAM SHARING • REGIONAL ACCESS TO BROAD AREA	AUDIO 2-WAY TV	50 (10% of number of stations at one time) x 10 CHANNELS/ STATION • 500	———
	STUDIO	STATIONS	50	500	URBAN CENTERS POP > 100K	• NETWORK BROADCASTS • EIRP PROGRAMMING	AUDIO 2-WAY TV	50 (all studios) x 10 CHANNELS/ STATION 500	
2 DIRECT TO HOME	MAJOR STUDIOS	HOMES	10	100 MILLION	EVERYWHERE - DEMOGRAPHIC DISTRIBUTION	• AUGMENTATION TO TOWER BROADCASTING • INCREASE S/N NUMBER OF CHANNELS	AUDIO 1-WAY TV	10 CHANNELS/ STATE • 500	
	MINOR STUDIOS	HOMES	500	30 MILLION	RURAL AREAS PRINCIPALLY	• FRINGE AREA ELIMINATION • PROGRAM ENRICHMENT IN RURAL AREAS	AUDIO 1-WAY TV	10 CHANNELS/ STATE 500 CHANNELS	

*Estimated

Table 4-5. Educational Special Services

FUNCTION	FROM	TO	NUMBER OF SOURCES	NUMBER OF SINKS	USER LOCATION	PRIMARY USE	INFORMATION	NUMBER OF CHANNELS
SPECIAL SERVICES								
• MEDICAL SERVICES/ HEALTH CARE EDUCATION	MEDICAL SCHOOLS AND HOSPITALS	MEDICAL SCHOOLS AND REGIONAL CENTERS	1 000	1 000	FIXED - DISPERSED NEAR MAJOR CENTERS	• TELEDIAGNOSIS • COMPUTER DATA BANKS • HOSPITAL BUSINESS EDUCATION	• 2-WAY TV • 2-WAY INTERACTIVE TERMINAL • 2-WAY FAST FACSIMILE	1 000 1 000 1 000
• MIGRANT WORKERS EDUCATION	DISTRICTS	FIELD SCHOOLS (Mobile)	2 000	5 000 SCHOOLS WITH 500 000 CHILDREN	MOBILE IN FARM AREAS	• PRIMARY INSTRUCTION AID • BROAD ACCESS FROM RURAL AREA • TEACHER DEVELOPMENT	• 2-WAY VOICE • 2-WAY FACSIMILE • COMPUTERAIDED INSTRUCTIONS • ONE-WAY TV	5 000 5 000 5 000 500 AT 10/1 SHARING
• HANDICAPPED EDUCATION	DISTRICTS	DISTRIBUTION CENTERS OR HOMES	16 000	30 000 CENTERS OR 28 MILLION PEOPLE	HOME OR CENTER-RIDDEN - DEMOGRAPHICALLY DISTRIBUTED	• PRIMARY INSTRUCTION AID • BROAD ACCESS FROM RURAL AREA • TEACHER DEVELOPMENT	• 2-WAY VOICE • 2-WAY FACSIMILE • COMPUTERAIDED INSTRUCTIONS • ONE-WAY TV	5 000 5 000 5 000 500 AT 10/1 SHARING
• LAW ENFORCEMENT EDUCATION • OTHER								

Referring to these tables it is seen that a variety of information is required depending upon the application, spanning the spectrum from two-way interactive television through one-way electronic blackboard or facsimile information, to one- and two-way voice interactive terminals. Data displays or slow-scan television representing inbetween information needs. The total number of channels is seen to be very high for many of the requirements. As an example, in services to schools in Table 4-2 simply to provide instructional aides to the teachers 160,000 two-way voice channels would be required and over 300 one-way TV channels. These numbers are large because an attempt is made to feed information from every School District or Board of Education headquarters to every one of the 65,000 schools in the U.S. Other requirements in these tables similarly reflect the ambitiousness of the job to be done.

The information contained in Tables 4-2 through 4-5 is summarized in Table 4-6 in which classes of services required by type and information bandwidth are collected under the different application headings. It is seen that the common denominator among all of these is a requirement for television be it one-way or two-way; and the number of television channels is very high. In addition, an even larger number of voice, facsimile, terminal, and blackboard services are required, the number and type varying with the application. In an attempt to simplify even the simplified summary information, Table 4-7 extracts minimum typical needs for educational services in three classes - one-way TV, or receive-only capability, - two-way TV for receive and transmit, and a third category that includes voice, fast facsimile, interactive terminals, and electronic blackboards. It is seen that a requirement exists for somewhere between 1000 and 1600 one-way TV channels simultaneously from the school districts

Table 4-6. Typical Summarized Requirements

APPLICATION	NUMBER CHANNELS	TYPE	INFORMATION BANDWIDTH (Each)	COVERAGE
Services to Schools	16,000 - 400,000 65,000 - 160,000 65,000 - 400,000 65,000 - 400,000 320 - 3,200	2-Way Voice 2-Way Facsimile Interactive Terminals Electronic Blackboards One-Way TV	20 kHz 200 kHz 100 Hz 1 kHz 5 MHz	Demographic Distribution
Open Universities	10,000 - 250,000 10,000 - 250 000 10,000 - 250,000 100 - 10,000 400 - 4,000	2-Way Voice 2-Way Facsimile Interactive Terminals One-Way TV 2-Way TV	20 kHz 200 kHz 100 Hz 5 MHz 10 MHz	Centers of Learning
Public TV	5,000 500 - 5,000 50 - 500	2-Way Audio One-Way TV 2-Way TV	20 kHz 5 MHz 10 MHz	Public TV Stations Basically Demographic, and Geographical Overlay
Special Services	1,000 1,000	2-Way TV Interactive Terminals Fast Facsimile	10 MHz 100 kHz 200 kHz	Urban Centers and Demographic

Table 4-7. Extracted Minimum Needs - Services to Education

TYPE	NO CHANNELS	FROM - TO	INFORMATION BANDWIDTH
One-Way TV (Receive Only)	1,600	16,000 Districts to 65,000 Schools	5 MHz
	1,000	10,000 Universities/Colleges to Large Learning Centers	5 MHz
Two-Way TV (Receive and Transmit)	160	16,000 Districts Interconnected, and for Program Distribution to 65,000 Schools	10 MHz
	400	4,000 Universities to 10,000 Small Learning Centers, Demographically Distributed	10 MHz
Two-Way Voice	260,000	Four Interactive Channels/School	20 kHz
Two-Way Fast Facsimile	65,000	One Full-Time Channel Per School, Shared Among Classes and Administration	200 kHz
Two-Way Interactive Terminal	65,000		100 kHz
One-Way Electronic Blackboard	65,000		1 kHz

to their schools or from universities and colleges to large learning centers. Simultaneously a two-way TV capability somewhere between 160 and 400 TV channels exists for interconnection of the 16,000 school districts for the purposes of program interchange and coordination, and to connect 4000 universities to 10,000 small learning centers with interactive TV. In addition about 260,000 two-way voice channels and 65,000 channels each for two-way fast facsimile, two-way interactive terminals, and one-way electronic blackboards would be needed on the basis of one full time channel per school shared among the classes and administration.

Table 4-7 thus represents a set of working requirements that establishes the needs to which the Educational TV Initiative System should be built. The design philosophy that has been adopted for the purposes of this study is to address the requirements of the services to schools, assuming that the system evolved can be duplicated or time-shared for serving the needs of the open universities, public TV, or special services. This is a fairly safe assumption in that the services to schools requirements result in the largest number of channels for one-way TV, and a representative number of channels for two-way TV for all of the applications. Furthermore, the total number of voice interactive channels, facsimile, terminals, or blackboards required is also fairly representative of the needs for all the other categories of application. Thus, an interactive voice system with 260, 000 channels would also meet the needs of all of the other categories of application. Thus, the requirements generated would translate to a need for about 1600 one-way TV channels, about 160 two-way TV channels, about 260, 000 two-way voice channels; and 65, 000 channels of fast facsimile, interactive terminals, and electronic blackboard. Of these it was felt that the last three represented needs that were more uncertain, many of which could probably be met by ground networks without too much difficulty. The last four needs, in fact, could be met by a satellite very similar to that of the Personal Communications satellite design discussed in Section 3. For all of these reasons the requirements evolved to a system with the capability for 1600 one-way TV channels, 160 two-way TV channels and 260, 000 channels of interactive voice.

In order to refine these requirements the network architecture is next discussed. To this end the connectivity was established as given by Figure 4-1. In this figure it is seen that one-way TV will be used to distribute programs from each school district to its own schools, regardless of how many districts occur in the area covered by a satellite beam. Furthermore, two-way channels of TV will be provided between Districts within the same beam or area, as well as between Districts in different beams or areas for program sharing or real-time distribution. This number of channels will probably not exceed 10 percent of the total TV channels. In addition, but not shown, are two-way interactive voice networks between

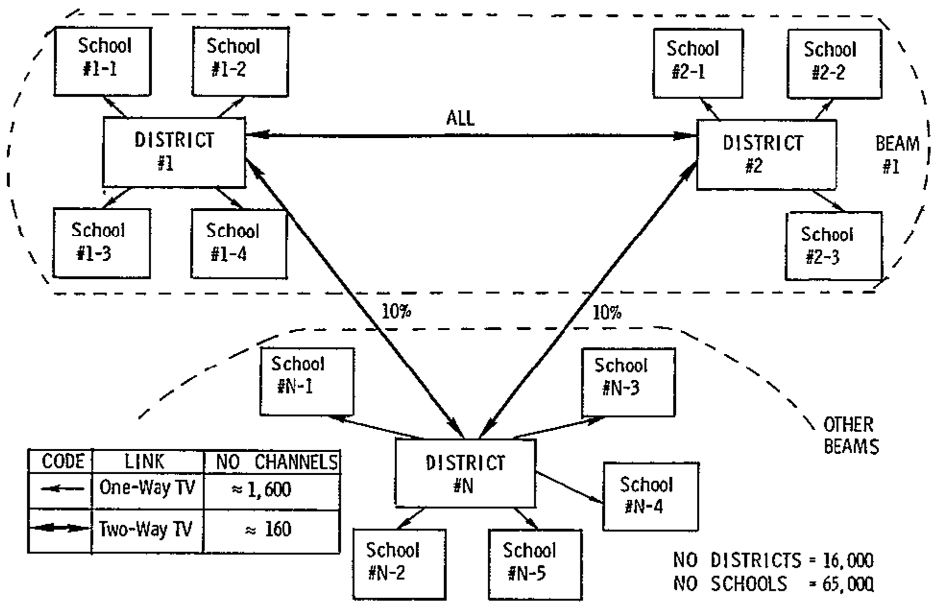

Figure 4-1. TV School Services

Districts and schools. The assumption of the existence of spot beams stems from a realization similar to that developed in the definition of the Personal Communications Initiative that the wide bandwidth of the signals, combined with the desire to have small and inexpensive terminals will make the satellite necessarily large and complicated and make for a large satellite antenna, and therefore resulting in small beamwidth and necessary replication of the beamwidth by multiple beams to obtain coverage of the required areas within the U.S.

A similar architecture was explored in Figure 4-2 for the open universities application in which two-way TV links are provided between universities and their small learning centers, and one-way TV provided to large learning centers, respectively. Furthermore, two-way TV circuits are provided between different universities and colleges for the purposes of program interchange. The architecture is fairly similar to that of Figure 4-1, as are the number of channels required. The architecture would not change whether a university and its centers were wholly or

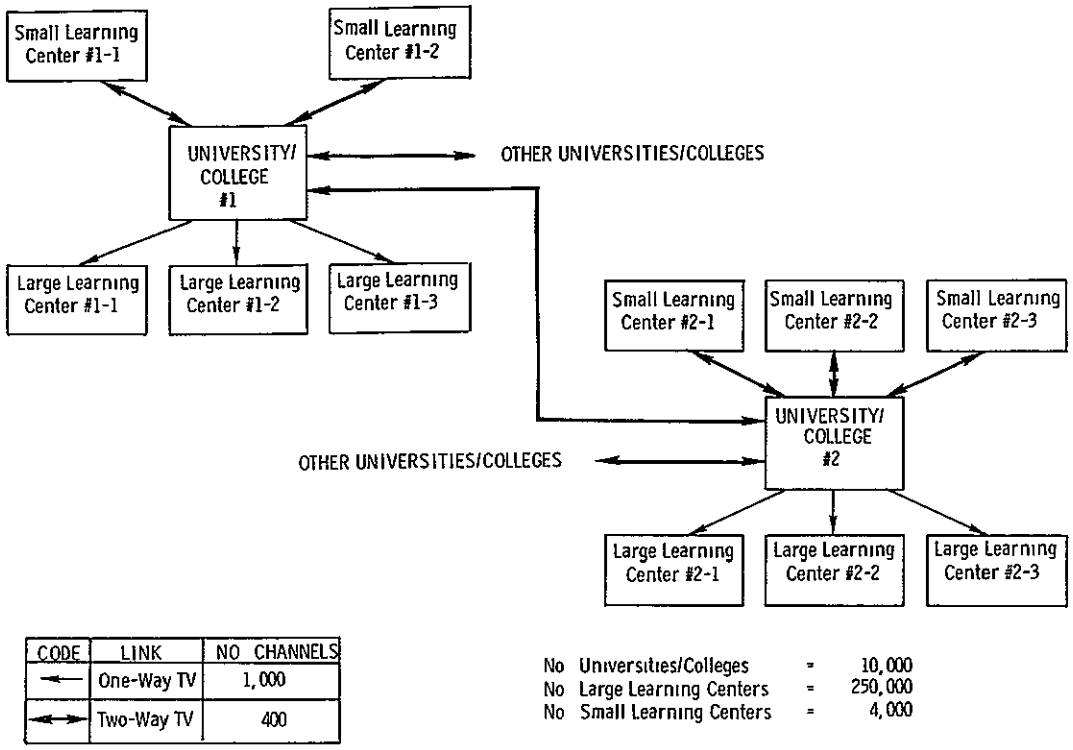

Figure 4-2. Open Universities

partially inside of a beam, whether several universities were inside of a beam, or whether they were entirely in different beams.

At this point it became imperative to define the size of beams required and their number, coverage, and location in order to develop a set of requirements of the number of channels per beam for various beams. Information was obtained from the references in Appendix C on the number of School Districts, universities, colleges, and schools for each State, extrapolated to 1990. The university population was estimated to follow the real population growth curve but the total number of schools was estimated to remain constant as in 1970, due to the reduction in the birth rate. The number of beams required to cover a state and the anticipated number of Districts, schools, universities, and colleges per beam were developed and shown in Tables 4-8, 4-9, and 4-10. In these tables the assumption was

Table 4-8. Beam Requirements - I

STATE	AREA (MI^2)	APPROX SIZE (MI)	NO SCHOOL DISTRICTS*	NO UNIVERSITIES AND COLLEGES**	NO BEAMS	NO DISTRICTS/ BEAM	NO UNIVERSITIES/ COLLEGES PER BEAM
Alaska	586,000	765	29	5	112	1	1
Texas	267 000	516	1202	184	51	24	4
California	158,000	400	1125	298	30	38	10
Montana	147,000	383	731	18	28	26	1
New Mexico	121,000	347	89	16	23	4	1
Arizona	114,000	337	286	27	21	14	1
Nevada	110,000	331	17	6	21	1	1
Colorado	104,000	322	181	42	20	9	2
Wyoming	98 000	313	159	12	18	9	1
Oregon	97,000	311	351	58	18	20	3
Utah	85,000	291	40	20	16	3	1
Minnesota	84,000	289	949	85	16	11	5
Idaho	83,000	288	115	15	16	7	1
Kansas	82,000	286	311	80	16	20	5
Nebraska	77,000	277	1572	40	15	104	3
South Dakota	77 000	277	711	26	15	47	2
North Dakota	70,000	264	394	18	14	28	1

* Estimated 1990 as in 1970
** Estimated 1990 by population growth
- Populated area with schools estimated at 25 percent of total area
- 50-mi dia equivalent area beams used

Table 4-9. Beam Requirements - II

STATE	AREA (MI^2)	APPROX SIZE(MI)	NO SCHOOL DISTRICTS*	NO UNIVERSITIES AND COLLEGES**	NO BEAMS	NO DISTRICTS/ BEAM	NO UNIVERSITIES/ COLLEGES PER BEAM
Oklahoma	70,000	264	701	54	14	50	4
Missouri	70,000	264	658	103	14	47	8
Washington	68,000	260	325	58	13	25	4
Georgia	59,000	242	193	93	11	17	8
Florida	58 000	240	67	94	11	6	9
Michigan	58,000	240	639	135	11	58	13
Illinois	56,000	236	1273	198	10	127	20
Iowa	56 000	236	453	76	10	45	8
Wisconsin	56 000	236	456	94	10	45	10
Arkansas	53 000	230	388	31	10	38	3
No Carolina	52,000	228	152	145	10	15	15
Alabama	51 000	225	118	73	10	12	7
New York	50,000	223	739	328	10	74	33
Louisiana	48 000	219	66	35	10	7	4
Mississippi	48,000	219	149	63	10	15	6
Pennsylvania	45,000	212	560	210	9	62	23
Tennessee	42,000	204	150	84	9	17	9

* Estimated 1990 as in 1970
** Estimated 1990 by population growth
- Populated area with schools estimated at 25 percent of total area
- 50-mi dia equivalent area beams used

Table 4-10. Beam Requirements - III

STATE	AREA (MI^2)	APPROX SIZE (MI)	NO SCHOOL DISTRICTS*	NO UNIVERSITIES AND COLLEGES**	NO BEAMS	NO DISTRICTS/ BEAM	NO UNIVERSITIES/ COLLEGES PER BEAM
Ohio	41,000	202	645	135	8	80	17
Virginia	41,000	202	129	91	8	16	12
Kentucky	40,000	200	193	52	8	24	7
Indiana	36,000	189	323	66	7	46	9
Maine	33,000	181	246	24	7	35	3
So Carolina	31,000	176	93	67	6	16	11
West Virginia	24,000	154	55	33	5	11	7
Maryland	11,000	104	24	70	3	8	23
Vermont	10,000	100	253	26	2	126	13
New Hampshire	9 000	94	153	28	2	76	14
Massachusetts	8,000	89	374	177	2	187	89
New Jersey	8,000	89	569	84	2	284	41
Hawaii	6,000	77	1	10	2	1	5
Connecticut	5,000	70	175	69	1	175	69
Delaware	2 000	44	26	10	1	26	10
Rhode Island	1 000	31	40	20	1	40	20

Estimated 1990 as in 1970

** Estimated 1990 by population growth

- Populated area with schools estimated at 25 percent of total area

- 50-mi dia equivalent area beams used

made that the total populated area that contains schools or School Districts, if drawn into circular or eliptical areas, would encompass about 25 percent of the total area of the state. Furthermore, by examining population density curves, it was determined that most of these areas would lie within about a 25-mi radius in cities and towns exceeding 50, 000 population. Thus, a preliminary conclusion was reached that if satellite beams with coverage of 50-mi diameter circles (or the area-equivalent elipses) were generated, and covered about 25 percent of the area of the States, that a first approximation of the required number of beams would be so obtained.

The number of beams containing a given number of school districts were then extracted from the distributions of the previous three tables. This information, as well as the distribution of the number of universities and colleges per beam are shown in Table 4-11. From this

Table 4-11. Beam Requirements - Educational TV

NO DISTRICTS PER BEAM	NO. BEAMS	NO UNIVERSITIES/ COLLEGES PER BEAM	NO BEAMS
1 - 10	140	1 - 5	364
11 - 50	373	6 - 10	166
51 - 100	55	11 - 25	70
101 - 200	30	26 - 50	4
201 - 300	2	51 - 100	3
16,000	600	4,000	607

table it is seen that there are 140 beams with 1 to 10 school districts in each and only two with 200 to 300 school districts per beam. Further, the distribution of schools in each beam was computed using an assumed distribution, since real data could not be located in the available time. Thus the average of four schools per district (given by the number of total schools and the number of total districts) was distributed as per Table 4-12 in which it is seen that the great bulk of the school districts have 1 to 10 schools with only a very small portion of them having more than 10.

The foregoing tables resulted in the derivation of the total number of uplink and downlink channels required for each class of beams, shown in Table 4-13. In this table it is seen that the rule is followed in the assignment of the number of channels per beam for the uplinks that no more than 100 districts should share an uplink channel, and in the school downlinks that no more than 100 schools should share a channel. These assumptions were fairly arbitrary but stemmed from the feeling obtained in reviewing the educational literature in Appendix C. Given those assumptions, the total

Table 4-12. Assumed Distribution of Schools Per District

SCHOOLS PER DISTRICT	AVERAGE	No. OF DISTRICTS	No. OF SCHOOLS
1-10	2.75	14,975	41,250
10-100	20	1,000	20,000
>100	150	25	3,750
	TOTAL	16,000	65,000

OVERALL AVERAGE = 4 SCHOOLS/DISTRICT

Table 4-13. Channel and Beam Requirements

NUMBER OF BEAMS*	DISTRICTS PER BEAM	SCHOOLS PER BEAM	DISTRICT UPLINKS		DISTRICT DEDICATED DOWNLINKS		SCHOOL DOWNLINKS		TOTAL DOWNLINKS, DISTRICTS AND SCHOOLS
			Channels Per Beam	Number of Uplink Channels	Channels Per Beam	Number of District Downlink Channels	Channels Per Beam	Number of School Downlink Channels	
140	1-10	1-40	1	140	0	0 (Share School Channels)	1	140	140
373	11-50	41-200	1	373	0	0 (Share School Channels)	2	746	746
55	51-100	201-400	1	55	1	55	4	220	275
30	101-200	401-800	2	60	2	60	8	240	300
2	201-300	801-1200	3	6	3	6	12	24	30
TOTALS 600	(16,000 Districts)	(65 000 Schools)		634		121		1370	1491

* NOMINALLY 50-MILE CIRCULAR OR EQUIVALENT AREA ELLIPTICAL

number of beams is 600, the total number of uplink channels is 634, the total number of downlink channels dedicated to schools is 1370, and a total number of downlink channels dedicated to districts is 121 making a total number of downlink channels to both districts and schools equal to 1491.

These numbers roughly match the intended 1500 one-way TV channels and 400 two-way TV channels shown in Table 4-7.

The distribution or availability of channels is emphasized in the tabular distributions of Table 4-14 in which it is shown that no assignment results in the sharing of a channel by more than 100 districts or schools. The total channel availability in each beam is further amplified in Table 4-15 in which it is seen that only two beams have three uplink channels and 15 downlink channels; whereas the largest number of beams have one uplink channel and at most 2 downlink channels, whereas 30 beams have 2 uplink channels and 10 downlink channels each. One way of interpreting these numbers is to consider that commercial television generally provides less

Table 4-14. Number of Districts and Schools per Channel

	UPLINKS	DOWNLINKS	
NO. BEAMS	DISTRICTS PER CHANNEL	DISTRICTS PER CHANNEL	SCHOOLS PER CHANNEL
2	67 - 100	67 - 100	67 - 100
30	50 - 100	50 - 100	50 - 100
55	50 - 100	50 - 100	50 - 100
373	11 - 50	11 - 50*	20 - 100
140	1 - 10	1 - 10*	1 - 40

* Districts Share School Channels

Table 4-15. Channels per Beam Summary

NO. BEAMS	UPLINK CHANNELS IN EACH BEAM	DOWNLINK CHANNELS TO DISTRICTS IN EACH BEAM	DOWNLINK CHANNELS TO SCHOOLS IN EACH BEAM	TOTAL DOWNLINK CHANNELS IN EACH BEAM
2	3	3	12	15
30	2	2	8	10
55	1	1	4	5
373	1	0	2	2
140	1	0	1	1

than 15 channels in any one service area, whose size is roughly the same as the beams for this system concept (in primary service) so the service available in those areas with the highest school density is equivalent to the entire capacity of commercial television, whereas the capacity in the bulk of the beams is equivalent to that of one or two closed circuit TV channels. This is further amplified in Table 4-16.

4.1.3 Summary of Requirements

The requirements derived in the above section are summarized in Table 4-17. Six hundred thirty four simultaneous TV broadcasts are cross-strapped to provide up to 1491 simultaneous downlinks. In addition, any 10 percent of the 16,000 school district headquarters were assumed to be able to exchange 10 percent of their program library in real-time with other district headquarters, resulting in a two-way TV capability of

Table 4-16. Channel Requirements

LEAST LOADED BEAM·	
1	UPLINK CHANNEL FROM DISTRICT
0	DOWNLINK CHANNELS TO DISTRICTS
1	DOWNLINK CHANNEL TO SCHOOLS
MOST LOADED BEAM	
3	UPLINK CHANNELS FROM DISTRICTS
3	DOWNLINK CHANNELS TO DISTRICTS
12	DOWNLINK CHANNELS TO SCHOOLS

Table 4-17. Requirements, Assumptions, and Ground Rules

- PROVIDE FOR CLASSROOM INSTRUCTION SERVICES IN SCHOOLS - TYPICAL OF SYSTEMS NEEDED FOR OPEN UNIVERSITIES, SPECIAL SERVICES, PUBLIC TV
- TIME PERIOD LATE 1980s TO 1990
- COVER ALL USA (EXCLUDING ALASKA AND HAWAII). 50x100 MI AREAS AROUND 600 CITIES > 25,000 POPULATION COVERS MOST SCHOOLS
- ALL COMMUNICATIONS DIRECT FROM BUILDING-TO-BUILDING THROUGH SATELLITE
  - COLOR TV - TASO GRADE 1 (GOOD) OR BETTER QUALITY
  - 16,000 DISTRICT HEADQUARTERS ORIGINATE 634 SIMULTANEOUS TV PROGRAMS (CHANNELS)
  - 65,000 SCHOOLS RECEIVE TV PROGRAMS - EACH PRIMARILY FROM ITS OWN DISTRICT
  - ANY 10 PERCENT OF DISTRICTS CAN EXCHANGE 10 PERCENT OF THEIR PROGRAMS IN REAL TIME (160 CHANNELS)
  - 4 CHANNELS OF INTERACTIVE AUDIO AVAILABLE IN EACH SCHOOL (260,000 TOTAL)
  - AVERAGE OF 10 CLASSROOMS PER SCHOOL EQUIPPED WITH TV RECEIVERS
  - NO MORE THAN 100 DISTRICTS SHARE AN UPLINK CHANNEL (AVG 25)
  - NO MORE THAN 100 SCHOOLS SHARE A DOWNLINK CHANNEL (AVG. 44)

160 channels. In addition, four channels of interactive audio are to be made available in each school for a total of 260,000 audio channels. A last assumption is that an average of 10 classrooms per school are equipped with TV monitor receivers. Since the average U.S. school contains 20 classrooms, this means that half of the school classrooms are equipped with TV monitors for instructional aid.

Additional considerations could include the provision of some transportable terminals for migrant workers schools and the desirability to keep the terminals very small to minimize cost. These, then, constitute the specification against which the system concept is defined.

4.2 CONCEPT DEFINITION

In this section the Educational Television Distribution concept is defined. The gross features of the concept are shown in Figure 4-3, which illustrates the multiple spot beam coverage implied by the requirement to cover 600 areas in the U.S., each about 50 mi diameter. The same principle as adopted in the Personal Communication system will also be adopted for the definition for the Educational TV concept, namely that of a single satellite in geostationary orbit that performs interconnection between all uplinks and downlinks, as required, without dependence on any ground nodes.

The required facilities for operation and control of the Educational TV System are of two categories:

1. The technical facilities that must be provided to route programs originating at School District headquarters to

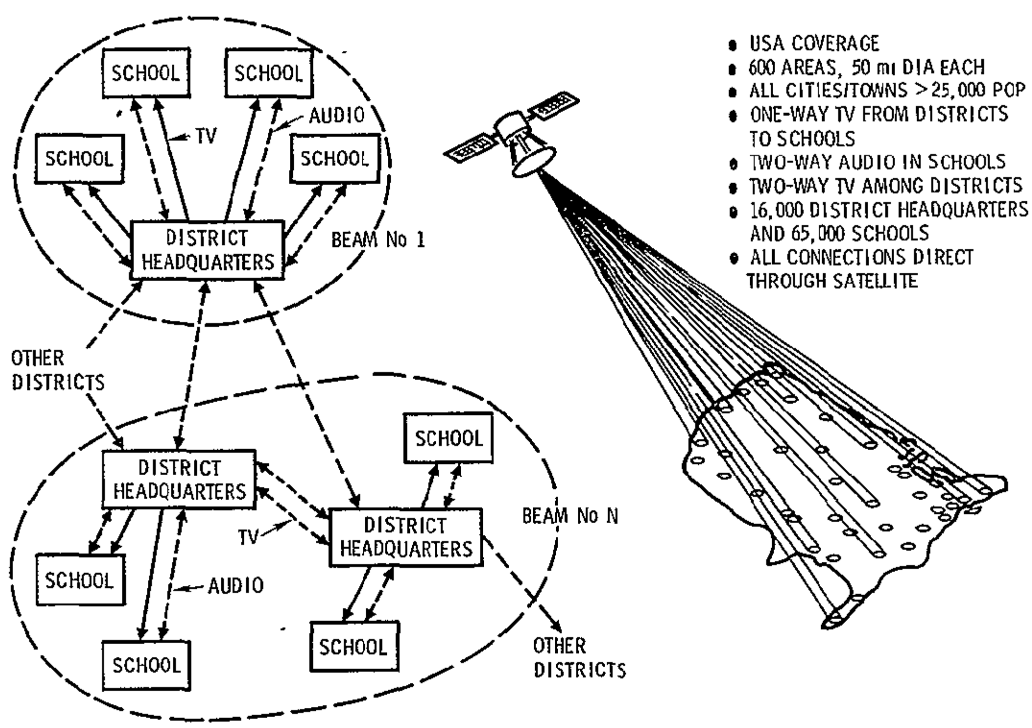

Figure 4-3. Educational TV Satellite Concept

schools within the district, and to other district headquarters.

2. The facilities, both technical and human, that must be provided to allocate and schedule the satellite resources.

The second item, above, is especially significant for any broadcast system that serves the needs of a community of viewers/listeners. To gain the benefit of the program material, the schedule of broadcasts must be known far enough in advance so that the audience may schedule themselves accordingly. While this constraint appears obvious, it is stressed here to illustrate the difference between a broadcast network and a personal communications network. In a personal communications network (whether satellite or terrestrial) the system must attempt in real-time to find idle circuits and switch connections to serve the parties (usually only two) involved. Provision must be made for busy signals and ringing tones. In a heavily loaded system, provision may be made for several priority categories and for queueing calls. The system may include automatic means for limiting call durations and interrupting calls that take more than the allocated time. Likewise, other means may be employed to regulate network traffic on a real-time basis.

In contrast, traffic regulation in a broadcast network is preplanned and is generally not a real-time requirement. Exceptions exist during emergencies, for important events meriting program interrupts and for real-time events, such as elections, meriting broad coverage. It appears that no machine can adequately handle these exceptions, so that overall network supervision and control must remain a human operator responsibility.

Given the advance scheduling requirement, the technical facilities for controlling the Educational TV System become relatively simple, compared with the Personal Communication System. Districts wishing programs from other districts would transmit their plans and requirements by auxiliary narrowband voice or teletype circuits to those districts and in parallel to a control center. These requests would be approved (or disapproved) by the center based upon availability of satellite resources at the desired time(s). An off-line reservation system would probably be used to assist these supervisory and scheduling functions, but the basic decisions would be made by humans.

Exceptions would be made in the case of school districts broadcasting to their own schools. Sufficient resources could be permanently reserved so that districts would retain direct control over programming and scheduling of programs to their own schools. In emergencies these dedicated channels could be pre-empted by the control center, with or without approval by the districts.

The required technical facilities for control of the Educational TV system may be deduced from the foregoing operational considerations. There must be a control center that determines channel allocations and satellite switching paths. Although these decisions are not normally performed in real-time, the resulting commands must be communicated to the satellite to effect control in real-time. Hence, the control center requires an uplink and downlink order wire, the former to transmit channel allocation and switching commands and the latter for telemetry of satellite communications payload status. The control center could be controlled by a national education agency. In addition, all school districts would be given facilities similar to those of the control center, except more restrictive in scope. They would be permitted to access other similarly equipped school districts through the satellite, but they would not have direct access to any schools other than those in their own district. Override control would remain with the control center, and would be based on nationally coordinated policies and scheduling. More than one control center may be desirable.

The order wire voice and signaling facilities can be readily provided by employing one or more narrowband channels in each beam for these purposes. The normal guard band between each FM-TV channel is 3.6 MHz wide -- more than ample space for any reasonable number of low power narrowband control channels.

In summary, the problems of signal routing and network control of the Educational TV System are much simpler than in the Personal Communications System. The required satellite and ground facilities can be readily provided. There are no state of the art constraints envisioned in this aspect of the system.

4.2.1 Link Calculations

The calculations of the required parameters of the link will begin with the consideration of the required carrier-to-noise density (C/N_o) ratio for adequate quality television transmission and reception. For television transmission, noise is specified as a weighted parameter, with the weighting determined by subjective testing. The weighting network attenuates noise at the upper end of the video band relative to noise at the lower end, since high frequency noise is more annoying to most viewers. However, care must be taken to maintain adequate signal-to-noise ratio at the color subcarrier frequency.

Subjective tests using CCIR weighting indicate that noise becomes just perceptible at levels of 47 to 48 dB below the picture signal, excluding the synchronizing pulse. The link budget requirements have been based on providing this video signal-to-noise ratio.

Frequency modulation is used, with signal parameters similar to those provided in commercial TV statellite service. The deviation ratio determines the FM improvement factor. The optimum deviation ratio for a given C/N_o ratio is the highest that can be used without requiring the predetection noise bandwidth to widen to the point where the carrier-to-noise ratio falls below threshold. The deviation ratio that permits operation in the lowest C/N_o environment is that ratio which provides a picture that just meets the picture signal-to-noise ratio requirement simultaneously with a carrier-to-noise ratio that just meets the threshold constraint. If the deviation is increased slightly beyond this optimum value to gain a higher FM improvement factor, the required higher noise bandwidth will cause the signal to become sub-threshold. A lower than optimum deviation ratio will result in a margin above threshold, but insufficient FM improvement factor to meet the video signal-to-noise ratio requirement.

Table 4-18 summarizes the important signal parameters that must be defined for link budget analysis. The numerical values have been chosen to be optimum in the sense described in the preceding paragraph.

The audio portion of the TV program can be transmitted on its own subcarrier with less than a 10 percent increase in total satellite EIRP. Accordingly, from Table 4-18 the total $(C/N_o)_t$ requirement has been adjusted to 86.0 dBHz. This requirement has been allocated in the following way:

downlink noise, $(C/N_o)_d$ = 88.0 dBHz
uplink noise (C/N_o) = 92.9 dBHz
intermodulation noise and external interference, $(C/N_o)_i$ = 93.9 dBHz

Table 4-18. FM-TV Modulation Parameters and Threshold Performance

VIDEO BANDWIDTH	4.2 MHz
PEAK FREQUENCY DEVIATION (equivalent 760 kHz test tone, without pre-emphasis	12 0 MHz
PRE-EMPHASIS ADVANTAGE / NOISE WEIGHTING ADVANTAGE (CCIR Recommendation 405-1 Vol IX, XIIIth Plenary Assembly, Geneva, 1974)	13.0 dB
RECEIVER PREDETECTION NOISE BANDWIDTH (Carson's Rule, 10% guard band)	36 0 MHz
PEAK-TO-PEAK PICTURE SIGNAL-TO-RMS WEIGHTED NOISE RATIO RELATIVE TO CNR IN PREDETECTION BANDWIDTH (above FM threshold)	39.0 dB
FM THRESHOLD (nominal) CNR	10.0 dB
LOSS IN FM IMPROVEMENT FACTOR AT 10 dB CNR FOR IDEAL LIMITER-DISCRIMINATOR	1.0 dB
BUDGETED RECEIVER HARDWARE LOSS	1 0 dB
NET PEAK-TO-PEAK PICTURE SIGNAL-TO-RMS WEIGHTED NOISE RATIO AT 10 dB CNR	47.0 dB
CARRIER-TO-NOISE DENSITY AT THRESHOLD FOR 36.0 MHz PREDETECTION BANDWIDTH	85.6 dB Hz

Link budgets as a function of frequency were calculated using the above C/N_o for uplink frequencies from 1.0 to 30 GHz and downlink frequencies from 1.0 to 20 GHz. At each frequency the 3 dB Antenna beamwidth footprint was taken to have a diameter of 50 mi (minor axis of ground ellipse) per the requirements of Section 4.1. Hence, the spacecraft antenna diameter would vary inversely with frequency, from a maximum of 665 ft at 1.0 GHz to 33.3 ft at 20 GHz. An rms roughness criterion of 1/32 of a wavelength and a 55 percent illumination efficiency were assumed at each downlink frequency band. Since the uplink and downlink bands usually differ in frequency by only a small percentage, the resulting estimates of gain apply equally to corresponding uplink bands. The exception is 20 to 30 GHz, where the uplink band is 50 percent higher in frequency. In that instance, the gain at 30 GHz was calculated using the roughness criterion derived for 20 GHz (i.e., $\sigma/\lambda = 3/64$ @ f = 30 GHz).

A rain loss corresponding to a rain rate of 10 mm/hr was budgeted for median earth station to satellite elevation angles. A rain rate of 10 mm/hr is exceeded by a cumulative total of less than 24 hr/yr, on the average, in typical areas on the Eastern seaboard. The rain loss at this rain rate would be considerably higher in Hawaii and Alaska because of the low elevation angles at those locations, and the resulting longer path through the rain.

It was considered highly desirable that the earth station antenna be manually pointed at the satellite to maximize the received signal, and then locked in position. It is likely that a pointing accuracy of 0.25-deg can be maintained between periodic adjustments. This error allowance also includes the errors in sstellite stationkeeping. No auto-tracking capability at the earth station was initially assumed. It was also felt desirable to hold the ground antenna sizes to less than 3 ft for the schools and less than 10 ft for the districts, to minimize costs. As a result, a significant pointing loss was found at the higher frequencies, because of the narrow beamwidths that result from the given sizes of earth station antennas. This pointing loss was found to be excessive with the larger antenna at 30 GHz and thus precludes the use of such an antenna without an autotracking capability at this frequency.

The downlink budgets are shown in Table 4-19, and the transmitter power requirement is plotted in Figure 4-4 for a 3-ft diameter earth station antenna. The uplink budget is shown in Tables 4-20 and 4-21 for a 3-ft and 10-ft ground antenna, respectively, and the transmitter power is plotted in Figure 4-5, for earth station antenna diameters of 3 ft and 10 ft. The reduced requirements with autotracking are apparent in this figure for the 10-ft antenna. The 3-ft antenna can be fixed-pointed.

Table 4-19. Downlink Budget Educational TV Initiative

		FREQUENCY GHz					
		1 0	2 0	5 0	10	15	20
TRANSMITTER POWER OUTPUT	dBW	P_1	P_2	P_5	P_{10}	P_{15}	P_{20}
FEEDLINE LOSSES	dB	0 1	0 1	0 2	0 4	0 6	0 8
SATELLITE ANTENNA GAIN (minor axis = 55 mi η = 55% σ/λ = 1/32)	dB	63 0	63 0	63 0	63 0	63 0	63 0
SATELLITE ANTENNA DIAMETER	ft	665 0	333 0	133 0	66 5	44 3	33 3
SATELLITE EIRP	dBW	P_1+62 9	P_2+62 9	P_5+62 8	P_{10}+62 6	P_{15}+62 4	P_{20}+62 2
FREE SPACE LOSS (at 30° elev Δ)	dB	184 2	190 2	198 2	204 2	207 7	210 2
RAIN LOSS (10 mm/hr)	dB	0	0	0 2	1 5	5 0	9 0
POLARIZATION LOSS	dB	0 2	0 2	0 2	0 2	0 2	0 2
EDGE OF CONTOUR LOSS	dB	4 3	4 3	4 3	4 3	4 3	4 3
DOWNLINK DEGRADATION MARGIN	dB	1 0	1 0	1 0	1 0	1 0	1 0
Σ DOWNLINK LOSSES	dB	189 7	195 7	203 9	211 2	218 2	224 7
GROUND ANTENNA RECEIVE GAIN (3 ft dia η = 55%)	dB	17 0	23 0	31 0	37 0	40 5	43 0
GROUND ANTENNA POINTING LOSS (0 25° error)	dB	0	0	0	0 1	0 3	0 6
RECEIVING SYSTEM NOISE TEMPERATURE (at feed)	°K	90 0	115 0	250 0	575 0	1000 0	1190 0
GROUND STATION NET (G/T) WITH POINTING LOSS	dB/°K	-2 5	2 4	7 0	9 3	10 2	11 6
$(C/N_o)_d$ = EIRP - Σ LOSSES + $(G/T)_{earth}$ - 10 log k	dB	P_1+99 3	P_2+98 2	P_5+94 5	P_{10}+89 3	P_{15}+83 0	P_{20}+77 7
TRANSMITTER OUTPUT POWER FOR $(C/N_o)_d$ = 88 0 dB Hz	Watts	0 074	0 095	0 22	0 74	3 2	10 7

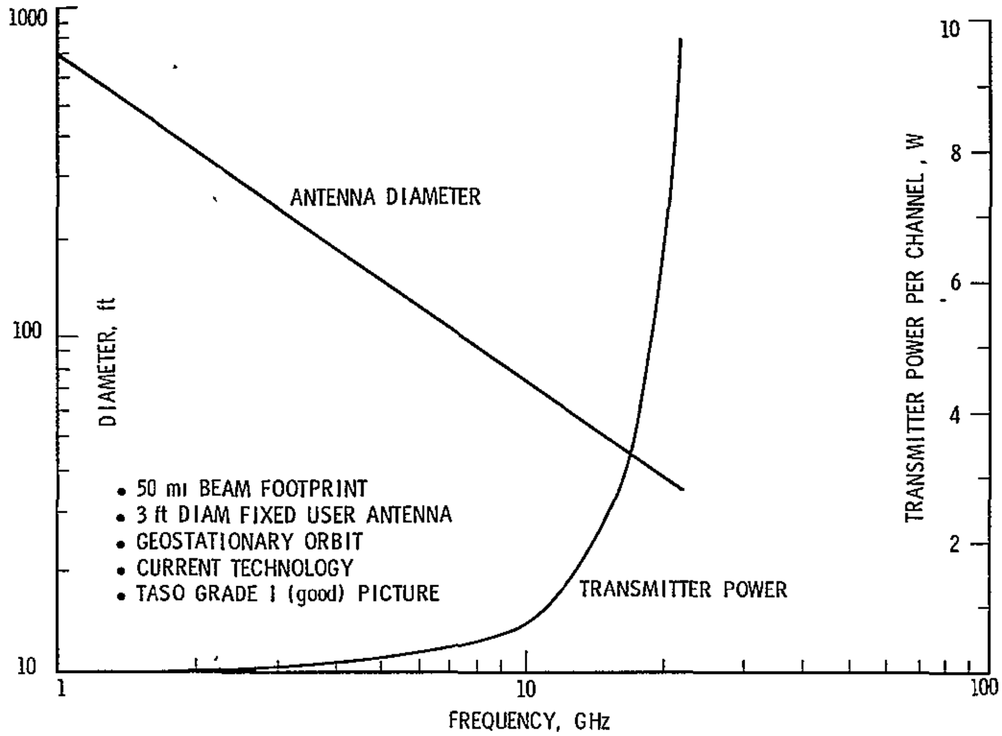

Figure 4-4. Satellite Antenna and Transmitter Needs

Table 4-20. Uplink Budget Educational TV Initiative

3-ft DIAMETER EARTH TERMINAL

		FREQUENCY GHz					
		1 0	2 0	5 0	10	15	30
TRANSMITTER POWER OUTPUT	dBW	P_1	P_2	P_5	P_{10}	P_{15}	P_{30}
FEED LINE LOSSES	dB	0 1	0 1	0 2	0 4	0 6	0 8
GROUND ANTENNA TRANSMIT GAIN (3 ft dia, η = 55%)	dB	17 0	23 0	31 0	37 0	40 5	46 5
POINTING LOSS (0 25° error)	dB	0	0	0	0 1	0 3	1 2
UPLINK EIRP	dBW	P_1+16 9	P_2+22 9	P_5+30 8	P_{10}+36 5	P_{15}+39 6	P_{30}+44 5
FREE SPACE LOSS (30° elev)	dB	184 2	190 2	198 2	204 2	207 7	213 7
RAIN LOSS (10 mm/hr)	dB	0	0	0 2	1 5	5 0	16 0
POLARIZATION LOSS	dB	0 2	0 2	0 2	0 2	0 2	0 2
EDGE OF CONTOUR LOSS	dB	4 3	4 3	4 3	4 3	4 3	4 3
UPLINK DEGRADATION MARGIN	dB	1 0	1 0	1 0	1 0	1 0	1 0
Σ UPLINK LOSSES	dB	189 7	195 7	203 9	211 2	218 2	235 2
SATELLITE ANTENNA DIA	ft	665 0	333 0	133 0	66 5	44 3	33 3
SATELLITE ANTENNA GAIN (η = 55% σ/λ = 1/32 at trans freq)	dB	63 0	63 0	63 0	63 0	63 0	65 6
SATELLITE RECEIVING SYSTEM NOISE TEMP (referred to feed)	°K	400 0	410 0	430 0	500 0	600 0	700 0
SATELLITE (G/T)	dB/°K	37 0	36 9	36 7	36 0	35 2	37 1
$(C/N_0)_\mu$ = EIRP − Σ LOSSES + $(G/T)_{sat}$ − 10 log k	dB Hz	P_1+92 8	P_2+92 7	P_5+92 2	P_{10}+89 9	P_{15}+85 2	P_{30}+75 0
TRANSMITTER OUTPUT POWER FOR $(C/N_0)_\mu$ = 92 9 db Hz	Watts	1 02	1 04	1 17	2 00	5 9	61 7

Table 4-21. Uplink Budget Educational TV Initiative

10-ft DIAMETER EARTH TERMINAL

		FREQUENCY GHz					
		1 0	2 0	5 0	10	15	30
TRANSMITTER POWER OUTPUT	dBW	P_1	P_2	P_5	P_{10}	P_{15}	P_{30}
FEED LINE LOSSES	dB	0 1	0 1	0 2	0 4	0 6	0 8
GROUND ANTENNA TRANSMIT GAIN (10 ft diameter 55% eff)	dB	27 5	33 5	41 5	47 5	51 0	57 0
POINTING LOSS (0 25° error)	dB	0	0 1	0 4	1 5	3 6	29 5
UPLINK EIRP	dBW	P_1+27 4	P_2+33 3	P_5+40 9	P_{10}+45 6	P_{15}+46 8	P_{30}+26 7
FREE SPACE LOSS AT 30° ELEV	dB	184 2	190 2	198 2	204 2	207 7	213 7
RAIN LOSS (10 mm/hr)	dB	0	0	0 2	1 5	5 0	16 0
POLARIZATION LOSS	dB	0 2	0 2	0 2	0 2	0 2	0 2
EDGE OF CONTOUR LOSS	dB	4 3	4 3	4 3	4 3	4 3	4 3
UPLINK DEGRADATION MARGIN	dB	1 0	1 0	1 0	1 0	1 0	1 0
Σ UPLINK LOSSES	dB	189 7	195 7	203 9	211 2	218 2	235 2
SATELLITE ANTENNA DIAMETER	ft	665 0	333 0	133 0	66 5	44 3	33 3
SATELLITE ANTENNA RECEIVE GAIN (η = 55% σ/λ = 1/32 at transmit freq)	dB	63 0	63 0	63 0	63 0	63 0	63 0
SATELLITE RECEIVING SYSTEM NOISE TEMP (referred to feed) (uncooled paramp)	°K	400 0	410 0	430 0	500 0	600 0	700 0
SATELLITE G/T	dB/°K	37 0	36 9	36 7	36 0	35 2	34 5
$(C/N_0)_\mu$ = EIRP - Σ LOSSES + $(G/T)_{sat}$ - 10 log k	dB Hz	P_1+103 3	P_2+103 1	P_5+102 3	P_{10}+99 0	P_{15}+92 4	P_{30}+54 6
TRANSMITTER OUTPUT POWER FOR $(C/N_0)_\mu$ = 92 9 dB Hz	Watts	0 091	0 095	0 115	0 25	1 12	6760 0

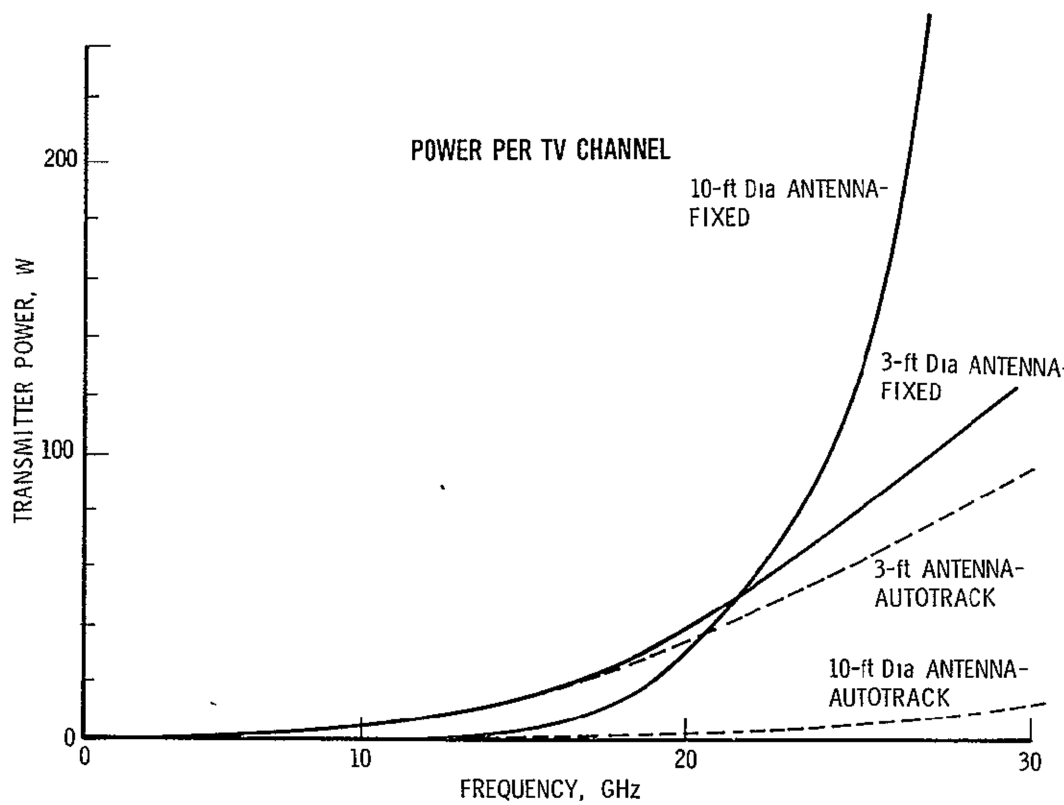

Figure 4-5. User Terminal Transmitter Power

4.2.2 Frequency Selection

A number of factors have to be considered when deciding the frequency of operation for the Educational TV system. The two paramount considerations are the availability of the required bandwidth since TV signals are notoriously broadband, and a very large number of channels is to be simultaneously transmitted. A second consideration is the limit placed on the flux density that may be delivered by the satellite to the ground, in order to avoid interference with fixed ground installations. The latter consideration will be discussed first.

The ITU has established maximum allowable limits of power flux density on the ground from satellite downlinks. These are shown in Table 4-22.

The power flux density on the ground may be expressed as

$$P_1 = \frac{(EIRP)_{sat}}{4\pi r^2} \ W/m^2$$

Table 4-22. Power Flux Density Limits dBW/m^2 in Bandwidth

FREQUENCY GHz	ELEVATION			BANDWIDTH
0.62 - 0.79	$\frac{0 - 20°}{-129}$	$\frac{20° < \theta < 60°}{-129 + \frac{2}{5}(\theta - 20)}$	$\frac{60° - 90°}{-113}$	4 kHz
2.5 - 2.535	$\frac{0 - 5°}{-154}$	$\frac{5° < \theta < 25°}{-154 + \frac{\theta - 5}{2}}$	$\frac{25° - 90°}{-144}$	4 kHz
2.5 - 2.640	-152	$-152 + \frac{3}{4}(\theta - 5)$	-137	4 kHz
3.4 - 4.2 7.25 - 7.3 7.3 - 7.75	-152	$-152 + \frac{\theta - 5}{2}$	-142	4 kHz
10 95 - 11 2 11.45 - 11 7	-150	$-150 + \frac{\theta - 5}{2}$	-140	4 kHz
12.5 - 12.75	-140	$-148 + \frac{\theta - 5}{2}$	-128	4 kHz
17.7 - 19.7	-115	$-115 + \frac{\theta - 5}{2}$	-105	1 mHz

The power flux density within a 1.0 MHz band is

$$P_2 = \frac{(EIRP)_{sat}}{4\pi r^2 B} \ W/m^2/MHz$$

where B is the equivalent bandwidth in MHz of the downlink signal.

An estimate of B may be found from the Carson's rule bandwidth. However, a more conservative (in this instance) approximation of P_2 may be obtained by using $B = 2\Delta F$, where ΔF is the peak frequency deviation, since the power spectral density of an FM signal near the edge of its Carson's rule bandwidth tends to be relatively low. Since $\Delta F = 12$ MHz, P_2 may be rewritten in dBm units as

$$P_2 = 10 \log(EIRP)_{sat} - 10 \log(4\pi r^2) - 10 \log B_{MHz}$$

For a nominal path length of 40,000 km and B equal to 24 MHz

$$P_2 = 10 \log(EIRP)_{sat} - 163 - 13.8$$

$$= 10 \log(EIRP)_{sat} - 176.8 \ dBW/m^2$$

in a 1.0 MHz bandwidth

Table 4-23 shows the flux density that would be delivered by the satellite, using the EIRP values taken from Table 4-19.

Note that Table 4-22 gives maximum values, which will be realized only when there is zero atmospheric loss, at the peak of the downlink beams, without the miscellaneous hardware losses budgeted in Table 4-19.

Table 4-23. Flux Density Delivered by Educational TV Satellite

FREQUENCY (GHz)	FLUX DENSITY PER 1 MHz BANDWIDTH, IN dBW/m^2	
	DELIVERED	PERMITTED (25-90 DEG)
1	-125.2	-106 (at 0.7 GHz)*
2	-124.1	-120 (at 2.5 GHz)*
5	-120.6	-118 (at 4.2 GHz)*
10	-115.5	-116*
15	-109 3	-104 (at 12 GHz)*
20	-104.3	-105

* Converted from Specification per 4 KHz Bandwidth

It is seen from Table 4-22 that a flux density delivered for the Educational TV satellite never exceeds that permitted above 25 deg elevation by more than 0.7 dB. This difference is considered insignificant due to the many assumptions made in the link calculation and the ease of slightly reducing the signal-to-noise ratio without material impact on picture quality. Thus the conclusion is reached that for satellite transmission to the contiguous 48 states the flux density limits imposed by the ITU are not a factor in selection of the operating frequency of the Educational TV satellite.

The question of the proper operating frequency, then, requires a review of the availability of appropriate frequency bands, as well as the impact of the operating frequency upon the required satellite antenna diameter and transmitter power. Reviewing Figure 4-4 it is seen that the power per TV channel is less than about 10 W for all frequencies of interest, whereas the antenna diameter becomes very large compared to conventional structures at frequencies much less than 5 or 10 GHz. Note that the antenna diameter remains constant in terms of the number of wavelengths spanned due to the constant footprint required for coverage reasons. This consideration drives the operating frequency to above 10 GHz. A review of Figure 4-5, however, indicates that for frequencies much above 10 GHz, the transmitter power for the ground terminal becomes so high that the cost of the terminals will increase significantly unless an autotracking 10-ft antenna is used at the districts. Thus, whether from the transmitter power or autotrack requirements, frequencies below 10-15 GHz are preferred by the user terminals. However, a more important consideration is that of available bandwidth. The requirements derived in Section 4.1 call for almost 1500 simultaneous TV channels to be transmitted by the satellite plus 634 more by the ground. The bandwidth of each TV channel, as transmitted in the FM mode, is approximately 36 MHz. Since any one beam could contain up to 15 channels, the maximum bandwidth occupancy of one beam would be 15 by 36, or 540 MHz. Due to frequency reuse with the multiple spot beam antenna, a minimum of three such frequency bandwidth regions will be required making the total downlink allocation required 1620 MHz. The uplinks will require at most three channels per beam, or 108 MHz. With frequency reuse the total uplink allocation needed is 108 by 3, or 324 MHz.

A review of Table 4-24, which summarizes the major frequency bands available for satellite use, shows that bandwidths of 1600 MHz are simply not available in any of the conventional satellite downlink bands including the 11 GHz down, 14 GHz up bands and are only available for operation in the nominally 20 GHz down, 30 GHz up regions. Two general areas are available for operation in these broad regions - these are expanded in Table 4-25. Table 4-25 shows that for the uplinks the 27.5 to 29.5 GHz region, which has 2000 MHz of bandwidth available, is the preferred operating band though the 324 MHz of bandwidth required could be accommodated in either band. For the downlink the 17.7 to 19.7 GHz band, which also has 2000 MHz of allocated bandwidth, is the preferred operating region

Table 4-24. Major Frequency Bands Available

FREQUENCY (GHz)	SERVICE (USA)	COMMENTS
0.62 - 0.89	TV, Satellite Mobile, Fixed	Narrow Band, Flux Limits
1.00 - 2 50	Fixed, Navigation, Mixed	Congested, Narrow
2 50 - 2.69	Broadcast Satellite, Fixed	Broadcast Only, Flux Limits
3 70 - 4 20	Fixed, Satellite Down	Commercial Comsats, Flux Limits
4 40 - 4 90	Fixed, Satellite, Mobile in ITU Reg 2 Gov, Nav, Sat in USA (under review)	Lightly Loaded
5.90 - 6.87	Fixed, Satellite	Commercial Comsats, Flux Limits
6.87 - 6.925	Possible Satellite Extension	Commercial Comsats, Flux Limits
6 925 - 7.125	Fixed + Mobile Satellite, Fixed	Congested, Mobile
7.20 - 8.40	Government Only	Congested, Military
8.40 - 8.50	Research	Use for Tests
10.95 - 11 7	Fixed, Satellite	Commercial, Flux Limits
11.70 - 12.2	Fixed, Satellite, Broadcast	Broadcast Only, No Flux Limits
12.50 - 14 5	Fixed, Satellite, Nav	Some Flux Limits
17.70 - 19 7	Fixed, Mobile, Satellite	Flux Limits, Rain Attenuation, Broad
19 70 - 20 2	Fixed, Satellite, Government	Government Only
27 50 - 29 5	Fixed, Satellite, Mobile	Broad, Some Mobile, Severe Rain Attenuation
29 50 - 30 0	Fixed, Satellite	Broad, Severe Rain Attenuation
30 00 - 31 0	Satellite, Government	Government
>31	Various, Mixed	Increasingly Available, Broad, but Severe Rain Attenuation

Table 4-25. Major Frequency Choices (for bandwidths of ≈ 500 MHz or more)

FREQUENCY	BANDWIDTH	POWER FLUX DENSITY LIMITS (ITU) AT ELEVATION ANGLES (dbW/M^2)		
		0-5 DEG	5-25 DEG	25-90 DEG
UPLINKS				
27.5-29.5 GHz	2000 MHz		N/A	
29.5-30.0 GHZ	500 MHz		N/A	
DOWNLINKS				
17.7-19.7 GHz	2000 MHz	-115/MHz	-115/MHz to -105/MHz	-105/MHz
19.7-20 2 GHZ	500 MHz		NO LIMITS (NOT SHARED)	

even though it has flux density limits imposed upon it, since as was shown above, these limits do not impose a penalty on the system for operation in the continuous 48 states.

For service to Alaska or Hawaii from a single satellite location with longitude over the U.S., the angle of arrival of the signal as seen by the ground would be less than 25 deg and thus the flux density limits might be exceeded. A solution, should service to those areas be desired from a single satellite location, would be to operate the more limited bandwidth services to Alaska and Hawaii in the 19.7 to 20.2 GHz band, where no limits are imposed since the service is satellite exclusive, with the services to the contiguous 48 states being supplied in the 17.7 to 19.7 GHz band.

The payload design then proceeds using the 20 and 30 GHz bands. This choice is fortuitous since these bands are currently very lightly loaded and it should not be difficult to obtain allocations for an Educational TV satellite system.

4.2.3 Payload Block Diagram

The communications payload consists of a number of transponders - one for each antenna horn - operating through diplexers, demodulating the TV channels to baseband, routing the signals through a switch, remodulating the signals, and transmitting them through the same horns via a diplexer. A block diagram of this satellite payload is shown in Figure 4-6. The approximate description of the major elements is as follows:

One Multibeam Antenna. 600 simultaneous but independent beams. Diameter = 9.5 m @ 20 GHz, 6.4 m @ 30 GHz.

600 Diplexers, Filters which separate uplink and downlink bands

600 RF Preamplifiers. Low noise, GaAs FET or uncooled paramp. Bandwidth = front end. 120 MHz. Gain = 20 dB

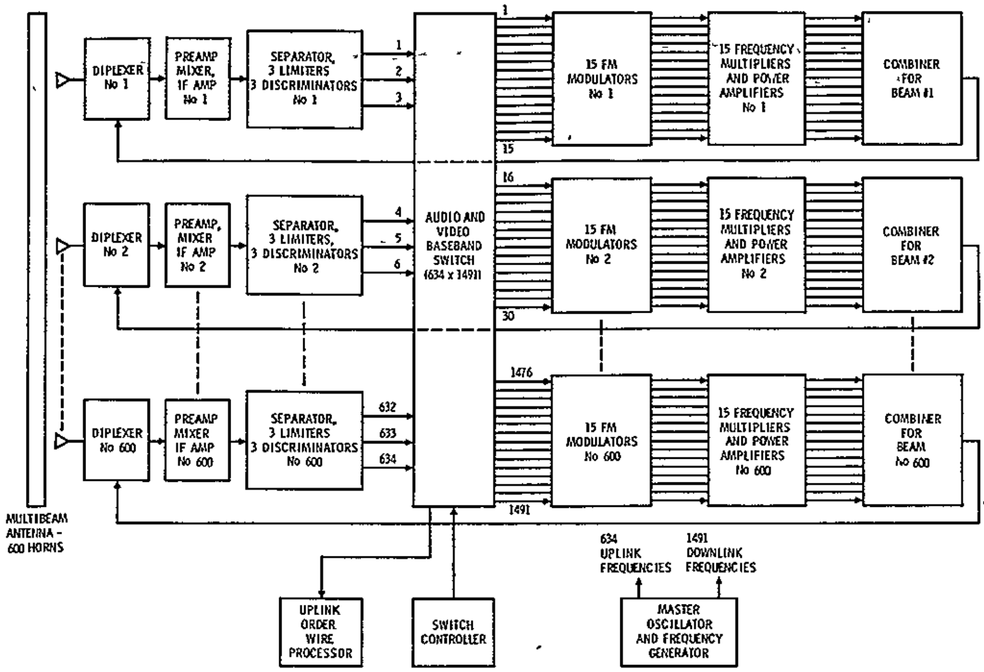

Figure 4-6. Educational TV Satellite Block Diagram

600 Mixer-Downconverters. Translates RF frequency to IF. Double conversion to cope with image response filtering requirements.

600 IF amplifiers. Consists of a 1st and 2nd IF sub-amplifier sections with a 2nd downconverter between. End-to-end gain of IF amplifiers is approximately 90 dB.

634 Channel Separation Filters. Limiter-Discriminator, nominal channel separation is 36 MHz. Includes 10 percent guard band. Provides minimum of 30 dB attenuation at edges of adjacent channels. Filters to be followed by FM limiter-discriminators.

One Video Baseband Switch. The basic requirement is for a nonblocking switch with 634 inlets and 1491 outlets. Paths through the multiple stages of the switch are established by the Switch Status & Control, which provides the desired fanout of originating program channels (uplinks) to downlink channels in beams to receive coverage. Crosstraps included as basic provisions since there are more outputs than inputs.

1491 Frequency Modulators. These accept baseband video signals and modulated audio subcarriers from the switch outlets. Each composite signal is frequency (or phase) modulated on a carrier frequency provided by the downlink frequency distribution unit. Baseband frequency shaping networks are provided in accordance with the type of modulator employed and the CCIR recommendations.

1491 Frequency Multiplier Groups. These accept inputs from the frequency modulators and provide outputs at the downlink frequencies.

1491 Power Amplifiers. An indivdual power amplifier per downlink channel is recommended. Since these amplifiers can be nonlinear (because FM is used) IMPATT diodes (several with combiners if necessary) could provide the required power output per channel (~15 W at 20 GHz). An alternative would be to provide a common amplifier for each beam. This would require up to a maximum of 15 channels for the highest density beams. Hence this option would require linear amplifiers with up to 225 W output, which would require advanced technology, and therefore is a less preferred option.

460 Power Combiners. Each combiner can accept inputs from up to 15 power amplifiers and sum them with minimum losses and interaction. (Note: 140 beams contain only a single downlink channel and hence do not require combiners).

1 Master Oscillator. Quartz crystal with long term accuracy of one part in 10^7.

1 Uplink Local Oscillator Generator. With frequency reuse, three bands of frequncies are required. The uplink local oscillator generator provides three frequencies that are spaced in such a way that all incoming frequency bands (from any beam) may be heterodyned to a common IF frequency band.

1 Uplink Local Oscillator Distribution Unit. Provides the necessary fanout and isolation of local oscillator frequencies to the mixer-downconverters. Three frequencies with 634 total outputs are required.

1 Downlink Frequency Generator. Generates up to 15 frequencies per beam at any one of three beam band assignments (45 frequencies, total).

1 Downlink Frequency Distribution Unit. Provides the necessary fanout and isolation of downlink frequencies to the FM modulators. Forty-five frequencies with 1491 total outputs are required.

1 Uplink Order Wire Processor 1 Downlink Order Wire Assembly Unit 1 Central Processor	For description, see discussion in Section 4.2.

4.2.4 Channel and Beam Connectivity

The way in which the satellite will allow programs to be disseminated among school districts and from school districts to the schools themselves needs discussion. It is recognized that the most elemental requirement is for each school district to broadcast programming to its own schools. This connectivity is illustrated on the left side of Figure 4-7, in which each beam operates independently - 634 districts generate

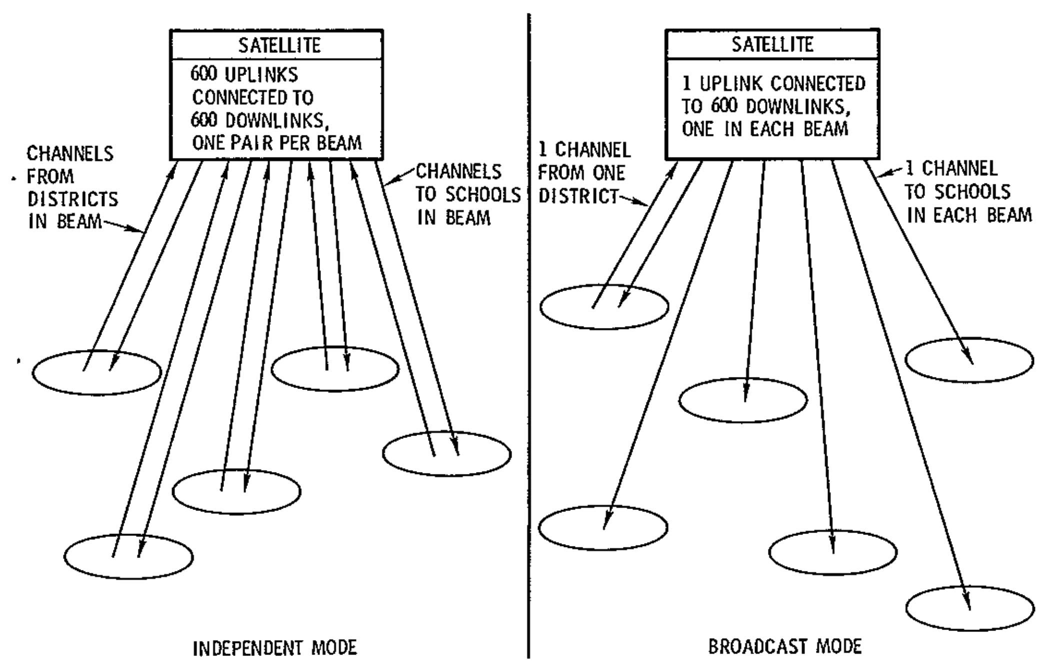

Figure 4-7. Simple Beam/Channel Connectivity

programming material that is broadcast over 634 downlinks - one pair per beam. The channel assignments can be entirely independent per beam. The uplinks can also be connected up to 1491 downlinks in a crosstrapping mode. Alternatively, the satellite can be operated in a broadcast mode where a program on one channel in one beam is strapped to 600 downlink channels, one per beam. Thus every school can receive the same information, which could be a historic event or public event for which real-time coverage is desirable. This connectivity is illustrated on the right side of Figure 4-7. As another alternative, the uplink can be connected to up to 1491 downlinks to attain channel redundancy in many of the beams, which might be useful in case of equipment malfunctions in some ground receivers. Other simple flexibility readily attained is illustrated in Figure 4-8 in which districts may broadcast programs directly to schools in other beams; or a district can be alone, broadcasting only to schools in its own beam with no other beams being active.

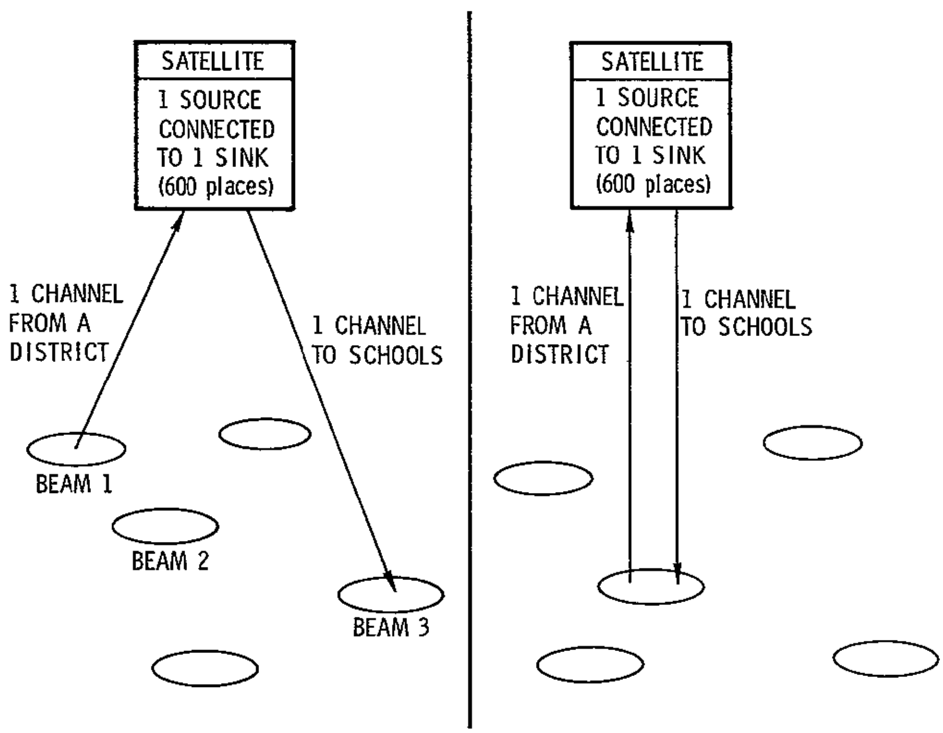

Figure 4-8. Simple Beam Channel Connectivity

An example of modestly complex connectivity might be as shown in Figure 4-9. Four different sources of program material in up to four beams are connected through the satellite and made available on up to four channels to the schools and districts in one particular beam. Due to the 634 uplink channels available, this connectivity can be repeated in 158 separate, simultaneous, and independent connections to 158 recipient beams. In addition, due to the total of 1491 downlink channels available, this same information can be sent in any combination on 857 separate and simultaneous broadcasts to schools in 442 other beams. This begins to illustrate the possibilities inherent in a satellite - switched concept.

An example of a moderately complex connectivity is illustrated in Figure 4-10, in which three channels of information are broadcast by the districts of one beam to their own schools, and nine channels of programs are added from districts via the satellite switch, thus making a total of 12 channels of different program material being simultaneously broadcast to schools and districts within a single beam. This

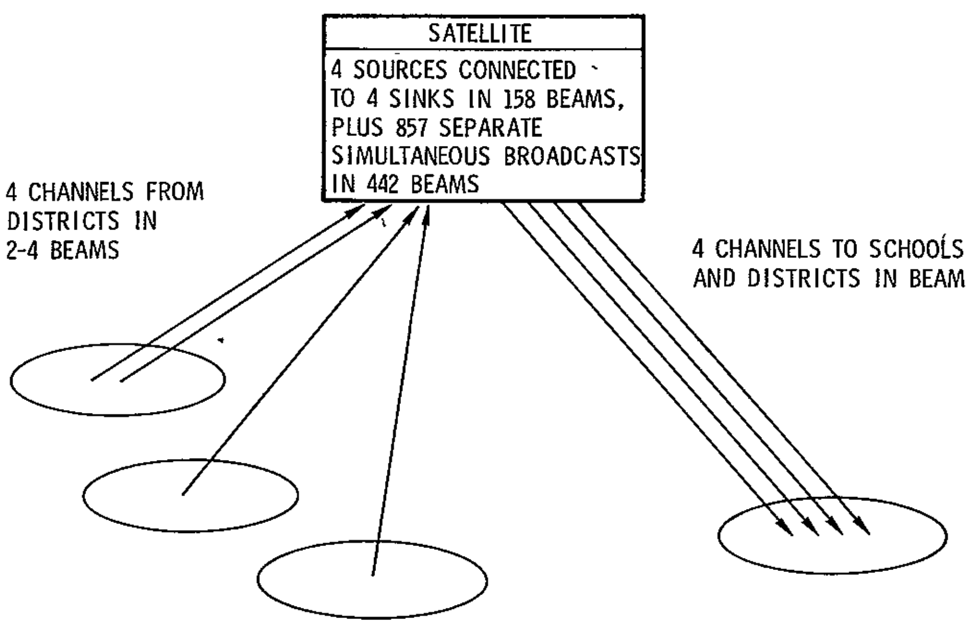

Figure 4-9. Modest Beam Channel Connectivity

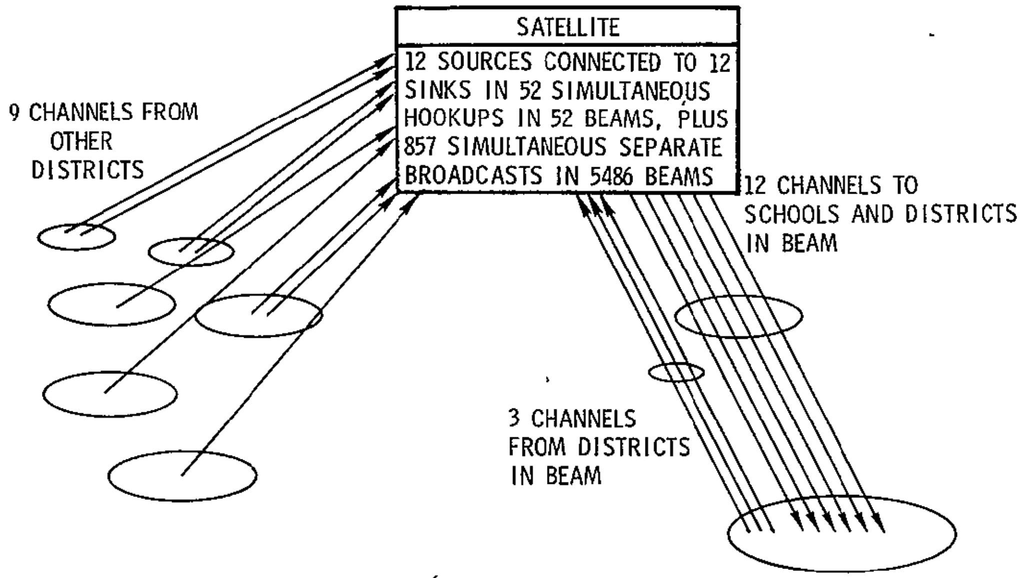

Figure 4-10. Moderate Beam/Channel Connectivity

collection of 12 channels can be repeated independently in 52 simultaneous hook-ups, due to the availability of 634 uplink channels. Simultaneously, due to the availability of 1491 downlink channels, 857 other channels can be crosstrapped to the same uplink programs, and sent to 548 other beams.

An example of the very complex and flexible connectivity possible with this satellite is illustrated in Figure 4-11, which shows collection of up to 15 program channels originating in 5 to 15 different beams connected to 15 downlink channels in one beam (or up to 15 different beams). This can be repeated in up to 42 beam locations independently and simultaneously. In addition, the rest of the 548 beams could carry up to 857 program channels sharing the program information originated by all the other sources with full flexibility for which program is put on which beam.

Figures 4-7 through 4-11 serve to illustrate the enormous power of a satellite of this type. Programs can be broadcast in real-time

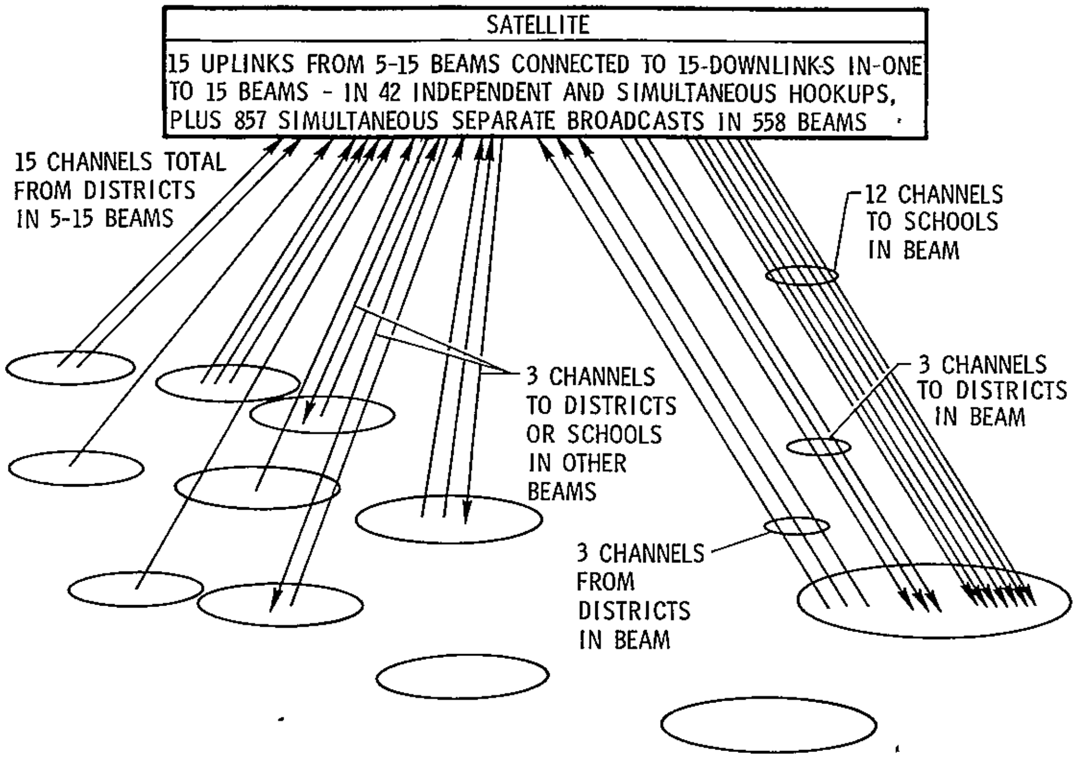

Figure 4-11. Complex Beam/Channel Connectivity

from one source to be received by all districts can broadcast information to their schools and not to the schools of other districts, or programs can be exchanged between districts and taped or instantaneously rebroadcast to the schools of the receiving districts. The net result is that schools in disadvantaged areas can reap the benefit of programs existing in taped library or line form in more advantaged areas; or national or state-level complete program library exchanges can be set up to minimize the total outlay for Educational TV programming. The flexibility thus available with a switching satellite would probably tax the ability of educational institutions to take advantage of such facilities, and lead to rapid growth.

4.2.5 Satellite Segment Definition

A number of subsystems of the satellite were defined in somewhat greater depth in order to allow confident design, performance, weight, and cost estimates to be made. These are discussed below. The depth of analysis performed is equivalent to that in the Personal Communications system of Sections 3.2.5 and 3.2.6, but the detail shown in this section is less, many points being referred to those sections as being fully applicable or by analogy.

4.2.5.1 Multibeam Antenna

The satellite antenna is to generate 600 simultaneous spot beams. While this is not as many as that of the Personal Communications System, this antenna is to operate with very wide instantaneous bandwidth at the highly separated frequencies of 20 and 30 GHz. Even though the antenna diameter at 20 GHz need by only 9.5m as determined in Section 4.2.1, this is 633 wavelengths, which is almost as large (in wavelengths) as the 67m antenna of the Personal Communications satellite (1117 wavelengths diameter). Furthermore, the mechanical tolerances allowable are more stringent by a factor of four, they are about half as stringent on a wavelength.

The specifications for this antenna are summarized in Table 4-26.

The antenna trades for selecting the preferred antenna type, which were performed for the Personal Communications system in Section 3.2.5.1, are fully applicable here and the reader is referred to that section for the details. These trades resulted in the choice of a multibeam lens as being representative of one of the two most desirable antenna types. In order to lend uniformity to the initiatives in this study, a space-fed lens was adopted even though an offset-fed parabola is also an attractive candidate.

Table 4-26. Educational TV Satellite Antenna Requirements

FREQUENCY	20 GHz DOWNLINK (λ = 0.015 m) 30 GHz UPLINK (λ = 0.01 m)
BANDWIDTH	540 MHz PER BEAM (instantaneous)
NUMBER OF BEAMS	600
COVERAGE	CONUS AT FIXED LOOK ANGLES
FIELD OF VIEW	0.094 rad EW x 0.0652 rad NS
POWER GAIN PER BEAM	63 dB AT 20 GHz AND AT 30 GHz
SIDELOBES	-45 dB AT MAXIMUM ANGLE OFFSET
MODULATION	FM
BEAM STEERING	10 mrad
ORBIT:	
ALTITUDE	35,871 km
LATITUDE	0 deg
LONGITUDE	100 deg WEST
POLARIZATION	CIRCULAR
RECEIVER NOISE TEMPERATURE	$\approx 900^\circ C$
ANTENNA SYSTEM NOISE TEMPERATURE	$\approx 1000^\circ C$
MAXIMUM POWER PER BEAM	200 W

The diameter of the antenna at 20 GHz was determined from its required gain from the link calculations performed in Section 4.2.1. The 63 dB gain translates to a diameter of 9.5 m at 20 GHz, with a resultant beamwidth of 1.92 mrad. This results in essentially the required 50-mi footprint on the ground. One difficulty of this antenna design is that operation at 20 and 30 GHz is required simultaneously, with the same gain and the same footprint at both frequencies. This is obviously impossibly unless the diameter of the antenna varies with frequency, and therefore the design solution chosen was to populate only a portion of the lens with 30 GHz elements in a smaller diameter than the maximum, while populating the full lens diameter only with 20 GHz elements. Such a lens obtains the same gain and beamwidth at 30 GHz with the inner lens being 6.4 m in diameter, while the full lens is 9.5 m diameter at 20 GHz.

A very serious problem will be sidelobe control, as far sidelobes cannot be less than 45 dB below the level of the mainlobe to avoid video interference. Thus the lens has to operate at a f/D of 2 or greater for adequate sidelobe control at the required number of beamwidths off-axis, and the illumination must be highly tapered. The design for the Personal Communications antenna could tolerate -15 dB close-in sidelobes and -35 dB far sidelobes due to the small signal-to-noise ratio in operation, and the digital data stream. The video Educational TV system has no such tolerance for interference, and will require stricter sidelobe control, digitizing the TV data stream or both in order to allow the great frequency reuse expected, with nonadjacent beams being on the same frequency. Otherwise more bandwidth will be needed, the system capacity restricted, or both. In this study, the matter could not be adequately addressed. Therefore, an f/D = 2 design was chosen, though it probably is not large enough for adequate sidelobe control. This design requires a feed assembly separated from the lens by at least 20 m. The feeds would consist of 600 horns fed by waveguides, operating in two orthogonal polarizations simultaneously to attain circularly polarized transmission.

The characteristics of the resultant antenna are illustrated in Table 4-27 and Figure 4-12. The weight of the antenna was calculated element-by-element and is shown in Table 4-28. The total antenna assembly is seen to be very light, weighing only 340 kg. It is likely that this weight would not change very much if the lens antenna were replaced by an offset-fed parabola. The adoption of this lens antenna for the baseband design is tentative, pending more extensive sidelobe suppression analyses that must be performed. It may well be that the design will be forced to PCM from

Table 4-27. Educational TV System Spaceborne Antenna Characteristics

TYPE	MULTIHORN FEED AND BOOTLACE LENS f/D = 2
FREQUENCIES	20 GHz DOWNLINK 30 GHz UPLINK
DIAMETER	9.5 m AT 20 GHz; 6.4 m AT 30 GHz
BEAMWIDTH	$1.92\ (10)^{-3}$ rad AT 30 GHz $1.92\ (10)^{-3}$ rad AT 20 GHz
POWER GAIN	63 dB AT 30 GHz 63 dB AT 20 GHz
NUMBER OF BEAMS	600
FEED	
TYPE	CIRCULAR WAVEGUIDE WITH FLARED CIRCULAR HORNS
DIMENSIONS:	
FEED DIAMETER	3.7 m
HORN DIAMETER	7.3 cm
DEPTH	1.5 m
WAVEGUIDE DIAMETER	0.88 cm
MATERIAL	GRAPHITE ALUMINUM COMPOSITE
NUMBER OF HORNS	600
POLARIZATION	2 ORTHOGONAL LINEAR

FM modulation of the video data in order to allow the -15 dB sidelobe levels that Appendix A indicates are realizable even for the first sidelobes. This would force the use of 44 Mbps PCM modulation per channel, but would not require greater bandwidth or a reduction in the number of channels accommodated. Furthermore, the linearity of the transponder components could be reduced. Thus PCM may be more desirable than FM.

The tolerances to which the antenna will have to be built are about half as those of the Personal Communications system measured in wavelengths and equal ±2 cm lens bending, ±4 cm focal plane axial tolerance ±4 cm radial focal plane tolerance - a not terribly difficult requirement to meet. This further substantiates the choice of the lens over the parabola, whose dimensional accuracy requirements are more stringent.

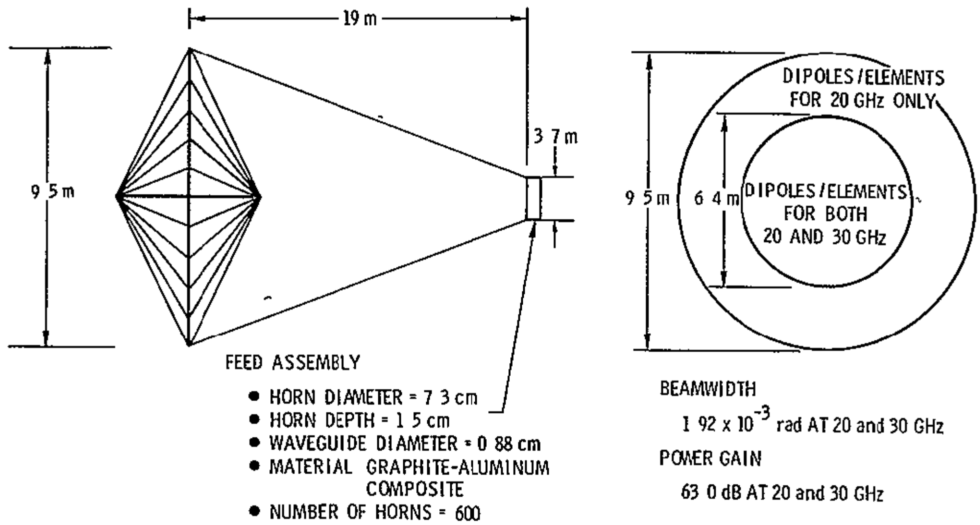

Figure 4-12. Educational TV Antenna Dimensions

Table 4-28. Weight Breakdown, Educational TV Antenna

FEED HORN ASSEMBLY	110 kg
– HORNS	
– SUPPORTS	
– WAVEGUIDES	
– RADIATORS	
LENS ASSEMBLY	32 kg
– ELEMENTS	
– FILMS	
– SHIFTERS	
– COMPRESSION STRUTS	
– STAYS	
– MAST	
SUPPORT STRUTS	167 kg
– LENS/FEED SUPPORTS	
– 4 STRUTS (SPACE FABRICATED BEAMS)	
CONTINGENCY	31 kg
TOTAL:	340 kg

4.2.5.2 Switch

The connectivity requirements of the Educational TV satellite imply a need for a flexible switch whose connection can be changed by program command. Based on the requirements of Section 4.1, and the desired connectivity options explored in Section 4.2.4, a set of requirements were drawn up that are reflected in Table 4-29. The basic requirements on this video baseband switch is to connect any one or more of the 634 uplink channels to any one or more of up to a maximum 1491 downlink channels. Restrictions on the connectivity permitted would be programmed by command into the central satellite processor that operates the switch, and would prevent disproportionate allocation of resources. An example of scrutinized connection might be the request of a district that desires to originate two programs simultaneously and to transmit them for national coverage. Such a connection would use up 1200 of the 1491 downlink channels available thus diverting substantially most of the satellite resources from any other use. Clearly a prohibited connection would be a national

Table 4-29. Educational TV Switch Requirements

- 634 UPLINK INPUTS
- 1491 DOWNLINK OUTPUTS
- FLEXIBLE CONNECTIVITY - 634 x 634 PORTS
- AT LEAST 857 OUTPUTS MUST BE FLEXIBLY STRAPPED TO OTHER OUTPUTS ON COMMAND
- 1-1491 OUTPUTS CAN BE STRAPPED TOGETHER FOR BROADCAST MODES
- NON-BLOCKING
- 5 MHz BANDPASS SIGNALS
- REAL-TIME RECONFIGURATION BY COMMAND
- CONNECTIVITY LIMITS CHANGED BY GROUND PROGRAM

distribution of three programs simultaneously, which would require more channel capacity than exists in the satellite.

Other ground rules will undoubtedly be drawn up in the process of studying the switch in more depth. Such exercises are left to follow-on studies. It is certain that manual supervisory control and override will be required in addition to programmed connectivity rules, and would probably be performed by the personnel in the control center.

The switch can be constructed as a relatively straightforward crosspoint diode switch matrix connecting 634 inputs to 1491 outputs. The number of crosspoint connections thus required is 945,000. A simple design concept for the switch is conceived as follows. The crosspoints consist of PIN diodes located on printed circuits on 1/4-in centers. This allows adequate spacing for shielding and for the coaxial cable runs to and from each crosspoint. If all of the connections were to be made on a single wafer, the wafer would have to contain about 10^6 diodes and have 1000 by 1000 crosspoints. At 1/4-in per center this is equivalent to 250 by 250 in. or almost 20 by 20 ft of switch card. This is clearly not a good solution because of its size. If the required number of crosspoints are divided among 10 wafers in a stack, each stack would have to be 7 by 7 ft; for 30 wafers, the size of each wafer drops to 4 by 4 ft; for 100 wafers to 2 by 2 ft; for 300 wafers to 1.2 by 1.2 ft; and for 1000 wafers to about 8 x 8 in.

In order to select a reasonable design, one must allow for space between the wafers to accommodate the coax cables leading to and from the crosspoint switch diodes and to connect them to the connectors on the switch housing. If such separation is assumed at 1 in. between wafers, which should be enough space for the cable runs, the total package length is under one ft for 10 wafers, 8.3 ft for 100 wafers, 25 ft for 300 wafers, and 75 ft for 1000 wafers. A reasonable design would seem to be one where the switch is divided into 300 wafers - each 1.2 by 1.2 ft, and packaged into 13 cases, each 2 ft long.

Such a package would consist, mostly of foam-filled coaxial cable and would probably weigh in the order of 0.01 lb/in.^{3} Since the volume is 36 ft.^{3} or 62,000 in.^{3}, the weight is estimated at approximately 620 lb. Another weight estimate comes from the average of 50 lb per ATR standard package case, of which there are 13 - which roughly matches the previous weight estimate. The power consumption of the switch can be estimated by an assumption that each diode, when active, requires 100 mW of drive power. Since there are a maximum 1491 diodes active at any one time, this implies a total power drain of about 150 W. These considerations are illustrated in Tables 4-30 and 4-31.

4.2.5.3 Propulsion and Power

An initial sizing attempt indicated that the satellite would weigh about 8500 lb and would require about 50 kW of power. The power estimate came from the requirement to transmit about 1500 TV channels at about 10 W per channel, which is 15 kW of radiated RF power. Since the efficiency of RF amplification is estimated at 30 percent, the requirement

Table 4-30. Sizing of Crosspoint Switch for Educational TV

NO. OF CROSSPOINTS	NO. OF WAFERS	NO. OF POINTS/WAFER	WAFER SIZE, ft
10^6	1	$10^3 \times 10^3$	20 x 20
10^6	10	316 x 316	7 x 7
10^6	30	182 x 182	4 x 4
10^6	100	100 x 100	2 x 2
10^6	300	57 x 57	1.2 x 1.2
10^6	1000	31 x 31	0.65 x 0.65

Table 4-31. Sizing of Crosspoint Switch for Educational TV

WAFER SEPARATION, in	NO. OF WAFERS	WAFER SIZE, ft	TOTAL PACKAGE LENGTH, ft	NO OF 2-ft LONG CASES
1	1	20 x 20	0 083	1
	10	7 x 7	0 83	1
	100	2 x 2	8 3	5
	300	1.2 x 1 2	25	13
	1000	0 65 x 0 65	83	37
1/2	1	20 x 20	0 083	1
	10	7 x 7	-NOT PRACTICAL-	
	100	2 x 2	-NOT PRACTICAL-	
	300	1 2 x 1 2	12	6
	1000	0 65 x 0 65	37	18

for DC power is about 50 kW. The power subsystem to generate 50 kW is expected to weight in the order of 3,330 lb in the 1987 time period, using 15 W/lb as the attainable weight efficiency in that time period. The power system would be a modular, solar array/battery combination similar to the design of the power system for the Personal Communications satellite that was discussed in Section 3.2.5.5.

In order to allow for a long transfer time of the satellite from low orbit to its final geostationary destination by self-powered ion engine transfer, the beginning of life size of the power system was increased, by 30 percent to allow for the expected degradation due to radiation damage during such a transfer trip. Thus, the power system arrays were sized for 65 kW in low earth orbit, while the distribution, conditioning, and batteries sized for 50 kW at beginning of-life in synchronous altitude. This is an entirely practical solar cell system, only twice as big as the one already flown on Skylab, and therefore clearly state-of-the-art.

The propulsion requirements for this satellite were examined in a manner very similar to that of the Personal Communications satellite in Section 3.2.5.4. A number of alternatives were examined for transfer of the satellite from low altitude, where it would be assembled by the Space Shuttle, to its final destination in geostationary orbit. Three of the major alternatives examined appear in Table 4-32. From this table it is seen that the satellite can very effectively use its high onboard power, needed for communication purposes after it reaches final orbit, for powering ion thrusters for effecting the transfer.

The total weight of the resultant propulsion system is, therefore, in the order of 2000 lb compared to 50,000 lb were a low thrust chemical system to be used. The satellite, could, of course, be divided into two parts and transferred to geostationary orbit using the IUS system, however, the maximum acceleration that the payload would see would be about 3 Gs. This is not compatible with the weight of the antenna system that was designed to withstand a maximum of 0.1 G, it being a deployable thin film structure.

Table 4-32. Propulsion Systems for Educational TV Satellite

PROPULSION SYSTEM*	POWER, kW	THRUST, lb	NO OF THRUSTERS	ISP	PROPELLANT WEIGHT, lb	SYSTEM WEIGHT DRY, lb	PENALTY TO OVERSIZE THE POWER SYSTEM BY 30%	TOTAL WEIGHT lb	THRUST TIME DAYS
CURRENT 30 cm ION ENGINE	50	0 535	17	3000	1926	645	867	3436	125
HI POWER 30 cm ION ENGINE	50	0.252	3	9000	595	365	867	1826	246
2 STAGE LOW THRUST CHEMICAL**	-								
STAGE 1	-	2700	1	313	32940	5810	-	38750	64 min
STAGE 2	-	1000	1	300	10750	1900	-	12650	51 min
TOTAL					43690	7710		51400	

* ESTIMATED SATELLITE FINAL WEIGHT = 8500 lb
** MAX. ACCEL $\simeq$ 0 1 g, 1000 ft/sec ΔV PENALTY

Undoubtedly the antenna could be redesigned to withstand 3 Gs without increasing the total weight of the satellite by more than 20 percent, should the option of using the IUS be desired. There is a serious disadvantage of using that option, however, in that final assembly of the satellite must then take place in geostationary orbit using a teleoperator or automated mechanisms, thus precluding the testing of the entire satellite in low orbit where the presence of the man in the shuttle allows thorough checkout, repair, adjustment, or even redesign prior to committing the satellite into transfer orbit.

The penalty that is paid for self-powered transfer is an additional 13 kW of power, which is an added 680 lb. Thus, the total weight of the propulsion system using the high-power 30 cm ion engines and including the oversizing required to allow for degradation of the power system is 1826 lb. As was the case for the Personal Communications satellite, the ion thrusters can be used for the transfer, obtaining a good degree of redundancy since multiple thrusters are required. Thus, a highly reliable transfer system would be so obtained. The attitude control system, however, probably should not utilize ion thrusters for two reasons (1) the lightest weight transfer system only requires three thrusters, which are clearly inadequate for translation and attitude control and (2) the power required by the ion engine attitude and translation control system would be in the order of 10 kW on-orbit, which would require a 20 percent increase in the power system of this satellite (where it was a negligible increase in the power of the Personal Communications satellite for which the ion thrusters doubled as on-orbit control). For these reasons a conventional monopropellant hydrazene attitude control system was configured and found to weigh 35 lb. Pulsed plasma thrusters were used for translation control, however, since only intermittent bursts are required for stationkeeping, and the number of engines chosen was six to allow for translation along three axes without reorientation. Thus, the satellite attitude and translation control system design is a hybrid hydrazine and pulsed plasma system.

4.2.5.4 Design

The design of this satellite follows a very similar procedure to that utilized for the Personal Communications satellite. The electronic components are first sized with the results as shown in the Table 4-33. Each component was reasonably carefully analyzed on the basis of large scale integrated fabrication, minimum interconnects, and mounting on the largest scale of single light-weight substrates. The estimates result in almost 2000 lb for the electronics and antenna and a 50 kW power requirement as assumed in Section 4.2.5.3.

A weight statement for the entire satellite is shown in Table 4-34. The total weight for the satellite is seen to be just under 10,000 lb. This includes the oversized solar array to allow for degradation in the transfer orbit, as well as a 20 percent contingency to reflect the uncertainties at this stage of the design.

Table 4-33. Physical Descriptions of Components - Educational TV

				PER UNIT			TOTAL		
ITEM	QTY	DESCRIPTION		in^3	lb	W	ft^3	lb	kW
ANTENNA	1	INCLUDES LENS, SUPPORTS 600 HORNS		-	700	-	-	700	-
DIPLEXER	600	ONE PER HORN/BEAM		0 1	0 01	-	0 03	6	-
RECEIVER	600	INCLUDES PREAMP MIXER/DOWNCONVERTER IF/VIDEO AMPLIFIERS AND SUBSTRATE		0 2	0 02	0 1	0 07	12	0 06
DEMODULATOR	634	INCLUDES FM DETECTOR FILTERS TO BASEBAND, AND STRUCTURE		0 01	0 001	0.002	0 003	0 63	0 001
SWITCH & CONTROL	1	SWITCHES 634 INPUTS TO 1491 OUTPUTS IN REAL TIME - PROGRAM CHANGED BY COMMAND INCLUDES STRUCTURE	CONTROL	2 000 0	200	200	1 1	200	0 2
			SWITCH	62 000.0	700	150	36 0	700	0 15
MODULATOR/ MULTIPLIER	1 491	INCLUDES FM MODULATOR FILTER PROGRAMMABLE FREQUENCY MULTIPLIER, AND STRUCTURE		0 2	0 02	0 1	0 17	30	0 15
TRANSMITTER	1 351	15 Watt DIODE AMPLIFIER PER CHANNEL AT RF INCLUDES STRUCTURE		3 0	0 1	33	2 3	135	44.6
	140	11 Watt LINEAR AMPLIFIER PER CHANNEL AT RF INCLUDES STRUCTURE		2.2	0 07	33	0 18	10	4 6
COMBINER	TOTAL 460	COMBINES HI PWR OUTPUTS RESULTING IN NOT LESS THAN 11 Watts PER CHANNEL AT RF INCLUDES SUBSTRATE		-	-	-	0 73	8 7	-
	373	COMBINES 2 CHANNELS @ 15 W/CHANNEL INPUT		0 2	0 02	-	0 04	8 0	-
	55	COMBINES 4 CHANNELS @ 15 W/CHANNEL INPUT		0 1	0 01	-	0 003	0.5	-
	30	COMBINES 8 CHANNELS @ 15 W/CHANNEL INPUT		0 06	0 006	-	0 001	0 2	-
	2	COMBINES 12 CHANNELS @ 15 W/CHANNEL INPUT		0 02	0 002	-	0 00002	0 004	-
FREQUENCY GENERATOR & DISTRIBUTOR	2	GENERATES 634 UPLINK SUBCARRIERS AND 1491 DOWNLINK FACTORS AND DISTRIBUTES INCLUDES CASE		200 0	20 0	200	0 46	40 0	0 4
MASTER OSCILLATOR	1	GENERATES MASTER FREQUENCY SYSTEM		200 0	20 0	200	0 23	20 0	0 2
		GRAND TOTAL					41 31	1 921 0	50 36

Table 4-34. Educational TV Satellite Weight Summary

ITEM	WEIGHT - POUNDS	
STRUCTURE AND THERMAL CONTROL		1 125
ATTITUDE CONTROL (Excludes Reaction Control System)		35
ELECTRICAL POWER AND DISTRIBUTION		4 480
Array (65 kW)	1,260	
Array Structure (Including Orientation and Deployment Mech)	1,065	
Distribution and Conditioning } 50 kW B O L	645	
Batteries	1,510	
ANTENNA		700
Feed Horn Assembly	242	
Lens Assembly	70	
Support Struts	368	
Guide Lines	20	
COMPUTER (Including Heat Pipes)		900
ELECTRONICS		265
Diplexers	6	
Receivers	12	
Demodulators	1	
Modulators Multipliers	30	
Transmitters	145	
Combiner	9	
Frequency Generators	40	
Master Oscillator	20	
Miscellaneous	2	
PROPULSION AND REACTION CONTROL		915
Propulsion and Reaction Control System (dry)	110	
Propellants and Reactants	805	
WIRING		100
CONTINGENCY (20 PERCENT)		1,280
SATELLITE GROSS WEIGHT		9 800

A layout of the satellite is shown in Figure 4-13 in which the most apparent structures are that for the multibeam antenna and the large solar arrays. The picture of a man is shown to the left of the lens of the antenna simply as scale comparison. The structural and modular design of the satellite would be envisioned very much as that of the Personal Communications satellite, to consist of a structure upon which would be mounted the horn clusters, the back of which would hold the electronic packages and propulsion packages. Similar modular packaging for on-orbit replacement and servicing, as shown for the Personal Communications satellite design in section 3.2.5.6, is employed here. The lens antenna itself unfolds, as does the Personal Communications satellite antenna, from a deployable package of minimal dimensions. It is connected to the main structural

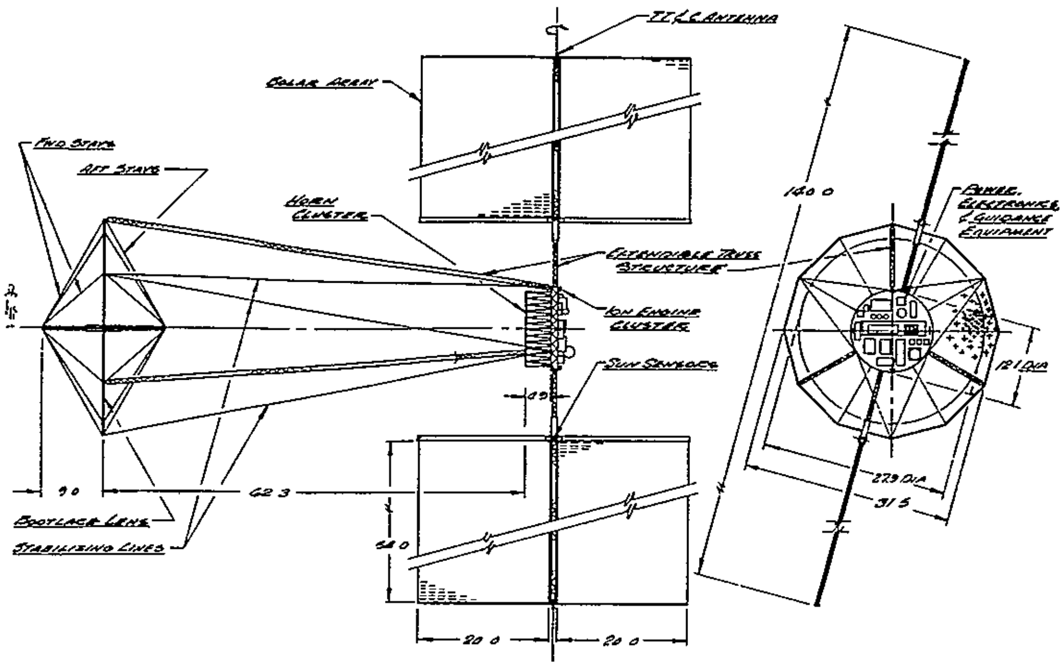

Figure 4-13. Educational Television Satellite

frame by three extendible beams of the "Astromast" variety, and stabilized by guy wires. The solar cells are gimballed on extendible masts to avoid sun shadowing due to the lens near eclipse. The full size of the arrays is not shown due to the scale of the drawing. Small components such as the hydrazene attitude control system could not be shown in this scale drawing.

An oblique view of the satellite in an artists' concept is shown in Figure 4-14 in which the two most apparent features to be pointed out are the mirror image of the USA in the shape of the feed horn assembly, and the attempt to show the dual-frequency antenna design, with the inner portion of the stretched membrane lens containing both sizes of crossed dipole elements, while the outer portion contains only the larger crossed dipoles. The man is not necessary for assembly or servicing although certainly is an option to be investigated for the assembly in low orbit, but is shown for scale comparison only.

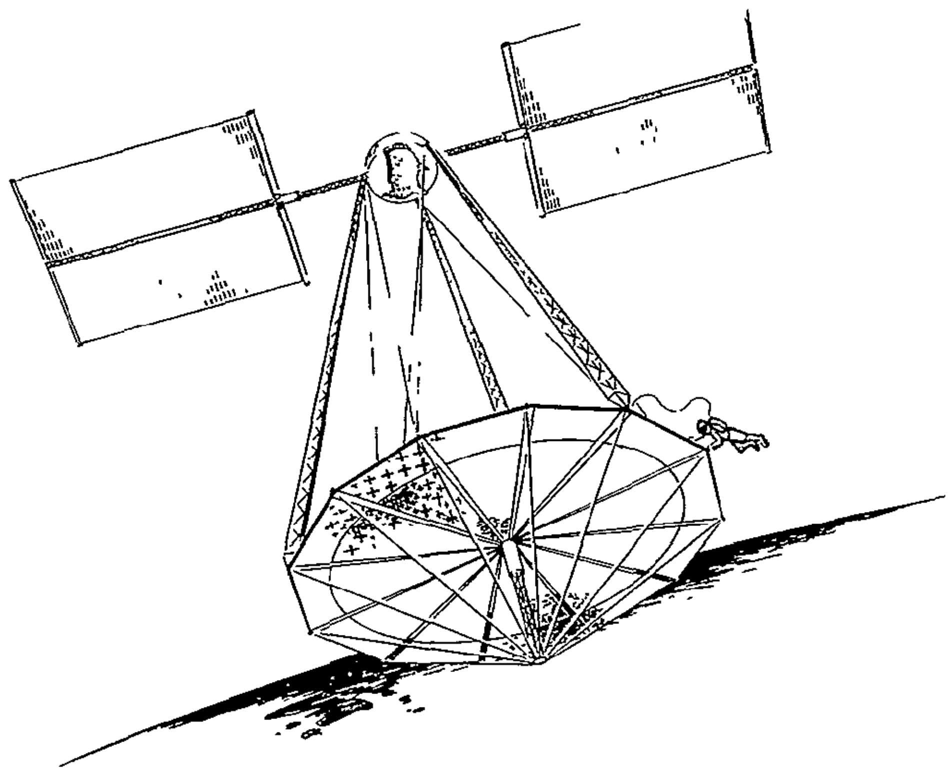

Figure 4-14. Educational Television Satellite

In contrast to the very large satellite of the Personal Communications system, this satellite can be packaged entirely in a single Shuttle Orbiter flight. A simple attempt at packaging resulted in Figure 4-15 proving the point, without claiming any optimization.

Whereas the design for the Educational TV initiative is not claimed to be unique or optimum, it probably serves to illustrate the magnitude of the task and to give a feeling for the technology and techniques required. This design is felt to be thoroughly practical in the late 1980 time period, requiring no technology breakthroughs and only extensions of currently understood techniques. The biggest need is for large numbers of components, as opposed to new highly demanding components, and for a multibeam antenna larger than has been designed previously.

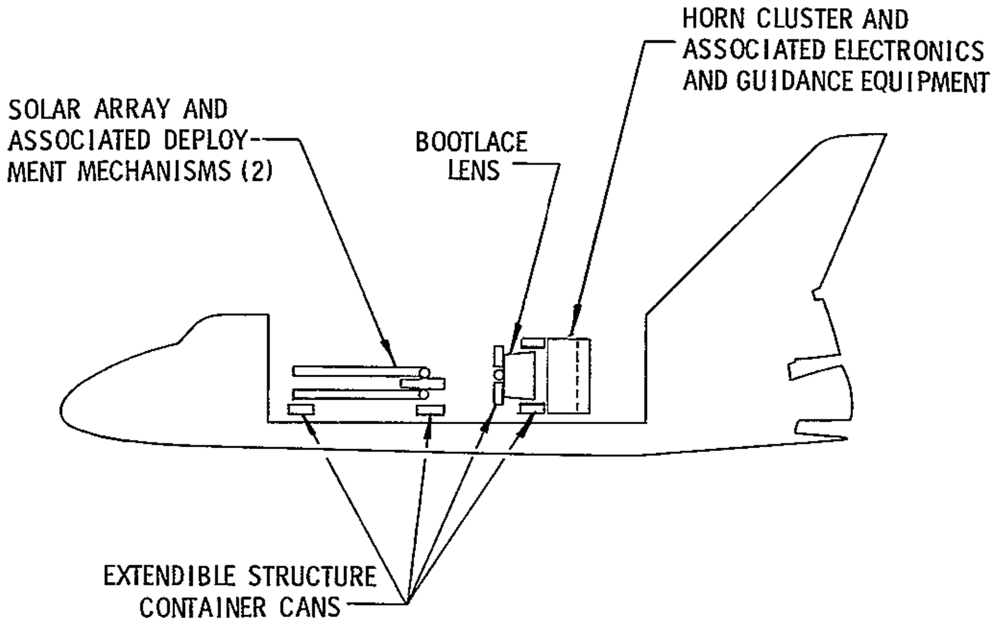

Figure 4-15. Educational TV Initiative Components Packaging

4.2.6 Ground Segment Definition

The ground segment for the Educational TV initiative has three portions:

1. The control center that operates the satellite.
2. Ground equipment used by schools for receiving the programs.
3. Equipment used by districts to broadcast the programs to the schools and interchange information within other districts.

This equipment is illustrated in Figure 4-16. The first item to be discussed is the equipment to be located in a typical school. As indicated in the link calculations of Section 4.2.1, the school receiver can consist of a 3-ft dia fixed-pointed antenna on the roof of a school building. A multichannel receiver would be fed from a diplexer, coupling anywhere from 1 to 12 TV

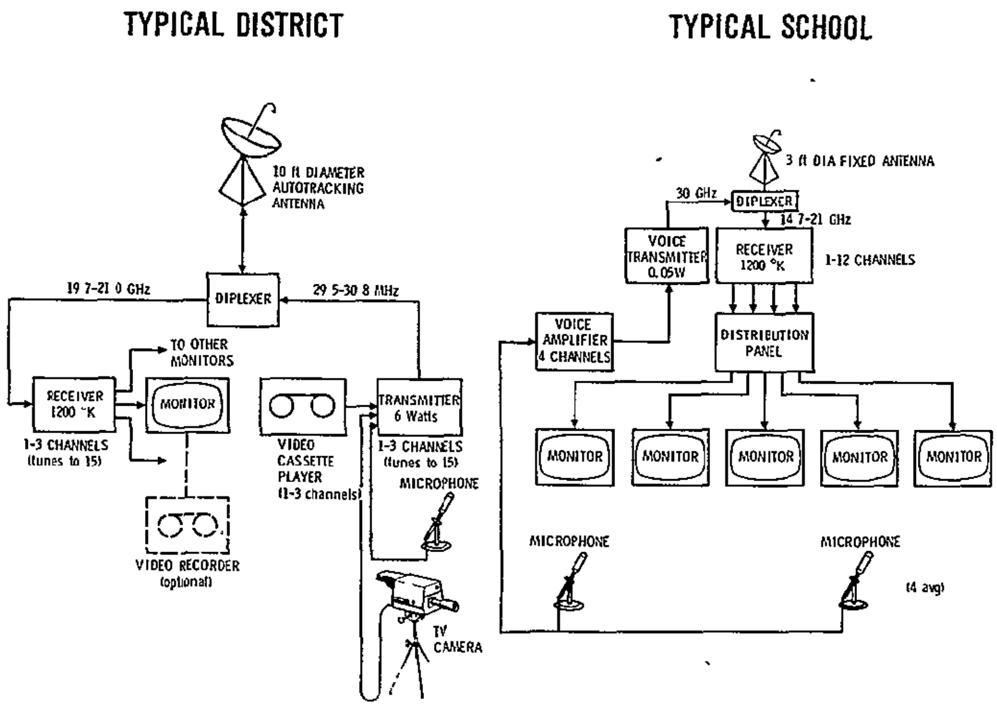

Figure 4-16. Educational TV Terminals

channels to a distribution panel, depending on the size of the school. The distribution panel would then feed individual programs to TV monitors located in the classrooms. The average school would contain 10 TV monitors. In addition, to allow for voice-interactive instruction, a 4-channel voice amplifier would be provided, feeding voice bandwidth transmissions through the diplexer to the antenna to communicate through the satellite. This voice transmitter is a low-power narrowband system, and the signals can be handled by the satellite switching network by tuning the voice transmissions to result in baseband information in the satellite just adjacent to the video information being sent to that school. Thus being switched simultaneously with the audio portions. It is envisioned that the TV monitors would be commercial TV sets with no modification whatsoever, and the only special purpose equipment would be a simple distribution panel, the receiver, diplexer, voice transmitter, and the antenna. Sixty-five thousand of these sets of equipments will have to be procured. The receiver can have a low cost front-end with noise characteristics typical of an uncooled FET diode.

A typical school district will have a two-way system with a 10-ft dia auto-tracking antenna, probably operating in the step-track mode. A diplexer feeds a receiver similar or identical to that of the schools, which connects to one or more TV monitors in the control center expected to be allocated in each School District. Video recorders are optional, allowing delayed transmission of material. Video casette players would be used to broadcast tape libraries to the schools upon request, which would feed a 6-W 30 GHz transmitter capable of broadcasting up to three channels, although tuning to any three of 15. In addition, a microphone would be available for allowing two-way audio interactive discussions in real-time, as well as coordination between districts through the audio system of the monitor and the order wire to the control center. Two-way interactive voice programs in conjunction with live TV, such as a famous professor presenting a lecture through a nationwide patch, would be handled by either patching a studio or a classroom into one of these transmitters or by packing the entire equipment into a small van and transporting it to the vicinity of the classroom. Sixteen thousand of these District terminals would be required, plus a small number of mobile or portable terminals to handle live patches.

The control center required for operating the satellite would be similar to that of the Personal Communications initiative control center, except it would not be as complex. The center would keep track of the satellites' ephemeris, command stationkeeping functions, monitor status plus health, determine servicing and maintenance flight requirements, and operate the backup equipment required to keep the satellite operating until a maintenance flight can be made. In addition, the control center would load the switching program into the satellite processor by command, maintain a channel assignment control in real-time to override the processor when needed, and bill users for the air time of their programs, if that is to be the philosophy of operation of the system. The number of hours of channel assignment to any one district is known by the satellite processor, and the operating costs of the satellite can be apportioned among the using districts in accordance with the time that they use the satellite, divided evenly among all users, or other options depending on the using agencies' intent. Although only one control station is needed in the USA, it may be desirable to have more than one for backup purposes, depending upon the chain of command.

4.2.7 Cost Estimates - Educational TV System

Cost estimates for the space-based Educational TV system are presented in this section. The procedures used in generating satellite cost estimates are based on the SCM and subsystem CERs described in Sections 3.2.7.1 and 3.2.7.2.

4.2.7.1 Educational TV Satellite Cost Estimates

The full-scale satellite for TV broadcast is preceded by a concept demonstration system. The rationale is described in Section 4.3, Development Plan. The SCM output for that satellite is reflected in Tables 4-35 and 4-36. The full-scale satellite was estimated by applying subsystem and component CERs to the weights provided by Table 4-37; the cost estimate is given in Table 4-38. The satellite cost is seen to be about $60 million, preceded by $156 million for RDT&E.

4.2.7.2 Ground Segment -- Educational TV System

The ground portion of this TV initiative consists of the antennas, receivers, transmitters, distribution panels, diplexers, casette players, TV monitors, and microphones located at the schools and districts. The cost estimates for each item of equipment, the quantity of each, and the basis for the estimates are shown in Table 4-39. In addition, yearly operations cost estimates are provided in the same table.

Table 4-35. Educational TV Concept Demonstration Satellite Cost Estimates

NC5-1-3A ED TV

* * * * ASSEMBLY DESCRIPTIONS * * * *

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	5.9	1.00	165834.	15851.	25685.	0.
303	SUN SENSOR	1	.3	.0	1.00	116150.	14519.	18541.	0.
403	NUTATION DAMPER	1	2.8	0.0	1.00	77256.	15984.	17010.	0.
603	CONTROL ELECTRNCS	1	7.4	3.5	1.00	1071594.	447818.	290184.	0.
606	EARTH SENSOR ASSY	2	4.1	1.0	1.00	397432.	153300.	216465.	156808.
1413	POWER CONVERTER	1	15.9	0.0	1.00	0.	0.	0.	0.

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
834	THRUSTER	8	.7	.1	.10	13754.	45762.	77273.	76092.

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	DIGITAL TELEMETRY	1	8.9	3.0	1.00	447801.	139061.	177581.	0.
403	CDU	1	12.3	7.5	1.00	1558932.	47819.	61065.	0.

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.5	1.00	44622.	16117.	36060.	0.
202	ANTENNA	1	8.4	0.0	1.00	349517.	137063.	75778.	0.
306	TRANSMITTER	2	2.1	10.9	1.00	152260.	47779.	139615.	60641.
401	RECEIVER	1	3.9	6.3	1.00	77256.	24775.	39973.	0.
503	COMMAND SIG COND	2	1.5	.9	1.00	20153.	30796.	41640.	6053.
603	DIPLEXER	1	3.1	1.0	1.00	57409.	15451.	21942.	0.
620	ANTENNA,10 FT	1	175.0	0.0	1.00	5084244.	1332000.	2551446.	0.
621	SWITCH UNIT	1	75.0	100.0	1.00	2730600.	2664000.	3742121.	0.

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	BATTERY	2	21.0	0.0	.10	25309.	20430.	75537.	51073.

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	53.6	1.00	621537.	91452.	233593.	0.
WIRING HARNESS	47.8	1.00	217962.	128223.	173453.	0.
THERMAL CONTROL	30.4	1.00	833632.	110992.	114082.	0.
POWER CONVERTERS	15.9	1.00	590016.	367560.	234718.	0.
PROPULSION FEED SYS	34.3	1.00	558139.	296332.	252305.	0.
STRUCTURE	232.6	1.00	1454788.	1116260.	712810.	0.
POWER CONTROL UNITS	66.6	1.00	464591.	298965.	381820.	0.
SATELLITE ADAPTER	45.7	1.00	65877.	34526.	36997.	0.

PROPELLANT WEIGHT 115.0

MISSION EQUIP WEIGHT 0.0

TOTAL SATELLITE WEIGHT 999.9

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Table 4-36. Educational TV Concept Demonstration Satellite Cost Summary

NC5-1-3A ED TV

(MILLIONS OF 1977 DOLLARS)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL DDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	2.6	1.6	4.2	0.0	1.1	1.1
THERMAL CONTROL	1.4	.2	1.6	0.0	.2	.2
ELECTRICAL POWER	3.3	1.3	4.5	.1	1.5	1.6
COMMUNICATIONS	14.5	5.9	20.4	.1	9.4	9.6
DATA HANDLING	3.4	.3	3.7	0.0	.3	.3
STABILITY AND CONTROL	3.1	.9	4.0	.3	.8	1.1
AUXILIARY PROPULSION	1.0	.5	1.4	.1	.5	.6
SPACECRAFT	29.2	10.5	39.7	.6	13.8	14.4
MISSION EQUIPMENT			0.0			0.0
SATELLITE			39.7			14.4
QUALIFICATION UNIT(S)			0.0			
GSE (AGE)			2.4			
LAUNCH SITE SUPPORT						.6
CONTRACTOR FEE			3.0			1.1
TOTAL SATELLITE			45.1			16.1
AVERAGE UNIT COST (1 SATELLITES)						16.1
TOTAL SATELLITE DDT+E AND RECURRING COST						61.2

4.2.7.3 Life-Cycle Cost

For the Educational TV system, life-cycle costs include (1) the Concept Demonstration Satellite launched into geosynchronous orbit by a Shuttle and IUS (shown in Tables 4-40 and 4-41), (2) the Technology Demonstration portion of the full-scale TV satellite launched to low orbit in a shared mode on the Shuttle (Tables 4-42 and 4-43), (3) the balance of the modules required for the full-scale TV satellite launched to low orbit on a shared Shuttle flight (Table 4-44), (4) on-orbit maintenance calculated at 8 percent of unit cost with launches on a Shuttle and IUS every other year (Tables 4-45 and 4-46), (5) mission control including \$50 million for equipment and \$7 million annual operation cost (Table 4-47), and (6) ground equipment -- acquisition and operation (Table 4-48). Total program life-cycle cost is given in Table 4-49 and is shown time-phased by fiscal years in Table 4-50. User costs by equipment, by district, school, and system are given in Table 4-51.

Table 4-37. Educational TV Satellite Weight Breakdown

	WEIGHTS (LB)	
	BASIC	W/CONTINGENCY
STRUCTURE	1990	2300
BASIC STRUCTURE	(925)	
SOLAC ARRAY ORIENTATION	(1065)	
THERMAL	200	200
ELECTRICAL POWER	3515	4040
ARRAYS	(1260)	
BATTERIES	(1510)	
POWER CONTROL	(645)	
WIRING	(100)	
ATTITUDE CONTROL	35	50
PROPULSION		
N_2H_4 THRUST SYSTEM	30	35
ION THRUST SYSTEM	80	120
PROPELLANT	805	895
MISSION EQUIPMENT		
COMPUTER	900	1035
TRANSPONDERS	200	230
FREQ GENERATORS	40	50
MASTER OSCILLATOR	20	25
ANTENNA	458	525
ANTENNA FEED	242	275
TOTAL SATELLITE		9800

Table 4-38. Educational TV Satellite Cost Estimate

	(THOUSANDS OF 1977 DOLLARS)	
	DDT&E	UNIT
STRUCTURE	30250	8460
THERMAL	4490	543
ELECTRICAL POWER	32250	16537
ATTITUDE CONTROL	6605	1615
N_2H_4 SYSTEM	1525	536
ION SYSTEM	4140	1794
COMPUTER	23968	7888
TRANSPONDERS	3852	1592
FREQ. GENERATORS	3752	2313
MASTER OSCILLATOR	2989	725
ANTENNA	16860	2657
ANTENNA FEED	7250	10267
SUBTOTAL	137931	54927
TOTAL (INCL. GSE, LAUNCH OPS SUPPORT, AND FEE)	155862	60420

Table 4-39. Educational TV System Ground Equipment Cost Estimate (Satellite-Based Alternative)

ITEM-EQUIPMENT	QTY	UNIT COST	TOTAL ($ 000's)	BASIS OF ESTIMATE
ANTENNA, DISTRICT - 10 ft	16000	5500	88000	REF 2 + $1000 FOR INCREASE TO 30 GHz
ANTENNA, SCHOOL - 3 ft	65000	880	57200	REF 2
RECEIVER, DISTRICT-2 chnl	32000	550	17600	REF. 2 + $90/CHANNEL FOR INCREASE TO 30 GHz
RECEIVER, SCHOOL - 3 1/2 chnl.	227500	500	113750	REF. 2 + $90/CHANNEL FOR INCREASE TO 30 GHz + QTY EFFECT
TRANSMITTER, DISTRICT - 1 1/2 chnl	23500	12300	289050	REF. 2
TRANSMITTER, SCHOOL - 1 chnl	65000	175	11375	ESTIMATE
DISTRIBUTION PANEL	65000	600	39000	REF. 4
CABLES & INSTALL	65000	720	46800	REF 4
CABLING (DISTRICT)	16000	100	1600	REF 4
CASSETTE (PLAYER/RECORDER)	81000	1000	81000	OFF-THE-SHELF
TV MONITORS, DISTRICT (2 EA) (INCL. MICROPHONES)	32000	500	16000	OFF-THE-SHELF
TV MONITORS, SCHOOL (12 EA) (INCL MICROPHONES)	780000	400	312000	OFF-THE-SHELF
TOTAL GROUND EQUIP.			1073375	

OPERATIONS & MAINT/yr	BASE	UNIT OR %	YEARLY AMOUNT ($ 000's)	
ANTENNAS	145200	5%	7260	
TV & CASSETTE EQUIP	409000	10%	40900	
ELECTRONICS EQUIP.	519175	7%	36342	
POWER	1063500 kW	$10/kW/yr	10635	BASED ON 4 hr OPERATION PER DAY, 200 days/yr
	94137	10%	9514	
TOTAL GRD EQUIP OPS & MAINT/yr			104651	

Table 4-40. Educational TV (Concept Demo) Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	308	308	TYPE,	ENDO	1 000	1 000	7	2		7	2		9
ELECTRICAL POWER	225	225	WATTS,	430.	1.000	1.000	5	1		5	1		6
TRACKING,COMMAND	298	298	ALT,	SYNC	1 000	1 000	27	11		27	11		38
STABILITY,CONTROL	20	20	TYPE,	3-AXIS	1 000	1 000	4	1		4	1		5
PROPULSION	34	149	TOT IMP(L)0		1 000	1 000	2	1		2	1		3
SPACECRAFT	835	1000					45	16		45	16		61
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000							
SATELLITE	885	1000					45	16		45	16		61
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										45	16		61

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT		1.00																		
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)		1																		1

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE				11	25	9																		
INVESTMENT				4	9	3																		
OPERATIONS																								
LOSSES																								
TOTAL				15	34	12																		

Table 4-41. Educational TV (Concept Demo) Launched from ETR Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars)

FISCAL YEAR	PAYLOAD TRAFFIC N	R	M	D	LAUNCH VEHICLE TRAFFIC A IUS	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																	6			6	6
1981												11	4			15	8			8	23
1982												25	9			34	9			9	43
1983	1				1.0	1.0						9	3			12	2			2	14
1984																					
1985																					
1986																					
1987																					
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1				1 0	1 0						45	16			61	25			25	66

Table 4-42. Educational TV (Technical Demo) Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	1700	1700	TYPE,	ENDO	1 000	1 000	30	9		30	9		39
ELECTRICAL POWER	1200	1200	WATTS,	1500	1.000	1.000	30	8		30	8		38
TRACKING,COMMAND	800	800	ALT,	LOW ORBIT	1 000	1 000	56	10		56	10		66
STABILITY,CONTROL	50	50	TYPE,	3-AXIS	1 000	1 000	8	2		8	2		10
PROPULSION	155	250	TOT.IMP(L)0		1 000	1.000	6	3		6	3		9
SPACECRAFT	3905	4000					130	32		130	32		162
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000							
SATELLITE	3905	4000					130	32		130	32		162
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF.													
TOTAL										130	32		162

FISCAL YEAR		1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																					
SPACECRAFT						1.00															
MISSION EQUIPMENT																					
SATELLITE SCHEDULE																					
NEW EXPENDABLE	1					1															1

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE						16	56	45	13															
INVESTMENT							8	17	7															
OPERATIONS																								
LOSSES																								
TOTAL						16	64	62	20															

Table 4-43. Educational TV (Technical Demo) Launched from ETR Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars)

FISCAL YEAR	PAYLOAD TRAFFIC N	R	M	D	LAUNCH VEHICLE TRAFFIC A	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																					
1983												16				16					16
1984												56	8			64	5			5	69
1985													17			62	7			7	69
1986	1					7						13	7			20	1			1	21
1987																					
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1					7						130	32			162	13			13	175

Table 4-44. Educational TV Satellite Launched from ETR Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars)

FISCAL YEAR	PAYLOAD TRAFFIC N	R	M	D	LAUNCH VEHICLE TRAFFIC A	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																					
1983																					
1984																					
1985													7			7	2			2	9
1986												13	16			29	3			3	32
1987	1					3						13	6			19	1			1	20
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1					3						26	29			55	6			6	61

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Table 4-45. Educational TV On-Orbit Maintenance Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	TOTAL	OTHER INPUTS		COST FACTOR DEV	PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000		5			25		25
SATELLITE	0	0						5			25		25
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL											25		25

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NONREFUNDABLE)								1		1		1		1		1				5

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE																								
INVESTMENT										1	3	2	3	2	3	2	3	2	3	1				
OPERATIONS																								
LOSSES																								
TOTAL										1	3	2	3	2	3	2	3	2	3	1				

Table 4-46. Educational TV On-Orbit Maintenance Launched from ETR Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars)

FISCAL YEAR	PAYLOAD TRAFFIC N	R	M	D	LAUNCH VEHICLE TRAFFIC A IUS	B SISC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																					
1983																					
1984																					
1985																					
1986																	6			6	6
1987													1			1	8			8	9
1988													3			3	15			15	18
1989	1				1 0	1 0							2			2	10			10	12
1990													3			3	15			15	18
1991	1				1.0	1.0							2			2	10			10	12
1992													3			3	15			15	16
1993	1				1.0	1 0							2			2	10			10	12
1994													3			3	15			15	16
1995	1				1 0	1 0							2			2	10			10	12
1996													3			3	9			9	12
1997	1				1 0	1 0							1			1	2			2	3
1998																					
1999																					
2000																					
TOTAL	5				5 0	5 0							25			25	125			125	150

Table 4-47. Educational TV Mission Control Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1 000	1 000							
TRACKING, COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	50			50			50
SATELLITE	0	0					50			50			50
AGE					0 000								
LAUNCH SUPPORT						0.000		7	7			91	91
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										50		91	141

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
DESIGNS AND REDESIGNS																			
SPACECRAFT																			
MISSION EQUIPMENT																			
SATELLITE SCHEDULE																			
NEW (EXPENDABLE)																			

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE						13	27	10																
INVESTMENT																								
OPERATIONS									7	7	7	7	7	7	7	7	7	7	7	7	7			
LOSSES																								
TOTAL						13	27	10	7	7	7	7	7	7	7	7	7	7	7	7	7			

Table 4-48. Educational TV Ground Station Equipment Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1 000	1 000							
TRACKING, COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY, CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	1073			1073			1073
SATELLITE	0	0					1073			1073			1073
AGE					0 000								
LAUNCH SUPPORT						0.000		105	105			1046	1046
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										1073		1046	2119

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
DESIGNS AND REDESIGNS																			
SPACECRAFT																			
MISSION EQUIPMENT																			
SATELLITE SCHEDULE																			
NEW (EXPENDABLE)																			

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE									268	590	215													
INVESTMENT																								
OPERATIONS												105	104	105	105	104	105	105	104	105	104			
LOSSES																								
TOTAL									268	590	215	105	104	105	105	104	105	105	104	105	104			

Table 4-49. Satellite Traffic and Cost Summary Through 2000
(millions of 1977 dollars)

SATELLITE NAME	PAYLOAD TRAFFIC	LAUNCH VEHICLE TRAFFIC 1ST STAGES	IUS	TUG	PROGRAM COSTS RDTE	PAYLOAD COSTS INV	OPS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
SATELLITE-BASED INITIATIVES													
EDUCATIONAL TV SYSTEM													
ED TV (CNCPT DEMO)	1	1 0	1 0		45	16		61	25			25	86
ED TV (TECH DEMO)	1	7			130	32		162	13			13	175
EDUC TV SATELLITE	1	3			26	29		55	6			6	61
ED TV ON-ORB MAINT	5	5 0	5 0			25		25	125			125	150
ED TV MISS CONTROL					50		91	141					141
ED TV GRND STA EQ					1073		1046	2119					2119
SUBTOTAL	8	7.0	6 0		1324	102	1137	2563	169			169	2732

Table 4-50. Total Program Costs by Fiscal Year Through 2000
(millions of 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVE																							
EDUCATIONAL TV SYSTEM																							
ED TV (CNCPT DEMO)			6	23	43	14																	
ED TV (TECH DEMO)						16	69	69	21														
EDUC TV SATELLITE								9	32	20													
ED TV ON-ORB MAINT									6	9	18	12	18	12	18	12	18	12	12	3			
ED TV MISS CONTROL						13	27	10	7	7	7	7	7	7	7	7	7	7	7	7	7		
ED TV GRND STA EQ									268	590	215	105	104	105	105	104	105	105	104	105	104		
SUBTOTAL			6	23	43	43	96	88	334	626	240	124	129	124	130	123	130	124	123	115	111		

Table 4-51. Educational TV System User Cost
Satellite-Based Alternative

EQUIPMENT ACQUISITION

USER	ANTENNA	RECEIVER	TRANSMITTER	DISTR. & CABLING	TV	CASSETTE UNIT	EQUIPMENT TOTAL COST	SATELLITE COST	TOTAL COST
DISTRICT OFFICE	5500	1100	18066	100	1000	1000	26766	-	26766
SCHOOL	880	1750	175	1320	4800	1000	9925	5723	15648
SCHOOL* SYSTEM	9020	8100	18766	5380	20200	5000	66466	22892	89358

ANNUAL OPERATIONS

USER	ANTENNA	ELECTRONICS	CASSETTE & TV	PWR	G & A	SATELLITE OPS	TOTAL ANNUAL OPS COST
DISTRICT OFFICE	275	1349	200	-	182	-	2006
SCHOOL	44	227	580	164	102	371	1488
SCHOOL* SYSTEM	451	2284	2520	656	590	1484	7958

*AN AVERAGE OF 4 SCHOOLS PLUS DISTRICT OFFICE IS ASSUMED.

4.3 DEVELOPMENT PLAN

The development plan for the Educational TV satellite follows the same rationale that was advanced for the Personal Communications satellite in Section 3.3. The major features are a step-wise demonstration in which each step serves a useful purpose rather than being deadended, and in which a number of steps are chosen to make meaningful progress without pushing the technology to undue risks. The development plan chosen for this satellite appears in Figure 4-17. It is seen to consist of three steps:

1. Demonstration of the concept
2. Demonstration of the technology
3. Demonstration of the complete system and going into the operational phase.

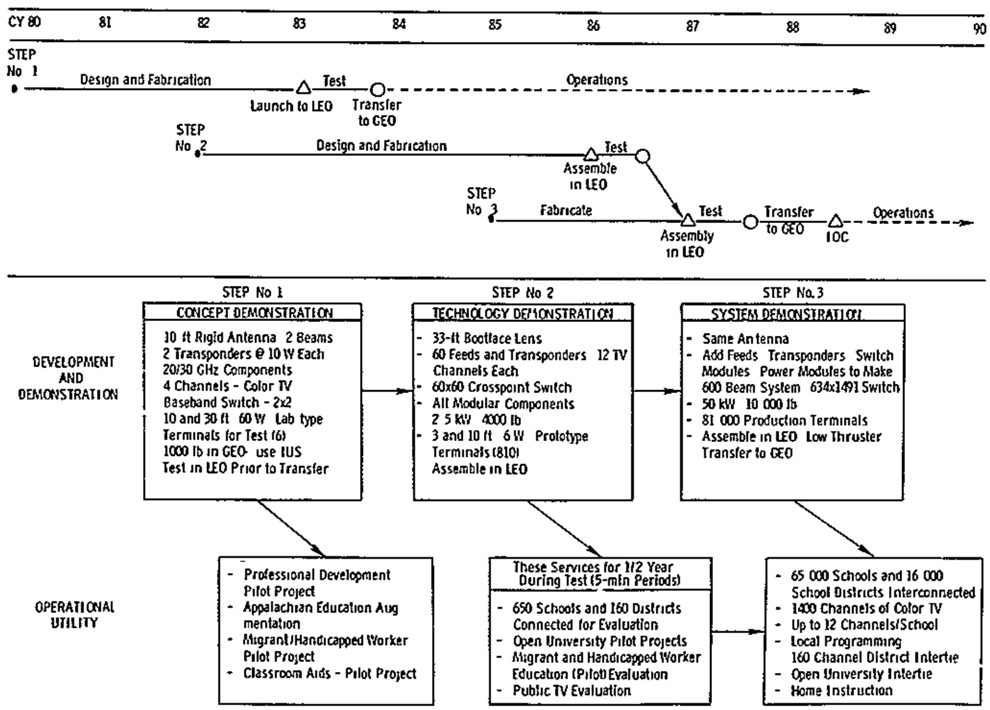

Figure 4-17. Development Plan for Educational TV Initiative

As for the Personal Communications development plan, this first step also assumes go ahead in 1980. It places into low orbit in 1983 a rigid antenna with only two beams and two feeds. Two transponders are provided for four channels of color TV, and connected through a 2 by 2 baseband switch. The components are designed to operate at 20 and 30 GHz to prove out the techniques at those frequencies. Once the satellite is found to operate well in low earth orbit it is transferred to geosynchronous using the IUS, and then can be used at least through the 1989 time period to augment pilot projects such as the Appalachian Educational Satellite Project, and to prove a number of pilot projects for classroom aids, migrant and handicapped worker education, and professional development programs that could be expected to welcome the two channels of color TV broadcast by this satellite. This demonstration would prove the concept of video baseband switching through 20 and 30 GHz transponders and the onboard switch, and would lend confidence to the next step to be discussed below.

The second step is a technology demonstration step similar to that of step 3 of the Personal Communications satellite. In this satellite, the final multibeam lens antenna would be placed in orbit, however, only a small number of modules consisting of horns, focal arrays, transponders, and power would be mated with it. The concept would demonstrate the final radiated power per transponder, the final technique for cross point switching, and all of the electronics in the multibeam lens antenna. About twelve TV channels for each of 60 feeds and transponders would be available, representing about half of the channel capacity, but only about 10 percent of the transponder complexity. A 60 by 60 crosspoint switch module would be orbited, representing about one percent of the entire capacity of the crosspoint switch. All of the components would be modular. This step is expected to weigh about 4000 lb and to consume about 2 1/2 kW.

The concept demonstration step would utilize laboratory test terminals probably in quantities of 10 or less, however, the second step would operate with prototype terminals with 3- and 10-ft antennas, procured in quantities of about 1000.

This technology demonstration step would be assembled in low orbit in 1986 and would be tested for about 6 months while in low orbit. During this time it could provide intermittent connections for augmentation of pilot projects, and demonstration of the technique among 650 schools and 160 districts implemented with prototype terminals. While transmission times would be short - in the order of 5 min or so - the concept could be evaluated by the school boards to decide whether they wished to go into full scale acquisition of the system.

Following the 6-month test the third step would be flown, which would rendezvous with the orbiting step 2 and add the rest of the feeds, transponders, switch modules, and power modules to make up the full system with a full complement of 600 beams, the required switch complexity, and DC power. Full spectral occupancy would be demonstrated and noninterference of the various beams tested. The production terminals would be manufactured and distributed, the system power level tested, and the full switching system flexibility exercised. Following successful test, the system would transfer to geostationary orbit using its own ion transfer engines, and upon arrival be retested in final orbit. The system would be placed into operation sometime between 1988 and 1989 at which time the operational capability of the first step would be dwarfed (though it need not be replaced).

The development plan components are somewhat expanded in Table 4-52 in which the goals, overall characteristics, operational use, features and characteristics of the satellite and terminals of each step are detailed. The net result is the conclusion that the Educational Television Satellite could be placed on line in a 1988 - 1989 time period if a dedicated, well funded program were begun in 1980.

Table 4-52. Development Plan for Educational TV

CY		82 – 85	86	87 – 89
STEP No. 2 DEMONSTRATE TECHNOLOGY STEP No. 3. DEMONSTRATE SYSTEM		83 △ TEST – – – 84 OPERATE – – – →	△ TEST △ ASSEMBLE ASSEMBLE	△ TEST △ TRANSFER △ IOC – – OPERATE – – →
GOALS		DEMONSTRATE BASEBAND SWITCHING 20/30 GHz COMPONENTS, USING LARGER EARTH STATIONS TEST IN LEO RETEST IN GEO	DEMONSTRATE FULL ANTENNA, 7 MODULES OF FOCAL ARRAY POWER, FINAL TECHNOLOGY EIRP ASSEMBLY TECHNIQUES TEST IN LEO WITH FULL SIZE TERMINALS	• DEMONSTRATE SYSTEM WITH FULL COMPLEMENT OF MODULES, EIRP AND SPECTRAL OCCUPANCY • ASSEMBLE IN LEO, TRANSFER TO GEO
OVERALL CHARACTERISTICS		WEIGHT 3000 lb GEO	WEIGHT 4000 lb LEO	WEIGHT 50,000 lb LEO GEO
OPERATIONAL USE		MIGRANT WORKER EDUCATION (pilot) PROFESSIONAL DEVELOPMENT (pilot) AUGMENTATION OF APPALACHIAN EDUCATION PROJECT	TESTBED FOR OTHER OPERATIONAL USES WHICH WILL BE ESTABLISHED WHEN SATELLITE FULLY ASSEMBLED	CLASSROOM INSTRUCTION AIDS PROFESSIONAL DEVELOPMENT OPEN UNIVERSITIES PUBLIC TV INTERTIE MIGRANT AND HANDICAPPED EDUCATION
SATELLITE	DESIGN/CONSTRUCTION	LABORATORY/EXPERIMENTAL PROTOTYPE RIGID/FIXED	• FINAL DESIGN MODULAR ADD-ON ASSEMBLED IN ORBIT	ADD ALL MODULES OF FINAL DESIGN
SATELLITE	ANTENNA	• RIGID REFLECTOR 30 ft DIA 2 FEEDS/BEAMS	BOOTLACE LENS 33 ft DIA DUAL FREQUENCY VARIABLE DELAY ELEMENT 60 FEEDS/BEAMS	• SAME AS LAST STEP ADD REST OF FEEDS (540) FOR TOTAL OF 600 BEAMS
SATELLITE	TRANSPONDERS	• 2 AT 10 Watts EACH 20/30 GHz DEVELOPMENTAL DEMODULATE/REMODULATE AT BASEBAND 2 TV CHANNELS EACH	10 AT 10W EACH • 20/30 GHz FINAL TECHNOLOGY 12 TV CHANNELS EACH	SAME AS LAST STEP ADD REST OF TRANSPONDERS (540) UP TO 12 TV CHANNELS EACH
SATELLITE	SWITCH	2 x 2 PORTS CROSS POINT VIDEO DEVELOPMENTAL/PROTOTYPE	60 x 60 PORTS • CROSSPOINT VIDEO FINAL/MODULAR TECHNOLOGY PROCESSOR MODULE	ADD REST OF PORTS (540) 600 x 600 PORTS TOTAL CROSS POINT VIDEO PROCESSOR ALL MODULES
SATELLITE	POWER	• 300 Watts • SOLAR CELL	1 kW SOLAR CELL MODULAR-DEPLOYABLE	ADD ALL MODULES AT FINAL DESIGN 48.5 kW 50 kW TOTAL SOLAR CELL
SATELLITE	PROPULSION/STABILIZATION	CHEMICAL ACS • IUS	CHEMICAL ACS AND SHORTTERM STATION KEEPING	ADD ION MODULES FOR TRANSFER PROPULSION AND LONG TERM STATIONKEEPING
TERMINALS	CHARACTERISTICS	LABORATORY TYPE • 2 TV CHANNELS EACH	PROTOTYPE FINAL DESIGN 1 12 TV CHANNEL EACH	PRODUCTION RUNS 1 12 CHANNELS (receive) • 1 35 CHANNELS (transmit/receive)
TERMINALS	NUMBER	4 W/30 ft ANTENNA (receive only) • 2 W/30 ft ANTENNA (transmit/receive)	650 W/3 ft (receive only) 150 W/10 ft (transmit/receive)	65,000 W/3 ft (receive only) 16,000 W/10 ft (transmit/receive)

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4.4 ALTERNATIVE CONCEPTS

A number of major options exist for distribution of the program material between school districts and their schools, and sharing of the information between school districts. The major alternatives are illustrated in Figure 4-18. Keeping in mind that the prime requirement from school district to schools is in the order of 12 TV channels maximum, this requirement can be met by establishing shortwave microwave links, coaxial cable runs, or even the physical transportation of video cassettes.

Program sharing between school districts is more difficult however, inasmuch as the great distances, combined with the requirement for 150 channels of TV, make it a very difficult problem to solve. The main alternatives for its solution appear to be a connection of the school districts via commercial comsat, with dedicated terminals at every school

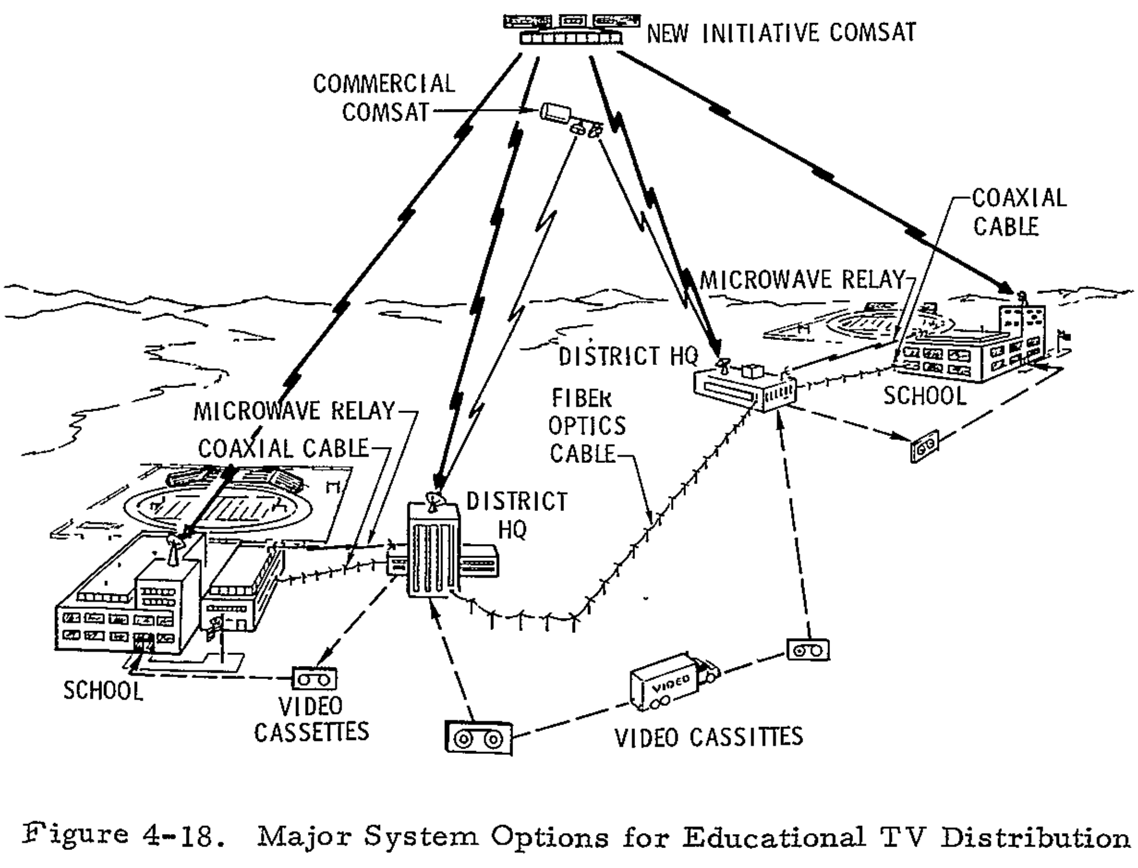

Figure 4-18. Major System Options for Educational TV Distribution

district; fiber optics cable, microwave links; buried millimeter waveguide; or the mass movement of video cassettes in a physical delivery mode.

4.4.1 Alternative Concept Selection

The commercial comsat solution appears to be very straightforward; each district would be outfitted with a 12-channel earth station using a 10-m antenna, and is estimated to cost about 1/2 million dollars each. The comsat itself would have to relay 150 TV channels. At 2 channels per average transponder, it would require 75 transponders on a full time lease basis. It is estimated that the satellite could be leased for about $50 million a year and the earth station initial cost would be $8 billion. The estimated 10-yr cost would therefore be $8-1/2 billion just for this interconnection, in addition to all the facilities required to distribute the programs to the schools. This seems like a very expensive solution, but nevertheless, will be maintained as a viable option until the costs of the other options are derived and compared.

In discussions with AT&T representatives, it was determined that the normal ground network expected to exist in the early 1990 time period will not have sufficient microwave capability to dedicate 150 TV channels to the use of the educational community. Thus dedicated capability must be provided by this system. In provision of this capability it is estimated, based on the total information base of Appendix C, that the costs of fiber optics, microwave links, or millimeter waveguide are roughly comparable on a per channel mile basis and are approximately 1/2 million dollars a mile. The estimated run length to connect 16,000 school districts in all the 48 states is a total of approximately 10,000 miles. This is derived approximately in Figure 4-19. Thus the approximate cost of the facilities for these options would be $5 billion. A more accurate derivation occurs in Section 4.4.3.

The trucking of video cassettes between the school districts to and from central library warehouses would seem to be a very attractive solution requiring no new technology or installations. For this reason a

Figure 4-19. Typical Fiber Optics Cable Run for USA Coverage

very preliminary analysis was made of the cost and nature of such a service. It was assumed that 10 warehouses would be established and dispersed throughout the country, and that trucks would pick up tapes and make a two-week round trip of the country covering 5000 miles and making about 16 stops at school districts, delivering and picking up tapes. The total number of tapes required is estimated in the following way.

Each district requires tapes to be transmitted for 5-hr program periods per day, five days a week, 200 days a year - which is 5000 tapes per year per district. However, since only about 10 percent of a district's program needs are assumed to be obtained from other districts, the actual number of tapes required per district per year is 500. This must be multiplied times about six channels per district on an average basis making a requirement for 3000 tapes per year per district, needed for every district. Since only about 10 percent of the districts are expected to exchange information at any one time, the total requirement for tapes is 3000 X 1600 or 4.8 million tapes per year. If a tape cassette costs about $10 each, and reuse of 10 percent each year is assumed - a one-time cost of $430 million is required for the circulating tapes.

The costs of trucking these tapes around is figured as follows. The 3000 tapes per district per year imply 1500 tapes per district per truckload trip. It was assumed previously that in these two weeks a truck can cover 5000 miles and make about 16 stops. Since we need about 10,000 miles driven every two weeks or so for distribution to all of the school districts we need a 200-truck fleet with each truck carrying 750 tapes. Seven hundred fifty tapes will readily fit into a large van or a small truck, including adequate space for random access. The total number of miles driven is 200 trucks X 5000 miles, divided by 2, to account for the weeks, which is 500,000 miles per week. Figuring a 40-week year this means 20 million miles per year driven. The cost of operating the vehicles themselves is estimated at 25 cents per mile and so the cost is $5 million per year. The salary of the drivers has to be figured at 400 drivers (to have the 2-1 standby ratio for sickness, breakdowns etc.), which is 400 X $25,000 salary per year or about $10 million yearly cost. The total cost of trucking is therefore $15 million per year.

In addition, 10 operation centers would be needed. These are automated warehouses for which we estimated 50,000 square feet for each, at $100.00 a square foot, or $50 million for the facilities. Assuming half of that cost for the operations, $25 million, is needed for that per year, the operating centers are therefore estimated to require a total of $500 million plus $250 million a year. In addition, information retrieval systems are required at every school district to be able to determine what programs are available and when, and to make reservations for them. A video CRT system similar to an airline reservations network connected by telephone line service is assumed, with the cost of each unit being about \$1000. Maintenance and operating costs are assumed to be another \$1000 per year per unit. These units would have to be distributed, not only to the school districts, but also to each school so that the individual teacher or educator could make program reservations. Thus the total expected cost is for 81, 000 units, which is \$80 million plus \$80 million per year.

Additional tape costs might be involved duplicating tapes for ensuring availability of popular programs. This would probably double the cost estimate of \$430 million for the tapes. The estimated total 10-yr cost is therefore, \$430 million for tapes, \$150 million for trucking, \$3000 million for facilities, and \$880 million for the information retrieval network, or a total of \$4.46 billion. This seems competitive with the other alternatives until it is realized that it is "apples and oranges" compared to the satellite or electronically linked ground alternatives. It does not provide the same service. It would take at least a week and probably two weeks to obtain a program; thus programs would have to be scheduled at least two weeks in advance. Nonavailability of tapes due to breakdowns, sickness of drivers, road accidents, inclement weather, floods, etc., would make the dependence on timely arrival of programs fairly hazardous. No real-time live capability would be provided, so that the educational network could not broadcast important national events, elections, events of historical significance, or have any regional or nation-wide broadcast capability.

For the above reasoning the trucking of video cassettes is probably not a really viable option as an equal capability alternate to the space solution. It must be borne in mind that it is easy to configure a satellite system that provides an equivalent capability to the trucking of video cassettes by simply not providing extensive switching aboard the satellite. However, it is impossible to configure a satellite with the extensive coverage of the concept described in this study that does not also have the capability for real-time broadcast at no extra cost. Thus the services provided will always be "apples and oranges". Furthermore, as will be shown in Section 4.4.3, the cost of the satellite option is about \$2.7 billion over a 10-yr period. This, however, includes all of the school equipment including the TV monitors, which are estimated to cost about \$1 billion in themselves. Thus if we add this billion to the equivalent service to be provided by video cassette trucking, including delivery of the cassettes from the school districts to the schools, optimistically assumed at no extra cost using normal school vans and drivers, the total cost of the cassette option is increased to about \$5.5 billion -- hardly a competitor, and with much poorer service.

For all these reasons the trucking of video cassettes is not analyzed further in this report, even though it is recognized that it has value and might be an interesting option under a different set of guidelines, assumptions, and ground rules.

For cost reasons alone it will turn out that the commercial comsat solution for the district-to-district links is probably non-cost competitive with fiber optic cables, as was indicated above. For this reason, the selected alternative consists of fiber optic cable with dedicated runs, connecting all the school districts together, with a total capability of 150 TV channels.

A second consideration with respect to the alternate concept is the link between a district and its schools. The major options at this point are an omnidirectional microwave broadcast, patterned after the Home Box-Office system or a system similar to the instructional television operated by USC, or use of coaxial cables to each school, much like that used for closed-circuit television distribution. Based on contacts with commercial suppliers, the estimated average cost of providing new coaxial cable runs is somewhere between \$5000 and \$10,000 a mile, making the cost for four runs from a district to its average number of schools, with an average run length of three miles each, about \$72,000 (with an assumed cost of \$6000 per mile). This is roughly comparable or cheaper than several estimates obtained for establishing four dedicated microwave links with costs ranging from $60, 000 to $180, 000 for the same capability, depending on the assumptions and the supplier. An additional consideration is that the microwave links might require an additional number of relay towers in difficult terrain or in the case of obstructions such as large buildings that might be typical of Boards of Education located in the middle of urbanized areas, whereas the cable can go around the obstructions with little increase in costs.

For all of the above reasons it was decided that the school districts should be connected to their schools via coaxial cable as the selected portion of the alternative concept.

4.4.2 Alternative Concept Definition

The selected alternate concept for the purposes of this study, based on the above arguments, is a system in which the school districts are connected to their schoold via dedicated coaxial cable runs and program material is interchanged between districts using a dedicated fiber optics cable run, as shown in Figure 4-20. The alternative concept further makes certain assumptions - the same distribution panels, monitors, two-way audio recorders and players, are used as the space alternative; and new cables are required everywhere, which are priced as part of the alternative system.

A number of other characteristics are important, particularly for the fiber optics interconnection network, which are outlined in Table 4-53. The total run length of the fiber optics cable is estimated as 10, 000 miles in the 48 states. In order to avoid switching a large number of channels at video, since each terminal only requires a maximum of 12 channels (even though the entire capacity of the network must be 150), it was elected to configure the system with 150 TV channels to each district. Thus each district terminal could be outfitted with a 150-channel optical transceiver.

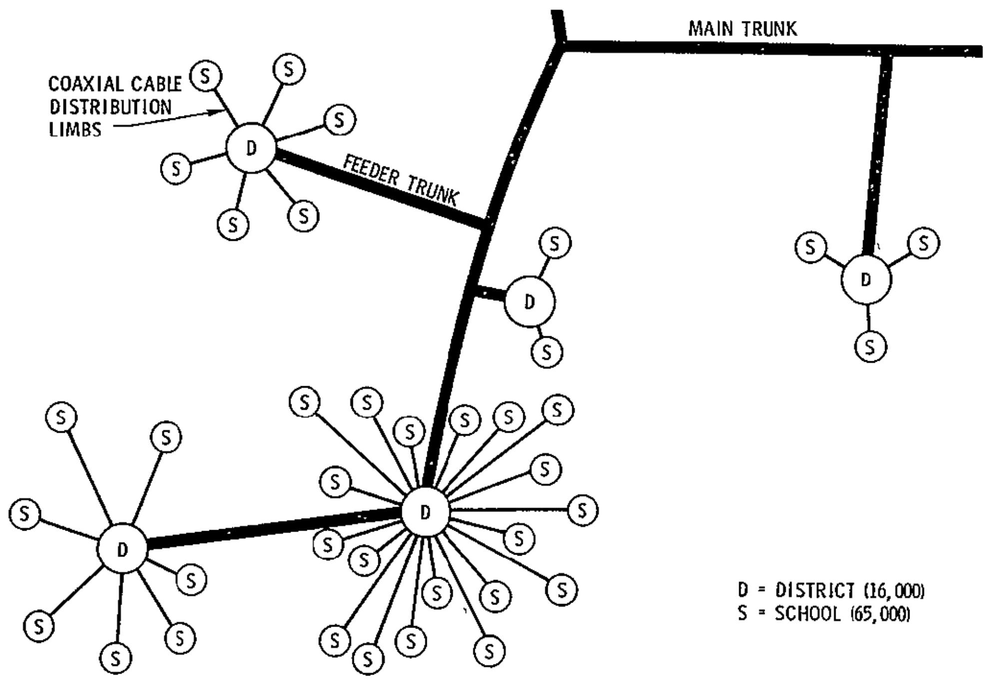

Figure 4-20. Educational TV Alternative Concept Network

Table 4-53. Alternative Concept Description - Educational TV

- USES SAME DISTRIBUTION PANELS, MONITORS, 2-WAY AUDIO RECORDERS AND PLAYERS AS SPACE ALTERNATIVE
- DISTRICTS DISTRIBUTE PROGRAMS TO THEIR SCHOOLS VIA COAXIAL CABLE
- ALL SCHOOLS REQUIRE ONE NEW CABLE TO THEIR DISTRICT
- DISTRICTS INTERCONNECTED VIA FIBER OPTICS NETWORK
  - ESTIMATED RUN LENGTH = 10,000 mi
  - 150 TV CHANNELS TO/FROM EACH TERMINAL
  - EACH DISTRICT HAS 150 CHANNEL TRANSCEIVERS
  - NO SWITCHING OF OPTICAL CHANNELS; ALL SWITCHING BY ORDER WIRE ACTIVATION OF DESIRED TRANSMITTERS AND RECEIVERS
  - TELEPHONE COMPANY DOES NOT EXPECT SUCH A COMMON USER PLANT TO EXIST IN THE TIME FRAME
  - DEDICATED FIBER OPTICS NETWORK PRICED IN SYSTEM
- COSTS OF INITIAL PROGRAM LIBRARY AND CONTINUED PROGRAMMING TREATED SEPARATELY

These transceivers are fairly simple consiting only of light emitting diodes and phototransistors. In addition, the electronics part of the transceivers would only have a maximum of 12-TV channel capacity. Thus switching of the optical channels along the cable runs of the network would be avoided, since that is an extremely expensive proposition, and all switching would be accomplished by order wire activation of the desired optical transmitters and receivers at each district terminal.

Additionally, it must be recognized that the costs to be derived for a system of this type do not include the costs of programming an initial library or continued programming for new programs as time passes. This is likely to be a very expensive part of the entire operation, however, it is common to both the space and ground alternative solutions. It is treated separately in the cost analysis to follow.

4.4.3 Alternative Concept Cost Estimate -- Educational TV

The same procedures outlined in Section 3.4.3 were used to generate cost estimates for the ground-based alternative Educational TV system. For this sytem, however, many of the same user equipment elements are required for both space and ground-based alternatives; hence the equipment shown in Table 4-54, is the same as a portion of that found in Table 4-39. Ground interconnect links of course replace the satellite, and are estimated to cost $1332 million for the coax cable links between districts and schools and $6670 million for the fiber optics cable and terminations to interconnect districts. It is assumed that district-to-school links would be an average of three miles or 195,000 total miles; each mile would require $6000 for cable and each school would require demodulation and related equipment of $2500, for a total of $20,500 per school ($20,500 X 65,000 schools equals $1332 million). The cost estimate for a fiber optics trunk is shown in Table 4-55. A 10,000-mile system was assumed for this study, hence, the $6670 million estimate.

Table 4-54. Ground Equipment Cost Estimate Educational TV System (Ground-based Alternative)

ITEM-EQUIPMENT	QTY	UNIT COST	TOTAL ($ 000's)	BASIS OF ESTIMATE
TV MONITORS, DISTRICT (2 EA) (INCL. MICROPHONES)	32000	500	16000	SAME AS SATELLITE-BASED ALTERNATIVE
TV MONITORS, SCHOOL (12 EA) (INCL. MICROPHONES)	780000	400	312000	
CASSETTE (PLAYER/RECORDER)	.81000	1000	81000	
CABLING, DISTRICT	16000	100	1600	
CABLING, SCHOOL	65000	720	46800	
DISTRIBUTION PANEL	65000	600	39000	
TOTAL EQUIPMENT			496400	
OPERATIONS & MAINT/yr	**BASE**	**UNIT OR %**	**YEARLY TOTAL ($ 000's)**	
TV AND CASSETTE EQUIP	409000	10%	40900	
OTHER ELECTRICAL	87400	7%	6118	
POWER	1006800 kW	$10/kW/yr	10068	SAME AS SATELLITE-BASED ALTERNATIVE
			57086	
G & A	57086	10%	5709	
TOTAL EQUIP OPS & MAINT/yr			62795	

Table 4-55. Fiber Optics Trunk Costs

- 150 Color TV Channels - Studio Quality
- Every Channel Distributed to Each of 16,000 Terminals
- Every Channel can be Fed From Each of 16,000 Distribution Nodes
- Network Switching Effected by Order Wire Control of Configuration of Terminals
- 50 Fiber Cable

ITEM	NUMBER	UNIT COST PER CHANNEL		INITIAL COST, MILLIONS	
		1979	1989	3000 MILES	10,000 MILES
- Head End	16,000	$1.57 K	$0.94 K	$2,260	$2,260
- Distribution End	16,000	1.43 K	0.86 K	2,060	2,060
- Installation of Nodes (Head End plus Distribution End)	16,000	0.56 K	0.33 K	790	790
- Cable		0.82 k/mi	0.33 k/mi	148	495
- Repeaters	Every 4 km	0.38 k/mi	0.15 k/mi	68	225
- Installation of Cable and Repeaters		0.56 k/mi	0.56 k/mi	252	840
TOTALS				$5,580	$6,670

Total estimated cost for the ground alternative is given in Table 4-56, and is seen to be $13.5 billion for the total RDT&E and 10 yr of operation. Time-phased costs by fiscal years is provided in Table 4-57. User costs by equipment, by district, school, and system are given in Table 4-58.

Table 4-56. Ground-Based Educational TV Cost (millions of dollars)

GROUND-BASED ALTERNATIVE TO SATELLITE INITIATIVE	Non recurring	Operating	Total
EDUCATIONAL TV SYSTEM (GROUND-BASED)			
ED TV GRD-BASED EQ	496	628	1124
ED TV TRANSMIT EQ	8002	4400	12402
SUBTOTAL	8498	5028	13526

Table 4-57. Total Program Costs by Fiscal Year Through 2000 (millions of 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
EDUCATIONAL TV SYSTEM (GROUND-BASED)																							
ED TV GRD-BASED EQ								60	213	174	49	63	63	62	63	63	63	63	62	63	63		
ED TV TRANSMIT EQ								960	3441	2801	800	440	440	440	440	440	440	440	440	440	440		
SUBTOTAL								1020	3654	2975	849	503	503	502	503	503	503	503	502	503	503		

Table 4-58. Educational TV System - User Cost (Ground-based Alternative)

EQUIPMENT ACQUISITION

USER	CASSETTE UNIT	TV	DISTR. & CABLING	EQUIPMENT TOTAL COST	INTERCONNECT LINKS	TOTAL COST
DISTRICT OFFICE	1000	1000	100	2100	416875	418975
SCHOOL	1000	4800	1320	7120	20500	27620
SCHOOL* SYSTEM	5000	20200	5380	30580	498875	529455

ANNUAL OPERATIONS

USER	CASSETTE & TV	CABLING	Pwr	G&A	INTERCONNECT LINKS	TOTAL ANNUAL OPS COST
DISTRICT OFFICE	200	7	-	21	22922	23150
SCHOOL	580	92	155	83	1127	2037
SCHOOL* SYSTEM	2520	375	620	353	27430	31298

*AVERAGE 4 SCHOOLS PLUS DISTRICT OFFICE PER SYSTEM

4.5 SPACE/GROUND COMPARISON

The space and ground alternatives as defined above are compared in this section to determine their relative merits and features.

4.5.1 Technical and Operational Comparison

The space and ground systems that were configured in Sections 4.2 through 4.4 are entirely equivalent in performance, both of them distributing the same program channel information to the same number of points in the same time with equal switching flexibility. Their cost comparison is the only meaningful attribute that could be treated in this space/ground comparison. There are additional considerations that should be addressed in future studies. Some of these are the marginal cost of adding new schools or districts to the system, the time to reestablish service following failures of satellite equipment vs. that for felled trees breaking the cables, etc. These were beyond the scope of this study, as were social considerations or environmental ones.

4.5.2 Cost Comparison

A comparison of costs to the user was performed, utilizing the costs derived in Sections 4.2.7 and 4.4.3. It was felt that meaningful measures for the user cost comparison would be the total cost per school per year, the cost per classroom hour, or the cost of per pupil hour. These costs were computed assuming six hours a day for instructional programming, five days a week, nine months out of the year and used the average number of half the classrooms outfitted, which is about 10 rooms per school for each of the 65,000 schools in the U.S. Furthermore, an average of 30 pupils per class was assumed. The resultant cost comparison is shown in Table 4-59, the first three columns of which compare these factors for the space and the ground alternative. It is seen that the space system is the least expensive by any one of the three measures in the first three columns by a factor of almost five. In order to provide a frame of

Table 4-59. User Cost Comparison - Educational TV

SYSTEM	COST PER* SCHOOL PER YEAR (DOLLARS)	COST PER CLASSROOM HOUR (DOLLARS)	COST PER PUPIL-HOUR (CENTS)	TOTAL** 20-YR COSTS (BILLIONS)	NET TOTAL ANNUAL SAVINGS COMPARED TO TEACHERS, $
SPACE INITIATIVE	4,200	0 36	1 2	2.73	7 3 BILLION
GROUND ALTERNATIVE	20,800	1.78	5.9	13.53	6 2 BILLION
TEACHERS	≈116,000	≈10 00	≈33 3	≈75.4	0

* Average of· 10 Classrooms per School Equipped for ETV; 6 Hr/Day, 5 Days/Week, 9 Mo/Yr, 30 Pupils/Classroom

** 10 Yr RDT&E, 10 Yr Operations and Maintenance; All User Equipment

reference for the order of magnitude of the costs both are compared against the average cost for an average teacher, which is probably in the order of $10 per hour without administrative burden. For the 10 classrooms in which instruction is provided simultaneously, the equivalent cost per school per year is $116, 000 as compared to $4200 for the space alternative and $20, 800 for the ground alternative.

It is thus seen that while both the space and ground alternatives are less expensive than the provision of live teachers, with the ground alternative being about five times less expensive, the space alternative is about 25 times less expensive and is by far the preferred alternative to either the current method or a ground solution.

Table 4-59 also lists the total costs to be expended on the space and ground alternatives in a 20-yr period. These include all user equipment and TV monitors, the approximately 10 yr required for research, development, test and evaluation and the 10 yr operations and maintenance, with a maintenance flight every 2 yr. The last column of Table 4-59 tabulates the net total savings in a 10-yr period of operating the space or ground alternative compared to the expenditures that would have to be made for the equivalent capability using live teachers. This column is the net in the sense that the total cost of the space or ground alternatives are taken out of the total savings prior to being shown on this table. The net savings are seen to be enormous and amount to $400, 000 per year per school district for the ground alternative and $457, 000 per year per district for the space alternative. Savings this large cannot be overlooked in planning new educational methods, facilities, and in finding funds to provide continuing educational services.

None of the costs in Table 4-59 include the costs of preparing and updating a tape library in which 90 percent of the educational TV material would be vested. The programming costs are now derived under a number of assumptions. First the production costs of an educational TV program hour run about $10, 000 on an average basis. Based on some of the references in Appendix C, this is not unreasonable since experience has shown that high quality programs average about that number. For example, "Sesame Street" runs between $25, 000 to $50, 000 per hour whereas straight documentaries cost between $5000 to $10, 000 per hour.

Second, it is assumed that an initial library of tapes will be prepared that will be good for 10 years and be so extensive as to allow a different program for every hour of a 6-hr day, 5 days per week, 9 mo per year for each of the 10 classrooms in a school, however, that 1000 districts in the U.S. share each program. Furthermore it was assumed, that all schools in a district will share programs. This means that there will be 16 different courses running simultaneously in the U.S. every hour of the day in a 9-mo year. The initial cost of the library will therefore be $1.86 billion or an equivalent one-time cost of $28, 600 per school.

It is furthermore assumed that 20 percent of such a library must be updated each year to allow for new trends in education and to allow for new material to be introduced. Thus, in addition to the $1.86 billion total, there is an expected expense of $370 million per year. The programming costs are thus equivalent to $28,600 plus $5800 per year for each school. To these costs must be added the costs of the tape cassettes for the programs, which are figured as follows. One hundred eighty six thousand tape cassettes are required in the initial library, and must be duplicated 1000 times each in order to be available for use by the classrooms that share the information simultaneously in the U.S. This means 186 million tape cassettes at an average cost of about $10,00, implying a total cost of $1.86 billion initially. The 20 percent of the library that is updated per year involves no new tape costs since the tapes are reusable. Thus the total cost per school raises the one time fixed investment to $57,200 plus $5800 per year. The total for each school would thus be $115,200 over a 10-yr period, or $11,520 per year. Since the programs are identical for every school in a district, that number multiplied by 16,000 gives a total 10-yr programming additional cost, which is $1.8 billion. The total system cost is thus shown in Table 4-60 for both alternatives for the equipment only and for the programming plus the equipment. The costs per classroom-hour including the extensive programming then rise to $0.61 for the space system and $2.04 for the ground system. It is seen that the relative comparisons, even including programming, still favor the space initiative by a very large margin. The net annual savings for 10 years compared to teachers shown in the last column of Table 4-59 would be "reduced" to "only" $4.3 billion for the space system and $5.4 billion for the ground system.

The conclusion is thus reached that even with the acquisition and distribution of a library of 375,000 one-hour programs of educational material, the cost comparison greatly favors television instruction, and within that framework, greatly favors a space solution as opposed to a ground alternative solution.

Table 4-60. Comparative Costs - Educational TV

COMPARISON BASIS	ALTERNATIVE	TOTAL 20-YR COSTS, DOLLARS	
		EQUIPMENT ONLY	PROGRAMMING PLUS EQUIPMENT
TOTAL COSTS	Space	2.73 B	4 57 B
	Ground	13.53 B	15.37 B
COSTS PER SCHOOL PER YEAR	Space	4,200	7,000
	Ground	20,800	23,600
COSTS PER CLASSROOM-HOUR	Space	0.36	0 61
	Ground	1 78	2 04
COSTS PER PUPIL-HOUR	Space	0.012	0 02
	Ground	0.06	0 07

5. ELECTRONIC MAIL INITIATIVE

This section of the study addresses the definition of a system to replace or augment physical handling of mail. The requirements are defined here and the concept definition proceeds to those requirements. Development plans are defined as well as alternate concepts performed on the ground to the same requirements as the space system. Finally the space and ground systems are compared.

5.1 ASSUMPTIONS AND GROUND RULES

A number of major assumptions were made to limit the scope of the investigation. The first assumption is that communications would flow direct from building to building through a satellite with no intermediate nodes. This assumption is fundamental and was adopted for a number of reasons. First, a recent RCA study for the U.S. Postal Service has investigated an electronic mail service system which exchanges mail electronically between regional major post offices centers, and thus there would be no sense in repeating a study of a system with ground nodes and mail carrier delivery of mail. Second, the principle being explored in this study focuses around the provision of many small, inexpensive terminals to the users, and pays the price of a large complex satellite to make a favorably economic trade off. Last, a system in which mail flows directly through a satellite can be readily scaled to obtain the characteristics of a far larger or smaller number of users by simply expanding or shrinking the mail volume handled, whereas that is not easily done in a multiple nodal system.

A second major assumption is that the only mail classes that will be covered will be those exchanging mail between government and business sectors of the total mail flow. That is, the home market would not be penetrated. The reason for this is partly practical and partly political. The government portion of the mail stream is well defined and an argument can be made for governmental efficiency if it should be possible to reduce the costs to the government of sending letters. The argument for reducing the cost to the homeowner is not so easily made in that the cost savings is not directly fed back to the cost of running the government. Furthermore, the government and business portions of the mail flow represent a relatively small fraction of the total mail flow and thus should any impact be made on the need for postal workers it would be a smaller impact than that from replacing the entire mail flow with electronic means. Keeping in mind that thePostal Service is the single largest employer in the U.S. with over 750,000 employees, the social impact of displacing those jobs by an Electronic Mail system is fraught with political problems. It is for these two reasons, primarily, that the only mail classes that will be covered in this study are mail flow from government to government, from government to business, business to government, and business to business.

Whereas the classes of mail are limited, the services will not be. Local as well as long distance mail is to be handled with a capacity equivalent to the needs of any individual element of government or business. Further assumptions are that each major complex of industrial buildings and each major government building is to have its own terminal. The internal distribution of mail within the buildings of the corporate complex would be the responsibility of the corporation (with its internal mail system as is being currently done). Likewise, the internal mail system of each governmental building would be retained. A further assumption is made that the time period of interest is in the late 1980s to the early 1990s. These assumptions are summarized in Table 5-1.

5.1.1 Definition of Requirements

The first part of the requirements is to define the mail volume that is to be handled, and its distribution. To this end the distribution of

Table 5-1. Electronic Mail - Assumptions and Ground Rules

- MAIL CLASSES COVERED - GOVERNMENT-GOVERNMENT
  - GOVERNMENT-BUSINESS
  - BUSINESS-GOVERNMENT
  - BUSINESS-BUSINESS
- COMMUNICATIONS DIRECT FROM BUILDING-TO-BUILDING THROUGH SATELLITE. NO INTERMEDIATE NODES
- LOCAL AS WELL AS LONG-DISTANCE MAIL
- ONE TERMINAL FOR EACH BUSINESS, AND FOR EACH GOVERNMENT BUILDING COVERED. INTERNAL DISTRIBUTION WITHIN CORPORATIONS NOT TREATED
- TIME PERIOD - 1990

the expected or forecast mail flow for the 1990 time period was obtained from the U.S. Postal Service. This forecast is shown in Figure 5-1. In this figure it is seen that the forecast runs between 66 to 120 billion pieces of mail to be handled in 1990. Of that, the first class mail stream is the one most subject to electronic mail handling, which is 41 to 75 billion pieces of mail. Within the first class stream the business and government sector is projected to run between 9 to 17 billion pieces of mail per year. A requirement was set for this study to handle 15 billion pieces of mail in the year 1990.

A number of other statistics were obtained from the Postal Service that are indispensable in defining the system concept. In the current post office system 40 percent of all the mail generated stays within a 2-hr driving radius of the Sectional Centers of which there are 527. Thirty percent of all the mail originated in a post office's jurisdiction stays within that area. A further set of assumptions made is that the number of businesses or therefore business terminals per city is roughly proportional to the population of that city. This assumption was necessary in order to determine the distribution of the terminals in the country. A similar

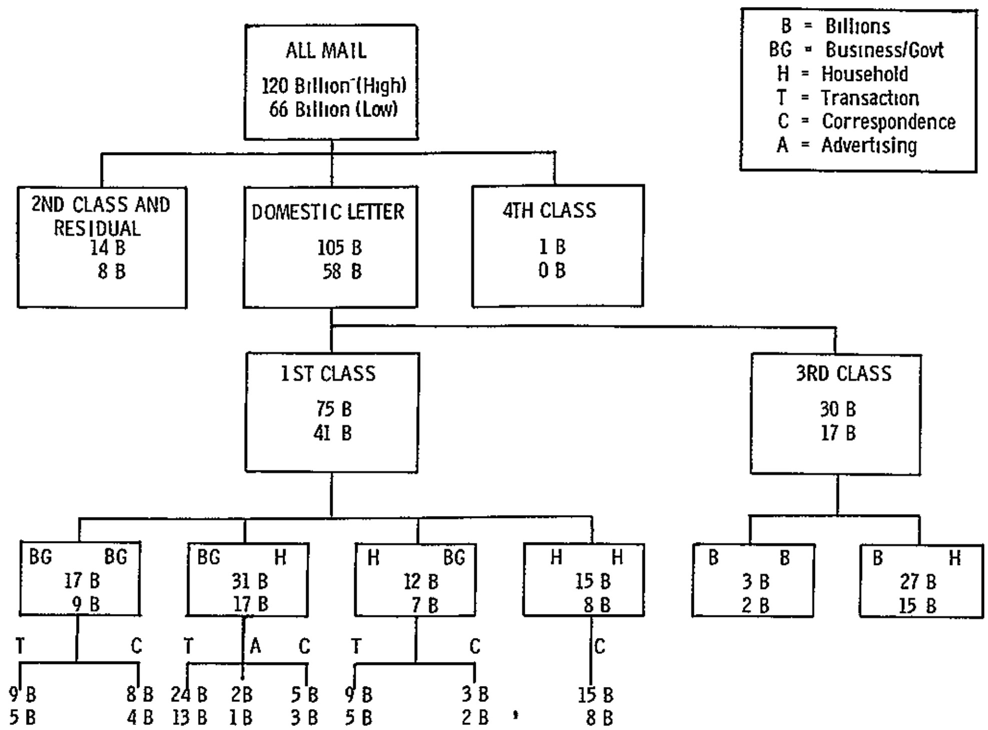

Figure 5-1. Composite Mail Flow Forecast - 1990

assumption also made is that the volume of mail handled by a business is roughly proportional to its size as measured by its sales volume. Correspondingly the mail volume handled by a government office is roughly proportional to the number of people employed by that office, and therefore to its size.

A last assumption made was that if a corporation had a number of major complexes throughout the country, each complex consisting of a set of buildings, one terminal would be provided for each major complex of buildings, the distribution between buildings of that complex being the responsibility of that corporation. A further assumption was that it was desirable to be able to handle any kind of matter from printed letters to digital tape to graphics. The definition of requirements for businesses was tackled first.

A review was made of the number of businesses as a function of their size. This distribution is shown in Table 5-2. It is seen that whereas the largest number of businesses are in the very small income class, that the bulk of the income or sales is generated by businesses with an income of a million dollara a year or more. Furthermore, that by far the lion's share of the income is generated by corporations at the million dollar level or more. This fact is summarized in Table 5-3, which supports the first conclusion that corporations alone should be considered in this study for outfitting with terminals for electronic mail.

The distribution of corporations by size, and the conversion of that distribution into the number of terminals requiring given data rate terminals to handle the volume of letters expected, will be derived following a discussion of the number of bits required to describe an average mail piece. It is well known that graphics reproduced by facsimilie require a far greater data rate than that described as printed text; and that requires far more data than the digital content of the letters themselves once the

Table 5-2. Business Distribution by Sales

Income Size Class, $/Yr	Number of Businesses			Total Income, Billions		
	Proprietorships	Partnerships	Corporations	Proprietorships	Partnerships	Corporations
< 25,000	8,007,000	537,000	466,000	48.8	3.9	2.2
25,000-49,999	1,171,000	136,000	185,000	41.7	4.9	5 2
50,000-99,000	800,000	134,000	250,000	56.0	9 5	16.1
100,000-199,999	432,000	114,000	613,000	59.4	16.2	138.5
200,000-499,000	193,000	80,000	613,000	55.7	24.4	138.5
500,000-999,999	32,000	22,000	166,000	21.6	15.3	111.8
1,000,000 or more	14,000	16,000	225,000	28.2	47.6	2,087.4

Table 5-3. Makeup of Business

TYPE	GROSS RECEIPTS (SIZE)	NUMBER
CORPORATIONS	2560 MILLION	1,900,000
PARTNERSHIPS	124 MILLION	1,040,000
PROPRIETORSHIPS	311 MILLION	10,650,000
TOTAL	2,993,000,000	13,590,000

blank spaces are removed. The number of bits per average mail piece is shown in Table 5-4, which was obtained from a publication by the Department of Commerce (Refs. 13 through 15).

Table 5-4. Bits per Average Mail Piece

Mail Piece Type	% of Total Mail	Bits/Mail Piece	Bits Per Average Mail Piece
• Typed or Printed Text of Letters and Documents	45	50,000	22,500
• Direct Digital Text of Letters and Documents	45	2,000	900
• Graphics			
/ Two Gray Scale Images	6	500,000	30,000
/ 64 Gray Scale Images	3	4,380,000	131,400
/ Color Images	1	8,750,000	87,500
		Total =	272,300 bits
		Total, allowing x 1.5 for TDMA packet overhead =	405,000 bits

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It is seen that whereas the graphics require the lion's share of the number of bits, their percentage of the total mail is small and so the average bits per average mail piece are shown as 272,300. Allowing a factor of 1-1/2 for address, destination, locations, and other identifying codes as well as perhaps some error correction, 405,000 bits will be used in this study to describe the information content in the average mail piece.

The business mail is then analyzed as shown in Table 5-5. In this table the variable is the class of corporations as distributed by their asset size. Asset was used as a more reliable indicator size of corporation rather than sales. This data came from the Forbes 500 Listings. One hundred thirty one thousand corporations exist today with assets over $1 million. Their distribution is also shown in Table 5-5. The total assets represented are just under $4 trillion and the percentage of the total assets are shown in the fourth column of Table 5-5 for each size class of corporation. The yearly mail volume that was assumed for the corporations was two thirds of the total mail volume - the total being 15 billion pieces of mail - the corporations were assigned a 10-billion mail volume per year. The distribution of that in proportion to the percentage of assets is then shown in the fifth column of Table 5-5. The yearly mail volume per corporation is then derived and converted to the number of letters per second per corporation. A further division is made to derive the number

Table 5-5. Business Mail

ASSET SIZE CLASS	NUMBER OF CORPORATIONS	TOTAL ASSETS	PERCENT OF ASSETS	YEARLY MAIL VOLUME, ALL CORPORATIONS	YEARLY MAIL VOLUME PER CORPORATION	LETTERS/SEC/CORPORATION	NUMBER OF MAJOR COMPLEXES PER CORPORATION (1 Terminal each)	LETTERS/SEC/TERMINAL	DATA RATE/TERMINAL (bps)	NUMBER OF TERMINALS
1 - 10M	108,000	0.54 trillion	0.14	1.4 billion	12 962	0.0012	1	0.0012	436	108,000
10 - 25M	11,700	0.2	0.05	0.5	42,700	0.004	1.5	0.0027	1 090	17 550
25 - 50M	5 000	0.19	0.05	0.5	100 000	0.009	2	0.0045	1 820	10 000
50 - 100M	2 800	0.21	0.05	0.5	178 000	0.016	3	0.0053	2 150	8,400
100 - 250M	1 900	0.32	0.08	0.8	421 000	0.039	5	0.0078	3,160	9 500
250M - 1B	1 100	0.55	0.14	1.4	1,270,000	0.118	10	0.012	4,860	11 000
1 - 2.5B	319	0.49	0.13	1.2	3 760 000	0.35	15	0.023	9 300	4 785
2.5 - 5B	103	0.39	0.10	1.0	9 700 000	0.69	20	0.04	17 820	2,060
5 - 10B	42	0.30	0.08	0.8	19 000 000	1.7	30	0.057	23,065	1,260
10 - 25B	21	0.35	0.09	0.9	42,900 000	3.9	50	0.078	31 600	1 050
25 - 100B	10	0.42	0.11	1.0	100 000 000	9.2	100	0.092	37 300	1 000
TOTAL	131,000	3.9 trillion	1	10 billion (corporations only)						174,000

COLLECTED RESULTS	
DATA RATE SIZE CLASS (kbps)	NUMBER OF TERMINALS
<1	108,000
1 - 3	35 900
3 - 10	25 200
10 - 40	5 370

of letters per second per terminal that have to be handled by estimating the number of major complexes owned by each corporation size class, which varies from one, in the $1 to $10 million class, to between 50 to 100 for the largest corporations in the United States. Thus the letters per second per terminal could be obtained and are shown in the ninth column. Multiplying by the 405, 000 bits per average mail piece, the average data rate handled by each terminal is then shown in the tenth column and is seen to vary between 486 bps for the smallest corporations to over 37, 300 bps for the largest corporation. The total number of terminals is also summarized in the eleventh column and is seen to be 174, 000 terminals. The collection of the results from the last two columns is shown in the box on the right in which 108, 000 terminals are seen to be satisfied with a terminal capable of sending and receiving at less than 1 kbps average, 35, 900 terminals would require a terminal data rate of 1 to 3 kbps, 25, 200 terminals would require a data rate terminal between 3 to 10 kbps, and only 5370 terminals would require terminal bit rate capacity between 10 to 40 kbps.

A last observation is that the corporations with over a million dollars in assets are mostly located near population centers with more than 25, 000 people. There are 846 towns and cities in the U.S. whose population exceeds 25, 000, as determined in Section 3. 1, and thus at least the locations of the required coverage are determined. It further appears that most of the corporations of such size are also located within about 25 miles of the center of these population regions as was determined in Section 4. 1. Thus, it appears that the required coverage for the Electronic Mail system is very similar to that of the Educational Television system, namely 846 separate coverage areas about 50 miles diameter each.

The number of terminals determined in Table 5-5 is shown distributed by city size class and by data rate of the terminal in Table 5-6. This distribution is divided by the number of cities, or number of beams, and shown as a number of terminals in each city or each beam in each data rate calss, in Table 5-7. In order for this information to be utilized it

Table 5-6. Number of Business Terminals

CITY SIZE CLASS	CITIES (Beams)	POPULATION FRACTION	No. TERMINALS - BUSINESS			
			<1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
>1,000,000	6	0.11	11,880	3,950	2,770	590
500,000-1,000,000	20	0.18	19,440	6,420	4,540	966
250,000-500,000	30	0 13	14,040	4,667	3,276	699
100,000-250,000	97	0 17	18,360	6,100	4,280	910
50,000-100,000	232	0 2	21,600	7,180	5,040	1,070
25,000-50,000	455	0 2	21,600	7,180	5,040	1,070
TOTALS	846	1	106,920	35,500	25,000	5,300
TOTAL No TERMINALS					172,725	

Table 5-7. Number of Terminals per Beam (City) - Business Mail

CITY SIZE CLASS	CITIES (Beams)	No. TERMINALS/BEAM			
		<1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
>1,000,000	6	1980	658	461	98
500,000-1,000,000	20	972	323	226	48
250,000-500,000	30	468	155	109	23
100,000-250,000	97	189	63	44	10
50,000-100,000	232	93	30	22	5
25,000-50,000	455	47	16	11	2
TOTALS	846				

must be added to the number of terminals per beam for the transmission of government mail. These numbers are now derived.

The number of government mail buildings required is derived in a sequence of tables beginning with Table 5-8. In this table the total yearly government mail volume, which was estimated at five billion average mail pieces, it is shown distributed by the building class defined as the size of the building determined by the number of people working in it. These are estimated by the first category at being 5 to 25 people all the way to over 1000 people per building. The number of buildings total is 370,000, as determined from References 16, 17. This includes all owned real property as well as leased office space and leased buildings throughout the United States. It does not include military installations overseas.

Table 5-8. Government Mail Buildings

BUILDING CLASS	FRACTION (ASSUMED)	NUMBER OF BUILDINGS	TOTAL NO. PEOPLE EMPLOYED	FRACTION OF MAIL VOLUME	YEARLY MAIL VOLUME, TOTAL	YEARLY MAIL VOLUME/ BUILDING	DAILY MAIL VOLUME/ BUILDING*	DATA RATE** BPS/BUILDING
5-25 (Ave = 10)	0.348	128,000	1.28 M	0 06	300 M	2,343	11 7	130
26-100 (Ave = 70)	0 6	222,000	15 5 M	0.7	3500 M	15,700	78.5	872
101-500 (Ave = 250)	0 05	19,000	4 75 M	0 22	1100 M	58,000	290	3,000
501-1000 (Ave = 750)	0.001	370	0.277 M	0 013	65 M	176,000	880	9,800
>1000 (Ave = 1500)	0.0005	185	0.277 M	0 013	65 M	350,000	1750	19,400
TOTALS	1	370,000	22 M	1	5 BILLION	-	-	-

*200 days/yr

**10 hr/day

The fraction of the total buildings in each building size class was assumed, there being no data that could be located on this parameter.

The third column of Table 5-8 then lists the total number of people employed in each building size class. The fraction of the mail volume was then derived by normalizing that number. This was the basic function entering the work: that the mail volume would be proportional to the number of people in each building. The yearly total mail volume for each size class of building was then derived and shown in column 6. Divided by the 200 days per year, column 7 shows the daily mail volume per building, which is seen to be an average of about 11 letters per day for the smallest building and 1750 letters per day for the largest building. This data was then converted to the equivalent data rate per building in bits per second using the previously derived number for the bits per average mail piece of 405, 000 and a 10-hr operating day, divided as 5 hr for transmission and 5 hr for reception. It is seen by this last column that the smallest buildings require only 130 bps transmission and receiving system, whereas even the largest of the buildings require less than a 20-kbps terminal.

In order to put this data into the same form for government mail that was derived for the business mail, Tables 5-9, 5-10, and 5-11 were prepared utilizing the data just derived in Table 5-8 as a distribution of building size class with each city size class, so that the total number of terminals of a given data rate in each city may be shown. The significant numbers are contained in columns 8 and 9. The information from these two columns is then transferred to Table 5-12 as the number of buildings or terminals in each size class per city that can be accommodated with a data rate of less than 1 kbps, which is shown in the second column in each city size class; the number of buildings that can be accommodated with a data rate of 1 to 3 kbps, which is shown in the third column, and the number of buildings from 3 to 10 and 10 to 40 kbps, which are shown in the fourth and fifth columns. This data appears in Table 5-12 as the number of terminals per city in each data rate class for each city size class. As expected the overwhelming number of terminals requires a data rate of less than 1 kbps.

Table 5-9. Government Mail

CITY SIZE CLASS	NO CITIES	POPULATION FRACTION	NO BUILDINGS	NO BUILDINGS PER CITY	BUILDING SIZE CLASS	FRACTION OF BUILDINGS IN SIZE CLASS (PER CITY)	NUMBER OF BUILDINGS IN SIZE CLASS (PER CITY)	DATA RATE BPS/BUILDING	DATA RATE PER CITY
>1,000,000	6	0 11	40,700	6783	5-25	0 348	2360	130	307,000
					26-100	0 6	4069	870	3 54 M
					101-500	0 05	339	3000	1 02 M
					501-1000	0 001	7	9800	68,600
					>1000	0 0005	3	19400	58,200
					TOTALS	1	6783	-	5 Mbps
500,000 - 1,000,000	20	0 18	66,600	3300	5-25	0 348	1148	130	150,000
					26-100	0 6	1980	870	1 72 M
					101-500	0 05	165	3000	500,000
					501-1000	0 001	4	9800	40,000
					>1000	0 0005	2	19400	38,800
					TOTALS	1	3300	-	2 45 Mbps

Table 5-10. Government Mail

CITY SIZE CLASS	NO CITIES	POPULATION FRACTION	NO BUILDINGS	NO BUILDINGS PER CITY	BUILDING SIZE CLASS	FRACTION OF BUILDINGS IN SIZE CLASS (PER CITY)	NUMBER OF BUILDINGS IN SIZE CLASS (PER CITY)	DATA RATE BPS/BUILDING	DATA RATE PER CITY
250,000 - 500,000	30	0 13	48,000	1603	5-25	0 348	557	130	72,400
					26-100	0 6	961	870	836,000
					101-500	0 05	80	3000	240,000
					501-1000	0 001	2	9800	19,600
					>1000	0 0005	1	19400	19,400
					TOTAL	1	1603	-	1 18 Mbps
100,000 - 250,000	97	0 17	62,900	648	5-25	0 348	225	130	29,200
					26-100	0 6	388	870	337,000
					101-500	0 05	32	3000	96,000
					501-1000	0 001	1	9800	9,800
					>1000	0 0005	-	19400	-
					TOTAL	1		-	472,000 bps

Table 5-11. Government Mail

CITY SIZE CLASS	NO CITIES	POPULATION FRACTION	NO BUILDINGS	NO. BUILDINGS PER CITY	BUILDING SIZE CLASS	FRACTION OF BUILDINGS IN SIZE CLASS (PER CITY)	NUMBER OF BUILDINGS IN SIZE CLASS (PER CITY)	DATA RATE BPS/BUILDING	DATA RATE PER CITY
50,000 - 100,000	232	0 2	74,000	318	5-25	0 348	110	130	14,400
					26-100	0 6	190	870	166,000
					101-500	0 05	16	3000	47,700
					501-1000	0 001	-	9800	-
					>1000	0 0005	-	19400	-
					TOTAL	1	318	-	228,100 bps
25,000 - 50,000	455	0 2	74,000	162	5-25	0 348	56	130	7,328
					26-100	0 6	97	870	84,500
					101-500	0 05	8	3000	24,300
					501-1000	0 001	-	9800	-
					>1000	0 005	-	19400	-
					TOTAL	1	162	-	116,000 bps

Table 5-12. Number of Government Mail Terminals

CITY SIZE CLASS	NO. CITIES	NO. TERMINALS/CITY IN EACH DATA RATE CLASS			
		1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
> 1,000,000	6	6,430	339	7	3
500,000 - 1,000,000	20	3,128	165	4	2
250,000 - 500,000	30	1,518	80	2	1
100,000 - 200,000	97	613	32	1	-
50,000 - 100,000	232	300	16	-	-
25,000 - 50,000	455	153	8	-	-
TOTALS	846	345,400	18,200	280	88
TOTAL		364,000			

This table is in the identical form as the equivalent table for business mail terminals (Table 5-6). They are, therefore, combined in Table 5-13 and added to form the total number of terminals per beam or per city required for both business and government mail. This last combination is then multiplied by the number of cities or beams to form the final result displayed in Table 5-14, which summarizes the information from the previous table. It is seen that out of the total 540, 000 terminals 452, 000 require a capacity of about 1/2 kbps or less, 53, 000 require 1 to 3 kbps; 25, 000 require 3 to 10 kbps and only about 5500 require 10 to 40 kbps. The conclusion is thus reached that the Electronic Mail system, even though having a tremendous total capacity and a very large number of terminals, is not very demanding in the data rate capacity of each terminal. This is a good result, since the system is likely to be able to work with fairly small satellites and with inexpensive small terminals.

Table 5-13. Number of Business and Government Terminals

CITY SIZE CLASS	CITIES (BEAMS)	NO TERMINALS/BEAM - BUSINESS				NO TERMINALS/BEAM - GOVERNMENT				NO TERMINALS/BEAM - TOTAL			
		<1 kbps	1-3 kbps	3-10 kbps	10-40 kbps	1 kbps	1-3 kbps	3-10 kbps	10-40 kbps	<1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
>1, 000, 000	6												
500, 000 - 1, 000, 000	20	1980	658	461	98	6430	339	7	3	8410	997	468	101
250, 000 - 500, 000	30	972	323	226	48	3128	165	4	2	4100	488	230	50
100, 000 - 250, 000	97	468	155	109	23	1518	80	2	1	1986	235	111	24
50, 000 - 100, 000	232	189	63	44	10	613	32	1	-	802	95	45	10
25, 000 - 50, 000	455	93	30	22	5	300	16	-	-	393	46	22	5
TOTALS	846	47	16	11	2	153	8	-	-	200	24	11	2

Table 5-14. Summary of Requirements - Business and Government Electronic Mail

City Size Class (Population)	Number of Beams (One per City)	Number of Terminals Per Beam*			
		.5 kbps	1-3 kbps	3-10 kbps	10-40 kbps
> 1,000,000	6	8410	997	468	101
500,000-1,000,000	20	4100	488	230	50
250,000-500,000	30	1986	235	111	24
100,000-250,000	97	802	95	45	10
50,000-100,000	232	393	46	22	5
25,000-50,000	455	200	24	11	2
TOTALS	846 Beams	452,000 Terminals	53,600 Terminals	25,000 Terminals	5,360 Terminals
Total Number of Terminals = 540,000					

* Assumes 10-hr day (5 hr transmit, 5 hr receive), 250 day/year

However, some further tabular work is necessary before starting the satellite design, in order to understand the total data rate that each beam is to carry, and the total throughput of the satellite. To this end, Table 5-15 is shown in which the total data rate for each city beam is shown.

This data rate is shown in the matrix in megabits per second (Mbps). This data is then totaled for each city size class and displayed as the total beam data rate required, in Table 5-16. From this table it is seen that the most heavily loaded beam for the six largest cities requires a total beam data rate of 12 Mbps, which is not a very large number, whereas the beams that are least lightly loaded are those for the smallest cities (as expected), and their data rate is only 250 kbps. The total data rate in each city size class and a total number of terminals in each city size class are shown in Table 5-17, which indicates that the total satellite throughput is about 650 Mbps. As satellites

Table 5-15. Business and Government Mail - Data Rate Requirements Summary

CITY SIZE CLASS	NUMBER OF CITIES (beams)	DATA RATE PER CITY BEAM (Mbps)			
		<1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
>1, 000, 000	6	2. 5	2	5. 5	2. 5
500, 000 - 1, 000, 000	20	1. 2	1	2. 7	1. 25
250, 000 - 500, 000	30	0. 6	0. 47	1. 3	0. 6
100, 000 - 250, 000	97	0. 2	0. 19	0. 52	0. 25
50, 000 - 100, 000	232	0. 1	0. 09	0. 26	0. 13
25, 000 - 50, 000	455	0. 05	0. 05	0. 13	0. 05

Table 5-16. Beam Data Rate - Electronic Mail

CITY SIZE CLASS (POPULATION)	NUMBER OF CITIES (BEAMS)	TOTAL NUMBER OF TERMINALS	BEAM DATA RATE, Mbps
1, 000, 000	6	61, 400	12
500, 000 - 1, 000, 000	20	100, 600	6
250, 000 - 500, 000	30	73, 300	3
100, 000 - 250, 000	97	83, 500	1
50, 000 - 100, 000	232	95, 700	0 5
25, 000 - 50, 000	455	97, 500	0. 25

Table 5-17. Business and Government Mail - Total Data Rate Summary

City Size Class	Number of Cities (Beams)	No of Terminals (Total)/Data Rate, Total (Mbps)			
		< 1 kbps	1-3 kbps	3-10 kbps	10-40 kbps
>1,000,000	6	50,000/15	6,000/12	4,800/33	600/15
500,000 - 1,000,000	20	82,000/25	9,800/20	7,800/54	1,000/25
250,000 - 500,000	30	60,000/18	7,000/14	5,600/39	720/18
100,000 - 250,000	97	66,000/20	9,200/18	7,400/52	970/25
50,000 - 100,000	232	77,000/23	11,000/22	6,500/46	1,200/30
25,000 - 50,000	455	77,000/23	11,000/22	8,600/60	900/23
TOTALS	846	412,000/124	54,000/108	40,700/284	5,400/136
SUM TOTAL, ALL		No. Terminals -- 512,000 Data Throughput -- 652 Mbps			

go, this is not a prohibitively large throughput. For example, a current typical satellite transponder has a bandwidth of 36 MHz, and if we assume a conservative 1-bps/Hz, the 650 Mbps throughput requires only 18 transponders. Thus the total throughput of the required satellite could be handled by satellites of todays' vintage without requiring any advanced technology other than perhaps an antenna and an onboard mail sorting system.

A last table was prepared to indicate the proportion of the total data rate per beam, as well as per satellite, that is due to "local" mail, and stays within a beam; as opposed to that which requires switching from beam to beam being "long distance" mail. The ratio was taken as 30 percent based on Post Office statistics. The data rate in Mbps per beam as well as the total for each city per beam for local as well as long distance mail is then shown in the Table 5-18. This table will be utilized in defining the access rate per beam as well as the switching requirements from beam to beam.

Table 5-18. Business and Government Mail - Data Rate Summaries (Local - Long Distance)

City Size Class	Number of Cities (Beams)	Data Rate, Mbps (per Beam/Total) Local (Within Beam)	Long-Distance (Beam-to-Beam)	Total
> 1,000,000	6	3 75/22.5	8 75/52 5	12.5/75
500,000 - 1,000 000	20	1.85/37	4.31/86.2	6 15/123
250 000 - 500 000	30	0 89/26 7	2.08/62.4	2 97/89 1
100,000 - 250,000	97	0.35/34.2	0 81/78 5	1.16/112.5
50,000 - 100,000	232	0.17/39.4	0.41/95.1	0.58/134
25,000 - 50,000	455	0.08/36.4	0.2/91	0 28/127
TOTALS	846	-/196.2	-/465.7	-/660

A final summary of the number of buildings and terminals, and their locations, and the kind of information that they will have to convey is shown in Table 5-19. In addition to the information already discussed, this last table contains several entries that need a little bit of explanation, one of them being the preferred or maximum terminal cost. This was set based on considerations of break-even with current mail operations. The bit error rate for graphics and letters was derived from References 13 through 15. This system requirements specification is then used in defining the system concept.

Table 5-19. System Requirements Specification - Electronic Mail

USERS

- NUMBER - 540,000
- TYPE. BUSINESS AND GOVERNMENT ONLY
  - / ALL CORPORATIONS >1M ASSETS (131,000)
  - / ALL LARGER GOVERNMENT BUILDINGS (370 000) (OWN AND LEASED)
  - / TOTAL MAIL VOLUME = 15 BILLION/YR
- MOBILITY - FIXED
- INFORMATION - 45% TYPED/PRINTED LETTERS
  45% DIRECT DIGITAL LETTERS
  6% 2 GRAY LEVEL FACSIMILE GRAPHICS
  3% 64 GRAY LEVEL FACSIMILE GRAPHICS
  1% COLOR GRAPHICS
- USER AGGREGATION - SEE TABLES
- ANTENNA SIZE LIMIT - 3 FT
- ACCESS TIME - <1 HOUR
- USE TIME -
  10 HR/DAY (5 TRANSMIT, 5 RECEIVE)
  250 DAYS/YR
- TERMINAL LIFE - N/A
- PREFERRED OR MAXIMUM TERMINAL COST
  COMMUNICATIONS $300
  PRINTER/READER $500
- SAFETY CONSIDERATIONS - N/A

SYSTEM

- FREQUENCIES/LIMITS - TBD
- NUMBER OF BEAMS - 846
- BEAM DIAMETER 30-100 MILES
- OPERATIONAL TIME 1990
- LIFE/SERVICING - 10 YR MINIMUM
- BIT ERROR RATES - $<10^{-5}$ GRAPHICS
  - $<10^{-12}$ LETTERS
- INTERFACES - USPS
  - SBS
- CONNECTIVITY 100% - RANDOM

5.2 CONCEPT DEFINITION

The Electronic Mail concept will be defined in this section, beginning with link calculations, going through considerations of frequency selection, a description of the payload block diagram, the user access technique, and a definition of the satellite and the ground segments and of their costs. The concept to be defined is based on the requirements of Section 5.1 and is illustrated in Figure 5-2. Though the diagram shows a 3-ft fixed antenna on the roof tops of the buildings, this was an assumption or wish, and not a requirement at this point of the study. Note the coverage in beams - each about 50 miles minor access - 846 of them being centered on U.S. cities with a population exceeding 25,000 people. The total number of buildings that will be interconnected through the satellite is 540,000, with up to 8700 buildings in each area. Government and business buildings both are serviced, and all buildings communicate directly through a single satellite.

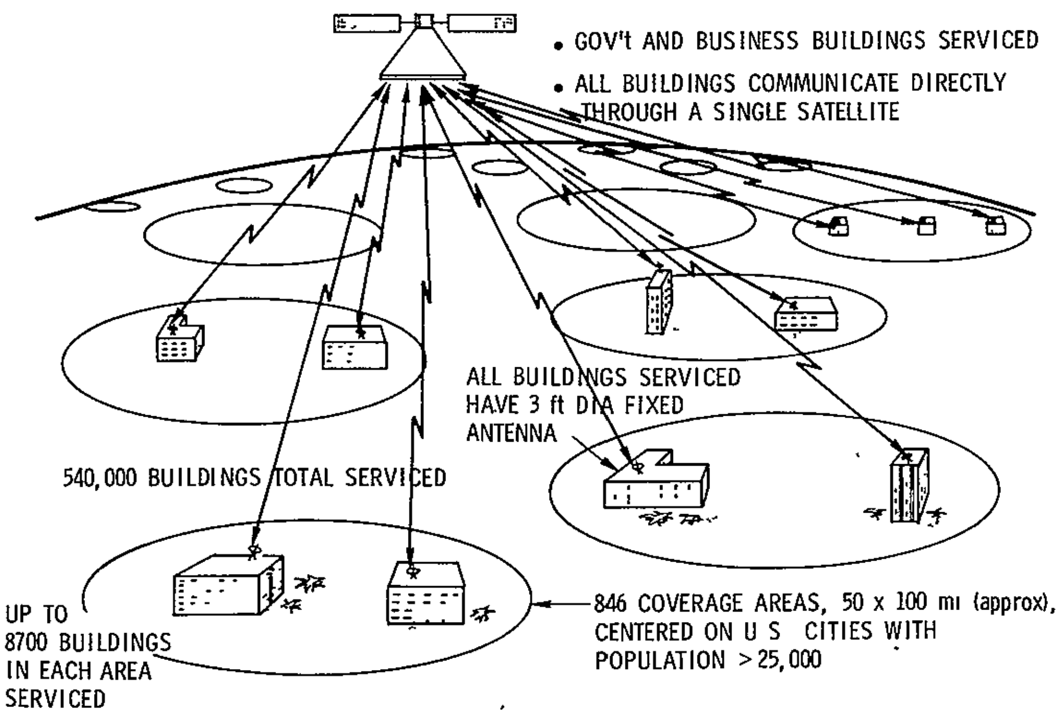

Figure 5-2. Electronic Mail Satellite Concept

5.2.1 Frequency Selection

The selection of the best operating frequency for the Electronic Mail system is fairly easy in the sense that the bandwidth requirements are not large, a total of 12 Mbits being required for the most loaded beam, with perhaps three or four times that number for all beams operating together (due to frequency reuse). Thus, less than 100 MHz total allocation is required. "Mail" delivery is not a real-time requirement. The operational concept calls for the "mail" to be exchanged with all terminals at least once a day, although preferably more often. However, if a piece of mail is late by a few hours, the service will not suffer and will still be better than the current U.S. Postal Service physical mail handling delivery schedules.

Thus it is concluded by a review of Table 5-20 that the best frequencies in which to operate are those at the 20 and 30 GHz bands, where the rain attenuation effect will simply be one of delaying mail delivery by a fraction of an hour at the cost of increasing buffer storage somewhere. The bandwidth required is readily accommodated in those bands, and there are no flux limits that need interfere. Thus, there is no reason to attempt to get allocations in lower frequency bands, which are much more congested. These considerations then lead to the 20 and 30 GHz band as being selected for the purposes of this study. While it is recognized that the system could be made to operate as well at lower frequencies, it must be borne in mind, however, that operation at a lower frequency would require a larger satellite antenna in order to maintain the roughly constant beamwidth needed for coverage, very much as in the Educational Television system. Furthermore, the maintaining of the constant beamwidth, and therefore constant gain for the satellite antenna, would require the user terminal antenna to increase directly with the decrease in frequency in order to maintain a constant link margin. All of these factors favor operation at a high frequency, high enough that allocations are no problem, and that assure interference-free operation. Since the rain attenuation will not produce unacceptable delays, there is no reason not to operate in the 20 and 30 GHz bands.

Table 5-20. Major Frequency Bands Available

FREQUENCY (GHz)	SERVICE (USA)	COMMENTS
0.62 - 0.89	TV, Satellite Mobile, Fixed	Narrow Band, Flux Limits
1.00 - 2.50	Fixed, Navigation, Mixed	Congested, Narrow
2.50 - 2.69	Broadcast Satellite, Fixed	Broadcast Only, Flux Limits
3.70 - 4.20	Fixed, Satellite Down	Commercial Comsats, Flux Limits
4.40 - 4 90	Fixed, Satellite, Mobile in ITU Reg 2 Gov, Nav, Sat in USA (under review)	Lightly Loaded
5.90 - 6.87	Fixed, Satellite	Commercial Comsats, Flux Limits
6 87 - 6.925	Possible Satellite Extension	Commercial Comsats, Flux Limits
6 925 - 7.125	Fixed + Mobile Satellite, Fixed	Congested, Mobile
7 20 - 8 40	Government Only	Congested, Military
8 40 - 8 50	Research	Use for Tests
10.95 - 11 7	Fixed, Satellite	Commercial, Flux Limits
11 70 - 12 2	Fixed, Satellite, Broadcast	Broadcast Only, No Flux Limits
12 50 - 14 5	Fixed, Satellite, Nav	Some Flux Limits
17 70 - 19.7	Fixed, Mobile, Satellite	Flux Limits, Rain Attenuation, Broad
19.70 - 20 2	Fixed, Satellite, Government	Government Only
27.50 - 29 5	Fixed, Satellite, Mobile	Broad, Some Mobile, Severe Rain Attenuation
29 50 - 30 0	Fixed, Satellite	Broad, Severe Rain Attenuation
30 00 - 31 0	Satellite, Government	Government
>31	Various, Mixed	Increasingly Available, Broad, but Severe Rain Attenuation

5.2.2 Link Calculations

Preliminary link budgets have been prepared based upon estimates of required data rates and reasonable equipment configurations. The highest average one-way data rate requirement has been estimated as 6.25 Mbps per beam. (The previous tables show 12.5 Mbps, but that is for both sending and receiving for each terminal.) This combines the data rate for all classes of terminals for cities in the largest population category (1,000,000), and assumes that the total government and business mail is transmitted during a 10-hr/day period of full duplex operation. This includes a safety factor of two since 5 hr of full duplex operation would "deliver all the mail". This data rate is approximated in only 6 of the 846 beams, with the average one-way data rate per beam being only about 0.39 Mbps.

For the purposes of demonstrating feasibility a worst case was assumed, in which a peak capacity of twice that required, or 12.5 Mbps is budgeted on uplinks and downlinks. The satellite antenna diameter was taken as 33.3 ft (10 m) and the earth station antennas were assumed to be of 3 ft diameter. No autotracking at the earth terminals was assumed, but a pointing loss corresponding to a 0.25-deg error was budgeted. This assumes that the antenna is oriented so as to peak the downlink signal, and thereafter its gimbals are locked. The resulting 0.25-deg error represents stationkeeping errors in the satellite, as well as any residual inaccuracies in ground antenna pointing. Use of the 20/30 GHz satellite communication band was assumed (20 GHz downlink, 30 GHz uplink). A rain loss of 10 mm/hr was budgeted. On the average, this rain rate is exceeded during 24 hr of each year for the typical eastern seabord location, but the average outage time due to rain is less than one hour. Since mail transmission can be delayed for several hours if necessary, the budgeted rain losses are, in effect, very generous and represent additional system transmission margins.

The downlink budget is shown in Table 5-21. It may be noted that 2 W per beam is adequate for the satellite (and only a few of the 846 beams require even this much power).

The uplink budget is shown in Table 5-22. Mainly as a result of the higher rain losses at 30 GHz, the uplink power required (for the largest cities) is higher than the downlink power. Less than 10 W is required. These results are very reasonable and well within present state of the art.

5.2.3 User Access

A number of different access schemes were considered in connection with the Electronic Mail satellite system. Among them were the scanning spot beam technique in which a single high-powered transponder dwells on a pair of beam locations long enough to exchange mail between

Table 5-21. Downlink Budget (f = 20 GHz)

TRANSMITTER POWER OUTPUT	dBW	2 9
FEEDLINE AND DIPLEXER LOSSES	dB	1 0
SATELLITE ANTENNA GAIN (33.3 ft dia η = 55%, σ/λ = 1/32)	dB	63 0
SATELLITE EIRP	dBW	64.9
FREE SPACE LOSS (30° elev ∢)	dB	210.2
RAIN LOSS (10 mm/hr)	dB	9.0
POLARIZATION LOSS	dB	0 2
POINTING LOSS (spacecraft antenna)	dB	0 2
DOWNLINK DEGRADATION MARGIN	dB	1 0
Σ DOWNLINK LOSSES	dB	220 6
GROUND ANTENNA RECEIVE GAIN (3 ft dia, η = 55%)	dB	43 0
GROUND ANTENNA POINTING LOSS (0.25° error)	dB	0.6
RECEIVING SYSTEM NOISE TEMPERATURE AT FEED (with 10 mm/hr rain)	°K	1200
GROUND STATION NET G/T	dB/°K	11 6
$(C/N_0)_d$ = EIRP - Σ LOSSES + (G/T) -10 LOG k	dB Hz	84.5
THEORETICAL (E_b/N_0) FOR $P_e = 10^{-6}$	dB	10 5
IMPLEMENTATION MARGIN	dB	3.0
INFORMATION RATE CAPACITY	Mbps	12 5

all users in those locations -- and then hops to another set of locations. By going through the entire combination of possibilities, mail is exchanged between all senders and receivers. This can be updated every hour or at least once a day. This seems to be the simplest satellite technique for the Electronic Mail System and has two big advantages; namely that intermodulation products are held down by time division multiple access, and thus the full power of the transponder can be used with no power backoff; and the second advantage that little if any storage need be provided in the satellite since the users' throughput equals the beam capacity at all times. It has a significant disadvantage, however, and that is that each user must then operate at the satellite throughput rate which, as we have

Table 5-22. Uplink Budget (f = 30 GHz)

TRANSMITTER POWER OUTPUT	dBW	8 0
FEEDLINE AND DIPLEXER LOSSES	dB	1 0
GROUND ANTENNA TRANSMIT GAIN (3 ft dia, η = 55%)	dB	46 5
POINTING LOSS (with 0.25° pointing error)	dB	1.2
UPLINK EIRP	dBW	52 3
FREE SPACE LOSS (30° elev)	dB	213 7
RAIN LOSS (10 mm/hr)	dB	16.0
POLARIZATION LOSS	dB	0 2
POINTING LOSS (spacecraft antenna)	dB	0 2
UPLINK DEGRADATION MARGIN	dB	1 0
Σ UPLINK LOSSES	dB	231 1
SATELLITE ANTENNA GAIN (dia + 33.3 ft, η = 55%, σ/λ = 1/32 at transmit freq)	dB	65 6
SATELLITE RECEIVING SYSTEM NOISE TEMPERATURE (referred to feed)	°K	1230
SATELLITE (G/T)	dB/°K	34.7
$(C/N_0)_\mu$ = EIRP - Σ LOSSES + G/T -10 LOG k ($P_e = 10^{-6}$ for 12.5 Mbps with 3 dB margin)	dB Hz	84 5

seen from Table 5-17, is over 600 Mbps. Thus, even the smallest terminal receiving only ten letters a day and requiring only a 150 bps terminal, must now have a terminal capable of 650 Mbps. This will result in high costs for the smallest users, and even for the intermediate size users; and was therefore rejected as being contrary to the principle of a complex satellite feeding many inexpensive user terminals. It is really quite the opposite; it is a satellite that is made simple at the expense of the users.

A preferred scheme was therefore evolved in which 846 transponders in the satellite operate in parallel through an 846 beam antenna, with the users within a beam being sampled many times a day at the beam rate (which varies from 250 kbps to 12.5 Mbps), and all information within a beam broadcast to all users in the beam in a classical TDMA mode. Each user with an intended receiver in the beam would then simply transmit the information during an assigned time slot and all users except the intended receiver would reject that information, receiving only information intended for them in other time slots. This is a very simple scheme and works well and each user need only have a terminal with a maximum of 12.5 Mbits throughput in the largest cities, and 250 kbits throughput in the smallest cities. This results in low cost terminals. The scheme requires more complexity in the satellite, however, because if a user wishes to access a receiver located in a different city he must go through some form of switching and storage system in the satellite to get to the proper beam for that city, and into the proper time slot for that user.

The following description of outgoing and incoming mail collection is made with reference to the basic access scheme, and is illustrated in Figure 5-3. In this figure, a basic sampling time of 10 min (which number will be justified later on in the discussion). In this case it is clear that the user transmission and reception will be in portions of a letter and the user set will have to have some storage for reconstructing

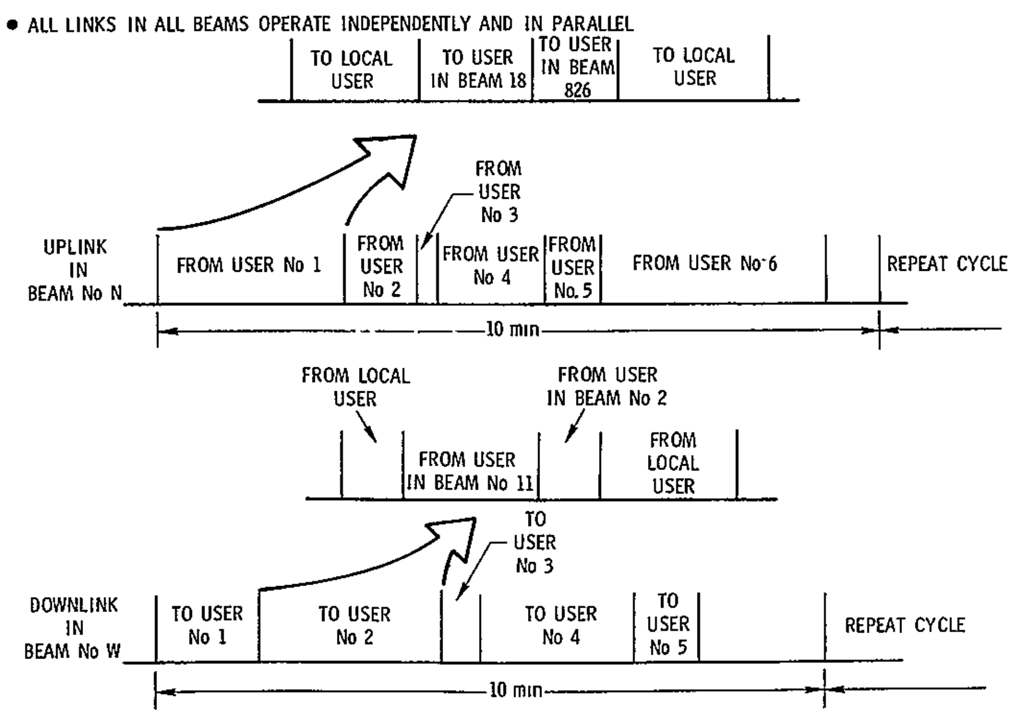

Figure 5-3. Electronic Mail Collection and Distribution

the entire letter. However, storage on the ground is fairly inexpensive and the basic principle that has been adopted in defining these concepts is that microelectronics progress will make information processing and storage among the most inexpensive components, either in space or on the ground, which should be maximized in holding the costs of the other components down.

The following is a short description of the process of outgoing mail collection, mail sorting and routing, and incoming mail distribution.

5.2.3.1 Outgoing Mail Collection

1. Outgoing mail is originated as hard copy or pictorial data in user offices. It is routed manually or electronically to the user's mailroom.

2. The user's mailroom organizes each piece of outgoing mail into a system-standard format: a header containing the sender's and recipient's address, the date and the time, a message serial number, a message type identifier (e.g., alphanumeric text, picture, terminal equipment designation code, etc.) The message proper is then affixed, followed by an end-of-message (EOM) signal.

3. Each piece of outgoing mail is fed mechanically into the page reader and stored electronically in the order of origination in the user's mailroom, awaiting a polling signal on the common order wire channel.

4. A common downlink order wire channel per beam sequentially polls all user mailrooms within that beam to initiate transmission of outgoing mail on the user uplink channel (UUC). The polling sequence is prestored in the satellite central processor.

5. Upon receipt of the user mailroom identification number in the polling sequence, the user mailroom transmits its accumulated outgoing mail on the UUC, followed by an end-of-transmission (EOT) signal. If the user mailroom holds no outgoing mail, he replies with an EOT signal. The transmission duration will be a fixed time slot designated by the satellite processor, or the end of the stored mail message, whichever occurs sooner.

6. The receipt of the EOT signal by the satellite causes the polling sequence to advance one step, to permit interrogation of the next user mailroom in that beam.

7. The collection of outgoing mail contines until all user mailrooms within a given beam have their mail collected. Concurrently, new pieces of mail are being originated in individual offices and stored in the user's mailroom, awaiting a second mail collection.

8. When the system is lightly loaded, its collection rate is sufficient to permit multiple collections during a working day. Under peak load conditions all the mail accumulating in each user's mailroom is required to be collected at least once in each 10-hr day.

9. The collection rate upon which the preliminary link budgets are based is twice the average rate at which outgoing mail is being generated in those beams serving the highest population densities. No significant collection delay is therefore anticipated unless the instantaneous mail generation rate exceeds twice its average value. (The averaging interval is based on a 10-hr day).

10. Since the mail input is generated independently by a large number of offices, sustained instantaneous rates exceeding twice the average rate are very unlikely, excluding normal diurnal and preholiday conditions. If the total normal daily volume of input mail could be presented instantaneously to the system, it would take the system somewhat in excess of 5 hr to collect it. However, such a situation has a probability of occurrence that is enormously small, and even then would exist in only 6 out of the 846 beams.

11. Abnormal patterns of mail origination and maintenance emergencies would be handled by operating the system at night. Furthermore, temporary mail overloads would be kept in paper form before being inserted into the Electronic Mail system, to minimize the need for high capacity storage in user mailrooms.

12. The collection of outgoing mail proceeds independently within every beam of the satellite system. A typical message structure is illustrated in Figure 5-4.

5.2.3.2 Mail Sorting and Routing

1. Each UUC is demodulated aboard the satellite to permit sorting and routing of mail. The first three decimal digits of the recipient's address code are identical to the three decimal digit number of the satellite beam and the user downlink channel (UDC) serving that recipient.

2. Each message (header, text, and EOM) is routed to an onboard message store. The store is partitioned into 846 storage areas, each one of which is uniquely associated with the recipient's satellite beam. (Alternatively, physical partitioning of the storage space is not necessary, provided sorting for real-time readout can be accomplished by sufficiently rapid random access).

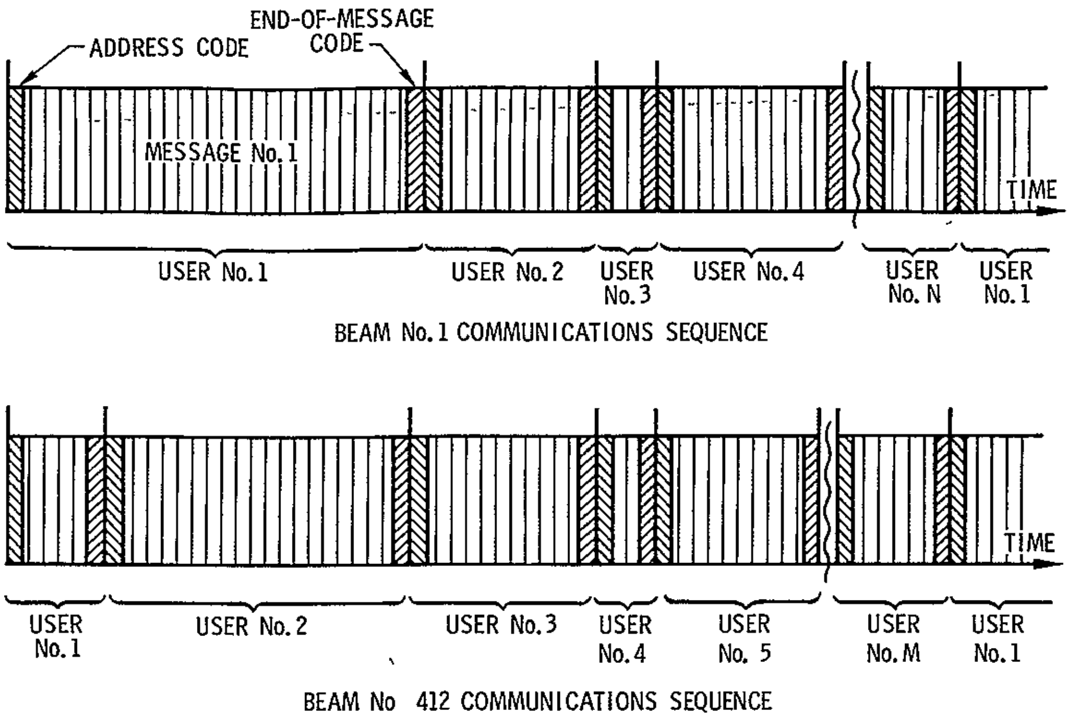

Figure 5-4. Multiple Access/Message Structure - Electronic Mail Concept

5. Hence, the onboard message store temporarily holds all the mail originated by every UUC, sorted into storage bins corresponding to the recipient's UDC.

6. Read out of the onboard store associated with each UDC proceeds concurrently with readin and nominally at the same average rate. Each UDC storage bin is required to have sufficient capacity to accommodate any temporary excess of the combined data rates to that UDC from all UUCs to the extent that they exceed the readout rate of the storage bin. In the absence of such peaks, there would not be a need for mass storage aboard the satellite.

7. Since unusual flows of mail sometimes develop wherein particular recipient(s) may temporarily receive a heavy flow of mail from many senders, means must be provided to prevent overflow of UDC storage bins and resultant loss of mail.

8. Overflow prevention can take two forms. The satellite could contain unreserved blocks of mass memory that can be allocated to particular UDCs that appear to be experiencing temporary overloads. This would expand UDC memory bin capacity where needed, without requiring every bin to be of maximum size.

9. Nevertheless, it is to be expected that there will be occasional conditions where prolonged heavy flows of mail to particular UDCs threaten to overload the total reserve satellite memory capacity. Therefore, the satellite must have the capability to detect an impending memory overflow and selectively refuse to accept mail to certain destinations until the congestion is cleared. (This is analogous to the mail embargo placed by the Postal Service to particular destinations that may be experiencing temporary problems).

10. Control of satellite congestion is therefore also accomplished by means of the downlink order wire channel in each beam. Interpolated within the normal polling sequence are the coded identification numbers of those UDCs for which mail is to be held at the point of origin. Upon receipt of the polling signal the equipment in the sender's mailroom recognizes the embargoed destinations and transmits the accumulated outgoing mail on the UUC, except for mail addressed to UDCs that cannot immediately handle the traffic. The mail that is so held is transferred to an off-line mass memory that is

selectively amptied when the congestion is cleared. The console display facilities identify destinations that are experiencing difficulty, thus permitting an operator to hold mail in paper form in cases of prolonged delay.

11. Since any particular user earth station may be experiencing a temporary outage, due to failures or rain, some form of receipt acknowledgment must be relayed back to the satellite so that mail is not lost. Each user mailroom will normally acknowledge on the uplink order wire every transmission addressed to it. The satellite looks for this acknowledgment. Should an acknowledgment not be received, the downlink transmission may be repeated once or twice, and should acknowledgment still be lacking, the address of the user mailroom equipment that appears to be malfunctioning is added to the list of UDCs for which mail is to be held in the satellite for a sufficient time to accommodate the normal acknowledgment delay, before being erased.

5.2.3.3 Incoming Mail Distribution

1. Every user mailroom is equipped to receive the user downlink channel (UDC). The UDC transmission consists of a sequence of messages, each one of which is a piece of mail in system-standard format (i.e., the header, the message, and the EOM).

2. One UDC is provided per satellite beam. Each UDC carries only those messages destined to recipients served by that beam.

3. Each user mailroom receiving system includes a decoder that responds only to recipients' addresses that it serves. These addresses are read from the header preceding each piece of mail.

4. The acceptance of an address code by the decoder causes the associated message to be routed to a buffer storage unit. The readout of the buffer store is under control of the user communications controller, which provides speed conversion, code conversion (if necessary), and assignment of output terminals as appropriate to the message type identifier code included in the header.

5. The decoding of an address to a recipient that it serves, followed by an EOM signifying the end of that message causes the user mailroom equipment to generate an acknowledgment signal, which is sent on the uplink order wire.

5.2.4 Payload Block Diagram

The satellite payload block diagram can now be derived from the operating ground rules in the previous subsection. This diagram is shown in Figure 5-5. It is seen to consist basically of 846 simultaneously

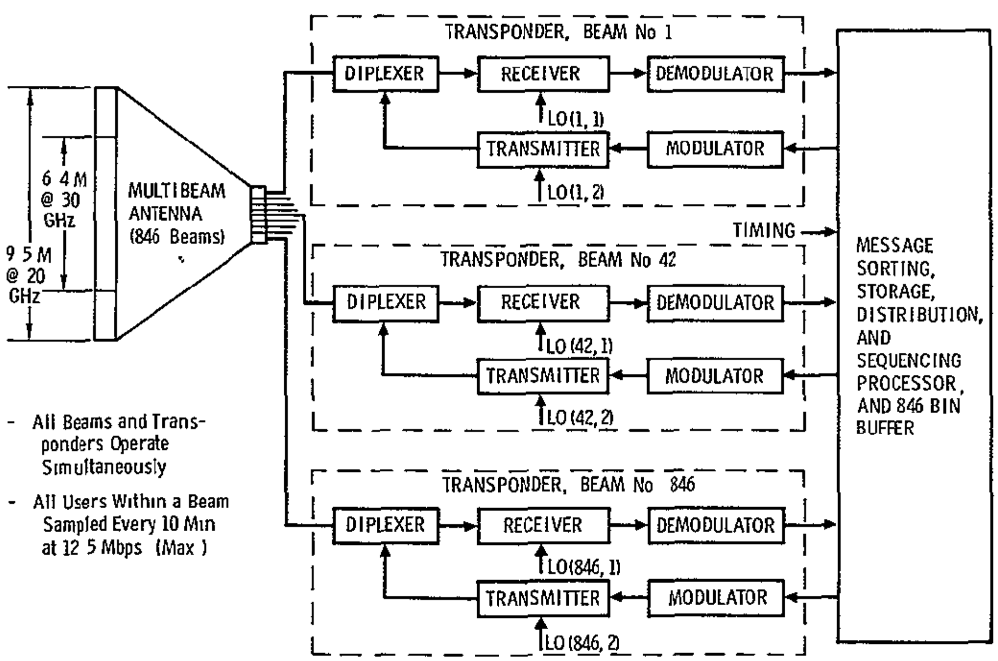

Figure 5-5. Satellite System Block Diagram - Electronic Mail

active transponders, one for each beam. The transponders demodulate the datastream to baseband and remodulate the messages after sorting, storage, distribution, and sequencing. All users within a beam are sampled at least every 10 min at a rate depending on the data rate of the beam, which varies from 250 kbps to 12-1/2 Mbps.

The multibeam antenna is virtually identical to that described for the Educational TV system in Section 4.2.5.1. It has a diameter of 9.5 m at 20 GHz and 6.4 m at 30 GHz. It would use a dual frequency lens design as described in Section 4.2.5.1. Except for the provision of 846 local oscillator signals to the receivers and the same number of different frequencies to the transmitters; and the presence of modulators and demodulators, the transponders appear similar to conventional transponders, with a bandwidth not exceeding that required for 12 1/2 Mbps data rate. (Each transponder could readily have a bandwidth in the order of 15 MHz.)

5.2.5 Satellite Segment Definition

The satellite segment is defined much as the Personal Communications satellite was defined in Section 3.2.5 and the Educational Television satellite defined in Section 4.2.5. The items upon which design attention was focussed were the antenna, the processor, propulsion and power, and system design.

5.2.5.1 Antenna

The antenna design is identical to that developed under Section 4.2.5.1 for the Educational Television initiative. It is a 20- and 30-GHz antenna, fashioned for this study as a multibeam lens. Due to the digital datastream, the 15 dB sidelobe ratio of the bias antenna, as predicted in Appendix A, will be entirely satisfactory, allowing all beams to occupy only three times the bandwidth occupancy of one beam, with nonadjacent beams being in the same frequency. Thus, since 12 1/2 Mbps or 12 to 15 MHz is all that is required for the highest rate beam, the entire frequency occupancy of the Electronic Mail system is less than 75 MHz of bandwidth. The weight and other characteristics of the antenna would be expected to be virtually identical to that shown in Section 4.2.5.1, and illustrated in Figure 4-12 and Table 4-28. As in that section, the antenna could be offset-fed paraboloid as well. The expected weight is 340 kg.

5.2.5.2 Onboard Processor

The onboard processor required for this satellite is basically a multibin buffer described functionally under the description of the user access in Section 5.2.3. Pictorially that function is illustrated in Figure 5-6. It is seen that a message received in beam No. 1 from one of the users in that beam, but intended to be received by another user in the same beam, bypasses the message storage process and is inserted into the datastream at the proper time slot by the message sequencer for that beam. This occurs in parallel in all beams. A message received in a given beam, but

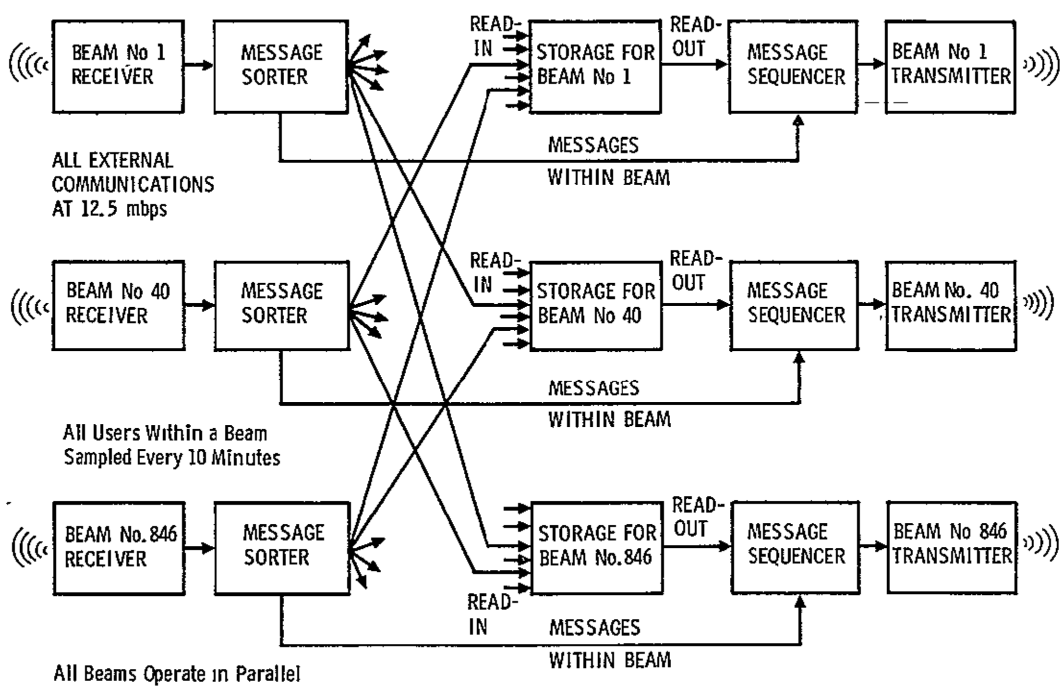

Figure 5-6. Onboard Message Routing and Sequencing - Electronic Mail

intended to be transmitted in a different beam to be received by a user in the other beam, is read into temporary storage in a buffer associated with that beam. There it awaits the proper time to be inserted into the downlink datastream to be properly sequenced with other messages. The storage bin of each beam thus accepts messages from all the other beams as messages addressed to users in that particular beam arrive at the satellite.

There may be many messages arriving at essentially the same instant of time, since the beams are not coherently sampled (nor can they be, due to their different beam data rates and number of users per beam). Thus the storage for any particular beam is sized to accept temporary loading of messages from all the beams as they come in. However, that storage bin (and every bin) is read out through the message sequencer at the average beam rate for that beam, which is calculated to be twice the incoming datastream rate. It is thus unlikely that large storage peaks will occur. Actually some excess storage would be needed to handle unusual situations, which would be provided for by floating buffers or by command override holds. This storage process would occur in parallel in all beams, and is a fairly straightforward process utilized in many computers today.

A first estimate was made for the required computation, processing, and memory for such a processor/buffer system. The total size, weight, and power estimates are based on 1990 technology projections and the data rate requirements as previously formulated. The computer controls the basic store and forward functions in the satellite. The blocking factor is assumed as 10,000 bits per block. The data rate is assumed at 12.5 Mbps in every beam, with a maximum aggregate of 660 Mbps, which is 66,000 blocks per second. This is a block rate of one every 15 µsec. The processing algorithm must do a sort (interpret) and route (initiate transfer) function, which is estimated as 250 instructions. In 1988, an average instruction time of 200 nsec is assumed which results in 50 µsec. Thus four 32-bit word length (4 x 5 µsec = 60 µsec) computers are necessary with some sort of common memory and multiprocessing configuration. Four machines in parallel and two back-ups are assumed, each with 1M bytes of memory. Packaging is one ATR militarized unit per, 32-bit word length computer.

The resultant processor/buffer characteristics projected to the time period are a weight of 408 lb, a power consumption of 2.4 kW; and a size of 6 ft^3 total, broken down as six 1-ft^3 ATR boxes. This appears to be a very reasonable processor to incorporate into the satellite in the time period.

5.2.5.3 Propulsion and Power

The propulsion system for the Electronic Mail satellite follows very much the design for the Educational Television system described in 4.2.5.3. Orbit transfer from low altitude to geostationary altitude will take place self-powered with three ion thrusters in parallel. The power that must be available for these thrusters in the order of 10 kW which, as it will be seen, is compatible with the power needs of the satellite in an operating mode.

The system will transfer itself in somewhat more than one year using this thrust level with only three 30-cm thrusters identical to those used of the SEPs propulsion development system. The stationkeeping propulsion was chosen as four smaller plasma jets operated in two pairs, with a total power requirement of 360 W overage. The reduced thrust is made possible by the small disturbing forces experienced in synchronous altitude. The total system weight for stationkeeping is less than 150 lb including propellant for three years on orbit. It is estimated that the satellite will be revisited every 2 years making a larger propellant load unnecessary, though it certainly could be provided at negligible weight penalty to the satellite. The attitude control system was selected to be a fairly standard small hydrazine thruster system with 12 thrusters in couples about three axes. The thrust level is about 0.1 lb and the total system weight is 190 lb making the entire propulsion system weight less than 1500 lb for all propulsion functions; and obviating the neef ror a separate orbit transfer vehicle.

Table 5-23 illustrates these numbers that were derived for a 5000-lb estimated weight of satellite. At this weight the satellite could readily be placed into orbit using an IUS, however, such an upper stage propulsion is not suggested inasmuch as the antenna design cannot withstand more than about 0.1 Gs. A design to withstand the three or so Gs of the IUS would be significantly heavier and more expensive. Such a tradeoff of course is possible and should be performed in follow-on design studies. For the sake of this study, self-powered transfer will be selected for orbit transfer, as was done for the two previous initiatives.

The power system design follows from the estimate of the total power consumption. This is in the order of 8 kW. A solar photovoltaic/ battery system was chosen as being the only reasonable one for that power

Table 5-23. Propulsion for Electronic Mail Satellite

FUNCTION	DESCRIPTION	POWER, kW	THRUST, lb	ISP, sec	PROPELLANT WEIGHT, lb	DRY WEIGHT, lb	TOTAL WEIGHT, lb	THRUST TIME, DAYS	DUTY CYCLE PERCENT
ORBIT TRANSFER	3 ION THRUSTERS IN PARALLEL, (30 cm SEPS-type)	10	0.096	3000	1130	15	1145	408	-
STATIONKEEPING	4 ION ENGINES, IN 2 PAIRS	0.36	0.004	2800	30*	120	150	-	20
ATTITUDE CONTROL	12 HYDRAZINE THRUSTERS IN COUPLES ABOUT 3 AXES	-	0.1	230	160	30	190	-	< 5
						TOTAL	1485		

*Propellant for 3 yrs
- 5000 lb satellite assumed

level in the time period. The total power system would be modular and would be expected to weigh in the order of 900 lb for a BOL power of 10 kW. The power system would be oversized by 30 percent, initially, to allow for the power degradation in the time the system spends during the orbit transfer from low altitude to final synchronous orbit, during which time the power level is expected to degrade about 30 percent. Thus the beginning of life power in low altitude orbit is about 13 kW, while the beginning of life capability in synchronous altitude is about 10 kW. The rest of the system sizing follows that of the Educational TV and Personal Communications initiative (Sections 3.2.5.5 and 4.2.5.5) in which somewhat more data are shown on power system sizing.

5.2.5.4 Design

The design of the Electronic Mail satellite follows very much the same philosophy as that of Educational Television and Personal Communications satellites.

A physical description of the major components is shown in Table 5-24, from which it is seen that the processor and the transmitter require the bulk of the power of the satellite, with an additional 360 W of power being required on-orbit by the translation ion engines. The power consumption shown for the transmitters is much larger than actually needed, since only six out of the 846 require the full 3 W – an average being less than 1 W.

A weight estimate for the satellite is shown in Table 5-25 from which it is seen that the total weight of the satellite is expected to be about 5300 lb. This includes a 20 percent weight contingency. Note that the solar arrays and the structure were sized for 13 kW to allow for a 3-kW degradation in the transfer from low to high altitude. The satellite weight is the smallest of all the three satellites, and this satellite is felt to be closer to today's state of the art and, therefore to realization, than the other two satellites treated. A layout of the satellite is shown in Figure 5-7 which is seen to be virtually a copy of the layout for the Educational Television satellite of Section 4, with the exception that the solar panels are smaller inasmuch as the initial power requirement is not 65 kW but 13 kW

Table 5-24. Physical Description of Components - Electronic Mail

ITEM	QUANTITY	DESCRIPTION	PER UNIT			TOTAL		
			IN^3	LB	WATT	FT^3	LB	KW
Antenna	1	Includes lens supports, 846 horns feeds		700		---	700	---
Diplexer	846	One per horn	.1	.01	---	05	8 5	---
Receiver	846	Includes preamp, mixer, IF, video amps and substrate - 30 GHz, F E T	2	02	.1	1	17 0	08
Demodulator	846	QPS K Detector, Filter, substrate	01	001	002	005	1 0	002
Processor	1	Buffer (846), Switch Processor, Control	10,300	400	2400	6	400	2 4
Modulator	846	QPS K Modulator Filter, structure	2	.02	1	1	17	08
Transmitter	846	3 Watts @ 20 GHz	4	01	9	2	35	6 8
Frequency Generator	2	Generates 846 uplink and 846 down-link subcarriers, distributes includes case	200	20	200	46	40	4
Master Oscillator	1	Generates master frequency for system	200	20	200	23	20	.2

Table 5-25. Weight Summary Electronic Mail Satellite

ITEM		WEIGHT - POUNDS
STRUCTURE AND THERMAL CONTROL		650
ATTITUDE CONTROL (Excludes Reaction Control System)		35
ELECTRICAL POWER AND DISTRIBUTION		900
Arrays (13 kW)	255	
Array Structure (Including Orientation and Deployment Mech)	215	
Distribution and Conditioning } 10 kW B O L	130	
Batteries } 10 kW B O L	300	
ANTENNA		700
Feed Horn Assembly	242	
Lens Assembly	70	
Support Struts	368	
Guide Lines	20	
COMPUTER		400
ELECTRONICS		265
PROPULSION AND REACTION CONTROL		1 625
Propulsion and Reaction Control System (dry)	305	
Propellants and Reactants	1,320	
WIRING		75
CONTINGENCY (20 PERCENT)		700
SATELLITE GROSS WEIGHT		5,350

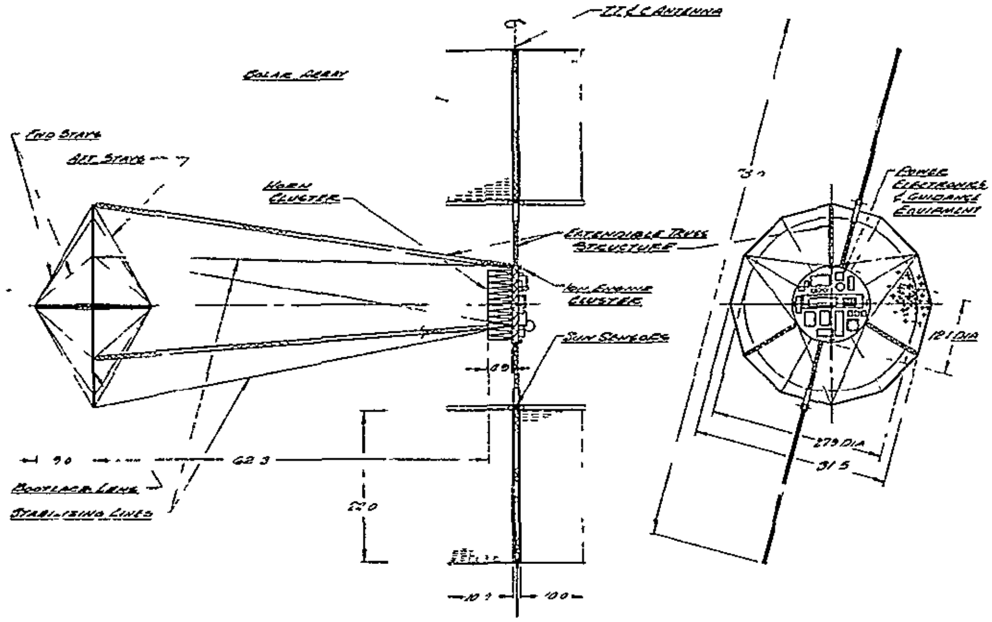

Figure 5-7. Electronic Mail Satellite

The layout and design of the antenna are identical, as are those for the modular horn clusters. The electronics of course are different, but the propulsion systems are very similar.

An artists' concept of the satellite from an oblique direction is shown in Figure 5-8, which is seen to be also identical to that of the Educational Television satellite except for the smaller solar arrays. The man is shown for scale of comparison only, not to imply that a man is needed for assembly.

The packaging of the components for the Electronic Mail satellite can certainly be accomplished in a single Orbiter payload bay as shown by the example of Figure 5-9. In fact, this packaging can probably be done in less space than indicated by the layout. The satellite would be assembled in low earth orbit in the same way that the Personal Communications and Educational Television satellites were assembled in Sections 3 and 4, with the electronics and horn interchangeable modular packages being utilized. The reader is referred to Sections 3.2.5.6 and 4.2.5.4 for a more complete discussion.

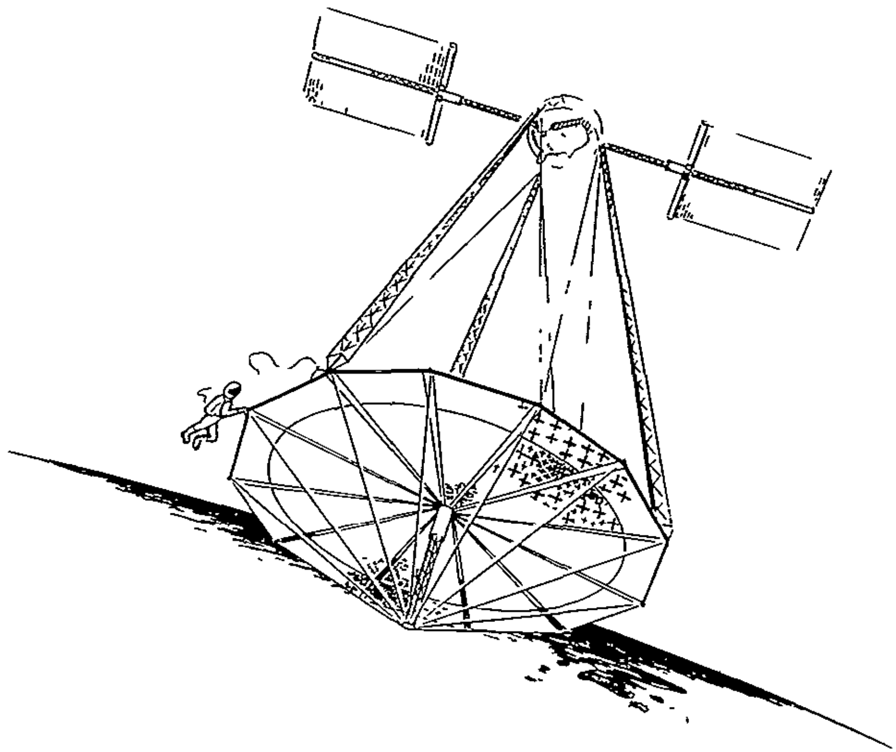

Figure 5-8. Electronic Mail Satellite

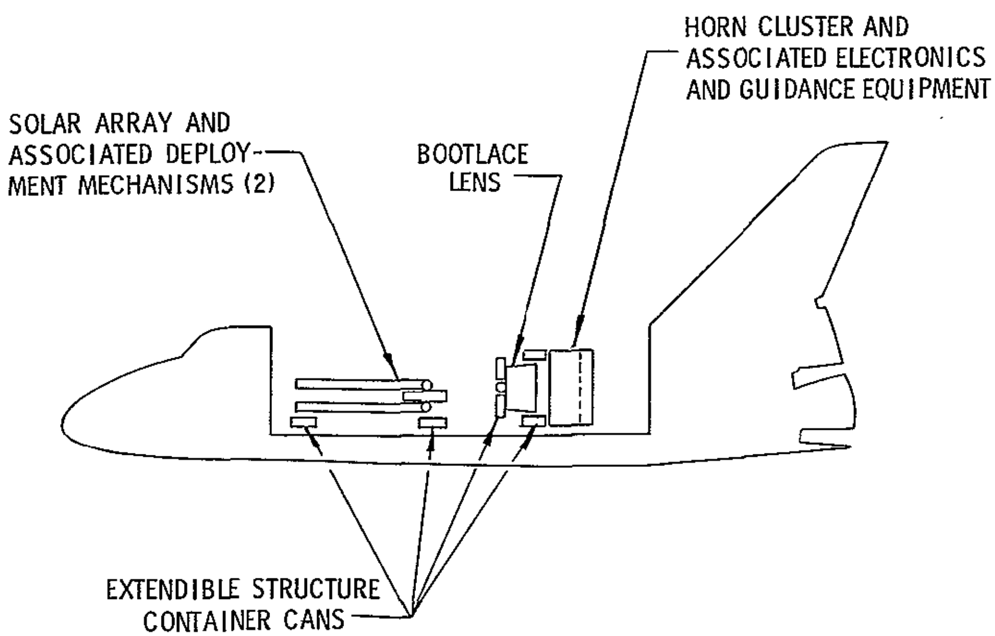

Figure 5-9. Components Packaging - Electronic Mail Initiative

5.2.6 Ground Segment Definition

In this section the user terminals will be defined including antenna, terminals, and input and output equipment. The link calculations of Section 5.2.2 showed that the links could be closed even for the largest and most heavily loaded beams, with a fixed 3-ft dia antenna on the roof of the building, and with only an uncooled FET frontend receiver. Four classes of terminals were identified as being necessary, from the smallest with a maximum speed capability of 500 bps or less, to the largest with a capacity of about 40,000 bps. The system operation described in Section 5.2.3 assumed that each user set would be contacted by the satellite on a periodic basis in a time division multiple access scheme. The frame period was selected as about 10 min for reasons which are discussed in this section. In the 10 min available between samplings, the user terminal may or may not be able to send (or receive) a complete letter. More than likely it will not, with the message being sent in portions until completed letters are assembled at the receiving end (or read at the transmission end) from piecemeal transmissions in a time sequence.

The size of the storage required is determined by the input and output machine speed and the beam data rate. One extreme would be to outfit the users with extremely fast input and output devices such as facsimile machines whose reading (or printing) rate would equal that of the data rate on the beam covering that user. Therefore, little if any electronic storage would be needed. The difficulty with this scheme is that it does not allow for breakdowns in some links to the intended users, and if an outage develops during a transmission attempt, the mail must pile up in the satellite. It is much simpler and cheaper to let the mail pile up on the ground in physical form or buffer storage, before it accumulates for many users, and to outfit the user terminals with slower facsimile units and larger buffer storage units. The opposite extreme would be found in facsimile readers and printers that were barely able to operate at the average speed of reception or transmission of letters required for the size of the terminal. The buffer storage would then have to store up to 5 hr worth of transmission or reception (or both), this being the daily transmission time at the average rate, and feed it to (from) the printer at its speed capacity.

The calculation for a required buffer storage is performed for somewhat faster use than the slowest fax machines, and is shown in Table 5-26. It is shown that the maximum buffer that would be required if the mail were collected and distributed only once per day varies from 9×10^6 to 7×10^8 bits from the smallest to the largest terminal. This is shown in the fourth column. The price of such a buffer will be excessive for at least the smallest units as will be shown in the cost section, and would determine the total cost of the terminal. If the mail is collected and distributed every 10 min, however, the receiver buffer may be as small as 3×10^5 to 2.3×10^7 bits for the largest buffer, which is much more reasonable.

Table 5-26. Buffer Store Required - Electronic Mail

TERMINAL SIZE	NUMBER OF TERMINALS	DATA RATE PER TERMINAL, (AVERAGE) (bps)	MAX. BUFFER REQUIRED IF MAIL COLLECTED/ DISTRIBUTED ONCE PER DAY (bits)	RECEIVER BUFFER IF MAIL COLLECTED EVERY 10 MIN (bits)	TRANSMITTER BUFFER, DUE TO LINK OUTAGES* (bits)	TOTAL TRANSMITTER BUFFER (bits)
SMALLEST	472,000	500	9×10^6	3×10^5	1.8×10^4	3.2×10^5
MODERATE	35,400	3,000	5×10^7	1.6×10^6	1×10^5	1.7×10^6
LARGE	25,000	10,000	1.8×10^8	6×10^6	3.6×10^5	6.4×10^6
LARGEST	5,730	40,000	7×10^8	2.3×10^7	1.4×10^6	2.4×10^7

* 1/100 LINKS UNAVAILABLE DURING ANY ONE-HOUR PERIOD, DUE TO WEATHER OR FAILURES; MAIL SENT EVERY 10 MINUTES

The transmitter buffer on the other hand only needs to accept read-in information from the fax machine if there exists a link outage, unless a complex random letter sorter and reader is dreamed up. Thus the transmitter storage capacity depends on the outage time and the number of links that are expected to be unavailable. It was felt reasonable, as a worst case, to assume that at most one percent of the links would be unavailable during any one hour period due to weather or failures. Thus the required transmitter buffer capacity is shown in the sixth column to vary from 1.8×10^4 to 1.4×10^6 bits from the smallest to the largest terminals. The total transmitter buffer then required is equal to the receiver buffer size plus that for link outages and is shown in the last column to be not much greater than that of the receiver buffer. These buffers will then allow system operation with a printer or page reader speed equal to the nominal required in the requirements definition of Section 5.1.

The smallest buffer or terminal operating at 500 bps average speed will send and receive a sample every 10 min. The transmission speed of the beam will allow up to 12 Mbps to be transmitted but the user sample will only take up a very small portion of it. For the smallest terminals operating at 500 bps 3/4 of an average letter can be transmitted per sample; whereas for the largest terminals operating at 40 kbps, the transmission system will allow an average of 30 mail pieces each way or 60 total per 10-min interval. Thus the requirements for the average speed of the input/output machines are seen to be about 500 bps for the smallest and 40,000 bps for the largest, with 10 min worth of buffering at the input and output ends.

Consider now today's average data facsimile machine, which transmits a page of copy in 4 min over a telephone line. Assuming the resolution to be adequate at 100 lines per in, and the size of the frame to be transmitted at 8 by 10 in. the number of bps required over the data line with that machine is 3333. This of course fits readily on a telephone line through a modem and is widely used today. The smallest facsimile machine required operates at only 500 bps rate, which is an equivalent of 0.25 pages per min or 4 min per page. This is indeed a small machine and can probably be produced in quantity for a very low cost. It would be similar to a Xerox 200 or a Graphic Sciences 4100. The largest machine is similar to that of others in production today with speed of 0.25 min per page or 4 pages per min. It would be similar to a 3M 9600 or Litton WASH-FAX III.

At this point the question needs to be raised whether the mail system should utilize optical character readers, facsimile machines, or digital direct inputs. Many large offices, particularly in the next 10 years, will have many electric typewriters connected as output terminal devices for use in conjunction with internal data processing centers, or use direct digital tape as input or output storage of letters and transactions. Since the direct digital form for letters is more efficient in bits per page than a facsimile machine by about two orders of magnitude, as shown in Section 5.2.1, should such direct digital forms of input and output be available, facsimile machines would not be needed. This, however, would not handle graphic materials. The opposite is true, however, if the terminals are outfitted with facsimile machines they can produce not only pictures and graphic line data but they can also produce and reproduce the equivalent of typed pages. For this reason, and for compatability and simple inter-operability, the input/output machines were selected to be facsimile machines. It is realized that in the future the entire mail terminal could be viewed as an extension of the data processing center.

The data content of a typical page, which was estimated at 405,000 bits in Section 5.2.1, is an average of typed letters, black and white graphics, and color graphics at different percentages of occurrence. More than likely the initial Electronic Mail system should not have the capability for color, since it would raise the cost, particularly for the smaller units. Black and white compatible color units could of course be used to allow larger units to communicate color information, whereas smaller units would only be able to send and receive compatible black and white.

The block diagram of the user terminals is shown in Figure 5-10. The transmitter power output is seen to vary with the size of terminal, as do the memory sizes of both the transmitter and viewer buffer, and the speed of the facsimile machines.

5.2.7 Cost Estimates -- Electronic Mail System

Cost estimates for the Electronic Mail system are presented in this section. The procedures used in generating satellite cost estimates are based on the SCM and subsystem CERs described in Sections 3.2.7.1 and 3.2.7.2.

5.2.7.1 Electronic Mail Satellite Cost Estimates

The full-scale satellite for Electronic Mail is preceded by a concept demonstration system. The SCM output for that satellite is reflected in Tables 5-27 and 5-28. The full-scale satellite was estimated by applying

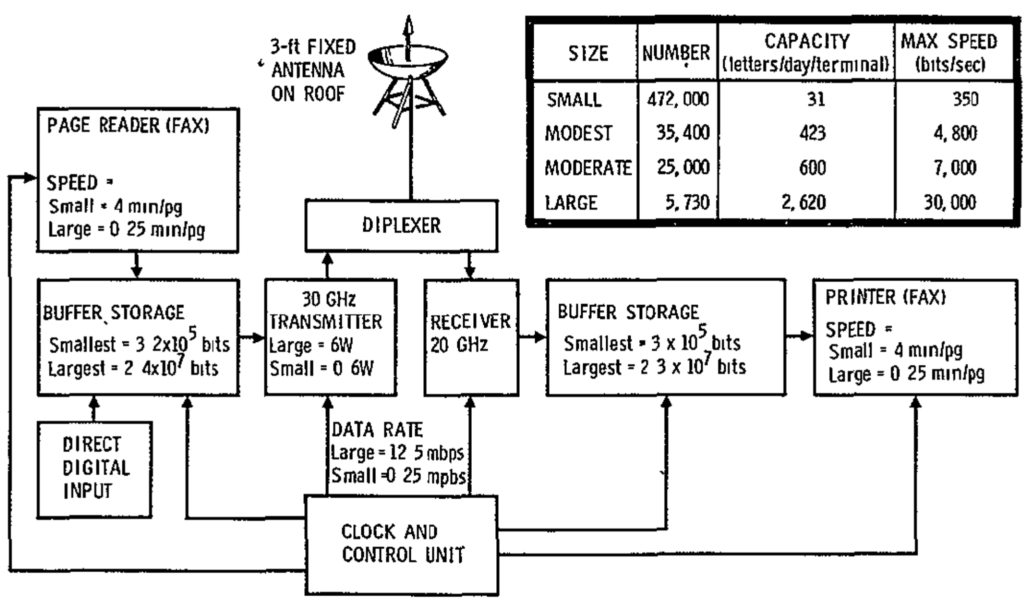

Figure 5-10. Electronic Mail User Terminals

Table 5-27. Electronic Mail Concept Demo Satellite

*** * * * ASSEMBLY DESCRIPTIONS * * * ***

STABILIZATION AND CONTROL

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	VALVE DRIVER ASSY	1	1.6	5.9	1.00	165834.	15851.	25685.	0.
303	SUN SENSOR	1	.3	.0	1.00	116150.	14519.	18541.	0.
403	NUTATION DAMPER	1	2.8	0.0	1.00	77256.	15984.	17010.	0.
603	CONTROL ELECTRNCS	1	7.4	3.5	1.00	1071594.	447818.	290184.	0.
606	EARTH SENSOR ASSY	2	4.1	1.0	1.00	397432.	153300.	216465.	156808.
1413	POWER CONVERTER	1	15.9	0.0	1.00	0.	0.	0.	0.

AUXILIARY PROPULSION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
834	THRUSTER	8	.7	.1	.10	13754.	45762.	77273.	76092.

DATA PROCESSING AND INSTRUMENTATION

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
203	DIGITAL TELEMETRY	1	8.9	3.0	1.00	447801.	139061.	177581.	0.
403	CDU	1	12.3	7.5	1.00	1558932.	47819.	61065.	0.

COMMUNICATIONS

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
103	BASEBND ASSY UNIT	1	2.0	.5	1.00	44622.	16117.	36060.	0.
202	ANTENNA	1	8.4	0.0	1.00	349517.	137063.	75778.	0.
306	TRANSMITTER	2	2.1	10.9	1.00	152260.	47779.	139615.	60841.
401	RECEIVER	1	3.9	6.3	1.00	77256.	24775.	39973.	0.
503	COMMAND SIG COND	2	1.5	.9	1.00	20153.	30796.	41640.	6053.
603	DIPLEXER	1	3.1	1.0	1.00	57409.	15451.	21942.	0.
620	ANTENNA,10 FT	1	175.0	0.0	1.00	5084244.	1332000.	2551446.	0.
621	SWITCH UNIT	1	75.0	100.0	1.00	2730600.	2664000.	3742121.	0.

ELECTRICAL POWER

IDENT	TYPE	NO.	UNIT WEIGHT	UNIT POWER	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
218	BATTERY	2	21.0	0.0	.10	25309.	20430.	75537.	51073.

EQUIPMENTS USING COST ESTIMATING RELATIONSHIPS

NAME	WEIGHT	DDTE FACTOR	D.E. COST	T.E. COST	VEHICLE PROD. COST	VEHICLE ENG. COST
SOLAR ARRAY	53.6	1.00	621537.	91452.	233593.	0.
WIRING HARNESS	47.8	1.00	217962.	128223.	173453.	0.
THERMAL CONTROL	30.4	1.00	833632.	110992.	114082.	0.
POWER CONVERTERS	15.9	1.00	590016.	367566.	234718.	0.
PROPULSION FEED SYS	34.3	1.00	558139.	296332.	252305.	0.
STRUCTURE	232.6	1.00	1454788.	1116260.	712610.	0.
POWER CONTROL UNITS	66.6	1.00	464591.	298965.	381820.	0.
SATELLITE ADAPTER	45.7	1.00	65877.	34526.	36997.	0.

PROPELLANT WEIGHT 115.0

MISSION EQUIP WEIGHT 0.0

TOTAL SATELLITE WEIGHT 999.9

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Table 5-28. Electronic Mail Concept Demo Spacecraft Cost Model (millions of 1977 dollars)

SUBSYSTEM COST	DDT+E DESIGN ENGINEERING	DDT+E TEST AND EVALUATION	DDT+E TOTAL DDT+E	RECURRING PRODUCTION ENGINEERING	RECURRING FAB AND ASSEMBLY	RECURRING TOTAL RECURRING
STRUCTURE	2.6	1.6	4.2	0.0	1.1	1.1
THERMAL CONTROL	1.4	.2	1.6	0.0	.2	.2
ELECTRICAL POWER	3.3	1.3	4.5	.1	1.6	1.6
COMMUNICATIONS	14.5	5.9	20.4	.1	9.4	9.6
DATA HANDLING	3.4	.3	3.7	0.0	.3	.3
STABILITY AND CONTROL	3.1	.9	4.0	.3	.6	1.1
AUXILIARY PROPULSION	1.0	.5	1.4	.1	.5	.6
SPACECRAFT	29.2	10.5	39.7	.6	13.8	14.4
MISSION EQUIPMENT			0.0			0.0
SATELLITE			39.7			14.4
QUALIFICATION UNIT(S)			0.0			
GSE (ACE)			2.4			
LAUNCH SITE SUPPORT						.6
CONTRACTOR FEE			3.0			1.1
TOTAL SATELLITE			45.1			16.1
AVERAGE UNIT COST (1 SATELLITES)						16.1
TOTAL SATELLITE DDT+E AND RECURRING COST						61.2

subsystem and component CERs to the weights provided by Table 5-29; the cost estimate is given in Table 5-30. It is seen to cost about $41 million, with the RDT&E phase costing about $107 million.

5.2.7.2 Ground Segment -- Electronic Mail System

The ground segment includes the receiving and transmitting equipment, the antenna, the facsimile archives, and the data storage required at the building sites. Cost estimates for each item of equipment, the quantity of each, and the basis for the estimates are shown in Table 5-31. In addition, yearly operations cost estimates are provided in the same table.

5.2.7.3 Life-Cycle Cost

These costs are based on the flow of the development plan, to be discussed in Section 5.3. The life-cycle costs include: (1) the Concept Demonstration satellite launched into geosynchronous orbit by a Shuttle and IUS (shown in Tables 5-32 and 5-33), (2) the Technology

Table 5-29. Electronic Mail Satellite Weight Breakdown

	WEIGHTS (lb)	
	BASIC	W/CONTINGENCY
STRUCTURE	730	900
BASIC STRUCTURE	(515)	
SOLAR ARRAY ORIENTATION	(215)	
THERMAL	85	100
ELECTRICAL POWER	760	870
ARRAYS	(255)	
BATTERIES	(300)	
POWER CONTROL	(130)	
WIRING	(75)	
ATTITUDE CONTROL	35	50
PROPULSION		
N_2H_4 THRUST SYSTEM	30	35
ION THRUST SYSTEM	275	315
PROPELLANT	1320	1515
MISSION EQUIPMENT		
COMPUTER	400	460
TRANSPONDERS	205	230
FREQ. GENERATORS	40	50
MASTER OSCILLATOR	20	25
ANTENNA	458	525
ANTENNA FEED	242	275
TOTAL SATELLITE		5350

Table 5-30. Electronic Mail Satellite Cost Estimate

	(Thousands of 1977 dollars) DDTE	UNIT
STRUCTURE	16000	3799
THERMAL	2789	326
ELECTRICAL POWER	9870	3959
ATTITUDE CONTROL	6605	1615
N_2H_4 SYSTEM	1525	536
ION SYSTEM	5760	4768
COMPUTER	18031	5266
TRANSPONDERS	3409	1542
FREQ GENERATORS	3752	2313
MASTER OSCILLATOR	2989	725
ANTENNA	16860	2657
ANTENNA FEED	7250	10267
SUBTOTAL	94840	37773
TOTAL (incl GSE, Launch Ops support, and fee)	107169	41550

Table 5-31. Electronic Mail System Ground Equipment Cost Estimate (Satellite-based Alternative)

ITEM-EQUIPMENT	QTY	UNIT COST	TOTAL ($ 000's)	BASIS OF ESTIMATE
ANTENNA, 3 ft	540000	700	378000	FROM REF. 2; SCALED FOR LARGE QUANTITY
RECEIVER, 20 GHz	540000	50	27000	BASED ON REF. 2, ESTIMATE ORDER-OF-MAGNITUDE COST REDUCTION
TRANSMITTER, 30 GHz				ORDER-OF-MAGNITUDE COST REDUCTIONS FROM REF 2
LARGE	270000	300	81000	
SMALL	270000	150	40500	
BUFFER, STORAGE & CONTROL				BASED ON REF. 3 ESTIMATES
USER 1	474000	443	209982	BIT CAPACITY = 3×10^5
USER 2	35000	4300	150500	BIT CAPACITY = 2×10^6
USER 3	25000	7500	187500	BIT CAPACITY = 6×10^6
USER 4	6000	23500	141000	BIT CAPACITY = 2×10^7
INSTALLATION			137796	20% OF EQUIPMENT COST
FAX				ORDER-OF-MAGNITUDE COST DECREASE FROM CURRENT PRICES PLUS
USERS 1-2	509000	300	152700	FIFTY PERCENT INCREASE FOR SIMULTANEOUS READ IN-OUT
USERS 3-4	31000	3000	93000	4-6 min/page USERS 1-2, 4 pgs/min USERS 3-4.
TOTAL EQUIPMENT			1598978	

OPERATIONS & MAINT/YR	BASE	UNIT OR %	YEARLY AMOUNT ($ 000's)	
ANTENNAS	378000	5%	18900	
ELECTRONICS EQUIP	975278	7%	68269	
FAX SERVICE	245700	12%	29500	TYPICAL SERVICE CONTRACTS @ 1% OF PURCHASE PRICE /mo
TAXES	1598978	2%	31980	
POWER	2222000 kW	$10/kW/yr	22220	10 hr/day, 200 days/yr
			170869	
G & A	170869	10%	17087	
TOTAL EQ OPS & MAINT. /yr			187956	

Table 5-32. Electronic Mail Satellite (Concept Demo) Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	308	308	TYPE,	ENDO	1 000	1 000	7	2		7	2		9
ELECTRICAL POWER	225	225	WATTS,	400.	1.000	1.000	5	1		5	1		6
TRACKING,COMMAND	298	298	ALT,	SYNC	1 000	1 000	27	11		27	11		38
STABILITY,CONTROL	20	20	TYPE,	3-AXIS	1 000	1 000	4	1		4	1		5
PROPULSION	34	149	TOT IMP(L)0.		1 000	1.000	2	1		2	1		3
SPACECRAFT	865	1000					45	16		45	16		61
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000							
SATELLITE	865	1000					45	16		45	16		61
ACE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										45	16		61

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT		1.00																		
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW EXPENDABLE)		1																		1

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE				11	25	9																		
INVESTMENT				4	9	3																		
OPERATIONS																								
LOSSES																								
TOTAL				15	34	12																		

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Table 5-33. Electronic Mail Satellite Individual Program Cost Breakdown through 2000 (millions of 1977 dollars) Launched from ETR

FISCAL YEAR	PAYLOAD TRAFFIC				LAUNCH VEHICLE TRAFFIC							PROGRAM COSTS									
					A	B	C	D	E	F	G	PAYLOAD COSTS					LAUNCH VEHICLE COSTS				PROG
	N	R	M	D	IUS	STSC					SHTL	RDTE	INV	OPS	LOSS	TOTAL	INV	OPS	LOSS	TOTAL	TOTAL
1978																					
1979																					
1980																	6			6	6
1981												11	4			15	8			8	23
1982												25	9			34	9			9	43
1983	1				1.0	1.0						9	3			12	2			2	14
1984																					
1985																					
1986																					
1987																					
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1				1 0	1 0						45	16			61	25			25	86

Demonstration portion of the full-scale Electronic Mail satellite launched to low orbit in a shared mode on the Shuttle (Tables 5-34 and 5-35), (3) the balance on modules required for the full-scale Electronic Mail satellite launched to low orbit on a shared Shuttle flight (Table 5-36), (4) on-orbit maintenance calculated at 9 percent of unit cost with launches on a Shuttle and IUS every third year (Tables 5-37 and 5-38), (5) Mission Control including \$35 million for equipment and \$5 million annual operating cost (Table 5-39), and (6) Ground Equipment -- acquisition and operation (Table 5-40). Total program life-cycle cost is given in Table 5-41. It is seen to be \$3.94 billion over a period of almost 20 years. It is shown time-phased by fiscal year in Table 5-42. User cost by equipment by type of user is provided in Table 5-43.

Table 5-34. Electronic Mail Satellite (Technical Demo) Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	800	800	TYPE,	ENDO	1 000	1 000	21	4		21	4		25
ELECTRICAL POWER	500	500	WATTS,	1000	1.000	1.000	7	3		7	3		10
TRACKING,COMMAND	700	700	ALT,	LOW ORBIT	1 000	1 000	49	7		49	7		56
STABILITY,CONTROL	50	50	TYPE,	3-AXIS	1 000	1 000	8	2		8	2		10
PROPULSION	350	450	TOT IMP(L)0		1 000	1 000	8	6		8	6		14
SPACECRAFT	2400	2500					93	22		93	22		115
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000							
SATELLITE .	2400	2500					93	22		93	22		115
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										93	22		115

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT					1.00															
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)					1															1

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE						11	40	33	9															
INVESTMENT							6	12	4															
OPERATIONS																								
LOSSES																								
TOTAL						11	46	45	13															

Table 5-35. Electronic Mail Satellite (Technical Demo) Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars) Launched from ETR

FISCAL YEAR	PAYLOAD TRAFFIC N	P	M	D	LAUNCH VEHICLE TRAFFIC A	B SISC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																					
1983												11				11					11
1984												40	6			46	5			5	51
1985												33	12			45	7			7	52
1986	1					7						9	4			13	1			1	14
1987																					
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1					7						93	22			115	13			13	128

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Table 5-36. Electronic Mail Satellite Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars) Launched from ETR

FISCAL YEAR	PAYLOAD TRAFFIC N	P	R	D	LAUNCH VEHICLE TRAFFIC A	B STSC	C	D	E	F	G SHTL	PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																					
1979																					
1980																					
1981																					
1982																					
1983																					
1984																					
1985													5			5	2			2	7
1986												7	11			18	3			3	21
1987	1					3						7	3			10	1			1	11
1988																					
1989																					
1990																					
1991																					
1992																					
1993																					
1994																					
1995																					
1996																					
1997																					
1998																					
1999																					
2000																					
TOTAL	1					3						14	19			33	6			6	39

Table 5-37. Electronic Mail Satellite On-Orbit Maintenance Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	TOTAL	OTHER INPUTS		COST FACTOR DEV	PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1.000	1.000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0.	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000		4			15		15
SATELLITE	0	0						4			15		15
AGE					0 000								
LAUNCH SUPPORT						0.000							
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL											15		15

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT																				
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)								1			1			1			1			4

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE																								
INVESTMENT										1	2	1	1	2		1	2	1	1	2	1			
OPERATIONS																								
LOSSES																								
TOTAL										1	2	1	1	2		1	2	1	1	2	1			

Table 5-38. Electronic Mail Satellite On-Orbit Maintenance Individual Program Cost Breakdown Through 2000 (millions of 1977 dollars) Launched from ETR

FISCAL YEAR	PAYLOAD TRAFFIC N R M D	LAUNCH VEHICLE TRAFFIC A IUS	B STSC	C	D	E	F	G SHTL	PROGRAM COSTS: PAYLOAD COSTS RDTE	INV	OPS	LOSS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
1978																		
1979																		
1980																		
1981																		
1982																		
1983																		
1984																		
1985																		
1986														6			6	6
1987										1			1	8			8	9
1988										2			2	9			9	11
1989	1	1 0	1 0							1			1	8			8	9
1990										1			1	8			8	9
1991										2			2	9			9	11
1992	1	1 0	1 0											8			8	8
1993										1			1	8			8	9
1994										2			2	9			9	11
1995	1	1 0	1 0							1			1	8			8	9
1996										1			1	8			8	9
1997										2			2	9			9	11
1998	1	1 0	1 0							1			1	2			2	3
1999																		
2000																		
TOTAL	4	4 0	4 0							15			15	100			100	115

Table 5-39. Electronic Mail Satellite Mission Control Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	EMOD	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0,	1 000	1 000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0,	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	35			35			35
SATELLITE	0	0					35			35			35
AGE					0 000								
LAUNCH SUPPORT						0.000		5	5			65	65
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										35		65	100

FISCAL YEAR -	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT				1 00																
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)					1	1	1	1	1	1	1	1	1	1	1	1	1			13

FISCAL YEAR FUNDING	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
RDTE						9	19	7																
INVESTMENT																								
OPERATIONS									5	5	5	5	5	5	5	5	5	5	5	5	5			
LOSSES																								
TOTAL						9	19	7	5	5	5	5	5	5	5	5	5	5	5	5	5			

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Table 5-40. Electronic Mail Satellite Ground Station Equipment Payload Program Cost (millions of 1977 dollars)

SUBSYSTEM	WEIGHTS DRY	WEIGHTS TOTAL	OTHER INPUTS		COST FACTOR DEV	COST FACTOR PROD	BASIC RDTE	AVG UNIT	FIRST UNIT	PAYLOAD PROGRAM COST ESTIMATE RDTE	INVEST	OPS	TOTAL
STRUCTURE	0	0	TYPE,	ENDO	1 000	1 000							
ELECTRICAL POWER	0	0	WATTS,	0.	1 000	1 000							
TRACKING,COMMAND	0	0	ALT,	LOW ORBIT	1 000	1 000							
STABILITY,CONTROL	0	0	TYPE,	SPIN	1 000	1 000							
PROPULSION	0	0	TOT IMP	0	1 000	1 000							
SPACECRAFT	0	0											
MISSION EQUIPMENT	0	0	COMPLXTY,	LOW	1 000	1 000	1599			1599			1599
SATELLITE	0	0					1599			1599			1599
AGE					0 000								
LAUNCH SUPPORT						0.000		188	188			1880	1880
MISCELLANEOUS													
SE AND TD													
RELIABILITY EFF													
TOTAL										1599		1880	3479

FISCAL YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
DESIGNS AND REDESIGNS																				
SPACECRAFT																				
MISSION EQUIPMENT							1 00													
SATELLITE SCHEDULE																				
NEW (EXPENDABLE)								1	1	1	1	1	1	1	1	1	1			10

FISCAL YEAR	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
FUNDING																								
RDTE								192	687	560	160													
INVESTMENT																								
OPERATIONS												188	188	188	188	188	188	188	188	188	188			
LOSSES																								
TOTAL								192	687	560	160	188	188	188	188	188	188	188	188	188	188			

Table 5-41. Satellite Traffic and Cost Summary Through 2000 (millions of 1977 dollars)

SATELLITE NAME	PAYLOAD TRAFFIC	LAUNCH VEHICLE TRAFFIC 1ST STAGES	IUS	TUG	PROGRAM COSTS RDTE	PAYLOAD COSTS INV	OPS	TOTAL	LAUNCH VEHICLE COSTS INV	OPS	LOSS	TOTAL	PROG TOTAL
SATELLITE-BASED INITIATIVE													
ELECTRONIC MAIL SYSTEM													
EMS (CONCEPT DEMO)	1	1.0	1.0		45	16		61	25			25	86
EMS (TECHNCL DEMO)	1	7			93	22		115	13			13	128
ELECTRNIC MAIL SAT	1	3			14	19		33	6			6	39
EMS ON-ORBIT MAINT	4	4 0	4 0			15		15	100			100	115
EMS MISSION CONTRL	13				35		65	100					100
EMS GRND STA EQUIP	10				1599		1880	3479					3479
SUBTOTAL	30	6 0	5 0		1786	72	1945	3803	144			144	3947

Table 5-42. Total Program Costs by Fiscal Year Through 2000 (millions of 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVE																							
ELECTRONIC MAIL SYSTEM																							
EMS (CONCEPT DEMO)			6	23	43	14																	
EMS (TECHNCL DEMO)						11	51	52	14														
ELECTRNIC MAIL SAT								7	21	11													
EMS ON-ORBIT MAINT									6	9	11	9	9	11	8	9	11	9	9	11	3		
EMS MISSION CONTRL						9	19	7	5	5	5	5	5	5	5	5	5	5	5	5	5		
EMS GRND STA EQUIP								192	687	560	160	188	188	188	188	188	188	188	188	188	188		
SUBTOTAL			6	23	43	34	70	258	733	585	176	202	202	204	201	202	204	202	202	204	196		

Table 5-43. Electronic Mail - User Cost (Satellite-Based System)

EQUIPMENT QCQUISITION

USER	ANTENNA	RECEIVER	TRANS.	BUFFER. MEMORY	INSTALL.	FAX	EQUIPMENT TOTAL COST	SATELLITE COST	TOTAL COST PER USER
1	700	50	215	443	88	300	1796	152	1948
2	700	50	300	4300	860	300	6510	2056	8566
3	700	50	300	7500	1500	3000	13050	2880	15930
4	700	50	312	23500	4700	3000	32262	12000	44262

ANNUAL OPERATIONS

USER	ANTENNA	ELECTR. EQUIP	FAX	TAXES	PWR	G & A	SATELLITE OPERATIONS	TOTAL ANNUAL OPS COST
1	35	56	36	36	40	20	3	226
2	35	384	36	130	40	65	30	720
3	35	652	360	261	60	139	40	1547
4	35	1997	360	643	60	310	171	3576

5.3 DEVELOPMENT PLAN

A development plan for the Electronic Mail initiative was defined using the same ground rules and philosophy carried out for the Personal Communications system in Section 3 and the Educational Television system of Section 4. The development plan thus follows the concept of measured steps for demonstration leading to an operational system, with all satellites orbited having operational utility. The development plan is illustrated in Figure 5-11. It is seen to be very similar to those shown in Sections 3.3 and 4.3, and assumes a concept demonstration step beginning in calendar year 1980. This satellite would demonstrate baseband switching using a minimum two-port processor buffer device operating in conjunction with two transponders of the right power and the right frequency, representative of the final device, but using a 10-ft rigid antenna with only two feeds. This device would only be able to operate at the beam rate typical of the smallest of the final beams required in the final satellite. A number

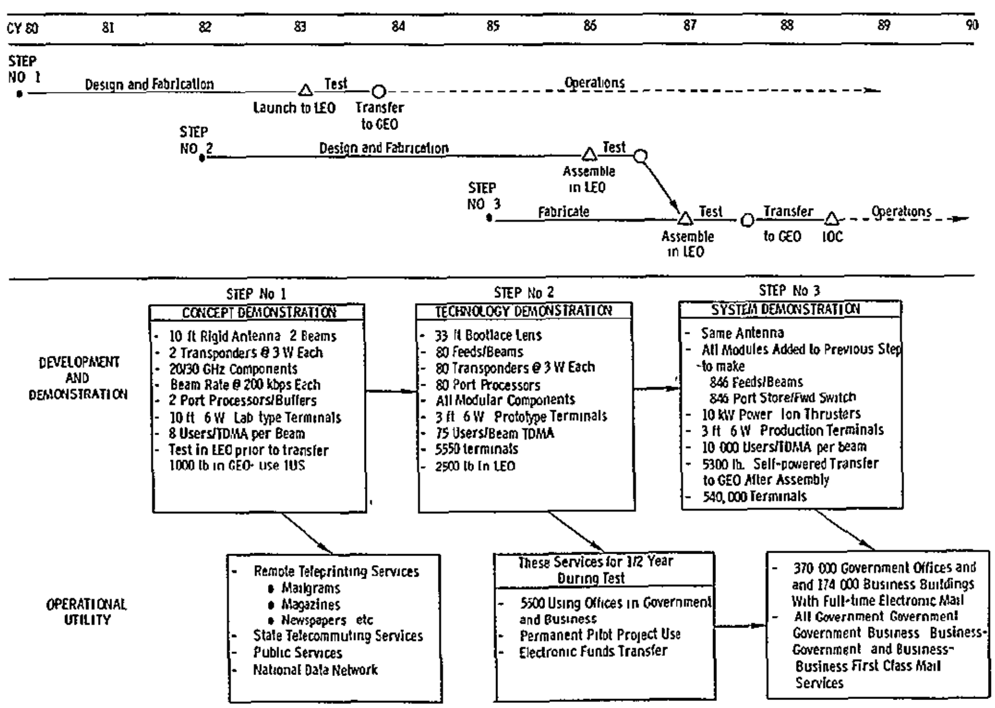

Figure 5-11. Development Plan for Electronic Mail Initiative

of laboratory or shelf-type terminals would be procured - 10 with less than 1 kbps capacity, five with a 5 kbps capacity, and two with 40 kbps capacity, to demonstrate the operation of the terminals at their eventual speeds.

The satellite would be tested in low earth orbit, even though its weight is only about 1000 lb, in order to maximize the use of the space shuttle. It would then be transferred to geostationary orbit using an IUS and following checkout be leased or sold for remote teleprinter applications, state telecommunicating service needs or public service communications of all types, or form the basis for a budding National Data Network. This operational capability would remain at least through the 1989, and perhaps later, time period.

The second step would begin construction in 1982 and would consist of the technology demonstration step featuring the final antenna - 9.5-m dia dual frequency lens antenna in a strategy identical to that used in Sections 3.4 and 4.4. This antenna would be orbited in 1986, deployed in low earth orbit, and assembled with about 10 percent of the feeds and transponders for the final satellite. They would be modular, as would be the power components and the space processor. Only 10 percent of the capacity would be expected to be orbited at this time. Seventy five users could be operated per beam with prototype terminals in a time division multiple access technique, in comparison with only eight users similarly accessed in the concept demonstrators step. A total of about 5500 terminals might be procured to test the system, with users located in most major cities as well as remote areas. The system operation would be tested in a simulation of the final system using the 5500 terminals in actual offices in selected government and business buildings, in a permanent pilot project application. These offices could become the first to utilize the satellite when it finally becomes permanently available at the conclusion of Step No. 3.

The third step follows theprinciples of the previous two initiatives as described in Sections 3.4 and 4.4 and mates the rest of the modules to the previously orbited ones, to make the final satellite. All of the feeds, beams, electronics, and all of the ports of the store-and-forward switch are orbited at this time, as are the rest of the modules of the power system, and the ion thrusters for the transfer. The entire assembly is checked out.

The production terminals would be procured and deployed. The total satellite TDMA with 10,000 users per beam maximum would be tested while the satellite is still in low orbit, though for only a few minutes at a time, and then the satellite would transfer itself to geostationary orbit, where final tests would be performed between 1988 and 1989. At this time it would enter the operational stage, connecting 540,000 terminals in 370,000 government offices and 174,000 business buildings as designed. Simultaneously the first satellite - the concept demonstration step - could be removed from operations, or it could remain to satisfy other public service needs in parallel with the Electronic Mail satellite. Thus, the Electronic Mail development plan could result in an operational system by 1989, nine years after system go-ahead.

This Electronic Mail system design was found to be fairly straightforward, and it is quite possible that the development plan outlined above is too conservative. It may well be that a single step or at most two steps would be adequate to lend confidence to the design. In that case about two years could probably be trimmed from this schedule, resulting in an operational satellite by 1987. However, to be realistic it is unlikely that a system of this size can be reviewed and approved as a new start by 1980 without an intervening year of detail system design study and perhaps a year or two of debate on the social issues. It is therefore, most likely that a satellite system with this much capacity will not see operation until the early 1990 time period, even though technologically it could probably be orbited three or four years earlier.

More detail on the goals, characteristics, operational use, and specifics about the terminals and satellites for each development plan step are shown in Table 5-44.

Table 5-44. Development Plan for Electronic Mail

CY	82 — 83 — 84 — 85 — 86 — 87 — 88 — 89 — 90
STEP No 1 DEMONSTRATE CONCEPT	(83) △ TEST — OPERATE → (89)
STEP No 2 DEMONSTRATE TECHNOLOGY	(86) △ TEST —△ ASSEMBLE
STEP No 3 DEMONSTRATE SYSTEM	ASSEMBLE —△ TEST —△— TRANSFER —△— IOC — OPERATE →

		STEP 1	STEP 2	STEP 3
GOALS		DEMONSTRATE BASEBAND SWITCHING 20/30 GHz COMPONENT, USE LARGER EARTH STATIONS TEST IN LEO THEN TRANSFER AND RETEST IN GEO	DEMONSTRATE FULL ANTENNA, 2 MODULES OF FOCAL ARRAY POWER MODULES FINAL TECHNOLOGY EIRP & ASSEMBLY TECHNIQUES TEST IN LEO WITH FULL SIZE TERMINALS	DEMONSTRATE SYSTEM WITH FULL COMPLEMENTAL MODULES POWER, AND SPECTRAL OCCUPANCY ASSEMBLE IN LEO TRANSFER TO GEO
OVERALL CHARACTERISTICS		WEIGHT 1000 LB GEO	WEIGHT 2500 LB LEO	WEIGHT 5300 LB LEO GEO
OPERATIONAL USE		REMOTE TELEPRINTING SERVICES, WESTERN UNION MAILGRAM EXTENSION STATE TELECOMMUTING SERVICES	• 1000 USING OFFICERS IN GOVERNMENT AND BUSINESS ON A PERMANENT PILOT BASIS ELECTRONICS FUNDS TRANSFER SERVICES	370,000 GOVERNMENT OFFICE • 170,000 BUSINESS CORPORATIONS ALL GOVERNMENT GOVERNMENT, GOVERNMENT-GOVERNMENT AND BUSINESS BUSINESS FIRST CLASS MAIL
SATELLITE	DESIGN CONSTRUCTION	LABORATORY/EXPERIMENTAL PROTOTYPE RIGID/FIXED	• FINAL DESIGN • MODULAR/ADD-ON ASSEMBLED IN ORBIT	ADD ALL MODULES AT FINAL DESIGN
	ANTENNA	RIGID REFLECTOR 10 ft DIA • 2 FEEDS/BEAMS	BOOTLACE LENS 33 ft DIA DUAL FREQUENCY VARIABLE DELAY ELEMENTS 80 FEEDS BEAMS	SAME AS LAST STEP ADD REST OF FEEDS (766) FOR TOTAL OF 846 BEAMS
	TRANSPONDERS	2 AT 3 Watts EACH 20/30 GHz DEVELOPMENTAL DEMODULATE/REMODULATE AT BASEBAND 1.2 Mbps CAPACITY EACH	80 AT 3 Watts EACH 20/30 GHz FINAL TECHNOLOGY DEMOD/REMOD AT BASEBAND 12 Mbps EACH	SAME AS LAST STEP ADD REST OF TRANSPONDERS 766 FOR TOTAL OF 846 12 Mbps EACH
	SWITCH	2 PORT STORE AND FORWARD SIMULTANEOUS READ IN READ OUT	80 CHANNEL STORE AND FORWARD SIMULTANEOUS READ IN READ-OUT MODULE OF FINAL SWITCH/PROCESSOR	SAME AS LAST STEP • ADD MODULES FOR COMPLETE 846 PORT CAPABILITY
	POWER	300 Watts SOLAR CELLS	1 kW MODULE • SOLAR CELLS • MODULAR, DEPLOYABLE	10 kW TOTAL SOLAR CELLS ADD ALL MODULES
	PROPULSION STABILIZATION	CHEMICAL ACS IUS	CHEMICAL ACS AND SHORT TERM STATION KEEPING	• ADD ION ENGINES FOR TRANSFER PROPULSION AND LONG TERM STATIONKEEPING
TERMINALS	CHARACTERISTICS	LABORATORY TYPE 10 ft ANTENNA FIXED 6 Watts • TDMA 8 USERS/BEAM	PROTOTYPES (final design) 3 ft ANTENNA FIXED • 6 Watts TDMA 75 USERS/BEAM	PRODUCTION RUNS 3 ft ANTENNA FIXED 6 Watts TDMA 10 000 USERS BEAM
	NUMBER	10 AT 1 kbps 5 AT 5 kbps • 2 AT 40 kbps	5000 AT < 1 kbps 500 AT 5 kbps 50 AT 40 kbps	473,000 AT 1 kbps 35 000 AT 2 kbps 25 000 AT 7 kbps 6 000 AT 30 kbps

5.4 ALTERNATE CONCEPTS

A number of major alternates exist to the satellite system solution for connecting the roughly 1/2 million terminals on government and business buildings. At the outset, use of the same facsimile machines and buffers as the ground segment of the space alternative is assumed, and only different means of interconnection of the buildings themselves treated.

The major viable system options are shown in Figure 5-12. The current technique of interchanging mail, of course, uses the U.S. Postal Service, with physical delivery and pickup and physical interchange of mail over the long haul, and using public and dedicated transportation systems. An obvious alternative is to collect mail physically at several regional centers and then to interchange mail between regional centers electronically using a commercial comsat with terminals at the Postal Service regional centers. Although clearly feasible, this is the architecture

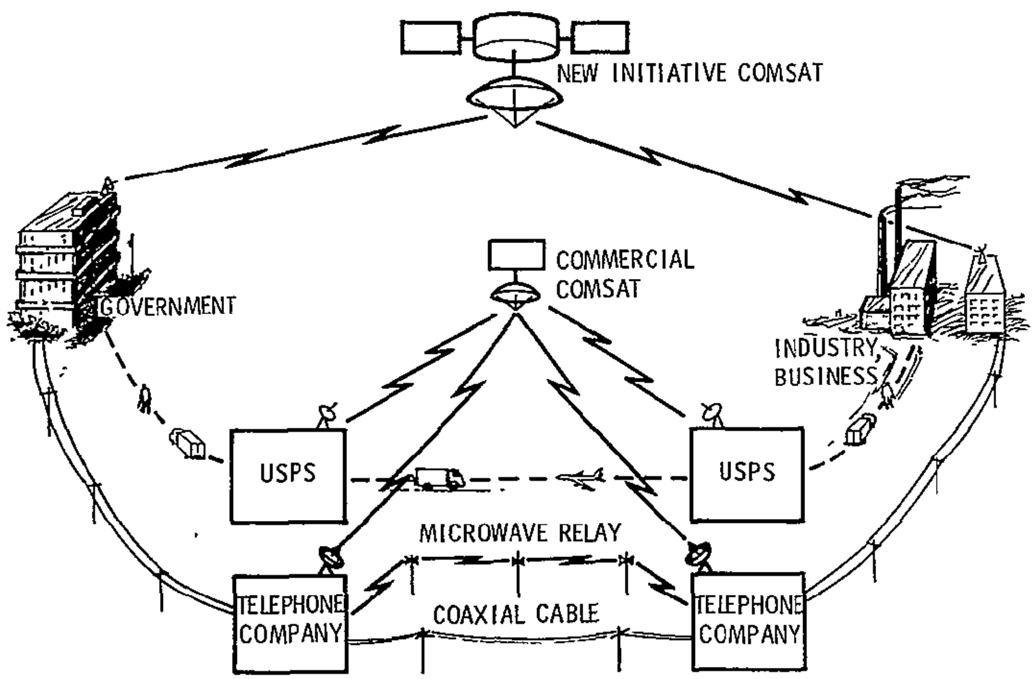

Figure 5-12. Major System Options for Electronic Mail

of the system concept investigated for the U.S. Postal Service by RCA as a system contractor. That study was completed during the course of this study, and its results will be included in the cost comparison in the Section 5.5. However, the disadvantages of a regional center system of that type are many and fundamental: physical delivery and pickup is required for the bulk of the mail between the centers and the users. Thus, dependence on the mail carrier is retained. While this accomplishes an easier fit into the existing social structure, it cannot help but result in increased costs.

A second major option is for all-electronic interchange building-to-building, but not using satellite terminals at the user buildings. This option, also illustrated in Figure 5-12, depends on the use of the telephone networks. Each building would be connected to the telephone company switched network through a telephone line. The telephone company normal data interconnection services being used for accessing the users. The means used by the telephone companies for their long-haul plant from exchange-to-exchange includes coaxial cables, microwave relay, and the use of commercial comsats. Although other transmission techniques, including buried millimeter waveguide and fiber optics, may come into play in the time period of concern, they need not be treated here, inasmuch as the entire telephone company plant can be treated as a black box, since their services and charges are well defined.

5.4.1 Alternative Concept Selection

Inasmuch as the RCA study for the U.S. Postal Service has defined system options utilizing commercial comsats for exchange of mail between regional centers, it is probably appropriate for this study to concentrate on the distribution of mail directly from building to building. The results of the U.S. Postal Service study will be included in the cost comparison in the sections below.

The only viable alternative left, therefore, is the one in which telephone lines are used to connect each building through the telephone switched plant. This alternative will be described below and costed in this section.

5.4.2 Alternative Concept Definition

Definition of the system concept utilizing the telephone networks proceeded after consultations with AT&T to determine the ground rules that might be appropriate to use for the network services likely to be available in the 1988 time period. It was determined that data interchange of 300 to 40,000 bps between 1/2 million terminals could probably be handled by the telephone networks expected to exist in the 1987-88 time period, so that no extra costs would have to be levied against the Electronic Mail system for establishing the lines or the switches required. It is estimated that capacity in excess of 40 kbps with a digitally equalized line, to any building of choice, will be standard in 1988. Furthermore, it was estimated that the switching system will not be overloaded by the addition of 1/2 million subscribers.

Inasmuch as all the user buildings are located in or near population centers, each building is assumed to have telephone service independent of Electronic Mail. Thus it will not be necessary to run entirely new telephone lines to the general vicinity of these buildings.

Further, the large terminal buildings in major complexes are assumed to have enough excess capacity in their normal telephone service that 40 kbps can be interwoven among the normal telephone traffic without requiring any additional telephone lines (local loops) to be run to the local telephone pole. It was assumed, however, that terminals in small buildings would require an additional telephone line from the local telephone pole, inasmuch as it is unlikely that they would have 40 kbps digital capacity available in addition to a voice channel in the absence of Electronic Mail. On the subject of charges by the telephone companies for the use of the network, it will be remembered that in the discussion of Section 5.1, it was determined by the U.S. Postal Service that about two-thirds of the "mail" to be exchanged stays within about 50 miles from the point of origin and thus will only be subject to local or extended zone flat rate monthly charges regardless of the number of "messages" sent per month. The one-third of the mail that represents long distance transmissions outside of 50 miles of the point of origin would be subject to toll rates. In order to be fair about the long distance toll rates, it must be remembered that those rates are set by regulatory agencies. Thus, the actual amounts charged per minute are about twice the rate at which the service could be offered in the absence of the regulatory burden - the excess being used to subsidize local telephone services. The toll rates are therefore taken at about one-half of the current values and represent unburdened costs, since it is uncertain what the regulatory burden will be in 1988.

These assumptions and conditions are summarized in Table 5-45. The alternative terminals are shown in block diagram form in Figure 5-13 in which it is seen that the control processor, transmitter, and receiver buffers, the facsimile readers and printers, are identical to those for thesatellite terminals. The only difference is the absence of a transmitter, receiver, diplexer, and antenna, and their replacement by modem that allows the digital information to be placed on a telephone line.

Table 4-45. Alternative Concept Description - Electronic Mail

- USES SAME FASCIMILE MACHINES AND BUFFERS AS SPACE ALTERNATIVE
- INTERCONNECTION OF TERMINALS VIA TELEPHONE NETWORKS
- ASSUMPTIONS AND CONDITIONS
  - EACH SMALL TERMINAL BUILDING REQUIRES ONE ADDITIONAL TELEPHONE LINE
  - LARGE TERMINAL BUILDINGS ASSUMED TO HAVE ENOUGH EXCESS CAPACITY IN TELEPHONE LINES
  - ALL SERVICES VIA NORMAL TELEPHONE SWITCHED PLANT
  - >40 kbps CAPACITY SERVICE WILL BE STANDARD IN 1988, ADEQUATE FOR ALL TERMINALS
  - 2/3 OF "MAIL" STAYS WITHIN 50 MILES OF POINT OF ORIGIN; IS SUBJECT TO LOCAL FLAT RATE CHARGES
  - 1/3 OF "MAIL" IS LONG DISTANCE, SUBJECT TO TOLL RATES
  - TOLL RATES TAKEN AT HALF OF CURRENT VALUES TO REMOVE REGULATORY AGENCY BURDENS

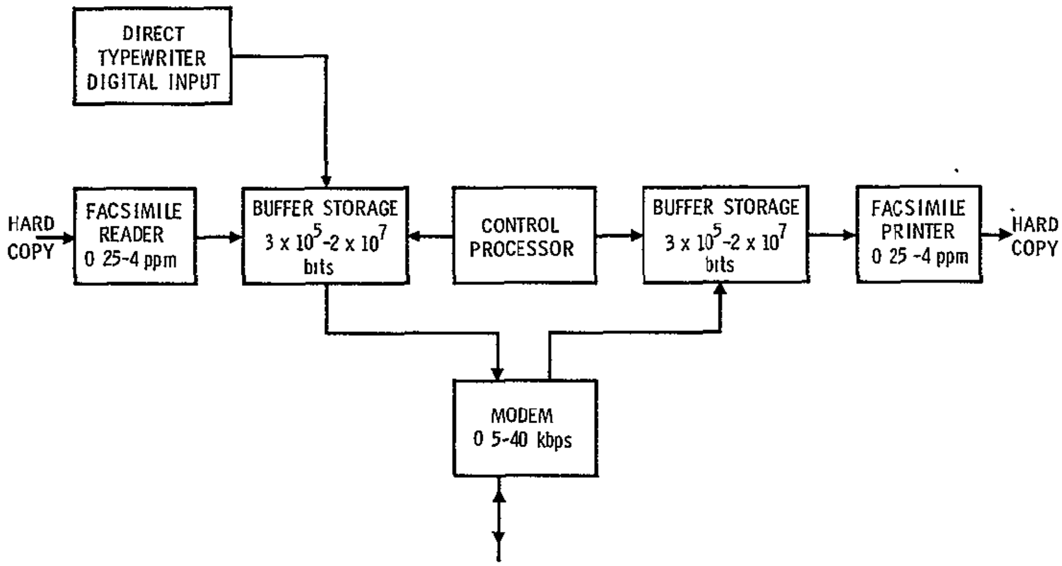

Figure 5-13. Electronic Mail - Alternative Terminals

The modem could be a feature purchased with each terminal or it could be supplied as a service by the telephone company, as the case may be. It was assumed for the sake of pricing that the modem would be a feature purchased as part of an alternate terminal, requiring but a telephone line with no interfaces except two or three pins on a terminal board. It will be remembered that 472,000 locations or buildings will require a service of 500 bps or less - 35400 requiring a service of 1 to 3 kbps, 25,000 requiring 3 to 10 kbps, and 5730 requiring 10 to 40 kbps.

5.4.3 Alternative Concept Cost Estimate

The same procedures outlined in Section 4.4.3 were used to generate cost estimates for the ground-based alternative Electronic Mail system. The user equipment shown in Table 5-46 is the same as a portion of that given in Table 5-31. In addition, ground telephone links replace the satellite. The charges of the network were calculated at $36,674 million over a 10-yr period. This assumed that 70 percent of the "mail" was long distance and charged at toll rates (less regulatory burden), and 30 percent

Table 5-46. Electronic Mail System Ground Equipment Cost Estimate (Ground-Based Alternative)

ITEM-EQUIPMENT	QTY	UNIT COST	TOTAL ($ 000's)	BASIS OF ESTIMATE
BUFFER, STORAGE & CONTROL				
USER 1	474000	200	94800	SAME AS SAT.-BASED WITH NO MEMORY STORAGE
USER 2	35000	3500	122500	SAME AS SAT.-BASED WITH 1/2 MEMORY STORAGE
USER 3	25000	5100	127500	SAME AS SAT -BASED WITH 1/2 MEMORY STORAGE
USER 4	6000	15500	93000	SAME AS SAT -BASED WITH 1/2 MEMORY STORAGE
INSTALLATION			87560	20% OF EQUIPMENT COST
FAX			245700	SAME AS SAT.-BASED ALTERNATIVE
TOTAL EQUIPMENT			771060	
OPERATIONS & MAINT/yr	**BASE**	**UNIT OR %**	**TOTAL/yr ($ 000's)**	
FAX SERVICE	245700	12%	29500	SAME AS SATELLITE-BASED ALTERNATIVE
ELECTRONICS EQUIP	525360	7%	36775	
TAXES	771060	2%	15421	
POWER	(651000 kW)	$10/kW/yr	16510	10 hr/day, 200 days/yr
			98206	
G & A	98206	10%	9821	
TOTAL EQ. OPS & MAINT/yr			108027	

of the "mail" stays within the flat rate coverage zone - roughly the 50-mi dia areas.

The total estimated cost for the ground alternative is $38.5 billion, given in Table 5-47. It is seen that the cost is dominated by the network charges, even though they are half of today's rates, the regulatory overburden having been removed. Time-phased costs by fiscal years is provided in Table 5-48. User cost by equipment and by type of user is provided in Table 5-49.

Table 5-47. Ground-Based Electronic Mail Cost

GROUND-BASED ALTERNATIVE TO SATELLITE INITIATIVE		Non recurring	Operating	Total
ELECTRONIC MAIL SYSTEM (GROUND-BASED)				
EM GRD-BASED EQUIP	10	771	1080	1851
EMS TEL CONNECTION	10	14	36660	36674
SUBTOTAL	20	785	37740	38525

Table 5-48. Total Program Costs by Fiscal Year Through 2000 (millions of 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
ELECTRONIC MAIL SYSTEM (GROUND-BASED)																							
EM GRD-BASED EQUIP									93	331	270	185	108	108	108	108	108	108	108	108	108		
EMS TEL CONNECTION											7	3673	3666	3666	3666	3666	3666	3666	3666	3666	3666		
SUBTOTAL									93	331	277	3858	3774	3774	3774	3774	3774	3774	3774	3774	3774		

Table 5-49. Electronic Mail - User Cost (Ground-Based Alternative)

EQUIPMENT ACQUISITION

USER	BUFFER. MEMORY	FAX	LOCAL CONNECTION	TOTAL COST PER USER
1	240	300	25	565
2	4200	300	25	4525
3	6120	3000	25	9145
4	18600	3000	25	21625

ANNUAL OPERATIONS

USER	ELECTR. EQUIP.	FAX	TAXES	Pwr	G & A	LOCAL SERVICE	LONG DIST.	TOTAL ANNUAL Ops COST
1	17	36	11	30	9	150	1891	2144
2	293	36	89	30	48	150	25605	26251
3	426	360	180	40	104	150	35850	37110
4	1302	360	432	40	215	150	149375	151874

5.5 COMPARISON OF SPACE AND GROUND ALTERNATIVES

This section compares the alternative solutions to the Electronic Mail distribution problem, with both alternatives sized against the requirements derived in Section 5.1. Technical and operational comparisons as well as cost comparisons will be treated.

5.5.1 Technical and Operational Comparisons

From the standpoint of technical and operational factors, the space and ground alternatives selected are completely equivalent with very little difference in the level, type, and quality of service. Minor differences might arise, such as an occasional outage of a link due to equipment failure, and this could occur both in the space and in the ground alternatives. Outage of a link in the space system due to rainfall could be expected on the average of no more than a few hours a year in a few of the links, however, the size of the onboard store in the satellite and the ground buffers were designed to handle such outage. The ground alternative system might also be subject to outages of similar duration, but probably due strictly to equipment failure; or in less expected cases, due to blocking of the network because of temporary overloads. The buffer store in the terminals is expected to handle those situations as well, so that from an operational point of view the ground and space systems services are essentially indistinguishable.

Both alternatives feature mail delivery and collection at least once every 10-hr day to and from 540,000 terminals. The fact that one uses a radio system with a relay 20,000 mi away, and the other uses hard wires to terminals that are interconnected by microwave relay towers or commercial comsats 20,000 mi away, makes no difference operationally and cannot be told apart by the user. It is assumed, of course, that the satellite system, including the radio components of the terminals, would be designed to have the same availability as the telephone networks exhibit. In practice, this is feasible. The bit error rates for the datastream that could be offered with the space system and the ground system are identical inasmuch as the digital transmissions can be regenerated at will -- so that no loss of quality or signal-to-noise ratio in the finished print would occur with either alternative.

5.5.2 Cost Comparison

The cost for the ground and space initiative alternatives were computed and are compared in this section against the current U.S. Postal operations, as well as the Postal Service hybrid space/ground alternative concept defined by RCA. At the outset, it must be recognized that to some extent the current Postal Service, as well as the RCA alternate, are "apples" whereas the space and ground alternatives defined in this study are "oranges". This is in the sense that the current study treated only the government and business mail segment of the total mailstream and did not treat the home segment which of course, the current Postal Service handles as does the hybrid alternative. However, in defense of making a comparison, it can be said that the RCA alternative also exchanges about 15 to 20 billion pieces of mail per year as do the space and ground alternatives of this study, and so the comparison is reasonably fair.

As far as the current Postal Service user charges (stamps) are concerned they are the only standard of comparison that can be used inasmuch as the mail costs to the user are well defined. These have just recently risen to 15 cents per letter.

There is an area of inaccuracy in that the mail costs to the government were treated in this study as a real expense, chargeable to the government on a per letter basis rather than on an average of each agency or department use. This tends to be a small error, however, as patterns of mail usage develop rapidly and stay very stable.

Within these guidelines and limitations a user cost comparison was prepared and appears in Table 5-50. This table includes a first column in which the total 20-yr costs of each alternative concept is shown. This cost includes all user equipment, the 10 yr of research, development, test and evaluation, as well as 10 yr of operation including maintenance, replacement, and

Table 5-50. User Cost Comparison - Electronic Mail

SYSTEM	TOTAL 20-YEAR COSTS (Billions)	COSTS PER LETTER (Cents)	PERCENT OF ANNUAL MAIL VOLUME TO BREAK EVEN WITH USPS	ANNUAL PROFIT/LOSS AT 15 CENTS PER LETTER
SPACE INITIATIVE - 540,000 Terminals	3.96	2.6	17	Profit of $1 9 Billion
GROUND ALTERNATIVE - 540,000 Terminals	38 5	25.3	---	Loss of $1.6 Billion
USPS HYBRID SPACE/ GROUND ALTERNATIVE - 360 Distribution Centers with Mail Carrier P/U-Delivery Plus 6220 Public Terminals	5 8 Center-Center 15.4 Mail Carriers 21 2 Total	2 9 Center-Center 7 0 Mail Carriers 9.9 Total	66	Profit of $1.1 Billion
CURRENT USPS	---	15.0	100	Break Even

- 1977 Dollars, All R&D, Investment, 10-Year Operations, and User Equipment Included
- Equipment Costs Prorated Over 10 Years
- 15 Billion Mail Pieces per Year for Space, Ground Alternatives, 22 Billion for USPS Hybrid, ≈70 Billion for Current USPS

refurbishment, for both alternatives. One maintenance flight every two years was costed for the space alternative.

The space initiative is seen to cost just under $4 billion during this 20-yr period. This cost includes purchasing and operating the satellite for 10 yr, the development of the precursor satellite, as well as purchasing, operating, and maintaining the 540, 000 terminals.

In the ground alternative the same assumptions are made, except the costs charged by the telephone networks are included as part of the operating costs, rather than satellites. These costs are charged at one-half of that required by the regulatory agencies, to remove the current regulatory overburden, and were charged at $12/month flat rate for local mail and 17 cents/min for long distance mail.

The Postal Service Hybrid alternative was chosen from among several major options studied by RCA. The three major ones consisted of Alternate A - with 150 distribution centers linked by satellite, an annual volume of 20 million mail pieces, about 2000 public terminals of low capacity, and mail carrier delivery for all mail not handled by the public terminals. Alternate B - includes 360 regional stations, an annual volume of 22 billion mail pieces, 6220 public terminals, and mail carrier delivery. Alternate C - includes 87 regional distribution centers, an annual mail volume of 24 billion pieces per year, 7100 public terminals, and mail carrier delivery.

Out of these three alternatives, it was decided to choose Alternative B inasmuch as it maximized the number of distribution centers, for a better comparison against the space/ground alternatives defined in this study.

The total costs for the U.S. Postal Service hybrid alternative were determined to be \$5.8 billion for a 10-yr operation period, including all development, test, and evaluation of the equipment to transfer mail from center-to-center. In addition, the cost for the mail carriers carrying 22 billion mail pieces per year at 7 cents each, over a 10-yr period, is about \$15.4 billion making a total of \$21.2 billion.

The equivalent costs per letter are shown in the second column, which represents the total costs in the previous column divided by the number of mail pieces carried in the time period. It is seen that the space initiative amortizes all of the costs over this period and breaks even at 2.6 cents per letter. The ground alternative cost is almost an order of magnitude higher at 25.3 cents per letter. The Postal Service hybrid space/ground alternative shows almost equal costs to the space initiative for the center-to-center portion at 2.9 cents per letter, but the cost of the mail carriers for the bulk of the mail must be added. Since this is about 7 cents per letter, the total is 9.9 cents per letter for all costs.

These are to be compared against the current Postal Service rates of 15 cents per letter. It is clear that Electronic Mail transfer, whether using pure space systems or space/ground hybrids, is a more efficient way of moving mail than the current method of physical handling. The pure ground alternative is noncompetitive however, primarily due to the costs stemming from the charges of the telephone network (those costs would approximately double if the currently regulated charges had been used). The 9.9 cents versus 2.6 cents for the hybrid and pure space initiative needs further explanation, since they are "apples" and "oranges" to some extent since they do not represent quite the same class of service. The hybrid system handles all classes of mail including home delivery, however, it generally does not result in mail collection or delivery with the timeliness of the space initiative, which collects and delivers mail every ten min on the average (with at least one complete letter being exchanged, for the smallest terminals, every 20 min and for the largest terminals, in a few seconds). There is also the convenience of being able to send mail directly from the user facility with the space initiative as opposed to having to physically deliver the mail to the post office in the hybrid system.

Perhaps a more dramatic way of comparing the concepts is in the fourth and last column of Table 5-50. In this column the annual profit or loss is shown if the users were charged at 15 cents per letter. Whatever agency, corporation, consortium, or other entity were to invest and operate the space initiative, they would make a profit of $1.9 billion per year (19 billion over a 10-yr period). The ground alternative would lose $1.6 billion per year at this user cost. The hybrid space/ground alternative would make a profit of $1.1 billion/year. The current U.S. Postal Service would break even (though they appear to lose money at 15 cents per letter). It is therefore seen that on a strict dollars and cents basis, the space initiative is by far the most attractive alternative, offering service either at extremely reduced rates compared to current practice, having the potential to make very large profits for whoever goes into that business, or a combination of both.

One other aspect of the Electronic Mail system is the cost to the user for the equipment and its operation, and how such facilities might be acquired and placed into 540, 000 buildings. Table 5-51 shows the equipment, operations, as well as the total cost for each of the four classes of user sizes considered. It is seen that for the small user the satellite-based system costs less than one fifth of that of the ground-based system on an average over a 10-yr period, whereas for the large users the cost savings is even more dramatic, being roughly a factor of 20 times cheaper. On the average, the satellite-based equipment is about 10 times cheaper to install and operate than the ground-based system. This stems from the telephone company charges in the alternative system.

Either system could be installed and operated by a private entity, purchasing the satellite and offering the service for fees plus profit; alternatively, an agency, corporation, or consortium could put up the satellite, while a number of sources could supply the earth terminals -- thus, fostering competition and low cost.

Table 5-51. Electronic Mail - Annual User Cost Comparison

USER SIZE	NO OF USERS	GROUND-BASED			SATELLITE-BASED		
		EQUIPMENT	OPERATIONS	TOTAL	EQUIPMENT	OPERATIONS	TOTAL
Small	472,000	57	2,144	2,201	195	226	421
Modest	35,400	453	26,251	26,604	857	720	1,577
Moderate	25,000	914	37,110	38,024	1,593	1,547	3,140
Large	5,730	2,163	151,874	154,037	4,426	3,576	8,002
AVERAGE	540,000	145	6,988	7,133	347	382	729

- All Costs in Millions of 1977 Dollars
- 10-Years Development/Demonstration
- 10 Years of Operations/Maintenance
- Equipment Acquisition Cost Prorated Over 10 Years

The method of acquiring and operating the system and means to minimize job dislocations have not been explored in this study. Clearly these are some of the most fundamental questions and need to be investigated in the process of more detailed definition of systems of this type.

6. EVALUATION AND SOCIAL CONSIDERATIONS

The three initiative system concepts discussed in Sections 3, 4, and 5 may now be evaluated on a comparative basis and some of their technical, operational, and social considerations discussed.

6.1 COST EVALUATION

The overall cost comparison for all three initiatives is shown in Table 6-1. In this table it is seen that in every case the space system is by far the least expensive alternative in terms of costs to the

Table 6-1. Overall Cost Comparison

ALTERNATIVE	ELECTRONIC MAIL	EDUCATIONAL TV	PERSONAL/EMERGENCY COMMUNICATIONS
SPACE	2.6 CENTS/LETTER	0.36 $/CLASS HOUR	0.7 CENTS/MIN
GROUND	9.9-25.3 CENTS/LETTER	1.78 $/CLASS HOUR	20 CENTS/MIN
CURRENT SERVICES	15 CENTS/LETTER (Stamps)	≈10 $/CLASS HOUR (Teachers)	13.3 CENTS/MIN (Telephones)
TOTAL COSTS OF SPACE SYSTEM INCLUDING RDT&E AND 10-yr OPERATIONS	3.9 BILLION	2.7 BILLION	2.3 BILLION
TOTAL 10-yr INCOME (or savings) POSSIBLE IF SPACE SYSTEM IS BUILT AND OPERATED, BUT USERS CHARGED AT CURRENT SERVICE RATES	23 BILLION	73 BILLION	48 BILLION

- 1977 DOLLARS
- IOC 1988-1990

user, even when hybrids such as the U.S. Postal Service Electronic Mail Hybrid alternatives are considered. In this table the bottom row shows the total 10-yr profit (or savings) if the space alternative is chosen but users charged as per the current cost of services. These numbers are seen to be $23 billion for the Electronic Mail initiative, $73 billion for the Educational TV initiative and $48 billion for the Personal Communications initiative. The annual profits (or savings) which will accrue are of course $2.3, $7.3, and $4.8 billion respectively, on an investment of $3.9, $2.7, and $2.3 billion, respectively. Savings or profits like these are so astoundingly large that they make a forceful point in favor of the space system concepts. It is also seen that with the low costs to the users, namely 2.6 cents a letter, 36 cents per class-hour, or 0.7 cents per minute, these systems could create their own constituency and their own markets upon being made public -- without a great deal of "selling".

Thus, it is felt that, at least from the standpoint of costs and return on investment, the space systems represent so attractive a business potential that any social or institutional problems could fall under the onslaught of those wishing to capitalize on that potential.

The cost numbers in Table 6-1 are based on 1977 dollars; as we all know too well, inflation is eroding our purchasing power at a fairly steady rate. For this reason the total program costs of both terrestrial and space alternatives are compared on the basis of inflated dollars in Table 6-2. An inflation rate varying between 6 to 10 percent per year average over a 20-yr period was assumed. It is seen that even with inflation, large cost savings or profit using space versus terrestrial systems are still present, and the numbers only become more impressive.

Consider, for instance, the Electronic Mail system, for which the terrestrial alternative costs over $100 billion as compared to $9.2 billion for the space-based system, using inflated dollars for the comparison. The inflated cost estimates were not converted into equivalent user costs on a cents/per call, cents per letter, or cents/per classroom-hour basis since it is expected that the cost of the "conventional services" will

Table 6-2. Effect of Inflation on Cost Estimates

- Total Program Costs in Billions, Including R&D, Investment, 10-Yr Maintenance, and User Equipment

SYSTEM	BASIS	GROUND BASED	SPACE BASED
ELECTRONIC MAIL	1977 Dollars	38.5	3 95
	Inflated Dollars	108 4	9.21
EDUCATIONAL TV	1977 Dollars	13.5	2.73
	Inflated Dollars	29.9	6.22
PERSONAL/EMERGENCY COMMUNICATIONS	1977 Dollars	20 8	2 29
	Inflated Dollars	63.2	5 25

also inflate at about the same rate. Thus the value of the users' cost savings will be essentially the same in inflated or in constant dollars, since the savings will be larger in actual number of dollars but the dollars' value will be lower. This will be true for all three space systems. Thus, the space systems are shown to be as attractive in an inflating economy as in a level one.

A further cost analysis was performed, comparing the total program costs using constant dollars, but taking into account the length and buildup of program costs on a per year basis, following the development plans discussed in Sections 3.3, 4.3, and 5.3. The costs are shown in Table 6-3 broken down as to the number and the type of satellites; launch and transfer vehicles required; payload RDT&E, investment, and operations; costs; and the launch vehicle costs. These data are then shown as the costs on a year-by-year basis to the year 2000 in Table 6-4. From the subtotals shown for the yearly expenditures in this time period, it is seen that the

Table 6-3. Satellite Traffic and Cost Summary Through 2000 (millions of 1977 dollars)

SATELLITE NAME	PAYLOAD TRAFFIC	LAUNCH VEHICLE TRAFFIC: 1ST STAGES	IUS	TUG	PROGRAM COSTS: RDTE	PAYLOAD COSTS: INV	OPS	TOTAL	LAUNCH VEHICLE COSTS: INV	OPS	LOSS	TOTAL	PROG TOTAL
SATELLITE-BASED INITIATIVES													
PERSONAL COMMUNICATIONS SYSTEM													
PCS (PRINCPL DEMO)	1	1 0	1 0		38	13		51	25			25	76
PCS (CONCEPT DEMO)	1	1 0	1 0		159	48		207	25			25	232
PCS (TECHNCL DEMO)	1	2 0			310	102		412	38			38	450
PERSONAL COMM SAT	1	2.0			130	259		389	38			38	427
PCS ON-ORBIT MAINT	10	10 0	10 0			169		169	251			251	420
PCS MISSION CONTRL					75		130	205					205
PCS WRIST RADIO					5	250		255					255
PCS WRIST RAD MAIN							225	225					225
SUBTOTAL		16 0	12 0		717	641	355	1913	377			377	2290
ELECTRONIC MAIL SYSTEM													
EMS (CONCEPT DEMO)	1	1.0	1.0		45	16		61	25			25	86
EMS (TECHNCL DEMO)	1	7			93	22		115	13			13	128
ELECTRNIC MAIL SAT	1	3			14	19		33	6			6	39
EMS ON-ORBIT MAINT	4	4 0	4 0			15		15	100			100	115
EMS MISSION CONTRL					35		65	100					100
EMS GRND STA EQUIP					1599		1880	3479					3479
SUBTOTAL		6 0	5 0		1786	72	1945	3803	144			144	3947
EDUCATIONAL TV SYSTEM													
ED TV (CNCPT DEMO)	1	1 0	1 0		45	16		61	25			25	86
ED TV (TECH DEMO)	1	7			130	32		162	13			13	175
EDUC TV SATELLITE	1	3			26	29		55	6			6	61
ED TV ON-ORB MAINT	5	5 0	5 0			25		25	125			125	150
ED TV MISS CONTROL					50		91	141					141
ED TV GRND STA EQ					1073		1046	2119					2119
SUBTOTAL		7 0	6 0		1324	102	1137	2563	169			169	2732
GROUND-BASED ALTERNATIVES TO SATELLITE INITIATIVES													
PERSONAL COMMUNICATIONS SYSTEM (GROUND-BASED)													
PC GRD-BASED EQUIP					2874		3603	6477					6477
PCS WRIST RADIO					5	250		255					255
PCS WRIST RAD MAIN							225	225					225
PCS TEL.CONNECTION					70		13800	13870					13870
SUBTOTAL					2949	250	17628	20827					20827
ELECTRONIC MAIL SYSTEM (GROUND-BASED)													
EM GRD-BASED EQUIP					771		1080	1851					1851
EMS TEL CONNECTION					14		36660	36674					36674
SUBTOTAL					785		37740	38525					38525
EDUCATIONAL TV SYSTEM (GROUND-BASED)													
ED TV GRD-BASED EQ					496		628	1124					1124
ED TV TRANSMIT EQ					8002		4400	12402					12402
SUBTOTAL					8498		5028	13526					13526

space systems, generally speaking, spend money earlier than the terrestrial systems. The terrestrial systems spend more money and do so later. The peak year funds required are $300 million, $733 million, and $626 million for the Personal Communications, the Electronic Mail, and the Educational TV space initiatives, respectively, with the yearly funds during the operational phase only $77, $200, and $125 million, respectively.

Table 6-4. Total Program Costs by Fiscal Year Through 2000
(millions of 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM																							
PCS (PRINCPL DEMO)			6	21	38	11																	
PCS (CONCEPT DEMO)					6	60	122	44															
PCS (TECHNCL DEMO)								37	175	183	55												
PERSONAL COMM SAT										80	227	120											
PCS ON-ORBIT MAINT											6	18	37	42	42	43	42	42	41	42	36	24	5
PCS MISSION CONTRL								19	41	15	10	10	10	10	10	10	10	10	10	10	10	10	10
PCS WRIST RADIO										1	3	51	125	75									
PCS WRIST RAD MAIN															25	25	25	25	25	25	25	25	25
SUBTOTAL			6	21	44	71	122	100	216	279	301	199	172	127	77	78	77	77	76	77	71	59	40
ELECTRONIC MAIL SYSTEM																							
EMS (CONCEPT DEMO)			6	23	43	14																	
EMS (TECHNCL DEMO)						11	51	52	14														
ELECTRONIC MAIL SAT								7	21	11													
EMS ON-ORBIT MAINT									6	9	11	9	9	11	8	9	11	9	9	11	3		
EMS MISSION CONTRL						9	19	7	5	5	5	5	5	5	5	5	5	5	5	5	5		
EMS GRND STA EQUIP								192	687	560	160	188	188	188	188	188	188	188	188	186	188		
SUBTOTAL			6	23	43	34	70	258	733	585	176	202	202	204	201	202	204	202	202	204	196		
EDUCATIONAL TV SYSTEM																							
ED TV (CNCPT DEMO)			6	23	43	14																	
ED TV (TECH DEMO)						16	69	69	21														
EDUC TV SATELLITE								9	32	20													
ED TV ON-ORB MAINT									6	9	18	12	18	12	18	12	18	12	12	3			
ED TV MISS CONTROL						13	27	10	7	7	7	7	7	7	7	7	7	7	7	7	7		
ED TV GRND STA EQ									268	590	215	105	104	105	105	104	105	105	104	105	104		
SUBTOTAL			6	23	43	43	96	85	334	626	240	124	129	124	130	123	130	124	123	115	111		
GROUND-BASED ALTERNATIVES TO SATELLITE INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM (GROUND-BASED)																							
PC GRD-BASED EQUIP											345	1236	1006	647	361	360	360	360	361	360	360	360	361
PCS WRIST RADIO										1	3	51	125	75									
PCS WRIST RAD MAIN															25	25	25	25	25	25	25	25	25
PCS TEL CONNECTION												35	35	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380
SUBTOTAL										1	348	1322	1166	2102	1766	1765	1765	1765	1766	1765	1765	1765	1766
ELECTRONIC MAIL SYSTEM (GROUND-BASED)																							
EM GRD-BASED EQUIP									93	331	270	165	108	108	108	108	108	108	108	108	108		
EMS TEL CONNECTION											7	3673	3666	3666	3666	3666	3666	3666	3666	3666	3666		
SUBTOTAL									93	331	277	3858	3774	3774	3774	3774	3774	3774	3774	3774	3774		
EDUCATIONAL TV SYSTEM (GROUND-BASED)																							
ED TV GRD-BASED EQ								60	213	174	49	63	63	62	63	63	63	63	62	63	63		
ED TV TRANSMIT EQ								960	3441	2801	800	440	440	440	440	440	440	440	440	440	440		
SUBTOTAL								1020	3654	2975	849	503	503	502	503	503	503	503	502	503	503		

The same form of expenditures by fiscal year for the case of inflated dollars is shown in Table 6-5, and for the case of discounted dollars in Table 6-6. The net results are shown in Table 6-7 in which the three space initiatives are compared with the terrestrial alternatives. The comparison is shown on the basis of constant 1977 dollars, inflated dollars, and discounted dollars with present value as of 1977. In all cases it is seen that the purely space-based alternatives are much less expensive than the terrestrial alternatives, and that the cost ratio is approximately the same whichever basis for comparison is chosen.

Table 6-5. Total Program Costs by Fiscal Year Through 2000 (millions of current -- inflated -- dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM																							
PCS (PRINCPL DEMO)			8	28	54	17																	
PCS (CONCEPT DEMO)					9	90	196	75															
PCS (TECHNCL DEMO)								63	316	349	112												
PERSONAL COMM SAT										153	460	258											
PCS ON-ORBIT MAINT											12	39	84	101	108	116	121	128	133	143	131	92	21
PCS MISSION CONTRL								32	74	29	20	22	22	25	25	27	29	30	33	34	36	39	41
PCS WRIST RADIO										2	6	110	284	181									
PCS WRIST RAD MAIN															64	68	72	76	80	86	91	96	102
SUBTOTAL			8	28	63	107	196	170	390	533	610	429	390	307	197	211	222	234	246	263	258	227	164
ELECTRONIC MAIL SYSTEM																							
EMS (CONCEPT DEMO)			8	31	61	21																	
EMS (TECHNCL DEMO)						17	82	88	25														
ELECTRNIC MAIL SAT								12	38	21													
EMS ON-ORBIT MAINT									11	17	22	20	20	27	20	25	31	28	29	37	11		
EMS MISSION CONTRL						14	30	12	9	10	10	10	12	12	13	13	15	15	16	17	18		
EMS GRND STA EQUIP								327	1239	1070	324	404	428	454	481	509	541	572	608	643	682		
SUBTOTAL			8	31	61	52	112	439	1322	1118	356	434	460	493	514	547	587	615	653	697	711		
EDUCATIONAL TV SYSTEM																							
ED TV (CNCPT DEMO)			8	31	61	21																	
ED TV (TECH DEMO)						24	111	117	38														
EDUC TV SATELLITE								15	58	38													
ED TV ON-ORB MAINT									11	17	36	26	41	29	46	33	52	36	39	10			
ED TV MISS CONTROL						20	43	17	13	13	14	15	16	17	18	19	20	21	23	24	25		
ED TV GRND STA EQ									483	1128	436	225	237	253	269	282	302	320	336	359	377		
SUBTOTAL			8	31	61	65	154	149	603	1196	486	266	294	299	333	334	374	377	398	393	402		
GROUND-BASED ALTERNATIVES TO SATELLITE INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM (GROUND-BASED)																							
PC GRD-BASED EQUIP											699	2655	2290	1561	924	976	1035	1096	1166	1233	1306	1385	1472
PCS WRIST RADIO										2	6	110	284	181									
PCS WRIST RAD MAIN															64	68	72	76	80	86	91	96	102
PCS TEL CONNECTION												75	80	3330	3530	3742	3967	4204	4457	4724	5007	5308	5627
SUBTOTAL										2	705	2840	2654	5072	4518	4786	5074	5376	5703	6043	6404	6789	7201
ELECTRONIC MAIL SYSTEM (GROUND-BASED)																							
EM GRD-BASED EQUIP									168	632	547	398	246	260	277	292	311	329	349	369	392		
EMS TEL CONNECTION											14	7889	8346	8847	9378	9940	10537	11169	11839	12550	13303		
SUBTOTAL									168	632	561	8287	8592	9107	9655	10232	10848	11498	12188	12919	13695		
EDUCATIONAL TV SYSTEM (GROUND-BASED)																							
ED TV GRD-BASED EQ								102	384	333	99	135	144	149	162	170	181	192	201	215	229		
ED TV TRANSMIT EQ								1633	6205	5355	1621	945	1001	1062	1126	1193	1264	1341	1421	1506	1597		
SUBTOTAL								1735	6589	5688	1720	1080	1145	1211	1288	1363	1445	1533	1622	1721	1826		

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Table 6-6. Total Program Costs by Fiscal Year Through 2000
(millions of discounted 1977 dollars)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SATELLITE-BASED INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM																							
PCS (PRINCPL DEMO)			5	14	23	7																	
PCS (CONCEPT DEMO)					4	34	62	21															
PCS (TECHNCL DEMO)								17	74	71	19												
PERSONAL COM SAT										31	79	39											
PCS ON-ORBIT MAINT											2	6	11	11	10	9	8	8	7	6	5	3	
PCS MISSION CONTRL								9	17	6	4	3	3	2	3	2	2	2	1	2	1	1	1
PCS WRIST RADIO											1	17	36	20									
PCS WRIST RAD MAIN															6	5	5	5	4	4	3	3	3
SUBTOTAL			5	14	27	41	62	47	91	108	105	65	50	33	19	16	15	15	12	12	9	7	4
ELECTRONIC MAIL SYSTEM																							
EMS (CONCEPT DEMO)			5	15	27	8																	
EMS (TECHNCL DEMO)						6	26	25	6														
ELECTRNIC MAIL SAT								3	9	4													
EMS ON-ORBIT MAINT									3	3	4	3	2	3	2	2	2	2	1	2			
EMS MISSION CONTRL						5	10	3	2	2	2	1	2	1	1	2	1		1	1	1		
EMS GRND STA EQUIP								90	291	216	56	60	54	50	45	41	37	34	30	28	26		
SUBTOTAL			5	15	27	19	36	121	311	225	62	64	58	54	48	45	40	36	32	31	27		
EDUCATIONAL TV SYSTEM																							
ED TV (CNCPT DEMO)			5	15	27	8																	
ED TV (TECH DEMO)						9	35	33	9														
EDUC TV SATELLITE								4	14	7													
ED TV ON-ORB MAINT									3	3	6	4	5	4	4	2	4	2	2	1			
ED TV MISS CONTROL						7	14	5	3	3	2	2	2	2	2	1	2	1	1	1	1		
ED TV GRND STA EQ									114	227	75	34	30	28	25	22	21	19	17	16	14		
SUBTOTAL			5	15	27	24	49	42	143	240	83	40	37	34	31	25	27	22	20	18	15		
GROUND-BASED ALTERNATIVES TO SATELLITE INITIATIVES																							
PERSONAL COMMUNICATIONS SYSTEM (GROUND-BASED)																							
PC GRD-BASED EQUIP											121	394	291	171	86	78	72	64	59	54	48	45	40
PCS WRIST RADIO											1	17	36	20									
PCS WRIST RAD MAIN															6	5	5	5	4	4	3	3	3
PCS TEL CONNECTION												11	10	364	330	300	273	249	225	205	187	169	155
SUBTOTAL											122	422	337	555	422	383	350	318	288	263	238	217	198
ELECTRONIC MAIL SYSTEM (GROUND-BASED)																							
EM GRD-BASED EQUIP									39	128	95	59	31	28	26	24	21	20	17	16	15		
EMS TEL CONNECTION											2	1171	1062	965	878	798	725	659	600	545	495		
SUBTOTAL									39	128	97	1230	1093	993	904	822	746	679	617	561	510		
EDUCATIONAL TV SYSTEM (GROUND-BASED)																							
ED TV GRD-BASED EQ								28	90	67	18	20	18	16	15	14	12	12	10	9	9		
ED TV TRANSMIT EQ								448	1459	1080	280	141	127	116	105	96	87	79	72	66	59		
SUBTOTAL								476	1549	1147	298	161	145	132	120	110	99	91	82	75	68		

Table 6-7. Cost Comparisons of Initiatives (Total Program Costs in billions of dollars)

SYSTEM	CONSTANT DOLLARS (1977)	INFLATED DOLLARS	DISCOUNTED DOLLARS (1977)
PERSONAL COMMUNICATIONS			
SATELLITE-BASED	2 29	5 25	0 76
GROUND-BASED	20 83	63 17	4 11
ELECTRONIC MAIL			
SATELLITE-BASED	3 95	9 21	1 26
GROUND-BASED	38 53	108 38	8 42
EDUCATIONAL TV			
SATELLITE-BASED	2 73	6 22	0 90
GROUND-BASED	13 53	29 97	4 55

6.2 TECHNICAL AND OPERATIONAL EVALUATION

The Electronic Mail space and terrestrial alternative system concepts were shown to be essentially equivalent in their technical and operational features, as discussed in Section 5.5.1. The same is true of the Educational TV initiative alternatives as discussed in Section 4.5.1.

In both of these initiative concepts, the performance that is obtained from either alternative is essentially indistinguishable, with the same number of users, timeliness and flexibility of service, and level of services provided. Both of the space initiatives make use of the 20/30 GHz bands, which are uncrowded and for which no difficulties are envisioned in obtaining allocations.

All of these initiatives use large-scale frequency reuse and thus are extremely efficient in terms of spectrum used per service delivered. The Electronic Mail initiative requires the least technology advancement and thus, is the lowest risk and the nearest-term of the three initiatives, with Educational TV being intermediate. The Personal Communications initiative is the largest, most risky, and farthest-term initiative of those analyzed.

The Personal Communications system performs a class of services that is difficult for the terrestrial alternative to match, either in coverage or in cost. The satellite, however, is extremely complex and very large. Frequency allocations might be obtained in a number of bands but the 4.7 to 4.9 GHz region appears particularly attractive. However, a variance request to the FCC, though not to the ITU would be needed. The wrist radio itself is essentially state-of-the-art with most components except the antenna, being similar to those found in digital watches worn daily by the millions. The price projection for the user costs - $10 for the computer wrist radio, is also based on today's market experience with digital watches. Since the number and type of components in a digital watch is almost identical to that required by a wrist radio-telephone, a similar cost experience would be expected.

Operationally, the current telephone networks perform services that the wrist radio system cannot match, offering essentially unlimited conversation time to each user with high signal-to-noise ratios. The space system must of necessity, limit the conversation time per user in order to attain access by the very large user population through a single "telephone exchange", and yet keep the satellite complexity within reason for the time period concerned. The same holds for the signal-to-noise ratio, which cannot match that of the telephone networks without increasing the satellite antenna and power by at least an order of magnitude from the already very large values. However, the resultant satellite development is felt to be a reasonable risk program with a 10-yr development cycle incorporating two demonstration satellite steps prior to orbiting the final components.

The terrestrial alternative, on the other hand, requires no new development, using simple applications of current techniques. However, it has such a cost disadvantage that even though it represents a less risky approach requiring a shorter development time, it appears much less attractive. Furthermore, the coverage of the terrestrial alternative is less in some important ways. Thus, another aspect of a ground/space comparison that needs to be discussed bears on the question of the function of the initiative. Is it an augmentation or a replacement of the telephone networks? In our view, it is an augmentation rather than a replacement. Its low signal-to-noise ratio, short duration messages, queue waiting time, the possibility of being in shadows or interference zones, and the possibility of required body reorientation to establish service makes the quality of service considerably lower than that which the public is used to via the excellent telephone services. It is therefore unlikely that a wrist radio would be used for truly mobile use when away from telephones for the convenience, recreation, pleasure, and emergency uses for which it was intended.

In order for the space system to be completely competitive with the quality and reliability available through the telephone networks, the user set would have to be considerably larger and more expensive, and the satellite would have to grow very much larger. Whereas there would still probably be cost savings compared to the ground system operation, and the coverage would be better particularly in disadvantaged or wilderness areas, some of the advantages of the constant availability and convenience of the wrist-mounted package would be lost compared to a heavy or clumsy pocket set or walkie-talkie. Tradeoffs, such as these should be performed in any follow-on studies.

6.3 SOCIAL CONSIDERATIONS

Social and institutional questions abound in considering these three initiatives. Most of them center on the questions of job displacement, general desirability of the form of progress, and threats to existing institutions.

6.3.1 Electronic Mail Initiative

The U.S. Postal Service is currently the single largest employer in the United States, employing in the order of 750,000 people. The impact of removing about 10 percent of the projected 1990 mail stream (the business-government segment) can only be estimated, but even if it is as small as only 10 percent of the jobs, that still implies 75,000 U.S. Postal Service people put out of work. Moreover, the 10 percent of the mail fraction removed is the first class/business/government mail that is one of the most profitable aspects of the U.S. Postal Service operation. Thus, it is likely that postal service rates to the rest of the users would have to rise somewhat as a result of diversion of a portion of the first class mail stream as considered in this study. Weighed against these considerations must be the fact that the first class mail stream is already being diverted by electronic funds transfers, remote printing, and facsimile operations in ever-increasing numbers. In part, this is responsible for the current financial plight of the U.S. Postal Service. Thus, the provision of an Electronic Mail system of the type described in this study can therefore be viewed as a gradual transition and continuation of an already on-going process which is inevitable, rather than a social scourge that people ought to consider stopping.

A second aspect that is often overlooked is that the Electronic Mail initiative will greatly augment the industry for the manufacture, sales, and maintenance of the user terminals as well as the aerospace and related fields for the satellites and launch vehicles. The number of jobs created must be roughly equal to the number of Postal Service jobs displaced in the sense that the money spent would probably stay mostly in this country, thus representing salaries paid to communications, aerospace, and maintenance workers rather than to mail carriers and sorters. Thus, it is imperative that systems of this type be viewed not as potentially threatening to jobs per se, but rather as requiring a shift in the skills of the workers employed while maintaining a roughly constant number of workers in the country.

This situation is very analogous to the introduction of the automobile around the turn of the century, which was seen by the railroad people as extremely job-threatening. In fact, the number of jobs created by the automobile greatly exceeded the number of jobs that could possibly have been provided by the railroads, even though there was a dislocation in the skill level and distribution of those jobs over a long period of time.

Progress is inevitable and viewed from the above perspective, adjustment to it is more constructive than its obstruction. The Electronic Mail Concept, or variations on such a design appears to represent a long-term trend to storing and moving information electronically rather than physically. Some version of this initiative is probably inevitable.

6.3.2 Educational Television Initiative

In considering the Educational TV initiative, the question that needs to be addressed is the role of the teacher in instruction vis-a-vis that of a TV box, albeit with a two-way voice capability system. The Educational TV system need not be viewed as a replacement for teachers, but rather as an augmentation of their skills, enabling the multiplication of teachers' effective hours. Experiments have been made by HEW and NIE and many state, local and private agencies which show that one-way TV with two-way interactive audio can be an extremely effective way of augmenting a teacher's educational tools. Perhaps more importantly, however, it can enormously enrich the educational experience for large numbers of students, which should be seen as the ultimate goal of the educational institutions. Furthermore, this enrichment need not occur at the expense of teachers' skills, which could then be focused on leading discussions around the lessons learned via the TV system.

There is also some evidence that todays (and tomorrows) students are likely to pay more attention to a TV screen than to a live teacher, inasmuch as they are so used to watching the TV screen at home for a great many hours. Educational TV satellite systems can capitalize on this by bringing the learning material into the environment in a form to which the students are most used to paying attention. This is particularly true of extended universities or home instruction. Thus the advent of mass Educational Television might actually increase the rate at which information is imparted to students, and more importantly, its comprehension and retention for the same expenditure of teacher hours or effort.

The above views are one side of an argument being debated in the educational institutions, and equal volumes could be found arguing the opposite. However, based on the success of some pilot programs, such as the Appalachian Educational Satellite Project and the India Satellite TV Distribution experiment, it seems reasonable to assume its validity at least in the long run. Thus, the Educational TV system should also not be viewed as one which destroys teachers' jobs, but rather as an additional tool in the same light as that of globes, blackboards, and textbooks that teachers now use in imparting their knowledge to the classroom. In addition, functions can be performed by the TV system which are in a class by itself, such as distributing events of local, national, or international importance in real-time, which can prove to be an invaluable educational aid. Furthermore, as in the Electronic Mail initiative, the jobs created equal those displaced, though they occur in different industries.

The social impact of mass Educational Television and the best means to overlay it on the existing educational institutions needs much study, which was beyond the scope or resources of this study.

6.3.3 Personal Communications Initiative

The Personal Communications initiative is an entirely different class of device than the previous two initiatives. In a sense it is more similar to the Citizens' Band Radio phenomenon, which has clearly shown that if the price of such sets is brought low enough, a great many people will buy them and use them as adult toys, quite apart from any consideration of their utility in emergencies or for personal or business messages. Whereas Citizens Band was initially intended for strictly business use it was rapidly taken over by masses of people, who used it in their own way. Thus, we now find that instead of being used for emergency messages, teenagers are making dates with each other on the air, and drivers warn each other of police speed traps. This Citizens Band use explosion has resulted in a sale of over 12 million sets in the U.S., with people paying several hundred dollars for the privilege of interfering with each other on the air. It is this interference caused by the total lack of discipline or control over the time and channel use of the air waves that has contributed to a sharp curtailment of the market, and therefore recent sales of CB sets, causing fiscal consternation and even bankruptcy in some large firms. This is not because the personal radio is no longer attractive, but because the potential users find that the sets are useless much of the time, at least in big cities. This is particularly true for emergency uses, which are at the whim of users to vacate the channel or abstain from using the emergency channel. Of course price predation is also responsible for the current CB slump.

The almost total lack of discipline in the CB radio applications would be replaced in the Personal Communications initiative of this study by a rigid discipline system enforced by the satellite computer system, which would make it impossible for anyone to interfere with any user channel while that user is assigned the privilege of talking over it. This is necessary not only for large scale multiple access but to ensure that the rather tiny wrist transmitter/receiver set can communicate effectively - it not being able to tolerate very much noise interference. It is this feature of multiple access control, and the portability and convenience of a wrist-sized set - constantly available - that makes a potential market of 25 million users not at all unlikely. This is especially likely considering the low price of the user set. At $10 a set, most of the sets could be sold even if their range were only a few miles and they did no more than today's CB sets.

The question of job displacement is not as pertinent for the Personal Communications initiative, inasmuch as the jobs created and displaced are all in the communications industry, and presumably the process is less disruptive or threatening. However, the usual questions of the new service being seen by existing institutions in a threatening way still apply. Thus the telephone companies could see this initiative as a potential competition for new telephone business. For several reasons, it is felt that this initiative is an extension, rather than a replacement, of the fixed telephone services.

The coverage of the satellite system will be truly 100 percent of the country, and cannot be matched economically by fixed telephones. However, the signal-to-noise ratio is poor compared to the high quality telephone networks. Furthermore, the severe constraints on user time limits that were espoused in this concept to maximize access by a large number of people to a much smaller number of channels do not then represent a competitive service. Whereas a one or two minute call is probably long enough to tell a friend that you will be late for an appointment, or ask someone to meet with you, it probably will not compete with long business negotiations, friendly chit-chat, or teenage line burning. There is also no need to use the wrist radio when in an office building or at home due to the availability of telephones.

Thus the Personal Communications system is seen primarily as a portable/mobile extension of the fixed networks, into areas where they do not have (and probably will not have) service for economic reasons. Further, the planned expansion by the telephone companies into mobile telephones will provide high capacity coverage of high speed users in high density urban areas only, whereas the Personal Communications initiative will provide lower capacity to very slowly moving users over a much larger coverage area. It is furthermore quite possible that the realities of signal propagation in a dense urban area so increas the link requirements as to make multipoint diversity systems, such as the cellular networks, much more reliable than even high angle satellite communications.

For all these reasons, it seems reasonable that fixed telephones, mobile car telephones in cellular systems, and a system such as the Personal Communications initiative should be viewed as complementary rather than competitive. Thus it is hoped that the current network institutions will see this concept as a business opportunity rather than a threat.

7. CONCLUSIONS

A number of major conclusions were reached in this study. They are summarized in Table 7-1. It has been shown that all three of the space communications initiatives chosen for analyses appear to be technically viable for IOC in the 1987-1990 time period. In order of increasing technological difficulty and risk, they are: the Electronic Mail Initiative, the Educational Television Initiative, and the Personal Communications Initiative.

Table 7-1. Conclusions

1. ALL THREE COMMUNICATIONS INITIATIVES APPEAR VIABLE FOR IOC IN 1987-1990
2. VERY LARGE CAPACITY SERVICES MADE POSSIBLE BY LARGE, COMPLEX SATELLITE AND MANY SMALL INEXPENSIVE USER TERMINALS
3. ELECTRONIC MAIL IS THE LIGHTEST AND MOST STRAIGHTFORWARD SATELLITE WHILE PERSONAL COMMUNICATIONS IS THE LARGEST AND MOST COMPLEX
4. NECESSARY DEVELOPMENT AND DEMONSTRATION FLIGHTS ALL RESULT IN OPERATIONAL UTILITY
5. NO NEW OTV DEVELOPMENT REQUIRED.
6. DRAMATIC USER COST SAVINGS OR PROFITS ARE POSSIBLE COMPARED TO CURRENT SERVICES.
7. TERRESTRIAL ALTERNATIVES ARE LESS ATTRACTIVE BY A FACTOR OF 5 TO 30.
8. PROFIT POTENTIAL IS SO ATTRACTIVE THAT PRIVATE SECTOR DEVELOPMENT IS HIGHLY LIKELY AFTER TECHNOLOGY DEMONSTRATION
9. SOCIAL/INSTITUTIONAL QUESTIONS ABOUND ROLES OF VARIOUS AGENCIES AND INDUSTRY REQUIRE DEFINITION
10. PROPER FREQUENCY ALLOCATIONS MUST BE PROTECTED IN GWARC-79

Each of these initiative system concepts employs the complexity inversion phenomenon whereby new dimensions of services to very large numbers of users outfitted with very small and inexpensive user terminals are made possible by a single large, complex satellite in geostationary orbit. It has been shown that at least one-half million Electronic Mail small terminals in user buildings can be interconnected through a single satellite, interchanging "mail" on the average of once every 10 min, but at least once a day. Every one of the 65, 000 schools in the United States can receive Educational Television broadcasts with monitors in half of the classrooms, the programs originating in District or Board Headquarters. Almost 1500 simultaneous TV channels can be broadcast nationwide, with 150 channels of TV being available for long range interconnect between School Districts for program sharing or live program origination. In addition, 260, 000 interactive voice channels can be provided, all with small terminals at each school and District. Twenty-five million citizens outfitted with $10 wristwatch-sized radio-telephones can communicate with each other through the Personal Communications satellite, with no interference and guaranteed access, for the same low cost regardless of distance - as effectively at 3 mi as at 3000 mi apart.

The required technology developments lie in the areas of large multibeam antennas, with very many simultaneous beams, transponders with demodulation/remodulation to baseband, onboard switching of many ports at baseband, high transmitted and prime power, and configurations designed for on-orbit servicing and attainment of high reliability.

In considering the development and demonstration of this technology it was found that all the demonstration flights needed could result in useful operational capability, thereby avoiding dead-ended developments, and bringing in revenues that could be used to offset the costs of the development flights themselves.

It was found that due to the high onboard power required for these initiatives, efficient use can be made of selfcontained ion engines to effect a self-powered transfer from the low-altitude orbits (where these satellites would be assembled by use of the space shuttle), to synchronous altitude where they will be operational. Thus, no new orbit transfer vehicle development is required for any of the initiatives, though if low thrust orbit transfer vehicles were developed for other purposes, they certainly could be used in these programs.

It has been shown that dramatic cost savings (or profits) are possible, utilizing the space initiatives compared to current services being provided. Furthermore, the leading terrestrial alternative concepts analyzed are more expensive than the space alternatives by a factor between 5 and 30. The overall cost comparison indicates that using the new space initiatives, "mail" can be sent at 2.6 cents per letter compared to the current 15 cents per letter of the U.S. Postal Service; that Educational TV can be disseminated at a cost of 36 cents per class-hour as compared to the approximate $10.00 per classroom hour necessary for teachers alone; and that Personal/Emergency communications can be provided at a call cost of less than 1 cent per minute, as compared to the average of local and long distance calls through current telephones of about 13 cents per minute.

In an inflating economy it is important to compare all the alternatives using inflated dollars. Furthermore, in comparing any options the use of present value discounted dollars is also useful. Both such comparisons were made, and the space concepts still came out way ahead of either the ground alternatives or of current types of services.

This study could only address three out of several dozen initiative concepts, many of which have a potential as attractive as the three selected, or even more so. Follow-on studies should examine these and other system concepts in at least equivalent depth.

It is likely that there is a very large profit potential for any corporation or consortium interested in pursuing these three applications and charging the users for the services provided. These applications could result in enormous savings compared to services at current rates, and/or net profits measured in the billions of dollars per year might be realized while still undercutting current service costs and providing better services. Thus funding and development by the private sector could very well occur if only the high risk technology needed is demonstrated. The roles of government versus that of the private sector in demonstration of this technology and provision of these services needs to be addressed, as it has not been in this study.

It is possible that pressures to develop initiative system concepts such as these could appear soon. Thus, it is extremely important that the appropriate social and institutional questions raised by systems of this type be examined. These questions include those relating to job dislocation and retraining of people displaced by the introduction of the new services; the questions of how to address the introduction of these services so that they become extensions, rather than replacements, of current services and thereby avoid the great opposition that the latter would undoubtedly bring; the roles of government versus industry, and that of various agencies vis-a-vis themselves; and the very questions of what is progress and what kind of a society we wish to become should be raised when addressing these initiatives. This study could not do so, but it is highly recommended that follow-on studies do.

The very important question of protection of frequency and orbit space for services such as these must be addressed. It is quite likely that precursor systems, or systems having other applications, will come into being in orbit, operating at the same frequencies which these initiatives would require. These early systems will have very small capacity in terms of information delivered per bandwidth used, because they probably will not have the large scale frequency reuse capability of the multiple beam antennas used in these initiatives. Their presence will be fully justified on the basis of meeting early needs for a variety of public service communications, however their very existence could preclude the fielding of highly capable initiatives such as analyzed herein simply because the best frequency bands are occupied. It would be tragic if we could not develop highly capable second generation systems because first generation systems with much less capacity enjoy squatters' rights on the orbit and frequency spaces required. Therefore, we must address the question of a mechanism by which we can phase-out earlier satellites before the end of their useful life in order to introduce more capable follow-ons. Who is to be compensated - by whom - and how much for the premature termination of such satellites' services?

A second question arises in this area, and that is of protection of the proper frequency and orbit spaces in anticipation of these extremely capable systems. Decisions will be made in GWARC-79 that could have a lasting effect for two decades. It would be tragic if GWARC-79 did not include at least a discussion on a proposal for deliberate protection of allocations compatible with these highly capable system initiatives.

A further comment concerns large geostationary platforms. Each of these three initiatives has been defined for independent operation. It is quite clear that many elements of these satellites appear very similar both in the antennas, transponders and the housekeeping subsystems. Thus, they could probably operate from a central platform furnishing housekeeping and structure to three payloads. The exact mechanization of how to best join these three services aboard a single platform requires definition. Such studies are desirable follow-ons to this study. The fact that the initiatives of this study were treated as separate satellites should not be construed as advocacy of single satellites or a criticism of multiple payload platforms.

Last, it must be said that none of the designs, costs, characteristics, performance, or any other attributes of the three system concepts evolved in this study should be considered as final or optimum in any sense of the word. They represent preliminary design concepts selected after little opportunity for deep tradeoff analyses, and in response to fairly arbitrary sets of self-imposed requirements whose sole purpose was to derive the likely weight, performance, and cost of highly capable satellites of this type in this time period, performing these functions. Doubtless, many other configurations are possible and some might be considerably better in a number of attributes than the configurations found within. The requirements were set by the author after some discussions with the using community, but without opportunity for feedback. It is quite possible that a set of requirements has been used that is inappropriate for the first development item, or the time period, and more appropriate for a later one. Thus, follow-on studies should examine requirements, as well as the best system configuration, performance, characteristics, and costs to meet those requirements, inasmuch as these considerations were not possible due to the small scope of this study.

Above all, this information should be made freely accessible to the communities and agencies that would be involved with their use; and the social and institutional questions and their general desirability should be thoroughly aired in public forums.

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APPENDIXES

APPENDIX A
MULTIBEAM ANTENNA STUDIES

A.1 INTRODUCTION

Various candidate antenna configurations were evaluated for a large aperture multibeam antenna (MBA) application. The antenna approaches studied include (a) multibeam reflector systems, (b) two dimensional arrays, (c) Butler arrays, and (d) lenses. A summary of the study is presented in the following paragraphs. Section A.2 reviews the requirements; the general characteristics of an MBA are considered in Section A.3; Section A.4 discusses each approach; the rough order of magnitude (ROM) weight estimates are presented in Section A.5; finally, Section A.6 presents the conclusions with regard to a baseline and an alternate configuration.

A.2 REQUIREMENTS

The requirements of the MBA system are that it provide coverage over conus from synchronous altitude, operate at a frequency of 5 GHz, and exhibit optimum gain commensurate with an aperture approximately 200 ft in diameter. The size of the antenna was somewhat arbitrarily chosen as being the largest one that could be designed with close mechanical tolerance and still be packaged within the shuttle. The angular coverage requirement of the MBA is illustrated in Figure A-1. As seen in the figure, a multibeam antenna on a satellite positioned at "A" requires a field of view (FOV) of ±3 deg to cover conus. If Alaska and Hawaii are included, a ±6 deg FOV is required. For the purposes of this study, a FOV of ±3 deg was assumed. Ground coverage (footprint) from each beam of an MBA depends on the scan angle from nadir. Figure A-2 shows the ground intercept distance (in the plane of scan) in miles as a function of scan angle from nadir for several beams exhibiting FOVs of ±0.005, ±0.05, and ±0.5 deg. The nominal half or FOV, of an aperture 200 ft in diameter is ±0.033 deg.

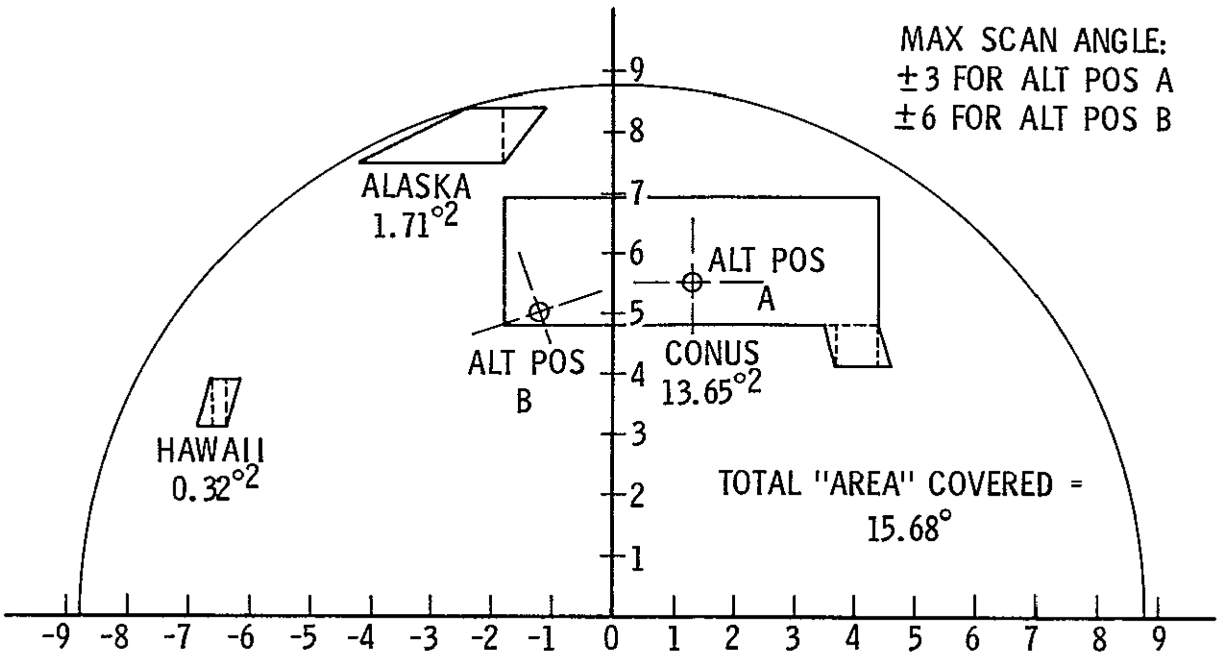

Figure A-1. Angular Coverage Requirement of MBA

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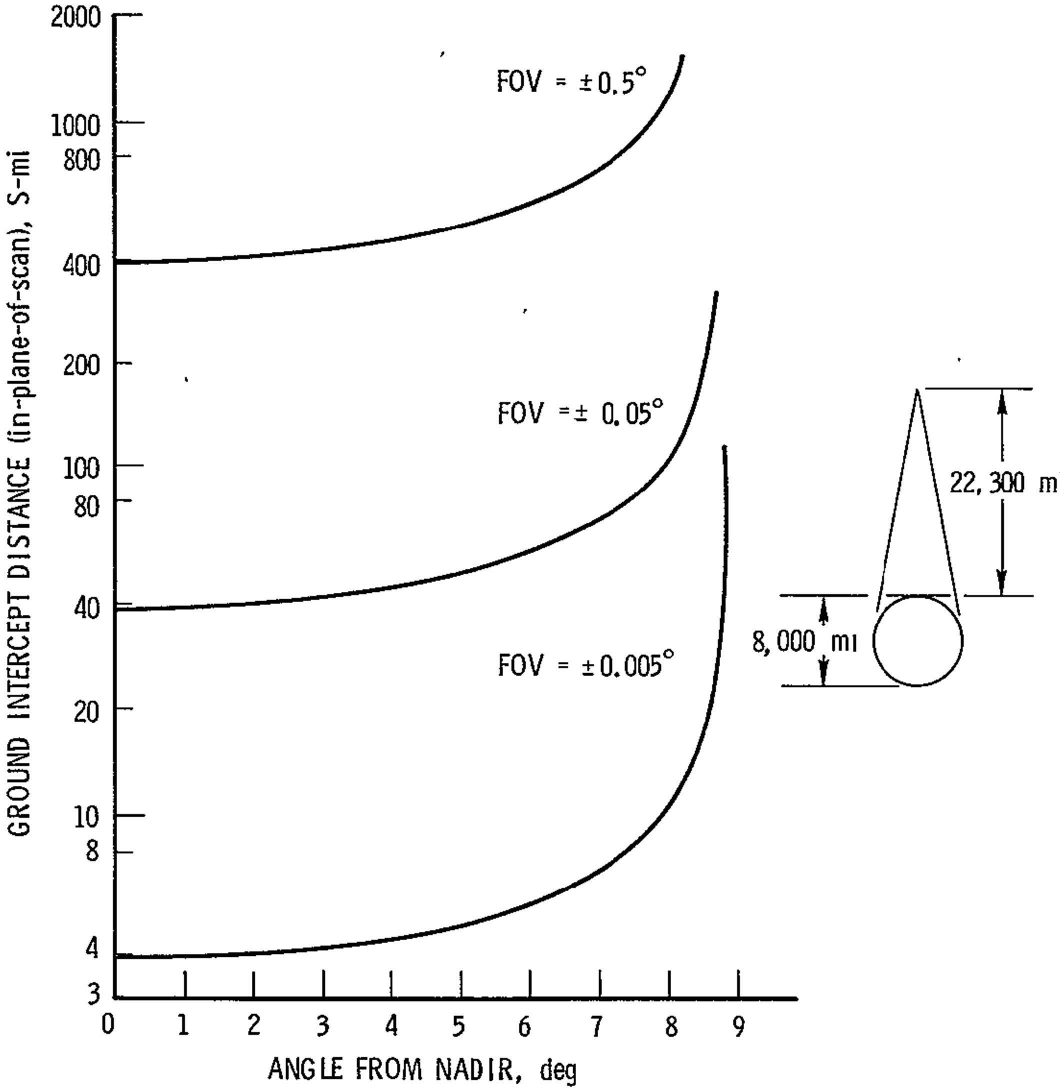


Figure A-2. Ground Intercept Distance from Synchronous Orbit

A.3 GENERAL MBA CHARACTERISTICS

General characteristics of an MBA system are depicted in Figures A-3 through A-5. Figure A-3 is a sketch illustrating sidelobe levels of an on-axis beam as a function of the illumination taper. It also shows a typical beam numbering scenario. The beams are arranged in a triangular lattice. Various crossover points between three adjacent beams are identified. MBA beam efficiencies as a function of this beam crossover are plotted in Figure A-4(a), with the product of maximum efficiency and crossover level versus crossover level being plotted in Figure A-4(b). Finally, the relationship between crossover level and f/D ratio for a lens and a parabolic reflector is shown in Figures A-5(a) and A-5(b) respectively.

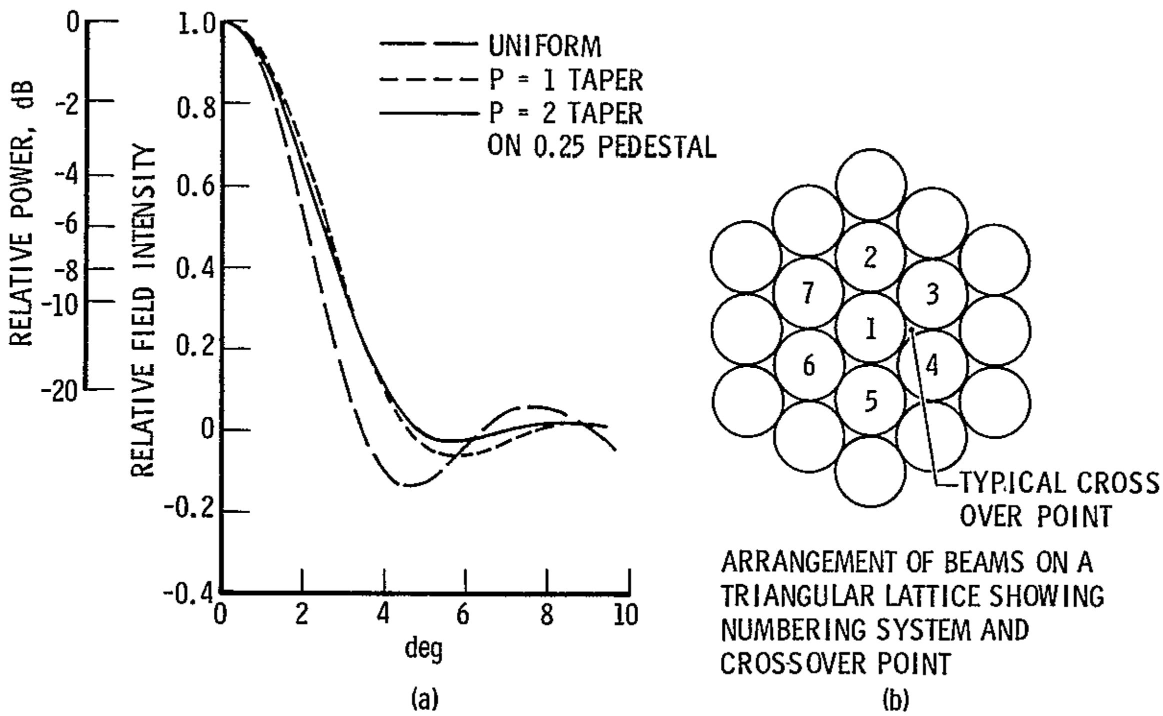
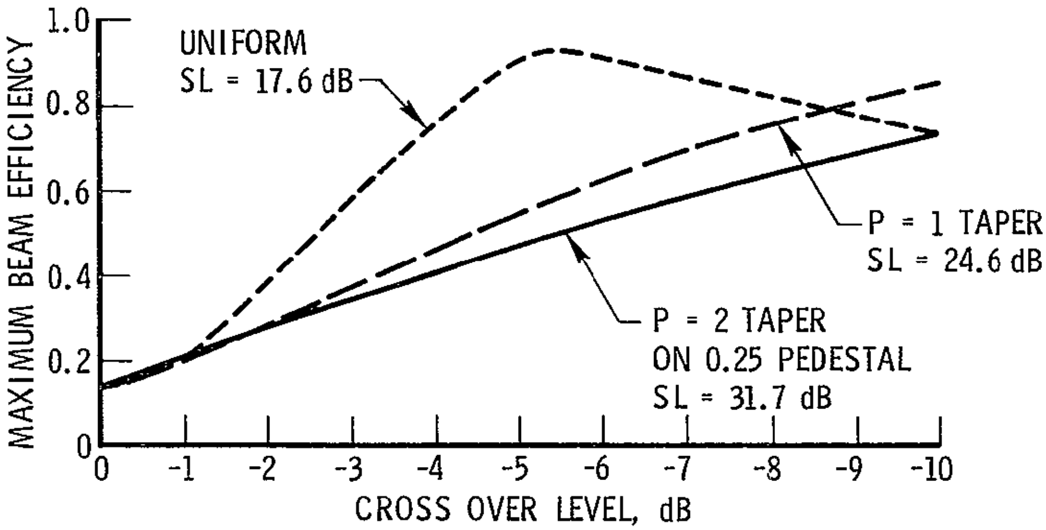
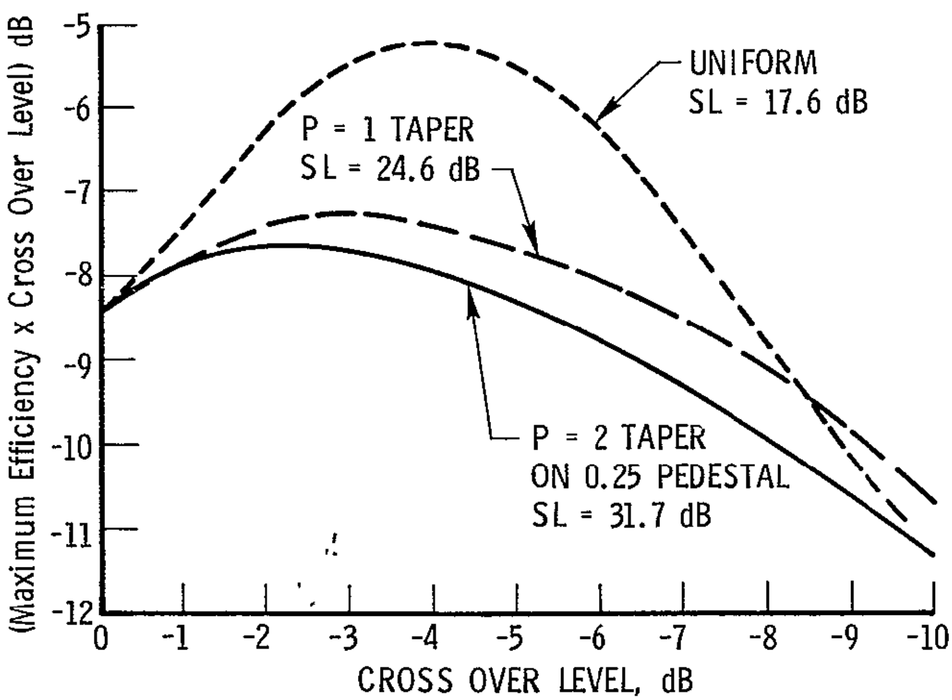


Figure A-3. MBA Beam Characteristics



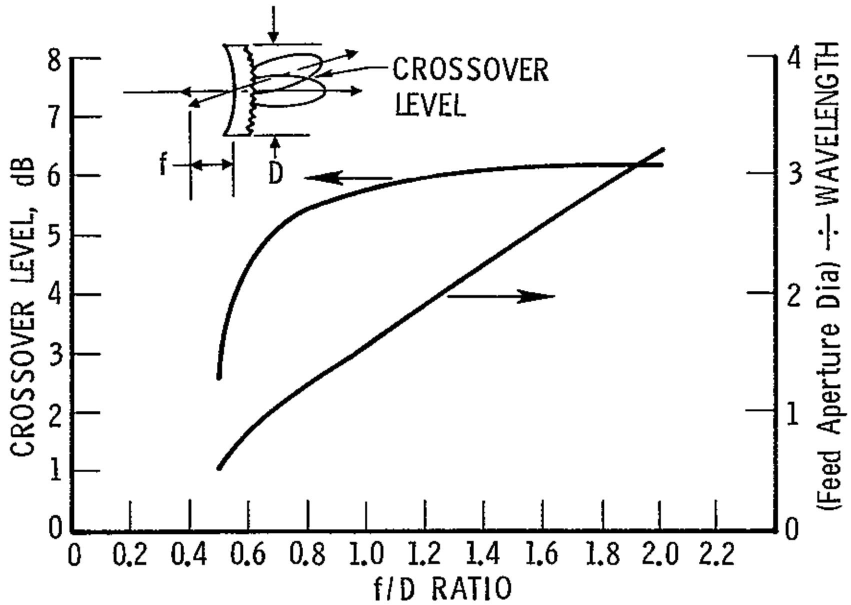
(a) MAXIMUM BEAM EFFICIENCY VERSUS CROSSOVER LEVEL OF THE BEAMS



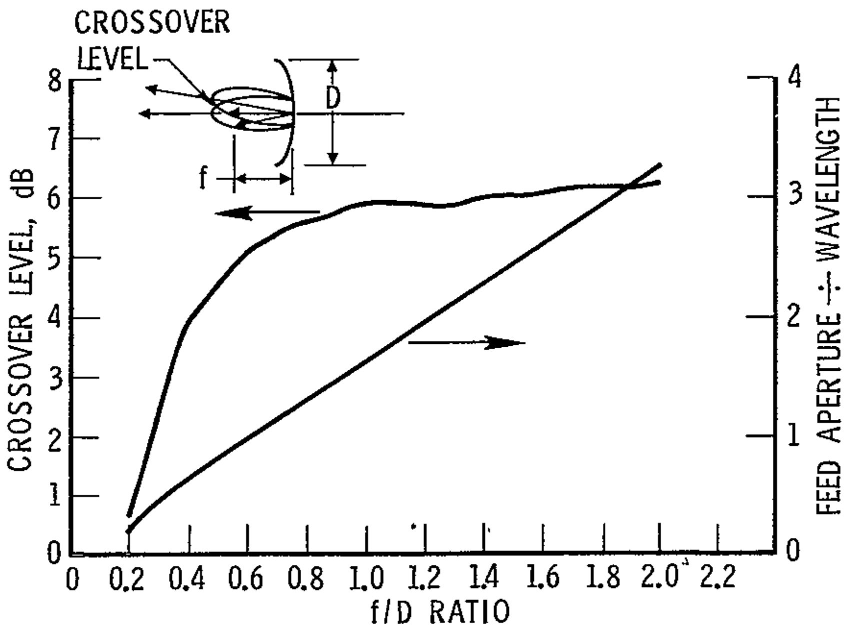
(b) PRODUCT OF MAXIMUM EFFICIENCY AND CROSSOVER LEVEL VERSUS CROSSOVER LEVEL

Figure A-4. MBA Efficiency

(a) Lens



(b) Parabolic Reflector



FEED BEAMWIDTH = 52 λ/D

Figure A-5. f/D versus Beam Crossover Level, for 10-dB Aperture Taper (Sidelobes ≃24 dB)

A.4 CONCEPTUAL APPROACHES

A.4.1 Reflector Systems

The paraboloid is a specific class of reflector-type antenna. Other reflector systems include the paraboloid-cassegrain, Gregorian, spherical, and bifocal configurations. The question as to which reflector type is the most attractive approach for achieving the requirements stated above requires many trade-off studies. One must consider losses associated with scan beamwidths as a function of frequency, spillover, defocusing, blockage, and phase errors. Other considerations are the physical size, weight, deployment mechanism, and feed support structure.

The investigation of reflector systems of this study effort has been primarily devoted to the analysis of the front-fed paraboloid reflector to ascertain whether it is a viable candidate for far-off axis scanning. The degree of emphasis on the paraboloid should not be interpreted as excluding other types of reflector configurations. One might conclude that the Gregorian and cassegrain reflectors are unattractive from the standpoint of blockage; however, it is believed that additional study should be conducted before excluding them. Bifocal and spherical reflectors also deserve further investigation.

The principle of beam scanning using a paraboloid is illustrated in Figure A-6. When the feed is displaced laterally from the axis of the paraboloid, the phase front emanating from the surface of the paraboloid is tilted, producing a scanned beam. The ratio of the angle of the scanned beam to the angular displacement of the feed is known as the "Beam Deviation Factor."

Literature search of paraboloidal antennas show that most articles on the subject of beam scanning with paraboloids are concerned with scan angles less than ten beamwidths. Reference A-1 is one of the few found that applies to the wide angle scan requirement. The article titled, "A Comparison of Experimental and Theoretical Properties of Wide Angle Beam Scanning Paraboloids," presents measured and computed data of 100 λ and

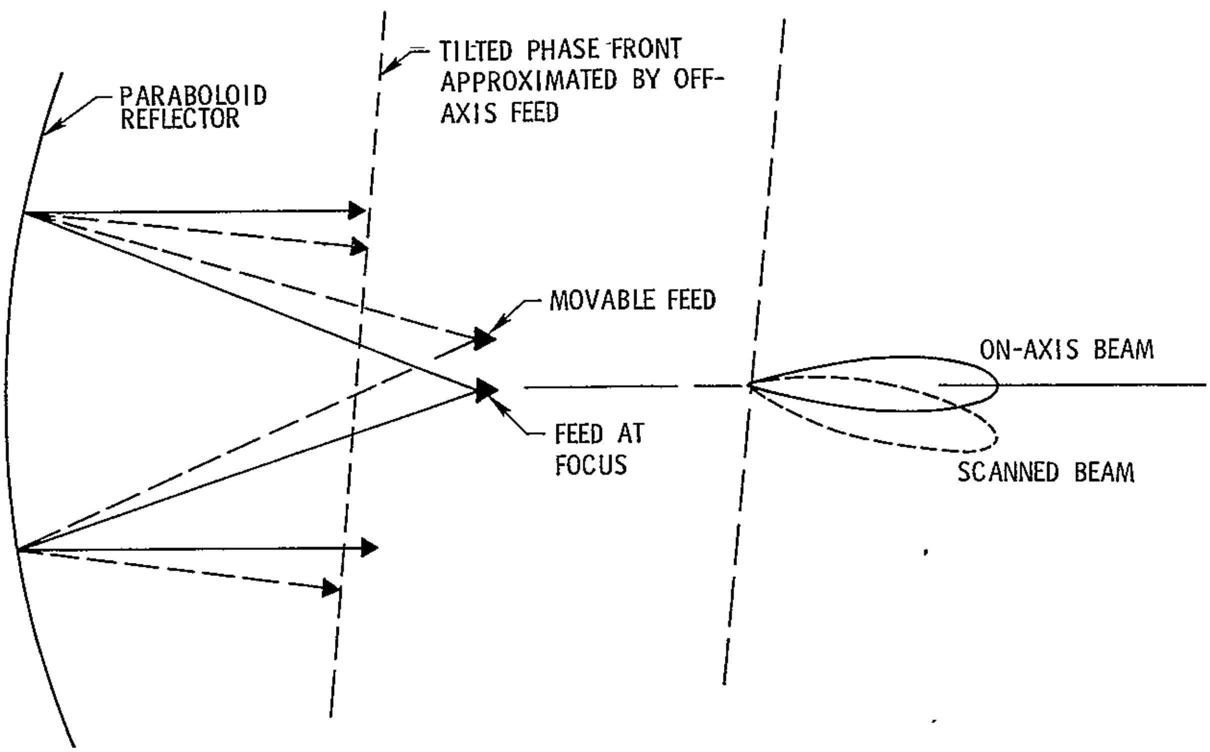


Figure A-6. Beam Scanning with a Paraboloid Reflector

400 λ dia apertures, respectively. Figures A-7 through A-10 were extracted from the article for reference purposes. Figure A-7 depicts the experimental antenna configuration. As indicated in the figure, the antenna was an 84-in. dia paraboloid with a focal length of 36 in., yielding a f/D of 0.428. For the particular experiment, the feed was positioned on the locus corresponding to maximum gain. The holding fixture for the feed permitted the axis of the feed to be pointed towards the vertex of the paraboloid. Figure A-8 shows physical coordinates of the feed. A focal plane offset corresponds to movement in a plane parallel to the aperture of the reflector, which contains the focus of the paraboloid. This is indicated by the horizontal line at the top of the figure. The coordinates of the locus for the experimentally determined, optimum scan curve and for the "Petzval"

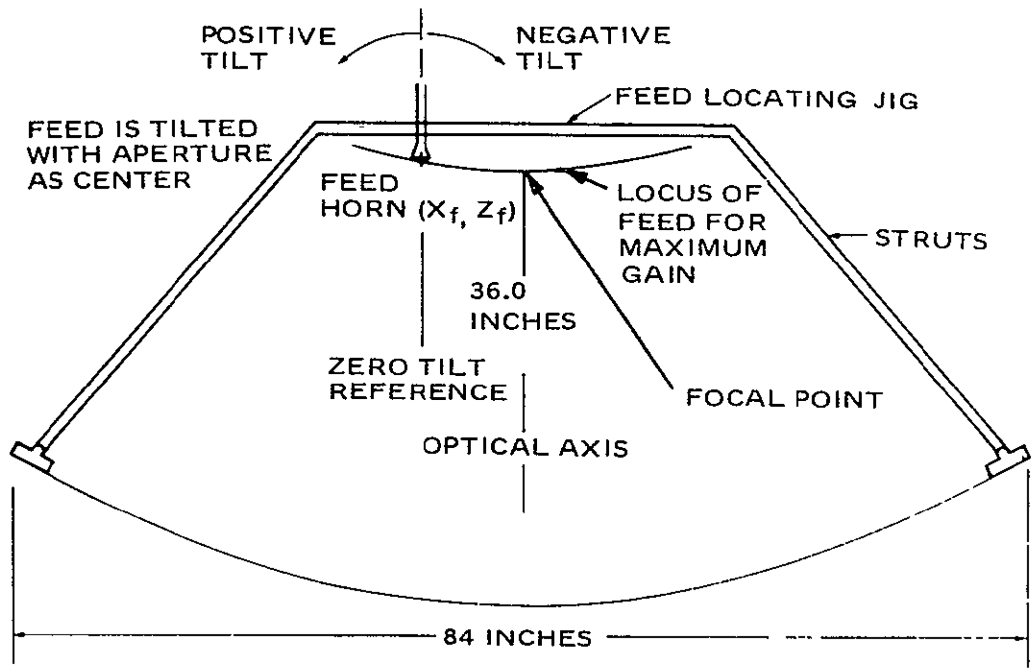


Figure A-7. Experimental Paraboloid Geometry and Coordinate Conventions

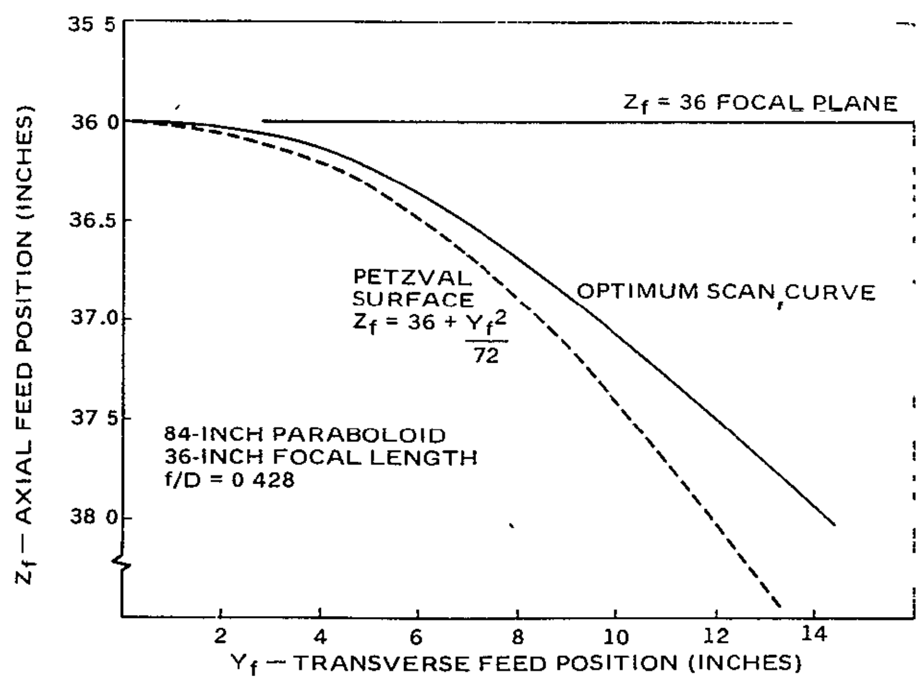


Figure A-8. Optimum Scan Surface and Petzval Surface for Experimental Parabola

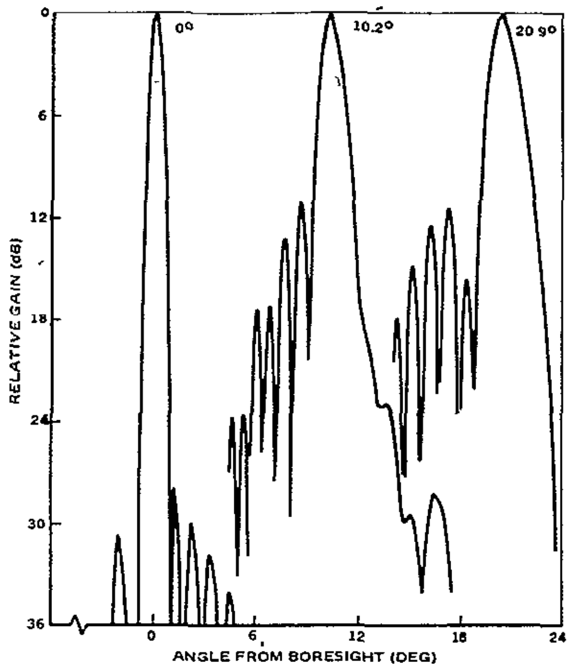


Figure A-9. Normalized Measured Patterns

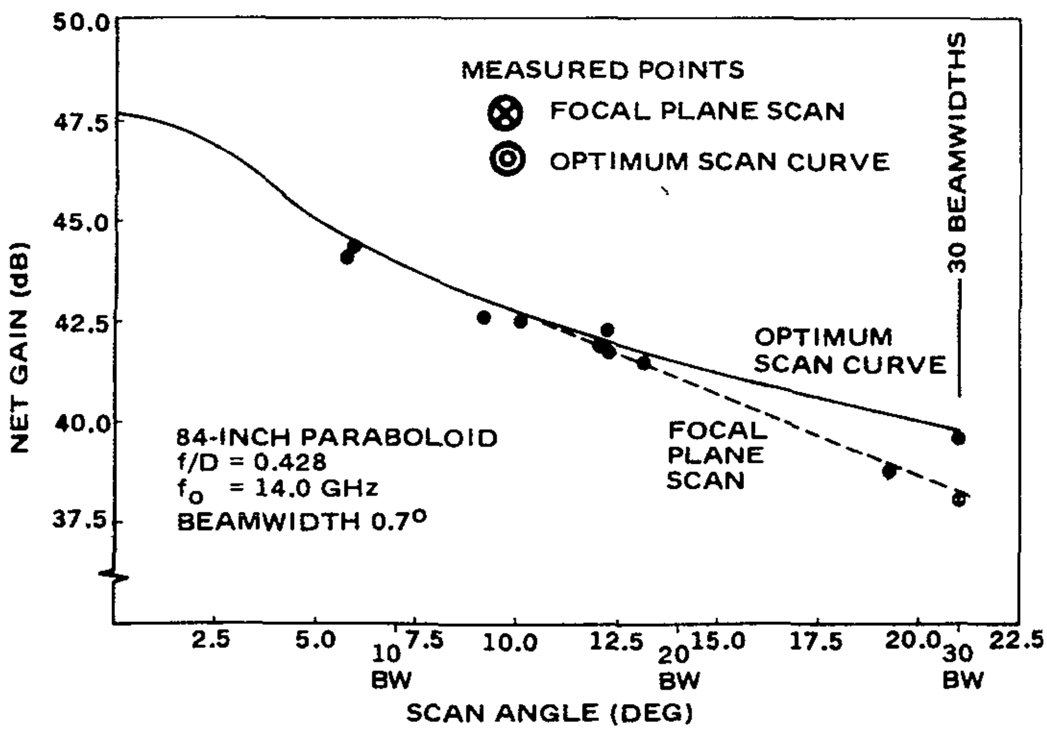


Figure A-10. Scan Gain versus Scan Angle surface are indicated by the solid and dashed curves, respectively. (In optics, the Petzval surface is defined as that locus which contains a sharp image when other aberrations are absent.) Radiation patterns of the 84-in. paraboloid as a function of scan angle are shown in Figure A-9. Absolute gain measurements as a function of scanned degrees and beamwidths are presented in Figure A-10. Note that as the beam is scanned 30 beamwidths from the axis of the paraboloid from the axis, the gain loss is approximately 8.7 dB. Computed radiation patterns and scan-gain loss curves for a 400 λ-dia aperture are shown in Figures A-11 and A-12. The scan loss gain at 45 beamwidths of scan is -11.25 dB. The high scan losses in gain reflected by Figures A-10 and A-12 show that reflector with small f/D ratios are not suitable for large scan angles. This conclusion is also substantiated by a recent Hughes study (Ref. A-2).

The remaining portion of the study of paraboloids concentrated on the investigation of the scanning characteristics of reflectors having large f/D ratios. The primary objective was to determine whether the paraboloid could be ruled out as a viable candidate for the large scan angle requirements on the basis of scan loss and sidelobe level only.

An in-house computer program (Ref. A-3) was utilized for the investigation. The program follows the work of Ruze (Ref. A-4) in computing a pattern in the plane of scan. For purposes of the gain calculation, it was assumed that the patterns through the beam axis orthogonal to the plane of scan remained the same as the on-axis beam pattern.

Calculations were performed for a series of paraboloid antennas (1016 λ dia) exhibiting f/D ratios of 1.0 and 2.0 with illumination tapers of -10.0 and -30.0 dB. Performance summary tables, computed radiation patterns, and scan loss characteristics of the four configurations are shown in Tables A-1 through A-4 and Figures A-13 through A-20. The data show scanning losses at 3 deg of 3.5 and 2.7 dB for paraboloids with f/Ds of 1 and respective illumination tapers of -10.0 and -30.0 dB. In the case of paraboloids with 2.0 f/D ratios, the losses at 3 deg scan angles are virtually negligible,

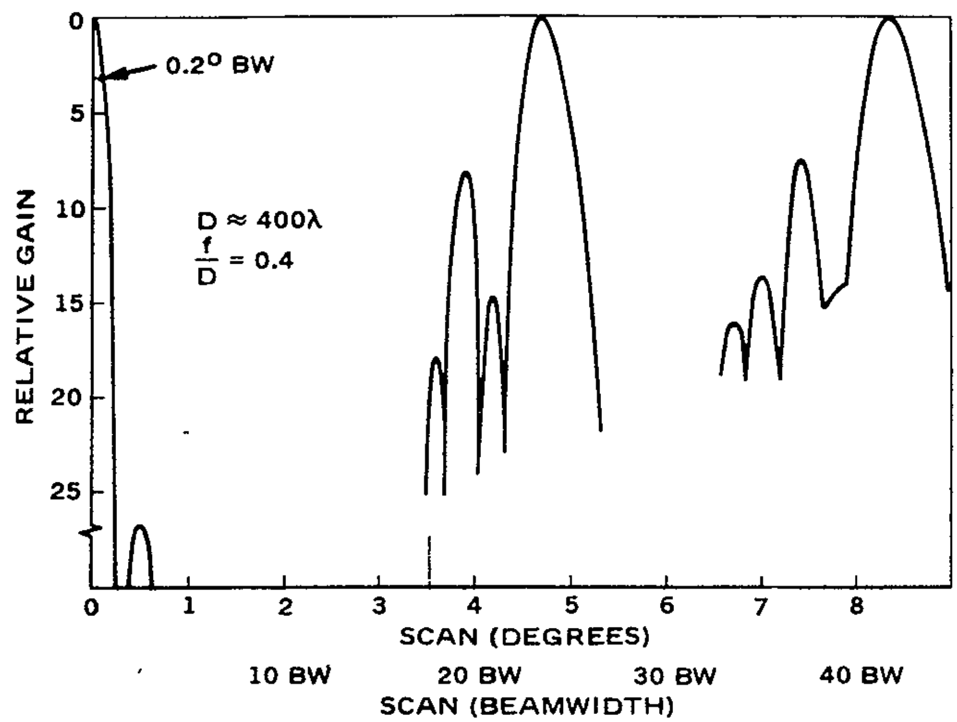


Figure A-11. Computed Pattern at 40 Beamwidths for 400 λ Aperture

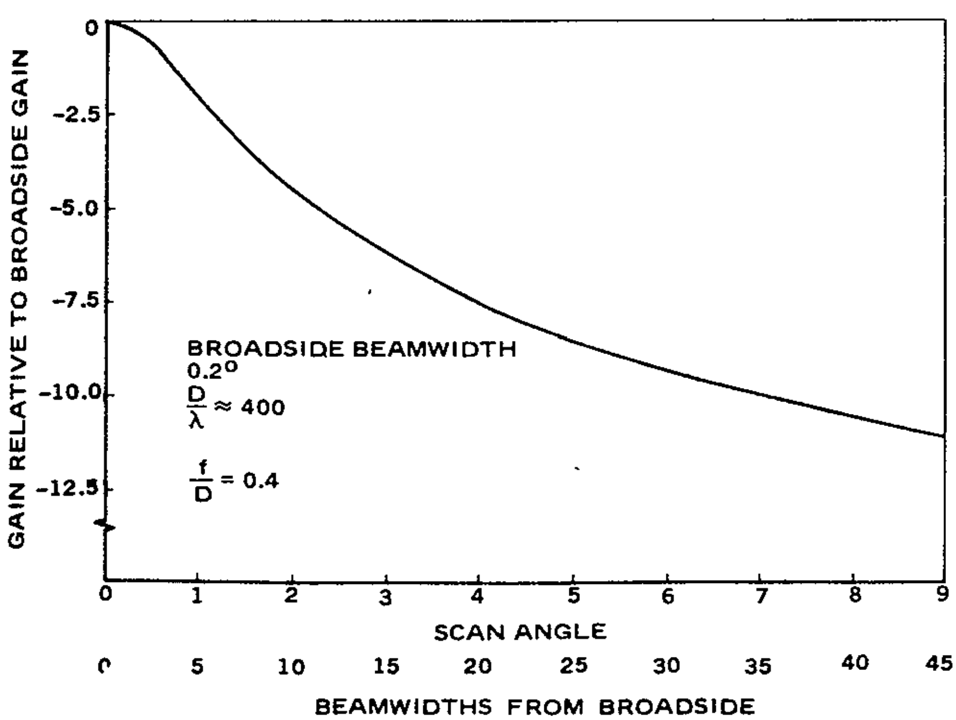


Figure A-12. Scan Gain Loss for 400 λ Aperture

Table A-1. Performance Summary of Paraboloidal Designs

Case I

(a) General Description

Reflector Diameter	200 ft (1016 λ at 5.0 GHz)
f/D Ratio	1.0
Aperture Illumination Taper	-10 dB

(b) On-Axis Performance

Aperture Gain (Maximum)	70.1 dB
On-Axis Directivity	69.7 dB
Illumination Efficiency	91.3 percent
Half Power Beam Width	0 065 deg

(c) Scanning Performance

Feed Angle, deg	0	2	4	6
Beam Angle, deg	0	1 93	3 92	5.93
Beam Deviation Factor	-	0.97	0.98	0.99
Scanning Loss (dB)	-	-2.21	-4.87	-6.65
Side Lobe/Comma Lobe (dB)	-22.20	-9.30	-10.90	-9.90

Table A-2. Performance Summary of Paraboloidal Designs

Case II

(a) General Description

Reflector Diameter	200 ft (1016 λ at 5.0 GHz)
f/D Ratio	1.0
Aperture Illumination Taper	-30 dB

(b) On-Axis Performance

Aperture Gain (Maximum)	70.1 dB
On-Axis Directivity	69.0 dB
Illumination Efficiency	77 percent
Half Power Beam Width	0.071 deg

(c) Scanning Performance

Feed Angle, deg	0	2	4	6
Beam Angle, deg	0	1.94	3.92	5 93
Beam Deviation Factor	-	0.97	0.98	0 99
Scanning Loss (dB)	-	-1.59	-3.88	-5.22
Side Lobe/Comma Lobe (dB)	25 50 dB	-11.60	-10 10	-11.80

Table A-3. Performance Summary of Paraboloidal Designs

Case III

(a) General Description

Reflector Diameter	200 ft (1016 λ at 5.0 GHz)
f/D Ratio	2.0
Aperture Illumination Taper	-10 dB

(b) On-Axis Performance

Aperture Gain (Maximum)	70.1 dB
On-Axis Directivity	69.7 dB
Illumination Efficiency	91.3 percent
Half Power Beam Width	0.065 deg

(c) Scanning Performance

Feed Angle, deg	0	2	4	6
Beam Angle, deg	0	1.98	3 97	5.98
Beam Deviation Factor	-	0.99	0.99	0.99
Scanning Loss (dB)	-	-0.18	-0.66	-1.46
Side Lobe/Comma Lobe (dB)	-22.10	-16.10	-12 70	-10.70

Table A-4. Performance Summary of Paraboloidal Designs

Case IV

(a) General Description

Reflector Diameter	200 ft (1016 λ at 5.0 GHz)
f/D Ratio	2 0
Aperture Illumination Taper	-30 dB

(b) On-Axis Performance

Aperture Gain (Maximum)	70.1 dB
On-Axis Directivity	69.0 dB
Illumination Efficiency	77.2 percent
Half Power Beam Width	0.071 deg

(c) Scanning Performance

Feed Angle, deg	0	2	4	6
Beam Angle, deg	0	1.98	3 98	5.98
Beam Deviation Factor	-	0.99	0.99	0.99
Scanning Loss (dB)	-	-0.13	0.48	-1.08
Side Lobe/Comma Lobe (dB)	-25.00	-18.00	-14.30	-12.00

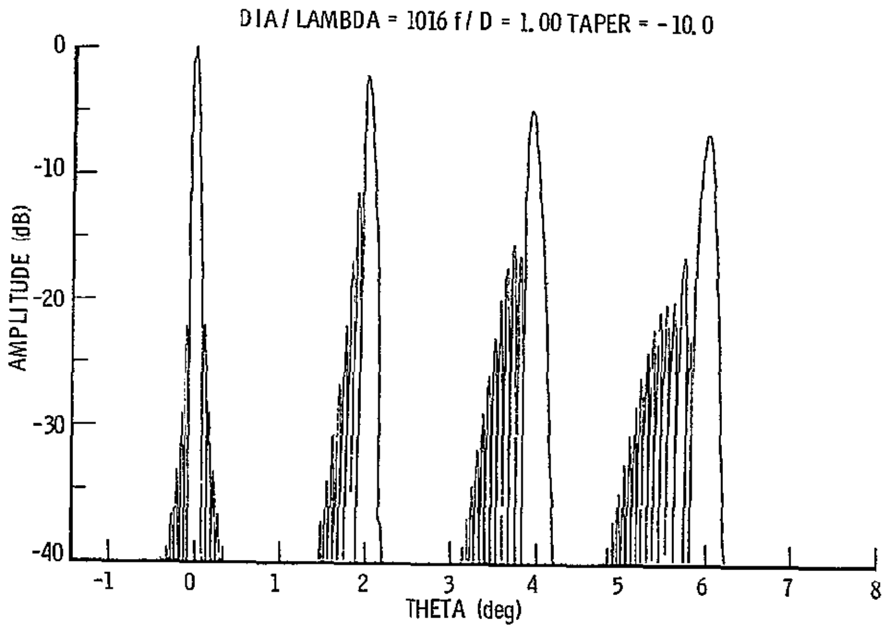


Figure A-13. Radiation Pattern of a Paraboloid

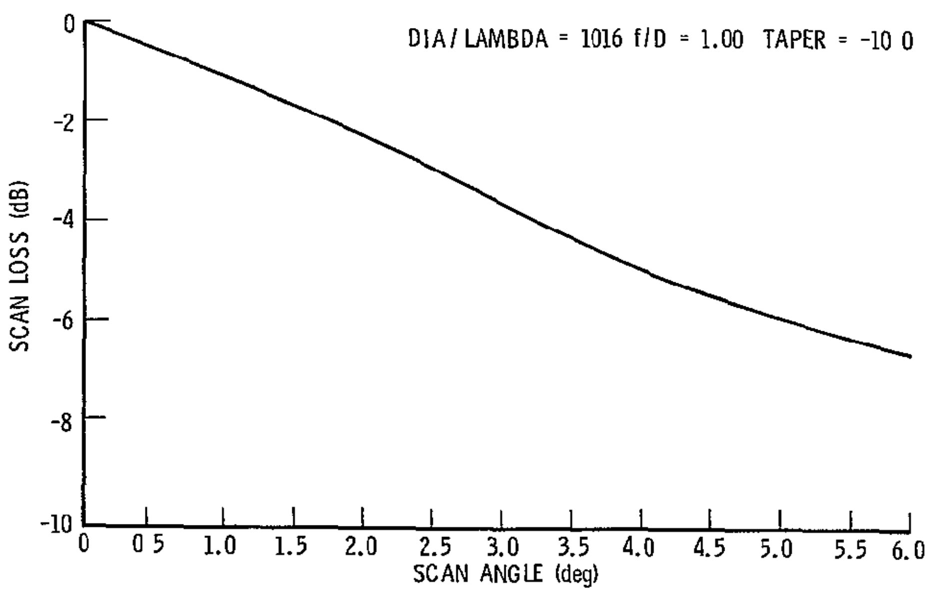


Figure A-14. Gain Loss Curve

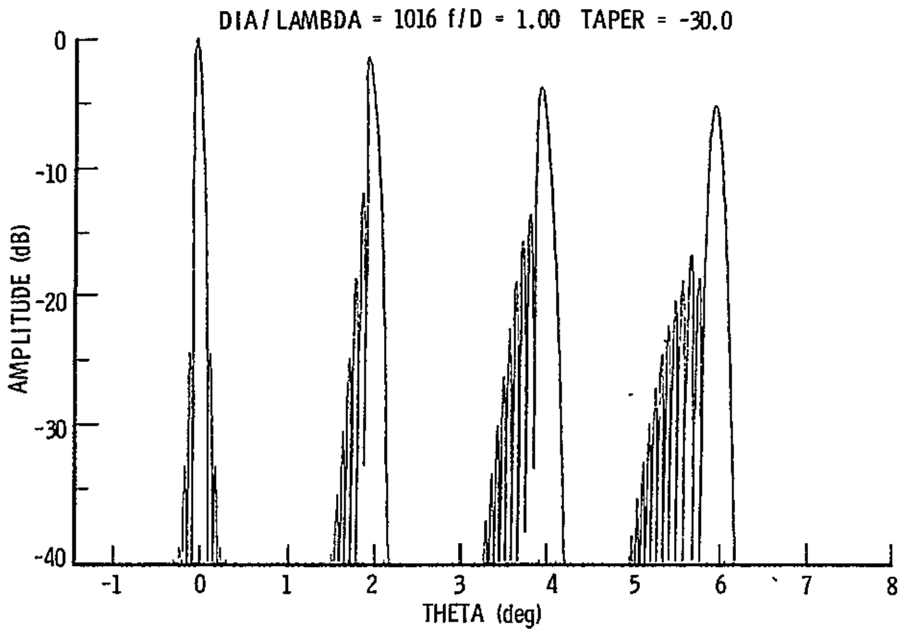


Figure A-15. Radiation Pattern of a Paraboloid

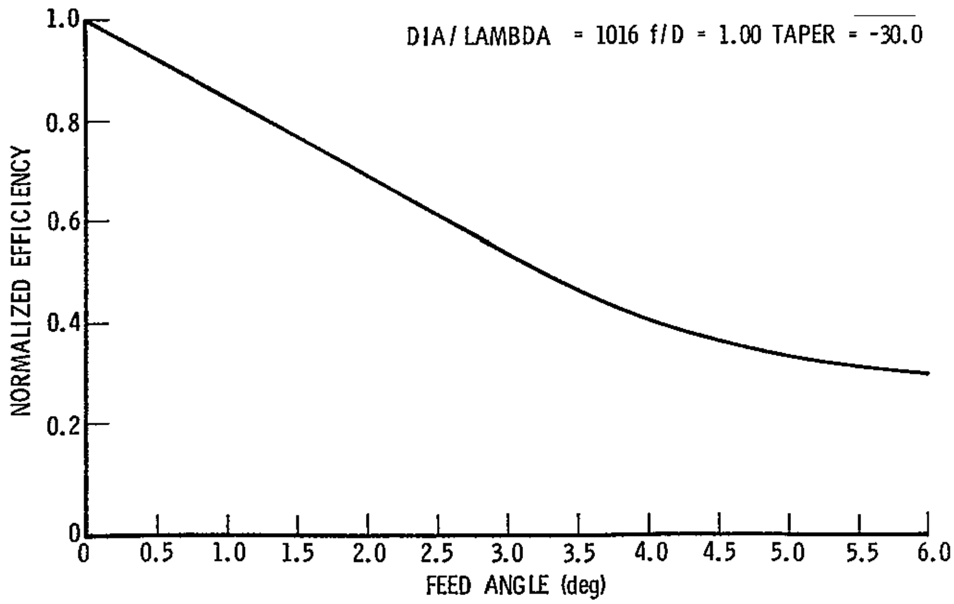


Figure A-16. Gain Loss Curve

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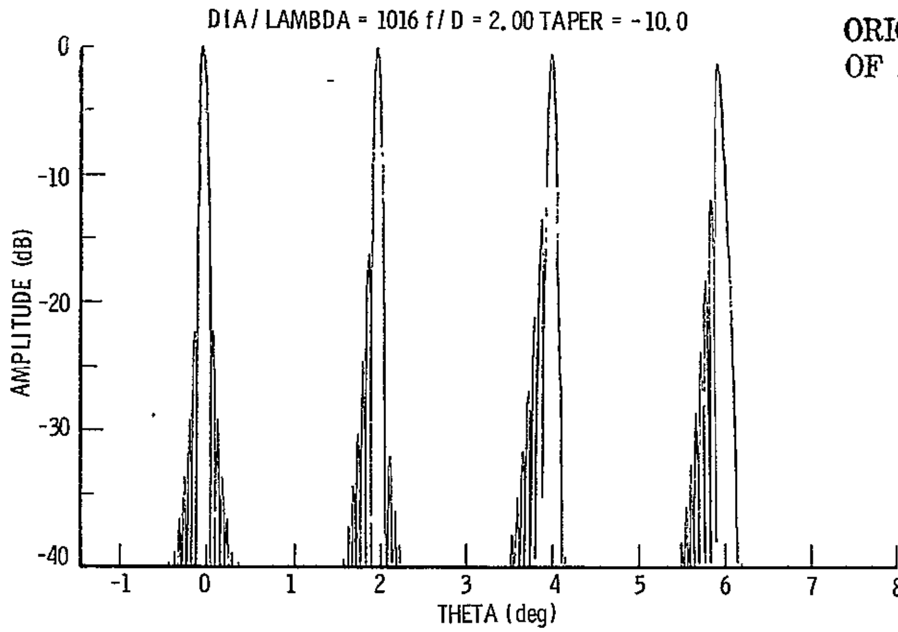


Figure A-17. Radiation Pattern of a Paraboloid

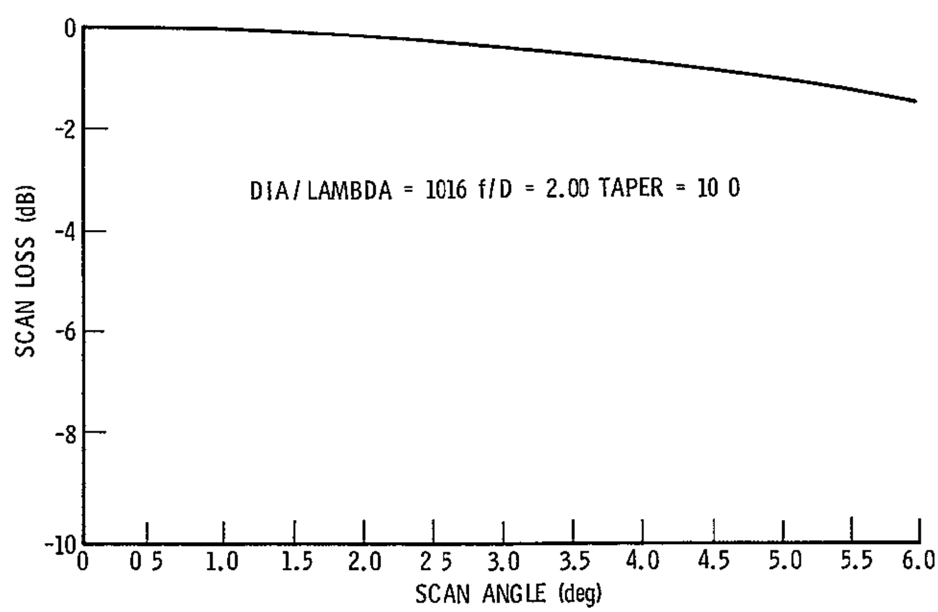


Figure A-18. Gain Loss Curve

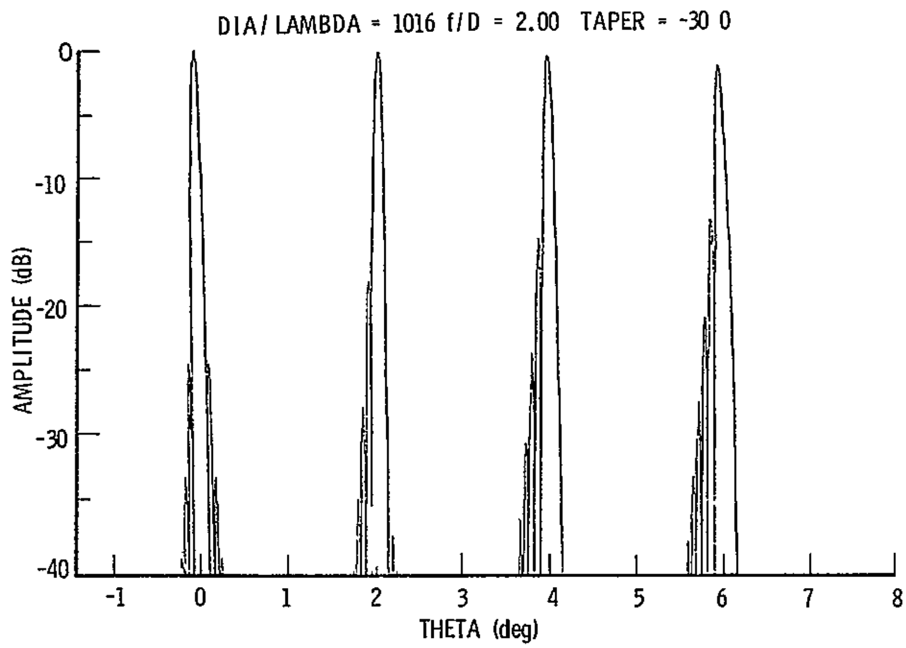


Figure A-19. Radiation Pattern of a Paraboloid

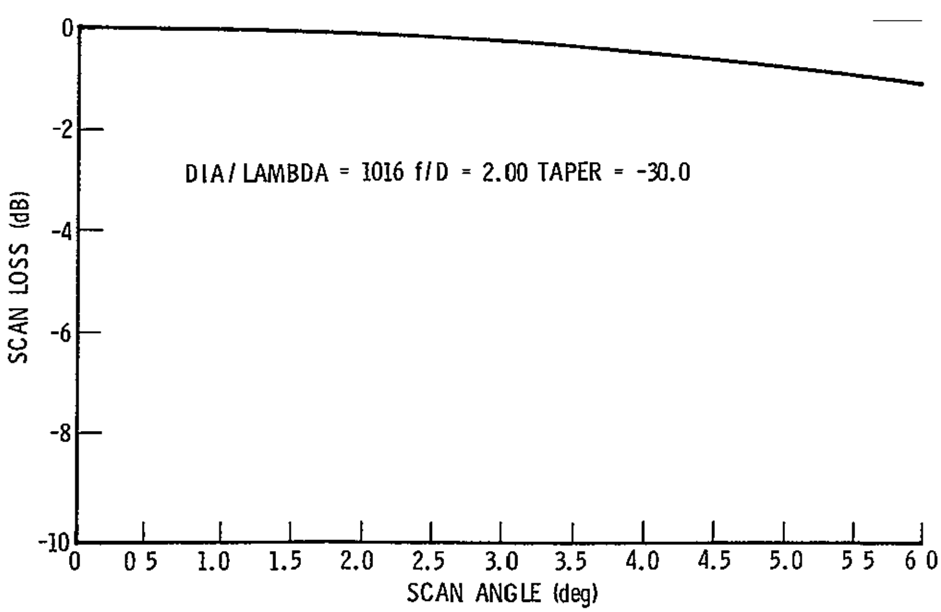


Figure A-20. Gain Loss Curve

being 0.42 and 0.31 dB for illumination tapers of -10 and -30 dB. The data also show that the comma lobe levels are decreased as the f/Ds and illumination tapers are increased. The lowest comma lobe levels are achieved for an f/D equal to 1.0 and an illumination taper of -30 dB.

In summary, the results of the present "quick-response-type" investigation indicates the paraboloid to be viable candidates for the requirement and worthy of further study, however, they will have to have a large f/D and a highly tapered aperture to achieve low scanning losses and acceptable comma lobes. Factors that must be addressed in any future comprehensive investigation include:

a. Achievable and required surface accuracy of reflectors (rms)

b. Phase error as a function of thermal distortions

c. Optimizing axial positions of feeds

d. Feed blockage

e. Support blockage

f. Spillover efficiency

g. Illumination efficiency

h. Feed defocusing effects

i. Mutual impedance when feeds are brought in close proximity

j. Feasibility of deploy mechanism

k. Feasibility of launch configuration

l. Weight and efficiency

m. Tolerable and achievable near and far sidelobe levels.

A.4.2 Planar Array

The planar array investigation focused on establishing the maximum achievable gain as a function of aperture size for multibeam corporately fed antennas utilizing either coaxial or waveguide transmission line networks. The scanning loss characteristics as a function of sub-array sizes were also addressed.

The theoretical limit on the achievable gain of a planar array is dictated by the loss of an array's corporate feed. For example, if one used copper-clad 0.141 type cable in the fabrication of the corporate feed network, the maximum achievable gain, assuming lossless array elements, is 39.2 dBi. In arriving at this figure, the ideal gains of a series of uniformly illuminated equiphase square apertures were computed. The RF path losses associated with each aperture were subtracted from the ideal gain values to arrive at net gains. The sizes of the apertures ranged from 5 by 5 ft to 60 by 60 ft. The data, shown in Table A-5, are plotted in Figure A-21. The aperture size corresponding to the 39.2 dBi gain (5 GHz) is 30 by 30 ft.

Table A-5. Square Aperture Performance Analysis 5 GHz

Aperture Size $(ft)^2$	Maximum Aperture Gain (dBi)	Minimum Corporate Feed Path Length (ft)	Cable Attenuation (dB)	Net Gain (dB)
5^2	32	5	1.4	30.6
10^2	38	10	2.8	35.2
15^2	41.6	15	4.2	37.4
20^2	44	20	5.6	38.4
25^2	46	25	7.0	39.0
30^2	47.6	30	8.4	39.2
35^2	48.9	35	9.8	39.1
40^2	50	40	11.2	38.8
50^2	52	50	14.0	38.0
60^2	53.6	60	16.8	36.8

*Times Wire and Cable Company's copper clad cable CL 50141T. Loss equals approximately 28 dB/100 ft. Weight equals 0.032 lb/ft.

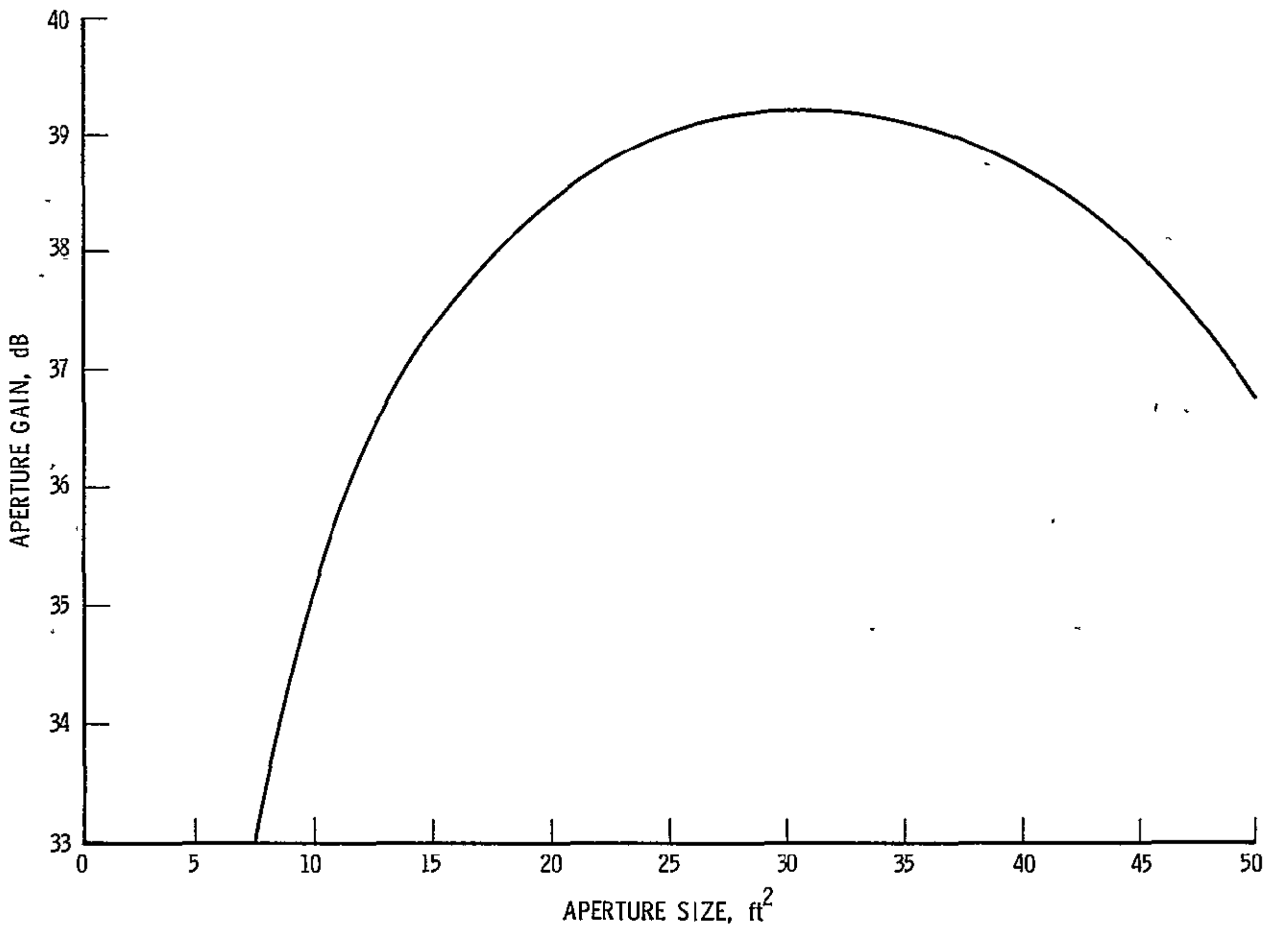


Figure A-21. Maximum Aperture Gain (5 GHz) using 0.141 Coaxial Copper Clad Corporate Feed Network (See Table A-5)

An analogous series of computations were performed assuming a corporate feed network consisting of R/G 49 waveguide (2 by 1 by 0.064 in. wall). The results are shown in Table A-6. The optimum size aperture is 400 by 400 ft with a maximum achievable gain of approximately 62 dBi.

Because of the large number of elements associated with the above designs and the complexity of any conceivable feed system, neither of the above corporately fed arrays are considered viable approaches for the present multibeam application. In the case of the 30 by 30 ft coaxial fed configuration approximately 23, 225 elements would be required, assuming half-wavelength spacings. Unless a Butler-type feed is used, separate

Table A-6. Square Aperture Performance Analysis
(Waveguide Feed 5 GHz)

Aperture Size $(ft)^2$	Maximum Aperture Gain (dBi)	Minimum Corporate Waveguide Length (ft)	Waveguide Loss (dB)	Net Gain (dB)
50^2	52	50	1.0	51
100^2	58	100	2.0	56
200^2	64	200	4	60
400^2	70	400	8	62
800^2	76	800	16	60

*RG 49 waveguide 2 by 1 by 0.064 in. wall.

corporate feeds would be needed for each beam. The weights of such feeds in the case of a 5000 to 10,000 multibeam array would be stupendous. The problems are compounded in the case of the 400 by 400 ft aperture. The number of elements could approach 4,000,000.

If one limited the size of the aperture to 200 by 200 ft and utilized sub-arrays as element models, the complexity of the array is significantly reduced. Unfortunately, however, as the sizes of the sub-arrays are increased, the scanning loss is also increased. Table A-7 shows the relationship between sub-array spacing and scanning loss. In these calculations, it was assumed that the element pattern of the sub-array was a $\cos^N\theta$ type pattern with a directivity equal to the directivity of a uniform illuminated equiphase square aperture. The sides of the square aperture was assumed to be equal to the spacing between sub-array modules.

Even with sub-array modules of 7.45 λ by 7.45 λ (corresponding to a scan loss of -3.0 dB), a 200-ft square aperture would still require over 15,000 sub-modules. Since the weight and complexity of a parallel-type corporate feed structure is still considered prohibitive, the corporately fed planar array approach was eliminated as a contender.

Table A-7. Scan Loss Vs Sub-Array Size

Scan Angle	Scan Loss	Sub-Array Spacing (λ)
3.61	-0.200	1.96
3.61	-0.400	2.75
3.61	-0.600	3.35
3.61	-0.800	3.86
3.61	-1.000	4.31
3.61	-1.200	4.72
3.61	-1.400	5.10
3.61	-1.600	5.45
3.61	-1.800	5.78
3.61	-2.000	6.09
3.61	-2.200	6.38
3.61	-2.400	6.67
3.61	-2.600	6.94
3.61	-2.800	7.20
3.61	-3.000	7.45
3.61	-3.200	7.69
3.61	-3.400	7.93
3.61	-3.600	8.16
3.61	-3.800	8.38
3.61	-4.000	8.60
3.61	-4.200	8.81
3.61	-4.400	9.02
3.61	-4.600	9.22
3.61	-4.800	9.42
3.61	-5.000	9.61

A.4.3 Butler Array

An example of an eight-element Butler array is depicted in Figure A-22. The array has eight independent beams. Each beam utilizes all elements of the array and has a gain equal to the aperture gain minus the gain associated with decreases in the projected aperture in the direction of the scanned beams. The gains are also degraded by the I^2R losses of the antenna elements, beam forming network, and interconnecting transmission line assemblies. A schematic of the beam forming matrix is shown in Figure A-23. It consists of a series of 3 dB directional coupler and phase shifters. Figures A-24 and A-25 are photographs of a beam forming matrix and an array. The matrix is an example of hardware implementation of the schematic shown in Figure A-23. The particular matrix (designed at Electronic Specialty Company) utilizes coupled mode 90-deg hybrids (Ref. A-5) in conjunction with Shiffman-type phase shifters (Ref. A-6). The elements are cavity-backed dielectrically loaded equiangular spirals. Figure A-26 is a schematic of a 16-element Butler array. It shows the rapid increase in complexity of a matrix as the number of elements are increased.

The design equations for determining the number of hybrids and phase shifters in a Butler array are as follows:

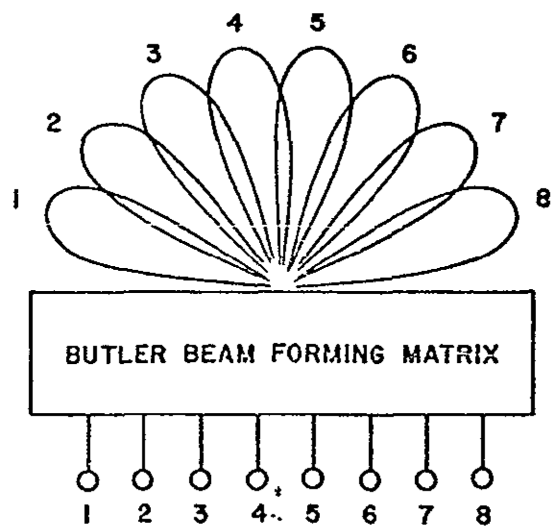
$$\text{Number of Hybrids} = N/2 \log_2 (N)$$

$$\text{Number of Phase Shifters} = N/2 (\log_2 N - 1)$$

where N = number of array elements or modules

The first step in applying these equations to the previously considered 200 by 200 ft aperture is to select the number of elements, or sub-array modules. Factors influencing the selection of the number of elements are (a) they must be a power of two and (b) their spacing should not result in excessive scanning losses. The number of elements, or sub-arrays, chosen as satisfying these criteria was 16, 384. The spacing between

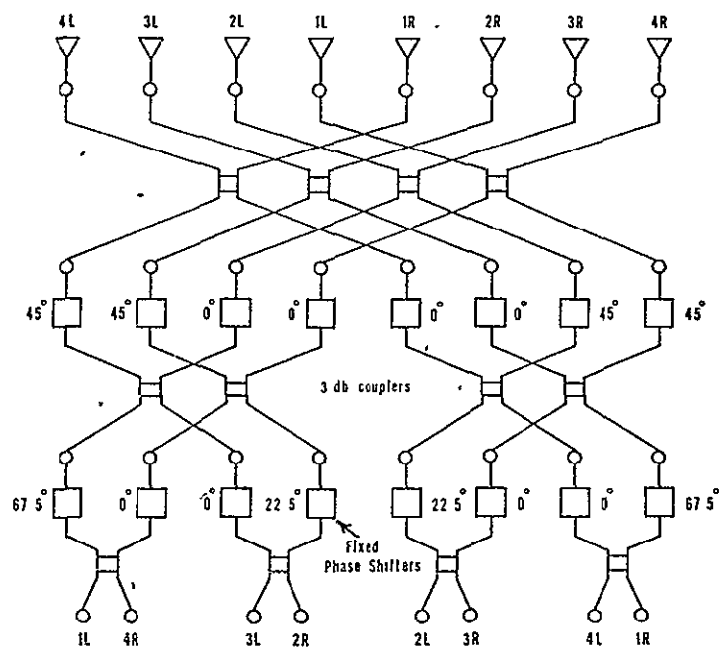
Typical Beams



Input Ports

Figure A-22. Butler Multiple Beam Eight-Element Array

Antenna Elements



Beam Input Ports

Figure A-23. Schematic of Eight-Element Butler Array

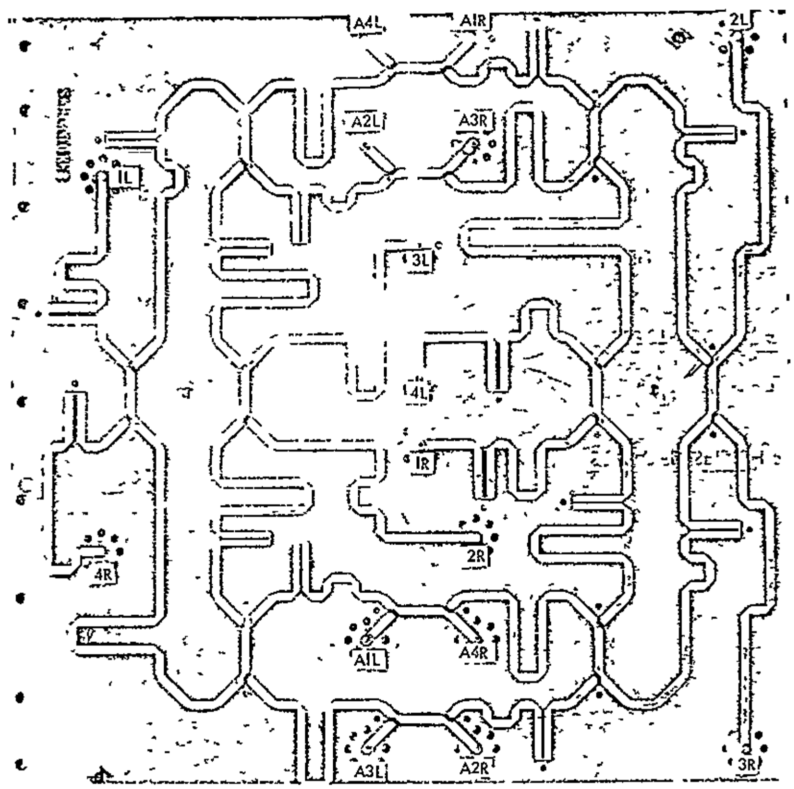


Figure A-24. Eight-Element Butler Matrix (2.5-5.0 GHz)

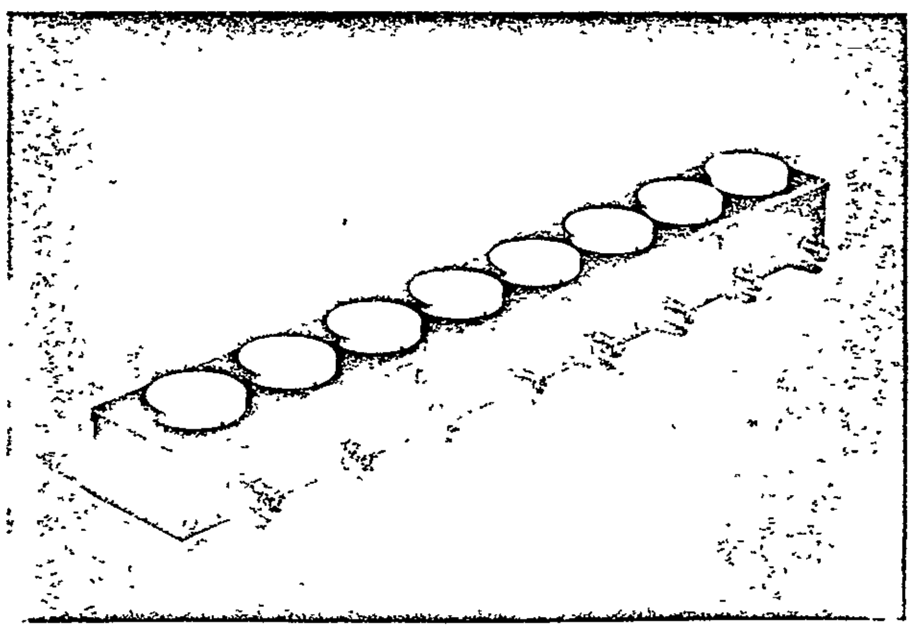


Figure A-25. Eight-Element Butler Array

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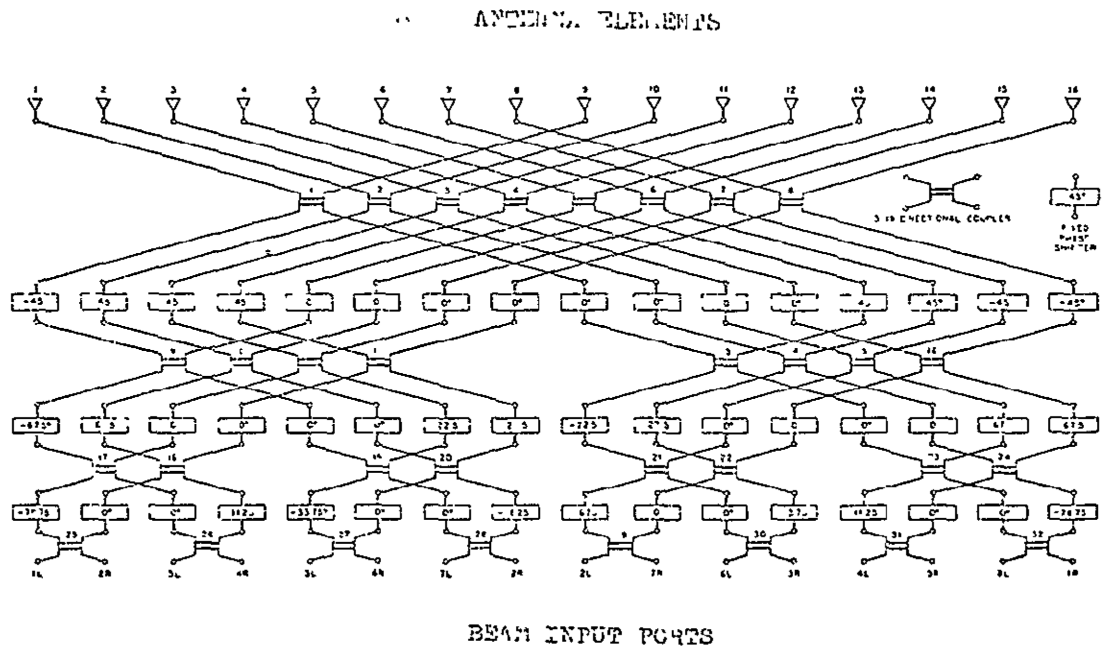


Figure A-26. Schematic of Sixteen-Element Butler Array

modules was 7.94 λ, resulting in a scanning loss of 3.4 dB (3.61 deg scan angle). The detailed design of the configured array is as shown in Table A-8. The number of hybrids and phase shifters are seen to be in excess of 200, 000.

Table A-8. Butler Array Configuration

Frequency	5 GHz
Size	200 by 200 ft
No. of modules	16, 384
Module size	18.75 by 18.75 in. $(7.94\ \lambda)^2$
No. of hybrids	114, 688
No. of phase shifters	106, 496
Sector coverage	±3.61 deg
Scan loss	-3.4 dB*

*at a scan angle of 3.61 deg

In view of the analyses regarding corporate feed losses with the planar array, the Butler array does not lend itself to an acceptable feed design. If the feed is coax, the losses associated with a large aperture feed would be prohibitive. If a waveguide-type feed system is utilized, the weight and packaging requirements would prove unsurmountable, particularly when one considers the feed would have to incorporate over 200, 000 hybrids and phase shifters. The Butler approach is thus considered very unattractive.

A.4.4 Bootlace Lens

The bootlace lens has been studied by a number of companies, with its suitability for multibeam application being well established. The design concept is considered a viable approach for the present multibeam application. In the study, various design aspects of the bootlace lens have been addressed. In addition, a lens design proposed by Grumman was reviewed and "sized" to the present 200-ft dia requirement. Comments on the applicability of the Grumman design are provided.

Table A-9 and Figures A-27 through A-32 were generated in support of the study. Figure A-27 was extracted from the Grumman proposal. The figure shows a packaged, partially deployed, and fully deployed bootlace lens configuration. The dimensions of the lens for the present requirement are as shown in Figure A-28. A summary of structural comments on the lens concept is given in Table A-9. Detailed comments are included in Appendix B. Since the proposed lens is flat on both sides, the distances of corresponding elements on the two surfaces from the axis of the lens are, in general, different. The variation in the spacing of elements on one face with respect to the other face is needed for the lens to satisfy the Abbe' Sine Condition. The equations relating the positions of the elements on the two surfaces are shown in Figure A-29. Figures A-30 and A-31 address the subject of refocusing the feed axially for scanned beams. Even though the example is for a waveguide lens, the improvement shown is also considered applicable to the bootlace design. Finally, Figure A-32 suggests a method of potentially analyzing the effects of a shroud around for various beams.

It is noted that a shroud was successfully used in the DSCS III antenna to reduce sidelobe for the far off-axis beams. The usefulness of the approach to the present configuration requires further consideration.

Table A-9. Summary of Structural Comments on Grumman MBA Concept

- Structural configuration is feasible.
- Best features
  - Packaged proportions are moderate.
  - Boostable and deployable as packaged.
  - Combination of technologies which basically exist today.
- Risk features
  - Extendable mast vulnerable to acceleration forces during and after deployment.
  - Zero-g qualification testing of mast and array will be impossible; modeling and analysis must suffice.
  - Structural dynamics and control possible.
  - R.F. effects of reducing f/D ratio from 2.5 to ~1.0.
- Alternate approaches to array deployment and configuration should be examined, including inflatable membranes, on-orbit fabrication.

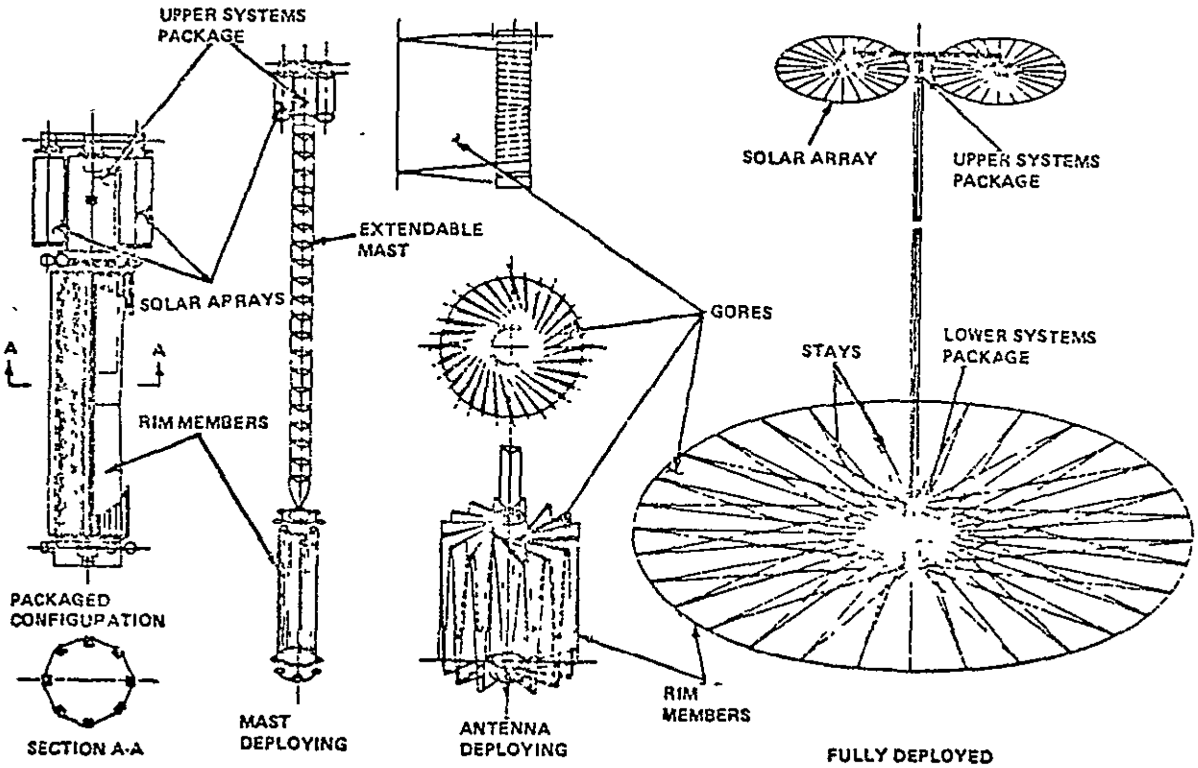


Figure A-27. Deployment Sequence

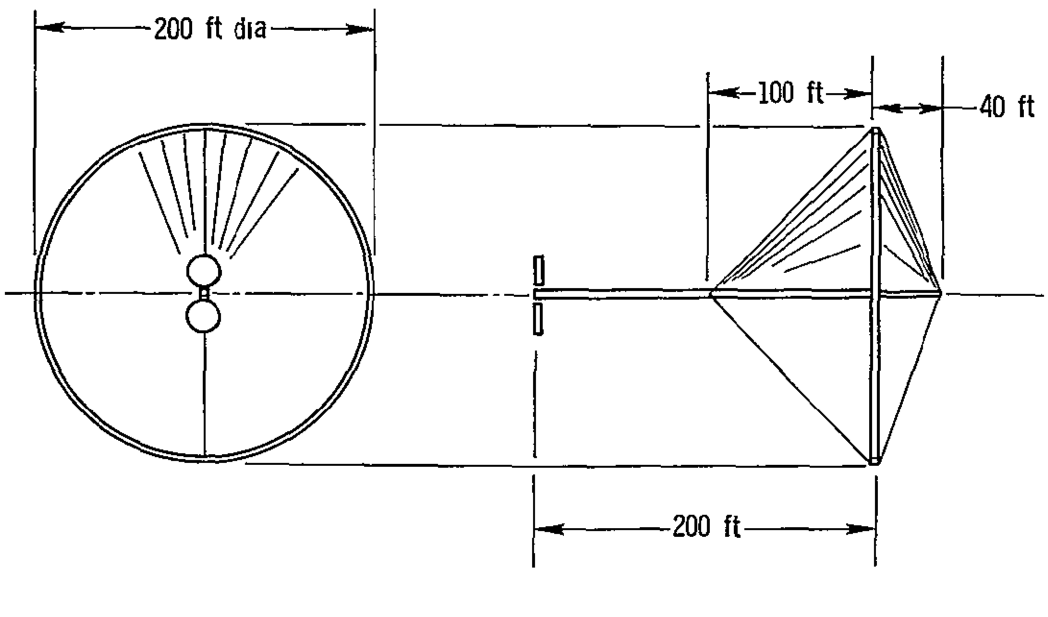


Figure A-28. Proportions for f/D = 1 with D = 200

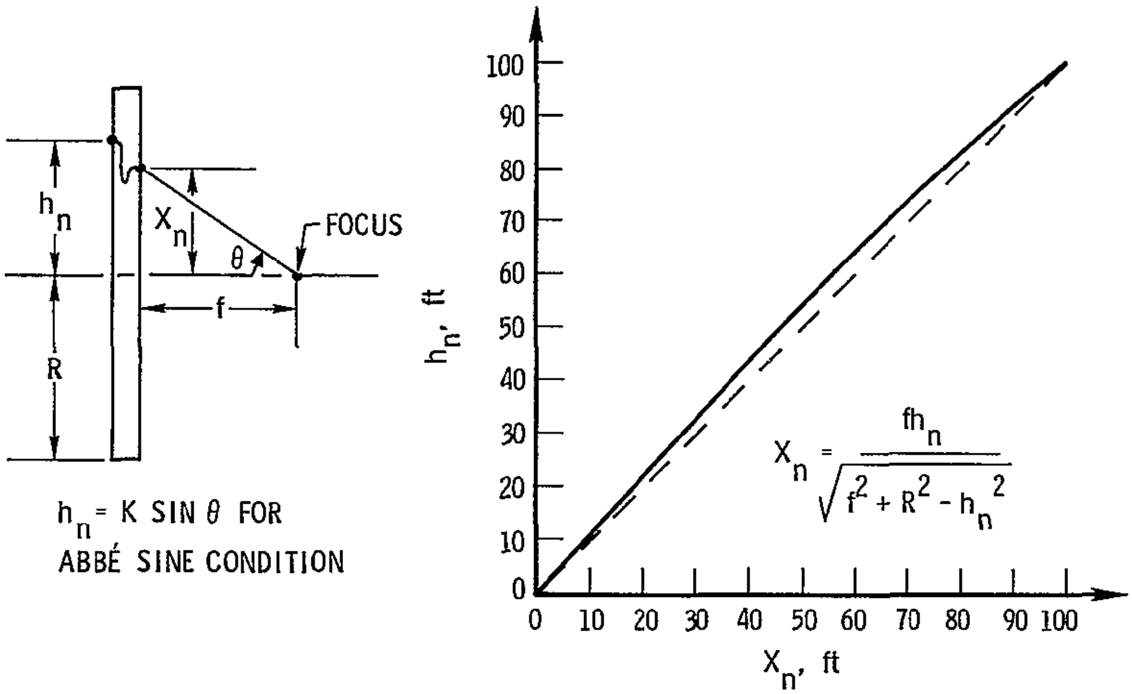
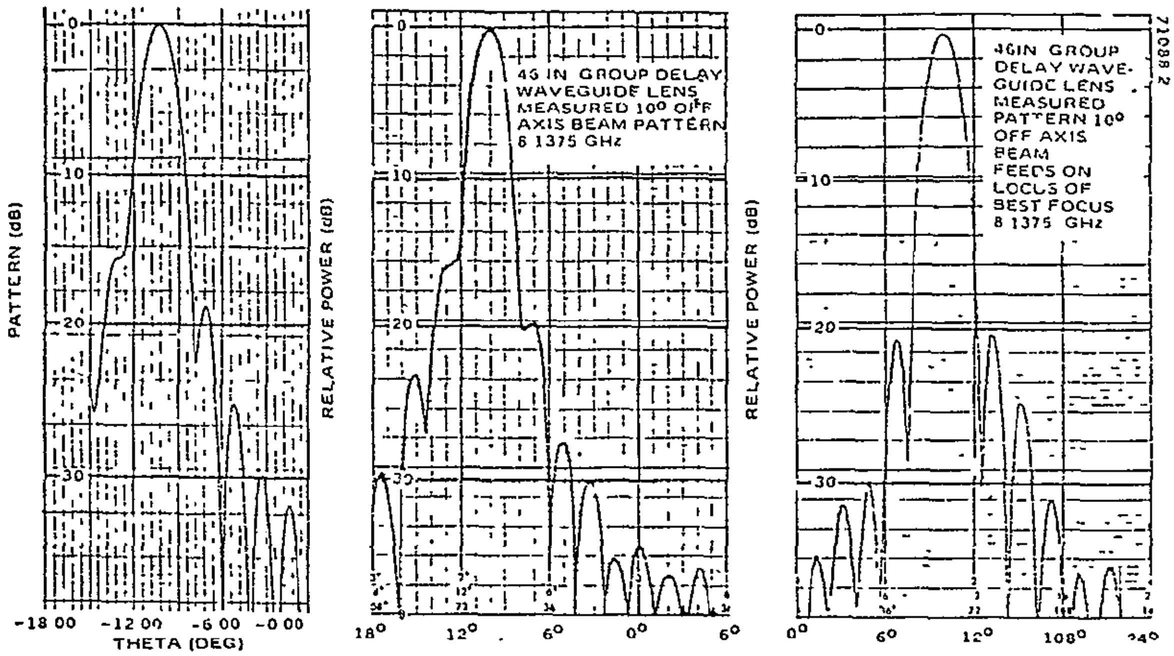


Figure A-29. Element Spacing Satisfying Abbe'Sine Condition using Flat Lens

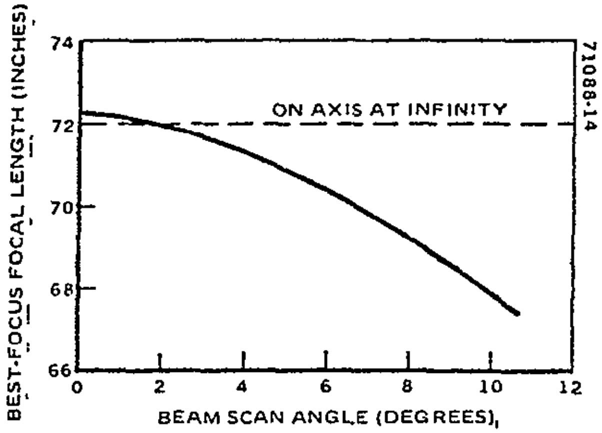


(a) CALCULATED 10° OFF-AXIS BEAM PATTERN SPHERICAL FEED LOCUS (F = 72")

(b) MEASURED 10° OFF-AXIS BEAM PATTERN SPHERICAL FEED LOCUS (F = 72")

(c) MEASURED 10° OFF-AXIS BEAM PATTERN LOCUS OF BEST FOCUS (F = 67.25")

Figure A-30. Example of Off-Axis Refocusing Five-Beamwidth Scan



Deviation of Best-Focus Focal Length from On-Axis Value. On-axis value is 72 inches for focussing at infinity.

LENS ANT.
ABBÉ SINE COND.
F/D = 1.57
FREQ = 8.1375 GHz

Figure A-31. Plot of Best Focal Length vs Scan Angle

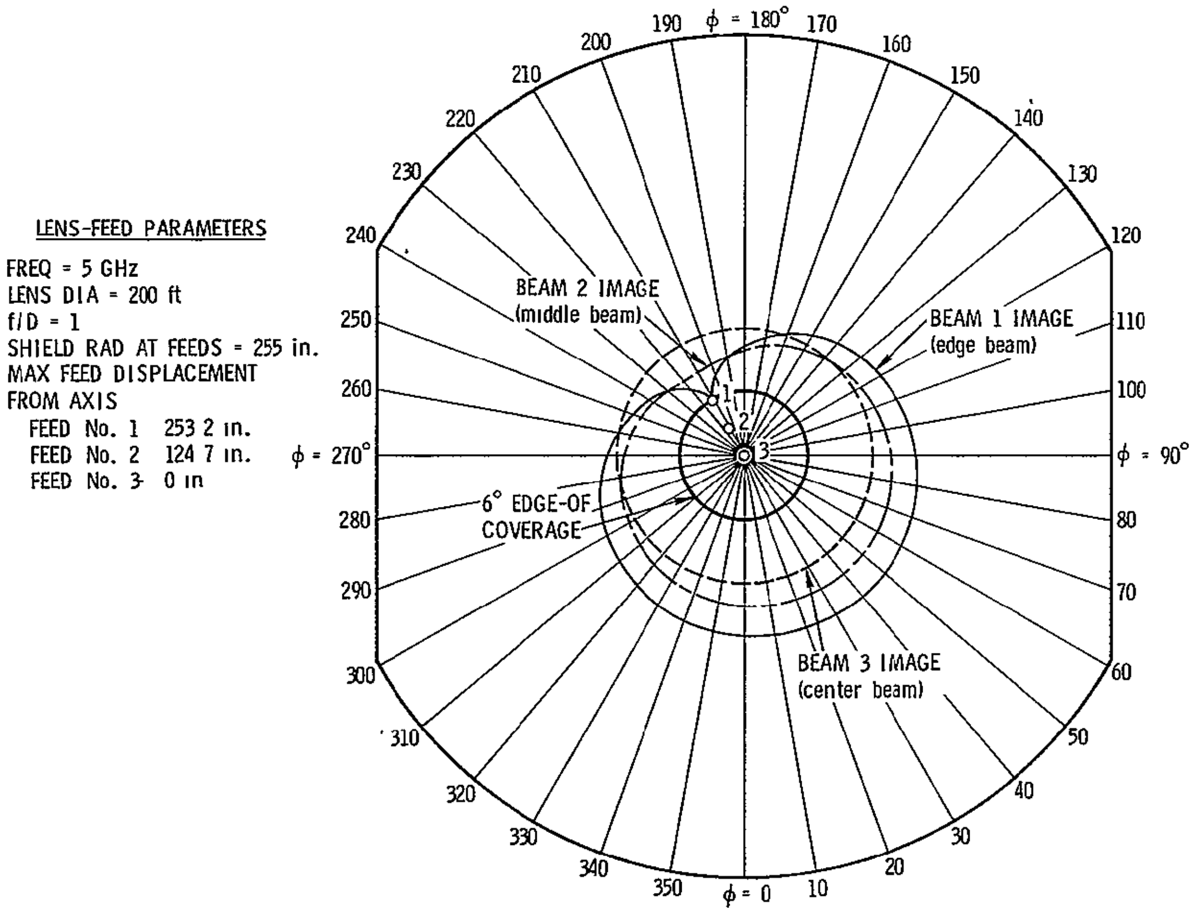


Figure A-32. Locus of Image Beam Due to Shield

A.5 ROM WEIGHT ESTIMATES

ROM weight estimates of several antenna approaches are shown in Table A-10. Of the approaches listed, the parabolic reflector and the bootlace lens are attractive candidate designs. The quoted weight of the parabolic reflector was arrived at from scaling quoted estimates from industry. The bootlace lens estimate was influenced by the Grumman design. The other estimates are simply best judgement.

Table A-10. ROM Weight Estimates (216 ft/66 Meter Aperture)

Antenna Type	Lens Weight (lb)	Feed Weight (lb)	Total Weight (lb)
Rotman Lens	8,000	12,000	20,000
Bootlace Lens	3,200	2,200	5,400
Parabolic Reflector	2,300	2,200	4,500
Butler Array	8,000	12,000	20,000
Gregorian Class Reflector	2,300	3,500	5,800

A.6 CONCLUSIONS

The results of the study to date show that corporately fed planar arrays and Butler arrays are unsatisfactory for large aperture multibeam antennas. The I^2R losses, weight, and complexity of the feed systems are prohibitive. Paraboloids with small f/D ratios are also considered unacceptable. Comma lobes rise as the beam is scanned and the scan losses are excessive. On the other hand, paraboloids with f/D $\geq$1.0 are very attractive. With a highly tapered illumination, the scan losses out to 3 deg can be held to less than 0.55 dB, with the comma lobes being approximately -11 dB for an f/D = 1.0 and -15 dB for an f/D = 2.0. Bootlace lenses also appear very satisfactory from a standpoint of RF performance, particularly if axial positioning of off-axis are optimized for low sidelobes. Insofar as weight and complexity are concerned, the paraboloid is believed to be somewhat superior to the bootlace lens, however, the position tolerances of the lens are less stringent, simplifying the mechanical design. Furthermore, the lens can be made active for electronic beam steering, beam amplification, or both, which is not possible with the paraboloids.

In summary, it appears that the paraboloid and the bootlace lens appear to be equally attractive alternates, as seen from Table A-11. These design approaches can be updated as future studies dictate.

Table A-11. Antenna Choice Considerations

PARAMETER	ANTENNA TYPES				
	Butler-Fed Arrays	Lens-Fed Arrays	Horn-Fed Parabolas	Array-Fed Parabolas	Lenses
Efficiency	Low	Low	High	Moderate	High
Sidelobe Control For Scanned Beams	High	High	Low	Moderate - High	Moderate
Frequency Independence of Scan Angle	Low	High	High	Probably Low	High
Electronic Steering of Ensemble of Beams	High	High	Moderate	Moderate	High
Weight (67 m)	High 20,000 lb	High 20,000 lb	Low 4,500 lb	Moderate 5,800 lb	Moderate 5,400 lb

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APPENDIX A

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APPENDIX B

SELECTION OF INITIATIVES

The process of selecting the final initiatives to be defined and evaluated in this study will be documented in this appendix. The major overall criteria that were followed for initiative evaluation are shown in Table B-1. This set of criteria was necessary in order to guide the selection process to a useful result - a definable concept with definable competitors that would be viable for the required time period and would fit into the concept of a large geostationary device that could eventually be a candidate for integration into multipurpose platforms or could stand alone in providing the useful services. At the outset, a decision had to be made on the number of initiatives or concepts that could be defined. Due to funding limitations, it was concluded that at most three with perhaps four concepts could be defined, costed, and evaluated. Thus, clearly a set of major options presented itself which are illustrated in Table B-2. These options span the range from definition and evaluation of a number of different implementations or designs for one application, for example a television system for educational purposes with three different system concepts; one interchanging information between a few hundred broadcasting stations, a second interchanging information between major centers of learning numbering in the several thousands, and a third distribution of educational programming material to all U.S. schools numbering in the several tens of thousands.

Table B-1. Overall Criteria for Initiative Selection

1. Useful/needed
2. Marketable
3. Definable Concept
4. Definable Competitor Concepts
5. Large (Complexity Inversion)
6. Viable for 1985-1990 Time Period

Table B-2. Major Options

1. Spectrum of Capabilities for One Application
2. Nominal Plus One Growth Capability for Two Applications
3. Nominal Capability Only for Three to Four Applications

Another option would be the analysis of a nominal capability for three or four different applications in which a point design would be made for each application. Intermediate options, of course, would exist. The advantages of the first option are that a good insight would be gained for the system design as a function of its requirements, and conclusions could be drawn on the preferred or best size of the job to be tackled, above or below which it no longer becomes competitive with ground systems. An advantage of the latter option in which a nominal capability is analyzed for several different applications, has the advantage that a spectrum of applications is covered although the disadvantage is that the wrong operating point may be chosen for each application at which the particular application might be terribly expensive or not very competitive, and little insight would be gained into that aspect with a point design.

In weighing the various options, it was decided that at this early stage of definition of these concepts that it was more important to analyze a spectrum of applications than a spectrum of capabilities for one application inasmuch as there were no ready customers waiting in the wings with money in their hands to finance a particular application, and that should such customers become apparent after a study of three or four different applications, it would then be appropriate for a follow-on study to better define the preferred set of requirements or operating points for that application.

A two-step procedure was followed in selecting the initiatives. First, a preselection was performed in which the hundreds of initiatives identified to date were reduced to approximately ten, utilizing the general guidelines and criteria discussed in Table B-1. The second step then involved a more detailed analysis of the surviving initiatives. This two-step process is illustrated in Table B-3.

Table B-3. Two-Step Selection Process

Preselection

- Preselect initiatives that probably fit a PSP, or have been associated with PSP in the past.
- The PSP concept is assumed to be large, complex, needed in the late 1980s or early 1990s, require technology that could be available then, and is probably useful.
- The preselection procedure uses judgment, rather than data, and does not perform an explicit evaluation.

Selection Process

- Perform numerical evaluation in two separate operations
  1. With equal weight to all attributes
  2. With weighting factors applied
- Use results of numerical evaluation to check an independent evaluation performed solely by judgment
  1. If they check - confidence in results
  2. If they do not check - resolve why, and iterate

The preselection rationale that was used involved a set of ground rules illustrated in Table B-4. These criteria were then applied to the initiatives set identified from the study of Advanced Concepts and Their Orbital Support Needs. A tabular listing of the major candidates and those surviving with the rationale for their survival are illustrated in Tables B-5 through B-7. Those candidates that survived this preselection process are listed in Table B-8 in which each surviving candidate is listed and the rationale for its selection discussed. The list of surviving major candidate initiatives is repeated without the rationale in Table B-9 for clarity.

The criteria utilized for the second step of selection are shown in Table B-10. These criteria are applied to the surviving candidates in the process of evaluation which combines judgmental and numerical factors.

Table B-4. Preselection Criteria

Communications

1. In order to be large, complex, and geostationary, missions must call for communications to/from small or mobile terminals over a large area or very high data rate, or both.

2. This implies that categories could include:

   a. Mobile communications - voice/data
   b. Fixed communications - video/data

Sensing

1. In order to be large and complex must be geostationary

2. Categories could be active or passive radar, and active or passive optics.

Support

No other categories are advisable, since the missions are not likely to have acceptance (example - night illumination)

All

Services to USA only - initially

Table B-5. Preselection - Communications Candidates

Candidates		Rationale
~~CC-1~~	~~Global Search + Rescue~~ Locator	Not GEO, Small
~~CC-2~~	~~Urban/Police Wrist Radio~~	Combine with CC-9
~~CC-3~~	~~Disaster Communications Set~~	
CC-4	Electronic Mail Transmission	Two versions needed: PO-PO (no union opposition) and Home-Home (more economically viable)
CC-5	Transportation Services Satellites	Use GPS plus GEO Communication Relay
~~CC-6~~	~~Advanced TV Broadcast~~	Like CC-11: rename rural educational TV
~~CC-7~~	~~Voting/Polling Wrist Set~~	Like CC-9
~~CC-8~~	~~National Information Services~~	Not USA; Like CC-4
CC-9	Personal Communications Wrist Radio	
~~CC-10~~	~~Diplomatic/U.N. Hot Lines~~	Not USA
CC-11	3-D/Holographic Teleconferencing	Could be video 2-D display - same Comsat
CC-12	Vehicle/Package Locator	

Table B-6. Preselection - Observation Candidates

Candidates		Rationale
~~CO-1~~	~~Advanced Resources/~~ Pollution Observatory	Low Altitude
CO-2	Fire Detection	
CO-3	Water Level and Fault Movement Indicator	Small, but retain as example
~~CO-4~~	~~Ocean Resources and~~ Dynamics System	Low Altitude
~~CO-5~~	~~Multinational Air Traffic~~ Control Radar	Low Altitude, Many
~~CO-6~~	~~U.N. Truce Observation~~ Satellite	Low Altitude
~~CO-7~~	~~Nuclear Fuel Locator~~	Not GEO
~~CO-8~~	~~Border Surveillance~~	Like CC-12
CO-9	Coastal Anti-Collision Passive Radar	Make into 200-mile limit radar monitor
~~CO-10~~	~~Astronomical Super Telescope~~	Low Altitude, Far Future
~~CO-11~~	~~Atmospheric Temperature~~ Profile Sounder	Low Altitude
~~CO-12~~	~~Synchronous Meteorological~~ Satellite	Like CO-2
~~CO-13~~	~~High Resolution Earth Mapping~~ Radar	Low Altitude
~~CO-14~~	~~Interplanetary TV Link~~	Not Public-Service Oriented

Table B-7. Preselection - Other Candidates

Candidates		Rationale
~~CS-1~~	~~Energy Generation - Solar/~~ Microwave	Far Term, too big
~~CS-2~~	~~High Efficiency Solar Energy~~ Generation	Far Term, too big
~~CS-3~~	~~Energy Generation - Nuclear/~~ Microwave	Far Term, too big
~~CS-4~~	~~Nuclear Waste Disposal~~	Not GEO
~~CS-5~~	~~Aircraft Laser Beam~~ Powering	Low Altitude, big, far term
~~CS-6~~	~~Night Illuminator~~	Too big
~~CS-7~~	~~Personal Navigation Wrist Set~~	Combine with CC-9
~~CS-8~~	~~Multinational Energy~~ Distribution	Low Altitude
~~CS-9~~	~~Energy Monitor~~	Similar to CC-12
~~CS-10~~	~~Vehicular Speed Limit Control~~	Similar to CC-12
~~CS-11~~	~~Space Debris Sweeper~~	Not public service
~~CS-12~~	~~Ozone Layer Replenishment/~~ Protection	Low Altitude
~~CS-13~~	~~Rail Anti-Collision System~~	Similar to CC-5, CC-12
~~CS-14~~	~~Burglar Alarm/Intrusion~~ Detection	Similar to CC-12
~~CS-15~~	~~Power Relay Satellite~~	Far term, too big
~~CS-16~~	~~Near-Term Navigation Concept~~	Function as Coastal Limit monitor-passive

Table B-8. Surviving Candidates After Preselection

Communications

- Personal/Emergency Communications
  - Combine personal wrist radio (CC-9) with search/rescue beacon, emergency panic button, and voting/polling. Communications only, not navigation. No self-location. Example of mobile system, small antennas.
  - Same satellite provides disaster and police C&C functions.

- Electronic Mail
  - One version is identical with CC-4. It is unlikely to be economically attractive, however will not have great societal impact.
  - A home-to-home or office system, with small boxes as terminals. Replaces all written communications functions of post offices, and reduces post offices to freight and package handling. UPS may take over; many jobs affected, but system could be economically viable. Example of fixed point-to-point system, small antennas.

- Air Traffic Control
  - Use GPS system like CC-5 for position sensing, and a COMSAT like CC-4 or CC-8 for two-way relay. The aircraft determine their position and altitude, and relay to controllers via COMSAT. All traffic controllers for en-route are in central location-central computing. Local airport controllers only for general aviation and taxi control. This is a fourth or fifth generation ATC in FAA terminology. Example of mobile aircraft communications.

- Package/Vehicle Locator
  - Like CC-12. Combines elements of border surveillance (CO-8), vehicle limit control (CS-10), burglar alarms (CS-14), and energy monitor (CS-9). It has the mile-long antenna NAVSAT, and CC-9-like COMSAT relay. The GPS satellites could replace the mile-long antenna. Example of small unattended self-navigating units.

Table B-8. Surviving Candidates After Preselection (Continued)

- Video Teleconferencing
  - Like CC-11, but make it easier to compare with ground systems by making it TV image (2-D) display only. Bandwidths unchanged. Example of point-to-point video.
- Rural Educational TV
  - Like CC-6 - similar functions and requirements. Example of broadcast video.

Sensing

- Fire Detection
  - Typically 10-ft optics in GEO. Other functions such as meteorology subsumed, as well as advanced Landsat. Example of large passive optical sensors.
- Earthquake Fault Movement
  - Small, but may be seen as good example of what NASA can do for safety (if can predict earthquakes accurately). After good design may be very much larger. Example of active laser, low energy. Combines CO-3 and CO-11.
- 200-Mile Limit Monitor
  - A smaller version of CO-9, to scan the coasts and detect/locate all fishing vessels. May be combined with CS-16 or GPS for near-term navigation of friendly vessels. Maps 200-mile swath offshore. Example of active radar at GEO.

Table B-9. Major Candidate Initiatives

<u>Mobile Communications</u>

- Personal/Emergency Communications
- Package/Vehicle Locator
- Air Traffic Control

<u>Fixed Communications</u>

- Electronic Mail (Home-Home)
- Video Teleconferencing
- Rural Educational TV

<u>Remote Sensing</u>

- Forest Fire Detection
- 200-Mile Limit Monitor
- Earthquake Fault Movement

Table B-10. Initiative Selection Criteria

<u>Utility/Marketability</u>

- Potential Benefits
- Popular Appeal
- Broad Current Acceptance
- Undesirable Effects

<u>Technology</u>

- Design Understanding
- Cost Understanding
- Credible Terrestrial Alternatives
- Data Bank

<u>Industrialization Impact</u>

- Early Availability
- Complexity, Size
- Adaptability to Communications Multi-purpose Platform
- Adaptability to Optical Multipurpose Platform

The judgment factors utilized are shown in Table B-11. These judgment factors were applied in conjunction with a set of weighting factors (also based on judgment) as shown in Table B-12.

The basic evaluation is then performed and shown on Table B-13 in which the judgmental factors, both weighted and unweighted, are shown for each of the surviving candidates for each element of the evaluation criteria list. A table compiling the summary scores in both the weighted and unweighted categories of the previous table was then prepared and is shown in Table B-14. The weighted and unweighted rankings are shown in the last columns on the right and are repeated in the evaluation results shown in Table B-15.

In assessing the results of this numerical/judgment evaluation technique, it must be borne in mind that the numerical scores should only be considered an aid to a process that must of necessity be subjective. Thus, initiatives that were ranked close together in the evaluation results should be considered of equivalent value; however, where the evaluation resulted in greatly differing ranks, the relative positions of the initiatives in the ranking table should be considered to be meaningful. Thus, in reviewing, it is clear that the communications-oriented initiatives are to be preferred over the observation initiatives such as Forest Fire Detection. The selected initiatives appear in Table B-16 together with a description of their function. The three initiatives that were selected for analyses include: a Personal Communications concept for interconnection of large numbers of people wearing wrist radio personal terminals with emergency functions as well as pleasure functions; an Educational TV distribution system for program dissemination and interchange for all school systems and at least open universities and learning centers; and an Electronic Mail system for exchanging information between business and government sectors of the total mail stream, but not including the home-to-home and home-to-other sectors of the mail stream. In addition, if time permits, it was decided that interconnection of rural telephones would be a useful fourth initiative function. This function could be a low capacity version of the Personal Communications Initiative.

Table B-11. Initiative Selection Criteria (Judgment Factors)

AREA	CRITERIA	JUDGMENT FACTORS, VALUE		
		3	2	1
UTILITY/MARKETABILITY	Potential Benefits	High	Intermediate	Low
	Popular Appeal	High	Intermediate	Low
	Current Acceptance	High	Intermediate	Low
	Undesirable Effects	Few	Some	Many
TECHNOLOGY	Design Understanding	Good	Fair	Poor
	Costs Understanding	Good	Fair	Poor
	Credible Terrestrial Alternatives* for Comparison	Yes	Limited	No
	Adequate/Available Data Bank	Yes	Limited	No
INDUSTRIALIZATION IMPACT	Early Availability Test Mid-80s; Ops - 90s	Yes	Maybe	No
	Complexity, Size	Large	In-Between	Small
	Adaptability to Multi-Purpose Communications Platform	Good	Fair	Poor
	Adaptability to Multi-Purpose Optical Platform	Good	Fair	Poor

* If no other way to perform function, then reverse the judgment element

Table B-12. Initiative Selection Criteria (Weight Factors)

	VALUE
UTILITY/MARKETABILITY	
- POTENTIAL BENEFITS	3
- POPULAR APPEAL	3
- BROAD CURRENT ACCEPTANCE	3
- UNDESIRABLE EFFECTS	3
TECHNOLOGY	
- DESIGN UNDERSTANDING	3
- COST UNDERSTANDING	2
- CREDIBLE TERRESTRIAL ALTERNATIVES	1
- DATA BANK	1
INDUSTRIALIZATION IMPACT	
- EARLY AVAILABILITY	2
- COMPLEXITY, SIZE	2
- ADAPTABILITY TO COMMUNICATIONS MULTIPURPOSE PLATFORM	2
- ADAPTABILITY TO OPTICAL MULTIPURPOSE PLATFORM	1

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Table B-13. Selection Evaluation - 1

	Utility/Market Ability				Technology				Industrialization Impact		One or the Other	
	Potential Benefits	Popular Appeal	Broad Current Acceptance	Undesirable Effects	Design Under standing	Cost Under-standing	Credible Terrestrial Alternative	Data Bank	Early Availability	Complexity Size	Adaptable to Multipurpose Comm Platform	Adaptable to Multipurpose Optical Platform
Mobile Communications												
Personal/Emergency Radio Telephones	3/9	3/9	3/9	3/9	3/9	3/6	3/3	3/3	3/6	3/6	3/6	1/1
Vehicle/Package Locator	2/6	2/6	-/6	3/9	3/9	3/6	3/3	3/3	3/6	3/6	3/6	1/1
- Air Traffic Control/ Collision Avoidance	3/9	-/6	2/6	3/9	3/9	3/6	3/3	3/3	3/6	1/2	3/6	1/1
Fixed Communications												
Electronic Mail (Home-Home)	3/9	3/9	-/6	1/3	3/9	3/6	3/3	3/3	3/6	3/6	3/6	1/1
- Electronic Mail (Post Office - Post Office)	2/6	2/6	3/9	2/6	3/3	3/6	3/3	3/3	3/6	3/6	3/6	1/1
- Video Teleconferencing	3/9	3/9	3/9	2/6	3/9	3/6	3/3	3/3	3/6	3/6	3/6	1/1
- Rural Educational TV	3/9	3/9	3/9	1/3	3/9	3/6	3/3	3/3	3/6	2/4	3/6	1/1
Remote Sensing												
Forest Fire Detection (Optical)	2/6	1/3	1/3	3/9	3/9	3/6	3/3	3/3	3/6	-/4	1/-	3/3
- 200 Mile Limit Monitor (Radar)	-/6	1/3	3/9	3/9	3/9	3/6	3/3	3/3	3/6	3/6	2/4	1/1
Earthquake Fault Movement Detector (Laser)	3/9	-/6	2/6	3/9	3/9	3/6	3/3	3/3	3/6	1/2	2/4	3/3

3/9 Value/Value × Weight Factor

Table B-14. Selection Evaluation - 11

	Score (Min = 11, Max = 36, Avg = 24)			Weighted Score				Ranking	Ranking
	Total	Total Less Min	Total Less Avg	Total	Normalized to 76	Total Less Avg (52)	Norm to 32	Weighted	Unweighted
Mobile Communications									
- Personal/Emergency Radio Telephones	34	23	10	76	100	24	100	1	1
- Vehicle/Package Locator	31	20	7	67	88	15	63	4	3
- Air Traffic Control/ Collision Avoidance	30	19	6	66	87	14	58	5	4
Fixed Communications									
- Electronic Mail (Home-Home)	30	19	6	64	84	12	50	7	5
- Electronic Mail (Post Office-Post Office)	30	19	6	67	88	15	63	4	4
- Video Teleconferencing	33	22	9	73	96	21	88	2	2
- Rural Educational TV	31	20	7	68	89	16	67	3	3
Remote Sensing									
- Forest Fire Detection (Optical)	28	17	4	57	75	5	21	9	5
- 200-Mile Limit Monitor (Radar)	30	19	6	65	86	13	54	6	4
- Earthquake Fault Movement Detector (Laser)	30	19	6	64	84	32	50	7	4

Table B-15. Evaluation Results

RANK	RANKED WITH EQUAL WEIGHT	WEIGHTED RANKINGS
1	Personal/Emergency Communications	Personal/Emergency Communications
2	Video Teleconferencing	Video Teleconferencing
3	Rural Educational TV (Equal Score)	Rural Educational TV
4	Vehicle/Package Locator (Equal Score)	Vehicle/Package Locator (Equal Score)
5	Air Traffic Control/Collision Avoid (Equal Score)	Electronic Mail, (P.O. - P.O.) (Equal Score)
6	Home-Home Electronic Mail (Equal Score)	Air Traffic Control/Collision Avoidance
7	P.O. - P.O. Electronic Mail (Equal Score)	200-Mile Limit Monitor
8	200-Mile Limit Monitor (Equal Score)	Electronic Mail (Home-Home)
9	Earthquake Fault Movement Monitor (Equal Score)	Earthquake Fault Movement Monitor
10	Forest Fire Detection	Forest Fire Detection

Table B-16. Selected Initiatives

INITIATIVE	FUNCTION
• Personal Communications	– Interconnection of Wrist Radio Personal Terminals – Pleasure, Business, Mobile Uses – Emergency Channels For: Panic Search/Rescue Disasters
• Educational TV	– Program Dissemination and Interchange Within All School Systems In CONUS – Open University Learning Center Program Distribution/Interaction – Public TV Interconnect?
• Electronic Mail	– Interconnection of Business and Government Buildings Directly
• Rural Telephones	– To Be Defined If Time Permits

The applicability of the selected initiatives to performing other functions that were similar although not necessarily identical, in the large number of initiatives initially considered for selection, are displayed in Table B-17. A review of this table indicates that analysis and definition of the three selected initiatives will have great applicability to other similar initiatives in the initial initiatives list, and thus verifies that this initial analysis will have broader use than for the three initiatives that are analyzed in depth in this study.

Table B-17. Applicability to Other Initiatives/Functions

Selected Initiative	Other Initiatives/Functions		Functions Satisfied
Rural/Educational TV	Very Similar		
	advanced TV broadcast	CC-6 (A)	fewer channels, same function
	public services broadcast	(5YP)	TBD
	Somewhat Similar		
	3D Holographic teleconferencing	CC-11 (A)	one way video presentations
	national information services	CC-8 (A)	video data bank access (x-rays, etc)
Personal/Emergency Communications	Very Similar		
	Urban/police wrist radio	CC-2 (A)	most functions, except scrambling/A/J
	Disaster communications	CC-3 (A)	all functions
	Voting/Polling	CC-7 (A)	lower capacity
	National information services	CC-8 (A)	emergency medical advice (voice)
	Personal Communications system No. 1026, 1027	(OFS)	all functions (TBD)
	Somewhat Similar		
	Global search/rescue	CC-1 (A)	USA only; most functions except location
	Vehicle/package locator	CC-12 (A)	comsat functions only
	Search/rescue satellite	5YP	most functions, except location
	Mobile services satellite	5YP	most functions
	hazard warning system No. 3065, 3066	OFS	TBD-many functions
Electronic Mail (Home/office inertie)	Very Similar		
	electronic mail-post office	CC-4 (A)	very thin route only, not high capacity
	national information services	CC-8 (A)	Data requests-facsimile
	Somewhat Similar		
	transportation services	CC-5 (A)	Comsat functions-no location
	voting/polling system	CC-7 (A)	regional collect ion system inertie
Video Teleconferencing	Very Similar		
	3D Holographic teleconferencing	CC-11 (A)	all functions, fewer channels
	Somewhat Similar		
	advanced TV broadcast	CC-6 (A)	all functions, to larger users only
	national information services	CC-8 (A)	video surgical sharing, etc.
	diplomatic/UN hotlines	CC-10 (A)	slow scan TV conferences
	multi-service domestic comsat No. 1020, 1021	OFS	TBD

APPENDIX C

CATALOG OF REFERENCE DOCUMENTS

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