BROADCASTING

10

Useful Applications of Earth-Oriented Satellites

SUMMER STUDY ON SPACE APPLICATIONS

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Useful Applications of Earth-Oriented Satellites

BROADCASTING

Prepared by Panel 10 of the
SUMMER STUDY ON SPACE APPLICATIONS
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PREFACE

In the fall of 1966, the National Aeronautics and Space Administration (NASA) asked the National Academy of Sciences to conduct a study on "the probable future usefulness of satellites in practical Earth-oriented applications." The study would obtain the recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program needed to provide the technology required to exploit these applications. NASA subsequently asked that the study include a consideration of economic factors.

Designated "The Summer Study on Space Applications," work began in January 1967, guided by a Central Review Committee (CRC) appointed by the Academy. The Study's Chairman was Dr. W. Deming Lewis, President of Lehigh University.

Technical panels were convened to study practical space applications and worked intensively for periods of two to three weeks during the summers of 1967 and 1968 at Little Harbor Farm in Woods Hole, Massachusetts. The work of each panel was then reported to the Central Review Committee, which produced an overall report. Panels were convened in the following fields:

Panel 1: Forestry-Agriculture-Geography

Panel 2: Geology

Panel 3: Hydrology

Panel 4: Meteorology

Panel 5: Oceanography

Panel 6: Sensors and Data Systems

Panel 7: Points-to-Point Communications

Panel 8: Systems for Remote-Sensing Information and Distribution

Panel 9: Point-to-Point Communications

Panel 10: Broadcasting

Panel 11: Navigation and Traffic Control

Panel 12: Economic Analysis

Panel 13: Geodesy and Cartography

The Panel on Broadcasting compiled an interim report during the summer of 1967. This was reviewed and prepared for publication as a final report under the leadership of the chairman, Mr. Wilbur Pritchard.

The major part of the Study was accomplished by the panels; the function of CRC was to review their work, to evaluate their findings, and, in the context of the total national picture, to derive certain conclusions and recommendations. The Committee was impressed by the quality of the panel's work and has asked that the panel reports be made available to specialized audiences. While the Committee is in general accord with the final panel reports, it does not necessarily endorse them in every detail. It chose to emphasize certain recommendations in its overall conclusions and recommendations, which have been presented in Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee.

In concluding this preface, it is emphasized that the conclusions and recommendations of this panel report should be considered within the context of the overall report of the Central Review Committee.

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1.0 INTRODUCTION

The study of broadcast satellites is a challenging and fascinating task. Of the potential applications of space, broadcasting is perhaps the most exciting, because of its nearness and its inherent capacity for good. The communications revolution made possible by satellites will be analogous to the transportation revolution created by the airplane 50 years ago. Great areas of the earth were then inaccessible for anyone but explorers, because of the practical difficulties of building highways and railroads. The airplane made any place reachable routinely if an airfield could be built and kept up. The satellite will do the same thing for communications. Radio and TV broadcast, no longer limited to receivers within a few miles of a transmitter, will be available to all receivers. The implications are spectacular. It is reassuring that the human race might turn the talent required to develop ICBM's, toward instructing half of itself to read and write.

Because we were a technically oriented panel, we solicited help from many people in broadcasting policies, economics, education, sociology, and law, with the idea of keeping our work compatible with non-technical realities.

We have taken as our objectives the identification of reasonable uses and users of broadcast satellites, selection of alternative systems to provide these services, and highlighting of technologies requiring improvement.

It was necessary for us to do a reasonable amount of engineering in order to have our different classes of systems designed on a commonly understood basis. We have tried to make these starting points clear, so that our results can be compared with others.

The economic studies were the most difficult because of their exceptional complexity, and interrelations with social, legal, and demographic problems. We did hypothesize a model problem, and examined the application of our different satellite and conventional techniques to its solution. We hope that these methods and ideas will be useful to those studying specific applications in context.

We have made a series of technical and quasi-technical recommendations to several agencies, and have commented briefly on the NASA programs included in NASA SP-142 (A Survey of Space Applications). These programs fit our classes of system well.

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2.0 SUMMARY

2.1 General Features of Broadcast Satellites

By virtue of its unique geometric relationship to the earth, a satellite in synchronous* equatorial orbit has operational possibilities not easily realized by other means. It has a constant line of sight to any point on the visible 43 percent of the earth's surface. The ability to connect a single point on the earth to myriads of others that can be simply equipped, and are not necessarily accessible by other means, has an unusual spectrum of applications. The inherent advantages of a satellite system are several and exploitable in a variety of ways. (See Section 3 for details.)

The advantage of a fixed satellite in permitting simplicity in the earth complex is so great that the use of any orbit other than synchronous equatorial needs exceptional justification. Use of inclined orbits, particularly the 63.5° prograde elliptical orbit favored by the Soviet Union, has unique features. This orbit permits greater payload with a particular booster, and coverage of latitudes above 75° N, at the expense of considerable earth terminal complexity. Full-time coverage is only possible with a multiplicity of satellites. In the absence of a compelling need for northern coverage, however, the advantages remain overwhelmingly with synchronous equatorial orbits, and this study has been so restricted.

Satellites permit much earlier introduction of broadcast receivers to areas where none exist than would be possible with ordinary means. It can be done without the tedious creation of a network of stations and means of distribution that, even in industrially mature countries like the United States, takes a long time.

A satellite broadcast system has the built-in advantage of reaching any location within a coverage area. This area can easily be made equal to the total required--be it a time zone, a whole country, or an entire region of the earth. Once the satellite system is set up, no further satellite costs are incurred as more ground terminals are added. Direct and limited-distribution broadcast systems seem to offer significant economic advantages, especially in countries that have little or no existing communications infrastructure.

The entire matter of broadcast-satellite economics is extraordinarily complicated. Comparisons are sometimes possible but are rarely valid, because the costs are usually ascribed to different people and entities. Section 5, in a quasi-tutorial manner, hypothesizes some situations and discusses some interesting generalities of this complex subject. We hope it will be a useful guide to planners, always remembering that any particular proposal will have to be studied in its political and social context to a far greater depth, to have a meaningful result.

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*In this and other sections of the report, the terms "synchronous" and "geostationary" are used interchangeably.

Where wide-area coverage is needed for common program material, a satellite is much more economical of spectrum space than is a terrestrial system. For example, to cover the United States with typical stations having only a 50-mile radius takes about 10 channels, to avoid interference between contiguous stations. The satellite can accomplish the same task with only one channel. This is a frequently overlooked advantage of satellites, and one that is not trivial, with spectrum space so valuable.

The average number of channels available to a home receiver in the United States is only three. A satellite could profitably add several to this, either nationally or sectionally.

Conventional TV stations have difficulty running profitably if they are devoted to educational and instructional programming in the broadest sense. By extending the coverage cheaply, and thereby expanding the audience to whom the program material is directed, a satellite system appears to be natural for the complex of programming called Public TV. Included within this elusively defined class would be public-interest broadcasting, cultural and educational material, and even instruction in the scholastic sense. Such a system is technically possible in a variety of realizations. The obstacles are largely social and political. The question as to who would originate and control program material is, therefore, a thorny point that is not covered in this report.

2.2 Categories of Broadcast Satellites

In Section 3 there is a list of services that have been identified as possible applications for satellites. Although they seem numerous, and comprise such varied services as TV networking, educational TV in less-developed countries, United Nations worldwide voice broadcasting, and direct Public TV in industrial areas, they may be arranged in four classes.

Class A includes systems of TV distribution in which a satellite broadcasts many channels to elaborate ground receivers, for rebroadcast. In the extreme case, these ground stations would use 85-foot or larger antennas, with helium-cooled receivers, and require further relay to nearby TV stations. This system is a simple substitute for the present microwave relay networking. It is easy to accomplish, and might well produce a noticeable savings in cost. It would effect no significant operational advantage, being a point-to-point rather than a broadcast system, and has not been considered here.

As a modification to the above, Class A distributional systems were examined, with somewhat more modest terminals, using 20-foot diameter antennas and nitrogen-cooled receivers. These could be located at existing TV transmitters or used as networking devices, depending on the economics. Several frequencies were studied: 2500, 12,000, and 35,000 MHz; and FM was considered only because of the overwhelming advantage it represents in radiated power requirements. Pulsed systems were not considered because the bandwidth-power tradeoff is not unlike that of FM. Using FM, the improvement factor above threshold is great enough to make any quality picture other than the best a bad bargain. Therefore, all FM cases consider only a top-quality picture. After looking at all three frequencies, 12,000 MHz was chosen as the best one for more thorough analysis. It turns out that a 630-lb satellite at 12,000 MHz can produce eight channels in each of three time zones. Such a system would be excellent for domestic United States distribution, or for any country where there is an existing TV network. Local TV standards would be satisfied since rebroadcast is necessary, in any event.

Class B assumes a more modest receiver complex than Class A. Rebroadcast is necessary, but it would normally be by cable or, occasionally, with a simple translator. This class is rather wide. At one end we might imagine a class which could be labeled "AB," almost as elaborate as A, for CATV systems, and at the other a receiver labeled "BC," so simple that it is almost in the direct-broadcast category. Section 3 describes a system in this class as a "Teleclub" educational system. It could be applied to a country like India. A similar system, not needing satellites because of the small territory covered, is in operation in American Samoa. In such a system, the receivers might cost between $1000 and $2000 each and would be located centrally in the towns. People would come to see them in a manner reminiscent of the birth of TV in many countries—including the United States.

The prototype system in Class B was a 2500-MHz FM system with an 8-foot antenna and a good, but uncooled, parametric amplifier receiver. Section 4 describes it in detail. Here, as in all FM cases, the overall bandwidth is never permitted to exceed 40 MHz, in deference to the realities of spectrum assignments. A 975 lb-satellite could provide six channels to an area of 7-1/2 square degrees, plus three channels to an additional area of $1^{\circ} \times 1^{\circ}$; e.g., India.

Class C is direct broadcast to home TV sets of the present type, supplemented by superior antennas and preamplifiers. After examining a variety of frequencies and modulation systems, the U.S. 525-line vestigial sideband AM system (VSB) was studied as a prototype. This would be compatible with existing receivers. It is no surprise that the economics and technology of this class of service are dependent on the assumed increase in ground receiver cost, because of the adapter kit. Without such a kit, the problem becomes technically difficult. The prototype system, for instance, uses three 5800-lb satellites, each of which could supply one channel of compatible color to an area of nine square degrees if the receiver adapter kit cost approximately $124. If this differential cost were zero, the spacecraft weight would have to increase from 5800 to over 20,000 lb to accomplish the same job. This would require a Saturn V-class booster.

In plotting curves of spacecraft weight vs angular coverage, there is a value of coverage for which the weight in orbit is minimum. The calculation of this curve and the existence of this minimum is discussed in Section 4 and Appendixes A, B, and C. Only in the case of class C systems, where the effective radiated power is high, does this minimum fall in a region of practical coverage. Such an "optimum" satellite would be the cheapest, and should be used if possible.

Class VC is the same as class C (that is, direct broadcast), but is FM voice instead of TV. This could be of great interest to the United Nations for a worldwide educational system not dependent on the vagaries of short-wave propagation. Here, the prototype choice was a 100-MHz good-quality system to all environments with only a $10 increase in receiver cost. A satellite of 60 dBW and 2300 lb would be "optimum" in the same sense as previously described, and would provide 10 modest-quality channels or one top-quality channel to an area as large as Africa.

In considering the above classes, the up-link has been ignored, since in all four cases the down-link limits. The origination of program material will presumably be from adequately powered transmitters on convenient frequencies normally used for point-to-point. In all cases, however, allowance for up-link noise has been made. The choice of up-link parameters will normally not be a critical factor in system planning.

2.3 NASA Programs

The NASA Office of Space Science and Applications publication, "Goals, Objectives and Project Descriptions for 1968-1975," lists three programs in the broadcast satellite area. They are:

1. Voice Broadcast Statellites and Community TV Broadcast Satellites - Feasibility No. 1

Both aspects of this program are clearly feasible. Community TV is needed and economically viable in a wide variety of realizations. Community TV broadcast is class B as previously defined in this report; Voice broadcast, class VC. For class B, the NASA program should be pursued and the technological areas recommended in this study followed on the Applications Technology Satellite (ATS) and similar programs. The voice-broadcast aspect should await a clearly defined need.

2. Direct Broadcast TV - Feasibility No. 1

This is direct broadcast to modified home receivers -- it is class C of this study. It is clearly feasible. The NASA programs, especially in the support technology areas, should be pursued.

3. High-Power Direct TV Broadcast - Feasibility No. 2

This is the broadcast of multi-channel color TV to unmodified home receivers. It would require very high-powered (megawatts) spacecraft and heavy payloads. Although it is technically feasible, the need at this time is questionable. Further economic and operational studies are required before going ahead. Since the problem is so much easier and cheaper, insofar as the space segment is concerned, with reasonably modified home receivers, we think that plans for this should be deferred until a conclusive study can be undertaken.

2.4 Technological Recommendations

2.4.1 Launch Vehicles

Although many vehicles exist with various payload capabilities to synchronous orbit, they were all developed for other missions and are far from optimum for this one. The object of our recommendation is to create a range of launch vehicles matched to the range of payloads, and possessing the required maneuverability, while exploiting existing boosters as much as possible.

1. Because the Titan IIIC with transtage will deliver a stabilized payload to orbit with no requirement for spin-up at perigee, it is an attractive vehicle wherever its payload capability is sufficient. The currently tested model will put 2000 lb in orbit. Transtage and core changes under

development will increase this to 3450 lb, and the seven-segment solid strap-on under development will make 5800 lb possible. This would be the Titan IIIM-Agena*. Adapting the Agena* to the present Titan IIIC will provide 4300 lb in orbit. This easily accomplished, low-cost change will quickly fill a gap in our payload-handling capacity. The complete program will provide a flexible family of maneuverable vehicles.

2. The Atlas-Agena class of boosters can deliver up to 850 lb to synchronous, equatorial orbit without spin-up. Uprating these to work with the Agena* stage will increase the deliverable payload to 1400 lb.

3. Adapt the Centaur Stage to the Saturn IB vehicle to provide a vehicle capability of 9500 lb in synchrouous eq[illegible]torial orbit (with an apogee kick stage).

4. Modify the Atlas SLV3C Centaur to the Atlas SLV3X Centaur to get a synchronous equatorial payload of 2700 lb. This may provide a cheaper vehicle than the Titan IIIC in this payload region.

2.4.2 Spacecraft Power

Spacecraft power is vital to the development of large satellites. We recommend accelerated R&D in thin-film solar cells, high-power deployable arrays, solar concentrators, heat dissipators, and isotope and nuclear reactor Brayton cycle systems. Concomitant work should be done on power handling and storage devices.

2.4.3 Spacecraft Antennas

Spacecraft antennas, especially large deployable ones and phased arrays, will be a common feature of broadcast satellites. We suggest a program to develop their technologies at all the appropriate frequencies. The effects of distortion due to solar radiation are particularly worth studying.

2.4.4 Attitude-Control Systems

Attitude-control and station-keeping will be critical to the long-life performance of satellites, especially those that do not require ground tracking. Better sensors, complete attitude-control systems, and low-thrust ion engines all need development. We recommend aggressive development of a system with 0.1° accuracy.

2.4.5 Spacecraft Electronics

Broadcast satellites in all frequency ranges require the development of suitable transmitters. We recommend a brisk program to develop and qualify triodes, klystrons, TWT's (traveling wave tube) and solid-state devices for the appropriate frequencies, power levels, and distortion limits. This is especially needed at very high powers and at millimeter wavelengths.

2.4.6 Spacecraft Life

We recommend a general study program on life improvement for spacecraft. The economic reasonableness of many systems is critically dependent on spacecraft life in orbit.

2.5 Other Recommendations (See Section 7)

2.5.1 Frequency Allocations—Domestic

Because frequency spectrum availability may pace the whole field, we recommend that the FCC initiate the allocation process, especially considering the following frequency assignments:

1. 108 MHz for FM direct broadcast
2. 470-890 MHz for direct-to-home broadcast (possibly restricted to the upper end of the band)
3. 2500-MHz band for ETV and other public TV services
4. 12,000 MHz for distribution service
5. Allocations in the 18-GHz and 35-GHz bands which may have important future uses

2.5.2 Frequency Allocations—International

We recommend action by the State Department with support from OTM (Office of Telecommunication Management), FCC, DOD, and NASA to define a U.S. position on the international allocation of frequencies for space broadcasting, to be pursued with the ITU.

2.5.3 Clear Channels

We recommend the allocations of clear channels wherever possible for satellite TV broadcast--especially in the UHF band. Consideration must be given now to reserving these channels for the satellite service.

2.5.4 Keeping Track of Current Users

We recommend that ways and means be created for keeping track of all current users in bands of interest. This will facilitate informed discussion and suggestions on the inevitable reassignments necessary to accomodate space services.

2.5.5 Noise and Interference

We recommend that an extensive study be supported--possibly by NASA--on the effects of interference and the possibilities and criteria for frequency sharing. Since some frequency sharing will be unavoidable between broadcast satellites and terrestrial services, we recommend that greater emphasis be given to the interference problem through both theoretical and experimental studies. The latter should include a measurement program using a high-power, satellite-borne transmitter.

Particular attention should be given to exploiting the discrimination achievable by virtue of the high-incidence angles typical for synchronous satellites. Local shielding of terrestrial stations may be possible using a knowledge of the (constant) angular direction of the satellite.

It may be possible to use actual signal statistics for realistic spectral-density criteria. This study could be combined with the technical recommendation on noise-environment measurements contained in Section 6.7, since the subjects are closely related.

2.5.6 Synchronous-Orbit Parking Space

The hitherto almost disregarded problem of space available in synchronous orbit is rapidly becoming serious. We recommend a careful, funded study leading to a U. S. recommended plan for allocating these slots. It should be recognized that orbital-slot assignments are in reality a part of the frequency-allocation problem.

2.5.7 Instructional TV Requirements

Because of the lack of consensus among educators about the attributes of an educational or instructional TV system that affect the technology (e.g., the desirability of color), we suggest that the Department of Health, Education, and Welfare initiate a study to clarify these points.

2.6 Conclusions

One cannot work on a study of this kind for 3 or 4 weeks without realizing that there are no pat conclusions. The situation is complicated and defies attempts to wrap it up neatly. This is especially true when one looks for generalizations rather than considering specific problems. Nevertheless, certain conclusions can be set down which may be useful when applied with discretion.

They are:

1. Technology has outstripped policy. There is no doubt that many kinds of broadcast satellites are possible now or in the near future, and their deployment and use will be limited not technically, but economically, politically, and demographically.

2. One can draw only the most general sorts of economic conclusion as long as one is dealing with abstract problems. For instance, the larger the underdeveloped area the more likely it is that satellites will be cheaper than terrestrial microwave relay. Precise conclusions can only be reached through careful analysis and, above all, in specific, real situations.

3. With the foregoing disclaimers always in mind, it seems that highly developed areas such as the United States, Western Europe and Japan might initially favor the use of Class A systems; the lesser developed areas, Class B mixed systems; and remote and far-flung services, Class C. It is important to remember that a service can be remote even in a densely populated area. For instance, broadcasting to the members of a particular profession in the United States may be quite similar technically and operationally to broadcasting to sparsely settled areas. It may well be that the educational needs of physicians, lawyers, and engineers may be so pressing as to make an educational satellite dedicated to them quite viable economically. Also it is clear that large countries have sparsely settled areas as well as close-packed areas; e.g., from a communication viewpoint, Alaska may be treated in that category.

4. The direct broadcast of FM voice is easy, but the Panel did not succeed in identifying any overwhelming need for it. Continental United States emergency service seems like a good possibility, but further study is required.

5. The lack of availability of radio-frequency-spectrum space is already a serious problem and, if active steps are not taken, it could become hopeless.

6. Of all the uses and users that we find for the different classes of satellites, two seem so technically easy, so economically reasonable, and so socially desirable, that we think steps should be taken to put them into effect. They are : (1) a multi-channel Class A distribution system for the use of American network TV, including both the present networks and public TV; and (2) a nine-channel Class B system of the "Teleclub" type for educational, instructional and informational TV for India.

7. Direct broadcast to unmodified home receivers* is technically quite possible, but will require a huge satellite. As of today, the only possible launch vehicle is the Saturn V at an estimated cost of $150 million per launch. The need for such service requires further study and evaluation.

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*We mean here the completely unmodified receivers with "rabbit ear" antennas inside concrete buildings in an urban environment. The Class "C" system, which assumes modest receiver modifications and outdoor antennas, is several orders of magnitude easier, and is discussed extensively in this report.

3.0 KINDS OF BROADCAST SERVICE CONSIDERED

3.1 General

Like standard radio broadcasting, satellite broadcasting has the feature of making communication possible between a transmitter and many receivers, without access to the intervening terrain. Satellites extend the range over which this is consistently possible from a few tens of miles to many thousands. Although terrestrial high-frequency communication is also possible over comparably long distances, it is erratic, and severely limited in available bandwidth.

This feature of satellites underlies several reasons for their attractiveness. Some of the most important are:

1. Faster introduction of service in areas not yet covered
2. Potentially lower cost of covering a large area
3. Potentially more efficient use of frequencies
4. Extension of program choice
5. Provision of specialized programming, i.e., Public TV

Each of these possibilities is analyzed in more detail below.

3.1.1 Faster Introduction of Service

A national broadcasting system is a complex undertaking, involving hundreds of transmitters, antennas and antenna towers, a number of studios, and miles of interconnection circuits. Even in the industrially advanced areas of the world, a considerable period elapsed before the service approached nationwide coverage.

For example, in the United States, commercial TV was instituted in 1939. By 1941, when growth was interrupted by the war, TV signals covered 20 percent of the homes. Expansion resumed in 1946, and by 1950, 91 percent of the homes had at least one program available. In 1952, network operation was extended across the country. Other technically advanced countries have followed the same pattern, most starting their TV service after the war. Typically, 10-12 years elapsed before the service reached 90 percent coverage with a single channel.

It is difficult to believe that the emerging and developing nations can soon attain the rate of growth shown by the developed areas. Limitations on production capability, the availability of trained personnel, the great investment involved, and the necessity for simultaneous development of the broadcast and communication industries tend to slow growth. In these parts of the world, a period of 25 years for country-wide service appears likely. This estimate is exemplified by such countries as Brazil, which has been able to install 32 transmitters over a period of 13 years, compared to about 1000 needed for full coverage. Iran has installed three transmitters over six years, compared to an estimated need of 100.

In contrast, satellite broadcasting offers "overnight" attainment of coverage. Some four to five years would be needed to produce the first operational satellite unit. Thereafter, additional coverage areas could be created at a rate determined by the scheduled production, say a new area every three months. National coverage of such countries as Brazil, Indonesia, India, and Nigeria would thus be possible in a very short time.

In the developed areas, the satellite may still be the fastest way of attaining full coverage. Economic factors enter here, but even countries like the United States and the United Kingdom are not completely covered. Italy appears to have the most comprehensive coverage program, with over 700 transmitters; often one transmitter is required for a single valley area. Such regions are automatically covered by satellite broadcasting, again with the coverage being attainable practically "overnight."

3.1.2 Potentially Lower Cost of Attaining Complete Coverage

When a TV broadcast service is established, it usually begins by introducing service into the large cities. For example, in the United States, the establishment of TV service in New York City in 1941 provided service to about 10 percent of the country's homes, a sizable fraction of the total. In contrast, the installation of one additional transmitter in 1949 increased the coverage by only 1.3 percent. Since then, the gain has been still smaller, and is now approaching 50,000 homes per transmitter added, or approximately 0.1 percent of the total in the country. Thus, the current per-home cost of extending coverage is about 100 times greater than when the first urban station was introduced.

It appears that the technical cost of providing reasonably complete service (95-98 percent) to a sizable area such as the United States is about one dollar per receiver per year. This value is apparently the same for all countries of the world.

The cost relations for satellite coverage are quite different from the above. This is because the satellite will reach all receivers within its antenna pattern provided that these are equipped with suitable antennas and "add-on" black boxes. The comparative cost relationships are shown in Figure 10.3.1.

Varying the signal strength also affects these cost relations. Weaker signals are acceptable in suburban and rural areas, where man-made noise and building absorption are lower, and outdoor mounting of antennas is no problem. For such service, the terrestrial system cost decreases by a factor of about 2, but the satellite cost decreases by a factor of the order of 10. For such types of service, it appears that the satellite would be much the cheaper method.

3.1.3 More Efficient Use of Frequencies

The strength of a radio signal decreases with distance from the transmitter, and eventually becomes unusable in a practical sense. For terrestrial TV service in the UHF band, this distance is about 50 miles. However, the signal can still cause interference to another station on the same channel. Because of this, the separation between stations on the same channel must be several hundred miles.

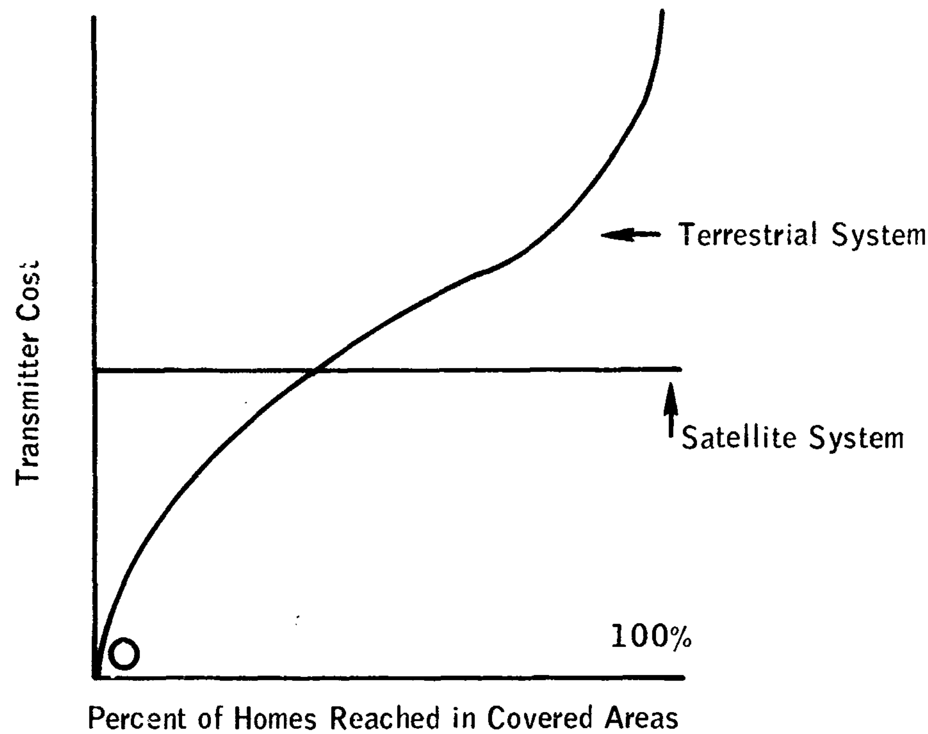

FIGURE 10. 3. 1. Comparative Cost Relationships.

In the United States, the current allocation plan for UHF allows from 30 to 40 stations per channel. This number takes into account co-channel and adjacent-channel interference, the location of cities, the needs of neighboring countries, and propagation variations. Each station has an effective coverage of about 8000 square miles, so that each channel covers approximately 300,000 square miles, or about 10 percent of the country. To provide a single program to the entire United States requires about 10 UHF TV channels if the terrestrial system is used.

In contrast, a single-channel space system could provide the same coverage, at a saving of 10 to 1 in frequency occupancy. It is, of course, true that the satellite and the terrestrial services are not exactly comparable. The ten-channel terrestrial service can carry some 400 independent programs, or a single program, or any combination between, and is so operated. The satellite is limited to a single program per channel. However, when national coverage is desired (as distinguished from local coverage), it is clear that the satellite is more efficient in its use of frequencies.

Another factor enters these considerations. This is the possibility of sharing frequencies between the satellite and terrestrial systems. The technical literature indicates that this is possible using commercially available equipment and existing sharing criteria. If the satellite signal is controlled so that it does not affect the normal coverage area of the terrestrial stations, there will be some loss in satellite coverage, from 100 percent to about 60 percent of the area covered. Under these conditions two satellite channels would be required to give national coverage. This simultaneous use may be the most attractive of the several approaches.

3.1.4 Extension of Program Choice

Because of the cost and frequency-allocation problems discussed above, the number of TV programs available in homes varies widely. In the larger cities, as many as nine channels are available. The choice decreases as the cities become smaller, reaching one or even none in the most remote areas.

Averaged over the United States, the number of channels available is three. Some 10 percent of the homes have only one program, about 15 percent two programs, and some 20 percent have five or more available. Approxmately 4 percent are outside the normal coverage area of any transmitter. Introduction of satellite service would increase the choice of programs. A strong-signal satellite would give everyone one or more additional channels, according to the design.

In other countries, the usual practice is to develop a single program to the 90-95 percent coverage level, then add a second national program. This addition could be done by satellite, as determined by relative cost factors.

3.1.5 Public TV

In the United States, at the present time, the average number of receivers is 100,000 per transmitter. This average varies in other countries, from a low of 7500 for Italy to a high of 205,000 for the United Kingdom (the number for Italy is small because of the extensive use of small transmitters). The average number in many countries appears to be about 70,000.

The number of receivers per national program in the United States and other countries having well-developed TV systems is rarely less than eight million and averages about 20 million in commercial practice.

It seems to require some 30,000-50,000 receivers per transmitter to justify the existence of the station on an economic basis. Similarly, unless the total audience for a program is about 600,000 to 1,000,000, i.e. some 20 stations using the same program, it does not appear possible to justify continued production of the program. (The technical cost of TV transmission is almost always between 5 and 10 percent of the total TV service.)

These factors indicate that the production and transmission of special programs of interest to relatively small fractions of the total audience is economically difficult by terrestrial broadcasting. This is exemplified by the reported economic troubles of the ETV service, which has been said to be "hovering between bankruptcy and receivership."

To size the problem, assume that a particular program is of interest to 2 percent of the potential audience. Then transmission can be economically justified only in areas where the coverage of the transmitter exceeds about 1.5 million receivers. This limits the programs to the 15 largest TV markets. Two percent of the total audience in these areas is about 600,000, which just meets the above economic limit.

Extending the program to less populous areas or attempting to reach a more specialized (and still smaller) audience would make the program still less attractive economically, especially in the absence of inter-connection facilities. For any of these cases, such a program would need support.

A satellite broadcast system appears to ease these problems of public broadcasting. For a single satellite system, the transmitter coverage and the potential program audience are the same. For the expected potential audience in North America- about 100 million in the early 1970's--programming to an audience interest level as low as 2/3 of 1 percent would appear economically feasible.

3.2 Definitions and Summary Charts

The many kinds of broadcast satellites that have been variously proposed seem to fall into three general categories depending upon the number of installations that receive directly from the satellite. The classification below reflects a progressive transfer of complexity, and therefore cost, from the receiver to the satellite:

Class A: A service involving distribution of program material for retransmission by conventional stations. The receiving stations are sophisticated and can be part of a networking system with antenna relay to a local transmitter, or they can be affixed directly to the transmitting station. The short nomenclature is "the distribution satellite."

Class B: A service involving distribution of program material to multiple users, normally by cable or simple radio retransmission. Community antenna systems and scholastic instructional systems are representative. The short nomenclature is "the community satellite."

Class C: A service providing signals directly to the general public. AM, FM, and TV in the United States are representative. The increased cost of a home TV set would not be great. The short nomenclature is "the direct broadcast satellite."

In principle, any of the above classes can be used for voice or television, although the problems differ. For voice, the problems of the A and B classes appear relatively simple; a combined voice-television satellite would be a small increment above a TV-only satellite. Therefore, Class C voice service can be isolated: for convenience this is designated as Class VC.

Each of the above classes was examined for existing services which potentially could be carried by satellite, and for new services made possible by the special features offered by satellite operation. Seventeen TV and seven voice services, described below, emerged from this examination.

It appeared obvious that a complete analysis of all of these potential services could not be made within the limits of the present study. Consequently, only a preliminary evaluation was made. A range of satellite possibilities was examined parametrically, and one example was picked for each of the four classes A, B, C, and VC. The results of this examination are given in the next section.

3.2.1 Description of Potential Satellite Services

The services potentially possible via satellite, and their definitions are:

Class A: Distribution

Americans Overseas Distribution
A distribution of American programs to overseas stations for retransmission to American personnel. The Armed Forces Radio and Television Service now has this responsibility.

Public TV Distribution
The distribution service visualized by the various drafts of the bill for the Public Television Corp. Educational television stations (ETV) now distribute to the stations by video tapes.

Regional Exchange Networking
A distribution service to link individual stations in areas not having networks, for example, in South America

TV Distribution
The distribution of TV programs for network operation. In the United States, the three commercial networks would use this service.

Class B: Community

CATV (Community-Antenna Television)
A service in which the transmitted signals are received on a community antenna, reaching the viewers by a cable system or by a translator (a low-power transmitter which receives signals from the broadcast station and retransmits on another frequency for gap filling)

ITV
The Instructional Television Service for schools having a central receiving system and cable distribution to the classrooms

"Teleclub"
A service intended for group watching using a community receiving set. TV in most countries started with this service

in local bars, or in a neighbor's house. Formal programs have been established in several countries.

Class C: Direct Broadcast

Regional TV
An international TV service for a group of contiguous nations having common language and interests, as in Central America

UN TV
An international TV service carrying UN and UNESCO proceedings and special programs

Urban TV
A general TV service intended, in particular, to reach homes in urban areas, and incidentally providing coverage to outlying areas. Conventional TV operates in this service in major cities.

Minimum Urban TV
The same as urban in intent, but designed to give minimum acceptable service

Cultural/Public TV
A service intended to provide programs of less than general interest in cultural and intellectual areas, including drama, music, art, and public affairs. The present service of Educational Television (ETV) during the evening hours is an example.

Rural TV
A general TV service intended, in particular, for reception in rural and remote areas. Establishment of a rural service grade was recommended by the Television Allocations Study Organization (TASO).

Americans Overseas TV
A service intended for the same audience as in the corresponding Class A service above, but designed for direct reception

Emergency TV
A service intended for operation at times of regional or national emergency, as in a flood, hurricane, or power blackout

Organizational TV
A television service intended for information dissemination to specialized groups, such as doctors, engineers, and school teachers

National TV

A service to be used by agencies of the federal government that are charged with the function of disseminating information to special groups—farmers, the fishing industry, etc.

Class VC (Direct Voice Broadcast)

UN Voice

A radio service similar to the UN service in Class C, but voice only

FM Voice

A general radio service, using FM, and similar to the U.S. FM Broadcast

Rural FM

A general radio service, similar to FM voice, but intended for rural and remote areas

Regional Voice

An international voice-broadcast service corresponding to the Class C Regional Service

International Broadcast

An international service in which programs are intended to be received by other nations. The Voice of America is such a service.

National Emergency

A voice version of the emergency service in Class C

Rural Education

A voice service intended to supplement educational facilities in rural and remote areas

In studying the above list, it will be found that there are similarities and differences in both technical and program aspects of the various services. The influence of program differences or similarities was not considered during this study: this involves matters of policy and operation outside its scope. Instead, emphasis was placed on technical and economic factors and only these factors were considered in selecting particular systems for study.

For each of the above services, estimates were made of the major technical requirements. The size of the potential audience, status of existing service, and value of satellite service (where it could be established) are listed in Table 10.3.1.

In Table 10.3.1, the number following the class is the power of 10 of the estimated number of receivers. For example, C6 is a direct broadcast service to one million receivers. The required performance quality is indicated by numbers. For TV, there are the following grades and corresponding signal-to-noise ratios:

0	CCIR Relay Quality	56 dB video
1	TASO "Excellent"	45 dB rf

1.5	TASO "Excellent"	39 dB rf
2	TASO "Fine"	34 dB rf
3	TASO "Passable"	30 dB rf

Coverage is indicated in square miles, or by N (National), T (Time) Zone), R (Regional) and W (World).

3.3 Description of Most Promising Systems

From the foregoing list of services, four systems were selected for parameter studies. In each case the title is intended to be suggestive rather than definitive. The TV distribution system for Class A is aimed principally at the United States, but with only slight changes could be used by any region with an existing complex of TV broadcast stations.

India is a tempting country to consider in planning a CATV system, because of its almost complete lack of existing facilities; but there seems to be no technical reason why a similar system could not be used in many countries--even including the United States.

The direct broadcast system C is described for the United States, but again, could easily be applied anywhere with an existing VSB-AM system.

3.3.1 Class A - the Distribution Satellite System

Class A satellites provide networking service to ground stations for rebroadcast. This type of service is applicable to public TV distribution, commercial networking, and exchange networking among nations in a common geographical region. Rebroadcasting from the ground station requires the satellite service to provide the highest-quality signal practical, i.e., CCIR relay quality (see Section 3.2.1). All Class A systems considered in this study have been configured for this transmission quality.

Terrestrial distribution of commercial TV programs from originating locations to broadcast stations represents a significant item of operating cost. AT&T's revenues for this service run about $65 million per year, of which about $30 million is for local "hook-up" and monitoring; $41 million is paid by the three major networks.

Since the distribution system is concerned with a fairly large number of receivers (ABC, CBS, and NBC have slightly over 500 affiliated stations), it is well suited to service via broadcast satellite. The video broadcast system described here, designed exclusively and optionally for network distribution, can reduce the above costs to less than half.

The basic system is designed for coverage of the United States less Alaska and Hawaii. (A separate satellite relay may be added to cover the latter two areas.) It consists of originating terminals for each of the networks at the major programming centers (New York, Los Angeles, Chicago); two geostationary satellites (one operational, one spare); and receiving terminals, each located near an affiliated terminal, or at a convenient site which serves a group of affiliates in one of the 230 TV market areas.

Within the continental United States there are three commercial TV networks, each using three broadcasting time zones. In testimony given to the Pastore Committee, NBC and ABC each expressed the need for three channels--one per broadcast time zone. If this requirement is applied to each of the existing commercial networks, and a fourth network for public TV is

TABLE 10.3.1. POTENTIAL BROADCAST SATELLITE SERVICES

Class	Type of Service	Quality	No. of Channels	Coverage	Present Service (Conventional Methods)	Value of Satellite
A2	Americans Overseas Distribution				Adequate	3
A3	Public TV Distribution	0	24	4T	None	TBD*
A3	Regional Exchange Networking	0	1	10^7	None, except Europe and some tape	TBD
A4	TV Distribution	0	18	3T	USA, Europe, Good (expensive) other--none	1
B4	CATV	1-2	3	National	Adequate in USA	TBD
B5	ITV	0-1	6	Sectional	Inadequate	TBD
B6	"Teleclub"	1-2	1	National	None	1
C5	Regional TV	2	1	10^7	None	1
C8	UN TV	2	1	10^7	None	1
C8	Urban TV }	1-3	3	10^6	ABC, CBS, NBC, etc.	
	Urban TV Minimum }				None in many areas	TBD
C7	Cultural/Public TV	1	3	3T	None	TBD
C7	Rural TV	3	1	N	Marginal	TBD
C5	Americans Overseas TV				None	3
C7	Emergency				None	3
C5	Organizational TV }	1	3	3T	Essentially none	1
C6	National TV }				None	

*TBD - to be determined

TABLE 10.3.1. (cont). POTENTIAL BROADCAST SATELLITE SERVICES

Class	Type of Service	Quality Q	No. of Channels N	Coverage C	Present Service (Conventional Methods)	Value of Satellite
VC8	UN Voice	3	1	W	Via VOA, etc.	TBD
VC7	FM Voice	1	3	N	USA--high, others--low	TBD
VC6	Rural FM	2	1	N	LO	1
VC6	Regional Voice	2	2	R	None	1
VC9	International Broadcast	3	1	W	None by FM	TBD
VC7	National Emergency	2	1	N	None	1
VC7	Rural Education	1	6	3T	Minimum	TBD

FM Voice Quality

Grade	S/N
1	50 dB
2	40
3	30

added, the total channel demand is 12. This demand is current (1967); it contains no growth capability. To provide growth capability for the four networks and to include the educational TV capability, channel capacity should be doubled, according to some estimates. A Class A broadcast satellite system which provides 24-channel networking service over the continental United States, with eight channels available in each broadcast time zone, is attractive technically and economically. The total service can be provided by a single 24-channel satellite weighing 630 pounds and launchable into synchronous equatorial orbit by an Atlas-Agena-class booster.

The system operates at 12 GHz nominal (K_u band), using frequency modulation. The satellite contains seven multiple-feed microwave antennas to provide 24-channel coverage. Power at the output frequency is supplied for all 24 channels by traveling wave-tube (TWT) amplifiers. Up-link reception, signal processing, and amplification for TWT drive is provided by 24 microwave and rf integrated-circuit transponders. Power for the 24 channels, as well as for attitude and station controls, and for housekeeping (telemetry and command) is provided by a sun-oriented solar array. Redundancy and appropriate derating techniques have been applied to assure the satellite a mean time to failure of 5 years.

Transmissions from the satellite are received by ground station paraboloidal antennas of 20-foot diameter operating into cooled parametric amplifiers of 200°K noise temperature. The ground-station signal processor converts the received signal from FM to the standard VSB/AM for rebroadcast by the local station with which it is associated. Thus the single, 24-channel satellite serves all the local broadcasting stations directly, each local station having a K_u-band receiver and signal converter tracking the satellite. Transmission to the satellite is made direct from the network points of origin. Each network has three of these, so that all may or may not be on at once. Network operations can thus be carried on via one small satellite rather than by land lines, with individual stations retaining local options for programs of local interest.

3.3.2 Class B—the Community Satellite System

3.3.2.1 Discussion of an Optimal TV Service to the Consumer (Class AB)

One of the technical tasks undertaken in this phase of the study could be summed up as follows: "Determine if satellites by themselves or in combination with other services, within the foreseeable future, could give the consumer a more desirable TV service than he now receives."

The important words here are "more desirable." From the consumer's viewpoint this could mean:

1. More comprehensive service: greater choice of programs or new services*
2. Better technical quality: better color, stereo sound, etc.
3. More economical: greater value. One has to assume

*A wide range of possibilities exists: stereo-sound music programs, facsimile for news, information, education, shopping services, computer services, etc.

that the consumer is willing to pay for more service and better quality, noting that a subscriber of a CATV service pays an average of $60 per year.

The following paragraphs relate to a hypothetical system based only on technical considerations. A useful purpose may be served in having an ideal model, recognizing that social and political factors in themselves are perhaps the most difficult part of the overall problem.

The first improvement was "More Comprehensive Service." Averaged over the United States, the TV viewer has a choice of three programs or channels, each alternating between a network-furnished portion and a locally originated one.

Let us construct a television service along the following lines: a single synchronous satellite covering the continental United States receives programs from the existing or future television networks and other sources from various parts of the country. Considering the three networking time zones, and assuming that eight different programs are available and suitably delayed for time zones, 24 receiving and transmitting channels are required on the satellite.

On the ground, the service to the consumer would be distributed by a large number of CATV systems, each of which has a ground installation to receive an excellent signal on all eight channels (equipment cost is about $75, 000). Numerous locally generated programs are also available for distribution at the CATV terminal. One can assume that there are enough channels available to the consumers to allow other services in addition to the eight satellite programs. The total number of programs or services thus could number 12 or even more, depending on demand and the economics.

The role of the existing television ground station is ensured by providing a service into distant, sparsely populated areas where CATV would be uneconomical*. Furthermore, television viewers would be able to choose between a free broadcast service and the CATV system with its monthly fee. Of course, each television station at any given time could utilize only one of eight satellite-transmitted programs, and any locally originated program would supplant the satellite signal.

The question arises whether this nation requires eight nationwide programs, and if they can be economically justified. Currently there are three networks giving service across the nation. The fourth network for public television will soon come into being. It would not be difficult to visualize that in the future, the United Nations might have a world-wide television broadcasting system. Two educational channels which could be used regionally, and shared across the nation, are a likely requirement. A spare channel should be reserved for a new service. Thus, it would be prudent to provide eight channels for each time zone.

How do program producers get paid for their services? For the conventional television station receiving the satellite programs, the currently existing affiliate contracts and relationships may have to change. Enforceable copyright laws, specifically designed to protect the program originator, would be needed to give this broadcasting concept a solid economic foundation. The same holds true of the CATV type of cable-distribution system which, unless it produces programs itself, will derive the signals for its subscribers from

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*The television broadcast station would receive the satellite programs through the same type of installation used by the CATV systems and at the same cost (approximately $75, 000).

the satellite broadcasts and other locally generated programs and services. Suitable contractual relationships will have to be developed between program producers so that the whole process becomes economically attractive.

Presumably, the sponsorship of national or network programs can be handled in a fashion similar to current practice: the advertisers contract with the network, which is essentially the program producer. It is the network's responsibility to provide maximum circulation of the satellite-broadcast network programs. The CATV systems and local television stations will have their own contractual relationships with the networks similar to current affiliates' payment practices.

Regarding the second goal--better technical quality of television pictures--signal distribution by cable to the individual homes will result in superior picture quality compared with today's average off-the-air broadcast signal. This discussion assumes that the satellite broadcasts are received by high-performance CATV or broadcast stations. The estimated average $75,000 cost of receiving stations provides for this high quality. The major factors that cause deterioration of television images in the home are listed in Table 10. 3. 2. Almost everyone has experienced one or more of these defects, and it is safe to say that CATV cable systems, properly maintained, would eliminate them. A nationwide broadcast system such as that envisaged here would make better utilization of the technical television standards, resulting in consistently better pictures in the home.

Finally, we shall examine the third criterion--cost to the consumer. At the outset, one has to differentiate between the cost of the programs and the cost of transmission to the home. For the former, it is assumed that the programs derived from the satellite distribution system are free to the consumer. This does not prevent the CATV system from charging the subscriber for specific programs such as weather, entertainment, and education, or for some special services. To compare the hypothetical system with current broadcasting, it is assumed that all programs derived from the satellite and all locally originated programs, piped by the CATV system to the homes, are free to the consumer, as are broadcasts of local television stations. It now remains to weigh the inducements that the hypothetical satellite CATV system offers to the television viewer against a monthly fee of approximately $5.

We have shown that there are two major advantages that may justify the subscription fee:

1. A more comprehensive program service. Based on the assumptions presented here, the viewer could have a choice of eight national and international programs, plus several local programs and services. The total number will depend on how many national and local programs can be supported economically and supplied free to the consumer.

2. Improved picture quality in the home. Table 10. 3. 2 shows most of the well-known defects of TV pictures. While a good installation does produce remarkably good television images in the average home, poor location with respect to the broadcast transmitter and a poor installation cause pictures received in the home to be of sub-standard quality. Reception of nationwide satellite programs by CATV stations with good equipment (cost, $75,000) and simultaneous distribution, together with local programs via cable or translator stations to the home, should give technically superior pictures.

TABLE 10.3.2. DEFECTS IN HOME TV SYSTEMS

DEFECT	CAUSE	EFFECT ON PICTURE
Multipath distortion	Propagation anomalies Antenna or transmission-line problems Room reflections	Multiple images (ghosts) Color distortion Poor synchronization Blurred images
Weak signal	Improper receiving antenna Poor location	Noisy Poor synchronization Impaired color quality Blurred images
Interferences	Co-channel interference because of propagation anomalies Adjacent channel interference because of receiver malfunction, unfavorable location, propagation anomalies Interfering signals from other television sets Man-made interferences Weather: lightning Airplane	Superimposed pictures "Venetian blind" effect Beat frequencies Synchronization instability Color distortion Flashes Flicker

3.3.2.2 National Community-Broadcast System for India

The primary purpose of this system is to aid national development by providing educational and informational programs in the areas of health (birth control, hygiene) and agriculture. The secondary use of the system is for instructional TV, both for secondary schools (ease teacher shortage and upgrade course content) and adult education (literacy). Other purposes may include political unification, entertainment, and community development.

Since less than 15 percent of India's population lives in major cities, a national TV system must be designed for rural reception in farm villages, 550,000 of which have populations under 2000 and 60 percent of which have fewer than 500 inhabitants. Account must also be taken of the language problem, since the official languages, Hindu and English, are understood by only 50 percent and 2 percent of the population respectively, the remaining people speaking 14 major languages and a large number of dialects.

The system chosen consists basically of a geostationary satellite broadcasting programs received from a master transmitting station to community-antenna receiving sites. A small village would have one such antenna/receiver connected to a TV set located typically in a school building, an assembly building, or in the mayor's home. A larger village may eventually have several receiving antennas and more than one TV set may be connected to one receiving antenna.

The example system provides three high-quality channels which are used for direct broadcast to the community receivers, as well as for distribution to local transmitting stations. The latter would rebroadcast into urban areas where the potential TV set density is high enough to warrant a simple local station typically covering a 50-mile radius. A first-generation system will probably use only black-and-white until the usefulness of color has been established by educators, since the TV set maintenance is easier. The monochrome choice also permits about 16 dB of preemphasis, to reduce the spectrum occupancy. Provision is made in the signal spectrum for four voice channels per picture channel to permit adding additional language sound tracks.

FM is the modulation choice for Class B systems. (See Sections 4.2.1 and 4.2.2 for details.) The ground receiver can be constructed with signal processing from FM direct to video, or with a modulation conversion from FM to the standard VSB/AM signal. Since system growth implies a proliferation of inexpensive, commercial-standard TV sets, the latter is the practical choice. Thus, the Class B teleclub receiver will consist of an eight-foot-diameter, S-band antenna; a parametric-amplifier front end of 2-dB noise figure; and a modulation converter which processes the FM signal into the appropriate VSB/AM standard. Distribution to standard viewing sets is accomplished by cable. This obviates concern over possible incompatibility with an established transmission standard, but does not significantly increase the Class B-receiver differential cost. World-wide operation of the system is thus facilitated, without loss of the considerable operating advantages of FM over a straight-through VSB system.

The two main technical/operational problems with the proposed system may be local power generation (or distribution) and receiver maintenance. These will clearly have to be addressed, and will require major effort and expenditure. Where local power is not yet available it may, for example, be generated by a "bicycle"-type generator which is either directly connected to the receiver or is used to charge up batteries periodically. Power drain of a large-screen, transistorized TV set can be kept below 50 watts, while one person can generate approximately 300 watts for 2 hours. The benefits to be gained are numerous, including the initiation of a national television industry with capability for operation, repair, and manufacturing.

3.3.3 Class C - the Direct-to-Home Broadcast System

The program material to be transmitted by satellite in the United States will most likely not be of a commercial nature. Such usage would to some extent weaken the local stations by depriving them of financial support in the form of advertising, and by reducing the available audience for which they would compete not only with each other but with the satellite as well. Such weakening of the local stations, it is argued, would threaten a large, widely owned investment in facilities now doing a satisfactory technical job, and fitting well into our social structure. Elected people in public life are dependent on the local stations as an efficient means of communicating with their constituencies. The very basis of our democracy would seem to be endangered if the local stations were therefore forced out of business.

On the other hand, the quality of life in the United States has suffered in certain respects, notwithstanding the technological gains of the past 30 years. We deplore the inadequacy of our transportation systems, the pollution of our environment, and the decline of our cities. It is now generally accepted that these trends will not reverse unless treated at the national level, and a great effort appears to be gathering momentum. Improved communications to various segments of our society may well be an important factor in this effort.

Three potential users of direct-to-home satellite emerge as follows:

1. Broadcasts by various agencies of the government which have been identified as "National Broadcasting"
2. Broadcasts by private national organizations identified in this study as "Organization Broadcasting." (The American Medical Association is a good example of one of these groups.)
3. Cultural broadcasts sponsored by government, foundations, industry, and by private donations, to reach all parts of the country, including the most sparsely settled areas

The first category, National Broadcasting, is now under study by the Department of Health, Education and Welfare (HEW). Various agencies of government are charged with the dissemination of information to special groups. Some examples are shown in Table 10.3.3.

Some agencies now use television and radio in a limited way; the Department of Agriculture and the Treasury Department (just before income-tax time) are examples. The broadcasters prefer commercial programming, which is more profitable, but they carry such government programs as a public service, which is an imposed requirement. Broadcasting on a broad scale is outside the budget of most agencies because of the high cost of national coverage. The satellite, on the other hand, deals effectively with the highly dispersed audience which characterizes this form of communication, and will permit longer and more effective programs.

TABLE 10.3.3. EXAMPLES OF NATIONAL BROADCASTING

Agency	Program Description	Audience
Department of Health, Education and Welfare	Reeducation of retired people to new occupations	Men and women aged 60 and over
	Information related to epidemics, drugs, treatments and other health matters	Physicians Surgeons Dentists
	Care of the invalid, social cases	Nurses Social workers
	Education of the underprivileged, technically obsolete persons unable to attend school	Public at large
Department of Agriculture	Agricultural techniques, combating plant disease and insects, domestic and foreign market conditions; meat, dairy production, and market data	Farmers Food processors Distributors
Department of Interior Bureau of Fisheries	Fish production and marketing	Coastal fishermen Processors
Treasury Department	Tax rulings	Accountants Tax lawyers Publishers
Department of Defense	Recruiting	Youths General Public

Obviously, a great deal of study is needed to determine which agency should have what hours, the extent of the audience, and the value of the transmissions. Much of the effectiveness of this new medium will depend upon the programming.

Organization Broadcasting can serve the many small but influential groups in our society. These groups fall into many classifications as follows:*

- Science, Engineering, and Technical
- Trade, Business, and Commercial
- Agricultural and Commodity Exchange

*See National Organizations of the U.S., Gale Research Co., Book Tower, Detroit, Michigan.

- Governmental, Public Administration, Military, and Legal
- Educational and Cultural Organizations
- Social Welfare Organizations
- Health and Medical
- Public Affairs
- Fraternal, Foreign Interest, Nationality, and Ethnic
- Religious
- Horticultural Organizations
- Veterans, Hereditary, and Patriotic Organizations
- Hobby and Avocational Organizations
- Athletic and Sports Organizations
- Miscellaneous (service organizations such as the Rotary Club)

Not all of these categories are necessarily appropriate to satellite broadcasting, but a few are notably suitable. Those listed below are examples of organizations having large memberships which are geographically widespread and homogeneous in their professions.

Scientific, Engineering, and Technical Organizations	Membership
• American Association for the Advancement of Science	60,000
• American Chemical Society	91,000
• American Institute of Aeronautics and Astronautics	33,000
• American Society of Civil Engineers	45,800
• Institute of Electronic and Electrical Engineers	200,000
• American Society of Mechanical Engineers	60,000
• American Society of Tool and Manufacturing Engineers	41,000
• Society of Automotive Engineers	24,000
• American Institute of Physics	35,000
• American Institute of Chemical Engineers	19,000
• Association for Computing Machinery	6,000
• American Concrete	10,000

These groups disseminate technical information, advance their professions, establish industry standards, stimulate educational activities, and recommend practices. Their members are constantly faced with the problems of continuing education and technical obsolescence. They wish to know what is new in their fields and what the interfacing disciplines are doing. The reading of their technical journals is difficult and time-consuming. Video presentations via satellite would greatly accelerate learning in the societies, to the benefit of the nation and its many problems. It might also solve the serious problem of the obsolescence of engineers, at a time when there is a great shortage of this talent.

Health and Medical Organizations

	Membership
• American Dental Association	95,000
• American Medical Association	176,000
• American Nurses Association	174,000
• American Pharmaceutical Association	32,000
• American Registry of X-ray Technicians	33,000

Our medical research has grown greatly in recent years. A major communications problem has developed in this profession, since an excessively long time—sometimes years—elapses between the research and the practitioner. In response to these pressures, a microwave video link has been installed in Atlanta to interconnect the medical schools and hospitals in that area. The satellite promises to fill a major role in medical communications.

There is the interesting possibility of a commercial direct-to-home satellite that would neither compete with standard broadcasting nor require government subsidy. The partial membership in just the two organizational categories listed above is over one million. If each member's dues were increased by $25 per year—a relatively small amount considering the greatly augmented service he would receive—the total would exceed $25 million. This sum might be sufficient to maintain a satellite system, assuming that time could be also sold to the government for its legitimate uses, and to the cultural-broadcast interests. The foregoing is only a suggestion. Intensive study is needed to validate the concept.

The potential uses of the Class C direct-to-home satellite abroad are listed in Section 3.2.1. A major difficulty in broadcasting internationally is the wide range of transmission standards. Another is the very high satellite power that would be required for wide coverage. The political and social aspects of such broadcasts seem to transcend even the difficult technical issues. For these reasons, the Panel believed that the U.S. service would come first, and no further consideration was given to foreign direct-broadcast satellite TV.

3.3.4 Class VC - the Voice-Only Direct Broadcast System

The technological study of FM voice broadcast, discussed in Section 4, combined with a study of the kind of voice service discussed in Section 3, led to the visualization of two basic satellites for voice broadcast. Both were designed to optimize the coverage area for a given signal quality, with minimum weight in orbit used as the design criterion.

The smaller of these satellites would provide two channels of FM service, at a minimum of 40 dB S/N when used with outdoor antennas in urban areas or with indoor antennas in other areas. This satellite would weigh 750 lb and could be launched with an Atlas-Agena vehicle. The satellite could cover the continent of Africa or equivalent area.

The larger satellite could provide single-channel 50 dB S/N to the same installations and coverage area or, alternately, 10-channel operation at 40 dB S/N. This satellite would weigh 2200 lb and could be launched with a Titan IIIC or by several other vehicle combinations.

Either satellite would satisfy the needs of the seven voice services considered, although the degree of effectiveness would be somewhat different. The 10-channel version could be used to satisfy the needs of several services at the same time.

The service, the satellite which appears most desirable, and the estimated degree of fulfillment of the service needs are:

Service	Satellite Weight	No. Channels	Estimated Value of Satellite
UN Voice	2200 lb	10	Fully satisfies
FM	2200 lb	1	Urban marginal, other good
Rural FM	750 lb	2	Fully satisfies
Regional Voice	750 lb	2	Fully satisfies
Int'l Broadcast	2200 lb	1	Urban marginal, other good
National Emergency	750 lb	2	Fully satisfies
Rural Education	2200 lb	10	Fully satisfies

In addition, the 2200-lb, 10-channel satellite could be used for combined services on a scheduled basis, as follows:

UN Voice	Fully satisfies
Rural FM	Fully satisfies
Regional Voice	Fully satisfies
National Emergency	Fully satisfies
Rural Education	Fully satisfies

The 750-lb satellite, used for combined services on a scheduled basis, would allow the following:

UN Voice	Partly satisfies
Rural FM	Fully satisfies
Regional Voice	Fully satisfies
National Emergency	Fully satisfies
Rural Education	Partly satisfies

In the opinion of the authors, the new techniques needed for either of the foregoing satellites can be achieved with a modest development program for an operating life-expectancy of about 5 years.

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4.0 TECHNICAL DESCRIPTIONS OF SPACE-GROUND SYSTEMS*

4.1 Class A (Distribution and Networking) Space-Ground Systems

4.1.1 Link Performance

Class A systems are based on the requirement for CCIR Relay quality signals. (See Section 3.2.1.) Frequency allocations were assumed for these systems at 2.5, 12 and 35 GHz.

For the Class A link analyses performed at these frequencies, the peak-to-peak signal to rms noise-power ratio was taken as 56 dB from blanking level to white with a video bandwidth of 4 MHz. With the carrier-to-noise ratio at threshold, the FM bandwidth per TV channel was found to be excessively large (56 MHz). To conserve spectrum space in the 2.5-GHz and 12-GHz bands while still satisfying link performance, it was decided to limit the bandwidth to 40 MHz, which required the carrier-to-noise ratio to exceed the threshold value by about 3 dB when the sync tip excursion was ignored. Analysis showed that the low duty cycle of the sync tip resulted in negligible splash-over energy in the guard band. FM was chosen because the modulation improvement in S/N ratio makes it an efficient way to achieve the required transmission quality. PCM could have been chosen instead, but the processing gains are equivalent and FM is simpler to handle. The ground stations are each based on a paraboloidal antenna of 20-foot diameter and a cooled parametric amplifier front end of about 1972 technology.

Assumptions underlying the link analyses are shown in Table 10.4.2. The margins shown assure performance at or above 56 dB peak-to-peak signal to rms noise from blanking to white level over 99 percent of the time in most locations at 2.5 and 12 GHz. At the maximum ground-station latitude, the zenith angle will be less than 45°; and rain losses in heavy rain (16 mm/hr) for this zenith angle will be less than 2.6 dB when the rain occurs at its usual maximum height of 10,000 feet and extends to the surface. This heavy a rain occurs less than 1 percent of the time throughout the United States.

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*Table 10.4.1 is a detailed summary of all the link calculations made, and is included for easy reference.

TABLE 10.4.1

SUMMARY OF LINK CALCULATIONS

Class	Freq MHz	Mod Sys	Ground Rcvr Temp °K	Ground Rcvr Ant Dia	G_A (dB)	$(G/T)_{dB}$	θ°	Li (dB)	Ls (dB)	Pix Qual.	$\frac{S_{B-W}}{N_{RMS}}$ (dB)	$\frac{S_{RMS}}{B_{RMS}}$ (dB)	$(\frac{S}{N})_{uw}$ (dB)	$\frac{C}{N}$ (dB)	FM Impr. (dB)	M	B_{RF} MH_z	ERP (dBW)
A	2,500	FM	200	20'	41.5	18.5	1.4	6.3	191.5	CCIR'	56	47	36.8	16	23.8	4	40	42.9
	12,000*	FM	250	20'	55.1	31.1	0.3	7.3	205.4	CCIR	56	47	36.8	16	23.8	4	40	45.3
	35,000	FM	1000	20'	64.4	34.4	0.1	13.3	214.6	CCIR	56	47	36.8	16	26.8	5.1	49	57.8
	35,000	FM	1000	8'	56.0	26.4	0.25	13.2	214.6	CCIR	56	47	36.8	16	26.8	5.1	49	65.8
										TASO								
B	800	VSB	500	12'	26.8	-0.2	7.2	7.6	181.6	1.5			39	39			6	67.4
	800	VSB	500	12'	26.8	-0.2	7.2	7.6	181.6	3.0			30	30			6	58.4
	2,500	VSB	290	8'	33.1	8.5	3.4	6.3	191.5	1.5			39	39			6	67.5
	2,500	VSB	290	8'	33.1	8.5	3.4	6.3	191.5	3.0			30	30			6	58.5
	2,500*	FM	290	8'	33.1	8.5	3.4	7.3	191.5	CCIR[2]	52	43	32.8	13	22.8	3.7	37.5	49.4
	12,000	FM	1160	4'	40.7	10.0	1.5	7.3	205.4	CCIR	52	43	32.8	16	22.8	3.7	37.5	65.8
	12,000	FM	1160	4'	40.7	10.0	1.5	7.3	205.4	CCIR[1]	56	47	36.8	16	23.8	4.0	40	66.1
										TASO								
C	800*	VSB	625	7'	20	-11.0	10	7.0	181.6	1.5			39					77.3
	800	VSB	625	7'	20	-11.0	10	7.0	181.6	3.0			30					68.3
	2,500	FM	435	3'	16	-10.4	10	6.3	191.5	CCIR	52	43	32.8	13	22.8	3.7	37.5	69.8
	12,000	FM	1160	2'	34.7	4.0	3	7.3	205.2	CCIR	52	43	32.8	16	22.8	3.7	37.5	71.6
VC			NF dB	Env. Noise			Pattern Loss	Line Loss		VOICE								
Urban	108*	FM	6	35	4		4.8	1	164.2	1	50		43.5	17	26.5	5	180kHz	67
Suburban	108	FM	6	15	4		4.8	1	164.2	1	50		43.5	17	26.5	5	180kHz	47
Rural	108	FM	6	0	4		4.8	1	164.2	1	50		43.5	17	26.5	5	180kHz	42
Urban	800	FM	12	15	8		4.8	1	181.6	1	50		43.5	17	26.5	5	180kHz	62
Suburban	800	FM	12	-5	8		4.8	1	181.6	1	50		43.5	17	26.5	5	180kHz	60
Rural	800	FM	12	-20	8		4.8	1	181.6	1	50		43.5	17	26.5	5	180kHz	60

*Prototype systems

TABLE 10.4.2

ASSUMPTIONS FOR CLASS A LINK ANALYSES

Frequency (GHz)	2.5	12	35
Ground-Antenna Diameter (ft)	20	20	20
Ground-Receiver Noise Temperature (°K)	150	200	700
Sky Noise Temperature (°K)	50	50	300
Atmospheric Losses in 0_2 and Water Vapor (dB)	0	0	2
Beam Edge and Squint Losses (dB)	4.8	4.8	4.8
Ground-Station Losses (dB)	0.5	0.5	2.5
Degradation Caused by Up-Link Noise (dB)	0.5	0.5	0.5
Video Bandwidth (MHz)	4.0	4.0	4.0
Modulation Bandwidth (MHz)	40.0	40.0	as required
Receiver Threshold (dB)	10.0	10.0	10.0
Margin above Breaking (dB)	3	3	0
Transmission Margin (dB)	3	3	3
Spacecraft Transmission Losses (dB)	0.5	1.5	3.5

4.1.2 Preferred System Frequency

The 12-GHz band was chosen as the preferred frequency for the Class A system for several reasons. At 2.5 GHz, the potentially available band (from 2.45 to 2.69 GHz) can accommodate at most six 40-MHz channels without guard bands and so fails to satisfy the model requirement. At 35 GHz, rain losses are not overcome by 3 dB margin; they are roughly 10.5 dB, while at 12 GHz they are under 2.6. The situation is even worse since the 20-foot receiving-antenna beamwidth is found to be under 0.1° at 35 GHz, requiring either a tracking subsystem of much better than one-mil precision in the ground station or further increase of the satellite ERP level by reducing the ground-antenna size. The alternatives are clearly impractical. At 12 GHz, the potentially available band from 11.7 to 12.7 can easily accommodate twenty 40-MHz channels and with the margins imposed, the transmission standards are met or exceeded over 99 percent of the time. Assumptions underlying the spacecraft technology are thus based on 12 GHz.

International Radio Regulations allocate the band from 11.7 to 12.7 GHz throughout the world to fixed and mobile common-carrier services (except aeronautical) and broadcasting. Satellite-broadcast-distribution services can be conducted in this band. However, for such services to be established, channel assignments must be secured and an experimental satellite program must be initiated expeditiously.

TABLE 10.4.3

LINK-PERFORMANCE DATA FOR CLASS A SYSTEMS

Frequency (GHz)	2.5	12	35	35
Ground-Antenna Diameter (ft)	20	20	20	8
Ground-Antenna Beamwidth (°)	1.4	0.3	0.1	0.25
Ground-Antenna Gain G (dB)	41.5	55.1	64.4	55.4
Ground-System Noise T_s (°K)	200	250	1000	1000
G/T_s (dB)	18.5	31.1	34.4	26.4
Incidental Losses (dB)	6.3	7.3	13.3	13.3
Space Loss (dB)	191.5	205.4	214.6	214.6
Quality; $\frac{S_{blank\text{-}wh}}{N_{rms}}$ (dB)	CCIR;56	CCIR;56	CCIR;56	CCIR;56
$\frac{S_{rms}}{N_{rms}}$ (dB)	47	47	47	47
$\left.\frac{S}{N}\right)_{rms}$ weighted for FM (dB)	36.8	36.8	36.8	36.8
$\left.\frac{C}{N}\right)_o$ (dB)	13	13	10	10
FM Improvement (dB)	23.8	23.8	26.8	26.8
Modulation Index	4	4	5.1	5.1
B_{rf} (MHz)	40	40	49	49
$\frac{C}{N}$ + Margin (dB)	16	16	16	16
ERP (dBW)	42.9	45.3	57.8	65.8

4.1.3 Technical Tradeoffs

A useful criterion of merit for a broadcast satellite is the payload weight per broadcast channel per unit area of coverage. For distribution and networking applications, this criterion must be applied over large areas, such as time zones of entire nations. A plot of satellite weight vs. suborbital coverage in square degrees facilitates choosing an optimum system model. Such plots can best be made with the number of channels a parameter.

In the continental United States, coverage from a single satellite may be obtained with various numbers of beams in different ways. Convenient divisions of coverage can be made by using either geographical time zones or broadcast time zones. Good coverage plans are obtainable with the subsatellite point at west longitudes between 85° and 100°. Table 10.4.4 lists the possibilities, geographical time zones being shown without quotation marks and broadcast time zones with quotation marks. In all cases, there is some overlap among beams, and the national borders with Canada and Mexico remain inviolate.

TABLE 10.4.4

MULTIPLE-BEAM COVERAGE PLANS FOR CONTINENTAL UNITED STATES

Number of Beams	Time-Zone Distribution		Size (Long° + Lat°)
3	E	1	2 x 3
	C	1	2 1/2 x 2 1/2
	MW	1	2 1/2 x 2 1/2
6	E	2	2 x 2
		1	1 x 1
	C	1	2 x 2
	M	1	2 x 2
	W	1	1 x 2
7	"E"	3	1 x 2
	"C"	3	2 x 2
	"W"	1	1 x 2
12	E	1	1 x 1
		1	1 x 2
		1	2 x 2
	C	3	1 x 2
		1	2 x 1
		1	2 x 2
	M	2	1 x 2
	W	2	1 x 2
12	"E"	1	1 x 1
		3	2 x 1
	"C"	1	2 x 2
		3	1 x 2
		2	2 x 1
	"W"	2	1 x 1
15	E	5	1 x 1
	C	4	1 x 1
	M	2	1 x 1
	W	4	1 x 1

NOTE:

E = Eastern
C = Central
W = Western
M = Mountain
MW = Mountain and Western

Quotation marks indicate broadcast time zones, not geographic time zones.

It can be seen from Table 10.4.4 that numerous possibilities exist: one can assign one or several channels per beam to arrive at various satellite configurations. Per-channel weight and power estimates for the satellite transponder are now necessary to arrive at weight-coverage plots. Table 10.4.5 shows the single-channel antenna-transmitter tradeoff with beam angle for an ERP of 45.3 dB at 12 GHz. An estimate of transponder weight is now possible. The technology of 1972 is assumed for this.

TABLE 10.4.5

SINGLE-CHANNEL ANTENNA-TRANSMITTER TRADEOFFS AT 12 GHz

Beam angle (°)	1/2	3/4	1	1 1/2	2	2 1/2	2 x 3
Antenna Diameter (ft)	11.5	7.66	5.75	3.83	2.87	2.3	2.87 x 1.92 elliptical
Antenna Gain (dB)	50.3	46.8	44.3	40.8	38.3	36.3	36.5
Transmitter Output Power (W)	0.303	0.682	1.26	2.81	5.0	7.94	7.55

The technology of 1966 makes it possible to design and fabricate integrated-circuit transponders that receive signals at S-band frequencies, process them down to IF or video, and reprocess them up to S-band at power levels up to 50 mW. Transponders of this type having 10-MHz bandwidths have been studied extensively in the NASA Orbiting Data Relay Network (ODRN) program. By 1972, it is quite reasonable to expect them to have a capability of 40-MHz bandwidths at S-band input and output frequencies which will accommodate the link-performance requirements of Table 10.4.3. Conversion to 12 GHz is made by low-level multipliers. Transponders of this type (see Table 10.4.6) include preamplifiers, filter, S-band mixer, IF amplifier, signal processing, and multiple-coax or stripline couplers for input and output. They are estimated to weigh 1.1 lb/channel. Adding multipliers to get to 12 GHz, down-converters and preamplifiers to handle the up-link signal, and connectors at input and output, the 12-GHz transponder may be estimated at 2.25 lb/channel.

Based on the ODRN result of 0.38 watt/channel power drain, the 12-GHz transponder of 1972 technology, multipliers and down-conversion included, may be expected to draw 0.8 watt/channel. This transponder of 2.25 lb and 0.8 watt power drain is the basic driver for the 12-GHz power amplifier. In a multiple-channel situation, Table 10.4.6 makes clear the need for traveling-wave tube amplifiers to satisfy the transmitter-power-output requirement.

TABLE 10.4.6

ODRN INTEGRATED-CIRCUIT S-BAND TRANSPONDER

Component	Weight	Power In	Power Out
Power Amplifiers (2) S-band mixers (2)	0.6 lb	0.175 W	0.1 W
S-band filters (2) Power Divider Preamplifiers and S-band mixers (2) I-f amplifiers (2) Summation Circuit Signal Processing, 2 channels Multiple-coax or stripline couplers	2.2 lb or 1.1 lb/ channel	0.38 W	

K_u - band traveling-wave tubes (TWT) based on the Lunar Orbiter design are available for space applications in 1967-1968. These tubes can provide useful power output over the range from one to 10 watts with an efficiency of 25 percent, and at a fixed weight of 1 1/2 lb. Addition of a power converter at 0.4 lb per watt of TWT output power and 90 percent efficiency results in a traveling-wave-tube amplifier (TWTA) weight of 5.5 lb for 10 watts output. A scaled design of 20 watts output, at 22.5 percent overall efficiency, will weigh 11 pounds. Limitations in the technology of ferromagnetic-core components place a floor of about 1 1/2 lb on the converter. Ninety percent is a typical figure for converter efficiency.

A TWT development now under way is expected to produce a 20-watt, two-pound, K_u - band TWT during 1969. Efficiency for the tube remains at 25 percent, for the power converter, 90 percent. Power converter and TWT development during the period 1967-1972 is not expected to reduce the weight requirement below the levels stated. Accordingly, the existing line of TWTA's will be used to size the satellite transmitter for power levels up to 10 watts. For 20-watt levels, weight tradeoffs are made between the available TWTA's and the 20-watt ones expected during 1969.

Sizing of satellites for coverage and number of channels depends upon the single-channel antenna-transmitter tradeoffs of Table 10.4.5 and an optimum combination of multiple-feed antennas. For example, the three-beam time-zone distribution of Table 10.4.4 can provide 3-, 6-, 9-, or 12-beam coverage of continental United States by using differing numbers of feeds (not exceeding four) with a single reflector for each time zone. Since alternative coverage plans for six and 12 beams are shown, weight comparisons of the satellites will depend directly on the weights for the combinations of antennas, transponders, and TWTA's compatible with the various coverage plans. (Details of satellite weight determination are given in Appendix C.) To illustrate the possibilities, consider the 12-beam case for three broadcast time zones.

For transponder and TWTA sizing, the antenna-transmitter tradeoff is sensitive only to overall beam shape and not to orientation. From Table 10.4.4, this leads to eight 2° x 1° beams, three 1° x 1° beams, and one 2° x 2° beam. Table 10.4.5 may be interpolated to determine the transmitter-output power required for each beam. These are then added and the total power requirement is found to be 28.8 watts. Figure 10.4.1 shows the weight of a single TWTA as a function of output power. With appropriate separation filters and multicouplers, this power may be supplied to 12 feeds by two or three TWTA's: two 10-watt units at 5.5 lb each and one 9-watt at 5.1 lb, or one 20-watt unit at 10 lb and one 9-watt at 5.1 lb. Since the tradeoff involves only one pound out of the ultimate overall satellite weight, deciding in favor of weight is less practical than deciding in favor of a simpler filtering problem per TWTA. The choice is made for three TWTA's; when the weight of 12 transponders at 2.25 lb each with associated multicouplers, filters, connectors, and waveguide runs to the feed at 0.4 lb per channel is added, the total communication subsystem weight less antennas is found to be 47.9 lb and the power demand on the spacecraft bus is 137.3 watts.

A further tradeoff must be made, however, in assessing the effects of TWT distortion on the signal. Since the TWT gain exhibits small variations with frequency, a constant-amplitude input signal will undergo amplitude modulation. This amplitude modulation is translated into phase shifts of the various spectral components so that an FM signal will undergo phase distortion in the TWT amplification process. Typical conversion coefficients are 0.02 dB/MHz and 3°/dB amplitude variation, respectively. For small bandwidths (on the order of 4 MHz), the peak-to-peak crosstalk ratio will be about 46 dB, which may not satisfy the 56-dB requirement for CCIR relay quality. To maintain this quality, it seems necessary to utilize a separate TWT for each TV channel. Even in the absence of multiplexing, it appears necessary to pursue the development of low-power K_u-band TWT's with FM/AM and AM/PM conversion coefficients reduced by an order of magnitude below those of 1967. When this tradeoff is made and the 12-channel communication system is sized, its weight increases to 71.9 lb.

To size the antennas, orientation must be considered. From Table 10.4.4, with the limitation of four or fewer feeds per reflector, one single-feed and four multiple-feed antennas may be used to cover the three broadcast time zones with 12 beams. Rib-and-mesh paraboloidal antennas of the 10-foot LEM type design will be employed. Using the data in Table 10.4.5 and the expression for rib-and-mesh antenna weight in Appendix C, and allowing about half a pound for supporting structure and extra feeds, the overall antenna subsystem weight in this case is about 15-1/2 lb. The satellite weight is then determined by the methods of Appendix C to be 435 pounds, including antenna-deployment mechanisms.

Applying this approach to the possibilities derivable from Table 10.4.4 yields results as in Figure 10.4.2, showing satellite weight as a function of coverage with number of channels as a parameter. To obtain these curves, the total coverage in square degrees for all beams in the satellite

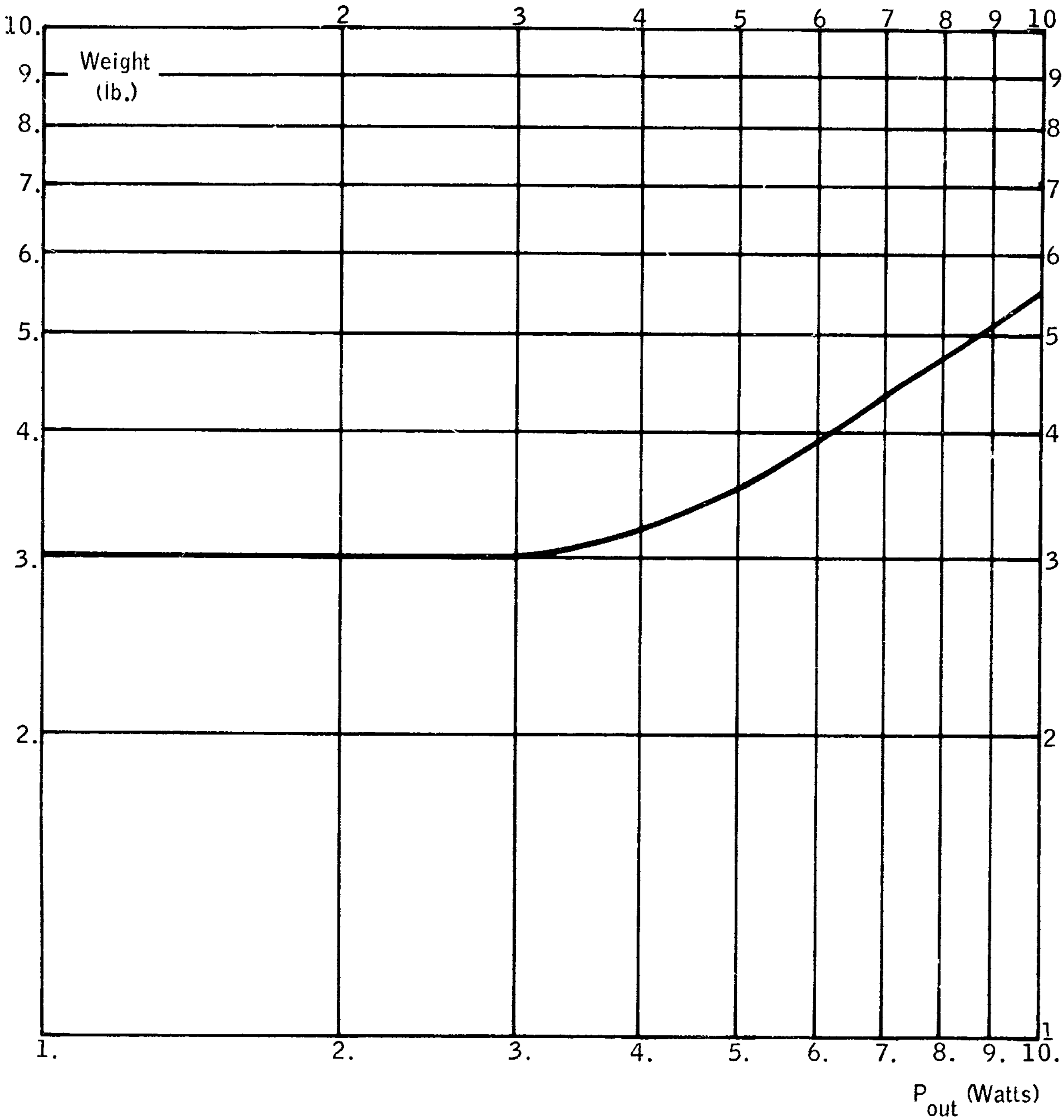


FIGURE 10.4.1. K_u-Band TWTA weight versus power output.

was plotted without regard to the reductions obtainable from beam overlap. Thus, the points marked X and labeled as coverage equivalent to the continental United States actually display the maximum non-overlapping coverage in square degrees, although the beam distribution was derived from an overlay on the map, which accounted for beam overlap, and kept the satellite radiation inside the U. S. borders. With the proper beam overlap, the total angular coverage in square degrees for all points X in Figure 10. 4. 2 will be 18-1/2, corresponding to the suborbital solid angle of the continental United States for a geostationary satellite stationed between 85° and 100° west longitude.

The weights in Figure 10. 4. 2 include fully redundant communications equipment (but not antennas). It is evident from the figure that the optimum model is the lower of the two X points for N = 12. A further quantitative comparison with this model can be made by obtaining the weight for the N = 3 configuration extended to 12 channels. As it stands at X, this configuration uses a separate antenna and single feed to cover each broadcast time zone. If each antenna is maintained fixed and is elaborated to have four feeds, the basic N = 3 configuration at X becomes an equivalent N = 12 configuration, but with the N = 3 antenna distribution; the weight for this configuration is 810 lb while the maximum coverage remains at 18-1/2 square degrees. This demonstrates the sharp minimum in the extended curve for N = 12. In most cases, a minimum of practical importance can be closely approached by examining the antenna and beam distribution directly on a map projection.

It is also of interest to examine what happens to the weight of the N = 12 configurations at points X if the satellite capacity is extended to 24 channels. This is a problem of practical importance. It has been suggested that in addition to four networks as described in Section 3. 3. 1, channel capacity be provided for instructional TV. This could require several channels per time zone if concurrent instruction in different subjects at different educational levels is to go on a broadcast basis. The new configuration, optimized for antenna as well as beam distribution, will have seven or eight multiple-feed reflectors, only three or four of them having as many as four feeds, and with fully redundant communications equipment will weigh 630 lb in one case and 660 lb in the other. Booster implications of these startlingly low-weight results will be discussed in Section 4. 1. 5. In this section, the tradeoff of frequency assignments with channel remains to be discussed.

In the 11. 7- to 12. 7-GHz band allocated to broadcast service, it is possible to get 20 channels of 40-MHz bandwidth with 5-MHz guard bands separating adjacent channels. This is adequate space to accommodate the sound channel associated with each video channel; the sync tip contribution to the signal spectrum lies almost totally within the 40-MHz band (less than 0. 01 percent of the sync tip energy falls outside it). Because eastern and western broadcast zones are well separated geographically, the same frequency assignments can be used for both, thus requiring eight of the 20 possible channel assignments to realize 12-channel coverage. This extends to a requirement for only 16 of the 20 possible channel assignments to provide 24-channel coverage in the TV broadcast distribution system. Technically, then, TV broadcast distribution service over the continental United States can be accommodated conveniently within the existing allocation at K_u-band. The

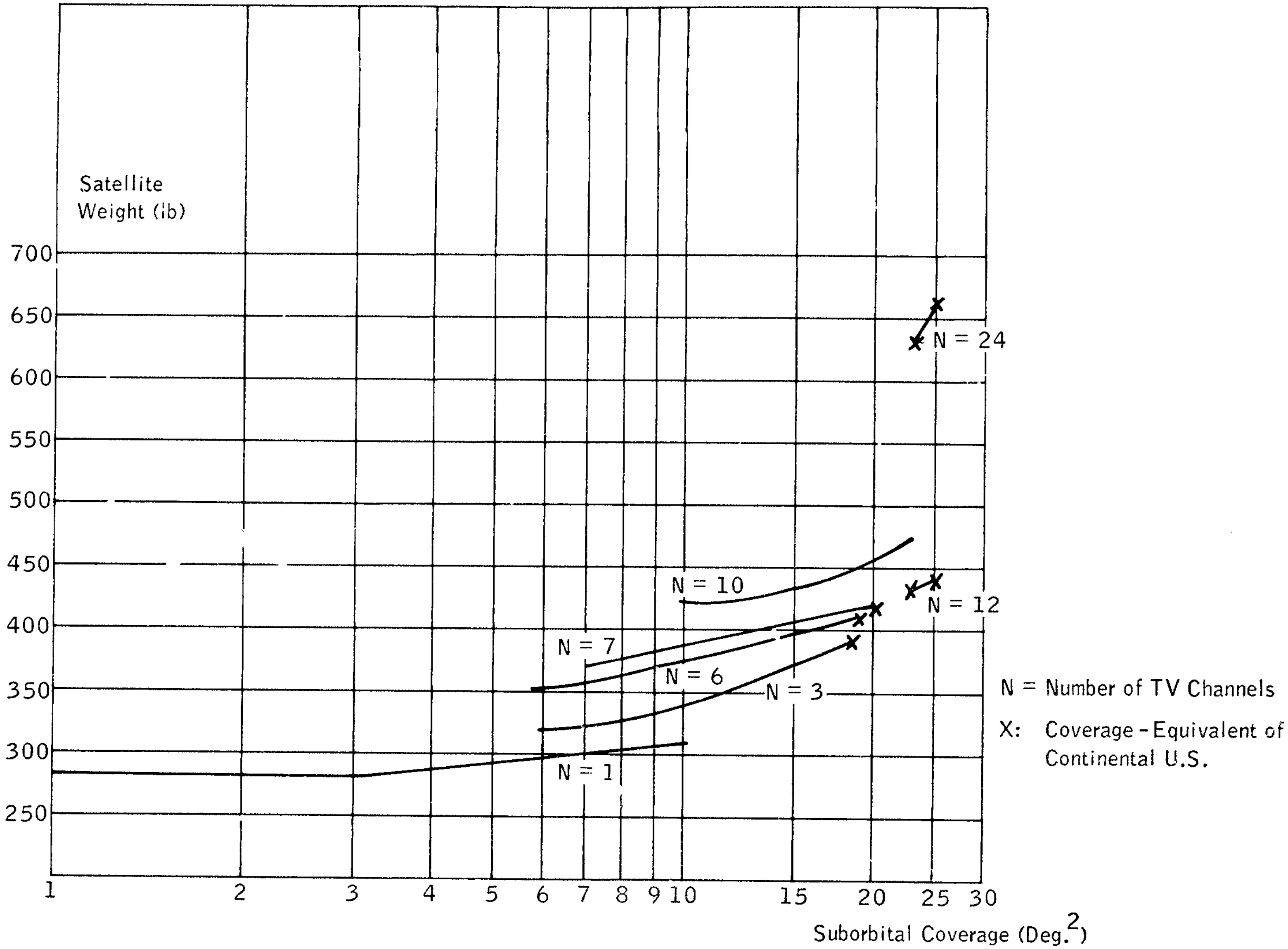


FIGURE 10.4.2. Weight versus suborbital coverage for TV distribution satellites.

problem to be faced is that of agreement on the principle and details of starting such a service, and the rapid obtaining of frequency assignments for it.

4.1.4 Stabilization

Satellite sizing, as described in Appendix C, is based on three-axis stabilization. For antenna beamwidths of one to two degrees, stabilization accuracy must be at worst 0.1° to provide satisfactory fixing of beam coverage areas on the surface. This will require an aggressive development program in sensors, low-thrust devices, and stabilization systems. This stabilization requirement will apply to both Class A and Class B systems.

4.1.5 Boosters

A 12-channel satellite weighing 430 lb could just be placed into synchronous equatorial orbit on an advanced Thor-Delta class booster with an apogee kick (AK) stage. The LOX-LH_2 upper stage for this class of booster has been suggested but is not currently planned for development. Should it be initiated, the resulting in-orbit payload capacity for this booster with AK stage would be about 430 lb. At this time, the apparent lack of weight margin is not comfortable. As development of booster and satellite progresses, it will probably become negative.

The Atlas-Agena class of boosters can deliver payloads for synchronous-equatorial orbit up to 850 lb. Scheduled updating for this class will increase its payload capacity to 1400 lb by 1971. Table 10.4.7 summarizes the payload-handling capacities for Atlas-Agena-class boosters.

TABLE 10.4.7

PAYLOAD-HANDLING CAPACITY FOR ATLAS-AGENA-CLASS BOOSTERS (10-foot shroud)

Booster	Payload in Synchronous Equatorial Orbit (lb)	Status
SLV3	750	Operational
SLV3A	850	Operational
SLV3A x N_2O_4 Agena*	1050	
SLV3X x N_2O_4 Agena*	1400	Scheduled for 1971

For the 1972-75 period, it is possible and economically attractive to consider launching two 12-channel distribution satellites on a single, uprated SLV3A. This establishes the broadcast satellite and a working spare for the four-network distribution service in a single launch. Alternately, two independent 12-channel satellites from a single launch could be used simultaneously for the independent services of four-network distribution and instructional distribution with spares provided in a second launch.

The uprated SLV3X could handle two 630-lb, 24-channel satellites in a single launch. This one launch establishes complete 24-channel satellite service and a working spare in orbit for the four networks and instructional TV. The choice for the 24-channel system falls on the uprated SLV3X.

4.1.6 Prototype System

Tradeoffs for broadcast distribution satellites led to the conclusions that for the continental United States, 12-channel satellites weighing 430 lb each were optimum. The 12-channel service is justifiable in 1967 with one channel in each of three broadcast time zones for each of the major networks and for public TV but it has no growth capability. When demands of the educational community are considered and the existence of other networks such as the Sports Network are accounted for, the need for at least a 24-channel service in the 1972-75 era is easy to support. With 1972 technology as a base, the prototype model system choice for broadcast distribution falls on the 24-channel satellite.

TABLE 10.4.8

CLASS A SUMMARY

Frequency (MHz)	Modulation	Ground Receiver		Picture Quality	Brf (MHz)	ERP (dBW)
		Ant. Dia. (ft)	Beam Width (Degrees)			
2,500	FM	20	1.4	CCIR Relay	40	42.9
12,000*	FM	20	0.3	"	40	45.3
35,000	FM	20	0.1	"	49	57.8
35,000	FM	8	0.25	"	49	65.8

*Prototype system

4.2 Class B (Community) Systems

4.2.1 Introduction and Assumptions

Promising Class B systems (as previously described in Section 3) include distribution of TV to CATV systems and broadcast of instructional TV to schools or t clubs where numerous persons congregate. The essential feature from a systems-design viewpoint is that a receiver having a cost between the Class A distribution system and Category C direct-to-home system is feasible.

For this reason, both FM and VSB/AM were considered, as well as frequencies of 800 MHz, 2500 MHz and 12,000MHz. Moreover, 4000 MHz and 7000 MHz could be equally attractive down-link frequencies, but are assigned for point-to-point service. Since community TV is broadcast, these frequencies were not considered further. Accordingly, the conditions of Table 10.4.9 were investigated.

TABLE 10.4.9

ASSUMPTIONS FOR CLASS B SYSTEMS

Frequency (MHz)	Modulation	Quality	Receiver		
			Dish Diameter (ft)	Noise Temp. (°K)	G/T (dB/°K)
800	VSB	TASO 1.5	12	500	-0.2
800	VSB	TASO 3.0	12	500	-0.2
2,500	VSB	TASO 1.5	8	290	8.5
2,500	VSB	TASO 3.0	8	290	8.5
2,500*	FM	CCIR (India)	8	290	8.5
12,000	FM	CCIR (India)	4	1,160	10.0
12,000	FM	CCIR (U.S.)	4	1,160	10.0

*Prototype system

4.2.2 Link Calculations

Link calculations to determine required satellite ERP per channel were performed very similarly and compatibly with Class A. The results are summarized in Table 10.4.10. Because of the great disparity in ERP requirements per channel due to VSB/AM and the 12,000-MHz conditions, FM at 2500 MHz was selected for further investigation. The present FCC instructional-television band of 2500-2690 MHz would afford up to four channels at these qualities if allocated to this purpose, or more at reduced quality, or greater ERP per channel.

4.2.3 Spacecraft Weights

Spacecraft weights for various coverage conditions were estimated using the methods of Appendix C, and generally similar to those described for Class A. Results are shown in Figure 10.4.3. Coverages considered were both "square," such as 2° x 2°, and "oblong," such as 2 1/2° x 3°. All are plotted in terms of square degrees. One, three, six, and nine TV channels were considered. The point shown as "E" on Figure 10.4.3 pertains to a system for India in which the main part of India is covered with six 2 1/2° x 3° beams — each carrying one TV channel. The small, northeastern part beyond East Pakistan is covered with three 1° x 1° beams.

The weight curves all show minima at very small coverage angles, but are near-linear in the region of practical interest.

Sizing of the satellite communications equipment at 2.5 GHz is based on 1972 technology in solid-state, S-band power amplifiers. Moreover, 1967 technology has permitted the demonstration of a solid-state, S-band power amplifier of 10-watt output, 30-dB gain, and 1-dB bandwidth of 200 MHz; but its efficiency was only about 11 percent. Expected progress in S-band power transistors should make possible an increase in efficiency to 20 percent during 1968. Based on projected availability of 8-watt, high-efficiency S-band transistors during 1968, it is expected that S-band, solid-state power

TABLE 10.4.10

SUMMARY OF LINK CALCULATIONS FOR CLASS B SYSTEMS

Freq (MHz)	Mod Sys	Ground Rcvr Temp °K	Ground Rcvr Ant Dia	Ga (dB)	G/T (dB/°K)	θ°	Li (dB)	Ls (dB)	Pix Qual.	Sb-W / N rms (dB)	S rms / N rms (dB)	$\left(\frac{S}{N}\right)$UW (dB)	$\frac{C}{N}$ (dB)	FM Impr. (dB)	m	Brf (MHz)	ERP (dBW)
									TASO								
800	VSB	500	12	26.8	-0.2	7.2	7.6	181.6	1.5			39	39			6	67.4
800	VSB	500	12	26.8	-0.2	7.2	7.6	181.6	3.0			30	30			6	58.4
2,500	VSB	290	8	33.1	8.5	3.4	6.3	191.5	1.5			39	39			6	67.5
2,500	VSB	290	8	33.1	8.5	3.4	6.3	191.5	3.0			30	30			6	58.5
2,500*	FM	290	8	33.1	8.5	3.4	6.3	191.5	CCIR[2]	52	43	32.8	13	22.8	3.7	37.5	49.4
12,000	FM	1160	4	40.7	10.0	1.5	7.3	205.4	CCIR	52	43	32.8	16	22.8	3.7	37.5	65.8
12,000	FM	1160	4	40.7	10.0	1.5	7.3	205.4	CCIR[1]	56	47	36.8	16	23.8	4.0	40	66.1

*Prototype system

amplifiers of 10- to 50-watt ratings with 30 percent overall efficiency could represent the technology of 1971. Development of such equipment is recommended, since it will be at least competitive in weight with TWTA's, and may well provide greater reliability and wearout life.

Since the primary applicational interest for Class B systems is probably for developing countries such as India, Brazil, or Indonesia, a relatively small number of TV channels is probably adequate, particularly since program material will be limited for some time. Three TV channels (curve B of Fig. 10.4.3) were therefore chosen as representing the best-example system. Each channel carries four voice channels for different-language sound tracks. (The added weight for the extra three voice channels is about 5 percent).

For two typical coverages, 2° x 2° and 3° x 3°, the required satellites weigh 435 lb and 595 lb respectively. For the former coverage, two satellites (operational plus spare) can easily be put into orbit with the uprated Atlas-Agena; the other case fits comfortably on a standard Atlas-Agena. No new booster developments are required for this application.

4.2.4 Calculations and Results

Link calculations were carried out for the above assumptions with the following results for the required satellite C/N and ERP:

Frequency	Modulation	Quality	C/N (dB)	ERP (dB)
800 MHz	AM	TASO 1.5	39	67.4
800 MHz	AM	TASO 3.0	30	58.4
2,500 MHz	AM	TASO 1.5	39	67.5
2,500 MHz	AM	TASO 3.0	30	58.5
2,500 MHz	FM	CCIR (India)	13	49.4
12,000 MHz	FM	CCIR (India)	16	65.8

The above C/N values include required margin. Required bandwidth for FM modulation turned out to be 37.5-40 MHz for the above case.

TABLE 10.4.11. CLASS B SUMMARY

Frequency (MHz)	Modulation	Ground Receiver		Picture Quality	Brf (MHz)	ERP (dBW)
		Ant. Dia. (ft)	Beam Width (Degrees)			
800	VSB	12	7.2	TASO 1.5	6	67.4
800	VSB	12	7.2	TASO 3.0	6	58.4
2,500	VSB	8	3.4	TASO 1.5	6	67.5
2,500	VSB	8	3.4	TASO 3.0	6	58.5
2,500*	FM	8	3.4	CCIR Relay	37.5	49.4
12,000	FM	4	1.5	CCIR Relay	37.5	65.8
12,000	FM	4	1.5	CCIR Relay	40.0	66.1

*Prototype system

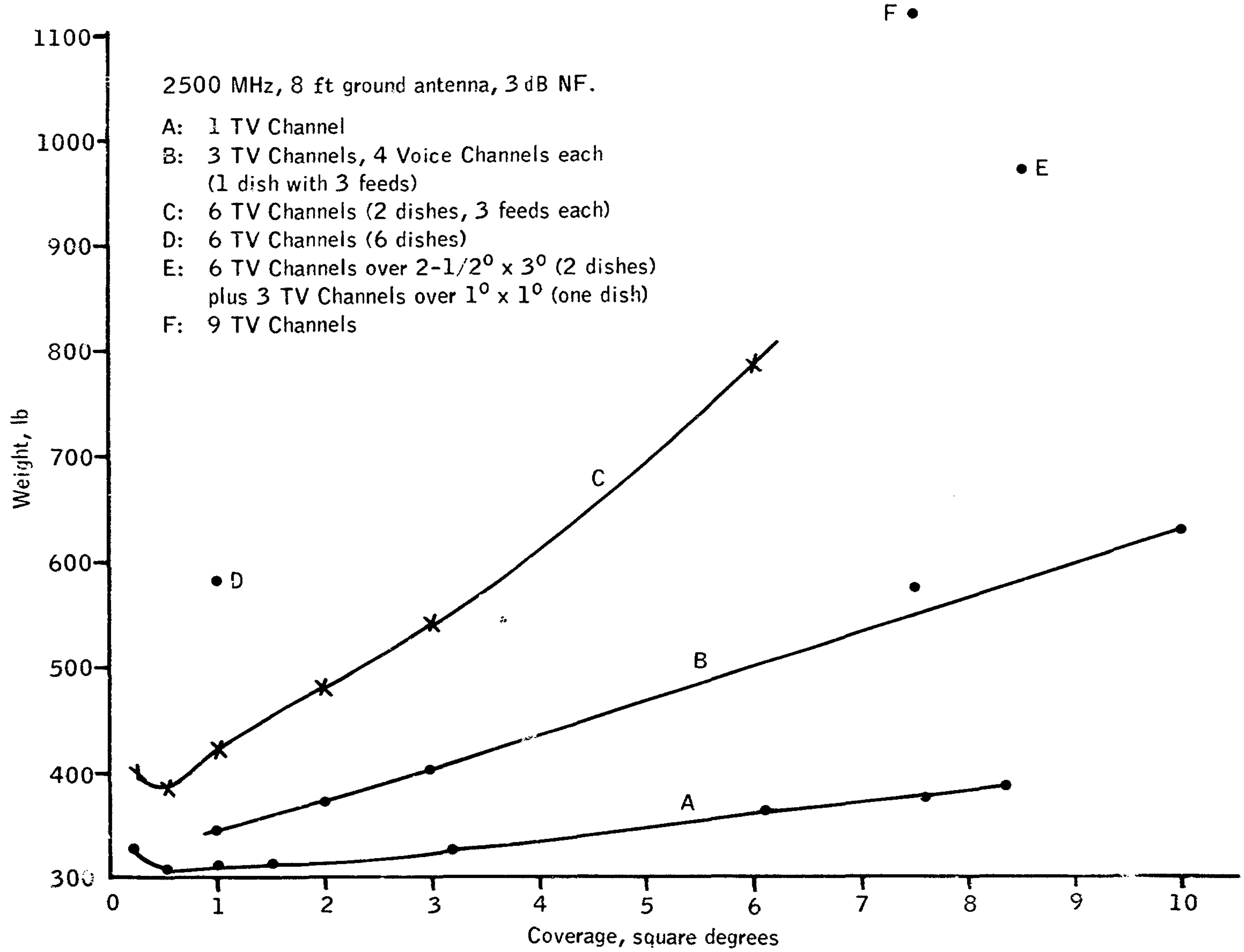


FIGURE 10.4.3. Satellite weight versus coverage.

4.3 Class C (Direct-Broadcast) Systems

The large number of variables and their wide range dictate the use of engineering judgment and experience to reduce the system-design problem to a manageable level, considering that a parametric treatment would yield no useful result. The following judgments or assumptions apply to the Class C direct-broadcast TV satellite system.

1. Thin-film roll-up rather than conventional solar-energy converters were chosen. This assumption implies a substantial investment to develop the required technology; but this cost would most likely be quickly recovered. Consider a TV satellite radiating 10 kW. The required dc energy is about 40 kW. Using a value of $1000 per watt for conventional cells on a deployable structure, the cost for one satellite would be $40 million. The thin-film roll-up power supply would cost about $100 per watt after development, or $4 million. The $36 million saving should cover the required development costs.

2. Batteryless design (but with provision for a small battery for housekeeping) rather than operation during eclipse is assumed. Whereas the telecommunications point-to-point satellites do provide for eclipse operation, this feature is impractical for a high-power satellite, as may be seen from the following example.

The battery weight for a 10-kW radiated-power satellite would be about 6000 lb, a severe penalty and believed to be impractical for a first-generation satellite. If the satellite were located over the Pacific Ocean and squinted toward the center of the United States, the eclipse would occur one hour later for each time zone squinted and thus delay the outage hour to a more suitable hour.

NOTE: Certain of the Class C satellite systems studied have narrow-beam antennas and rather low power. For example, a satellite providing TASO Grade 3 service using a 1° antenna requires only 100 watts of radiated power. This satellite could have batteries for eclipse operation.

3. The weight of large spacecraft reflector antennas was not fully resolved at the time of the study, being dependent upon the form of construction (rib, petaline, etc.). It was therefore assumed that the weight would be proportional to its diameter to the 2.3 power, $W_A = KD^{2.3}$. This choice was made after the following considerations. Structures which scale proportionately in three dimensions follow the third-power law. Large ground antennas obey a 2.7-power law. If the thickness (and density) of a space antenna were held constant, the square law would hold. The 2.3 power was therefore adopted. The exponent and constant of proportionality are derived from the Vista design.

4. Oriented solar-supply systems that have only one degree of freedom were chosen in preference to those having two degrees. The trade-off is a modest increase in array weight to avoid the significant added complexity of turning the plane of the array normal to the sun line.

5. Choice of 800 MHz as the frequency for the direct-to-home systems is ideal, requiring minimum "add-on" to mass-produced UHF monochrome or color receivers. This choice avoids the need for microwave-frequency translation in the preamplifier, or an additional band in receivers of the future that will be fitted for satellite reception. This frequency propagates well through the ionosphere and troposphere, and allows the use of relatively

broad-beam antennas on the ground. These antennas can be more crudely made than their microwave equivalents, with wide spacing between slats or tubes used in their construction, and they do not require as rigid mounting. The satellite antenna also is not unduly complicated. Finally, 800 MHz is available on millions of receivers, but this end of the UHF spectrum has as yet not been exploited.

One recommendation of the study is that a block of channels around 800 MHz be reserved by the FCC for satellite broadcasts in the United States, because of their unique suitability for this purpose.

6. Compatible VSB in preference to double-sideband AM or FM was chosen for several reasons. No modulation converter would be needed and thus the receiver installation again would be of minimum cost and would have the largest ready audience. The frequency plan now in use could be retained, except that the directivity of the ground antenna toward a high-angle satellite would probably avoid the present requirement of a six-channel spacing between assignments in one area. The exclusive channel assignments would relieve the system design of any power-flux density or spectral-flux density constraints which constitute an important limitation of the microwave frequencies.

7. The coverage provided by a broadcast satellite is dependent upon the figure of merit of the receiver, G/T, where G is the antenna gain and T the front-end noise temperature. The cost of receiver installation increases with the figure of merit. It is likely that receivers having various figures of merit will be used, with the choice dependent upon individual taste with respect to picture quality, and the cost. Three receivers were therefore chosen, two representing reasonable lower and upper bounds of quality and the third a medium grade.

The low-cost installation was assumed to have an antenna with 12 dB of gain. A corner reflector widely used today for UHF reception and costing $10.50 would meet this gain requirement. It is assumed that the antenna would be mounted within 20 ft of the receiver so as to limit the transmission-line loss to 1 dB. It was further assumed that a 1975 receiver would have a low-noise front end with a noise figure of 7 dB. This would be achieved by incorporating a 4-dB noise-figure transistor now available in experimental quantities and allowing a 3 dB loss for circuits and switching. To avoid building-attenuation, the antenna would be mounted on a window bracket or on the roof with not more than 20 ft of lead-in cable. Allowing for installation material and labor, a total cost of $42.20 results. A do-it-yourself installation might result in less than half this cost.

The medium-cost installation was assumed to have a 7-ft parabola having a gain of 20 dB. This antenna is made of formed aluminum tubing of rather wide spacing to reduce wind resistance and ice loading, lower cost of materials, and provide easy installation. As a result the aperture efficiency is reduced to about 30 percent. This antenna is sold today for $55.00.

An antenna-mounted preamplifier having a 5-dB noise figure (4-dB transistor and 1-dB loss) and 30-dB gain assures a receiver-noise figure which is substantially that of the preamplifier even with a fairly lossy transmission line (old, long, wet) and high-noise-figure receiver. This receiver may be considerably inferior to that assumed for the low-cost case. The antenna and mounting and other installation materials were estimated to be $74. Adding $30. to cover installation and labor, and $20 for the estimated 1975 preamplifier cost, a total cost of $124 provides a G/T_r of -8dB.

For the high-cost case, a well-built 9-foot parabola having an efficiency of 55 percent and costing $147, is assumed, using a cost of $6 per dB of its 24.5 dB of gain.

An antenna-mounted preamplifier is also assumed for this case, and its noise figure is taken as 3.5 dB. Using $40 as an estimated cost for this, and adding the antenna cost, installation, material, and labor, the add-on system would cost $362 and provide a G/T of -1.1 dB.

8. Consideration must be given to the significant ambient noise in rural and urban locations. The values shown in Table 10.4.12 are derived from the Voice Broadcast Mission Study (Contract NASW-1476), based upon a limited number of measurements. The receiver noise temperatures and the ambient man-made noise temperatures are added to give the system noise temperatures.

The foregoing is summarized in Table 10.4.12. Table 10.4.13 gives the satellite ERP to provide TASO Grades 1-1/2 and 3 service. (See Appendix A for details of ERP computation).

9. There is believed to be no experience that will permit the derivation of a functional relationship between satellite-radiated power and weight. Using data derived from the Vista study and other sources, Table 10.4.14 was constructed.

It was assumed that a simple power law would relate the weight-to-capacity ratio of the three basic transmitter subsystems as follows:

$W = W_t + W_h + W_r$ where W_t = weight of electronics and circuits, W_h = weight of the heat pipe and W_r = weight of the radiator. The power laws shown below are suggested:

$$W_t = K_t P_t^{1/2}, \quad W_h = K_h P_t, \quad \text{and } W_r = P_t^{3/2}$$

The constants of proportionality may be derived from Table 10.4.11 and the functional relationship so obtained is shown in Figure 10.4.4.

The satellite weight required to provide TASO Grade 3 service for various satellite-antenna beamwidths is shown in Figure 10.4.5, where the abscissa is given in square degrees. The general shape of the curves shows that for a given G/T_s — the receiver figure of merit including ambient noise—a minimum required satellite weight results for a fairly broad range of antenna beamwidths. This results from the trade-off between the satellite-antenna weight and its power-generation system (direct current to radio frequency) weight, with these being equal at the minimum point. Considering the -1.1 dB G/T curve as an example, nearly all the available weight, after allowing for structure, stabilization, harness, secondary propulsion, command control, and telemetry, is in the antenna for the 1° coverage. For the 10° (100 square degrees) coverage, on the other hand, practically all of the available weight is taken by the power supply and dc to rf conversion equipment.

TABLE 10.4.12

RECEIVING-SYSTEM CHARACTERISTICS

	Locations								
	Rural			Suburban			Urban		
Ambient Noise (°K)	0			625			5500		
	System Noise dB above 1°K	Ant. Gain	G/T	System Noise dB above 1°K	Ant. Gain	G/T	System Noise dB above 1°K	Ant. Gain	G/T
Low-Cost Installation	30.7	11	−19.7	32.5	11	−21.5	38.2	11	−27.2
Medium Cost	28	20	−8	31	20	−11	37.9	20	−17.9
High Cost	25	24.5	−1.1	29.9	24.5	−5.4	37.7	24.5	−13.2

TABLE 10.4.13

SATELLITE ERPS (dBW)

	Locations					
	Rural		Suburban		Urban	
TASO Grades	1.5	3.0	1.5	3.0	1.5	3.0
Low Cost	86.0	77.0	87.5	78.5	93.5	84.5
Medium Cost	74.3	65.3	77.3	68.3	84.3	75.2
High Cost	67.5	58.4	71.7	62.7	79.5	70.5

TABLE 10.4.14

ESTIMATED WEIGHTS FOR A 5 KW (pk) SATELLITE TRANSMITTER

Item	Quantity	Total Weight (lbs)
Klystrons	4	300
Heat Pipes	4	120
Thermal Radiators	4	110
Hybrids	3	30
Diplexer	1	20
Driver-Exciter	1	120
		700

The curves can be used for other TASO grades. For example, the satellite weight for TASO grade 1-1/2 which has a S/N ratio of 39 dB (9 dB greater than grade 3) can be obtained by subtracting 9 dB from the numerical values of the G/T_s parameter shown on the curves.

The coverage factor, square degrees, is plotted against receiver system figure of merit for two satellite weights and two TASO grades in Figure 10.4.6. This curve is derived directly from Figure 10.4.5. Also given is a table which gives G/T_s for three receivers of low, medium, and high cost in rural, suburban, and urban environments.

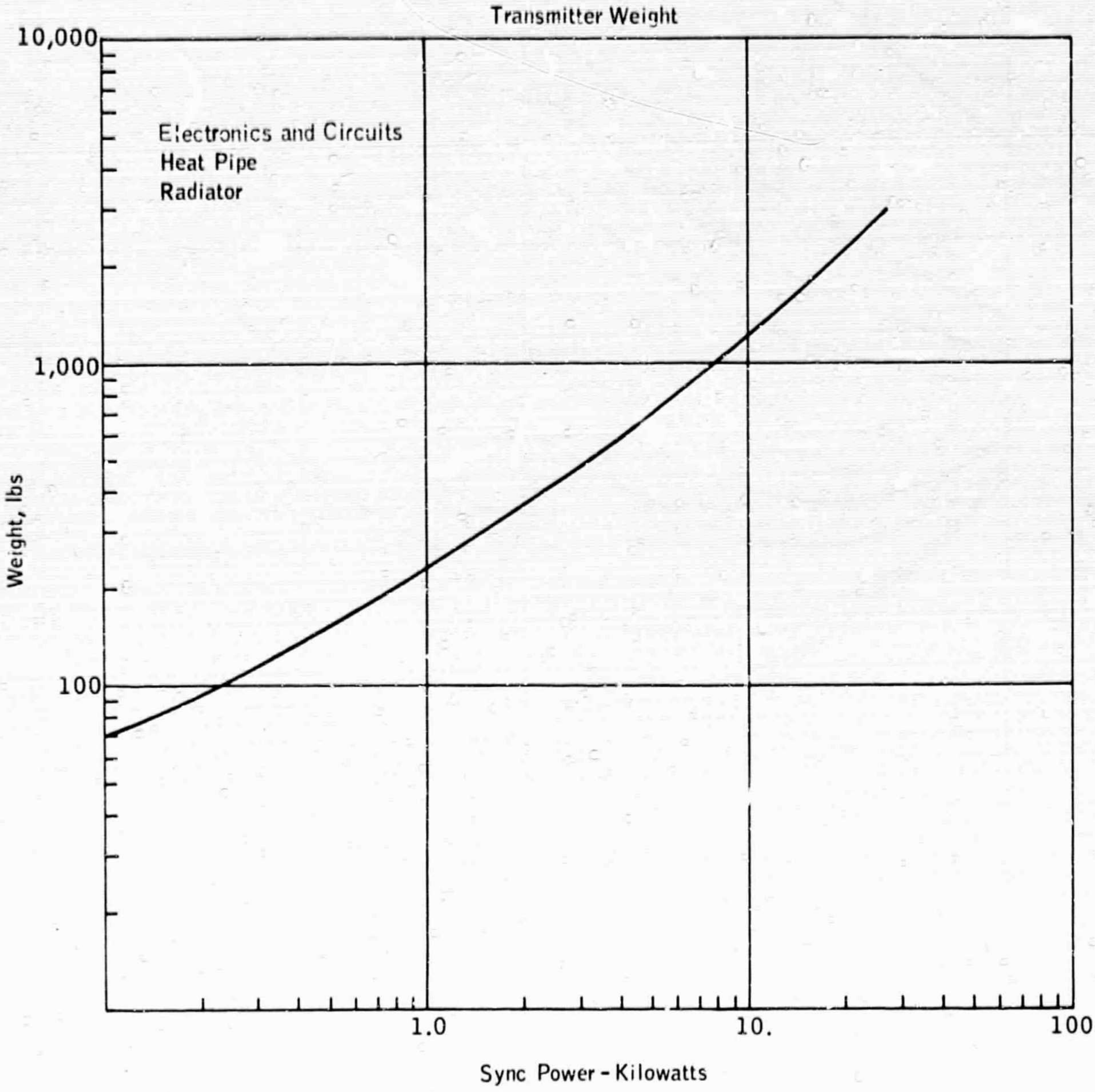


FIGURE 10.4.4. Transmitter weight.

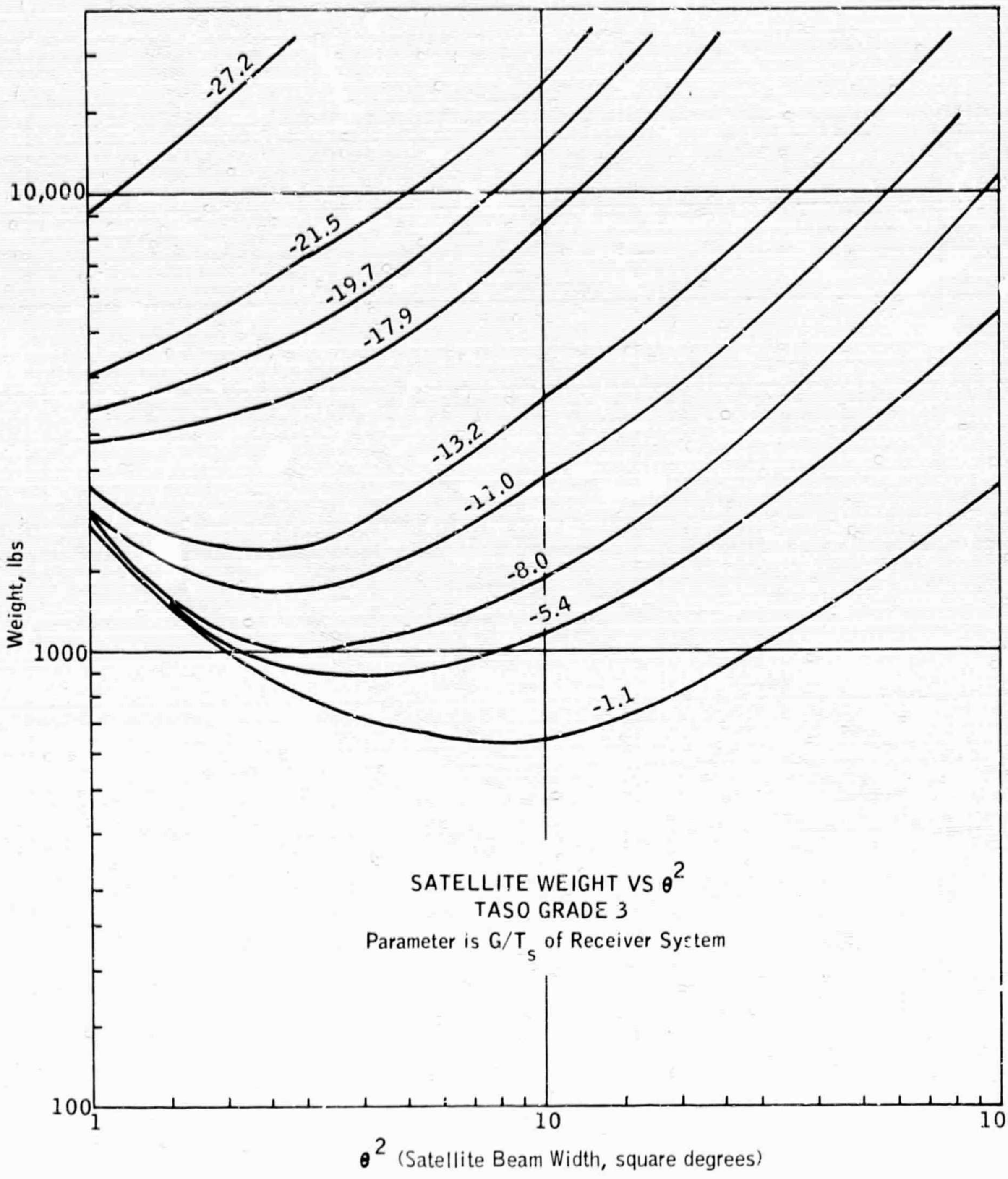


FIGURE 10.4.5. Satellite weight versus θ^2, TASO Grade 3 (parameter is G/T_s of receiver system).

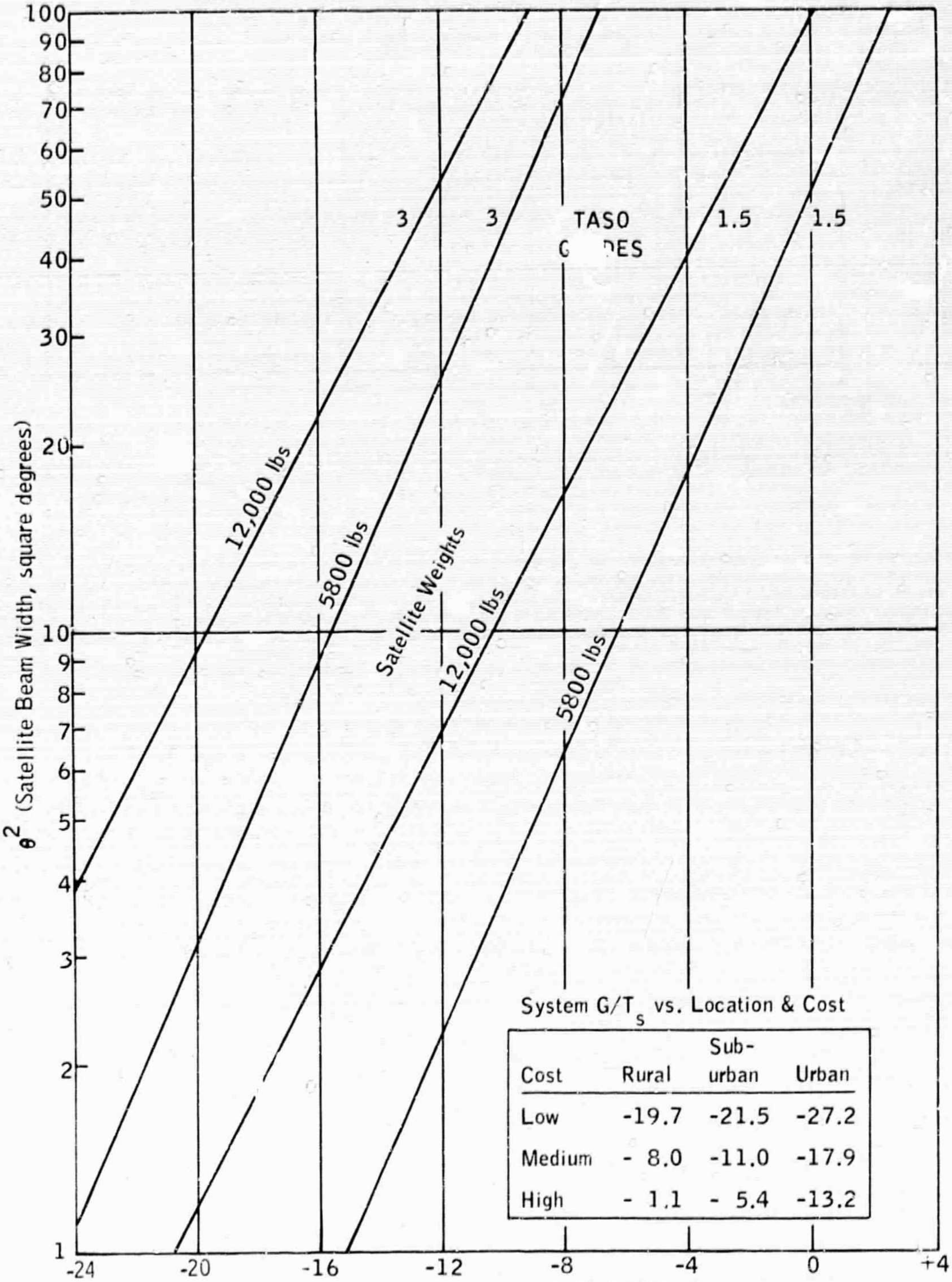


FIGURE 10.4.6. System G/T_s versus coverage θ^2.

TABLE 10.4.15

CLASS C SUMMARY

Frequency (MHz)	Modulation	Ground Receiver Ant. Dia. (ft)	Ground Receiver Beam Width (Degrees)	Picture Quality	BRF (MHz)	ERP (dBW)
800*	VSB	7	> 10	TASO Excel.	6.0	77.3
800	VSB	7	> 10	" " Passable	6.0	68.3
2,500	FM	3	10	CCIR Excel.	37.5	69.8
12,000	FM	2	3	" " Excel.	37.5	71.6

*Prototype system

4.3.1 Prototype System

A prototype system would provide U.S. coverage using three single-channel satellites, each of which illuminates about 1/3 of the country, with a satellite antenna having a diameter of about 30 ft and a beamwidth of 3°. The satellite broadcasts 800-MHz signals that are compatible with UHF receivers in the United States (NTSC standards) with an effective radiated power of 68.3 dBW. This corresponds to 2250 watts of radiating energy which is delivered to the feed of a parabolic antenna that is rigidly mounted to the structure of a 3-axis stabilized spacecraft. The spacecraft — weighing about 5800 lb in orbit — is put into its synchronous equatorial station using the Titan III-M and its transtage providing for all of the maneuvers for thrust vectoring, injection error, and final station attainment. The dc power input to the klystron output stage is 9.5 KW. The solar supply is seen oriented about one axis using a sun sensor and motor drive. Thin-film, polycrystalline, photovoltaic, solar-energy conversion is assumed for the 1975 launch date of this operational satellite. No provision is required for N-S station drift because the largest receiver antenna contemplated has a 10° beam width and would thus accommodate the figure-8 motion of the satellite as seen from the ground. Batteries for housekeeping only are provided for this first-generation system, since the weight penalty for eclipse operation would be excessive, considering the short loss of availability.

The ground receivers are assumed to have a 7-ft parabolic antenna pointed toward the satellite, and to have a 20-dB gain. This antenna is now in production. The antenna mast carries a preamplifier having a noise figure of 5 dB and a gain of 30 dB so that the picture quality (signal-to-noise ratio) is not sensitive to the condition or length of the transmission line or the quality of the monochrome or color receiver front end. The cost of this antenna, preamplifier, and transmission-line equipment is estimated at $124.00. This receiver provides a TASO Grade 2 picture which is midway in the region characterized as "fine" by 50 percent of the viewers in tests reported by the Television Allocations Study Organization (TASO) in 1959. The signal-to-noise ratio (sync tip/rms measured in 6-MHz bandwidth at the receiver input) is 34.5 dB. This is a high-quality picture and less than 30 percent of the viewers would rate this S/N ratio lower than "fine."

The quality of picture signal would depend upon the location. It would improve by 5 dB in a rural location and would degrade by 8 dB in a noisy (mostly automotive) urban location. In the former instance, the picture would be almost free of perceptible noise and in the latter the picture would be "passable" to 70 percent of the viewers. Obviously the system will accommodate receiver add-on costs of various amounts depending upon quality of picture required and location, the better and costlier installation providing the better pictures in any given location.

4.3.2 Launch Vehicles

In considering launch vehicles appropriate to an operational launch in 1975, the Saturn V was passed over because of the high cost (estimated to be as much as $200 million). (Compare with the total capitalization of Communication Satellite Corporation, also $200 million.) An operational system is assumed to be one having a commercial basis, or having cost effectiveness. Sights were therefore lowered to members of the Titan III and the Saturn IB family.

The Titan IIIC with its five-segment solids is capable of a 2000 lb payload in synchronous equatorial orbit and 4000 lb using a kick stage. A decision was made to consider only the transtage mode, in the interest of a greatly simplified injection procedure. The Titan III is programmed to grow to 5800 lb capability, by incorporating developments from other Air Force programs.

TABLE 10.4.16

GROWTH OF TITAN IIIC BASED UPON INCORPORATING DEVELOPMENTS OF OTHER AIR FORCE PROGRAMS

Vehicle	Payload (Synch-Equat) (lb)	Cost/lb
T-IIIC	2,000	$10,000
T-IIIC/15:1 + IMU	2,450	$ 7,000
T-IIIC/8533[2]	3,450	$ 4,500
T-IIIM/Transtage[3]	5,800	$ 3,000

[1] Ablative skirt on Stage I engine and 15: 1 expansion ratio.

[2] Improved Bell engine in transtage

[3] MOL modification for ETR launch (7 segment)

The Saturn IB/Centaur remains an attractive vehicle with a payload capability of 9500 lb for the TV broadcast mission. However, this launch vehicle is not programmed at this time.

4.4 Class VC (Voice-Only Direct Broadcasting) System

Voice broadcasting can be accomplished by amplitude or frequency modulation of the carrier. Considerations of spectrum utilization and cost of building stable receivers usually restrict use of AM to frequencies below 30 MHz, and FM to higher frequencies. The international table of allocations follows this pattern.

Recently completed NASA studies have shown that AM on the shortwave bands is technically feasible, but difficult and expensive. In view of this, AM broadcasting was not considered. The same NASA studies have shown that FM transmission is relatively simple.

Frequencies of 100 and 800 MHz were investigated. United States FM standards were assumed. Receivers were assumed to be of average quality. Site noise, building and line loss were considered. Ionospheric loss was assumed to be negligible. Antennas costing $0 (built-in), $10 and $20 were considered. The specific assumptions for the 100-MHz band are shown in the following two tables.

Location	Site Noise*, above KTB	Building Absorption
Urban	+35 dB	12 dB
Suburban	+15 dB	6 dB
Rural	0 dB	9 dB

*measured using an antenna with horizontal directivity

Antenna Cost	Forward Gain	Noise Discrimination
$ 0 (linearly polarized)	-3 dB	0 dB
$10 (circularly polarized)	+4 dB	2 dB
$20 (circularly polarized)	+8 dB	4 dB

The following values were used:

• FM-improvement factor	26 dB
• Receiver-noise figure	6 dB
• Pre-emphasis gain	7 dB
• Space loss (22, 300 mi)	163 dB
• Beam-edge loss	3 dB
• Range correction	1.8 dB

See Appendix B for link calculations.

Under these assumptions, it was found that a spacecraft producing signal of 40-dBW ERP could give fully satisfactory rural and suburban coverage with outdoor antennas. This value also gives fully satisfactory rural and suburban coverage with indoor antennas. An ERP of 75 dBW is needed for urban coverage with indoor antennas. All of these values are for 50-dB S/N, a high-quality service, and could be reduced by 10 dB for an acceptable S/N of 40dB. Figure 10.4.7 shows the effect on coverage and power of changing S/N.

Estimates made of the satellite weight for several of these cases are summarized by the curves of Figure 10.4.8. Minimum satellite weight was found to occur at a coverage angle (antenna beamwidth) around 15°, ample for all of Africa, and with some pattern shaping, for all of North and South America. Weight of a 40-dB S/N ratio, two-channel satellite would be about 750 lb. A single-channel, 50-dB S/N ratio satellite would weight about 2000 lb, well within the capability of existing boosters.

A single such satellite for the Americas would have a potential audience of about 100,000,000 receivers in the early 1970's. For Africa, the audience would be about 4,000,000.

At the 50-dB S/N ratio signal, the satellite would be satisfactory for all of the voice-broadcast services discussed previously. At the 40-dB S/N ratio, it would be marginal for instructional use.

The analysis indicated that the 100-MHz band is somewhat preferable to the 800-MHz band. The basic reason for this is the greater building absorption at 800 MHz, not compensated by its lower urban noise. If outdoor antennas are used, a satisfactory service can be established for about the same satellite powers as at 100-MHz.

Launching of optimally designed voice-broadcast satellites does not appear to be a problem. The 40-dB S/N ratio, two-channel system to cover Africa could be launched with a SLV3A/Agena. The 50-dB S/N ratio satellite would require a Titan IIIC. Some up-rating of these vehicles would be required if the coverage area were greatly reduced. For example, to restrict coverage to the United States would require a Titan IIIX-Agena.

The cost of making one channel of FM radio service available by conventional terrestrial techniques appears to average about 30¢ per receiver per year in the United States (excluding the costs of the receivers). This figure is derived by dividing the average station operating cost by the average potential audience.

Annual costs of two satellite systems are calculated in Table 10.4.17 (details in Appendix D).

The estimates in the following table emphasize the importance of using the satellite to cover a large number of receivers. When this is possible, the satellite appears to be very advantageous in cost as compared to terrestrial systems (at 30¢ per receiver per year). It appears, based on the following calculations, that an audience of 50,000,000 would justify a satellite system rather than a terrestrial one. If interconnection costs are lower than in the United States, then even smaller audiences would prefer satellite service.

It should also be noted that a simple cost comparison of alternatives is not necessarily the best criterion for selection. For Africa, as an example, multiple channel availability, or capacity of the system to grow, or accessibility to the remotest areas are important considerations. The 30¢ cost of terrestrial service in the United States, where many diverse means of distributing information are available, should not be construed as the value of the

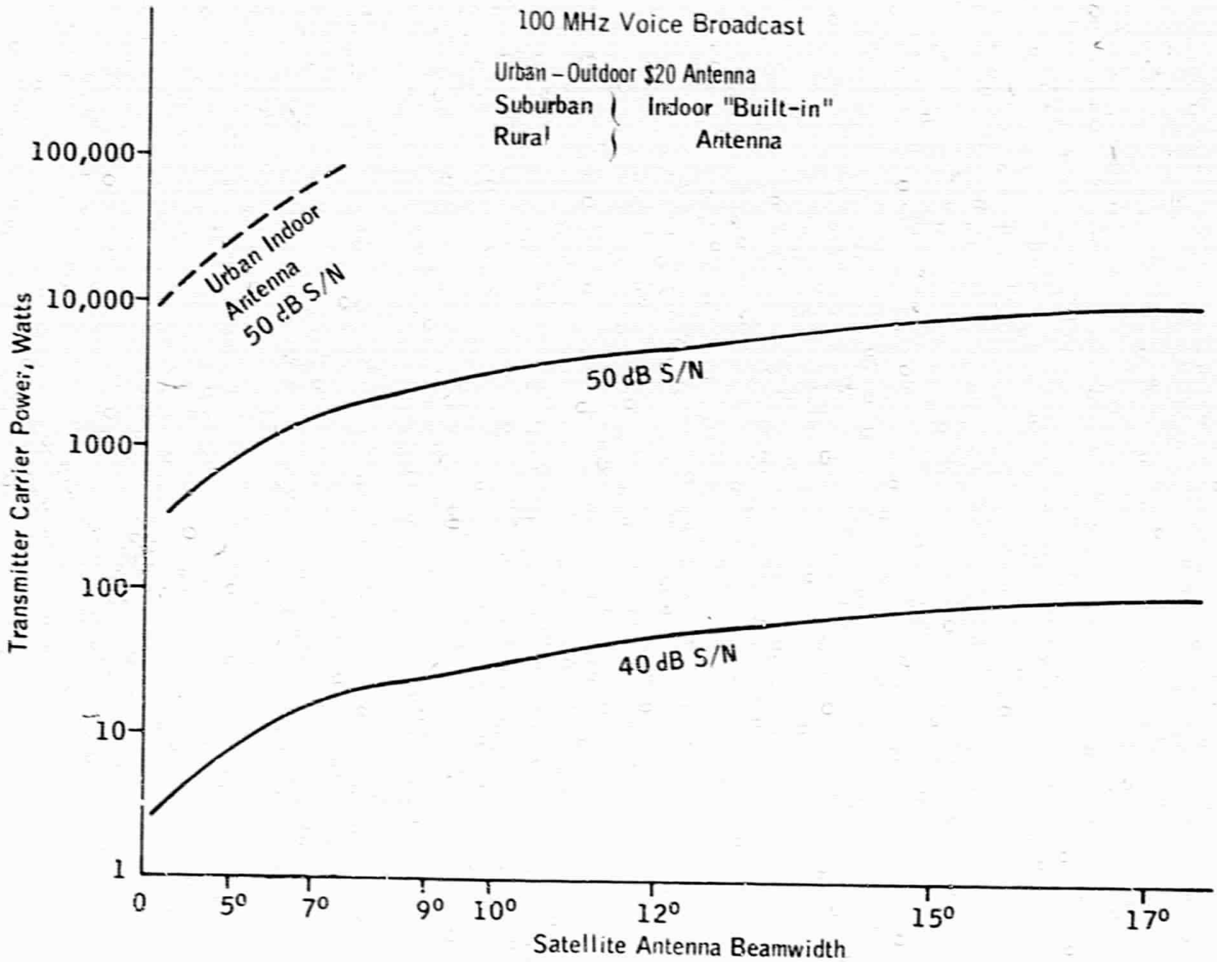


FIGURE 10. 4. 7. Transmitter carrier power versus satellite antenna beamwidth.

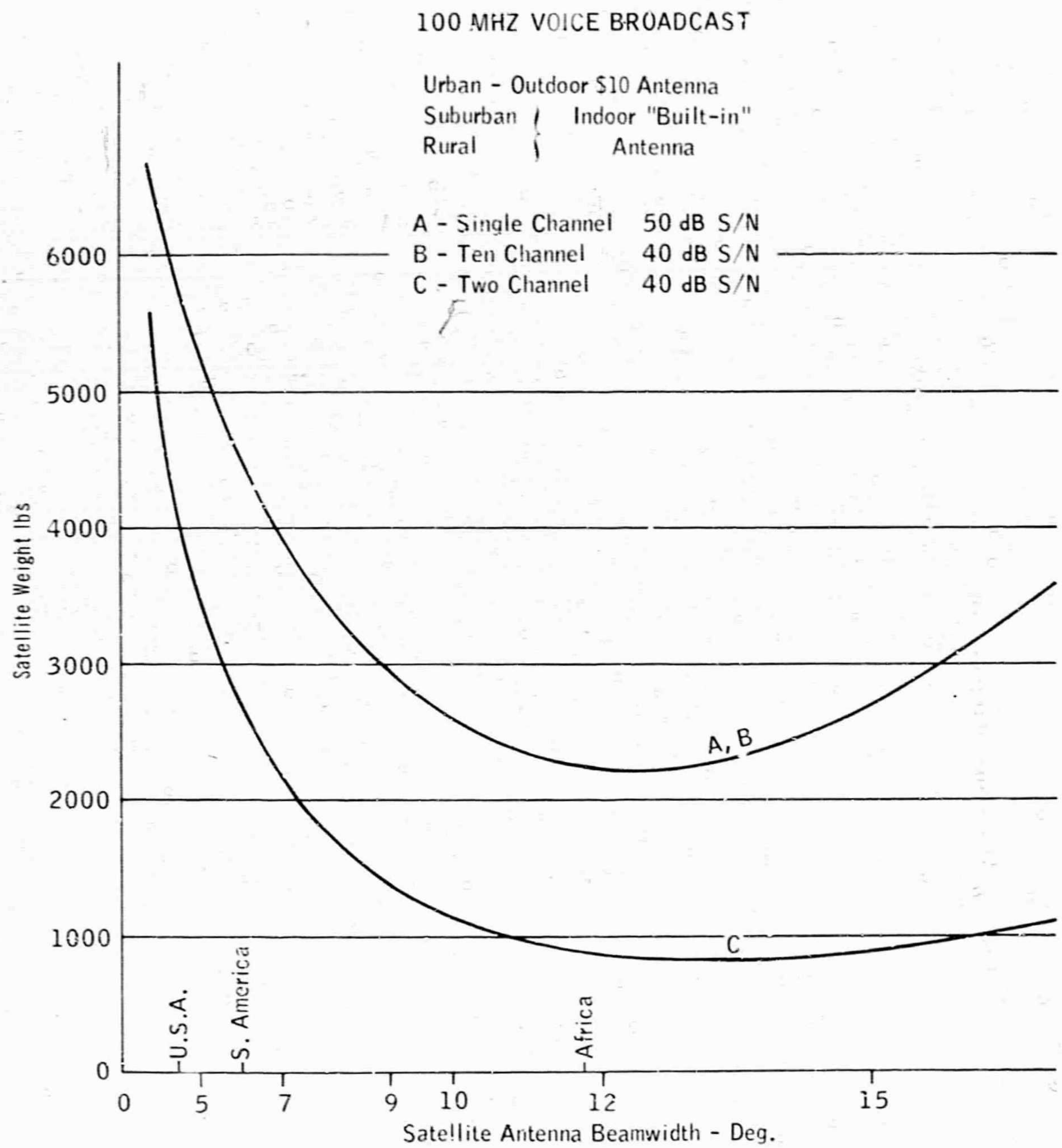


FIGURE 10.4.8. Satellite weight versus coverage, Class VC.

service in regions where this flexibility and redundancy are not available. The value of service should be much higher in such regions.

TABLE 10.4.17

ANNUAL COSTS OF TWO SATELLITE SYSTEMS

Area	Number of Receivers	Annual Costs Without Receivers: 2 Channels (40 dB S/N)	Annual Costs Without Receivers: 1 Channel (50 dB S/N)	Annual Costs With Receivers: 2 Channels (40 dB S/N)	Annual Costs With Receivers: 1 Channel (50 dB S/N)
Africa	4,000,000	$1.98	$3.85	$10.75	$12.70
Americas	100,000,000	$ .08	$ .16	$ 8.85	$ 8.90

4.5 Voice Broadcast (Addendum) Rationale For Signal Selection

Detail calculations (See Appendix B) were made for 100 and 800 MHz, and for the various combinations of noise and antenna. These gave:

	Required Satellite ERP, 50 dB S/N: Urban	Suburban	Rural
100 MHz			
$0 Antenna Indoor	75 dBW	62 dBW	44 dBW
$10 Antenna Outdoor	67 dBW	47 dBW	42 dBW
$20 Antenna Outdoor	61 dBW	71 dBW	38 dBW
800 MHz			
$0 Antenna Indoor	92 dBW	86 dBW	76 dBW
$10 Antenna Outdoor	62 dBW	60 dBW	60 dBW
$20 Antenna Outdoor	54 dBW	52 dBW	52 dBW

In considering these, the requirement for +75 dBW of satellite power for urban indoor antennas appeared excessive, and the +38 and +42 dBW for rural outdoor antennas appeared marginal. A +60 dBW on 100 MHz appears to be a reasonable compromise, considering completeness of coverage and cost of installation. Choice of this frequency has the advantage that many receivers covering this frequency are now in use. The outdoor antenna in urban environments is a deficiency, but it is partly compensated by the fact that existing FM is basically an urban service, and therefore there is less need for urban coverage by satellite. Considering these factors, 60 dBW for 50-dB S/N (50 dBW for 40-dB S/N) appear reasonable compromise values.

Voice broadcast by FM is simpler and less demanding than TV broadcast. Thus, it appears technically reasonable to expect that it will be the first direct-broadcast service developed. In view of this, only satellite technology which has been either flight tested or is now in advanced development, ready for flight test, was selected.

For the solar arrays, use of conventional cells mounted on flexible substrate (roll-up design) was assumed. The antenna was assumed to be rib-stabilized open metal mesh. Attitude control was assumed to be sun-oriented for the panels and earth-horizon-scanning for the antenna. Techniques were assumed to be similar to those of Nimbus, which has demonstrated in excess of 10,000 hours of in-orbit operating life.

TABLE 10.4.18

CLASS VC SUMMARY

Frequency (MHz)	Modulation	Env. Noise (dB > KtB)	Receiver Location	Signal/Noise	Brf (MHz)	ERP (dBW)
108*	FM	35	Urban	50	180	67
108	FM	15	Suburban	50	180	47
108	FM	0	Rural	50	180	42
800	FM	15	Urban	50	180	62
800	FM	-5	Suburban	50	180	60
800	FM	-20	Rural	50	180	60

*Prototype system

5.0 COST ANALYSIS

5.1 Introduction

A combination of political, social, technical-and economic factors will determine the advisability of providing broadcasting service via satellites. The factors are all interrelated, their relationship being beyond the scope of this study. In the economic area alone, the problems are difficult and require many simplifying assumptions.

The purpose of this analysis is to derive and compare the relative costs of the several transmission alternatives examined. (The detailed calculations and assumptions are in Appendix D, "Economic Details.") In several instances the cost estimates are at best informed guesses. This is tolerable when the estimate is consistent for all programs (i.e., cost of TV receivers) or relatively insignificant to the over-all calculation (i.e., R&D). Fortunately, there are large differences in the costs of alternative programs, so that wide discrepancies in most cost elements will not change the relative standings.

Perhaps the most significant conclusion to be drawn from this analysis is that satellites appear to be the most cost-effective for this particular service in the hypothetical area. Obviously, it cannot be reasoned that this will hold true in all actual locations and for all services. One can conclude, however, that in some, perhaps many areas, satellites will be very cost-effective in providing broadcast services.

5.2 Idealized Model

In order to simplify the economic and technical considerations, while providing a realistic environment to illustrate the relative cost standings of technically competitive means of delivering a TV signal, a somewhat idealized model nation is necessary. Most characteristics of this "ideal" location are averages of the existing developing nations.

The model nation has rudimentary communications, no TV development, and a need to disseminate information rapidly to the population of outlying areas. There are no problems of class, language, or political sub-boundaries which affect either the technical solution or the economic variables.

The sole criterion is the cost-effectiveness of introducing television service as quickly and broadly as possible. No credit is given to alternatives which facilitated other objectives (i.e., providing a backbone telecommunications network). Programming costs, to produce the information to be distributed, are not included, since they are assumed to be the same for all systems considered. The period considered is the 10 years from 1972 to 1981.

The geographical characteristics of the model nation are illustrated in Figure 10.5.1 and are summarized below:

Size	-	1,000,000 square miles (1,000 miles square)
Population	-	70,000,000 people (70 per square mile)
Cities	-	1 of 5,000,000 people
	-	8 of 1,000,000 people (separated by 500 miles)
	-	16 of 100,000 people (separated by 250 miles)
	-	500 of 10,000 people (separated by 50 miles)
	-	20,000 of 2,500 population (separated by 7 miles)
Environment	-	airports are primitive to second-class, located at 16 largest cities
	-	roads vary between gravel and blacktop (average speed equals 20 mph)
	-	trained personnel are not available
	-	maintenance facilities are sparse
	-	terrestrial communications are sparse except in major cities

5.3 Alternative Systems

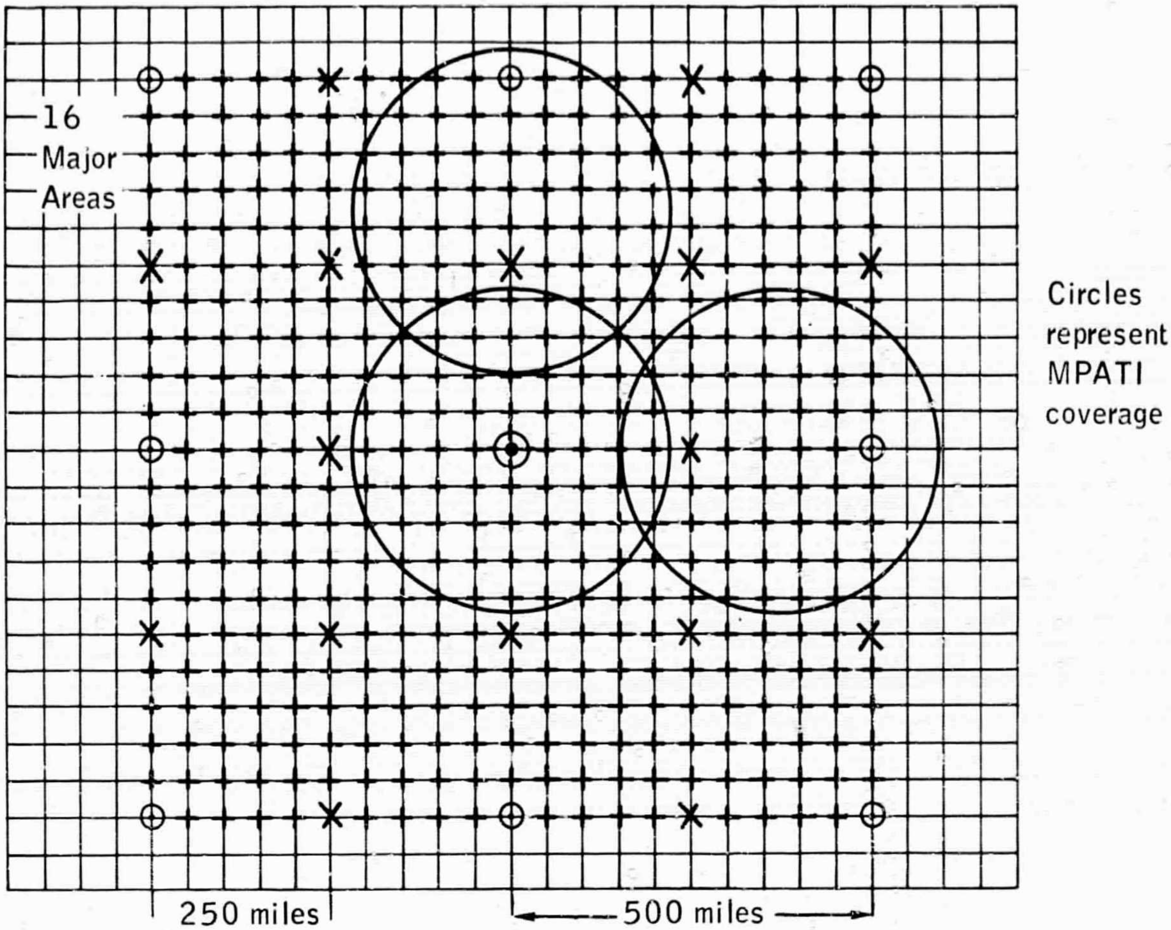
Acceptable program dissemination can occur in either of two ways. In one method, programs are viewed by a group of viewers who come to the 20,000 dispersed locations. The second method delivers programs to 1,000,000 locations (sets). Groups of people or even a single family will have access to the sets. The number of people per set differs, as well as the distance traveled by the viewers. Needless to say, the cost of the two methods will vary.

Eight different systems are designed and costed. Three of these utilize satellites. All systems provide identical service (as much as possible) so that the costs can be comparable. The most rudimentary means of delivering TV imaging are considered, progressing from oxcart through all auto and train distribution. The requirement for rapid distribution eliminates these methods from further evaluation. Television tape was selected as the deliverable product after preliminary analysis of imaging methods eliminated film and video recorders. Detailed costs for the systems are in Appendix D.

5.3.1 Non-Satellite Systems

5.3.1.1 Automotive/Aircraft Distribution

All TV tapes are produced in one city. C-140 type aircraft pick up and deliver these tapes to 16 of the larger cities. Smaller aircraft of the Cessna-Beechcraft-Piper variety distribute the tapes from these 16 locations



Legend		Population
-ф-	City	5,000,000
○	Cities	1,000,000
×	Cities	100,000
+	Cities	10,000 (not indicated)

Typical "Airborne" coverage areas shown by larger circles

Smaller cities and villages not shown - see text.

FIGURE 10.5.1 Geographical characteristics of a model nation.

to 60 drop and pickup points throughout the nation. From these locations automobiles take over and distribute the tapes to 20,000 towns and villages by existing roads. The entire system cycles each day--tapes being returned in the same manner as delivered. In this alternative system, one video display in each of the 20,000 areas provides 12 hours of programming. (See Table 10. D. 1).

5. 3. 1. 2 Aircraft Distribution

Tapes are produced and circulated through the 60 drop and pickup points in the same manner as in the automotive/aircraft distribution system (5. 3. 1. 1), with the variation that the smaller aircraft deliver the tapes to the 20,000 towns and villages. Again, one video display in each area provides 12 hours of programming. (See Table 10. D. 2).

5. 3. 1. 3 Airborne Broadcast

Tapes are produced as before, but no distribution is required. Aircraft stationed at a centrally located airport fly to seven "stations" where they broadcast 12 hours a day by UHF (VHF) to the receiving sets. The Midwest Program of Airborne Television Instruction (MPATI) provides the prototype for this method of service. (See Table 10. D. 3).

5. 3. 1. 4 Terrestrial Telecommunications Distribution (Microwave and coaxial plus 25 broadcast stations)

Terrestrial microwave systems interconnect all cities of 10,000 or more population. Program material is broadcasted from the 25 largest cities by conventional UHF (VHF) broadcast stations to all receiving sets within a 50-mile radius. Distribution to the remaining 20,500 locations is provided by coaxial cable. (See Table 10. D. 4).

5. 3. 1. 5 Terrestrial Telecommunications Distribution (Microwave plus 200 broadcast stations)

This system is essentially the same as the above (5. 3. 1. 4) except that 200 of the cities above 10,000 population rebroadcast by conventional UHF (VHF) broadcast stations. Because of overlapping broadcast areas and gaps in coverage, the number of broadcasters was increased from an absolute minimum of 125 to 200. (See Table 10. D. 5).

5. 3. 2 <u>Satellite Systems</u>

5. 3. 2. 1 Class A (Distribution Satellite)

Program material is relayed from a central transmitter location through a synchronous equatorial satellite to 200 receiving locations. Programs are retransmitted via conventional broadcast (UHF or VHF) to all receiving sets within a 50-mile radius of each location. (See Table 10. D. 6).

5.3.2.2 Class B (Community Broadcast Satellite)

Program material is relayed from a central transmitter location through a synchronous equatorial satellite to 70,599 receiving locations. Twenty-five of these rebroadcast to the larger cities through conventional UHF (VHF) broadcasting stations each having a radius of 50 miles. Five hundred seventy four locations rebroadcast with stations having 20-mile radius. Some 70,000 receiving stations serve individual receivers. (See Table 10.D.7).

5.3.2.3 Class C (Direct-Broadcast Satellite)

Program material is relayed from a central transmitter location through a synchronous equatorial satellite to 1,000,000 receiving sets throughout the nation. (See Table 10.D.8).

5.4 Comparative Costs

When comparing the summary costs of each alternative program presented in Table 10.5.1, several observations become apparent:

1. Distribution via satellite is significantly cheaper than via the terrestrial distribution alternatives.
2. Airborne distribution deserves further attention. While operational problems may be significant, the costs appear lower than for direct broadcasting via satellite.
3. Terrestrial distribution systems which require large usage of tape will be very expensive compared to those not requiring the use of tape.
4. The Class A satellite system is obviously not optimized and is not a reasonable solution. The primary reason for this stems from a technical assumption that 20-foot antennas and cooled preamplifiers operating at 12 GHz are optimum (or at best reasonable) for the earth station.
5. The lowest-cost alternative is a hybrid satellite distribution system utilizing conventional TV broadcasting facilities to reach the high-density users and going directly to the user in regions of low population densities (Class B system).

The cost data indicate that the Class A satellite system should be redesigned. The use of expensive ground receiving stations does not result in adequate (compensating) economies in the space segment of the system. It appears that with appropriate redesign, the three satellite-system alternatives could be competitive; thus it would be inappropriate to select a clear preference based on this analysis. In all probability, the optimum-designed satellite system dedicated to TV service would be similar to the Class B design. Such a system would probably require relatively inexpensive antennas and preamplifiers for those locations which need CCIR-relay quality signals for rebroadcast to the consumer. Receiving-equipment performance and cost could be reduced for locations which would not rebroadcast via conventional means.

TABLE 10. 5. 1

ECONOMIC COMPARISON OF PROGRAM ALTERNATIVES

Program	Number of Users	Annual Cost of Displays	Annual Transmission Costs	Total Program Annual Cost [1]
Aircraft distribution of tape	20, 000	$618, 700, 000 [2]	$ 54, 300, 000	$673, 000, 000
Aircraft and Auto distribution of tape	20, 000	618, 700, 000 [2]	37, 300, 000	656, 000, 000
Terrestrial plus 25 broadcasters	1, 000, 000	71, 700, 000	189, 300, 000	261, 000, 000
Terrestrial plus 200 broadcasters	1, 000, 000	71, 700, 000	76, 200, 000	147, 900, 000
Airborne Broadcasting	1, 000, 000	71, 700, 000	25, 300, 000	97, 000, 000
Satellite with 200 receivers (Class A)	1, 000, 000	71, 700, 000	60, 300, 000	132, 000, 000
Satellite witn 70, 599 receivers (Class B)	1, 000, 000	71, 700, 000	17, 300, 000	89, 000, 000
Satellite with 1, 000, 000 receivers (Class C)	1, 000, 000	71, 700, 000	51, 300, 000	123, 000, 000

[1] Annual costs are a simpie arithmetic sum of depreciation, amortization plus maintenance and operation charges. The cost of capital is assumed to be zero and costs are expressed in 1967 dollars.

[2] Includes $613, 000, 000 annually of television tape.

Each of the various systems has been considered solely on its ability to deliver educational material to the population. Electronic communications systems can be more versatile, however, and an educational-TV satellite might also be used to supply telephone and telegraph service. A careful analysis that considered the multiple communications needs of an area would probably enhance the economic attractiveness of satellites. It is self-evident that they are more versatile than the physical distribution of TV tapes, for instance.

5.5 Generalized Comparison of Satellite Systems and Non-Satellite Systems

The costs shown in this summary are for systems which serve an entire area and population with 1,000,000 receivers (except for the auto and auto-airplane systems which serve only 20,000 receivers).

It is reasonable to assume that a developing area might want to start more slowly and build its system gradually so as eventually to serve the entire population. Should this be the case, it is then reasonable to speculate as to how the costs of the various alternatives might vary as they are extended to larger and larger parts of the region.

Figure 10.5.2 is designed to portray the costs of the most cost-effective systems. The vertical axis denotes annual transmission costs (omitting the cost of the TV receivers). The horizontal axis shows the number of locations capable of receiving transmissions directly from the satellite. For the model nation assumed in this study, the comparison of costs indicates the following preferences:

Coverage desired	Preferred method
less than 7 largest cities	microwave transmission
between 7 and 1000 of largest locations	Class A satellites
between 1000 and 460,000 locations	Class B satellites
more than 460,000 locations	Class C satellites

The latter preference is calculated by determining the number of satellite receiving stations necessary to make the Class B and C systems have equal costs.

These specific preferences result from the assumptions of this specific model. The results appear to be generally applicable, however. It appears that when a few relatively close locations are to be interconnected, terrestrial distribution is preferred (most cost-effective). As the number of locations, or the mileage required to interconnect them, increases, satellites become preferable. A satellite system with the general characteristics of the Class A system is preferred for some intermediate number of locations. After some point, it appears preferable to reduce the ground receiving-station costs as much as possible. This is done by using as large a satellite as is available (Class B or C). The exact parameters of the satellite system can be specified only after an examination of the country involved. One can imagine a country of severe terrain, separating only a few widely scattered cities, where installation and maintenance of terrestrial interconnections would be impractical. Under these conditions a Class A satellite system could be preferred (most cost-effective) from the beginning. As the number of locations to be interconnected increases, the Class B satillite becomes preferred. Under conditions of many small, widely scattered locations, the Class C direct-broadcast satellite could show promise.

5.6 Effect of Population Density and Satellite System Design

In any satellite distribution system the designer must decide, for each community, whether to build a rebroadcast station serving unmodified TV receivers, or to provide a special front end amplifier for each receiving set. If it is assumed that a centrally located rebroadcast station costs $375,000 initially and has an annual cost of $112,000 (approximately 0.3 of investment), then Figure 10.5.3 illustrates the number of receiving sets necessary in that area to justify the building of such a rebroadcasting station. The horizontal axis represents the investment dollars required to receive an adequate signal from the satellite. Thus, it is possible to determine for each population center the conditions necessary to justify the construction of a $375,000 rebroadcast station.

5.7 FM Voice Broadcasting

The technical characteristics and summary costs of this service have been discussed in detail in section 4. Program costs are calculated in Appendix D. (See Tables 10.D.9, 10.D.10).

It appears (to the Panel) that the low cost of wide-area voice broadcasting (FM) warrants consideration of the services it can provide.

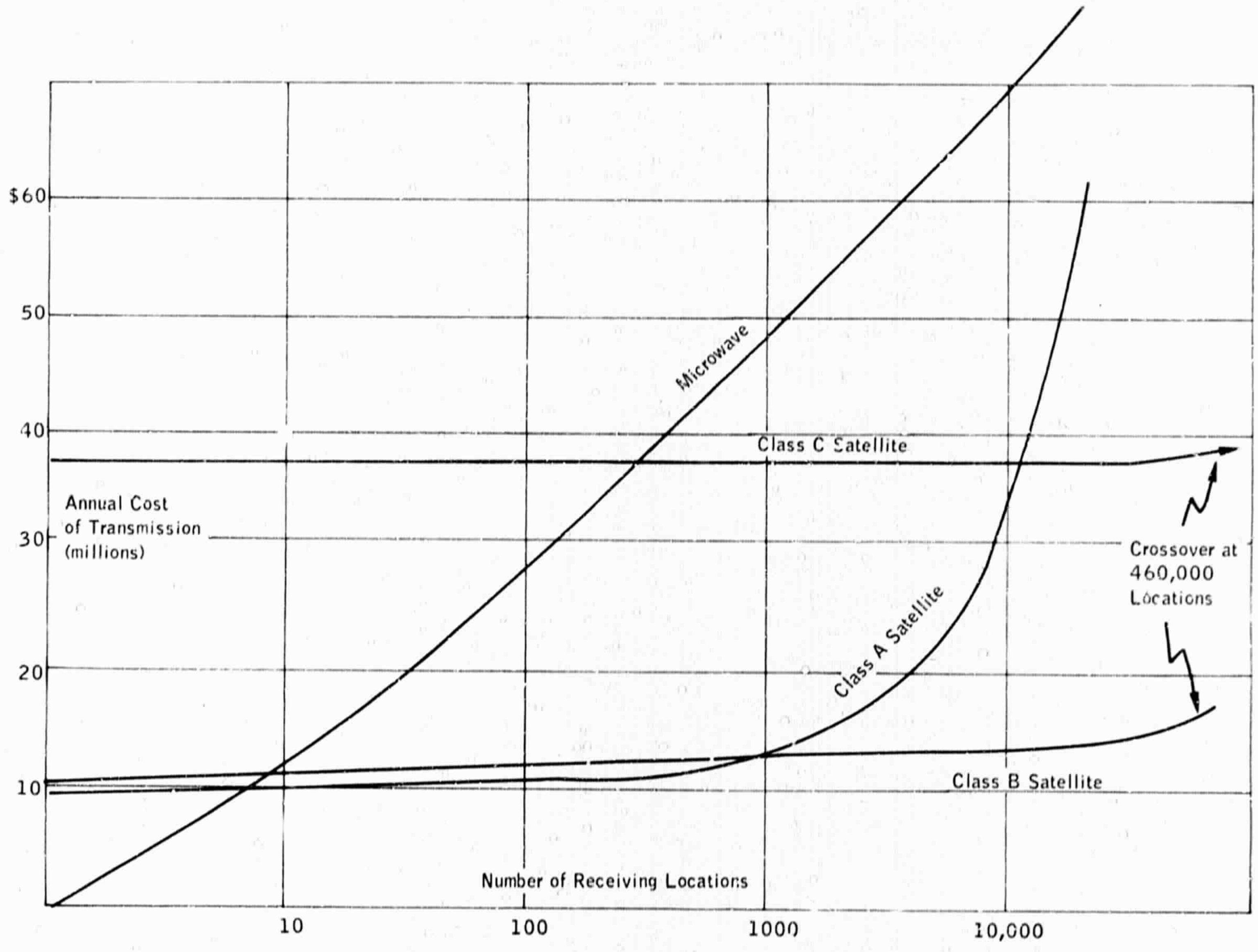


Figure 10.5.2 Comparison of Satellite and Microwave Distribution Systems Costs (Includes Broadcast Stations)

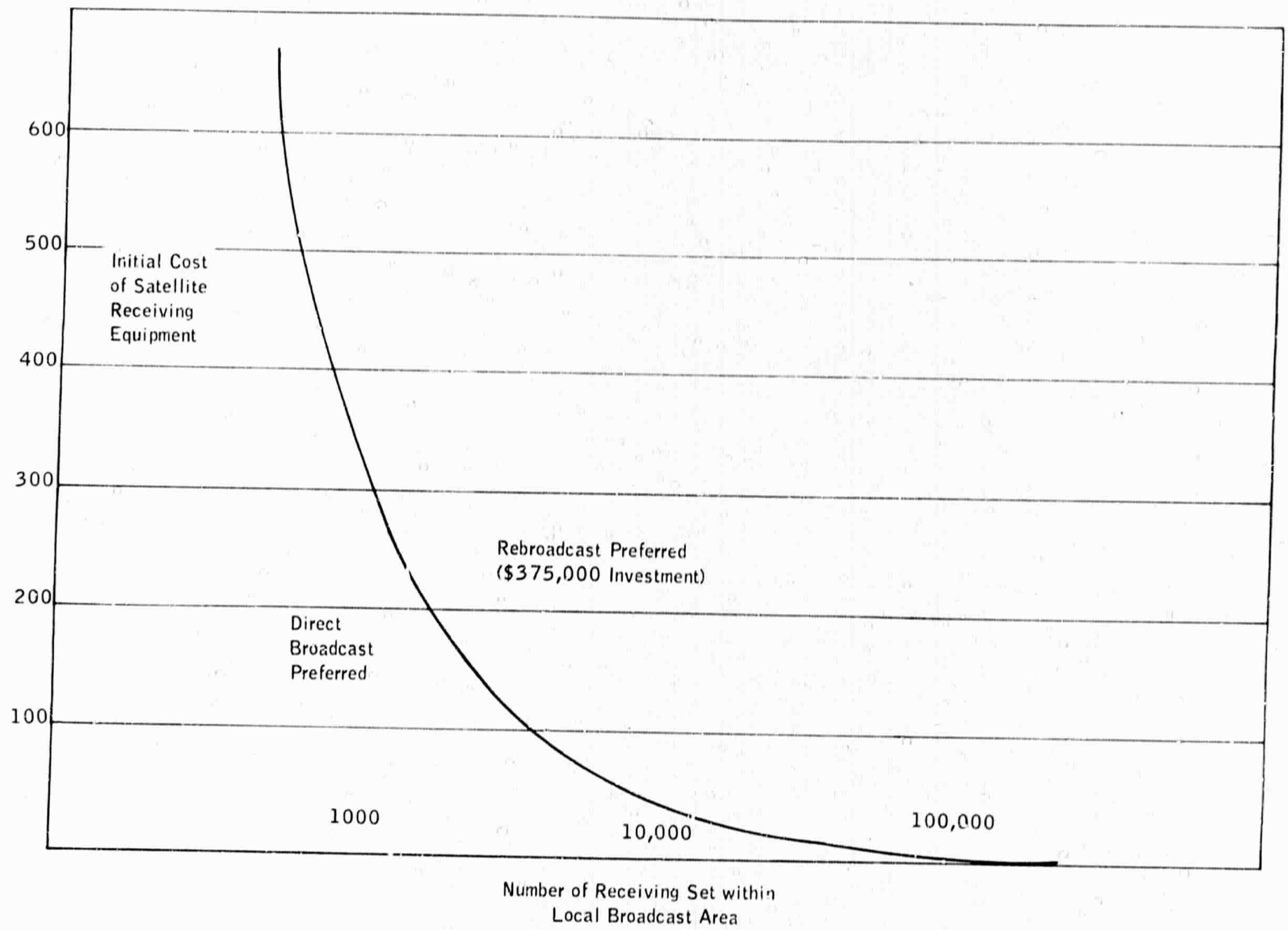


Figure 10. 5. 3 Effect of Localized Receiving-Set Density on Satellite-System Design

6.0 TECHNOLOGICAL RECOMMENDATIONS

6.1 Vehicles

The launch vehicles in the national space program have been developed for particular purposes, and as would be expected, the vehicle stages are in some measure optimized to accomplish the design missions. For example, the Atlas-Centaur has been developed for the lunar mission, with both single-burn capacity for direct flight and second-burn capability for lunar transfer from an orbital coast.

The Saturn IB has design capability for injection and heavy payloads in low satellite orbits. In the same way, the Titan IIIC was developed for low-altitude orbital injection, and is not efficiently employed in the synchronous orbit. Since this is the orbit of interest to broadcast satellites, an updating of the staging of our current launch-vehicle family is required to provide increased synchronous-orbit capability and a more reasonable price.

Launches of the Delta-class vehicle used for Syncom cost over $10, 000 per pound of payload in orbit. By improving the staging of existing vehicles, it is expected that a range of payload weights in synchronous orbit of 2000 lb to 12, 000 lb can be made available at a cost per pound of from 1/3 to 1/4 of the current values.

The development of new vehicles or of new stages such as the 260-inch-diameter solid first stage cannot be justified on the needs of the broadcast-satellite program. When this new stage can be justified by the needs of the total space program, further reductions in cost may be expected.

Specific recommendations for the launch-vehicle program are as follows:

1. Because the Titan IIIC with transtage will deliver a stabilized payload to orbit with no requirement for spin-up at perigee, it is an attractive vehicle wherever its payload capability is sufficient. The current tested model will put 2000 lb in orbit. Transtage and core changes under development will increase this to 3450 lb, and the seven-segment solid strap-on under development will make 5800 lb possible. (This is Titan IIIM and Agena*.) Adapting the Agena* to the present Titan IIIC will provide 4300 lb in orbit. This easily accomplished, low-cost change will quickly fill a gap in our payload-handling capacity. The complete program will provide a flexible family of maneuverable vehicles.

2. The Atlas-Agena class of boosters can deliver up to 850 lb to synchronous, equatorial orbit without spin-up. Uprating these to work with the Agena* stage (N_2O_4 + Aerozine 50 as propellants) will increase the deliverable payload to 1400 lb. This cost-effective action is strongly recommended.

3. Adapt the Centaur stage to the Saturn IB vehicle to provide a vehicle capability of 9500 lb in synchronous equatorial orbit.

4. Modify the Atlas SLV3C Centaur to the Atlas SLV3X Centaur to get a synchronous equatorial payload of 2700 lb. This may provide a cheaper vehicle than the Titan IIIC in this payload region.

6.2 Space Power

Basic to the continued application of space for man's benefit is the development of space power systems of larger size, longer life, and of lower specific weight than those now available. Direct conversion of solar energy to electric power by means of photocells will continue for at least the next ten years as the principal primary power source. Silicon-cell solar systems of 50-kW capacity are now under study.

The possibility for further reducing the weight and the cost of solar-cell systems and providing greater flexibility in stowing during launch has been introduced with the "thin-film solar cell" now under active research and development. Thin-film cells have been fabricated from gallium arsenide, cadmium telluride, and cadmium sulphide, but the development of only the cadmium-sulphide cells has progressed beyond the laboratory stage. Cadmium-sulfide cells of 50 square centimeters (3" by 3") are now being produced with efficiencies of 4 to 5 percent on a pilot production line. Degradation of the cells now occurs in simulated space environment during thermal cycling.

The problem appears to be related to the method of attachment of the current collecting grid, so that material selections and fabrication procedures should provide a solution. Damage by radiation does not appear to be a problem, and for doses corresponding to 10 years in the Van Allen belt there is no measurable degradation due to electrons, and only 5 to 10 percent due to protons.

In order to exploit fully the advantages of the thin-film cells, lightweight structures to handle the large areas must be developed. Preliminary studies of possible structures for deploying, supporting, and retracting thin-film arrays indicate that structure weights of 0.1 lb/square foot of array or less may be practical. If such structural weights are possible, the specific weight of arrays made with present cadmium-sulfide thin-film cells would be 40-50 lb/kW. A 10-kW array would weight about 500 lb and cover about 2200 square feet.

Thin-film cells are amenable to mass-production techniques. The cost of individual cells and arrays of cells might be substantially reduced by producing larger cells and automating the methods for mechanically and electrically connecting cells to form arrays. At present, the 3" x 3", 4-5 percent efficient cells cost $19/cell or $60/watt. When the present grid problems are solved, the cost with the present pilot line should be cut nearly in half. Manual techniques for cell interconnection presently being investigated require less labor than for silicon arrays. Automation of cell interconnection appears to be possible, and would cut the cost of assembling an array to a small fraction of the present cost of several hundred dollars per watt for conventional silicon arrays.

Solar energy in space may also be utilized with a concentrator designed to focus the sun's rays into a high-temperature storage unit or on to a thermionic diode. If the overall efficiency of power systems using concentrators is greater than that of photocells, the area of the concentrator may be less than that of the photocells, and provide a degree of design freedom.

Research on concentrators and thermal storage systems has been initiated at a modest level, and for systems to be used with vehicles of the Saturn class, some demonstration hardware has been produced. Continuation and possible acceleration of this work should be explored so that every possible opportunity for using the "free" solar energy of space may be exploited.

For a long-time power requirement in space (more than 5 years), energy other than from the sun is available only from radioactive isotopes or from nuclear reactors. For hundreds of kilowatts or megawatts, the nuclear-reactor systems currently appear to offer the only practical possibility for space power.

Although it is not obvious from present needs that powers large enough to require a nuclear-reactor energy source will be needed for application satellites, it may be presupposed that the power needs will grow with time, and the prudent course would provide advanced research and development on reactor systems for future needs.

Isotope-energy systems may be competitive in the same power range as solar systems if, for operational reasons, large solar panels that must be oriented continuously to the sun are not desirable or tolerable.

Conversion of the isotope and reactor heat energy to power is possible with static systems such as thermo-electrics and thermionics, and dynamic systems such as the Brayton and Rankin power cycles. Small isotope-thermoelectric systems have already been demonstrated successfully in space flight, and others are under development for flight. Reactor systems have been under development at a modest rate for a number of years (e. g., SNAP-2 and SNAP-8) and continued efforts to create the extremely difficult technology for these systems will be needed for many years ahead.

6.2.1 Battery Power Sources

Full 24-hour communications require that the satellite power source be capable of supplying up to 72 minutes of power while the satellite is eclipsed. The weight of the batteries for this period can exceed the weight of the rest of the power supply. However, since only 160 cycles are required of the battery in a 2-year period, the use of silver-zinc batteries instead of nickel-cadmium batteries may be possible, with further development. This may enable batteries with specific weights of 50 watt-hours/pound instead of 12 to 15 watt-hours/pound, or at least a three-fold reduction in weight.

Specific recommendations are as follows:

1. Accelerate research and development of thin-film solar cells to improve their efficiency and stability and to reduce their weight and cost.
2. Conduct ground and flight investigations on methods for the stowage, deployment, and space support of multi-kilowatt (5-50 kW) thin-film solar-cell arrays. Continue development of silicon solar-cell arrays now in progress.
3. Investigate solar concentrators and solar-energy storage systems for use with Brayton and thermionic power systems.
4. Accelerate development of solar-Brayton power systems to provide 20 to 100 kilowatts.

5. Continue research and development of multi-kilowatt isotope heat sources packaged for radiation protection of spacecraft electronics and for public safety during reentry.

6. Continue development of nuclear-reactor systems for the multi-kilowatt and megawatt power needs of the future.

7. Conduct research and development on "power conditioning" systems for multi-kilowatt power systems, including components such as protective relays, inverters, converters, voltage regulators, transformers and a system development with emphasis on achieving long life, high efficiency, and low weight.

8. Consider a silver-zinc battery program with a goal of 50 watt-hours per pound.

6.3 Spacecraft Antennas

The first and simplest satellites lacked stabilization, and used omnidirectional antennas. SYNCOM, Relay, and IDCS used spin stabilization to hold the satellite axis constant. Hence they used axial, stacked-array antennas with gains of about 8 dB.

Today's state of the art is the electronically despun phased array which generates a true "beam" spinning counter to the satellite spin so that it always points earthward. Gain (for the ATS-I and DATS) is now about 14 dB and the value could be increased. Also soon to be investigated in the ATS and IDCS programs is the mechanically despun antenna with a slightly smaller weight.

In the advanced applications program at transmission frequencies below 1000 MHz, problems ensue because of the large antennas. At millimeter-wave frequencies finer antenna tolerances are required but the antennas are smaller. This provides the possibility for accurate machining or otherwise finishing the antenna surface so that no great mechanical difficulties are expected. At the higher frequencies, the antennas may also be stowed without folding.

Large, relatively lightweight erectable or unfurlable antennas have been built in parabolic shapes, with diameters up to 50 feet. They have consisted of electrically conductive metallized cloth or wire mesh stretched over lightweight ribs to form the reflecting surface. Construction of this type is applicable for VHF through SHF systems, microwave antennas weighing more, for the same size, because of the finer mesh and tighter tolerance requirements of the surface. Currently, NASA has under construction for flight on a later ATS satellite a 30-foot operative antenna designed for storage within the 10-foot diameter Atlas-Centaur shroud.

For the very large antennas for high gain in the UHF band, weight is the critical design factor, and continued development is required to create an antenna material amenable to lightweight, truss-type construction which will be self-damping, insensitive to thermal variations, and if possible, self-rigidizing.

In the microwave-frequency region, beams shaped to minimize the interference with other service are desirable. In the low-frequency range, methods can be adapted to reduce the side lobes of the main beam to reduce partially the undesired radiation. Efforts are required to reduce beam-control theory to practice and adapt practices now employed on ground antenna systems to reduce interference in space flight.

Specifically, it is recommended that:

1. Continued ground development and flight investigation be made of large-aperture antennas designed for light weight, small volume for convenient storage, and high efficiency.

2. Basic and applied research be continued on distributed solid-state phased-array antennas, leading ultimately to flight investigations.

3. Multibeam feed techniques for beaming power from the antenna to more than one target be investigated.

4. The mutual interference of multiple narrow-beam antennas on spacecraft be investigated.

6.4 Attitude Control and Station Keeping

The success of many of the application satellites may depend on their capability for remaining on an assigned station in an equatorial synchronous orbit, and on the accuracy with which they can maintain the pointing of their antennas toward the earth. Low-cost, high-gain ground antennas may be used if ground antenna tracking is not required to compensate for spacecraft deviations in position or angle.

The motion of a satellite in synchronous orbit is perturbed in an east-west direction by the non-uniform gravitational field of the earth, so that a velocity increment of 0 to 7.0 ft/sec per year must be applied to the satellite to hold it at a particular longitude. This correcting velocity is small and is, on current satellites in orbit, provided by cold gas or hydrogen peroxide.

The satellite orbit is perturbed cyclically in the north-south direction by lunar and solar effects, and accurate maintenance of the orbit requires a total velocity increment approaching 200 ft/sec during the year. It is calculated that as much as 12 percent of the initial satellite weight may be required for fuel to maintain the orbit over a 5-year satellite life if a chemical fuel, even with a specific impulse as high as 300 sec., is used. This large fuel-weight requirement for orbit maintenance has led to continuing research on higher-impulse engine systems such as ion engines, that may be developed to have total initial weights of engine and fuel that are lower than those for the chemical systems, and have a life-expectancy appropriate for the mission.

Disturbance torques introduced by the operation of the station-keeping thrustors may introduce attitude errors, and have a very significant effect on the performance of the entire system. Low-thrust propulsion is required, particularly if a gravity-gradient-control system is used.

In the case of thrustors for attitude control, the problem is one of providing a small impulse bit per firing. For even stringent attitude control, it is unnecessary to reduce thrustor size below 10^{-4} pounds in order to obtain reasonable firing times; and successful attitude control can be obtained for a wide range of spacecraft weights and sizes by thrustors in the range of 10^{-3} and 10^{-4} pounds of thrust. The fuel-use rate for attitude control is not high, and specific impulse values that are obtained from decomposition of hydrazine or hydrogen peroxide are acceptable.

Desired improvement in attitude control encompasses three areas: accuracy, reliability, and long life. It may be desired to achieve antenna-pointing accuracies as small as $\pm$ 0.05°. Estimates of the precision capability of infrared horizon scanners indicate accuracies of $\pm$ 0.05°. But when attitude-control and antenna-alignment errors are considered, the pointing accuracy is degraded to $\pm$ 0.2° or more. For services which require precise pointing, use of monopulse or interferometer sensing is required. For this case, the satellite attitude may be crudely controlled and only the gimbaled antenna is precisely pointed. The development of a radio-frequency angle sensor is required.

For applications involving pointing accuracies of the order of $\pm$ 0.3 degrees or more, it is desirable to use horizon scanners. Indeed, even if rf sensors are used, horizon scanners are still required for satellite positioning and initial orientation. Therefore, scanners have a definite future in communications satellite applications, and work should be pursued to improve their reliability and accuracy. This includes more accurate readout of scanner position and more accurate data processing. Use of sensors operating in the CO_2 band is mandatory. To improve reliability and lifetime, areas of attack are the scanning mechanism, scanner readout, and complete use of integrated circuits in signal-processing electronics.

Use of three-axis gravity-gradient stabilization is desired for some applications, and work in this area should be expedited. Three-axis stabilization by more positive means, such as by reaction systems, has been used with some satellites, but the design lifetimes have been reasonably short. Ground and flight verification of accurate, long-lived, three-axis stabilization by high-impulse reaction systems should be demonstrated as soon as possible.

It is recommended that:

1. Ground and flight evaluation of high-performance chemically-fueled thrustors or ion engine thrustors of about 10^{-4} to 10^{-3} pounds thrust be undertaken to establish their performance and operational characteristics, including life in orbit.
2. Ground and flight performance of three-axis stabilization systems of high accuracy be accomplished both of the gravity-gradient and reaction type to measure the performance and operational characteristics of the systems, including their life in orbit.
3. Research and development be accelerated on sensors operating in a wide range of frequencies (rf, infrared, etc.) for attitude reference. Flight evaluation of an rf interferometer for extreme accuracy of angle measurement is of particular interest.

6.5 Spacecraft Electronics

The past development of transmitting equipment for space missions has provided a variety of reliable long-lived components and units for low-power applications of 1-10 watts of radio-frequency output. All of these, within their range of capability, and with some extrapolation to higher performance levels, are available for new programs.

Future programs will require equipment to operate in space at frequencies into the millimeter-wave bands and at power levels several thousand times those used heretofore.

Equipment to operate at high powers has been developed for ground use. Typically,

1. Transistor techniques are used for power levels up to 5 watts at 100 MHz.
2. Gridded tubes are used up to many kilowatts at frequencies up to about 500 MHz.
3. Traveling-wave tube amplifiers are used at frequencies above about 500 MHz for lower powers.
4. Klystrons are used for higher powers and high frequencies.

The technology for ground equipment has been optimized toward low initial cost with lesser attention given to tube efficiency and extremely long life. Most of the equipment is not rugged enough for space qualification.

In the area of spacecraft electronics with particular emphasis on the transmitter, it is specifically recommended that:

1. Tube development be emphasized and the technology be created for:
   a. Cathodes having reproducible long life at the high current densities required for efficient tube operation
   b. Cooling of tube elements
   c. Rugged construction
   d. Production and inspection to provide "flaw-free" equipment for reliable, long-lived operation

2. Intensive research be conducted on a variety of methods for increasing the efficiency of transmitter tubes, so that the prime satellite power can be reduced, with concurrent reductions in spacecraft weight and cost. Suggested approaches include, among others, the use of digitally modulated AM systems, cyclotron resonance devices, AM modulation of crossed-field devices, and mixed focusing of linear tubes.

3. Development be undertaken of traveling-wave tubes in the range of 1-25 watts power output with reduced FM-to-AM and AM-to-PM conversion coefficients. Specifically, a reduction of an order of magnitude is required.

4. Transmitters with the following characteristics be developed and evaluated in ground and flight investigations where practical:
   a. Gridded tube @ 800 MHz and 10 kW
   b. Solid-state @ 2500 MHz and 50 watts
   c. TWT @ 2500 MHz and 100 watts
   d. Klystron @ 12 GHz and 5 kW
   e. Klystron @ 36 GHz and 6 kW

5. Methods be investigated for extending the low-noise receiver technology developed for ground receiving for spacecraft use, so that up-link transmitter interference with ground links can be minimized.

6.6 Satellite Life

In operational satellite systems, lifetime of the satellite becomes a dominant factor in the economic viability of the system. Methods of predicting and attaining a specific design life are thus of basic importance.

At present, little attention is given to the problem of lifetime, as distinguished from the problem of reliability. Some attempts have been made by assuming an exponential law and a mean time to failure. This has the advantage of allowing simple calculation, but laboratory test and in-orbit experience both indicate that the assumptions are not valid. Improvements in prediction methods are needed. The failures which occur indicate that improvements in design and production practices are also needed.

It appears that a new approach can be based on the concept, "time to first failure." Some of the factors which enter into this are:

1. Nature and variation of the environment
2. Consumption of expendables, such as attitude-control and station-keeping gas. This is influenced by environmental factors and by tolerances involved in equipment design.
3. Deterioration of components which eventually causes component failure. This is influenced by choice of component, operating conditions, and by the local environment.
4. Performance drift, often associated with deterioration, which can eventually cause a system to be outside acceptable limits
5. Irreducible risk associated with uncontrollable natural events such as meteoroids and solar flares
6. So-called "infant mortality" caused by poor workmanship, handling accidents, hidden flaws, etc.

All of these factors are affected by the system concept used, i. e., the degree of redundancy, the amount of subsystem sectionalization, the design tolerances assumed, and so on.

It is recommended that:

1. Programs be established to extend and improve our basic knowledge and understanding of the life-determining processes of spacecraft in orbit
2. Techniques be developed for applying the knowledge that is obtained in all phases of design, development, and fabrication
3. Techniques be developed for evaluating the results obtained from application of the new understanding

6.7 Noise-Environment Measurements

Below about 1000 MHz, man-made environmental noise limits system performance for urban service, and hence sizes the satellite to be used for particular ground receivers. The cost of the space segment is therefore strongly dependent on the assumptions made about the level of urban noise and VHF/UHF TV broadcast calculations in this report. Unfortunately, many of the data appear to be both incomplete and old. They were taken before more recent improvements in automobile ignition systems, home appliances, etc.

It is therefore recommended that current measurements of man-made noise be made in various urban environments, at frequencies between 50 and 1000 MHz, with spot checks in some of the higher bands.

7.0 OTHER RECOMMENDATIONS

7.1 Frequency Allocations

An important and immediate problem facing the establishment of any system discussed in this report is the absence of assigned frequency bands for satellite broadcasting. It is in the national interest that the economic, social, and political benefits which broadcast satellites can bring to this and other countries not be vitiated by a lack of appropriate spectrum allocation.

It appears that there is an optimum frequency for each class of service, the exact value depending on the type of modulation, expected number of receivers, propagation, and other factors. Usually the optimum is broad, so that a range of frequencies is usable without penalty. The optimum and usable frequencies for the several types of service are approximately as follows:

Class*	Modulation	Optimum (MHz)	Usable Range (MHz)
A	FM	12,000	2,000-35,000
B	FM	2,500	1,000-12,000
	AM	1,000	200- 2,500
C	AM	1,000	200- 2,500
	FM	2,500	200-12,000
VC	FM	100	30- 1,000

*See Section 3.2 for definitions

The selected bands should be within the usable ranges and, preferably, should be reasonably close to the optimum frequencies.

For operational systems, the bands may be selected by national, regional, or international arrangement. For a national service, the decisions may be made unilaterally, provided that appropriate steps are taken to prevent interference to other countries. This is relatively easy for small coverage areas, and would be an acceptable procedure for systems in Class A, for many systems in Class B, and possibly for some in Class C.

Regional agreements (e.g., among the countries in the Americas) are encouraged by the International Radio Regulations (para. 118). Since it appears relatively easy to avoid interference to other regions for these broadcast services, and since countries in a region often have commonality of interest, this approach may be adequate to solve problems not solvable by national allocations.

International agreement should be sought through the International Telecommunication Union. The entire problem of space broadcast is now being studied by agencies of the Union but it will be some time before agreement can be reached. Therefore, if an early operational system is to be established, national or regional allocations should be sought promptly.

For experimental systems, there does not appear to be a problem. Operations may be conducted under existing international agreements, subject to appropriate interference control, as covered by paragraph 115 of the International Radio Regulations.

It is therefore our recommendation that the Federal Communications Commission initiate the allocation process by issuing a notice of inquiry regarding the use of various frequency bands for the several classes of domestic satellite broadcasting. Of particular interest are allocations in each of the following bands:

1. 108 MHz for FM direct voice broadcast
2. 470-890 MHz (UHF) for direct-to-home satellite TV broadcast and for CATV distribution, possibly restricted to the upper part of the band
3. 2500-MHz band for ETV and other community services
4. 12,000-MHz band for distribution services
5. Higher frequencies, such as 18 and 35 GHz, which may have some use either in the up link or in applications requiring limited coverage area and less than "99 percent" assured availability

Of equal importance is the international allocation of satellite-broadcast bands. It is recommended that the Administration, through the State Department, with support from the FCC, OTM, and NASA, take vigorous action to define a U. S. position in this area, and that this position be pursued with the ITU.

Consideration should be given to allocating clear channels for both domestic and international use where possible (e. g., at 12 GHz and one or more UHF bands). In other bands, controlled sharing criteria should be defined.

In arriving at any kind of reasonable allocations, some "rejuggling" of assignments is unavoidable, since none of the above recommended bands is currently vacant. In order to be able to make intelligent reassignments and to set up sharing criteria, it is desirable to have information on the current users of the frequency bands of interest, the percent of time they are actually on the air, the equipment investment involved, and the fraction of this investment that remains be written off. It is recommended that the means and budgets be established to collect, process, and publish these data in a methodical and continuing way for both commercial and government services.

7.2 Study of Frequency-Sharing and Interference Problems

Since some frequency sharing will be unavoidable between broadcast satellites and terrestrial services, we recommend that greater emphasis be given to the interference problem through both theoretical and experimental studies. The latter should include a measurement program using a high-power, satellite-borne transmitter.

Particular attention should be given to exploiting the discrimination achievable by virtue of the high incidence angles typical for synchronous satellites. Local shielding of terrestrial stations may be possible using knowledge of the (constant) angular direction of the satellite.

It may be possible to use actual signal statistics for realistic spectral-density criteria.

7.3 Allocation of Synchronous-Orbit Longitudes

Because of the desirability of the synchronous equatorial orbit for broadcast satellites as well as for point-to-point communications and other applications, the number of satellites in such orbits may become large in the 1970's. Since the number of longitude "slots" is limited by many considerations, appropriate U. S. and international regulation may be required. Study of this problem is recommended.

In setting up new synchronous satellite systems, limits should be placed on antenna beamwidths, polarization, the maximum allowable values of in-orbit drift angle during the satellite's operational lifetime, and other parameters. Further studies need to be carried out to determine appropriate values for them now and in the future.

Consideration should also be given to the extent to which it is technically and economically feasible and desirable to apply the "antenna-farm" concept of satellites in the synchronous orbit.

7.4 Application to Instructional TV

Although the panel did not address itself directly to the educational, instructional, and behavioral issues involved in the actual application of satellite technology to ITV and ETV, it became evident through some of the information presented during this study that no consensus exists in this area. Some of the questions which appear to require resolution are: Does instruction using ITV have to be completely TV-based (a la Samoa) or does supplementary (high-grade) TV instruction have significant educational value? Is black and white preferable to color for ITV? What is the level and type of training required for teachers working with ITV? How "customized" to the local area does programming have to be to be effective (national vs regional vs local school districts)?

It is suggested that these subjects require controlled behavioral-science measurements and experiments, and it is recommended that steps be taken by the Department of Health, Education, and Welfare to collate and evaluate existing data, determine what further tests are required, and implement and promote the use of these.

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APPENDIX A

TYPICAL TV-LINK CALCULATIONS

All the link calculations for TV were made the same way, with slight variations to suit the different cases. The communications equation is:

$$C = \frac{P_T G_T}{4\pi R^2} \quad \frac{G_R \lambda^2}{4\pi} \quad \frac{1}{L_i} \tag{1}$$

or

$$C = \frac{ERP}{4\pi R^2} \quad \frac{A_R}{L_i} \tag{2}$$

Form (2) is basic to an appreciation of the physics of communication. Note that the received carrier is dependent only on ERP and the effective physical size of the receiver antenna. It does not depend on frequency explicitly. The differences in link performance at various frequencies are a result of differences in practically realizable values of receiver sensitivity, transmitted power, antenna size; differences in incidental losses, e.g., atmospheric and ionospheric; differences in environmental noise levels, etc.

If B is the rf bandwidth to be received, we can write

$$\frac{C}{N} = \frac{ERP}{(4\pi R/\lambda)^2} \quad \frac{Gr}{kTB} \quad \frac{1}{L_i} \tag{3}$$

$\left[\frac{4\pi R}{\lambda}\right]^2$ is usually called the "space loss." Putting everything in

decibels and rearranging we have:

$$ERP = \left[\frac{C}{N}\right] + L_s + L_i + B - \left[\frac{G}{T_s}\right]_{dB} - 228.6 \tag{4}$$

Bandwidth and temperature are taken in dB above 1 Hz and 1°K repectively. Equation (4) is the conventional one used by communicators for scheduling power budgets.

As an example, we consider the case of a distribution system (Class A) at 12,000 MHz. (λ = 2.5 cm) A 20' antenna, 55 percent efficient, has a gain G given by

$$G = \zeta \left[\frac{\pi D}{\lambda}\right]^2 \longrightarrow 55.1 \text{ dB} \qquad (5)$$

$$T = 250° \text{ K} \longrightarrow 24 \text{ dB}$$

$$\left[\frac{G}{T}\right]_{dB} = 31.1 \text{ dB}$$

$$L_S = \left[\frac{4\pi R}{\lambda}\right] \longrightarrow 205.4 \text{ dB} \qquad (6)$$

At the sub-satellite point, R = 19, 360 nautical miles. To allow for antenna-pattern shape and extra distance to the horizon we take a loss of 4. 8 dB. Up-link noise contributes the equivalent of another 0. 5 dB. Spacecraft and earth-terminal rf losses plus atmospheric attenuation (exclusive of rain) contribute another 2 dB. Thus

$$L_i = 4.8 + .5 + 2.0 = 7.3 \qquad (7)$$

$$ERP = \left[\frac{C}{N}\right]_{dB} + B_{dB} - 47 \qquad (8)$$

The CCIR standard for U. S. 525-line color TV is a ratio of 56 dB blanking to white signal-to-rms noise. This is a peak-to-peak excursion and is 9 dB greater than the rms value of a test tone of the same excursion. We also have allowed a total of 10. 2 dB for the combined effects of receiver weighting, the much less subjective effect of FM noise compared to AM and some slight preemphasis consistent with good color transmission. Hence, the required $\left[\frac{S}{N}\right]$ for use in the link calculation is

$$\left[\frac{S}{N}\right] = 56 - 9 - 10.2 = 36.8 \qquad (9)$$

If we are to achieve this value with a carrier-to-noise ratio $\left[\frac{C}{N}\right]$ at threshold (receiver "breaking") of 10 dB, we need an FM-improvement factor of 26. 8 dB.

$$\text{Since } \left[\frac{S}{N}\right] = 3M^2 (1 + M) \left[\frac{C}{N}\right]$$

$$3M^2 (1 + M) = 480 \qquad (10)$$

$M = 5.1$

$B = (1 + M)2b$ b = video bandwith of 4MHz

$$B = 49 \text{ MHz} \tag{11}$$

This bandwidth is probably impractical in the real world of frequency allocations and we arbitrarily restricted it to 40 MHz. For a video bandwidth of 4 MHz, this requires, from Equation 11, a modulation index of 4 and from Equation 10 results in an FM improvement of only 23.8 dB. By assuming a (C/N). of 13 dB rather than 10, an improvement of only 23.8 dB is needed to yield the desired 36.8 dB of (S/N). We have saved bandwidth at the expense of carrier power. We allow a further margin of 3 dB for rain and similar effects. Note that there is a total margin on "breaking" of 6 dB because of the BW power trade-off. Using a value of 16 dB for (C/N) and a B of 40 MHz in Equation 8 we get a value of ERP.

$$\begin{aligned} ERP &= 16 + 76 - 47 \\ ERP &= 45 \text{ dB} \end{aligned} \tag{12}$$

The result is rather insensitive to variations in required S/N allowances for weighting or subjective effects and other "post-detection" numbers. The FM improvement makes the achievement of excellent picture quality rather easy at the expense of bandwidth. We have only calculated FM cases for the highest appropriate quality because of this.

In the calculation of VSB cases, we use the same procedure except to fix the RF bandwidth B at 6.0 MHz. The quality figures used were TASO and in a VSB-AM case the (S/N) is equal to the (C/N). In these cases, the resulting ERP goes dB for dB with the picture quality and significant reductions in satellite power go with reduced picture quality.

DEFINITION OF SYMBOLS

C = Received Carrier Power

N = Noise Level

P_T = Transmitted Power

G_T = Transmitter Antenna Gain

G_R = Receiver Antenna Gain

R = Distance

λ = Wavelength

ERP = Effective Radiated Power

L_s = Free-Space Propagation Loss

L_i = Incidental rf losses

A_R = Area of Receiving Antenna

k = Boltzmann's Constant (1.38 x 10^{-22} joules/cycle -°K)

D = Antenna Diameter

B = rf Bandwidth

M = Modulation Index

T_s = System Temperature

b = Video Bandwidth

S = Signal Level

Sync-Tip Spectral Distribution

Link calculations for broadcast distribution systems are based on CCIR relay quality signals (Sec. 4.1.1). Limiting the RF bandwidth to 40 MHz employs the full available rf band per channel for the signal from blanking level to zero. But the frequency modulator in the satellite must be linear from zero to sync tip. The spectral distribution of the sync tip must be shown to lie essentially within the 40-MHz rf bandwidth if this system is to be acceptable.

NTSC Standard I-F-4 defines the sync tip as a rectangular pulse riding on the video blanking level, with a pulse duration δ of 1/12 the horizontal line period T. The line frequency is 15,750 sec. so that

$$\frac{\delta}{T} = \frac{1}{12} \quad (1)$$

$$\text{and } \frac{1}{T} = 15,750 \quad (2)$$

The line spectrum of a periodic, rectangular pulse of amplitude E is well known as

$$g(\omega) = \frac{E\delta}{2\pi} \frac{\sin K\left[\frac{\omega\delta}{2}\right]}{K\omega \quad \delta/2} ; \quad K = 1, 2, 3, \ldots \quad (3)$$

where, as usual,

$$\omega = \frac{2\pi}{T} \quad (4)$$

Zeros of g (ω) occur for

$$K \frac{\omega\delta}{2} = n\pi ; \quad n = 1, 2, 3, \ldots \quad (5)$$

and at least 99 percent of the energy in the pulses is contained within the second zero. Substituting from (1) and (4) in (5)

$$K = 12\,n; \qquad (6)$$

the second zero means

$$K_2^{(o)} = 24. \qquad (7)$$

The baseband b corresponding to $K_2^{(o)}$ is, from (2)

$$b = \frac{24}{T} = 0.38 \text{ MHz} \qquad (8)$$

and the rf bandwidth, using M=4 from the link analysis, is

$$B_{rf} = 2\,b\,(M + 1) = 3.8 \text{ MHz} \qquad (9)$$

Thus, not only the second zero, but also the 20th, of the sync-pulse spectrum falls comfortably inside the rf bandwidth of 40 MHz. The sync-tip spectral energy outside this rf band will be negligible.

From (1), the sync-tip duty cycle is about 8 percent. The CCIR definition of the video waveform implies that the fractional peak power over blanking level required by the sync tip is less than $\left(\frac{0.3}{0.7}\right)^2$, or under 18.5 percent. Since the sync tip is modulated with the same M as the video signal, all improvement and loss factors will be the same in both cases. An increase of 0.7 dB in spacecraft power and in transmitter power will then provide a signal-to-noise ratio for the sync-tip equal to that for the picture signal. This is clearly unnecessary; the sync separator does not require so clear a signal. Increasing the power capability of the spacecraft by 0.3 dB will over-cover the average power demand for the sync tip and will still provide a sync-tip S/N of about 54 dB. This is excellent for the sync separator and will not affect the spacecraft sizing significantly.

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APPENDIX B

COMPUTATION OF ERP FOR 100-MHz VOICE-BROADCAST SATELLITE + 8-dB INDOOR ANTENNA IN URBAN LOCATION

As previously stated in Appendix A (Equation 4):

$$ERP = \frac{C}{N} + L_s + L_i + B - \left[\frac{G}{T_S}\right]_{dB} - 228.6$$

L_s = 164 dB (22, 300 mi)

L_i Computation:

	dB
Beam-edge loss	3.0
Range correction	1.8
Up-link noise contribution	0.4
Building attenuation	12.0
Fading and miscellaneous	3.0
	20.2

B = 180 kHz 52.5 dB

$T_1 \doteq F_1 \times 290°K$ (environmental noise temp.)

F_1 Computation:

	dB
Ambient noise	35.0
Receiver-antenna discrimination	- 4.0
Building attenuation	-12.0
	19.0

T_1 = 23,000° K

T = (F-1) 290° K; for N_f = 6 dB, $T \doteq 1000°$ K (receiver noise temperature)

$T_S = T_1 + T$ = 24,000° K 43.8 dB

$$G = 8 \text{ dB receiver-antenna gain)}$$

$$\frac{G}{T_S} = 35.8 \text{ dB}$$

$$\frac{C}{N} = 17 \text{ dB}$$

$$ERP = 60.9$$

Computation of $\frac{S}{N}$

$$\frac{S}{N} = 3 M^2 (1 + M) \frac{C}{N}$$

$$\Delta f = \pm 75 \text{ kHz (deviation)}$$

$$b = 15 \text{ kHz}$$

$$M = 5 = \frac{\Delta f}{b}$$

$$3M^2 (1+M) = 26.5 \text{ dB}$$

$$\frac{S}{N} = 50 \text{ dB (including pre-emphasis)}$$

$$\frac{S}{N}_{(flat)} = 50 - 7 \text{(preemphasis improvement)} = 43 \text{ dB}$$

$$\frac{C}{N} = 16.5 \text{ dB required (rounded to 17 dB)}$$

APPENDIX C

SATELLITE SIZING

C. 1 Introduction

To establish the characteristics of the various broadcast services, coverage areas were selected, satellite-and ground-station performances defined, and gross satellite-weight estimates made. Because of the large number of cases considered, satellite-weight estimates were made on the basis of proportionality and scaling rather than detailed evaluation of each subsystem. The objective was an empirical equation to relate satellite weight to the rf power requirements. From the resulting in-orbit weight, the required booster was determined. The purpose of this appendix is to present the background for these calculations.

C. 2 Satellite Operation

The satellites were considered to be in synchronous equatorial orbits and to be three-axis stabilized so that the antennas are properly oriented. Non-gimbaled parabolic antennas were used. Electrical power is supplied by a solar array which is rotated about an axis normal to the orbit plane to provide near-normal solar incidence. Deployable arrays employing silicon solar cells were used for array powers up to 1.5 kilowatt and thin-film arrays were used for greater powers.

Satellite attitude control is to be provided by a three-axis active system using hydrazine. Attitude sensing is provided by redundant infrared horizon scanners. The smallest thrust attainable using hydrazine is about 0.5 lb, and for satellites weighing less than 2000 lb, this will result in high propellant requirements. Therefore, for this class of satellite, the hydrazine is decomposed by electrically heating it to enable thrusts of 0.05 lb. The hydrazine is used without decomposition for station keeping and initial positioning.

The ground antennas were assumed to be either sufficiently broad-beamed or to include tracking capability such that north-south station keeping is not required. East-west station keeping within one degree is provided.

C. 3 Power-Supply Weight

1. Based on the use of solar cells of 11 percent conversion efficiency and an aluminum honeycomb substrate, the solar-array weight in pounds will be given by $W_1 = 0.116P_1$, where P_1 is the total array power in watts for normal incidence.

2. For a thin-film array, $W_1 = 0.05P_1$

3. For a 1.2-hour maximum eclipse and a battery specific of 12 watt-hours per pound, the battery weight will be given by $W_2 = \frac{0.1\ P2}{(1-\eta)}$, where P_2 is the total continuous satellite load; where η = depth of discharge (35 per cent assumed) assuming 16 percent radiation degradation in 5 years and assuming the worst sun-incidence conditions (solstice conditions), P_1 and P_2 are related by $P_1 = 1.31\ P_2$.

4. Array drive mechanism, array shaft, and control electronics, $W_3 = 18 + 0.06\ W_1$.

5. Power-control unit, shunt elements, equipment converters, $W_4 = 22 + .02P_2$

6. Cables and harnesses, $W_5 = 25 + .03W$, where W = total satellite weight.

C.4 Attitude-Control-System Weight

1. Propellant Weight to Control Solar Radiation Torques.
The upsetting torque of solar radiation is given by:

$$T_d = \frac{S\ (1 + \sigma)\ AK_1}{C},$$

where

S = the solar constant

σ = reflectivity coefficient (assumed 0.5)

A = projected satellite area facing sun

C = velocity of light

K_1 = center of gravity -- center of pressure offset.

On inserting the values for the various constants, the following expressions for propellant weights are obtained:

$$W_6 = \frac{0.48\ P_1}{Isp}$$ for a silicon cell array with $K_1 = 0.3$ ft.

$$W_6 = \frac{3P_1}{Isp}$$ for a large thin-film array with $K_1 = 1$ ft.

These expressions include a factor of 1.4 to account for the possibility that the center of pressure is equidistant from two control axes. This is a worst case.

2. Propellant Weight for Limit Cycle Operation

The propellant weight per control axes for limit cycle operation using pulse-ratio modulation is

$$W_7 = \frac{\mu F \Delta^2 T}{4 \theta_D \, Isp}$$

where

μ = control torque to satellite inertia ratio

F = thrust in pounds

T = satellite lifetime in seconds

θ_D = control dead zone (radians)

Δ = value on-time per thrusting interval.

A dead-zone, θ_D, of 0.1 degrees is used for weight estimation. This leads to an overall pointing accuracy of approximately $\pm$ 0.25 degrees which is appropriate for beamwidths as narrow as one degree.

For A and B class of services (TV distribution and limited direct TV), use of decomposed hydrazine is assumed. A maximum thrust of 0.05 lb and Ispz = 120 seconds are used. For this case, the propellant weight for limit cycle operation is 12 lb. This figure is actually an upper limit based on μ = 0.0003, and μ will usually be less than this value.

For the class C or VC service, a value of $\mu = 10^{-4}$, a thrust of 0.5 lb, and a specific impulse of 225 seconds are appropriate. In this case, the propellant weight for limit cycle operation can be maintained at less than 40 lb for 5 years.

3. Attitude-Control-Equipment Weights

Control Electronics	12 lb
Earth Sensors (4)	19
Sun Sensors	2
Star Sensors (2)	6
	39 lb

C.5 Propulsion-System Weight

The propellant weight for initial positioning, station keeping, and attitude control is given by

$$W_8 = W \left[\epsilon^{\frac{\Delta V}{gI}} - 1 \right] + W_6 + W_7$$

$$W_8 \equiv \frac{W \Delta V}{g I_{sp}} + W_6 + W_7 \quad \text{for small values of } \frac{\Delta V}{gI}$$

ΔV = the total velocity required for positioning and station keeping (300 fps assumed)

W = satellite weight

Isp = specific impulse

The weight of the valves and plumbing is approximated by $W_9 = 18 + 0.06 W_8$.

Assuming a factor of $0.12 W_8$ for the tank pressurant and pressurant tank, the entire propulsion weight is given by

$$W_P = 1.18 \frac{W \Delta V}{g I_{sp}} + W_6 + W_7 + 18$$

$$W_{p1} = 0.0498 W + 0.00616 P_2 + 33 \text{ for class A and B.}$$

$$W_{p2} = 0.0498 W + 0.0205 P_2 + 64 \text{ for class C and VC.}$$

C.6 Antenna Weights

Experience indicates that the weight of an antenna varies approximately as $D^{2.3}$, where D is the antenna diameter. Since antenna beamwidth may be expressed as

$$\beta = 70 \frac{\lambda}{D} \quad ,$$

a relationship between weight and beamwidth is

$$W_a = 758 \left[\frac{\lambda}{\beta} \right]^{2.3}$$

C.7 Structure and Thermal Control

For satellites of Class A and B, a weight factor of $W_S = 0.15$ W is assumed for structure alone.

C.8 Telemetry, Tracking, and Command

A weight of 30 lb is assumed for the TTC subsystem.

C.9 Communications Subsystem Weights W_c

These have been estimated from data on weights of existing low-level integrated circuits and existing transmitters at the frequencies investigated.

C.10 Total Satellite Weights

The total satellite weight, representing the sum of the preceding expressions, is given by

$$W = \frac{0.3412\,P_2 + 167 + W_c + 758\,\left(\frac{\lambda}{\beta}\right)^{2.3}}{0.77}$$

For Class C satellites, use of a thin-film array is assumed and the battery is sized to provide only housekeeping during eclipses. The expression for weight that corresponds to these assumptions is

$$W = \frac{0.1099\,P_2 + 214 + W_t + W_c + 758\,\left(\frac{\lambda}{\beta}\right)^{2.3}}{0.82}$$

Where

W_c = weight of communications equipment

W_t = weight of thermal-control equipment

C.11 Power Requirements

Average power requirements by subsystem are listed below.

	Class A and B	Class C
Attitude-control electronics	34	34
Telemetry and command	8	8
Propulsion (hydrazine decomposition)	40	--
Solar-array drive	3	12
Battery trickle charge	$.05P_2$	5
	$85 + .05P_2$ W	59W

The load power is given by

P_2 = 89.5 + 1.05 Pc (Class A and B)

P_2 = 59 + Pc (Class C and VC)

where

Pc = DC power to communications repeaters

C.12 Satellite Weight vs Ground Coverage

Throughout this report, the basic plot for each class of service is satellite weight in orbit vs angular ground coverage. It is arrived at as follows:

$ERP = G_t P_t$, where: P_t = Trans. power and G_t = Antenna Gain

$$\therefore ERP = \frac{27,500}{\beta^2} P_t$$

For a nonsymmetrical beam β^2 is replaced by the product of the two beamwidths. From the previous section, the satellite weight is given by an equation of the form:

$$W = a P_t + \frac{b}{\beta^{2.3}}$$

Combining the two yields

$$W = \frac{a\ ERP}{27,500} \beta^2 + \frac{b}{\beta^{2.3}}$$

Differentiating the above equation and equating to zero shows that this plot will have a minimum at a value of β^2 that increases with ERP. For Class C and VC satellites, this minimum occurs at values of coverage that are practical.

APPENDIX D

ECONOMIC DETAILS

TABLE 10. D. 1

PROGRAM COSTS
AUTOMOBILE/AIRCRAFT DISTRIBUTION SYSTEM

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
Autos	1, 200	$ 2, 000	$ 2, 400, 000	1	$ 2, 400, 000 ①
Large Aircraft	8	2, 000, 000	16, 000, 000	10	1, 600, 000 ②
Small Aircraft	64	50, 000	3, 200, 000	10	320, 000 ③
Program Tapes	--	--	613, 000, 000	1	613, 000, 000 ④
Tape Duplicating Machines	42	25, 000	1, 050, 000	1	1, 050, 000 ⑤
Video Display Units	20, 000	350	7, 000, 000	1-1/2	4, 670, 000 ⑥
Training	--	--	5, 000, 000	10	500, 000
R&D	--	--	10, 000, 000	10	1, 000, 000 ⑦
Auto Maintenance Facility	--	--	--	--	--
Aircraft Maintenance Facility	--	--	--	--	--
Video Display Facility	--	--	--	--	--
Total			$657, 650, 000		$624, 540, 000
Operation & Maintenance Personnel					
Auto Maintenance	1, 200	$ 5, 000			6, 000, 000
Auto Drivers	1, 800	5, 000			9, 000, 000
Tape Reproduction	224	5, 000			1, 120, 000
Large Aircraft Crew	24	20, 000			480, 000
Aircraft Fuel & Oil	--	--			--

TABLE 10. D. 1 (Continued)

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Small Aircraft Crew	192	$ 15,000			$ 2,880,000
Administration	20%	--			3,896,000
Contractor Maintenance					
Large Aircraft	7,480 flight hours	300			2,244,000
Small Aircraft	83,776 flight hours	75			6,283,000
Total					$656,443,000 ⑧

Notes: Automobile/Aircraft Distribution System

① Four hundred areas with 400 miles daily equals 160,000 miles per day. Each car drives at the average speed of 20 miles per hour for 8 hours or 160 miles/day. One thousand cars are required plus 20 percent for maintenance allowance. Each car wears out after 6,000 miles or approximately 1 year of service.

② Each aircraft delivers to four of the 16 major distribution points daily. Four aircraft are required each day. A maintenance factor of 2 brings the total required to 8.

③ Each of the 16 areas has 60 drop points. Each aircraft makes 15 drops per day, if all planes fly every day.

④ Tape cost $50 per hour. Twenty-eight hundred locations need 12 hours of tape, 365 days a year. Each tape is played at approximately seven locations in sequence (20,000 locations).

⑤ Each machine produces four identical tapes simultaneously Working 24 hours a day produces 100 tape hours daily. The daily requirement for 2800 tape hours requires 28 machines. A maintenance factor of 1.5 creates the need for 42 machines.

⑥ Twenty thousand locations

⑦ R&D expense includes development work in video tape recorders, film and tape, reproduction and display equipment.

⑧ Excludes cost of maintenance for video display units.

TABLE 10. D. 2

PROGRAM COSTS
AIRCRAFT DISTRIBUTION SYSTEM

Cost Elements	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
Large Aircraft[1]	8	$2,000,000	$ 16,000,000	10	$ 1,600,000[2]
Small Aircraft	300	50,000	15,000,000	10	1,500,000[3]
Program Tapes[1]	--	--	613,000,000	1	613,000,000[4]
Tape Duplicating Machines[1]	42	25,000	1,050,000	1	1,050,000[5]
Video Display Units[1]	20,000	350	7,000,000	1-1/2	4,670,000[6]
Training	--	--	5,000,000	--	500,000
R&D	--	--	10,000,000	--	1,000,000[7]
Total			$667,050,000		$623,320,000
Operations & Maintenance					
Personnel					
Tape Reproduction	224	5,000			1,120,000
Large Aircraft Crew	24	20,000			480,000
Small Aircraft Crew	900	15,000			13,500,000
Administration	20%	--			3,020,000
Aircraft Fuel & Oil					
Contractor Maintenance	--	--			--
Large Aircraft	7,480 flight hours	300			2,244,000
Small Aircraft	392,000 flight hours	75			29,453,000
Total[1]					$673,137,000[8]

TABLE 10. D. 2 (Continued)

Notes:

① Notes 2, 5, 6, 7, and 8 are identical to notes on Auto/Aircraft Distribution System.

③ 160, 000 miles must be traveled each day. Assuming each can fly 533 miles per day, 300 aircraft are needed.

TABLE 10. D. 3

PROGRAM COSTS
AIRBORNE BROADCASTING SYSTEM

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
R&D			$ 5,000,000	10	$ 500,000
(1) Aircraft	21	$ 600,000	12,600,000	10	1,260,000
Airborne Electronics	21	70,000	1,470,000	10	147,000
Airborne Communications	21	750,000	15,750,000	10	1,575,000
Spare Engines	28	44,000	1,232,000	10	123,000
Miscellaneous Aircraft Equipment	--	--	1,000,000	10	100,000
Ground Transmitter Stations	7	400,000	2,800,000	10	280,000
Ground Transmitters	7	1,100,000	7,700,000	10	770,000
(2) Fringe Area Translators	56	40,000	2,240,000	10	224,000
Spare Parts	7	175,000	1,225,000	10	122,000
(3) Video Tape Recorders	21	45,000	945,000	10	94,500
Miscellaneous Equipment	--	--	2,000,000	10	200,000
Sub-total			53,962,000		5,396,000
TV Receiving Sets	1,000,000	200	200,000,000	3	66,700,000
Total			$253,962,000		$72,096,000
Operation & Maintenance					
(4) Flight Crews	42	50,000			2,100,000
(5) Maintenance Personnel	--	--			1,000,000
(5) Fuel & Oil	--	--			6,480,000

TABLE 10. D. 3 (Continued)

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Operation & Maintenance (cont)					
(5) Miscellaneous Supplies	--	--			$ 1, 670, 000
(6) Engine Overhaul	112	16, 000			1, 790, 000
Ground Station O & M	7	530, 000			3, 710, 000
Video Tape O & M	7	75, 000			525, 000
Video Tape	7	184, 400			1, 291, 000
Tape Duplication	--	--			1, 000, 000
TV Set O & M	1, 000, 000	5			5, 000, 000
Total					$96, 662, 000

Notes: Airborne Broadcasting System

(1) Twenty-one aircraft are required to maintain 12 hours of broadcasting to the seven areas. Each aircraft flies 8 hours; two out of every 3 days. Flying at 23, 000 feet, each aircraft covers an area with 210-225 mile radius.

(2) Each of seven areas requires eight fringe-area translators.

(3) Each of seven areas requires three video tape recorders.

(4) Each aircraft requires three crews.

(5) Based on 2920 flying hours per year.

TABLE 10.D.4

PROGRAM COSTS
TERRESTRIAL DISTRIBUTION 25 BROADCASTERS

Cost Element	Quantity	Unit cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
R&D			$ 5,000,000	10	$ 500,000
Microwave	21,000 (2)	$ 7,000 (1)	147,000,000	10	14,700,000
Coaxial	140,000 (3)	3,200 (1)	448,000,000	10	44,800,000
Local Broadcasters	25	365,000	9,100,000	10	900,000
TV Receivers	1,000,000	200	200,000,000	3	66,700,000
Total			$809,100,000		$127,600,000
Operation & Maintenance					
Microwave	25%	$147,000,000			$ 36,700,000
Coaxial	20%	448,000,000			89,600,000
Local Broadcasters	25%	9,200,000			2,300,000
TV Receivers	1,000,000	5			5,000,000
Total					$261,200,000

Notes: Terrestrial Distribution 25 Broadcasters

1 Costs of microwave and coaxial cable based on costs from "DOD Rule of Thumb Pricing Guide," May 1966 (DOD cost assumed as 60 percent of total cost). Networking, terminals and control centers add another 40 percent.

2 Mileage required to connect all ci[illegible] of 10,000 population or greater.

3 Mileage required to connect the cities to the 20,000 villages of 2500 population or greater.

TABLE 10.D.5

PROGRAM COSTS
TERRESTRIAL DISTRIBUTION WITH 200 BROADCASTERS

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
R&D			$ 5,000,000	10	$ 500,000
Microwave	21,000 (1)	$ 7,000 (2)	147,000,000	10	14,700,000
Local Broadcasters	200	365,000	73,000,000	10	7,300,000
TV Receivers	1,000,000	200	200,000,000	3	66,700,000
Total			$425,000,000		$ 89,200,000
Operations & Maintenance					
Microwave	25%	$147,000,000			$ 36,700,000
Local Broadcasters	200	85,000			17,000,000
TV Receivers	1,000,000	5			5,000,000
Total					$147,900,000

Notes: Terrestrial Distribution with 200 Broadcasters

(1) Mileage necessary to connect all cities with population of 10,000 or greater.

(2) Based on "DOD Rule of Thumb Pricing Guide," May 1966.

TABLE 10. D. 6

PROGRAM COSTS
CLASS A DISTRIBUTION SATELLITE SYSTEM

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
① R&D					
Ground			$ 1, 000, 000	10	$ 100, 000
Space			20, 000, 000	10	2, 000, 000
Satellites (310 lb)	3	$ 4, 500, 000	13, 500, 000	5	2, 700, 000
② Launch Services	3	6, 000, 000	18, 000, 000	5	3, 600, 000
Miscellaneous Support Equipment			1, 000, 000	5	200, 000
Ground Transmitter	1	2, 500, 000	2, 500, 000	10	250, 000
Ground Receiving Stations	200	500, 000	100, 000, 000	10	10, 000, 000
UHF (VHF) Rebroadcast Stations	200	350, 000	70, 000, 000	10	7, 000, 000
TV Sets	1, 000, 000	200	200, 000, 000	3	66, 700, 000
Total			$426, 000, 000		$ 92, 550, 000
Operation & Maintenance					
Orbit Services					200, 000
Ground Transmitter	20%	2, 500, 000			500, 000
Ground Receiving Stations	20%	100, 000, 000			20, 000, 000
Rebroadcast Stations	20%	70, 000, 000			14, 000, 000
TV Sets	1, 000, 000	5			5, 000, 000
Total					$132, 250, 000

Notes: Class .. Distribution Satellite System

(1) R&D Breakdown

Ground:

Satellite Earth Station	$1.0	million

Space:

Microwave solid-state integrated circuits	$1.5	million
KU Band TWT	1.0	million
Satellite development	17.5	million

(2) One of the Delta class launch vehicles assumed to exist in 1972.

TABLE 10. D. 7

PROGRAM COSTS
CLASS B COMMUNITY SATELLITE SYSTEM

Cost Element	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
① R&D			$ 25, 000, 000	10	$ 2, 500, 000
Satellites (595 lbs.)	3	$5, 000, 000	15, 000, 000	5	3, 000, 000
② Launch Services	3	6, 000, 000	18, 000, 000	5	3, 600, 000
Ground Transmitter	1	2, 500, 000	2, 500, 000	10	250, 000
Miscellaneous Space Support Equipment		1, 000, 000	1, 000, 000	10	100, 000
Ground Receivers & Stations					
Village Receivers	70, 000	250	17, 500, 000	5	3, 500, 000
Town Stations	574	20, 000	11, 500, 000	10	1, 150, 000
City Stations	25	375, 000	9, 400, 000	10	940, 000
TV Sets	1, 000, 000	200	200, 000, 000	3	66, 700, 000
Total			$299, 900, 000		$81, 740, 000
Operation & Maintenance					
Orbit Services					200, 000
Ground Transmitter	(20%)	2, 500, 000			500, 000
Town Stations	(20%)	1, 115, 000			223, 000
City Stations	(20%)	940, 000			188, 000
Village Receivers	70, 000	15			1, 050, 000
TV Sets	1, 000, 000	5			5, 000, 000
Total					$88, 901, 000

Notes: Class B Community Satellite System

[1] R&D

Altitude stabilization	$ 2.5 million
Microwave solid-state amplifiers	1.5 million
"S" Band integrated circuits	3.0 million
Satellite development	18.0 million

[2] One of the Delta class launch vehicles assumed to exist in 1972.

TABLE 10.D.8

PROGRAM COSTS
CLASS C DIRECT BROADCAST SATELLITE

	Quantity	Unit Cost	Total Cost	Useful Life (years)	Annual Cost
Initial Investment					
R&D					
Ground			$ 5,000,000		$ 500,000
Space Related			60,000,000 (1)	10	6,000,000
Satellites (12,000 lbs.)	3	$15,000,000 (2)	45,000,000	5	9,000,000
Launch Services	3	35,000,000 (3)	105,000,000	5	21,000,000
Ground Transmitter	1	2,500,000	2,500,000	10	250,000
TV Sets	1,000,000	242	242,000,000	3	81,000,000
Total			$459,500,000		$117,750,000
Operation & Maintenance					
Orbit Services					200,000
Ground Transmitter	20%	2,500,000			500,000
TV Sets	1,000,000	5			5,000,000
Total					$123,450,000

(1) R&D on Spacecraft

Thin-cell solar power	$ 3,000,000
Lumped tube transmitter	2,500,000
Antenna	2,000,000
Stabilization & propulsion	3,500,000
Qualification Satellite	35,000,000
Support & miscellaneous	14,000,000
	$60,000,000

(2) Satellite uses thin film solar power estimated to cost $100 per DC Watt

(3) At the moment, there is no launch vehicle designed for 12,000 pounds in synchronous equatorial orbit. Approximately 11,000 pounds can be placed for $30,000,0[illegible].

TABLE 10. D. 9

Program Costs
FM Voice Broadcasts
1 Channel
50 dB S/N

Cost Element	Quantity	Unit Cost	Total Investment	Useful Life (years)	Annual Cost
Initial Investment					
R&D	1	$30,000,000	$ 30,000,000	10	$ 3,000,000
Sateilite (2000 lb)	4	15,000,000	60,000,000	10	6,000,000
Launch Services	3	20,000,000	60,000,000	10	6,000,000
Ground Transmitter	1	1,000,000	1,000,000	10	100,000
Total			$ 151,000,000		$ 15,100,000
Operation & Maintenance					
Launch Services					200,000
Ground Transmitter					500,000
Sub Total					$ 15,800,000
Ground Receivers	4,000,000	$ 35	140,000,000	4	35,000,000
Total, Africa			$ 291,000,000		$ 50,800,000
Ground Receivers	100,000,000	35	3,500,000,000	4	875,000,000
Total, America			$[illegible],651,000,000		$890,800,000

TABLE 10. D. 10

Program Costs
FM Voice Broadcasts
2 Channels, 40dB S/N

Cost Element	Quantity	Unit Cost	Total Investment	Useful Life (years)	Annual Cost
Initial Investment					
R&D	1	$25,000,000	$ 25,000,000	10	$ 2,500,000
Satellite (750 lbs.)	4	5,500,000	22,000,000	10	2,200,000
Launch Services	3	8,000,000	24,000,000	10	2,400,000
Ground Transmitter	1	1,000,000	1,000,000	10	100,000
Total			$ 72,000,000		$ 7,200,000
Operation & Maintenance					
Launch Services					200,000
Ground Transmitter					500,000
Sub Total					$ 7,900,000
Ground Receivers	4,000,000	$35	$ 140,000,000	4	35,000,000
Total, Africa			$ 212,000,000		$ 42,900,000
Ground Receivers	100,000,000	35	3,500,000,000	[illegible]	875,000,000
Total, America			$3,572,000,000		$882,900,000

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