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An Assessment of the Status and Trends in Satellite Communications 1986–2000

An Information Document Prepared for the Communications Subcommittee of the Space Applications Advisory Committee

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1986 TO 2000

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SUMMARY

This document was prepared in response to a request by the Space Applications Advisory Committee (SAAC) for information relevant to the status and trends in satellite communications activities. This information was to be used to support that committee's efforts to conceive and recommend long range goals for NASA communications activities. Included in this document are assessments of: (1) the outlook for satellite communications (including current applications, some potential future applications, and impact of the changing environment such as optical fiber networks, the Integrated Services Digital Network (ISDN) standard, and the rapidly growing market for Very Small Aperture Terminals (VSAT); (2) the restrictions imposed by our limited spectrum resource; (3) the technology needs indicated by the discussed future trends. Potential future systems discussed include: large and powerful satellites for providing personal communications; VSAT compatible satellites with onboard switching and having voice capability; large satellites which offer a pervasive T1 network service (primarily for videophone); and large geostationary communications facilities which support common use by several carriers. Also, discussion is included of NASA particular needs and possible future systems. Based on the mentioned system concepts, specific technology recommendations are provided for the time frames of now to 1993, 1994 to 2000, and 2000 to 2010.

E-3270

NASA LEWIS RESEARCH CENTER REPORT TO THE SAAC COMMUNICATIONS SUBCOMMITTEE INFORMATION IN SUPPORT OF LONG TERM PLAN DEVELOPMENT

1.0 INTRODUCTION

1.1.0 Information Requested by SAAC

This report has been prepared in response to a request by the Space Application Advisory Committee (SAAC) for information relevant to future satellite communication activities.

On April 2, 1986 the communications subcommittee through its chairman, Leonard Jaffe, requested NASA Lewis to investigate and report on the following areas:

(1) Satellite communications - plans and technology developments - U.S. commercial, U.S. military, and European

(2) NASA satellite communications needs

(3) Future commercial requirements

(4) Frequency/geostationary arc congestion and the resultant impact

(5) Costs and systems trades in U.S. domestic telecommunications

(6) Technology developments required

1.2.0 NASA Lewis Response

On April 10, 1986, NASA responded with a plan of action, with the NASA Lewis Research Center (NASA Lewis) agreeing to perform the bulk of the work and to report results to the SAAC at their August 16-25, 1986 meeting at Woods Hole. The tasks identified required approximately 24 man-months of effort, but only nine man-months were available. It was agreed that: (1) NASA Headquarters would cover the European developments; (2) the Jet Propulsion Laboratory would provide information on the market demand, technology needed, and current status of mobile satellite communications; and (3) the Department of Defense would be consulted and asked to relate military space communication plans to these studies only after the completion of this report.

As the work began, initial contacts with the U.S. space communications industry indicated that NASA Lewis did not have appropriate access to higher managers to uncover the industry's policies and plans for the future. It was mutually agreed that the contacts with industry would be covered by the SAAC Communications Subcommittee via a series of interviews conducted on June 24 and 25, 1986.

On the same days as these interviews, NASA Lewis gave a "data dump" to the Communications Subcommittee, during which progress was reported. Discussions with the subcommittee resulted in a slight reshaping of the study areas into those contained in this report. Furthermore, the subcommittee directed that the work be based upon existing reports and references, as much as possible, to give support and credibility to information presented and the conclusions reached. This report responds to that guidance.

Following a summary of findings (Section 2.0), the three major sections of the report are presented:

<u>Section 3.0</u>: Outlook for Satellite Communications

<u>Section 4.0</u>: Spectrum/Orbit

<u>Section 5.0</u>: Technology Need and Plans

In Section 3.0, three major current applications of satellite communications are discussed - television signal distribution, trunking for voice and data, and very small aperture terminals (VSAT's). The changing environment, principally terrestrial fiber optics and ISDN, is evaluated for its impact. Future applications of satellite communications are presented, both for commercial use and to satisfy NASA's communications needs. In Section 4.0, the spectrum/orbit capacity, demand, and projected shortfall are identified. Section 5.0 discusses needed technology developments based upon the projected uses of satellite communications identified in Section 3.0. The concluding portions of the report, Sections 6.0, and 7.0, identify technologies common to groups of future satellite communications users, present a timetable for technology development, and indicate areas requiring further study.

2.0 SUMMARY OF FINDINGS

2.1.0 Coverage

In order to identify significant future technology developments needed in the area of satellite communications, the current and projected status of the arc/spectrum resource was examined, several potential future commercial applications resulting from current trends were postulated, and NASA's own downstream communications needs assayed. The potential commercial applications included personal communications, orbiting switchboard/very small aperture terminals (OS/VSAT), videophone, and geostationary multiservice, multiuser communications facilities.

2.1.1 <u>Arc/spectrum resource</u>. - With respect to the arc/spectrum resource, the U.S. geostationary arc capacity is 1608 equivalent 36 MHz transponders. This is based on 34 C-band and 33 Ku-band satellite slots, 500 MHz frequency allocation per slot, and two times frequency reuse. Going to three times frequency reuse at Ku-band, and then to 1.5° spacing at Ku-band, would increase the arc capacity to 2000 and 2400 transponders respectively.

Various market demand forecasts over the last few years have tended to show that the demand could equal the arc capacity by the early 1990's. The capacity expanding Ku-band considerations discussed above could extend this to the late 1990's or early 2000's. These forecasts were predicated on demand growths and technology trends envisioned at the time, and consequently do not reflect major developments over the last three years such as the long haul fiber optic networks and the growing proliferation of microterminals and VSAT systems. The potential exists for the demand for certain higher bandwidth services, such as video conferencing, to develop much faster than expected. While it is not feasible to quantify with any certainty the impact these will have on the demand for satellite delivered services, some sources believe that VSAT demand will equal or exceed the loss due to fiber optic trunking systems. If VSAT technology could be developed to transmit voice effectively (VSAT's are currently limited to mostly data over the double-hop Cand Ku-band systems), the demand for the service might sharply increase, as it provides a means of bypassing the terrestrial network and its costly "last-mile" distribution problem.

Means of further expanding satellite and overall arc capacity are possible by developing higher frequency bands such as Ka-band (30/20 GHz) and developing technologies enabling higher degrees of frequency reuse. Ka-band has unique characteristics that make such systems particularly suitable for the VSAT bypass technology discussed above. Associated developments in multibeam technology, on-board processing and switching, and intersatellite link technology have the potential for greatly expanding the arc capacity and can be adapted to Ku-band as well.

2.2.0 Needed Technology Developments

In consideration of the possible future commercial applications and of NASA's own potential communications needs, a number of common technology development requirements recurred. These developments were, basically:

Large and complex multibeam antennas
- Phased array feeds (MMIC based)
- Deployment and control of large precision surfaces
- Methods for generating and isolating hundreds of beams
- Polarization variation tracking (for Ka-band)

Advanced on-board processing and switching
- "Operational ACTS" to order of magnitude greater capacity
- Reduced power, weight, volume, requirements
- Circuit/packet switching capabilities
- ISDN compatibility

Bulk demodulation technology
- Single device demod of thousands of narrow band channels
- Voice compression advances

Intersatellite links

Some of the rationale for the need for the foregoing technology developments is summarized below.

2.2.1 <u>Personal communications</u>. - In commercial applications, the most intriguing and the most challenging is the concept of truly personal communications by satellite. As was true of most of the applications reported herein, this concept has been proposed and evaluated by others. The concept embodies the concept of a "wireless" phone which the user can carry or "wear" anywhere, with which he is able to access a large satellite and thus realize nationwide communications on a personal basis. The success of this concept hinges on the availability of large precision antennas, high capacity satellite baseband processors, and high capacity bulk demodulators (devices for simultaneously demodulating 1000's of narrowband channels and aggregating these into a wideband digital stream, compatible for baseband processing)

2.2.2 Orbiting switchboard/very small aperture terminals (OS/VSAT). - The concept of terrestrial bypass is increasingly becoming important to users as terrestrial costs continue to rise while, at the same time, earth station technology is rapidly diminishing in cost. Very Small Aperture Terminals (VSAT) are available at costs ranging from $2,500 to $5,500 at C-Band for low data rate applications (typically 1.2 kbps), and about $12,000 at Ku-Band for higher rate applications (typically 100 kbps). Currently these technologies make use of star networks, sending all data to a remote master station for regeneration and redistribution. With this double hop, the delay would make voice unacceptable and is not used except in extreme cases. Processing satellites could replicate the function of the master station and eliminate the double hop. Users would be able to include voice in their networks and eliminate the expense of the master stations. The necessary developments are modest extensions of the NASA ACTS technology. Lower uplink burst rates are necessary to reduce the EIRP of the VSATS commensurate with their lower throughput. In the extreme of reaching very narrowband users, as are now prevalent in this market, fixed uplink beams are a necessity (ACTS currently uses scanning beams on both the uplink and downlink). Baseband processing will be necessary for interconnecting these small users and the required capability is similar to the current ACTS technology (though with greater capacity). Consideration should be given to packet switching in parallel with circuit switching, as this parallel feature is inherent in the ISDN standard. As was the case with personal communications, bulk demodulators are essential, especially for the extreme application of the more narrowband users.

2.2.3 Videophone. - Duplex videophone has been proposed and user experiments have been performed to test its acceptability to the consumer. High transmission costs have always been an impediment to the quality and acceptance of this useful method of communications. With the advent of optical fiber, this impediment will gradually pass. In the interim (until optical fiber becomes pervasive), satellites have been proposed as a method of introducing this service to the urban areas and maintaining coverage to surburban and rural areas. Large, high capacity (approx. 12 Gbps) satellites have been suggested as appropriate. In effect, a pervasive wideband (3 Mbps) service would be made available on a nationwide basis, primarily for this video service. Ka-Band was suggested as the most desirable band, as this has the potential of large frequency reuse with physically small antennas (400 spot beams are typical). Needed technologies are complex multibeam antennas, SAW demodulators, and on-board switching.

2.2.4 Geostationary multiuser communication facilities. - Large geostationary communication facilities aggregate various payloads on the same structure for synergistic benefits, and to conserve orbital arc. One application of this technology would be the enabling of smaller nations to jointly purchase and use sophisticated satellite technology which they could not effectively use individually. An extreme example is utilization of the allocated expansion bands at C and Ku-Band. It appears that each nation will be allowed only one orbit position for domestic use in these bands. In the course of economic growth, most nations will eventually need more capacity. This can be done through appropriate frequency reuse, but will involve sophisticated and expensive satellite technology. Shared purchase and operation of such technology will greatly enhance the usefulness of these expansion bands, as several frequency reuses are feasible even with current technology. Considerable institutional and other problems exist for such sharing, however.

2.2.5 NASA needs - The possible future missions of NASA dictate the communications needs. Future science missions, whether in LEO, GEO, or deep space, will likely use more advanced sensors and require greater capacity in data acquisition and relay systems. As well as increased capacity, such systems in orbit will require intersatellite links with science platforms and with each other. Multiple downlinking of information directly to users is also likely to be a requirement. These data acquisition and relay systems must be highly reliable and provide as complete coverage as possible. Completion of TDRSS (Tracking and Data Relay Satellite System), upgrading of TDRSS in the nineties, and eventual deployment of TDAS (Tracking and Data Acquisition System) in the early 2000's are a must.

Interconnectivity will also be a requirement for the Space Station in LEO and for any other space stations/spaceports which might be constructed in the future in response to the President's National Commission on Space (NCOS) recommendations. Various links will be needed between stations/spaceports/bases, incoming/outgoing spacecraft, Earth, etc.

Establishment of manned lunar bases in response to NCOS recommendations will require an advanced communication system. Three satellites could provide reliable full surface coverage. Reliability of communications will be a must because of the hostile environment. A personal communications system similar to that described earlier will likely be needed for frequent personnel surface excursions from the bases for exploration, sampling, or even mining purposes. These reliable mobile/personal units would include voice and data communications, and navigation and position determination features. A similar system is likely to be needed for any Mars/asteroids manned bases.

Attendant to all these will be an essential upgrade of the NASA DSN (Deep Space Network) to support the many critical manned activities associated with the lunar and Mars missions. Such an upgrade may go beyond the terrestrial net and require the establishment of an orbiting satellite system.

3.0 OUTLOOK FOR SATELLITE COMMUNICATIONS

3.1.0 Current Applications

This chapter presents a look ahead as to potential future roles of the satellite as a medium for delivering telecommunication services. Such a look ahead would be incomplete without an examination of the current communications satellite role, and what environmental changes, both internal and external, are taking place which might alter that role. Current applications to be examined are wider distribution, trunking services, and the new and growing customer premises services provided via VSAT's.

3.1.1 Video distribution. - Video distribution has been and is likely to continue as a major application of satellite communications. As of May, 1986, over 230 transponders (refs. 3.1, 3.2, and 3.3) were transmitting video on a full or part-time basis. This service probably best characterizes the advantages of satellite technology in terms of providing economical point-to-multipoint distribution. Video applications can be categorized as network television (commerical broadcast), noncommercical or public broadcast (PBS), cable television (CATV), occasional use video and direct broadcast services (DBS).

The three major television networks should be providing program distribution totally by satellite by 1987 (ABC and CBS via C-band and NBC via Ku-band). Several transponders may be utilized by any one network to accommodate time zone programming, multiple simultaneous feeds for sporting events, news pickups, backup and test channels. Twenty-seven transponders are now utilized for these applications. Five independent broadcasters ("super stations" such as WTBS) also lease transponders for video distribution.

PBS instituted a satellite program distribution system in 1978. PBS currently utilizes 4 transponders for not only traditional television programming but also educational programs for colleges, businesses, etc. The PBS budget for fiscal year 1985 for operation of the satellite innerconnection system was over $9 million.

The use of satellites by the CATV industry began in 1973 in the U.S. and grew to a current utilization of over 70 transponders. By 1986, the number of cable systems had reached 7300 with the number of subscribers reaching about 40 million. Services available from CATV include movies, religious and educational programming, sporting events and ethnic programs. These services are made available by satellite programmers who purchase or lease transponders from satellite operators. The SATCOM and GALAXY satellites are the dominant spacecraft utilized by the cable industry.

Occasional use video represents a variety of TV programming such as sports, news feeds and partial-day cable programming, and also business and educational one-way video teleconferencing. Estimates of these transponders that are not used full-time by any one user have surpassed 70 in number. Occasional use transponders, in some cases, are rented out on an hourly or one-half hour basis from a number of brokers (resale carriers) who have acquired blocks of satellite capacity, or satellite carriers who have set aside specified transponders for this service. This method allows users who do not require a full-time transponder to rent on an as-needed basis and thus also avoid the full monthly rental rate. Some of the resale carriers are the Bonneville Satellite Corporation, Netcom Enterprises and Robert Wold Company. A recent estimate of 20 transponders were being leased by these resale carriers.

High-power direct broadcast of video to homes via satellite has not materialized since eight applicants were granted provisional construction permits in November, 1982. This service now has the potential of becoming a subscription service opportunity for current cable TV programmers through the scrambling of their signals, but not at high power. No transponders are currently used for the purpose of direct-to-home broadcasts although it is well known that over 1 million C-band backyard dishes are in place receiving CATV and network television signals. The market for these C-band TVRO's has exploded in the last couple of years. However the recent advent of signal scrambling by the programmers has drastically reduced the growth of this market. Dish owners will be required to purchase/lease decoders or pay a subscription fee as well.

Regardless of this current situation, backyard dish owners may serve as the potential market for true DBS service in conjunction with satellites having 40 W of power/transponder.

Estimates (1985) of the number of TVRO earth stations that are utilized for video distribution services can be broken down as follows:

NUMBER OF TVRO EARTH STATIONS
(ref. 3.4)

Commerical and Independent Networks	12,300
PBS	200
CATV	8,500
SMATV ("Private Cable")	1,500
LPTV (Low Power TV)	150
Multipoint Distribution Systems	250
Subscription TV	150
Videoconferencing Networks (such as Hi-net)	750

Finally video distribution utilizes approximately 40 percent of the transponders that are currently on-orbit.

3.1.2 Trunking. - A dramatic expansion of fiber-optic cable networks is planned for the domestic telecommunictions industry over the next several years with 60,000 route miles of fiber-optic cable planned to be operational by 1989 (ref. 3.5). Currently one-third of these miles have been cutover. These fiber networks, which will be pursuing the anticipated $78 billion long haul market, are anticipated to limit the role of the satellite trunking business.

Traditionally some long-haul trunking services e.g., communications among the major nodes in a carrier's network across the U.S., have been provided by satellite. Satellites have augmented the terrestial capacity of the major long-haul carriers-ATT, GTE, and MCI. Private lines for corporate networks have been provided through satellite-based carriers that include American Satellite, RCA Americom, SBS, Western Union, etc. Customers who have utilized these carriers include Xerox Corporation, Ford Motor Company, Lockheed Corporation, J.C. Penney Co., etc. Private satellite trunking networks have been utilized to help control the millions of dollars of expenditures on corporate telecommmunications. For example, when GSA aggressively pursued cost reduction methods for the Federal Telecommunications System it was noted that satellite technology utilized between Washington and San Francisco resulted in a savings of more than 60 cents on the dollar in 1981.

At the end of 1985 it was estimated by the Communications Center of Clarksburg (ref. 3.1) that over 60 transponders were utilized in public switched networks. Estimates of private voice and private data transponder utilization for this same period have been approximated as 50 and 25 transponders, respectively. Now, however, several of these long-distance carriers, including GTE Sprint and SBS, are in the mode of shifting services to fiber-optic systems. Other satellite carriers are also starting to feel the terrestrial competition.

Two recent long haul company mergers are indicators of the trend that reflects the migration of services from satellites to fiber-optics. First, MCI (the number 2 ranked long haul carrier) acquired SBS (the number 4 ranked long haul carrier). SBS's residential customers are being shifted to MCI's land lines. This terrestrial network will consist of 28,000 route miles/350 million circuit miles when MCI's 7,000 route miles of fiber optic cables are cutover. Utilization of this network will leave the satellite portion of MCI/SBS to transmit data, backup voice and teleconferencing.

The second major merger involved the third ranked long haul carrier GTE Sprint and the sixth ranked long-haul carrier United Telecommunications. The resulting long-distance telephone unit is now known as U.S. Sprint Communications Co. It is anticipated that some customers will be transferred to the fiber-optics network which has already cutover 6,200 miles. Twenty-three thousand route miles are proposed to be cutover by 1990.

The trend of fiber implementation is similar with the number one carrier AT&T. According to the network planning director at AT&T Communications (ref. 3.6), AT&T's total long-distance domestic circuit mileage on satellites, which has never been higher than 10 percent, is expected to be largely eliminated during 1986. Increasing traffic demand will be handled by a fiber-optic network that will be about 11,000 miles by 1987.

Time delay due to transmission by satellite is one of the reasons that some services are migrating to terrestrial systems. For example, Allnet Communication Services, Inc., a long distance telephone company is phasing satellite out of its network because of the delay. More important however, are the recent dramatic improvements in both cost and capacity of fiber-optic systems, which should make them the future dominant means of long-haul transmission. It is becoming evident that fiber-optics will be the lowest cost alternative for any high volume trunking mission.

This view indicates that satellites may play a minimal, if any role at all, in high-volume trunking communications. However, as discussed in the next section 3.1.3, trends to higher power (45 W) satellite transponders, satellite switching, and VSAT's indicate that satellites have the potential to halt the migration of services to terrestrial networks.

3.1.3 Very small aperture terminals (VSATS). - VSAT is an acronym for Very Small Aperture Terminal and is used to describe a new class of earth station characterized by its small size and low cost. Typical aperture size is under 1.8 m and these have the attributes of simplicity of installation and use.

VSATs are intended for use at the user's immediate facility and are usually designed for relatively low rate data (ref. 3.7).

Two popular methods of accessing a satellite with VSATs are spread-spectrum modulation in conjunction with Code Division Multiple Access (CDMA) and relatively narrowband Time Division Multiple Access (TDMA) (ref. 3.8). An alternative, and more complex method, is Multiple Frequency Time Division Multiple Access (MFTDMA) where both frequency and time accessing is used to distinguish users (ref. 3.9).

The emergence of this new class of earth station was stimulated by three events (ref. 3.10): the U.S. industry investment in DBS-TV technology; the success of Equatorial Communications with over 25,000 receive only and 1,000 transmit/receive micro earth stations installed; and the decision of Federal Express to purchase 50,000 small two-way earth stations for networking their field centers.

Since these terminals are small, it is usually necessary to use a very large earth station to receive and regenerate the transmitted data signals before distribution to other micro terminals. Consequently, microterminal to microterminal communications involve two satellite hops for a total of 1/2 sec delay. This delay is acceptable for data but is unacceptable for voice.

With the use of a baseband processor on the satellite, the function of the major earth station can be replicated and the double hop eliminated. With this technology, acceptable voice communications could also be enabled. This concept was recently proposed as an application of the NASA ACTS baseband processor technology (ref. 3.11)

Currently two frequency bands are being used for VSAT networks, C-Band and Ku-Band. Both use conventional satellites in those respective bands. Ku-Band, being a higher frequency, offers about 7 dB more gain than C-Band for the same size aperture. On the other hand, Ku-Band suffers significant rain attenuation at times. Probably the most important advantage of Ku-Band is the freedom from the need to coordinate with terrestrial services (ref. 3.8).

Estimates of the market for such earth stations have been made and are illustrated in figure 3.1 as the number of earth stations in place versus time. The larger estimate, made by Compucon, Inc., is about twice that of International Resource Development, Inc (IRD). It is believed that Compucon's estimate is higher due to inclusion of an assummed offering by AT&T/Harris which they expect to at least equal the system planned by Federal Express. IRD's estimate is essentially that required by Federal Express. Neither estimate includes widespread use of voice because of the inherent double hop with these systems. Data rates on the C-Band terminals are typically 1200 bps. This rate is then multiplexed to a higher rate of 150 kbps which is then spread to an 8 Mhz bandwidth with a suitable PN code (ref. 3.7). Similar data rates and higher are available with the Ku-Band VSAT's. Operating in a TDMA mode, the uplink burst rate is typically 128 kbps and the downlink 512 kbps. Of course, each terminal would use only a small portion of this capacity, but such terminals have been proposed for 16 kbps voice (ref. 3.12).

The bulk of these existing VSATS are used in inquiry applications. As such, only a small portion of data is transmitted to the master station and a relatively large amount returned. Consequently, hundreds or possibly thousands of VSATs can be served by a single transponder. Estimates have been made for the transponder requirements required to accommodate the terminal population estimates of figure 3.1 and are shown in figure 3.2. The lower estimate was provided by IRD. The upper estimate was obtained by scaling the IRD estimate by the same ratio as that between the population estimates in figure 3.1

Again, the disparity between the estimates is partially accounted for by Compucon's assumption that AT&T in partnership with Harris will undertake a VSAT venture on the same scale as Federal Express. An average of 90 to 100 transponders could be postulated for VSAT use by 1995.. This represents about 10 percent of the transponders expected to be available in that time frame.

An estimate of the distribution of terminal types has been made for 1994 by IRD and is shown in figure 3.3. Of the estimated 263 thousand terminals in place, 55.2 percent of them are expected to be two-way earth stations. IRD also estimated the distribution of sales for the same year and are shown in figure 3.4. 84.5 percent of the sales are expected for two-way earth stations at an average price of $9,500.

As previously mentioned, these estimates do not include widespread use of voice. With new technology satellites, having baseband processing, voice could be included and a substantially greater number of terminals and transponder requirements would result. Also, the character of the earth stations could change with substantially higher burst rates being used. This would tend to drive up the cost and possibly size of the earth station, but substantial capacity increases would also occur. This potential future is discussed further in "Terrestrial Bypass", Section 3.3.2.

3.2.0 Impact of Changing Environment

3.2.1 Fiber optics. - A number of long haul fiber optic networks are being implemented to capture portions of the U.S. domestic long distance service market (inter-LATA communication traffic; LATA = Local Access Transport Area) which is growing at an annual rate of approximately 7.8 percent. Revenues are projected to rise from the 1985 figure of 57.6 to $78 billion in 1989.

Table 3.1 (ref. 3.5) summarizes the systems currently under construction. This chart breaks down the plans of the four nationwide and the nine regional systems (note the number of regional systems climbs to 16 if the seven members of the NTN consortium are included). The planned number of route miles exceeds 60,000. The electronics proposed to be utilized in these systems over the next few years will provide bit rates generally of either 405 or 565 Mbps. Most of the networks are concentrating implementation in the eastern U.S. where over two thirds of the U.S. domestic traffic resides. Pontential capacity gluts could arise in many cities where at least three fiber optic networks will vie for customers.

One-third of the proposed networks, or 20,000 miles, have been cutover. This figure may climb to over 75 percent by the end of 1986 if construction schedules are maintained.

There are several factors that have been involved in creating the carrier's shift to fiber optic systems. One of these factors is the growing bandwidth capability. Fiber optic systems were capable of transmitting 45 Mbps, or 672 voice channels per fiber in the late 1970's. Current system implementation include electronics capable of 565 Mbps or 8,064 voice channels. 1.7 Gbps electronics will be commercially available by 1987. Attenuation is also quite low for the silica glass fibers being installed. Losses range from 0.4 dB/km for optical communications at 1,300 nm to 0.2 dB/km for 1550 nm. Along with the greater carrying capacity of optical fibers is smaller size and weight. A fiber cable with a capacity of 50,000 channels is 1.25 cm in diameter and weighs only 1.2 kg/m. AT&T has installed many cables with 144 fibers bundled together.

Another reason for the shift to fiber-optic systems is that the lines are less susceptible to noise and electromagnetic interference from outside sources, much less than copper cable or satellite links. Also, since virtually no electromagnetic radiation leaks from the fiber cable, and it is difficult to tap into a glass fiber without detection, it is a good medium for applications requiring confidentiality and security.

Other advantages of utilizing fiber optics include: these systems are well suited to the trends of digital networks (e.g., ISDN); fiber system reliability is very high and this reliability is enhanced even more by the use of these systems within switched digital networks that automatically reroute upon failure of any individual circuit or portions of the network; modular design, where each component of a fiber optic system can be upgraded individually; and, finally, one of the most important attributes of a fiber optic system is that of minimal delay time in transmission.

A summary of these characteristics of fiber optic systems and those for satellites per F. Guterl and G. Zorpette of IEEE (ref. 3.6) are noted in table 3.2

It is anticipated that fiber optic systems will significantly reduce the two-way service applications of satellites. H.S. Braham (refs. 3.11 and 3.13) of TRW has been active in assessing the satellite role in the "fiber era." He has noted that point-to-point trunking produces most of today's satellite revenues for two-way service. Braham further indicates that this service will become obsolete as fiber will reduce the current terrestrial cost of transmission by a factor of 10 or more and even be much cheaper than satellite transmission on transcontinental links. Even though a good portion of an end-to-end circuit cost is the "last mile," Braham estimates that fiber systems will provide service at 20 cents/voice circuit minute which is 6 cents less than 1985 estimates for the average Fortune 500 company cost (700 mile average distance).

The Spring 1985 issue of Commercial Space (ref. 3.14) presented several views by leading industry officials on the fiber/satellite trade-off position. Thomas Leming of MCI noted that west of the Mississippi that fiber is too expensive because there's not enough traffic. He noted that 30,000 circuits are required before fiber is economical.

Richard Cassam of Sprint stated that the distance threshold for economical satellite use has been about 750 miles. However, now satellites are not always the solution but rather optical fiber can be used when the traffic volume between two nodes is above 20,000 to 30,000 circuits.

Fred MacPhearson the director of network planning for Starnet, the long-distance telephone subsidiary of Ford Motor Co., noted that satellite carriers were responding to the fiber challenge with price reductions. In 1984, a 1.5 Mbps channel was available for $22,000 to $24,000 per/month. In early 1985 the price dropped to $15,000 to $16,000 and in 1986 the price could fall to $12,000.

Alfred Goldman (ref. 3.15) has illustrated the cost differences for certain city pairs utilizing these two technologies. He determined that when comparing costs for the intercity portion of a transmission (excluding the local loop) that the monthly voice circuit cost for a New York to Chicago line would be $625 for a satellite carrier and $261 for a fiber optic carrier.

Another cost comparison/cost trade analysis of fiber optics versus satellites (and microwave) was performed by Compucon, now Spectrum Planning, in a multiclient study (ref. 3.16) examining the competition in the long haul telecommunications market. Table 3.3 presents costs for the three technologies for various circuit capacities and route lengths. The conclusions drawn by Compucon are given in table 3.4.

Economic analyses such as the one performed by Compucon conclude that a fiber optic system in most circumstances is the preferred transmission medium. "Terrestrial Bypass," Section 3.2.2 will present an application that may strengthen the satellite role in the future and counter the impact of fiber optic systems. For new satellite technologies such as electronically hopped antenna beams and on-board switching will provide the means to provide more economic communications through independent voice/data networks or through the augmentation of existing terrestrial networks for thin route or low data rate links. While fiber may dominate trunking routes, satellites with functioning switches will be more flexible and cost-effective. As a result large customer premise based satellite networks may evolve. This development will allow satellites to proliferate by the year 2000.

3.2.2 Integrated services digital network (ISDN). - ISDN is an acronym for the Integrated Services Digital Network standard formulated by the CCITT (International Consultative Committee on Telephony and Telegraphy) and included in its 1984 recommendations. The purpose of the standard is to encourage and simplify implementation of dial-up digital access throughout the world. Features of the standard include direct digital access for voice and data by all users. This encompasses relatively wideband access having multichannel and multiservice capability.

The basic access to an ISDN network includes 2 B channels of 64 kbps each and 1 D channel of 16 kbps. All three channels are provided on a dial-up basis. The two B channels can be used for voice or data. The D channel is used for signaling as well as packet switched communications.

North America and Japan also include a primary access of 1.544 Mbps. This can be arranged as either 23 B channels and 1 D channel (all at 64 kbps) or 24 B channels. For the rest of the world the primary access is 2.048 Mbps which can be arranged as 30 B channels and 1 D channel or 31 B channels (all at 64 kbps). Again, the D channel is intended for signaling and packet switched communications. A dedicated signaling channel, the E channel, has been proposed but no standard has yet been agreed upon.

With this recognized standard it is expected that the existing terrestrial network will eventually become fully digital with relatively wideband access provided to every user (up to 144 kbps). In North America a hinderance to this development is the heavy investment in the existing analog plant by the BOC's (ref. 3.17). In addition, the digital plant is based on 56 kbps access instead of the required 64 kbps. However, this latter constraint is much easier to overcome than the former. The existing twisted wire pairs would support ISDN only up to about 6,000 ft. The average loop length in the U.S. exceeds 12,000 ft (ref. 3.17). Consequently, full ISDN access would require either installation of intermediate Digital Loop Carrier equipment or replacement of the twisted pairs with a wideband loop technology such as optical fibers.

AT&T has announced that the 4ESS switch will be available in 1987 having compatibility with the ISDN format (ref. 3.18). Also, the 5ESS will support both basic and primary ISDN access (ref. 3.19).

With these considerations it has been estimated that ISDN will be available in a few selected cities by 1987 and in all major cities by 1990 (ref. 3.17, p. 88).

Widespread availability of this wideband service will encourage the transition to duplex videophone. Freeze frame devices are already being used over existing analog facilities (ref. 3.20). Such devices sell for about $1400 and would likely be much less expensive with the production volume implied by widespread use.

It has been estimated that 4000 such videophones will be in use by 1992 and 35,000 by 1995 (IRD)

Implementation of ISDN by satellite systems has been proposed (ref. 3.21). One of the major differences of a satellite system is the significant propagation delay of about 1/4 sec. This will have a major impact on how signaling channels are used and require different protocols than are used in the terrestrial system where delays may be as small as 10 μsec. Suitable protocols have already been developed and tested in previous satellite systems. The use of such protocols necessitates the use of protocol interfaces in those earth stations that use terrestrial facilities as "tails." In addition, such interfaces may also be required for local communications equipment which is expected to be designed for ISDN compatibility (which will assume the shorter terrestrial-like delays)

The impact on satellite design, of requiring ISDN compatibility, will be significant. First the wideband access per user will more than double the power requirements over the usual 56 kbps. In addition, for a fixed number of users, the spectrum requirements would more than double. Circuit switched data/voice capability is required which implies a baseband switch on the spacecraft. The 2B+D minimum access implies a satellite switch having both circuit switched and packet switched capability. However, it may be possible to use suitable interfaces within the earth stations which will circumvent this requirement. With these, the satellite may be transparent to the user while operating in a conventional TDMA mode. However, circuit switched capability would still be needed as a minimum.

The ACTS baseband processor could provide ISDN capability provided the aforementioned protocol conversions were performed in the earth stations. This capability would include basic (2B+D) as well as primary (23B+D) access.

Service cost estimates for basic access with an operational Ku-Band satellite system are given in table 3.5. These were estimated by extrapolating from the results given in "Terrestrial Bypass," Section 3.3.2. The analysis assumed the use of a 1.5 Mbps earth station, a 3 Gbps satellite (6x frequency reuse), and 3,400 earth stations at $25K each. The rate shown is cost, in cents per minute, for the basic access of 144 kbps. Of course, partial access is also possible at reduced rates.

In the ISDN environment, satellites are likely to be used in the same way they are used for conventional services. A comparison of costs will be made in each case and the satellite method selected when favorable.

As previously mentioned, ISDN will most likely be available only in the major cities through 1995. Consequently, satellites will be used in a complementary fashion, to provide ISDN service to the smaller cities and surburban areas.

3.2.3 Spectrum/orbit congestion. - Geostationary communications satellites are positioned in the equatorial plane at the proper distance to be stationary with respect to the earth. In order for a satellite to be in view of its intended coverage area it must be positioned within a specific segment of the 360° equatorial arc. This segment is also determined by the minimum elevation angle allowed which tends to be greater with higher frequency of operation. For C-band the allowable arc for the contiguous United States (CONUS) is about 88°, for Ku-band 78°, and for Ka-band only about 20°. Figure 3.5 illustrates the CONUS orbital arc for C-and Ku-bands. From system interference considerations, there is a minimum allowable spacing in the geostationary arc. Thus, the extent of the arc and the minimum spacing determine the number of satellites that can be placed over the intended coverage area. The potential number of satellites in the arc and the throughput capacity per satellite, then, determine the communications throughput of the arc. All of the above factors are functions of technology and, as a result, advances in technology have improved the arc capacity over time. For example, the earlier C-and Ku-band systems were constrained to minimum spacings of 4 and 3° respectively. Advances in technology have enabled this spacing to be decreased and consequently in 1983 the FCC mandated that all new systems both C-and and Ku-band be compatible with 2° spacing. With a portion of the CONUS arc reserved for Canada and Mexico, this permits a total of 67 satellite positions, or slots, in the arc for U.S. satellites (34 C-band slots and 33 Ku-band slots). The 2° spacing will not be fully phased in until the older equipment has been retired from service and this will not occur before the early or possibly mid 1990's (ref. 3.22). Thus the arc capacity in slots will gradually grow from 38 with the earlier spacing to 67 with the 2° spacing. Currently there are 25 U.S. domestic satellites in orbit occupying a total of 28 slots (hybrid C/Ku satellites count as two slots each). Twenty-four (24) more satellites (29 slots) have been approved by the FCC for a total of 57 slots spoken for. The original round of filings to the FCC in 1983 included four more Ku-band systems for a total of 9 Ku-band slots. Although these four were initially rejected on financial grounds, one of these, National Exchange Incorporated, has reapplied for their two satellite Ku-band system. If approved, the total number of slots spoken for would be 59, leaving only 8 slots available (room for 4 C-band and 4 Ku-band satellites, or 4 hybrid satellites). Thus the C and Ku orbital arc slot availability is virtually all claimed now, leaving further arc capacity expansion to other means such as greater satellite throughput and use of other frequency bands (such as Ka), all requiring the development of enabling technologies. This is discussed more fully in section 4.0.

Each of the available frequency bands has its unique characteristics and consequent advantages and disadvantages. As frequency is increased from C-band to Ka-band signal outage due to rain attenuation becomes progressively worse. While this is not of much concern at C-band, it begins to be felt by Ku-band and at Ka-band specific measures must be taken to deal with it. Site diversity and adaptive power control are means considered to contend with rain outage at

Ka-band, but these increase system complexity and introduce other problems. On the other hand, as frequency increases, the size of the antennas required, both on the ground terminals and the spacecraft decrease in size (or conversely have a much higher focusing power for a given size). Thus, this makes the higher frequency systems particularly attractive for multibeam frequency reuse. A Ka-band antenna has a focusing power of 25 times that of an equivalent size C-band antenna and can achieve a 6 times frequency reuse with a 24 beam CONUS coverage (fig. 3.6) thus making one Ka-band satellite equivalent in capacity to 6 C or Ku-band satellites, as they are conventionally used.

There is 500 MHz of frequency spectrum allocated for communication satellite use at both C-band and Ku-band and 2,500 MHz at Ka-band. The C-band allocation must be shared with terrestrial systems, the Ku-band allocation is exclusively for space systems, and all but 500 MHz of the Ka-band allocation must be shared with terrestrial systems. Because of interference considerations, and especially if Ka-band were to develop largely as customer premises applications (e.g., VSAT's), sharing with terrestrial systems might not be practical. This would leave only 500 MHz for Ka-band satellite operation.

In terms of the arc capacity for each band, it was noted earlier that C-band has 34 slots and Ku-band has 33 slots. Ka-band, because of the high (30°) minimum elevation angle imposed due to rain attenuation, is constrained to about a 20° arc segment centered about 100° West Longitude. But because of the narrow beam widths at Ka-band, 1° spacing is possible. Thus on the order of 20 slots are available. If one Ka-band satellite is equivalent to 6 conventional C or Ku-band satellites, then, the capacity at Ka-band is equivalent to 20x6 = 120 conventional satellites or almost double that of the entire C and Ku-band arc capacity (67 slots combined). Thus, Ka-band would have the potential for tripling the U.S., arc capacity from a mere 20° of geostationary arc. If the entire C or Ku-band arc could be used for Ka-band, this capacity could be multiplied many times. The development of intersatellite link technology could enable this, and would therefore be especially important in expanding the arc, particularly at Ka-band.

3.3.0 Future Applications

In what follows, a look is taken at the general range of usefulness of the communications satellite: what services it is ideally suited for providing, both now and in the future, and what services it can effectively provide, though not uniquely suited to do so. The trends in several applications are examined: personal communications, terrestrial bypass, videophones, and large geostationary communications facilities. NASA's own communications needs for the future are briefly surveyed, with emphasis on space communications. These possible future applications, in conjunction with projected spectrum/orbit resources (to be discussed in Section 4), are then examined in Section 5 for their technology/R&D implications.

3.3.1 General range of usefulness. - In the years ahead, communications satellites will be faced with growing competition from terrestrial systems in areas where the satellite has dominated or played a significant role. Transcontinental U.S. and transoceanic fiber optic cables will be installed, providing considerable wideband capacity increases for domestic trunking and for overseas traffic. Increasing availability of switched data circuits in the terrestrial net will threaten, if not actually erode, the role satellites have played in providing inter and intra-company data and other communications services. Communications satellites can, however, continue to dominate other transmission media in those applications particularly suited to the satellite. The satellite can also maintain, if not increase, market share in areas threatened by new terrestrial approaches.

Communications satellites have been considered the optimum choice for point-to-multipoint, mobile, and remote/thin route traffic. They have also been one of the successful alternatives in providing bypass of local telephone operating companies (telcos).

Point-to-multipoint applications are based on the inherent broadcast capability of the satellite. Such applications include:

(1) Network and Cable TV Distribution
(2) Direct Broadcast Video
(3) Corporate Data/Videoconferencing Private Networks
(4) Multisite Periodical Printing
(5) Financial Information Services

These services migrated to, or orginated on, satellites due to the satellite capability to transmit, relatively reliably, wide bandwidth over long distances. Terminals can be rapidly installed almost anywhere, modified, or taken down and moved as needed. These "instant", easily reconfigurable networks overcome the often long lead times required for terrestrial tie-ins.

The provision of mobile services is another niche for the communications satellite. Of the main categories of mobile service (land mobile, aeronautical, maritime, and personal communications), only maritime is currently being provided by satellite. Twelve applications for land mobile systems have been filed, and aeronautical systems have been studied. With respect to personal communications, some long distance "beeper" services may currently utilize satellite circuits, but only because the satellite is an alternate signal path in a carriers network.

Remote or thin route traffic is well-suited to the satellite. Distance and terrain pose no obstacles for the satellite, whereas installation of terrestrial microwave relays or cabling through heavy jungle, over mountains, and the like could be extremely costly relative to the amounts of traffic carried. Wherever it is difficult to make physical terrestrial connections, temporary or permanent transmit and/or receive earth stations can be installed relatively easily.

As well as providing effective, flexible point-to-point services for remote or thin route applications, the communications satellite can play an important role in linking metropolitan and other areas in countries where extensive terrestrial systems do not exist. The Palapa satellite links the numerous islands of Indonesia. The Indian multiservice satellite Insat provides point-to-point communications and TV distribution, and weather monitoring as well.

Finally, the satellite has been, and can continue to be used, as a means for bypassing the local telcos or the entire terrestrial network. Bypass has been engaged in by many companies for any of a number of reasons: desired services unavailable from the local telco; long delays (often 6 months or more) in installation of lines, corporate desires for control over the network; and/or cost-effectiveness of the bypass system versus the "standard" system. Currently, bypass via satellite can take several forms. One of these is the location of earth terminals directly on users premises. Another is the transmission via microwave or cable (including fiber optic cable) to a local "teleport," where the signals are then beamed to satellites. With increasing commitment of the RBOC's and other carriers to an ISDN, and with the spread of fiber optic cable and its wideband capabilities, some of the reasons for bypass will fade. However, the satellite system should maintain its share of growth if: the system (including earth terminals) is made more cost-effective; higher quality, more cost competitive services are offered; and if the space-based system is structured to complement, as well as compete with, the terrestrial system. A step toward the latter would be the configuring of satellite systems to be compatible with ISDN standards, thus positioning such systems as alternate communications paths to the new terrestrial nets.

3.3.2 Specific applications. - We discuss here four potential applications which will have a major impact on satellite technology. All require large factors of frequency reuse and all require some form of an on-board circuit switched capability.

Personal communications - The advent of cellular land mobile technology has introduced sufficient spectrum reuse to enable land mobile telephone on a large scale. The NASA MSAT-X program with Canada will lead to technology that will extend mobile coverage to rural areas as well. The popularity of mobile communications indicates a rising interest of the consumer in personal communications. The wireless telephone is is further indication of this interest.

The technology of the wireless telephone has obvious extensions. As currently configured, the wall mounted unit detects when the transceiver is "off-hook" and opens the line for use by the user. An extension of this would allow several receivers to access the same wall mounted unit. Translating this concept to the office, all phones in the same office could access one wall unit which could be connected to a suitable number of lines. Each user would then carry his personal communicator with him and always be able to make or receive calls wherever he might be.

Extending this further, the wall mounted unit could be a street mounted unit which would monitor all the personal communicators within a 1,000 ft rad. Each communicator would generate its own identifying code and uniquely identify its owner.

Using a cellular concept with a large multibeam satellite, such personal communications could be made available on a nationwide basis. Such technology would enable an era of truly personal communications.

Such concepts have been proposed (ref. 3.23) and lead to many personal services besides voice, including navigation, emergency radiolocation, store/forward alphanumeric messages, paging, etc.

The potential market for such a service can be postulated by examining projections of current telephone usage. We will assume that such a service will be inexpensive so that at least 10 percent of the population would be interested in subscribing.

Figure 3.7 shows projections of the number of calls placed within the local telephone operating companies. These were obtained by extending 10 yr trends of filings with the FCC. This shows that about 350 billion local calls will be placed in 1986 and these will increase to over 600 billion by the year 2000. The number of toll calls is significantly less, ranging from 50 billion in 1986 to about 200 billion in the year 2000. The number of circuits needed to support such traffic can be arrived at with a few reasonable assumptions. If we: count 24 hr of every day as potential service time; assume a 7:1 peak/average ratio for local calls; assume a 2:1 peak/average ratio for toll calls; and assume 10 min as the average call duration; then the required number of lines can be estimated as shown in figure 3.8. The number of lines required to process local calls ranges from 48 million in 1986 to about 80 million in 2000. Significantly fewer lines would be required for toll calls, ranging from 2 million in 1986 to about 8 million in 2000. Assuming 16 kbps voice, and 10 percent of the population opting for this service, the required spectrum for local calls would range from 75 to 130 Ghz over this time frame. For toll calls the spectrum range would be 3 to 13 Ghz. The need for local service cannot be ignored as FCC reports show that 90 percent of personal calls are local. This would imply the need for large factors of frequency reuse to meet these spectrum needs. These are needed because only one, or at most two, satellites could be used in this service. This results from the omnidirectional pattern of the user transceivers and the consequent inability to discriminate against satellites.

Assuming a basic allocation of 500 Mhz, the year 2000 local application would imply about 260 times frequency reuse (achievable with 1,800 spot beams). If the system is restricted to mostly toll calls (by appropriate charges), the spectrum needs are more modest, needing a reuse factor of about 13 (achievable with 50 to 90 spot beams)

With less basic allocation than 500 Mhz, the required spectrum reuse would be higher and the number of spot beams would increase in a corresponding manner.

Previously proposed concepts assummed an operating frequency of 3 Ghz and a smaller user population than mentioned above (ref. 3.23). With the same frequency and the larger user population, an aperture size of about 130 ft (40 m) would be required. A suitable feed technology would also be needed which could generate the required 1,800 spot beams.

To achieve the required frequency reuse it will be necessary to use a very complex feed arrangement. If only a few feeds were needed it would be practical to use discrete radiating elements to establish the coverage pattern. With the large number of beams required in this case, such simple feeds would not be possible. Rather, some form of phased array feed will be necessary where the radiating elements are used in a shared fashion. This implies multiplexing of several signals per feed element with each signal having different phase relationships. Concepts for such feeds have been proposed at frequencies as low as UHF (ref. 3.24) and as high as Ka-Band (ref. 3.25). With such techniques it is possible to generate a large number of adjacent beams. Isolation is achieved by arranging the beams in four or seven beam clusters where each of the beams is isolated by using a different portion of the frequency allocation in each. Isolation is achieved from cluster to cluster by designing for good sidelobe performance of the individual spots and using a suitable size cluster.

With 1,800 beams and about 8 million channels (assuming one satellite and the local calls application), there would be about 5,000 channels per beam (on the average). To provide complete interconnectivity, it will be necessary to demodulate each of these channels. If each demodulator weighed only 1 oz and consumed only 1/4 W, the total weight and power would be unacceptable. Consequently, it is necessary to develop bulk demodulation technology with which single devices demodulate 100's or 1,000's of channels simultaneously. Two known techniques for doing this are variations on the FFT and make use of either digital processors or use SAW device processors (ref. 3.26). Figure 3.9 shows estimates of power requirements for these two technologies as a function of the number of channels per demodulator (ref. 3.27). These assume a fixed total composite bandwidth of 1,000 Mhz. It would appear that the digital FFT device would be superior in the range of channels/demodulator of interest.

To interconnect all these beams, a baseband processor would be required to perform the circuit switching function. A $8x10^6$ by $8x10^6$ switch capability would be needed for the year 2000 local application and a $8x10^5$ by $8x10^5$ for the toll application. This latter capability is equivalent to four 4ESS switches. It has been shown that an operational version of the NASA ACTS baseband processor would be equivalent to one 4ESS switch (ref. 3.11). Therefore the required processor would have 8 to 40 times the circuit capacity of an operational ACTS processor.

These factors would suggest the need for an aggressive antenna technology program with emphasis on techniques for large factors of frequency reuse and methods for deploying large precision structures. Also implied is an aggressive program in solid state switch technology which realizes both low power and weight while at the same time allowing for increased complexity and clock speed. The scale would be on the order of the DOD VHSIC program. Finally, development of bulk demodulation technology would be necessary with the preferred technology being the digital FFT.

<u>Terrestrial bypass with VSAT technology</u>. - The advent of satellite technology has made possible various forms of communications with a cost that is distance insensitive. Conventional terrestrial communications are distance sensitive and the question naturally arises "at what distance does it pay to use a satellite?" Such trades are necessary and the results different for each class of service. Terrestrial costs include those for local distribution within the local access transport area (LATA) and those for trunking between LATA's. Due to the large volume of traffic on the trunking paths, this cost component is usually small compared to local distribution costs. It is this latter cost with which satellites must compete. To do so, means must be found where the LATA interconnects can be bypassed and direct satellite access provided to users.

As discussed in Section 3.1.3, a new class of very small aperture satellite terminals (VSAT) have been developed for this purpose. This class of terminal is most advantageous in inquiry applications. For these, the user uses the system only on an occasional basis and only transmits a small portion of data when he does. Large blocks of data may be returned but, again, only on an occasional basis.

Equatorial Communications has specialized in this market and has fielded over 25,000 receive only terminals as well as 1,000 two-way terminals. Federal Express is planning to purchase 50,000 two-way earth stations for document transmission between their distribution centers and also directly to customer premises. In contrast to the Equatorial terminals, these terminals will likely experience high utilization.

An example comparison of costs for a receive only application is shown in table 3.6 (ref. 3.10).

Clearly, the Equatorial method offers significant cost advantages in receive only operations. Part of the disadvantage inherent in the terrestrial system is that duplex lines are always supplied even though only one-way is desired. Also, there is no effective way of sharing the local lines with others and, consequently, the full-time charge must be paid even though the line may be used only intermittantly.

A comparison for two-way service is shown in table 3.7 (ref. 3.10) which indicates an advantage for the Equatorial approach but not as great as in the receive only case. For greater distances between terminals, the terrestrial distance charge will rapidly increase the advantage of satellites as the above satellite costs are independent of distance. For example, if the average long distance mileage were 75 instead of 25 miles, the terrestrial cost would increase to $463 for the one-way service and $472 for the two-way service.

As was mentioned in Section 3.1.3, these satellite networks depend on large master earth stations for signal regeneration and distribution. The inherent double hop, in conjunction with restrictions on data rate and terminal activity, make voice applications unacceptable.

VSAT technology is also available at Ku-Band which can support higher terminal activity because of the use of TDMA as the accessing method. However, these also are designed to be used in conjunction with large master stations and have the same double-hop character.

What is needed to enable use of this technology with voice is to replicate the function of the master station on the satellite. In this way voice as well as data applications could be supported and this could provide ISDN service to smaller communities and rural areas (see Section 3.2.2).

Such a concept has been proposed and analysis indicates costs would be very competitive with terrestrial equivalent services, being about 1/3 the terrestrial cost for a 700 mile path (ref. 3.28). This analysis allowed for the benefit of optical fibers in the terrestrial link but only for the long distance lines. A summary of this analysis was provided by the author of reference 3.10 and is shown in figure 3.10. For the switched access case, the access charges account for 1/2 the total charge. These are significantly less for large users but, even so, the total terrestrial charge is more than double the expected satellite charge.

In order to keep the VSAT cost low, it was assumed the burst rate would be 5 Mbps. The throughput was assumed to be 1.5 Mbps maximum. This throughput would support up to about 47 32 kbps channels which could be either voice or data, or one ISDN primary access (see Section 3.2.2).

Projections for VSAT populations in Section 3.1.3 indicated that upwards of approximately 100 transponders would be needed by 1995 to meet the data-only demand of VSATS. From the above analysis, economic voice service could also be provided via VSATS and switching satellites. Since demand for voice is a factor of 2 to 3 times larger than data (see Section 4), the composite voice/data VSAT transponder demand could be 300 to 400 transponders by 1995.

To meet this need satellites must exercise modest frequency reuse (2 to 3 times) and employ some form of baseband processing for full interconnectivity. Also, some form of bulk demodulation may be needed, depending on VSAT transmit bandwidth.

The required frequency reuse of 2 to 3 times implies the use of 14 to 21 contiguous spot beams. A phased array feed may not be essential to realize such coverage but it would offer more versatility and reliability. Alternatively, scanned beams can be used as with the NASA ACTS experimental satellite. Such scanning can also be performed with phased array feeds.

An operational ACTS baseband processor operating with 3 Gbps throughput would be an appropriate configuration. This would imply about 4 satellites with 6 times frequency reuse to meet the 300 transponder demand.

With 3 Gbps of throughput and 5 Mbps channels, about 600 discrete demodulators would be required for this spacecraft. This number could not be reduced with digital FFT bulk demodulators as they are limited to about 10 Mhz bandwidth. SAW demodulators may be more appropriate in this case.

With the 1.5 Mbps terminal throughput, such a system could successfully provide service to the largest corporate users as well as the bulk of small users. In this, the aforementioned satellite system would be providing a service equivalent to an 4ESS switch.

There is also substantial market for users with intermittant data needs but who also have a need for voice. VSAT technology can meet the needs of these users only if more narrowband methods are developed for satellite access. Traffic would likely be one or two voice channels or one ISDN basic access (see Section 3.2.2). Such methods are under study by TRW for NASA Lewis (ref. 3.27). These satellites would perform the function of an 5ESS switch although not with the same circuit capacity. An example case will be illustrated. The parameters for a Ku-Band VSAT terminal are illustrated in table 3.8.

A compatible processing satellite would be one having 24 fixed uplink spot beams (arranged in a four beam clusters for 6x frequency reuse) and six downlink scanning beams with a burst rate of 120 Mbps each. The spacecraft parameters are illustrated in table 3.9.

The downlink power budget obtained for these parameters is illustrated in table 3.10.

The uplink power budget is given in table 3.11, where 3 db of extra margin is added to the Eb/No to minimimze the uplink degradation.

Such a satellite would have a capacity of 720 Mbps. Each beam would serve a maximum of 100 channels but normal traffic skew would reduce this to an average of about 58 per beam for a total of 1,392 terminals. This assumes continuous operation of each terminal which could support 16 voice or 32 kbps channels each for a total of 22,272 channels per satellite. Since these channels need not be assigned on a dedicated basis, many more subscribers than this could actually be accommodated.

The required baseband processor would be smaller than an operational ACTS BBP (3 Gbps) but larger than the experimental ACTS BBP (200 Mbps).

Twenty-four 100 channel digital FFT bulk demodulators would be needed to replace the 1,392 discrete demodulators which would otherwise be needed.

The RF power requirements for all six scanned beams would be about 200 W and the dc power about 570 W (at 35 percent efficiency). A phased array MMIC feed could be used to generate this power and with 24 elements this implies 8 W amplifiers. Smaller amplifiers could be used if more elements are needed.

Considerations of these facts would suggest a 5ESS function could be replicated with a VSAT compatible satellite having on-board switching. The satellite would be about the same size as the experimental ACTS if not smaller. It would offer significant circuit capacity, though not as great as the 5ESS, for integrated voice and data and possibly be a means of providing ISDN service to surburban and rural areas by means of low cost VSATs.

Thus it appears that VSAT compatible orbiting switchboard satellites (OS/VSAT) could effectively replicate the 4ESS and 5ESS functions at a competitive cost, and could provide an effective terrestrial bypass for a large segment of users.

Videophone. - American Telephone and Telegraph first started transmitting a video type service in the early 1930's called TELEPHOTOGRAPH (ref. 3.29). This service was used regularly to transmit photographs for the news services. The picture to be transmitted was wrapped around and attached to a cylinder which rotated. A scanning light beam modulated by the various shades in the picture was reflected from the image surface onto a photoelectric cell for transmission.

Having accomplished the capability to successfully transmit photographs electrically it was thought, "why not transmit live pictures intercity?" This development brought the radio networks a new niche in the public information distribution market. They were now able to provide their affiliates with live or movie programs nationally, allowing the whole nation to simultaneously see the same program at the same time. This type of service has proved to be extremely successful, both in a terrestrial and satellite environment.

In the early 1960's, American Telephone and Telegraph developed a service called PICTUREPHONE[1], which was introduced to the public at the 1964 Worlds Fair in New York. Additionally, AT&T had a live experiment with Westinghouse between Pittsburgh, Pa. and New York. Neither of these two uses proved as successful as had been hoped.

PICTUREPHONE[1] required compensated local loops and T2 (6.3 Mbps) digital rates between local exchange offices. Also, it was only available on a point-to-point basis. As a result, the cost of usage was very high and the demand very low.

AT&T, in an attempt to revitalize the PICTUREPHONE[1] service, repackaged it into PICTUREPHONE MEETING SERVICE[1]. With this service AT&T established a number of fully equipped meeting rooms around the country. These rooms were

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[1]Registered Trademark of AT&T

rented on a per hour basis. Use of these facilities proved less than successful and as a result AT&T has closed many if not all of the locations.

Other organizations that have recently established some form of video offerings are as follows:

(1) Hilton Hotels and AT&T - Conference room dedicated to this offering with full motion 1.5 Mbps point-to-point digital interactive videoconferencing, with one monitor table and associated zoom lens camera(s). See figure 3.11.

(2) Holiday Inn - This approach is different from the Hilton application in that this is a one way broadcast video with one broadcast to many other Holiday Inns around the country. Voice requirement is handled by out of band audio/response systems. See figure 3.12.

(3) Other - A number of the OCC's have been doing some work in the video arena. Their success has been, to date, marginal.

The current teleconferencing market consists of three broad segments. These segments are:

(1) Audio - the transmission of voice only, largely between groups of people in a meeting type environment. This is not to preclude the audio application between two individuals.

(2)Freeze-Frame or Limited Motion - The basic requirements for either Freeze-Frame/Limited Motion (FF/LM) are essentially the same in terms of studio hardware for full motion video. FF/LM transmits the signal over a narrowband communications facility, normally 56 kbps. The picture quality is usually very good and can be likened to strobe lights flashing in terms of the number of pictures transmitted.

(3) Full Motion - Videoconferencing reflects the capability to transmit at a level which gives the impression to the viewer that the object being viewed appears to be in normal motion as well as associated audio. Full motion can be subdivided into three catagories, these being: (a) Motion, full color at 56 kbps; (b) Full motion at 1.5 Mbps; and (c) Full bandwidth at 45 Mbps and higher.

The University of Wisconsin has recently completed a market study to determine the potential market value of teleconferencing through 1990. These estimates are as follows:

YEAR	VALUE $M
1986	600
1988	1700
1990	3700

These numbers have been somewhat confirmed by conversations with various industry persons.

It is projected that when ISDN becomes a reality in the early 1990's, this will give a real boost to the videoconferencing market. With the availability of an ISDN type network with its dial up capability, random videoconferencing can be accomplished without the need for expensive dedicated facilities.

The aforementioned duplex PICTUREPHONE[1] experiments by AT&T required use of 2 T2 digital carriers (6.3 Mbps each) for conveying the video information. To provide pervasive PICTUREPHONE[1] service by this method would lead to impressive spectrum requirements. Without significant video processing improvements, the in-plant upgrade to PICTUREPHONE[1] would be on the order of the ratio between T2 bit rates and voice grade digital rates. Consequently, about a factor of 100 increase in spectrum capability would be required.

The introduction of optical fibers in the terrestrial plant could easily meet or exceed this requirement. Currently, optical fibers are only being installed on long distance trunks where the traffic volume is sufficient to justify the investment. However, with continually decreasing costs of fiber, the minimum traffic to justify the fiber upgrade is also decreasing. Ultimately the cost of right-of-way and installation will be the limiting impediment to this trend.

Satellites can provide an interim solution for the major urban areas and perhaps a permanent solution for surburban and rural areas. Wideband channels could easily be provided on a nationwide and dial-up basis. Such a satellite solution has been proposed (ref. 3.30) in which a system of 3 to 6 satellites of 12 Gbps capacity, each, would provide nationwide service. The proposed satellite made use of dual 4 x 8 m multibeam antennas at Ka-Band to achieve up to 400 switched spot beams. The satellite weight and power requirements were estimated at 3,800 lb and 4,200 W. Though each satellite had a large capacity, switching was simplified by the large basic access of 3 Mbps. It was estimated that the wideband service could be made available at $2000/month plus $1.40/min/duplex call.

As was mentioned above, further video compression gains may yet occur. In these cases it might eventually be possible to convey PICTUREPHONE[1] or videophone over an ISDN primary and perhaps basic access. In this event, the satellite systems of "Terrestrial Bypass," section 3.3.2 may be more appropriate.

<u>Geostationary communication facilities</u>. - Multipurpose/Multiuser Trends - There has been a trend in recent years to multipurpose and/or multiuser satellites. These satellites have often been of more than one frequency as well. Among such recent (1983 and later) satellites are:

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[1]Registered Trademark of AT&T

ARABSAT	regional multifrequency (1985)
ASC	domestic U.S. multifrequency (1985)
CHINASAT	domestic multipurpose (1985)
INSAT	domestic multipurpose (1983)
INTELSAT VI	international multifrequency, multipurpose (1987)
OLYMPUS	European regional multifrequency (1987)
SARIT	Domestic multifrequency, multipurpose (1989)
TELE-X	Regional (Nordic) multipurpose (1987)

The trend in these satellites has also been one of increasing mass, power, and capacity, as indicated in figures 3.13 to 3.15 from reference 3.31.

Separate studies of potential communications payloads for large geostationary facilities were performed for NASA by Ford Aerospace and by RCA-Astro Electronics (refs. 3.32 and 3.33). Their conclusions included the following:

Large GEO facilities may be needed for efficient utilization of the geostationary arc in the late 1990's and early 2000's.

Such facilities appear to be cost effective.

The concepts are technically feasible.

Institutional, regulatory, and insurance issues exist.

Because of these results, both contractors recommended that further, more detailed studies be conducted at an operational system level.

Capability for Relieving Congestion - The Ford and RCA payload studies concentrated their efforts on addressing the future traffic in ITU Region 2, and especially in CONUS. Payload concepts defined for various satellite service scenarios included those that could significantly reduce congestion of the satellite arc. Two examples of these concepts are described below.

A Ford concept designated as Scenario V is depicted in figure 3.16. This high capacity CONUS fixed satellite service concept has a payload weight of over 2,200 kg. It's design addresses the distributional characteristics of CONUS traffic. To emphasize how a large facility such as this could relieve the arc congestion, seven of these "large satellites" could address 100 percent of the year 2008 projected CONUS traffic. This is possible through frequency reuse; C-band = 4 times, Ku-band = 9 times and Ka-band = 12.2 times. The largest reflector employed would be rigid and have a diameter of 15 ft.

A scenario known as Payload Concept 2, figure 3.17, that was developed by RCA, addresses 20 percent of the CONUS fixed service traffic anticipated in the year 2000. The utilization of multiple spot beams results in frequency reuse factors of 9.1 times for C-band, 6.3 times for Ku-band and 5.4 times for Ka-band. On-board switching and processing provides full connectivity between the three bands. The payload mass to provide this high capacity is 2144 kg.

Expansion Band - A large geostationary facility such as those described above would also be well suited to utilize the expansion bands around C and Ku-band that were proposed for planning at the Second Session of WARC 88. The expansion bands provide an additional 300 MHz at C-band and 500 MHz at Ku-band.

Each ITU member administration will receive one allotment consisting of a guaranteed orbital position within a predetermined arc segment. Each allotment will be given the full 800 MHz bandwidth. As communication requirements increase, further capacity could be made available through use of geostationary communication facilities providing significant frequency reuse.

Reliability/Servicing/Assembly at the Space Station - With considerable aggregation of capacity on, and capital investment in a single spacecraft, questions arise as to the reliability and/or lifetime of the system. Currently, existing and planned satellites have a lifetime of 10 yr. Extension of life much beyond ten years raised questions as to technical obsolescence. Such extensions are possible through improved reliability: radiation hardened components; redundant systems; increased station keeping capabilities; and the like. The technical obsolescence question may be answered by having a capability to service the spacecraft and payload, including replacement of payload components and systems.

The size required of some systems may necessitate assembly and check out at the Space Station in LEO, and then transfer to GEO. It may also be possible to assemble the system in GEO, given a suitable space transportation and servicing infrastructure.

3.3.3 <u>NASA communications uses</u>. - NASA's Communications needs of the future are both terrestrial and space oriented. The needs in space are, and will continue to be, driven by missions. Terrestrial needs to some extent are also driven by missions, but institutional requirements play a major role as well.

With respect to NASA's communications needs in space, a lead time of 10 yr is often required for development of a particular technology or technologies, flight test and demonstration, and eventual deployment of an operational object or system. Potential missions for the nineties and into the teens of the next century, therefore, must be examined to determine likely technology development requirements for the eighties and nineties.

In 1985, NASA published a three volume "NASA Space Systems Technology Model" (refs. 3.34 to 3.36). Included in these documents were potential missions out to about the year 2000, with some having no date given - simply ">1995." Example information on these missions is given in tables 3.12 and 3.13, which are abridged from the references.

Planning beyond the year 2000 - in fact, to 2035 and later - was recently undertaken by two groups: the President's National Commission on Space (NCOS), and an in house NASA Advanced Missions Working Group (AMWG). The National Commission on Space was charged with formulating a "bold agenda" for the U.S. Civilian Space Program for the next 50 yr. NCOS has proposed (ref. 3.37, p. 5) that three equally-weighted overall goals guide the program:

(1) Advance understanding of the planet Earth, its solar system, and the universe.

(2) Explore, prospect, and settle the solar system.

(3) Stimulate space enterprises for the direct benefit of the people on Earth.

Various specific recommendations made by the NCOS include advancing science via extensive observation from space of our planet, returning samples from selected planets, moons, asteroids, and comets, and use of astronomical facilities farther and farther from Earth, including on the surface of the moon. Specific pre-2015 milestones contained in the NCOS recommendations consider a full LEO spaceport in 2008 and a lunar spaceport in 2013. Robot prospectors would roam the moon and return samples around the year 2000, and a human outpost would be established circa 2005. The year 2015 would see the establishment of a manned outpost on Mars. NCOS recommendations also include the development of various cargo and passenger vehicles during that time frame to provide economical transport for material and personnel.

At the same time that the NCOS was conducting its studies, the in house NASA AMWG was examining advanced missions that should be considered by NASA over the next 50 yr. A number of future scenarios dependent on assumed NASA annual budget growth levels and program emphasis (balanced, commercial, lunar, or Mars), were developed by the group. The missions contained in the scenarios (ref. 3.38) were the same or similar to those of the NCOS. However, several milestone dates were usually given for each mission, depending on the scenario budget growth factor and/or program emphasis assumed. A comparison of a number of the NCOS and AMWG milestones is given in table 3.14 (taken from ref. 3.38).

Space may be classified by domain, as in ref. 3.38. That is, missions may be classified as low earth orbit (LEO), geosynchronous/cislunar (GEO), lunar, Mars, asteroid, or deep space. The particular domain affects the communications requirements: round-trip signal time ranges from fractions of a second at LEO to hours at the outer reaches of the Solar System. Power constraints are much less stringent for LEO spacecraft communications than for deep-space spacecraft.

As can be seen, the roster of potential future missions is quite varied, ranging from near earth to deep space, manned and unmanned. Digital voice, data and video communications are needed for transmission/relay of science data from Earth observations and from planetary and deep space missions, for command and control of various spacecraft, for communications between spacecraft, station, and base crews, for tracking of spacecraft, and for other purposes such as providing the links for teleoperations. Increased capabilities are needed to handle the increasing number of missions, the relaying of output of new generations of sensors with order of magnitude improvements in spatial, spectral, and temporal resolution, and the increasing need for interconnection. The space station, for example, will have need to interconnect with polar and co-orbiting platforms, with crew performing EVA, with teleoperated devices performing various unmanned services, with in and out-bound manned and unmanned transfer vehicles, with Earth, and eventually with other stations farther out, such as in GEO or on the moon. A preliminary design by the Harris Corp. provides more than 60 communications links, using 30 antennas.

Establishment of a manned lunar outpost, and eventually operational bases, will require lunar surface-to-surface and surface-to-space interconnects. Satellites at three libration points could provide complete lunar coverage. Personal portable communications with access to the satellites may be necessary, particularly from the surface of the far side of the moon. As it will be likely that the personal communicators will need to be low power and will have low gain, high gain on the satellite will be required. Use of scanning spot beams by the satellite will also be likely, requiring, in turn, on-board switches to interconnect the beams and multiple users. Various signals will have to be routed between "rovers" and bases on the surface, orbiting lunar facilities, incoming and outgoing spacecraft, Earth, and perhaps other destinations/origins such as the space station.

The foregoing discussion has focused on NASA's needs in space. Terrestrially, NASA currently has NASCOM and PSCN. NASCOM is a network of leased communications services providing for the operational flow of data among earth stations, control facilities, and users. The current system is to be upgraded to meet demands of missions with high data rates. Currently the system can throughput 56 kbps on most circuits. This is to be increased to 224 kbps. Other upgrades are to include digital voice circuits, greater use of fiber optics in links between the earth stations and NASCOM, and TDMA capability. The system will require additional upgrading at later dates as demand grows. However, some future traffic is likely to be transmitted direct to users from the TDAS system when in place.

The PSCN, or Program Support Communications Network, is to become fully operational during 1986. The system is to provide FTS voice between 16 NASA locations via a digital network employing both terrestial and satellite circuits. The system also provides packet and circuit switched data, facsimile, electronic mail, voice and video conferencing and high volume data transfer between Class VI computers. Much of this net is likely to be eventually replaced by "FTS-2000", a new government-wide telecommunications system currently being procured by the GSA. Many, if not all, of the PSCN features are to be provided by FTS-2000: integrated voice/data services, including high-speed data and packet services, video services, voice mail, etc. Depending on the eventual FTS-2000 configuration, some NASCOM traffic may be viable via FTS-2000.

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4.0 SPECTRUM/ORBIT RESOURCE AVAILABILITY

4.1.0 U.S. Geostationary Arc Capacity

This section examines the theoretical capacity of the U.S. portion of the geostationary arc and possible means of expanding the capacity through various methods. Other sections in the chapter examine the forecast demand for satellite services, current utilization of existing capacity, and, finally, the arc saturation situation. Effects of various technology developments on spectrum/orbit resource availability are discussed throughout.

The arc/spectrum resource and the amount of communications capabilities it provides is determined by two basic parameters: (1) the number of satellites which can be accommodated in orbit; and (2) the capacity which can be handled by each individual satellite.

The number of satellites which can be accommodated in orbit is fixed by how closely they can be placed together and by the total space they may occupy. Both of these factors are determined by technical limitations. Available space is first limited by the fact that all commercial communication satellites are at geostationary altitude in space directly above the earth's equator. This establishes their orbit dynamics so that each satellite appears fixed in space when viewed from the earth's surface and results in all of the world's geostationary communication satellites being located in an orbital ring of 360° around the earth. For domestic U.S. communications, the space in geostationary orbit is further limited to that portion of the 360° ring which can be realistically viewed by earth stations located within the U.S. Because earth terminal antennas must be pointed above the horizon at some elevation angle, the portion of the geostationary ring capable of serving the 48 contiguous states (foregoing coverage of Hawaii and Alaska) is 88° of orbital arc (55° to 143° W Longitude) for C-band satellites, and 78° of orbital arc (60° to 138° W Longitude) for Ku-band satellites (fig. 3.5). (C-band (4 to 6 GHz) and Ku-band (12 to 14 GHz) refer to those bands of the frequency spectrum which are currently used by U.S. domsats.)

With domestic satellites constrained to operate in these limited orbital arcs, the total number of available satellites is then simply dependent on how close they can be placed together. Spacing between satellites is required to avoid signal interference problems. In order to maximize use of the orbital arc, it is general practice to have each satellite utilize the full frequency spectrum available in either the C-or Ku-bands. This means that the uplink transmit frequencies for all satellite systems are at 5.9 to 6.4 GHz (C-band) or 14.0 to 14.5 GHz (Ku-band). For an earth station looking toward the geostationary orbit, discrimination between satellites is provided by using directional earth station antennas with beamwidths of 2° or less and by spacing the satellites along the orbital arc. The required orbital spacing is determined by the Federal Communications Commission based on acceptable mutual interference levels and regulated through their licensing procedures. For the first generation systems, the minimum allowable spacing of C-band satellites was 4° and for Ku-band satellites, 3°. Advancements in satellite antenna technology over the 10 years commercial systems have been in operation have reduced the mutual interference levels considerably. Consequently, in August of 1983, the FCC ruled that future C- and Ku-band satellites may be spaced at 2°. However, C-band spacing will be provisionally held at 3° until all of the older systems are phased out, probably around 1990. The current satellite position assignments and the FCC 2° spacing plan are listed in tables 4.1 and 4.2 respectively.

The number of satellite positions or orbital "slots" potentially available for use by U.S. domsats is the portion of the geostationary arc visible from the U.S. less that portion allocated to Canada and Mexico, divided by 2° per slot. It is believed that domsats of South American nations, and several have applied for slots, can co-exist in the same slots as Northern Hemisphere countries because their beams are directed south and would not cause significant interference. Under these assumptions, with 68° of arc available for the U.S. for C-band, 66° for Ku-band, and 2° spacing, there are 34 C-band slots and 33 Ku-band slots, for a total of 67 satellite positions for the U.S.

The other parameter which determines the value of the domestic arc/spectrum resource is the amount of telecommunications capacity which can be supported by each individual satellite. The first factor which limits this capacity is the frequency bandwidth allocation. Under international agreement, there is 500 MHz of bandwidth allocated for U.S. domsats at both the C- and Ku-bands. While these bandwidths are fixed, the amount of communication capacity they can support is heavily dependent on the technologies which are applied in their utilization.

4.1.1 Arc capacity with current technology. - It is easiest to examine bandwidth utilization by employing current transponder capacity as a baseline measurement unit. In all first generation domsats (and in many future systems), the 500 MHz of allocated bandwidth is divided into 40 MHz segments. After allowance for guard bands, each bandwidth allocation will then support 12 transponders with each transponder having a bandwidth of 36 MHz. A 36 MHz transponder is a convenient measure of capacity since it will easily support 1000 one-way voice circuits or one one-way video circuit. Present day satellites employ polarization isolation to reuse the 500 MHz, effectively doubling the capacity per satellite. This frequency reuse technique is discussed in more detail later, along with other potential frequency reuse technologies not yet employed.

The current state-of-the-art for U.S. domsat systems, both C and Ku-band, consists of dual polarization, CONUS coverage, 24 36 MHz transponders per satellite (Ku-band transponders often utilize other bandwidths eg. 54 and 72 MHz but the total is equivalent to 24 36 MHz transponders). This is foreseen to continue to be representative through the mid 1990's even though some system filings indicate (e.g., Martin Marietta, Federal Express) more frequency reuse by having narrow spot beams overlay selected metropolitan areas. These do not, however, achieve wide area or CONUS coverage.

The number of transponders that can be supported by the U.S. geostationary arc today is then 24 transponders per slot x 67 slots = 1608 transponders.

Another likely evolutionary step in satellite technology leading to expanded arc capacity is triple frequency reuse at Ku-band. Figure 4.1 illustrates a representative concept by Ford Aerospace depicting 3 times Ku-band frequency reuse by means of two east/west spot and one CONUS beam with complete on-board connectivity. Here, the beam sizes are nonuniform for better traffic balance although this could be impractical in higher frequency reuse (more beams) systems for reasons mentioned later.

This type of frequency reuse is equivalent to three sets of 12 36 MHz transponders or 36 transponders per Ku-band satellite. Thus a slot in the orbital arc could accommodate 24 C-band and 36 Ku-band transponders as either two separately colocated satellites or as a single hybrid (C-and Ku-band) satellite.

Thus, the arc capacity would become 34 slots x 24 C-band transponders and 33 slots x 36 Ku-band transponders for a total of 2004 transponders.

A further evolutionary step in arc capacity expansion, although less likely, is reduction of satellite spacing at Ku-band. According to Ronald Lepkowski, Chief of the FCC's Satellite Radio Branch, "We might go to 1.7° or 1.5° in Ku-band, but there is a cost barrier below 2° in C-band" (ref. 4.1). If the spacing at Ku-band were reduced to 1.5°, the Ku-band arc capacity would be increased to 44 slots for a total arc capacity of 2400 transponders.

The evolutionary development of the U.S. geostationary arc capacity is shown in the table 4.3 and figure 4.2

Possible ways of expanding the arc capacity are discussed in the following section.

4.1.2 Arc/spectrum expansion and required technologies. - Since closer satellite spacings and additional frequency allocations at C and Ku-bands are unlikely, the remaining option is to expand the capacity per satellite by either: (1) increasing the communications capacity per transponder; or (2) increasing the number of transponders per satellite through frequency reuse techniques.

Transponder capacity can be increased through more advanced modulation and signal compression techniques. Techniques are being developed which promise to double the number of full motion video channels and limited motion video conferencing channels that can be carried per transponder. Techniques having the potential of providing as many as 6,000 half voice circuits per transponder are being developed (amplitude companded single sideband modulation (ACSSB)). These would be used in high density trunking applications, but would not be representative of the overall transponder voice capacity, however.[2]

The number of transponders per satellite can only be increased if some method is employed to reuse the allocated frequency spectrum such that more than one transponder can operate with the same 36 MHz bandwidth of frequency. This reuse can be accomplished in several ways including: (1) use of polarization isolation; and (2) use of multiple spot beams.

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[2]Some controversy exists as to the extent ACSSB can be used in satellite systems. Western Union in their 1983 demand forecast study (ref. 4.2) estimated 50 percent usage in satellite trunking systems. Others (e.g., Hal Braham, (TRW) suggest ACCSB is difficult to maintain in a reliable operating mode and is probably only suitable for very large voice trunking systems. Also, being an analog technique, it is not directly compatible with the trends toward digital networks such as ISDN.

Polarization isolation is currently used on most C-and Ku-band systems to effectively double the 500 MHz frequency allocation. That is, two signals transmitted at the same frequency but with different polarizations can be easily recognized at the receiver and processed separately. By using polarization isolation, two transponders can use the same 36 MHz frequency band and the number of transponders on a single satellite can be doubled. The other attractive technique for frequency reuse involves the use of multibeam antennas. Multibeam or spot beam antennas follow the trend of spacecraft antenna evolution which has resulted in the development of more and more sophisticated beam shaping techniques. The need for beam shaping is easily seen if we consider the great distances involved in the satellite communication path and realize that the strength of the transmitted signal diminishes as the square of the distance it travels.

Early communication satellite antennas permitted the power to spread over very large surface areas (e.g., an entire hemisphere), thus requiring very large ground terminal antenna systems to receive the low signal strength. Modern U.S. domsats focus the power within the boundaries of the contiguous 48 states (CONUS) thus permitting smaller ground terminals. This type of beam focusing has resulted in large increases in received power, but still has not permitted frequency reuse other than polarization reuse.

At times, the wide distribution of the signal from a CONUS beam is desirable (e.g., as in broadcasting), but in many cases it results in a wasteful use of the frequency spectrum resource. If a message or signal is intended for only one location, as in point-to-point telephone conversation, it would be beneficial to use a frequency to transmit the signal in a beam covering only that location and no other. If this were possible, then the same frequency could be used to transmit a different signal to a different location and frequency reuse could be achieved. This is the principle of frequency reuse with spot beam antennas.

Ideally, maximum frequency reuse would be achieved if the signal power destined for a specific location were exactly focused on that location and no other. Unfortunately, in practice, this is not practical. The enormous antenna sizes required for such highly focused beams, as well as other factors, make such ideal frequency reuse too expensive. Advances in technology, however, will undoubtedly make limited but highly valuable frequency reuse through spot beams a common practice in many future satellites at frequency bands other than C-band.

Significant C-band spot beam frequency reuse is less likely because of: (1) current satellite usage; and (2) antenna size constraints. Most transponders on current and future C-band satellites are used to provide wide area distribution of signals such as cable TV or other video programming and hence take advantage of the nationwide coverage of CONUS beams. The use of spot beams for this type of service would be counterproductive. In addition, the size of C-band satellite antennas is already large and to achieve any significant frequency reuse through a doubling or tripling of their diameter would result in high penalities in weight and cost.

Spot beam useage is more promising for the higher frequency band satellites, such as Ku and Ka band systems, because of another factor which affects beam focusing - the frequency of the transmitted signal. As with antenna diameter, the focusing of the beam power is directly proportional to the square of the transmitted frequency. Thus, when using the same size antenna, beam power focusing will be increased by a factor of 9 for Ku-band at 12 GHz over C-band at 4 GHz. While increasing the practicality of frequency reuse, the increase in focusing capability at Ku-band is also important for another reason. That is, it increases the signal power reaching the earth's surface. This is important because as the signal frequency is increased to Ku-band, it is affected more significantly by the atmosphere. This is shown in figure 4.3. Compared to C-band, the signal attenuation at Ku-band in clear weather is not greatly attenuated but it is much more affected by adverse weather such as rain.

Because increased signal power is desirable and many times even necessary for high quality signal reception at Ku-band, it is likely that the focusing advantage of spot beams will be used in many future Ku-band satellites using antennas comparable in size to those now used at C-band. The capability for frequency reuse, therefore, would be an added benefit, and it is anticipated that the use of a frequency may be doubled or even tripled using such systems. (The reason only triple reuse is possible with a 9 fold increase in focusing is explained below.)

Although frequency reuse through multibeam antenna technology appears to be a powerful technique for enhancing the arc capacity, its efficiency is considerably diminished by the fact that the communications traffic distribution across the U.S. is very nonuniform. The variation of the magnitude of traffic among the 10 largest U.S. metropolitan areas varies by a factor of 5 to 1. This has the effect of driving down the theoretical throughput of a multibeam satellite. A 10 beam satellite operating with current techniques would have an overall throughput efficiency of only about 45 percent. In order to keep the complexity of a multibeam satellite manageable, the transponder and beam sizes would be relatively uniform. The beam capacity would of necessity be sized to accommodate the largest traffic area, and the others would, therefore, be oversized for their respective coverage areas. Although having a much greater capacity than a single beam system, considerable spectrum is wasted, nevertheless. Fortunately, there is a technique that holds promise for ameliorating this inefficiency.

By dividing the satellite communications signals into short compressed bursts of information and scanning the spot beam over a large area, several earth stations may transmit and receive at the same frequencies by taking turns or timesharing. The use of time bursts to communicate with the satellite is a digital technique called time division multiple access (TDMA). The time slot allocated to a given earth station can be lengthened or shortened to accommodate a varying amount of communications needs. By having a satellite beam dwell on an area just long enough for the earth stations in that area to transmit and receive their information content, then sequentially move onto the other areas, ensures that the beam is carrying communication signals a high percentage of the time, and thus employing the spectrum efficiently. This sequential sampling technique, or "scanning," can improve multibeam system efficiency by factors of 2 to 3. Scanning beam systems would require more complex beamforming components, but the efficiency and flexibility of the communications system is greatly enhanced.

The use of multiple spot beams which is critical to frequency reuse also imposes another requirement on the satellite which is not faced by CONUS beam systems. To use the spot beam concept, switching is required onboard the satellite to direct signals to the proper beams. A capability must be provided to permit signals to be switched from any point of origin (uplink beam) to any destination (downlink beam). This switching may be performed with large volume transmissions where many messages are aggregated together or on a call by call basis. By reducing the transmissions down to individual call units (voice channels), the ultimate in flexibility can be achieved. A typical Ka-band satellite should be capable of routing over 100,000 voice channels among service terminals distributed around the nation. In essence, such a capability will transfer the switchboard from the earth to the sky. The size and complexities of these switches require technologies which are beyond state of the art, but as with the antennas, developments achieved through NASA-sponsored contracts have shown the necessary advances are possible.

While frequency reuse via the multibeam approach can expand arc capacity, a penality is paid in terms of flexibility in orbital arc location of the final system. The antenna and feed system must be designed for a specific coverage and cannot be moved very far in orbit without distorting the coverage pattern. Martin Marietta, in their filing to the FCC for their multibeam Ku-band system, desires positions at 75° and 77° W. and states that their system concept would drastically lose capacity if moved beyond 115° W. Figures 4.4 and 4.5 show the prime location and illustrate the problem if the satellite were placed at 140° W. Advanced technologies such as phased array antennas or phased array feed systems could enhance the multibeam frequency reuse approach to expanding arc capacity by enabling greater flexibility in orbital arc locations and aiding in pointing accuracy.

If the above-described techniques for frequency reuse are employed, the available arc/spectrum resource at C- Ku-bands can be expanded significantly. The technologies required to enable this form of efficient frequency reuse are yet to be developed and qualified for commercial operation.

4.2.0 Forecasted Demand For Communication Satellite Services

Over the past several years (1979 to the present) a number of studies were conducted to estimate the future demand for communications satellite supplied services. These studies have generally suggested that saturation of the C and Ku-band orbital arc will occur sometime in the 1990's. The latest of these publications occured in 1984 before a number of major changes in telecommunications occured. These changes introduce a major element of uncertaintly into the estimates of how much traffic will be carried by various types of transmission systems, e.g., satellite versus terrestrial. These recent changes include deregulation of the industry, technological break-throughs in, and rapid implementations of, long haul fiber optic systems, and the present rapid growth of very small aperture terminals (VSAT's) enabled by cost breakthroughs in earth station technology. The impact of these changes will be discussed below after a brief review of the earlier studies.

In 1979 the results of two NASA-sponsored studies conducted by two major communications common carriers, the Western Union Telegraph Company and U.S. Telephone and Telegraph Corporation, a subsidiary of International Telephone and Telegraph, were published. These studies forecasted the domestic demand for telecommunication services from that time to the year 2000. They also identified that portion of the total demand that could be best served by satellite systems. They further discovered that at the forecasted growth rates of satellite communications services, the area of the geostationary arc or region of space where U.S. domestic communication satellites must be located, would become overcrowded or saturated by the early 1990's. That is, without major advancements in communications satellite technology, further growth would be precluded. These considerations formed the basis and rationale for the initiation of the NASA ACTS communications technology program. During the next few years, because of the dynamic nature of the communications industry, unforeseen service growth trends emerged, new companies entered the field, new technologies were introduced, and other changes in character occurred that compelled an updating of the original forecasts.

These forecasts and the potential arc saturation problem were recently reassessed (1983) by the same two carriers, and the same conclusion was evident--saturation of the U.S. geostationary arc by satellites employing the presently used frequency bands, even with consideration of expected evolutionary improvements in technology, by the early 1990's (refs. 4.2, 4.3, 4.4, 4.5, 4.6, and 4.7).

In 1984 NASA published a synthesis of the Western Union and ITT reports, incorporating what was felt to be the most appropriate features of each, and incorporating new information available at that time (ref. 4.8).

As a consequence, the synthesis resulted in slightly lower transponder demand totals for year 2000 than either of the two studies. These are shown for comparison below and in figure 4.6.

Satellite Addressable Demand, Equivalent 36 MHz Transponders

	1980	1990	2000
ITT	360	1370	3600
WU	273	1140	2800
NASA	400	1150	2450

Note that these are estimates of "Satellite Addressable" demand, or that amount considered feasible for transmission by satellite and not actual in-orbit transponders or busy transponders. For example, the actual in-orbit transponder counts for 1980 and 1985 were 156 and 516 respectively. Furthermore, the satellite addressable figures are based on 100 percent utilization, i.e., the transponder forecasts express the underlying demand estimates as fully utilized transponders. Some controversy exists concerning the degree of utilization of transponders and this will be addressed in more detail later. A plot showing the satellite addressable forecast including the expected transponder supply is shown as figure 4.7.

Satellite addressable traffic was derived from estimates of the total and net long haul (between major metropolitan areas) traffic by considerations of crossover distances, delay tolerance, and other miscellaneous characteristics based on the contractors' market acumen. Furthermore, Western Union has an uncertainty of about 20 percent associated with their forecasts. Total traffic was aggregated for estimates for 9 categories of voice services, 17 data services, and 9 video. These service categories are shown in table 4.4. The demand estimates for each service category were formulated in terms appropriate for that service category. For example trunked voice forecasts involved number of calls per year, message lengths, daily peak hour factors, and call blocking probabilities over a typical trunk size, resulting in number of voice channels required. Video was based on number of networks and their requirements, degree of CATV distribution, expected parameters of various classes of videoconferencing such as conference lengths, conferences per year, degree of motion and resolution required and was finally expressed as a channel requirement. Data was treated in a similar fashion. Transponder estimates were derived from the voice, data, and video forecasts by also obtaining forecasts for expected transponder throughput capacities. A summary of the results of this process follows:

ESTIMATED TRANSPONDER THROUGHPUT CAPACITIES

		1980	1990	2000
Voice, 10^3 1/2 ckts.:	Total Traffic..	2,580	7,245	17,444
	Inter-SMSA.....	2,283	6,777	16,526
	Satellite Addressable..	371	1,828	6,816
Data, 10^{12} bits/year	Total..........	1,900	9,500	30,000
	Inter-SMSA.....	900	4,600	16,000
	Satellite Addressable..	40	1,700	13,000
Video, channels	Virtually All is Addressable	57	158	233
Videoconferencing, channels	Virtually All is Addressable	3	1,970	8,225

Forecasts for transponder throughput capacity (Western Union) used to derive transponder requirements are shown in table 4.5

The "Overall" satellite addressable traffic is composed of two segments, "Trunking" and "Customer Premises Service" (CPS), which have different sets of economics associated with them, i.e., different earth station costs, no terrestrial interconnection costs for CPS, etc. Several changes have occured in the last couple of years that would affect this mix. These include deregulation, which has tended to relax long haul transmission costs and is putting upward pressure on local distribution costs thus making CPS more attactive for by-pass. The consequent rapid appearance of such lower cost CPS terminals (VSAT's) than were assumed in the study, and the introduction of long haul fiber optic transmission systems which are lowering current terrestrial costs and competing with the satellite trunking traffic are other changes. Figure 4.8 shows the satellite addressable forecast with a ±20 percent variation. Table 4.6 shows the voice, data, and video components of the overall forecast.

Note from the above table of transponder forecasts that CPS systems command a very large share of the addressable data traffic because of the economics of data transmission, wide bandwidth requirements, etc. This is being borne out by the growth of VSAT systems which are being driven primarily by data transmissions needs.

Other demand forecasts. - Another recent study, by COMSAT (ref. 4.9) estimated the transponder requirements for U.S. Domestic satellite traffic and U.S. Atlantic Ocean Region (AOR) traffic. See pp. 347-348 of this reference for the specific technical assumptions employed in this study. The COMSAT transponder demand forecasts are for the 1985 to 2000 period. COMSAT started with their estimate of satellite addressable demand for voice, data, video, and videoconferencing in units of half circuits, Mbps, and channels respectively. COMSAT formulated these into two sets of transponder requirements by, in the first case, assuming present day technology and transmission techniques, and secondly assuming advanced all-digital technology. They also show the C and C and Ku-band arc capacity and make inferences about its saturation. Figure 4.9 (ref 4.9, p. 356, fig. 5) portrays these estimates. This figure indicates that with current technology and improved antennas (closer satellite spacing as mandated by the FCC) saturation of C and Ku-bands could occur by 1991. The implementation of advanced, all digital technology would postpone saturation until the year 2000 era.

COMSAT portrayed what advanced technology could do, not necessarily implying that it would be fully implemented in this fashion. It seems reasonable that in the year 2000 there will be a mixture of older technologies and the newer technologies in place. Figure 4.9 depicts their results. It can be seen that without implementation of advanced techniques, C & Ku-band will saturate by 1991. By postulating the degree of implementation of advanced digital technology by the year 2000, an estimate of the time frame of saturation can be obtained from the curve. For example, a 60 percent implementation of advanced technology would imply a saturation time frame of 1995, and an 80 percent degree of implementation would imply saturation in 1997, shown added to COMSAT results in figure 4.9. The COMSAT traffic estimates are for fixed satellite service (FSS) and assume transmission is mostly trunking traffic and the use of generally larger earth stations. COMSAT makes a significant statement here (page 359 of their report) to the effect that their conclusions regarding saturation postponement with advanced digital technology could be completely upset with the widespread implementation of small aperture earth stations (VSAT's). This is happening now and it remains to be seen to what extent this market will grow.

A comparison of the NASA and COMSAT forecasts (assuming a modest amount (20 percent) of the older technology remaining in the year 2000 digital systems) indicates they are in reasonable agreement:

Year 2000 Transponders

NASA	2,424
COMSAT (with 20% mix of older systems)	1,912
COMSAT (ideal, digital)	1,409

Since these are two of the most recent major studies published in the last two years, and their transponder estimates are similar it would seen reasonable to accept these numbers as a representative year 2000 satellite addressable transponder demand.

The caveats associated with the acceptance of these estimates would pertain to the rapid adoption over the last couple of years of transmission technologies that would impact these demands. The two big effects are fiber-optics and microterminals (also called very small aperture terminals, or VSAT's).

Long haul fiber-optic systems (discussed in another section of this report) will shift the economics of voice and data transmission more in favor of terrestrial means. Video, because of its broadcast nature, will remain primarily a satellite delivered service. However, fiber is only the long haul high density trunked portion of the end-to-end user connection and might typically represent only one third or less of the cost to the user for service. The rest of the cost is in the local loops, from the fiber trunk terminations to the end user. If a means were available to avoid this segment of the charge, considerable reductions could be made in user charges. This is exactly the incentive for various "by-pass" schemes including the rapid implementation of VSAT's. Thus fiber optic systems and VSAT's represent opposite influences on the demand for satellite transponders. Fiber would tend to capture some otherwise trunked satellite traffic and VSAT technology would permit more customer premises type satellite traffic. The net effect of these influences is unquantified at this time. In a recent private conversation with Mr. Walter Morgan of the Communications Center of Clarksburg (CCC), it was learned that a proprietary client study (client unspecified) recently performed by CCC indicated that the potential demand for VSAT services would more than compensate for transponder demand decline from fiber optic competition. For this reason the basic transponder demand forecasts for satellite addressable traffic, as exemplified by the NASA forecast, will remain unchanged at this time. That is, it will be assumed that satellite traffic captured by fiber systems will be made up for by additional VSAT traffic. Study procurements are being initiated at NASA Lewis to examine this issue in a more quantified way.

Based on these satellite addressable demand forecasts and the state-of-the-art arc capacity, the need for expanded arc capacity can be seen:

	1990	1995	2000
Forecasted Demand, Transponders	1,100	1,750	2,450
Arc Capacity, Transponders	1,600	1,600	1,600
Shortfall, Transponders	-----	150	850

850 transponders are equivalent to 35 conventional 24 transponder satellites or 50 percent more capacity than the arc can support with that technology. This capacity could probably be ultimately met by the techniques of three times frequency use at Ku-band and closer Ku-band spacing, but from[3] table 4.7, estimates of systems in place, it can be seen that some of the earlier Ku-band technology is still in place even by the year 2000.

From 1990 to 2000 the satellite addressable traffic is shown to be growing at a rate of about 8.3 percent/yr. This is modest in terms of some historical growth rates such as that of INTELSAT, which has experienced 15 to 20 percent

[3]Constructed internally by NASA from a variety of sources including the open literature, contacts with the FCC, Satellite System Applicants, ref. 4.10, etc.

growth over long periods of time. If the 8.3 percent growth rate were to continue beyond the year 2000, the transponder demand could double in another 9 yr, for a total of 4,900 transponders. This is far beyond the 2400 transponder arc limit enabled by Ku-band frequency reuse and closer spacing. This growth would have to be accommodated by development of technologies for additional frequency reuse and/or higher frequency bands such as Ka-band.

A look at the expected supply of C and Ku-band transponders to the year 2000 and the respective arc limits is shown in figures 4.10 and 4.11. C-band is shown to level off at 744 transponders, 72 less (3, 24 transponder satellites) than could be accommodated in the 816 transponder C-band arc. This is because the supply is estimated on the basis of FCC approved filings and assuming replacement with 24 transponder C-band satellites as the old systems fail. Ku-band replacements in the mid-90's are assumed to incorporate the capacity expanding technologies discussed above, thus showing the supply climbing above the present 792 transponder limit.

4.3.0 Actual Transponder Usage

Current transponder usage is a subject of some controversy. The FCC and at least one private firm, the Communications Center of Clarksburg, actively monitor transponder activity to gain information on transponder utilization. Other firms, such as Satellite Systems Engineering (SSE) make their own estimates. The findings seem to differ somewhat as discussed below.

The FCC has been conducting monitoring of transponder activity on a quarterly basis for the last couple of years. The results of one of their recent surveys are reproduced in table 4.8 and a more detailed (satellite by satellite) set of results is included with the reference material. The FCC results imply utilization of 68 and 48 percent for C and Ku-band respectively, with an overall utilization of 64 percent.

The FCC describes their transponder loading assessment as a "quick look" since they monitor each transponder only briefly (about an hour) once a quarter, returning for a second look at those initially registering as inactive. This method has been criticized by some as being misleadingly conservative since it does not present a true statistical picture of round-the-clock transponder activity. The FCC is preparing to initiate a program of continuous real-time monitoring of transponder activity (ref. 4.11) that will give a much more realistic picture of the situation.

The Communications Center of Clarksburg (CCC) maintains their own independent monitoring of transponder activity and purports that a much higher usage level actually exists. Details of their transponder monitoring activities, i.e., exactly what transmissions, for how long, etc. are carried on each transponder, are not available since these are confidential studies provided for clients. However, Walter Morgan, president of CCC, has stated that, for example, RCA and WU satellites are running at 95 and 85 percent utilization respectively. The FCC results would imply they are at about 75 and 80 percent. Although there may be a number of unused transponders now, he believes there may be a shortage about two years from now. Some of the results that have been published or provided to NASA by the CCC appear in table 4.9 and figure 4.12. Figure 4.13 is another estimate by SAT Time Inc. and appears in reference 4.12. From the table of current transponder applications it would appear that 413 out of the total of 504 are devoted to transmission activities. This would imply a utilization of about 82 percent.

Wilbur Pritchard, President of Satellite Systems Engineering, has stated that at present there is about a 20 percent overcapacity of satellite transponders, and that this is not atypical of normal operating procedures in other industries. He further states that this will disappear due to the crunch caused by the Challenger accident. An analysis of the list of transponder applications appearing in the October '85 edition of SSE's Satellite Marketing Digest would imply an 87 percent utilization.

Relevant comments by others in the industry include Alan Parker of Ford Aerospace at the TV Digest's Satellite Summit in Washington, DC spring of 1986. He can virtually guarantee a shortfall in transponder supply from 1989 to 1995 (refs. 4.13 and 4.14).

4.4.0 Arc Saturation Situation

Figure 4.14 presents an overlay of the U.S. domestic satellite addressable demand, the expected supply, and the arc capacity. The arc capacity with state-of-the-art technology is 1,608 transponders. Older systems will be phased out by the early to mid 1990's allowing this full arc potential to be realized. Beyond this time the arc capacity could be expanded by the means discussed earlier, but there's no complete assurance that it will be. Thus, on the curve for arc capacity on figure 4.14, breakpoints are shown for three different levels of technology implementation: state-of-the-art, 3 x frequency reuse at Ku-band, and closer spacing at Ku-band. With no improvements over state-of-the-art it is seen that the arc capacity is exceeded in the mid 1990's by the expected supply of transponders in orbit. Implementation of three times frequency reuse at Ku-band could accommodate the supply projection, but based on satellite addressable traffic, this increased capacity of 2,000 transponders would be equaled by 1996. Moving Ku-band satellites to 1.5° spacing would accommodate the satellite addressable traffic to the year 2000.

The supply curve is shown falling away from the satellite addressable demand curve after about 1992 because the supply curve is based on a projection of existing and planned systems. Presumably, if this gap actually exists, other system applications would be filed to capture this demand. In that case, the capacity expanding techniques discussed earlier would have to be developed and implemented.

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5.0 TECHNOLOGY/R&D NEEDS AND PLANS

5.1.0 Technology Needs

The potential future applications of communications satellites discussed in Chapter 3 are revisited, with more detailed discussion being presented on the research and technology developments needed to eventually make these potential applications reality. This chapter then concludes with a discussion of the proper role for NASA in achieving the developments and what activities might be undertaken by NASA.

5.1.1 Personal communications. - In Section 3.3.2 it was shown that the potential for personal communications can be staggering, with up to 8 million circuits needed by the year 2000. This is equivalent to 130 GHz for 16 kbps voice. With a basic allocation of 500 MHz, this would imply a frequency reuse factor of about 260 times. To meet this need with multibeam antennas, about 1800 spots would be needed with a 7 spot cluster reuse. At 3 GHz this would imply the use of a 130 ft aperture. With a smaller frequency allocation, the frequency reuse factor would need to be larger and the aperture would increase proportional to the root of this factor.

The feed array would be very complex but, in principle, similar to the phased array feed proposed for the third generation LMSS (ref. 3.13).

For personal communications, higher frequencies would be needed than proposed for LMSS (UHF). This will increase the likelihood of finding sufficient spectrum, and minimize the size of the antenna. MMIC based implementation of the feed would be necessary because of the complexity.

Baseband processing would be essential to provide full interconnectivity. The processor capacity would be at least an order of magnitude larger than that of an operational ACTS processor. However, with further advances in voice compression, the actual data throughput may increase only by a factor of 2 to 4.

Some form of bulk demodulation would be required. To keep the personal communicators simple and small, narrowband modulation methods must be used. Discrete demodulators would be prohibitively heavy and consume too much power. Bulk demodulators would demodulate hundreds or even thousands of channels simultaneously. The devices would likely be a digital implementation of the FFT algorithm for spectral processing.

Addition of intersatellite links would provide access to international satellites and enable worldwide personal communications.

5.1.2 OS/VSAT networks. -In "Terrestrial Bypass," Section 3.3.2, it was shown that satellites with on-board switching, in conjunction with low cost VSATs, can provide an effective bypass of the terrestrial LATA networks. Effectively, they would replicate the functions of the 4ESS and 5ESS terrestrial switches and at substantially less access cost.

Two possible futures forseen concentrate on two classes of users. A relatively high volume user (30 to 40 voice channels or 1.5 Mbps aggregate access) can be serviced by an operational ACTS satellite with reduced burst rate channels. The reduction in burst rate minimizes the EIRP of the VSAT and reduces cost. Such a satellite would serve the function of a 4ESS switch, routing traffic between these relatively heavy rate users.

An alternative system focuses on users who need only occasional service. In this case the VSATS are quite narrowband and differ very little from current Ku-Band VSAT practice. Because of the narrow bandwidth, fixed beams are used on the uplink. However, scanning beams can be used on the downlink.

Both concepts require baseband processing. The former would operate at a capacity of about 3 Gbps whereas the second would operate at a capacity of 760 Mbps. The circuit switching technologies are similar to those developed for ACTS.

SAW demodulators need to be developed for the high rate application. Compactness and minimum power consumption should be the goal.

New technology developments will be needed in bulk demodulator technology for the low rate user case. Digital FFT processors are needed which can simultaneously demodulate >25 narrowband channels of 128 to 512 kbps each.

Both systems will make use of scanning beam antennas. Development of MMIC based phased array feeds are needed to support the complex beam control and to enhance reliability.

5.1.3 Videophone. - Videophone service is likely to become pervasive within the urban community when optical fibers are available for short haul service as well as long haul service. In the interim, satellites can be used to introduce the service to the urban community and extend service to surburban areas permanently.

The degree of achieved video compression will have a significant impact on the size and power of the spacecraft. In section 3.3.2 two cases were examined. With video service at 3 Mbps (1/2 T2 rate), large and complex satellites of 12 Gbs each would be needed. Circuit switched capability would also be needed but would be simplified somewhat by the large basic access (3 Mbps). In this case baseband switching would not be necessary but it would offer more flexibility.

SAW demodulator development would also be required to minimize the weight and power of the nearly 4,000 demodulators.

Complex antenna feeds, probably MMIC based phased arrays would also be required as up to 400 spot beams would be used.

With further advances in video compression, the satellites of "Terrestrial Bypass," Section 3.3.2, may be used instead. In this case the needed technologies are the same as stated above for the OS/VSATS.

Intersatellite links would enable interconnects with international satellites and provide international videophone service. These should be designed according to the ISDN primary access hierachy as these are likely to become standard (see Section 3.2.2).

5.1.4 Large geostationary communication facility. - Ford Aerospace and RCA Astro-Electronics in the performance of their Communications Platform Payload Definition Studies, referenced earlier in section 3.3.2, identified both enabling and supporting technologies critical to the eventual implementation and operation of various payloads applicable to a large geostationary facility. A summary of the assessment of these critical technologies follows.

Large unfurlable antennas for mobile applications (30 m) and fixed services (10.5 m) that would provide multiple spot beams are critical items. Critical areas associated with these antennas include microstrip feed arrays for a mobile reflector and very high surface tolerance for the fixed service reflector. The construction and mechanics for these unfurlable antennas also require development.

Ford noted that the highest economic payoff item is to develop a methodology to track polarization variation at Ka-band. This would yield the capability to re-use the 2.5 GHz of bandwidth in high density traffic areas such as New York and the Chicago/Detroit area. The payoff is high for CONUS systems due to the distributional characteristics of the CONUS traffic.

Another desirable technology item is a high speed and lightweight baseband processor. High efficiency modulators and demodulators with high speed, lightweight, on-board routing will increase link capacity and on-board flexibility to improve fill factors and thus lower equivalent cost per circuit. High speed programmable frequency shifters in addition to conventional baseband switching will allow second tier switching and increase interconnectivity. This approach can be utilized to route down to the T 1 level.

Intersatellite links represent another key technology. Currently, technology development in this area is proceeding in the TDRSS and military systems utilizing RF links. However RF links are limited to about 5 GHz bandwidth and indications are that future growth, particularly in trans-oceanic traffic, will saturate these links. Development of the higher capacity optical links should therefore be pursued. These laser ISL's, besides providing higher capacity, will also offer the advantages of smaller aperture and interference immunity.

Ford and RCA identified a number of other technologies that are not as critical as those listed above. These include: analog-to-digital on-board format conversion to accept analog uplink and perform digital conversion on-board for digital routing; satellite high power amplifiers that can function in a dual-mode for operating in high rain areas; and dual polarizers for receive and transmit functions to be performed by one antenna.

Finally there are key support technology areas that can enhance the critical technologies and will also result in weight and power reduction for the major components. These key support areas are:

Device Processing (CMOS-SOS, etc.)
Discrete GaAs Power Amps, Receivers, other
MMIC (RF components)
VLSI (digital components)
Materials technology (DRO's, structural, etc.)
Optical (interconnects, switching, etc.)
Radiation Hardening (all, for long life)

With respect to the reliability or servicing of large GEO facilities, several studies are needed prior to any technology development efforts. Given particular space transportation and servicing system infrastructure, at what point does servicing become more attractive than increased reliability? What type of servicing, of bus and of payload, is cost effective? Designing for greatly increased reliability or for ease of servicing and component/system replacement is likely to result in a heavier and more costly (initially) facility overall.

Alternatively, given that a certain level of facility servicing is desired/required, what are the implications for service systems design?

Once these and similar questions have been answered, appropriate technology development can be undertaken. Areas that are likely to require effort, regardless of the type(s) of servicing/repair to be done, are: radiation hardening of components for increased life, remotely connectable waveguide interfaces and fasteners/disconnects for quick connect/disconnect of components or systems, built in test equipment for fault isolation and detection, and safing capability to permit servicing and module access.

5.1.5 NASA technology needs. - Earlier discussions have pointed out that NASA missions for the next two and a half decades (and beyond) require increased communications capacities, interconnectivity, and other improvements. The technology developments required to provide them are, for the most part, the same as those discussed above: large high-gain, large frequency reuse multibeam antennas, on-board switching and processing, intersatellite laser and microwave links, highly reliable long-lived, energy efficient components and devices, and so forth.

Currently, NASA's space communications needs are being met by the three station Deep Space Network (DSN), the fourteen station Space Tracking and Data Network (STDN), and the initial satellite in the Tracking and Data Relay Satellite System (TDRSS). The second satellite was lost in the Challenger disaster.

The TDRSS when completed will consist of three geostationary satellites, including an in-orbit spare. The system will provide tracking and data relay service for low earth orbiting spacecraft, providing 85 percent coverage of user orbits versus the 15° provided previously by the STDN. When TDRSS is fully operational, three STDN stations will be consolidated with the DSN, the White Sands, N.M. Station will become part of the TDRSS, and all other STDN stations closed. The TDRSS network control center will be located at NASA GSFC in Greenbelt, MD. The TDRSS is anticipated to meet NASA needs into the mid or late 1990's. However, the growing number of science and other missions in LEO, GEO and beyond, plus increased utilization of sensors with order of magnitude improvements in spatial, spectral, and temporal resolution will outstrip the capability of TDRSS. An advanced version of TDRSS may be deployed in the 90's as an intermediate step before the development of the Tracking and Data Acquisition System (TDAS) described below. It would have greater capability than the original TDRSS, and incorporate some of the planned TDAS features.

NASA plans to replace TDRSS with TDAS in the early 2000's. This second (third) generation TDRSS will have greater (Gbps) capacity, increased reliability, intersatellite laser or 60 GHz links, direct to user downlinks, and no orbital blind spots. A deep-space relay payload package may also be part of the system. Because of the likely increased capacity requirements, direct to user requirements, and so forth, the following technology developments are likely prerequisites:

On-board beamforming
On-board high capacity switching
Sophisticated antennas
Low-noise receivers
Reliable high power amplifiers at Ku and higher frequencies
Laser or 60 GHz intersatellite links

These developments and others are indicated in table 5.1, taken from reference 5.1

Also being considered by NASA is an Orbiting Deep Space Relay Station (ODSRS) to provide deep space tracking and communications support of deep space probes in the post 1995 to 2000 era. Such an orbiting relay station is likely to have optical links with the deep space probes because of the greater capacity and lower transmitter power requirement compared to microwave. As the ODSRS has received only low level of effort attention to date, requirements are not well defined. It is not yet clear whether such orbiting stations will be significantly more effective than an improved terrestrial net.

With respect to the deep space probes themselves, many of these missions will require communications packages able to withstand operational extremes such as high temperature for the Galileo mission, and high impact forces for the comet rendezvous/asteroid flyby mission. Most deep space and planetary communications packages will require low noise, and power-efficient systems. Needed, for example, would be power amplifier devices with efficiencies greater than 50 percent and power levels greater than 5 W at X and K-bands. NASA Lewis Research Center is currently developing a TWT which exceeds 55 percent at 20 W at X-Band. Also, a 48 W TWT has already been demonstrated at Ka-Band having 50 percent efficiency.

The likely interconnectivity requirements of TDAS have already been discussed. Mention was made in an earlier section regarding such needs for the space station and other operations, including lunar, as well. Missions beyond the moon, e.g., Mars, begin to fall outside the time frame of interest. However, interconnectivity technology developed for the earlier missions may be utilized for these missions also, or form the basis for new developments. Required technology developments are again those alluded to earlier: large, high gain, small beamwidth, fixed and scanned multibeam antennas, on-board switching/processing, and intersatellite links.

As can be seen, many of the communications technology developments needed by NASA for its own systems are the same or similar to those required for a number of commercial systems.

5.2.0 NASA Role/Activities

The NASA space communications program has had as its goals the following:

(1) Develop technology to more effectively utilize the geostationary orbit;

(2) Advance communications technologies to reduce adoption risk by industry and enable enhancement of their competitive posture in the world marketplace;

(3) Increase commercialization of space through a broadening of existing space communications applications;

(4) Utilize the shuttle and Space Station facilities with their unique manned, gravity-free environment to carry out pioneering programs in communications system and subsystem technology where necessary, e.g., large antennas;

(5) Conduct technology and development programs to insure readiness of key spacecraft communications technology in support of NASA missions;

(6) Develop and support U.S. and NASA interests in international and domestic communications regulations with an emphasis on commercial communications;

(7) Utilize NASA's communications program resources to provide consultation, perform system studies, and plan and conduct space experiments in support of other government agencies' missions.

In light of the above goals, the role of NASA in developing needed technology or providing fundamental research and development in the area of space communication can be a varied one. It can range from performing in-house efforts to the awarding of conrtacts and grants for efforts to be performed by industry and academia. The efforts themselves can range from the development of basic devices to complete communications systems, to experimentation with devices/components/systems and, finally to the demonstration/verification of components or systems in space.

Currently, the NASA communication program calls for several major flight experiment programs to support its goals, e.g., the Advanced Communications Technology Satellite ACTS, the Mobile Satellite Program, and the Laser Intersatellite Link experiments. These programs will demonstrate initial versions of some of the needed technology outlined earlier in this report: on-board switching and processing, large multibeam antenna, and intersatellite link technology. However, considerable work in still necessary to advance the state-of-the art to the needed levels.

NASA can, with the appropriate funding, pursue activities as outlined above: perform in-house efforts and fund efforts by contractors and universities. Emphasis should be on those areas where little or no work is being performed by industry itself because of cost and/or perceived risk levels.

A potential future NASA flight demonstration program might be a large experimental facility in GEO orbit. Such a facility may serve several purposes: in addition to providing demonstration in GEO of advanced communications components and/or systems, it may serve as a platform for Earth observations experiments.

Possible communications demonstrations could include large unfurlable multibeam antennas, compatibility of diverse payloads, GEO-GEO intersatellite links, large-scale switching, and communications payload servicing in GEO. The latter assumes that studies will have shown some form of GEO servicing desirable, and that an appropriate servicing infrastructure exists at the time of interest. Other technological developments requiring demonstration in GEO for acceptance could also be done. The facility could serve as a pilot or forerunner of a commercial large multiuser, multifrequency and/or multiservice GEO facility.

REFERENCE

5.1 NASA Space Systems Technology Model. NASA TM-88174, 1985. (Available Only from NASA Office of Aeronautics and Space Technology, Code RS, NASA HQ, Washington, D.C., 20546).June, 1985.

6.0 CONCLUSIONS/SUMMARY

In the course of this evaluation four major futures were considered for satellite communications. These areas were personal communications, terrestrial bypass, videophone, and large geostationary communication facilities. Other futures like DBS-TV, though very likely, were not considered as they were not judged to have need of major technology developments.

6.1.0 Common Technologies Needed

In the consideration of these four possible futures, common technology needs recurred. In each concept, frequency reuse was needed which led to need for large and complex multibeam antennas. Phased array feeds, primarily MMIC based, will be needed to minimize weight and power requirements as well as enhance reliability. Both fixed and scanning beams recurred, with each offering unique advantages. Therefore it was clear that an aggressive antenna program needed to be pursued which included phased array feed development (MMIC based) and deployment and control of large precision surfaces. Methods for generating and isolating hundreds of beams should be studied and integrated with the feed developments.

On-board processing was a recurring theme, though it varied in capacity with the concept. The ACTS baseband processor was viewed as an appropriate start and as having capability for extension to satisfy the needs of several of the concepts. The major exception was with personal communications. In this, the baseband processor would need to have an order of magnitude greater circuit capacity than forseen for operational ACTS. Consequently, advancements in complexity are needed while at the same time reducing the power and weight penalties.

For personal communications and one variation of OS/VSATS, narrowband uplinks are necessary to minimize the complexity and EIRP of user transmitting facilities. Consequently, developments of bulk demodulation technology are needed to reduce the weight and power impact of 1,000's of discrete demodulators. These devices would be designed so that a single device could simultaneously demodulate 100's of narrowband channels. Appropriate technologies are already being explored as part of the DOD VHSIC program. These need to be further refined to meet the unique needs described herein.

Intersatellite links offer the advantages of connecting domestic satellites with international satellites. With the prevalent on-board switching it will be possible, with intersatellite links, to directly dial international calls. This is judged to be an important adjunct to the above developments, complementing and enhancing their utility.

6.2.0 <u>Timing of Developments</u> -The timing of the above developments should be designed to make maximum advantage of NASA resources and achieve timely availability of the needed technologies. Toward this end, the cited technology developments were categorized into three time frames, reflecting the perceived timeliness of need.

6.2.1 Near term (now -1993). - In the near term, upgrades of TDRSS and ACTS technology would provide a basis for extending fundamental knowledge and creating new applications for commercial and government users. Applications of ACTS technology to enable single-hop circuits through VSATS would provide quality voice enhancements to an already thriving industry. With modest improvements, ACTS technology in conjunction with VSAT technology could provide an interim ISDN service to urban areas and maintain the same to surburban and rural areas. This will be an increasingly important service as international communications begins to align with this standard. Improvements in frequency reuse and use of phased array feeds will contribute to this success.

6.2.2 Mid term (1994 to 2000).- In the mid term, greater emphasis should be placed on enhancing the OS/VSAT potential. Bulk demodulation of >25 narrowband channels (128 to 512 kbps) would extend integrated voice and data service to the smallest of users. On-board processing should be refined to make maximum advantage of this narrowband technology. Features should be added to the processor to enable both circuit switched and packet switched communications to enhance compatibilty with the ISDN format.

6.2.3 Far term (2000 to 2010). - In the far term, technologies should be pursued which will lead to truly personal communications by satellite. This PC/SAT will make use of large aperture antennas on the order of 30 to 50 m. Therefore, techniques for fabricating and deploying large precision structures should be pursued. Large and complex MMIC phased array feeds should be explored (methods appropriate for thousands of elements). The ACTS baseband processor technology should be reviewed/revised to lead to much larger capacity processors suitable for processing and switching millions of circuits while at the same time restraining weight and power penalties. Bulk demodulation must be developed on a truly large scale with each device processing thousands of narrowband channels. Voice compression advances are needed to further reduce the bandwidth required for digital voice. Truly personal communications would use digitally processed voice at data rates near 9600 bps.

7.0 NEEDED STUDY AREAS

The time and resource guidelines given to NASA for compiling this report, excluded new work being done by the NASA study team. Instead, the report was restricted to summarizing of work already done. However, in the course of performing the compilation, it became evident to the study team that the proposed future applications were not defined as well as they should be for planning future NASA programs. Consequently, the study team recommends detailed studies be performed to determine:

(1) Market Analyses and Technology Assessments to Define Appropriate Satellite Capacity and Time Frame of Need.

(2) Definition of Transceiver Technology, Modulation Type(s), Channel Bandwidth, Demodulation Technology.

(3) Definition of On-Orbit Switch for Full Interconnectivity for each of:

(a) Personal Communications

(b) OS/VSATS

(c) Videophone

(d) Lunar Base Communications Support

Specific topics particular to each application are as follows:

(1) Personal Communications-

As mentioned in section 3.3.2, a universal personal communications system might be required to service the entire population, which could entail on the order of an 80 million circuit capacity system. The pressing question is how to obtain the required spectrum (or equivalently, the required frequency reuse).

(2) OS/VSATS-

Voice traffic is rarely, if ever, included in current VSAT networks. This is due to the inherent double-hop in a satellite "star" network (remote-master-remote). With on-board switching and higher EIRP satellites, it will be possible to replicate the function of the master station on the spacecraft and eliminate the double-hop. Consequently, acceptable single-hop voice could be included in an OS/VSAT. Given this event and the decreasing cost of VSATS, how much voice could one expect such a system to capture? Would such a system be be able to compete with optical fiber?

(3) Videophone-

The need for spectrum is as pressing as in Personal Communications. However, this service could be done effectively at Ka-Band where a large basic allocation is available. This would reduce, somewhat, the need for frequency reuse, but it would still be impressive (about 60 times)

(4) Lunar Base Communications Support-

The need for communications takes many forms including fixed, lunar mobile, space mobile, personal mobile, satellite-satellite, lunar-earth. Each of these modes need to be defined in terms of capacity, transceiver parameters, and the spacecraft compatible payload.

A preliminary assessment of needed technology has been made and is illustrated in figure 7.1. The study and/or proof-of-concept phase is indicated as open bars and the experimental and/or operational phase as darkened bars. These would be better defined after the above studies are completed.

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TABLE 3.1. - U.S. FIBER OPTIC LONG DISTANCE SYSTEMS

NETWORK	ANNOUNCED* LENGTH (MI)	MAJOR OWNERS	SUPPLIERS	FIBER COUNT	BIT RATE	ESTIMATED COST	LATEST ESTIMATE OF TOTAL CUTOVER MILES
NATIONWIDE:							
AT&T	10,200	AT&T	AT&T Technologies, Philips, R-C**, Telco Systems, NEC	24	40, 405, 417, 565	several $100 million	5,200
MCI	7,000	MCI	Siecor, Northern Telecom, R-C, Fujitsu	6, 22, 44***	405	$600-700 million	2,500
NTN:							
Consolidated Net	730	Consolidated Communications	Northern Telecom, R-C	12	565	NA	300
LDX Net	2,200	LDX Group	Ericsson, AT&T Tech., Pirelli, Siecor, Fujitsu	24	565	$110 million	600
LiTel	1,600	Several Private Investors****	Pirelli, Northern Telecom, SAT	18	140-565	$77-85 million	675
Microtel	1,300	Microtel	Ericsson, NEC, ITT	10	405	$60 million	731
SouthernNet	1,500	E.F. Hutton and Independent Telcos	Siecor, AT&T, Ericsson, NEC	10	405	$70 million	331
Southland Fibernet	330	Southland Communications	Ericsson, NEC	10	405	NA	272
Wiltel	3,500	Williams Co./TS&S	Siecor, NEC	10	405	$100 million	214
U.S. Sprint	23,000	GTE/U.S. Telecom	Ericsson, General Cable, Siecor, Fujitsu, Stromberg Carlson	6-32***	565	$2-4 billion	6,200
REGIONAL:							
Bandwidth Technologies	300	Optinet, Inc.	Northern Telecom	18	565	$21 million	100
Digi-Net	900	Private	AT&T Tech., Northern Telecom	32	405	$65 million	550
Electra	550	Cable & Wireless/MKT Railroad	Fujitsu, Telco Systems, AT&T Tech.	16-24***	405	$50 million	550
Indiana Switch	733	27 Independent Telcos/ U.S. Switch	Not Announced	6-22 (est)	560	$23 million	0
ICC	109	ICC	Not Announced	25-47***	140	$19.9 million	0
Lightnet	5,000	Southern NE Telephone/ESX Corp.	AT&T Tech.	38-48***	90-417	NA	700
Mutual Signal	404	Walker Telecommunications	Siecor, NEC	10	565	$30 million	0
Norlight	550	Five Midwest Utilities ****	Alcoa/Fujikura, Philips, Ericsson	12	130-565	$33 million	0
RCI	580	Rochester Telephone Corp.	AT&T Tech., Fujitsu	24	405	$90 million	580
TOTALS:	60,486					$4,902.9 million	20,503

NA = Not Announced
* rounded
** R-C = Rockwell-Collins
*** varies from different segments
**** detailed in profile, too numerous to list

(Reference 3.5)

TABLE 3.2. - COMPARATIVE CAPABILITIES: FIBER OPTICS VERSUS SATELLITES

Characteristics	Fiber-Optic systems	Satellites	Comments
Bandwidth	Limited only by electronics at terminals theoretical bandwidth of fiber is 1 terahertz	Most transponders have bandwidths of 36,54,or 72 MHz	565 Mb/s currently available on fiber-optics lines;1.7 Gb/s recently announced by AT&T for 1987; satellite bandwidth depends on frequency reuse and number of spot beams
Immunity to interference	Immune to electromagnetic Interference	Transmission subject to Interference form various sources, including micro wave	
Durability of links	Storms can knock down overhead lines	Storms can disable individual antennas but leave network intact	
Security	Difficult to tap without detection	Signals must be encoded for security	
Multipoint capabilities	Primarily a point-to-point medium	Point-to-mulitpoint communications easily implemented	Large area of coverage makes satellites only cost-effective means of reaching sparsely populated regions; multipoint-to-single-point communications also useful for data collection
Flexiblity	Difficult to reconfigure to meet changing demand	Easy to reconfigure if hardware has been appropriately designed	
Connectivity to customer site	Local loops required	With antenna installed on customer premises, as with 14/12-GHz band, local loops not required	

(Reference 3.6)

TABLE 3.3. - COSTS COMPARISONS OF MICROWAVE RADIO, FIBER-OPTICS, AND SATELLITE 250 - 3,000 MILES AT VARIOUS CIRCUIT DENSITIES

Channel Cross Sections	Technology Medium	Voice Circuits	Costs Per Circuit Mile, Distance - Miles: 250	500	1,000	2,000	3,000
6,048 to 8,100 voice circuits	Digital M/W 1:3	6,048	* 3.97	3.65	3.56	3.51	3.48
	Fiber-Optics: 12 Fibers, 90 Mb/s	6,720	6.49	6.38	6.31	6.26	6.20
	+ Satellite: 135 Mb/s (16 Kb/s voice)	7,956	16.00	8.00	4.00	* 2.00	* 1.33
	Analog FM M/W 1:3	8,100	4.53	* 3.22	* 2.61	2.29	2.16
13,440 to 23,008 voice circuits	Fiber-Optics: 24 Fibers, 90 Mb/s	13,440	3.85	3.74	3.68	3.65	3.62
	Digital M/W 1:7	14,112	2.98	2.73	2.66	2.62	2.59
	Analog SSB M/W 1:3	16,200	4.18	2.89	2.28	1.96	1.87
	+ Satellite: 405 Mb/s (16 Kb/s voice)	23,008	12.80	6.40	3.20	* 1.60	* 1.07
	Analog FM M/W1:7	18,900	3.83	* 2.57	* 1.97	1.66	1.56
	Fiber-Optics: 24 Fibers, 135 Mb/s	20,160	* 2.68	* 2.56	2.50	2.48	2.45
27,000 to 40,320 voice cricuits	Analog SSB M/W 1:5	27,000	3.88	2.60	2.00	1.69	1.58
	Fiber-Optics: 12 Fibers, 405 Mb/s	30,240	1.73	1.61	1.55	1.53	1.50
	+ Satellite: 565 Mb/s (16 Kb/s voice)	32,100	12.00	6.00	3.00	1.50	* 1.00
	Analog SSB M/W 1:7	37,800	3.68	2.42	1.82	1.51	1.42
	Fiber-Optics: 12 Fibers, 565 Mb/s	40,320	* 1.44	* 1.30	* 1.24	* 1.22	1.20
60,480 to 68,180 voice circuits	Fiber-Optics: 24 Fibers, 405 Mb/s	60,480	* 1.12	* 1.00	* 0.95	* 0.93	0.90
	+ Satellite: 1,200 Mb/s (16 Kb/s voice)	68,180	10.40	5.20	2.60	1.30	* 0.87
80,640 voice circuits	Fiber-Optics: 144 Fibers, 90 Mb/s	80,640	2.14	2.02	1.96	1.94	1.92
	Fiber-Optics: 96 Fibers, 135 Mb/s	80,640	1.65	1.53	1.47	1.45	1.42
	Fiber-Optics: 24 Fibers, 565 Mb/s	80,640	0.96	0.84	0.78	0.76	0.74
	Fiber-Optics: 12 Fibers, 1.2 Gb/s	80,640	* 0.91	* 0.78	* 0.72	* 0.70	* 0.67

* Most cost-effective in cross-section category shown.
\+ Satellite figures represent 4:1 compression.
Reference 3.16

TABLE 3.4. - CONCLUSIONS DRAWN BY COMPUCON, INC.

Channel Density Number of Voice Circuits	Conclusions
6,048 to 8,100	Digital microwave is most cost-competitive for distances of 250 miles or less. Analog microwave is the lowest cost for 500.
13,440 to 23,008	Fiber optics is the most cost-competitive technology for this channel density at distances of less than 500 miles. Analog microwave is the least expensive alternative for 1,000 mile route segments. Satellite is the lowest cost for segments of 1,5000 miles or more.
27,000 to 40,320	The inherent cost-efficiencies of fiber optics technology with increasing channel density are clear here. Fiber optics is the least expensive medium for all but the longest routes. Satellite is less expensive for routes longer than 2,4000 miles.
60,480 to 80,640	For channel densities exceeding 60,000 fiber optics is in completation only with itself. The most cost-effective configure-attion is 12 fibers at 1.2 Gb/s, followed closely by 24 fibers at 565 Mb/s.

TABLE 3.5. -

ITEM		COST PER CALL-MIN
Satellite Charge		4.79
E/S Charge		3.59
Billing		2.91
E/S Maintainence		2.88
Sales & Advertising		6.86
Profit		13.47
	Total	34.51

TABLE 3.6. - COMPARISON OF COSTS FOR A 1000 SITE RECEIVE ONLY NETWORK 2400 BPS

ITEM	MONTHLY COST
Equatorial Technology:	
Earth Station, $2500/84 mos.	46
Installation, $350/84 mos.	6
Satellite Services 2400bps	17
Maintenance	15
Network Connect Fee	10
Total	94
Terrestrial Equivalent:	
Demodulator, $1000/84 mos.	18
Local Loop Interconnect, 5 mi average length @$132 +2.50/mi	145
Long-Haul Costs @ 25 mi. average length @$4/mi.	100
Total	263

TABLE 3.7. - COMPARISON OF COSTS FOR A 1000 SITE TWO WAY NETWORK 2400 BPS

ITEM	MONTHLY COST
Equatorial Technology:	
Earth Station, $5500/84 mos.	100
Installation, $800/84 mos.	15
Satellite Services:	
2400bps to 1000 sites	50
2400bps from 1000 sites	10
Maintenance	50
Network Connect Fee	30
Total	255
Terrestrial Equivalent:	
Demodulator, $1500/84 mos.	27
Local Loop Interconnect, 5 mi average length @$132 +2.50/mi	145
Long-Haul Costs @ 25 mi. average length @$4/mi.	100
Total	272

TABLE 3.8. - Ku-BAND VSAT PARAMETERS

Item	Value
Diameter, Meters	1.2
Noise Temperature, ^{o}K	225
Power, watts	3
Modulator	BPSK
Uplink Symbol Rate, Ksps	512
Uplink Coding	Rate 1/2 Conv.
Decoding	Rate 1/2 Sequen.
BER performance	10^{-7} @ Eb/No=7.0 db

TABLE 3.9. - Ku-BAND SATELLITE PARAMETERS

Item	Value
Uplink Ant. Diam. M	1.23
# of Uplink Beams	24
Downlink Ant. Diam. M	1.44
# of Downlink Beams	24 spots for 6 scanning beams
Noise Temp. ^{o}K	650
RF Power/Scanned Beam, W	33
Burst Rate, Mbs	120
Modulation	QPSK
Encoding	Rate 1/2 Sequent.
Decoding	Rate 1/2 Conv.
BER	10-7 @ Eb/No=8.5 db

TABLE 3.10. - DOWNLINK POWER BUDGET

ITEM	VALUE db	VALUE Watts
Eb/No, db	10.00	
Bit Rate, db	80.79	
Boltzman's Constant, db	-228.60	
Noise Temp., db-K	23.52	
No, dbW	-205.08	
Received Pwr, dbW	-114.29	
Terminal Gain, db	41.32	
Rain Loss, db	4.00	
Atmospheric Loss, db	0.80	
Path Loss, db	-205.84	
EIRP, dbW	53.44	
Ptg. Loss, db	-0.80	
S/C Antenna Gain, db	39.60	
Line Loss, db	-0.50	
Transmitter Power, dbW (W)	15.14	(32.65)

TABLE 3.11. - UPLINK POWER BUDGET

ITEM	VALUE db	VALUE Watts
Eb/No, db	11.50	
Bit Rate, db	57.09	
Boltzman's Constant, db	-228.60	
Noise Temp., db-K	28.13	
No, dbW	-200.47	
Received Pwr, dbW	-131.88	
S/C Gain, db	39.57	
Rain Loss, db	-8.00	
Atmospheric Loss, db	-0.60	
Path Loss, db	-207.18	
EIRP, dbW	44.33	
Ptg. Loss, db	-1.00	
Terminal Gain, db	42.66	
Line Loss, db	-0.50	
Transmitter Power, dbW (W)	3.18	(2.08)

TABLE 3.12. - SAMPLE MISSIONS, MISSION PARAMETERS*

MISSION NO.	MISSION NAME	STATUS	START DATE	LAUNCH DATE	OFFICE	LAUNCH VEHICLE	TRANSFER VEHICLE	OPERATIONAL LOCATION	INCLINATION (deg)	Flight Duration (yr)
P-1	Galileo	Approved	Ongoing	1986	OSSA	Shuttle	Centaur	Jupiter orbit		4.4
P-2	Ulysses	Approved	Ongoing	1986	OSSA	Shuttle	Centaur	Heliocentric orbit		4.5
P-3	Venus Radar Mapp	Approved	Ongoing	1988	OSSA	Shuttle	Centaur	Venus orbit (near-polar)		1
P-4	Mars Observer	Planned	1985	1990	OSSA	Shuttle	**	Mars sun-sync.	92.8	3-5
P-5	Comet Rendezvous	Planned	1987	1991	OSSA	Shuttle	Centaur G'	Cometary body orbit		6.3
P-6	Comet Coma S Ret	Planned	1987	1992	OSSA	Shuttle	TOS	Cometary coma		2
P-7	Lunar Geoscience	Planned	1988	1991	OSSA	Shuttle	**	Lunar orbit	95	1-2
P-8	Saturn Orb/Titan	Candidate	1989	1993	OSSA	Shuttle	Centaur G'	Saturn orbit		5.9
P-9	Uranus Flyby/Pro	Candidate	1990	1995	OSSA	Shuttle	Cen. G'-Star	Uranus orbit		7.2
P-10	Near-Earth Aster	Candidate	1991	1995	OSSA	Shuttle	TOS	Heliocentric orbit		2
P-11	Mars Sample Retu	Candidate	1991	1996	OSSA	Shuttle	Centaur G'	Mars surface and orbit		3
P-12	Mars Dual Networ	Candidate	1992	1997	OSSA	Shuttle	**	Mars surface and orbit		2.7
P-13	Mainbelt Asteroi	Candidate	1993	1996	OSSA	Shuttle	Centaur G'	Asteroid belt		6-9
P-14	Saturn Flyby/Pro	Candidate	1993	1998	OSSA	Shuttle	Cen. G'-Star	Saturn		3.2
P-15	Mars Aeronomy Ob	Candidate	1994	1997	OSSA	Shuttle	**	Mars orbit	77.5	2-3
P-16	Venus Atm Probe	Candidate	1994	1999	OSSA	Shuttle	PAM-A	Venus		0.33
P-17	Comet Nucl S Ret	Candidate	1994	1999	OSSA	Shuttle	Cen. G', SEPS	Comet nucleus		5
P-18	Neptune Flyby/Pr	Candidate	1995	2000	OSSA	Shuttle	Cen. G'-Star	Neptune		>12
P-19	Titan Buoyant St	Opportunity	>1995	ND	OSSA	Shuttle	Cen. G'-Star	Titan		5.4
P-20	Saturn Ring Rend	Opportunity	>1995	ND	OSSA	Shuttle	NEP	Saturn rings		10.1
P-21	Pl Det/Astro Tel	Opportunity	>1995	ND	OSSA	Shuttle		600 km (Earth)	28.5	5
P-22	Multi-Aster S R	Opportunity	>1995	ND	OSSA	Shuttle	NEP	Asteroid belt		**
P-23	Outer Planet Orb	Opportunity	>1995	ND	OSSA	Shuttle	NEP	Outer planet orbit		12.2
A-1	Spartan	Approved	Ongoing	1985	OSSA	Shuttle		LEO		<2 days
A-2	Space Telescope	Approved	Ongoing	1986,1991	OSSA	Shuttle		600 km orbit	28.8	15
A-3	Roentgen Satelli	Approved	Ongoing	1987	OSSA	Shuttle		475 km orbit	57	1.5
A-4	COBE	Approved	Ongoing	1988	OSSA	Shuttle		900 km orbit	99	1
A-5	Gamma Ray Observ	Approved	Ongoing	1988	OSSA	Shuttle		400 km orbit	28.5	>2
A-6	Solar Opt Telesc	Approved	Ongoing	1990	OSSA	Shuttle		460 km orbit	57	7-21 days;
A-7	Extreme UV Explo	Approved	1985	1989	OSSA	Shuttle		550 km orbit	28.5	1
A-8	GP-B Shu Test Fl	Planned	1985	1989	OSSA	Shuttle		LEO		10 days
A-9	Cosmic Ray Expr	Planned	>=1986	>=1989	OSSA	Shuttle		Varied		
A-10	X-Ray Timing Exp	Planned	1987	1990	OSSA	Shuttle		400 km orbit	28.5	2
A-11	AXAF	Planned	1987	1991	OSSA	Shuttle		550 km orbit	28.5	10-15
A-12	Pinhole Occulter	Planned	1988	1991	OSSA	Shuttle		435 km orbit	28.5	5 days
A-13	SIRTF	Planned	1988	1992	OSSA	Shuttle		>600 km orbit	28.5	10-15
A-14	Gravity Probe-B	Planned	1988	1992	OSSA	Shuttle		650 km orbit	90	1-2
A-15	Solar Seis Obser	Planned	1988	1993	OSSA	Shuttle		L1 Libration point		2
A-16	SUPERMAG	Planned	1988	1993	OSSA	Shuttle		LEO	28.5	2
A-17	Far UV Spectr Ex	Planned	1988-90	ND	OSSA	Shuttle	SSUS-D	GEO	28.5	5
A-18	Solar Cor Diagno	Planned	1988-90	ND	OSSA	Shuttle	IUS	600 km orbit	33	3
A-19a	SSAP: FRUTELC	Candidate	1988-2000	ND	OSSA	Shuttle		400 km orbit	>=28.5	10
A-19b	SSAP: Lensecraft	Candidate	1988-2000	ND	OSSA	Shuttle		LEO	>=28.5	10
A-20	OVLBIO	Candidate	1990-1995	ND	OSSA	Shuttle	**	>1000 km	>45	>2
A-21	Starprobe	Candidate	1990-1995	ND	OSSA	Shuttle	Centaur	Heliocentric		5
A-22	Hi Thr X-Ray Exp	Candidate	1990-1995	ND	OSSA	Shuttle		400 km orbit	28.5	2
A-23	Large Depl Refl	Candidate	1993	1997	OSSA	Shuttle		700 km orbit	**	10
A-24	Adv Solar Observ	Candidate	1990-2000	ND	OSSA	Shuttle		LEO	**	5-10
A-25	S S X-Ray Telesc	Candidate	1990-2000	ND	OSSA	Shuttle		430 km orbit	57	7-15 days;
A-26	Ot Interferomete	Opportunity	>1995	ND	OSSA	Shuttle		400-700 km	28-50	5
A-27	Grav Wave Interf	Opportunity	>1995	ND	OSSA	Shuttle		LEO	**	1-5
A-28	COSMIC	Opportunity	>1995	ND	OSSA	Shuttle	**	463-556 km	28.5	10-15
A-29	100-m Th Ap Tele	Opportunity	>1995	ND	OSSA	Shuttle	**	500 km, GEO	28.5	10
A-30	Adv Interpl Expl	Opportunity	ND	ND	OSSA	Shuttle	**	L1 Libration; 15 x 50 halo		4
A-31	Hvy Nuclei Explo	Opportunity	ND	ND	OSSA	Shuttle		400 km orbit	56	2
A-32	X-Ray Spectr Exp	Opportunity	ND	ND	OSSA	Shuttle		400 km orbit	28	1
A-33	Hi Energy Tr Exp	Opportunity	ND	ND	OSSA	Shuttle		450 km orbit	28.5	2
A-34	Sim Astronom Exp	Opportunity	ND	ND	OSSA	Shuttle	SSUS-A/IUS	GEO	28.5	3
A-35	Mol Line Surv Ex	Opportunity	ND	ND	OSSA	Shuttle	SSUS-D	600 km orbit	28.5	3
A-36	H Maser Redshift	Opportunity	ND	ND	OSSA	Shuttle	**	Eccentric GEO		0.3
A-37	Laser Het Gr Wav	Opportunity	ND	ND	OSSA	Shuttle	**	Heliocentric		**
A-38	H Maser Gr Wave	Opportunity	ND	ND	OSSA	Shuttle	**	Heliocentric; 1 AU x 6 AU		10
A-39	DART	Opportunity	ND	ND	OSSA	Shuttle	SSUS-D	Heliocentric; 1 AU x 5 AU		10
A-40	GRITS	Opportunity	ND	ND	OSSA	Shuttle		400-600 km	28.5	10

MISSION NO.	Physical Characteristics: Total Mass (kg)	Physical Characteristics: Physical Size(m)	Physical Characteristics: Max Antenna Diameter(m)	Data Proc. Data Volume (bits/day)	Data Proc. On-B Storage Capac.(bits)	Data Proc. Storage I/O Rates(kbps)	Data Proc. On-B Memory Size(bits)	Data Proc. On-B Proc. Speed(ops)	Data Proc. On-B I/O Rates(kbps)	Comm. Link Data Rates(kbps)
P-1	1970	5.1 x 4.4(d)	4.8	1 x 10E10	9 x 10E8	8-806	3.2 x 10E6	*	0.04-134	8-134
P-2										
P-3	1224	4.7 x8.9 x1.9	3.7	1 x 10E10	1.8 x 10E9	806.4	2.5 x 10E6	*	*	268.8
P-4	**	**	**	5.2 x 10E8	5.2 x 10E8	6	1.6 x 10E4	**	0.03	1.5-32
P-5	**	**	**	1.45 x 10E9	9 x 10E8	**	**	**	**	52.5
P-6	**	**	**	**	**	**	**	**	**	0.032-0.128
P-7	**	**	1	5.2 x 10E8	5.2 x 10E8	6	1.6 x 10E4	**	0.03	1.5-32
P-8	**	**	**	7 x 10E8	9 x 10E8	**	**	**	**	24.2
P-9	**	**	**			**	**	**	**	4.6
P-10	2000	**	1	9.8 x 10E8	9 x 10E8	12	1.6 x 10E4	**	0.03	8-32
P-11	8471	11.7 x 3.9(d)	**	5.2 x 10E8	5.2 x 10E8	**	**	**	**	0.01-20
P-12	760;707	**	**	**	**	0.5-8; 0.1-4	**	**	**	8; 1
P-13	**	**	**	1.6 x 10E7	1.6 x 10E7	**	**	**	**	20
P-14	820	**	**	1.3 x 10E9	9 x 10E8	**	**	**	**	20
P-15	**	**	**	9 x 10E8	9 x 10E8	**	**	**	**	**
P-16	**	**	**	**	**	**	**	**	**	1
P-17	**	**	**	1 x 10E7	1 x 10E7	**	**	**	**	**
P-18	**	**	**	**	**	**	**	**	**	**
P-19	1885; 2730	**	3.7	**	2.6 x 10E8	**	**	**	**	20
P-20	6700	15.4 x 4.3(d)	3.6	**	**	**	**	**	**	**
P-21	2628	13(1)	**	**	10E8-10E9	**	**	**	**	2 x 10E3
P-22	**	**	**	**	**	**	**	**	**	**
P-23	6739	15.4 x 4.3(d)	3.6	**	**	**	**	**	**	**
A-1	1136	0.6 x 0.8(d)		*	1 x 10E10	12.5	*	*	*	
A-2	11070	13.6 x 4.3(d)	*	1 x 10E10	3 x 10E9	4-1024	*	3.5 x 10E5	*	4-1024
A-3	2300	2.3 x 4.6(d)	*	6.2 x 10E8	*	*	*	*	*	*
A-4	3110	5.5 x 4.0(d)	0.8	*	1.6 x 10E8	4-640	*	*	*	8
A-5	15900	9.2 x 4.5(d)	**	3 x 10E9	10E8-10E9	32	**	**	**	32; 512
A-6	3415	7.3 x 3.9(d)		**	**	**	**	**	**	**
A-7	**	**	0.75	**	**	16	**	**	**	50
A-8	1569-2174	**		**	**	8	**	**	**	8
A-9										
A-10	1400	4 x 2 x 1.5	**	1 x 10E9	1 x 10E7	64	**	**	**	10-64
A-11	10000-12000	16 x 3.1(d)	**	10E9-10E11	1 x 10E10	1000	3.2 x 10E8	**	**	**
A-12	4242-5303	32 x 5.5(d)	**	**	**	2000	**	**	**	>1400
A-13	7000	8.7 x 3.1(d)	**	**	**	**	**	**	**	<=3000
A-14	1460	4.5 x 3.1(d)	**	2.2 x 10E7	5 x 10E5	<1	1 x 10E6	1 x 10E5	**	0.512
A-15	1187	**	0.9	**	**	**	3.2 x 10E7	**	**	150; 40
A-16	5000	**		1 x 10E9	1 x 10E7	84	**	**	**	
A-17	1050	15 x 3(d)	**				**	**	**	40
A-18	400	**	**	>1 x 10E9	**	<=5000	**	**	**	5-5000
A-19a	**	**	**	**	**	<=30	**	**	**	<50
A-19b	**	**	**	**	1 x 10E8	**	<=1.2 x 10E6	**	**	<=1 x 10E5
A-20	**	15-20(d)	15-20	10E11-10E14	**	4 x 10E4	**	**	4 x 10E4	1.2 x 10E5
A-21	1300	4.5 x 1.0(d)	1	4 x 10E8	2 x 10E9	100	1.5 x 10E6	**	100	30-300
A-22	5000	**	**	**	**	**	**	**	**	8 or 64
A-23	27000	**	**	**	**	**	**	**	**	**
A-24	4200-12600	**	**	**	**	**	**	**	**	5 x 10E4
A-25	1300	7.5 x 1.0(d)		**	**	**	**	**	9000	**
A-26	2200	100 x 15 x 9	**	10E10-10E12	10E10-10E11	**	**	**	**	10E2-10E5
A-27	16000	1000	**	**	**	**	**	**	**	**
A-28	41935	4 x 34 x 31	1	10E10-10E12	1 x 10E9	**	**	**	1000; 4	32 or 1000
A-29	8000	100(d)	**	10E10-10E12	10E10-10E11	**	**	**	**	10E2-10E5
A-30	700	**	**	**	**	4	**	**	**	4
A-31	4000	**	0.75	**	**	2	**	**	**	2
A-32	1375	**	0.75	**	**	10	**	**	**	10
A-33	3100	**	0.75	**	**	10	**	**	**	10
A-34	2000	2 x 3(d)	**	**			**	**	**	100
A-35	800	1 x 3.5(d)	3.5	1 x 10E6	**	10	**	**	**	10
A-36	200	**	**	**	**	**	**	**	**	**
A-37	**	**	**	**	**	**	**	**	**	**
A-38	**	**	1.4	**	**	**	**	**	**	**
A-39	150	**	1.9	**	**	**	**	**	**	**
A-40	**	**	**	**	**	**	**	**	**	**

ND Not determined
* Performance requirement not available
** System definition insufficient to permit specification

* REF. 3.34. P. 1-340, 341 (MODIFIED)

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TABLE 3.13. - SAMPLE MISSIONS, MISSION PARAMETERS*

MISSION NO.	MISSION NAME	STATUS	START DATE	LAUNCH DATE	OFFICE	LAUNCH VEHICLE	TRANSFER VEHICLE	OPERATIONAL LOCATION	INCLINATION (deg)	Flight Duration (yr)	Physical Characteristics: Total Mass (kg)	Physical Characteristics: Physical Size(m)	Physical Characteristics: Max Antenna Diameter(m)	Data Proc. Data Volume (bits/day)	Data Proc. On-B Storage Capac.(bits)	Data Proc. Storage I/O Rates(kbps)	Data Proc. On-B Memory Size(bits)	Data Proc. On-B Proc. Speed(ops)	Data Proc. On-B I/O Rates(kbps)	Comm. Link Data Rates(kbps)
E-1	Crustal Dyn Proj	Approved	Ongoing		OSSA															
E-2	GOES G,H	Approved	Ongoing	As Requested	OSSA	Delta 3914		GEO		7	337	*	*	*	*	*	*	*	*	*
E-3	NOAA G-H	Approved	Ongoing	As Requested	OSSA	Atlas F		830 km orbit	*	2	1700	*	*	*	*	*	*	*	*	*
E-4	Landsat-4 Repair	Approved	Ongoing	1986	OSSA	Shuttle		370 km orbit	98.2											
E-5	LAGEOS-II	Approved	Ongoing	1986	OSSA	Shuttle	IRIS, AKM	6000 km orbit (near-polar)			425	2(d)								
E-6	CRRES	Approved	Ongoing	1987	OSSA	Shuttle		400 x35800 km	24	<=3	2260	1 x 1.8(d)	0.4	9.2 x 10E8	7.5 x 10E8	256	*	*	*	256; 16
E-7	UARS	Approved	1985	1989	OSSA	Shuttle		600 km orbit	57	1.5	4550	10.7 x 4.6(d)	*	*	5 x 10E8	32	*	*	*	1; 32; 512
E-8	SSTO	Planned	1985	1992	OSSA	Shuttle		LEO		Indefinite	**	**	**	**	**	**	**	**	**	**
E-9	TOPEX	Planned	1986	1989	OSSA	Shuttle	**	1300 km orbit	63	3-5	1200-1800	**	**	**	**	**	**	**	**	**
E-10	Space Plasma Lab	Planned	1986	1989	OSSA	Shuttle		LEO		7-9 days;	**	**	**	**	**	**	**	**	**	**
E-11	ISTP	Planned	1987	1990	OSSA	Shuttle	PAM-D, TOS	varied		**	721-1650	**	**	**	**	**	**	**	**	**
E-12	Magn Field Expl	Planned	1987	1990	OSSA	Shuttle	SSUS-A	600 km orbit	97	5	400	**	**	**	1 x 10E8	**	**	**	**	**
E-13	Geopotential Res	Planned	1988	1991	OSSA	Shuttle		160 km orbit	90	0.6	2200;2000	10.6 x 0.9(d)	**	**	**	**	**	**	**	**
E-14	Orb Lidar Facili	Candidate	1986-89	ND	OSSA	Shuttle		LEO	**	7-15 days;	2300	**		**	**	**	**	**	**	2 x 10E3
E-15	Earth Obs System	Candidate	1989	1993	OSSA	Shuttle	**	500-1000 km	sun-sync	Indefinite	7000-10000	70	*	**	1 x 10E12	**	**	**	**	1 x 10E6
E-16	Sp Oxygen Laser	Candidate	1990-2000	ND	OSSA	EOS or Shuttle		LEO	**	**	**	**	**	**	**	**	**	**	**	**
E-17	Soil, Snow Moist	Candidate	1990-2000	ND	OSSA	Shuttle		465 km orbit	sun-sync	2-3	**	**	10	**	**	**	**	**	**	**
E-18	FIREX	Candidate	1990-2000	ND	OSSA	**	**	700 km orbit	90	3-5	**	**	10	**	**	5 x 10E4	**	**	**	**
E-19	Grav Grad Missio	Candidate	1990-2000	ND	OSSA	**		**	**	**	**	**	**	**	**	**	**	**	**	**
E-20	Sh Topog Mapping	Candidate	ND	ND	OSSA	Shuttle		250 km orbit	polar	7-15 days;	500	**	12 x 0.6	**	**	**	**	**	**	**
E-21	Adv Oper Met Sys	Candidate	ND	ND	OSSA	**	**	GEO and polar		**	**	**	**	**	**	**	**	**	**	**
L-1	Exobiology Progr	Approved	Ongoing																	
L-2	Sp Bio Research	Approved	Ongoing																	
L-3	Bio Sys Research	Approved	Ongoing																	
L-4	Sp Medicine Prog	Approved	Ongoing																	
L-5	SETI	Opportunity	1988	ND	OSSA	Shuttle	**	13 Libration Point		10	**	600(d)	300	1 x 10E16	**	**	**	**	**	3 x 10E5
C-1	TDRSS	Approved	Ongoing	1985	OSTDS	Shuttle	IUS	GEO		10	1905	*	*							<3 x 10E5
C-2	Search and Rescu	Approved	Ongoing	1984	OSSA	Atlas-F		834 km orbit	98.8	1-2	850	*	*							*
C-3	Mobile Comm Prog	Approved	Ongoing	1988	OSSA	Shuttle	**	GEO		**	**	**	20							**
C-4	ACTS	Approved	Ongoing	1989	OSSA	Shuttle	SSUS-A	GEO		*	1270	*	3	**	**	**	**	**	**	2.4 x 10E5
C-5	Geo Platform	Candidate	1989	1993-94	OSSA/OSF	Shuttle	**	GEO		8	5000-10000	**	**							**
C-6	TDAS	Candidate	1990	>1995	OSTDS	**	**	GEO		**	**	**	**							1 x 10E6
C-7	Hi Freq Dir Broa	Candidate	>=1990	ND	OSSA	Shuttle	**	LEO or Geo	**	7-10	5000-15000	**	100 or 65x66							**
C-8	CDSRS	Opportunity	>1995	ND	OSTDS	**	**	GEO		**	**	**	**							**
T-1	Scout	Approved	Ongoing		OSF						21320	22.5(l)	*		*	*	*	*	*	*
T-2	Delta	Approved	Ongoing		OSF						191000	33(l)	*		*	*	*	*	*	*
T-3	Atlas-F	Approved	Ongoing		OSF						118450	30(l)	*		*	*	*	*	*	*
T-4	Atlas/Centaur	Approved	Ongoing		OSF						146000	38(l)	*		*	*	*	*	*	*
T-5	Space Shuttle	Approved	Ongoing		OSF			LEO		100 flights	2000000	37(l)	*		*	*	8 x 10E5	*	*	50K; 5K; 1K;
T-6	SSUS/PAM	Approved	Ongoing		OSF	Shuttle		LEO to GEO			3788	2.2(l)	*		*	*	*	*	*	*
T-7	IUS	Approved	Ongoing		OSF	Shuttle		LEO to GEO, planetary			10886; 3956	5.0; 6.7; 2.4	*		*	*	*	*	*	16
T-8	Centaur G & G'	Approved	Ongoing	1986	OSF	Shuttle		Planetary, LEO to GEO			25400	9 x 4.4(d)	*		*	*	3.9 x 10E5	*	*	64; 32; 16;
T-9	Transf Orb Stage	Approved	Ongoing	1987	OSF	Shuttle		LEO to GEO			4710-15740	1.5-5.2(l)	*		*	*	*	*	*	*
T-10	Orb Maneuv Veh	Planned	1986	1990	OSF	Shuttle		LEO, GEO		10	5200	1 x 4.5(d)	**		**	**	**	**	**	**
T-11	SDLV	Planned	1987	1995	OSF			LEO			**	**	**		**	**	**	**	**	**
T-12	Reusable OTV	Planned	1988	1995	OSF	Shuttle		LEO to GEO		10-50 missions	**	**	**		**	**	**	**	**	**
T-13	Aft Cargo Carrie	Planned	ND	1993	OSF	Shuttle		LEO			**	7 x 8.5(d)								
T-14	Manned OTV	Candidate	1991	1997	OSF	Shuttle		LEO to GEO		20-50 missions	**	**	**		**	**	**	**	**	**
T-15	Prop Tanker	Candidate	ND	1995-98	OSF	Shuttle/SDLV		LEO			**	**	**		**	**	**	**	**	**
T-16	Tether Trans Sys	Opportunity	>1995	ND	OSF	Shuttle	**	LEO and GEO		**	5770	**	**							**
T-17	Heavy Lift L V	Opportunity	ND	2000	OSF			LEO or higher		**	**	**	**		**	**	**	**	**	**
T-18	Shuttle-II	Opportunity	ND	2002	OSF			LEO		**	**	**	**		**	**	**	**	**	**
U-1	Micrograv Sci Ob	Approved	Ongoing		OSSA															
U-2	Micrograv Mat Sc	Approved	Ongoing		OSSA															
U-3	Spacelab	Approved	Ongoing	1985	OSF	Shuttle		LEO		7-9 days	4560-9375	7.0 x 4.1(d)		64 x 10E9	3.8 x 10E10	3.2 x 10E4	1 x 10E6	3.2 x 10E5	1 x 10E3	<5 x 10E4
U-4	Tethered Sat Sys	Approved	Ongoing	1987	OSF/OSSA	Shuttle		LEO		1.5-6.5 days	<2500	3.8 x3.6 x2.4	**	**	**	**	**	**	**	**
U-5	Space Station	Planned	1987	Early 1990s	OSS	Shuttle		500 km orbit	28.5	Indefinite	**	90(l)	**	**	1.5 x 10E12	2.25 x 10E5	**	**	**	1.2 x 10E5
U-6	Geo Sp Station	Opportunity	>1995	ND	OSF	Shuttle	**	GEO		Indefinite	60000	**	**	**	**	**	**	**	**	**
U-7	Tether Power Gen	Opportunity	>1995	ND	OSF	Shuttle	**	LEO and GEO		**	8250	**								
U-8	Geo Platform Bus	Opportunity	ND	1998	OSF	Shuttle	**	GEO		**	**	**	**	**	**	**	**	**	**	**

ND Not determined
* Performance requirement not available
** System definition insufficient to permit specification
(blank) Not applicable

REF. 3.34, P. 1-342, 343 (MODIFIED)

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TABLE 3.14. - ADVANCED MISSIONS LONG-RANGE PLANNING

MAJOR MILESTONES --- ALL PROGRAMS

	1%	2.4%				NCOS
	BALANCED	BALANCED	COMMERCIAL	LUNAR	MARS	REPORT
PHASE I SPACE STATION	1994	-->	-->	-->	-->	1994
PHASE II SPACE STATION	2001	-->	-->	-->	-->	1999+
STS II	2028	- 10	-5A/-4B	- 7	- 5	2000
UNMANNED CARGO VEHICLE	2000	-->	-->	-->	-->	1998
GEO PLATFORM	1998	-->	-->	-->	-->	*)
GEO SORTIES	2011	-->	- 3	- 2	- 3	*)
GEO SHACK	2014	-->	- 2	+ 4	- 2	*)
GEO SPACE STATION	2022	-->	+4A/N/AB	+ 3	+ 9	*)
LUNAR RELAY SATELLITE	2016	-->	-->	-15	- 7	*)
LUNAR SURFACE SORTIES	2032	- 10	+ 3	-22	- 6	2005
LUNAR ORBIT STATION	>2035	-->	-->	2035	>2035	*)
LUNAR CAMP (1ST HAB MOD)	>2035	2022	2028	2010	2030	2005
LUNAR BASE (3RD HAB MOD)	>2035	2029	2035	2020	2034	2007+
MARS ROVER/SAMPLE RETURN	2008	-->	-->	-->	-->	*)
MANNED MARS LANDING	>2035	2031	2035	2035	2016	2015
MARS CAMP (1ST HAB MOD)	>2035	2035	>2035	>2035	2024	2015
MARS BASE (3RD HAB MOD)	>2035	-->	-->	-->	2032	2025
COMET SAMPLE RETURN	2015	-->	+ 1	2015	-->	*)
PLUTO ORBITER	2009	-->	+0A/+20B	2009	-->	*)
VENUS SAMPLE RETURN	2017	-->	-->	-->	-->	*)

DELTAS = YEARS RELATIVE TO BAL/1% PROGRAM
--> = NO CHANGE > = BEYOND RANGE
N/A = NOT APPLICABLE

*) IMPLIED IN NCOS REPORT BUT NOT SPECIFIED

(7/3/86/HT/JvP)

(FROM REF. 3.38)

TABLE 4.1. - FSS SERVICES - CURRENT ASSIGNMENTS JULY 30, 1986

Orbital Position	Designated Frequency	Owner	Satellite Name	Launch Date	Remarks
143°	C	RCA-Alascom	Aurora I	1982	
139°	C	RCA-Alascom	Satcom 1R	1983	
134°	C	Hughs Comm.	Galaxy I	1983	
131°	C	RCA-Americom	Satcom 3R	1981	
128°	C/Ku	Am. Satellite	ASC 1	1985	
125°	C	AT&T	Telstar 303	1985	
122.5°	C	Western Union	Westar V	1982	
120°	C/Ku	GTE	Spacenet I	1984	
117.5°	Ku	Canada	Anik C-3	1982	
116.5°	C/Ku	Mexico	Morelos II	1985	
113.5°	C/Ku	Mexico	Morelos I	1985	
110°	Ku	Canada	Anik C-2	1984	
109°	C/Ku	Canada	Anik B	1983	
105°	Ku	GTE	GStar II	1986	
104.5°	C	Canada	Anik D	1982	
103.°	C/Ku	GTE	GStar I	1985	
099°	Ku	MCI/SBS	SBS I	1980	
	C	Western Union	Westar IV	1984	
097°	Ku	MCI/SBS	SBS II	1981	
096°	C	AT&T	Telstar 301	1983	
095°	Ku	MCI/SBS	SBS IV	1982	
093.5°	C	Hughes Comm.	Galaxy III	1986	Launch failure Ariane
091°	Ku	IBM/SBS	SBS IV	1984	
	C	Western Union	Westar III	1979	
086°	C	AT&T	Telstar 302	1984	
085°	Ku	RCA Americom	Satcom K2	1985	
083°	C	RCA Americom	Satcom IV	1982	
081°	Ku	RCA Americom	Satcom K1	1985	
079°	C	Western Union	Westar II	1974	
074°	C	Hughes Comm.	Galaxy II	1983	
072°	C	RCA Americom	Satcom II-R	1983	
070°	C/Ku	Brazil	Brazilsat II	1986	
069°	C/Ku	GTE	Spacenet II	1984	
065°	C/Ku	Brazil	Brazilsat I	1985	

TABLE 4.2. - FSS SERVICES - 2° SPACING PLAN ASSIGNMENTS

Orbital Position	Designated Frequency	Applicant	Satellite Name	Launch Date	Remarks
146	C	RCA Americom	Aurora II	TBD	Serving Alaska
144	C	Western Union	Westar VII	1992	
142	C	RCA Alascom	Aurora I	1982	Moved from 143°/serving Alaska
140	C	Hughes Comm.	Galaxy IV	1991	
138	C	RCA Americom	Satcom 1-R	1983	Moved from 139°
136	Ku	GTE Satellite	GStar III	1992	
	C/Ku	GTE	Spacenet IV	1991	
134	Ku	Comsat General	Comgen 2	1994	New entrant
	C	Unassigned			C-band vertical polorization authorized
132	C	Hughes Comm.	Galaxy I	1983	Moved from 134°
	Ku	Western Union	Westar B	1996	New authorization
130	C	RCA Americom	Satcom 3-R	1981	Moved from 131°
	Ku	Hughes Comm.	Galaxy B	1992	
128	C/Ku	AM Satellite	ASC I	1985	
126	C	AT&T	Telstar 303	1983	Move from 125°
	Ku	Martin Mar.	MM B	1994	New entrant
124	C	Western Union	Westar V	1982	Move from 123
	Ku	Federal Express	Fednet B	1993	New entrant
122	C	Unassigned			C-band vertical polarization authorized
	Ku	IBM/ISBS	SBS V	1987	124° was planned and property of IBM
120	C/Ku	GTE	Spacenet I	1984	
117.5	Ku	Canada	Anik C-3	1982	
116.5	C/Ku	Mexico	Morelos II	1985	
113.5	C/Ku	Mexico	Morelos I	1985	Canadian
110	C	Canada	Anik C-2	1984	
109	C/Ku	Canada	Anik B	1983	Arc
105	Ku	GTE Satellite	GStar II	1986	
104.5	C	Canada	Anik D-1	1982	

TABLE 4.2. - Concluded.

Orbital Position	Designated Frequency	Applicant	Satellite Name	Launch Date	Remarks
103	C/Ku	GTE Satellite	GStar I	1985	
101	C/Ku	Ford Aero	Fordsat I	TBD	
99	C	Western Union	Westar IV	1982	
	Ku	MCI/SBS	SBS I	1980	Acquired by MCI
97	C	AT&T	Telstar 301	1984	Moved from 96^{o}
	Ku	MCI/SBS	SBS II	1981	Acquired by MCI
95	C	Hughes Comm.	Galaxy III-R	1987	Moved from 93.5, launch failure Ariane 9/25/85
	Ku	MCI/SBS	SBS III	1982	Acquired by MCI
93	C/Ku	Ford Aero	Fordsat II	TBD	New entrant
91	C	Western Union	Westar III	1979	
	Ku	IBM/SBS	SBS IV	1984	Temporary to 101^{o} and property of IBM
89	C	Unassigned			C-band vertical polarization authorized
	Ku	Unassigned			
87	C/Ku	GTE	Spacenet III	1986	
85	C	AT&T	Telstar 302	1985	Moved from 86^{o}
	C/Ku	Argentina	Nahuel II	1989	Request filed with IFRB
	Ku	RCA Americom	SATCOM K1	1985	
83	C/KU	Am Satellite	ASC II	1987	
81	C	RCA Americom	Satcom IV	1982	Move from 83^{o}
	Ku	RCA Americom	Satcom K2	1985	
80	C/ku	Argentina	Nahuel I	1989	Request filed with IFRB
79	C	Western Union	Westar II	1974	
	Ku	Martin Mar	MM A	1994	New entrant
77	Ku	Federal Express	Fednet A	1993	New entrant
76	C	Comsat General	Comstar D-4	1981	Move from 125^{o}
75	Ku	Comsat General	Comgen 1	1993	New entrant
74	C	Hughes Comm.	Galaxy II	1983	
73	Ku	Western Union	Westar A	1995	
72	C	RCA Americom	Satcom 2-R	1983	
71	Ku	Hughes Comm.	Galaxy A	1992	
70	C/Ku	Brazil	Brazilsat II	1985	
69	C/Ku	GTE	Spacenet II	1984	
67	C	RCA Americom	Satcom VI	TBD	
	Ku	RCA Americom	Satcom K3	TBD	Ground spare
65	C/Ku	Brazil	Brazilsat I	1985	
64	C/Ku	Am Satellite	ASC IV	1991	
62	C	RCA Americom	Satcom VII	1991	
	Ku	IBM/SBS	SBS VI	1991	Property of IBM

TABLE 4.3. - DEVELOPMENT OF THE U.S. C AND Ku-BAND GEOSTATIONARY ARC CAPACITY

Time Frame	Freq. Band	Spacing Degrees	Freq. Reuse	Transp's Per Sat	Arc Slots	Arc Capacity, Transponders	Total C & Ku Arc Capacity
Early 70's	C	4	1	12	17	204	204
Mid 70's	C	4	2	24	17	408	408
Late 70's	C	4	2	24	17	408	
	Ku	3	1	12	22	264	272
Early 80's	C	4	2	24	17	408	
	Ku	3	2	24	22	528	936
Late 80's	C	2	2	24	34	816	
	Ku	2	2	24	33	792	1608
Mid 90's	C	2	2	24	34	816	
	Ku	2	3	36	33	1188	2004
Late 90's	C	2	2	24	34	816	
	Ku	1.5	3	36	44	1584	2400

TABLE 4.4. - SERVICES

Voice	Data	Video
MTS, Residential	Computer	Broadcast Video
MTS, Business and WATS	o Terminal/CPU	Network, commercial
Private Line	Data entry	Network, non-comm. (PBS)
Other	Remote job entry	CATV
-- Mobile	Inquiry response	Occasional
-- Public radio	Timesharing	Educational
-- Commercial and religious	Point of sale	Public service (telemedicine)
-- Occasional	Videotext	Recording channel
-- CATV	Telemonitoring	
-- Recording		
	o CPU/CPU	Videoconferencing
	Data transfer	one-way
	Batch processing	two-way
	Message	-- full motion
	USPS EMSS	-- limited motion
	Mailbox	-- freeze frame
	Administrative	
	TWX/Telex	
	Facsimile	
	Mailgram	
	Com. word proceesing	
	OTS	
	Secure voice	

TABLE 4.5 - VOICE AND DATA TRANSPONDER (35 MHz) THROUGHPUT FORECASTS

	1980	1990	2000
Voice			
Trunking half circuits/ 36 MHz Transponder			
Analog	1200	3000	6000
Digital	844	2531	3375
Percent Analog	100	75	50
Digital	0	25	50
CPS (all digital) half circuits/ 36 MHz transponder	562	1640	2187
Digital voice data rate, Kbps	64	32	24
Data			
Trunking transponder, Mbps	54	81	81
CPS transponder, Mbps	36	52.5	52.5

VIDEO CHANNEL TRANSPONDER (36 MHz) THROUGHPUT FORECASTS

	1980	1990	2000
Broadcast			
Network	1	1	2
CATV	1	2	3
Occasional	1	1	2
Education	1	2	3
Public service	1	2	3
Recording channel	1	2	3
Videoconferencing trunking			
Full motion	1	2	3
Limited motion	12	24	36
Slow scan	300	600	900
CPS			
Full motion	1	1	2
Limited motion	7	14	21
Slow scan	180	350	525

TABLE 4.6. - SUMMARY OF VOICE, DATA, AND VIDEO DEMAND FORECASTS, EQUIVALENT 36 MHz TRANSPONDERS

		1980	1990	2000
Total	Voice	2150	2526	4035
	Data	1663	1336	1213
	Video	60	250	312
	Total	3873	4112	5560
Net long haul	Voice	1902	2364	3824
	Data	808	652	639
	Video	60	250	312
	Total	2770	3266	4775
Satellite addressable				
Overall	Voice	310	641	1594
	Data	33	254	518
	Video	60	250	312
	Total	403	1145	2424
Trunking segment	Voice	310	638	1578
	Data	0	17	41
	Video	60	240	295
	Total	370	895	1914
CPS segment	Voice	0	3	16
	Data	33	237	477
	Video	0	10	17
	Total	33	250	510

TABLE 4.7. – U.S. DOMESTIC FIXED SERVICE SATELLITE IMPLEMENTATION SCENARIO IN EQUIVALENT 36 MHz TRANSPONDERS

SAT. NAME	FREQ.	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	2001	2002	2003	2004	2005	2006
AURORA I	C	24	24	24	24	24	24															
								24	24	24	24	24	24	24	24	24	24					
																		24	24	24	24	24
AURORA II	C								24	24	24	24	24	24	24	24	24	24				
																			24	24	24	24
ASC I	C/KU	36	36	36	36	36	36	36	36	36	36											
	24/12											60	60	60	60	60	60	60	60	60	60	60
ASC II	C/KU					36	36	36	36	36	36	36	36	36	36							
DEL/ARI	24/12															60	60	60	60	60	60	60
ASC IV	C/KU						36	36	36	36	36	36	36	36	36	36						
	24/12																60	60	60	60	60	60
COMSTAR D-4	C	24	24	24	24	24	24															
								24	24	24	24	24	24	24	24	24	24					
																		24	24	24	24	24
COMSTAR COMGEN1	KU								24	24	24	24	24	24	24	24	24	24				
																			36	36	36	36
COMSTAR COMGEN2	KU									24	24	24	24	24	24	24	24	24	24			
																				36	36	36
EXPRESSTAR A	KU				36	36	36	36	36	36	36	36	36	36								
															48	48	48	48	48	48	48	48
EXPRESSTAR B	KU					36	36	36	36	36	36	36	36	36	36							
																48	48	48	48	48	48	48
FORDSTAR 1	C/KU							48	48	48	48	48	48	48	48	48	48					
	24/24																	54	54	54	54	54
FORDSTAR 2	C/KU							48	48	48	48	48	48	48	48	48	48					
	24/24																	54	54	54	54	54
GALAXY 1	C	24	24	24	24	24	24	24	24													
DEL										24	24	24	24	24	24	24	24	24	24			
																				24	24	24
GALAXY 2	C	24	24	24	24	24	24	24	24													
DEL										24	24	24	24	24	24	24	24	24	24			
																				24	24	24
GALAXY 3	C		24	24	24	24	24	24	24	24	24	24										
DEL													24	24	24	24	24	24	24	24	24	24
GALAXY 4	C						24	24	24	24	24	24	24	24	24	24						
																	24	24	24	24	24	24
GALAXY A	KU							24	24	24	24	24	24	24	24	24	24					
																		36	36	36	36	36
GALAXY B	KU							24	24	24	24	24	24	24	24	24	24					
																		36	36	36	36	36
GSTAR 1	KU	24	24	24	24	24	24	24	24	24												
ARI											36	36	36	36	36	36	36	36	36	36		
																					36	36
GSTAR 2	KU	24	24	24	24	24	24	24	24	24	24											
ARI												36	36	36	36	36	36	36	36	36	36	
																						36

TABLE 4.7. - Continued.

SAT. NAME	FREQ.	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	2001	2002	2003	2004	2005	2006
TELSTAR 301	C	24	24	24	24	24	24	24	24													
										24	24	24	24	24	24	24	24	24	24			
																				24	24	24
TELSTAR 302	C	24	24	24	24	24	24	24	24	24												
											24	24	24	24	24	24	24	24	24	24		
																					24	24
TELSTAR 303	C	24	24	24	24	24	24	24	24	24												
											24	24	24	24	24	24	24	24	24	24		
																					24	24
RCA SATCOM K1	KU	24	24	24	24	24	24	24	24	24												
											36	36	36	36	36	36	36	36	36	36		
																					36	36
RCA SATCOM K2	KU	24	24	24	24	24	24	24	24	24												
											36	36	36	36	36	36	36	36	36	36		
																					36	36
RCA SATCOM K3	KU						24	24	24	24	24	24	24	24	24	24						
																	36	36	36	36	36	36
MM A	KU									36	36	36	36	36	36	36	36	36	36			
																				36	36	36
MM B	KU									36	36	36	36	36	36	36	36	36	36			
																				36	36	36
WESTAR III	C	12																				
WESTAR IV	C	24	24	24	24	24	24	24														
									24	24	24	24	24	24	24	24	24	24				
																			24	24	24	24
WESTAR V	C	24	24	24	24	24	24	24														
									24	24	24	24	24	24	24	24	24	24				
																			24	24	24	24
WESTAR VI**	C				24	24	24	24	24	24	24	24	24	24								
DEL/ARI/LONG															24	24	24	24	24	24	24	24
WESTAR VII	C							24	24	24	24	24	24	24	24	24	24					
																		24	24	24	24	24
WESTAR A	KU										24	24	24	24	24	24	24	24	24	24		
																					36	36
WESTAR B	KU											24	24	24	24	24	24	24	24	24	24	
																						36
TOTALS	C	324	336	336	360	360	432	456	480	480	480	480	480	480	480	480	480	480	480	480	480	480
	C/KU	108	108	108	108	108	252	348	348	348	420	420	420	420	444	468	516	528	528	528	528	528
	KU	144	156	156	192	228	276	384	432	528	612	648	672	672	684	696	708	768	780	792	804	816
TTL XPNDRS		576	600	600	660	696	960	1188	1260	1356	1512	1548	1572	1572	1608	1644	1704	1776	1788	1800	1812	1824
NO. SATS.		25	26	26	28	30	39	44	46	49	50	51	51	51	51	51	51	51	51	51	51	51
NO. SATS. + Ka		0	0	0	0	0	0	0	0	0	0	0	53	54	56	57	58	60	61	62	63	64

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TABLE 4.7. - Continued.

SAT. NAME	FREQ.	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	2001	2002	2003	2004	2005	2006
GSTAR 3	KU							24	24	24	24	24	24	24	24	24	24					
																		36	36	36	36	36
SPACENET I	C/KU	36	36	36	36	36	36	36	36	36												
	12/24										60	60	60	60	60	60	60	60	60	60		
																					60	60
SPACENET II	C/KU	36	36	36	36	36	36	36	36	36												
	12/24										60	60	60	60	60	60	60	60	60	60		
																					60	60
SPACENET III*	C/KU						36	36	36	36	36	36	36	36	36	36						
	12/24																60	60	60	60	60	60
SPACENET IV	C/KU						36	36	36	36	36	36	36	36	36	36						
	12/24																60	60	60	60	60	60
SATCOM 1R	C	24	24	24	24	24	24	24	24													
										24	24	24	24	24	24	24	24	24	24			
																				24	24	24
SATCOM 2R	C	24	24	24	24	24	24	24	24													
										24	24	24	24	24	24	24	24	24	24			
																				24	24	24
SATCOM 3R	C	24	24	24	24	24	24															
								24	24	24	24	24	24	24	24	24	24					
																		24	24	24	24	24
SATCOM IV	C	24	24	24	24	24	24	24														
									24	24	24	24	24	24	24	24	24	24				
																			24	24	24	24
SATCOM VI	C						24	24	24	24	24	24	24	24	24	24						
																	24	24	24	24	24	24
SATCOM VII	C						24	24	24	24	24	24	24	24	24	24						
																	24	24	24	24	24	24
MCI/SBS I	KU	12	12	12	12	12																
							36	36	36	36	36	36	36	36	36	36	36	36				
																			36	36	36	36
MCI/SBS II	KU	12	12	12	12	12	12															
								36	36	36	36	36	36	36	36	36	36	36				
																			36	36	36	36
MCI/SBS III	KU	12	12	12	12	12	12	12														
									36	36	36	36	36	36	36	36	36	36	36			
																				36	36	36
IBM/SBS IV	KU	12	12	12	12	12	12	12	12	12												
											36	36	36	36	36	36	36	36	36	36		
																					36	36
IBM/SBS V	KU		12	12	12	12	12	12	12	12	12	12										
ARI													36	36	36	36	36	36	36	36	36	36
IBM/SBS VI	KU							12	12	12	12	12	12	12	12	12	12					
																		36	36	36	36	36

TABLE 4.7. - Concluded.

*LAUNCH FAILURE 9/12/85 - ARIANE
**LAUNCH FAILURE / RETRIEVED BY SHUTTLE

NOTES:

1. ASSUMES NO U.S. LAUNCHES OF COMMERCIAL SATELLITES BEFORE MID-1989 UNLESS OTHERWISE INDICATED. THIS IS DUE TO THE LOSS OF THE SPACE SHUTTLE, TITAN, DELTA AND ARIANE. BEST ESTIMATES ARE THAT SUSTAINED COMMERCIAL U.S. LAUNCHES CANNOT BEGIN FOR UP TO 24 TO 36 MONTHS. ARIANE IS CURRENTLY BOOKED FOR THE NEXT 36 MONTHS AND WILL NOT REGAIN LAUNCHING UNTIL MID-1987 TIME FRAME.

2. THE TOTAL C,C/KU AND KU FREQUENCY BAND FOR 1984 AND 1985 ARE

	1984	1985
C	288	324
C/KU	0	72
KU	36	120
TTL XPNDRS	324	516
NO. SATS.	16	25
NO. SATS. + KA	0	0

3. UPDATED SEPT. 4, 1986

TABLE 4.8. - 'QUICK-LOOK' SUMMARY OF DOMSAT LOADING, MARCH 1986

C-Band Summary

TIME	Inactive	SCPC	TV/FM	Digital	FDM/FM	Other	Total
Dec. '85	154	38	125	49	58	2	426
Sept. '85	137	37	125	44	57	8	408
March '86	133	43	120	57	56	4	414
Ku-Band Summary							
Dec. '85	45	10	15	18	1	1	90
Sept. '85	23	9	13	21	2	0	68
March '86	55	9	21	19	1	1	106

TABLE 4.9. - DEMAND FOR TRANSPONDERS

		YE85	YE90	YE95YE
1	Scheduled video	126	135	140
2	Occasional video	116	160	170
3	Private voice	49	137	185
4	Private data	24	120	170
5	Government	14	35	50
6	Public networks	69	25	30
7	Other	15	20	25
8	Growth	14	20	30
9	Restoration	18	25	35
10	Inventory	53	42	-322
11	Failed	6	35	40
		504	754	553

Prepared for NASA by the Communications Center of Clarksburg
(Replacement satellites not included)

TABLE 5.1. - SYSTEM/PROGRAM TRACKING AND DATA ACQUISITION SYSTEM (TDAS)

MAJOR TECHNOLOGY INNOVATIONS:

- o Laser intersatellite links
- o High capacity microwave switch technology

TECHNOLOGY NEEDS:

- o Advanced electromagnetic analysis techniques for large antennas
- o Advanced computer-aided design and analysis techniques for large antennas
- o Advanced, long-lifetime, high performance solar/battery systems
- o Develop advanced fuel cells
- o Develop improved electric auxiliary propulsion systems
- o Improve atmospheric drag and solar pressure models
- o Improve tracking systems
- o Study and development of automated navigation systems
- o Develop optical data links
- o Study and develop an in-orbit optical telescope receiver
- o Develop Ku-, Ka-, and V-band data transfer systems as needed
- o Develop advanced modulation schemes to improve bandwidth utilization
- o Improvements in reflector antenna technology for spacecraft communications
- o Develop improved microwave lens technology
- o Develop improved phased-array antenna technology
- o Advancements in multibeam antenna technology
- o Advanced development of IF switch technology
- o Advanced development of baseband processing technology
- o Major advances in error correction technology
- o Improved TWTA efficiency and reliability
- o Develop improved high current density electron guns

* REF. 5.1, P. 4-21

TABLE 5.1. - Concluded.

TECHNOLOGY NEEDS (CONT.):

- Develop high efficiency multistage depressed collector for TWTAs
- Develop higher power, greater efficiency, reliable, long life IMPATT diode amplifiers
- Develop low-loss power combiner technology
- Develop low frequency, high power bipolar transistor amplifiers
- Develop improved low noise receivers
- Advance GaAs diode laser technology for intersatellite links
- Develop thermal control systems with increased specific mass
- Develop adequate model of spacecraft arcing

REFERENCES:

J. Schwartz and J. Spilker, "NASA Tracking and Data Acquisition in the 1990s; Support for Low Earth Orbit Missions," June 1981 (Draft).
Personal communication with contact.

* REF. 5.1, P. 4-22

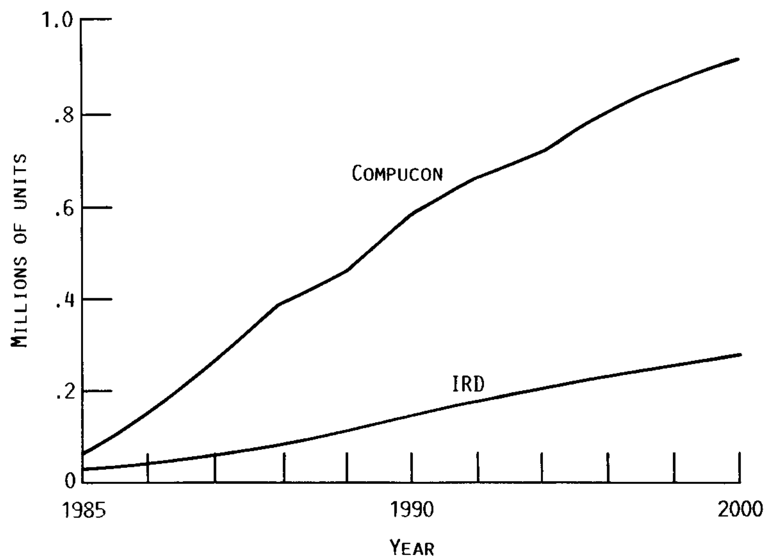


FIGURE 3.1. - NUMBER OF VSATS INSTALLED.

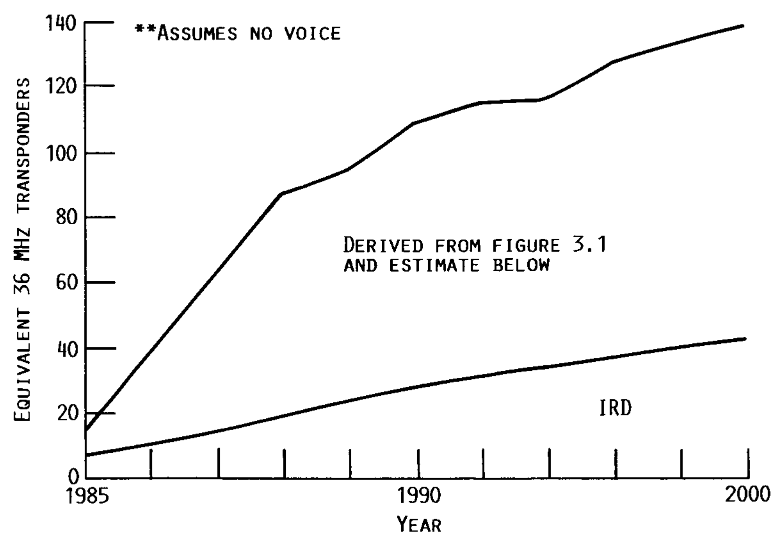


FIGURE 3.2. - VSAT TRANSPONDER REQUIREMENS.

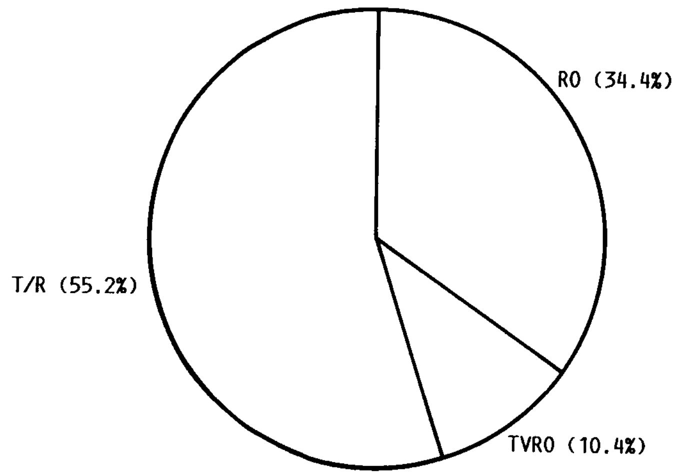


FIGURE 3.3. - 1994 DISTRIBUTION OF VSAT UNITS; 263,000 (IRD, INC).

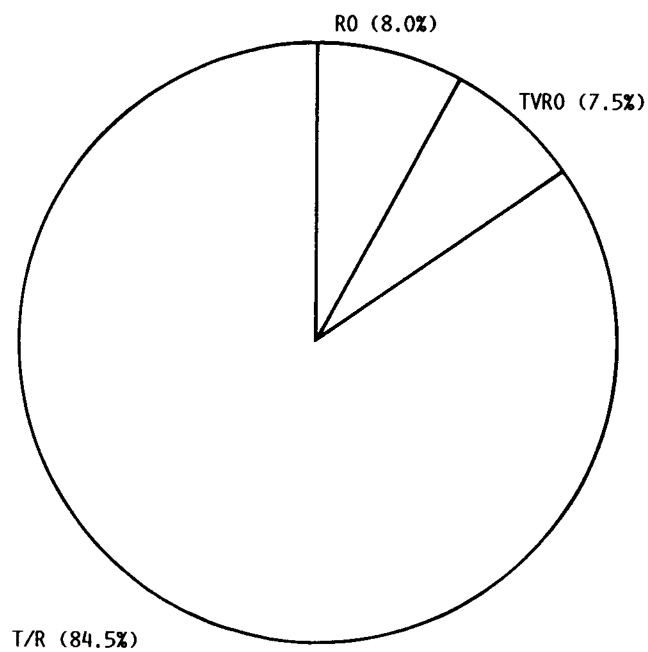


FIGURE 3.4. - 1994 DISTRIBUTION OF VSAT SALES; $142 MILLIONS (IRD).

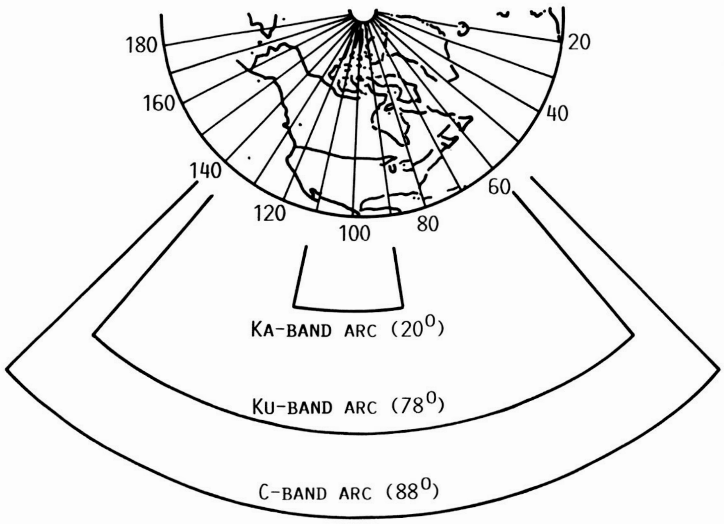


FIGURE 3.5. - DOMESTIC COMMUNICATIONS SATELLITE ORBITAL ARC VIEWING THE U.S.

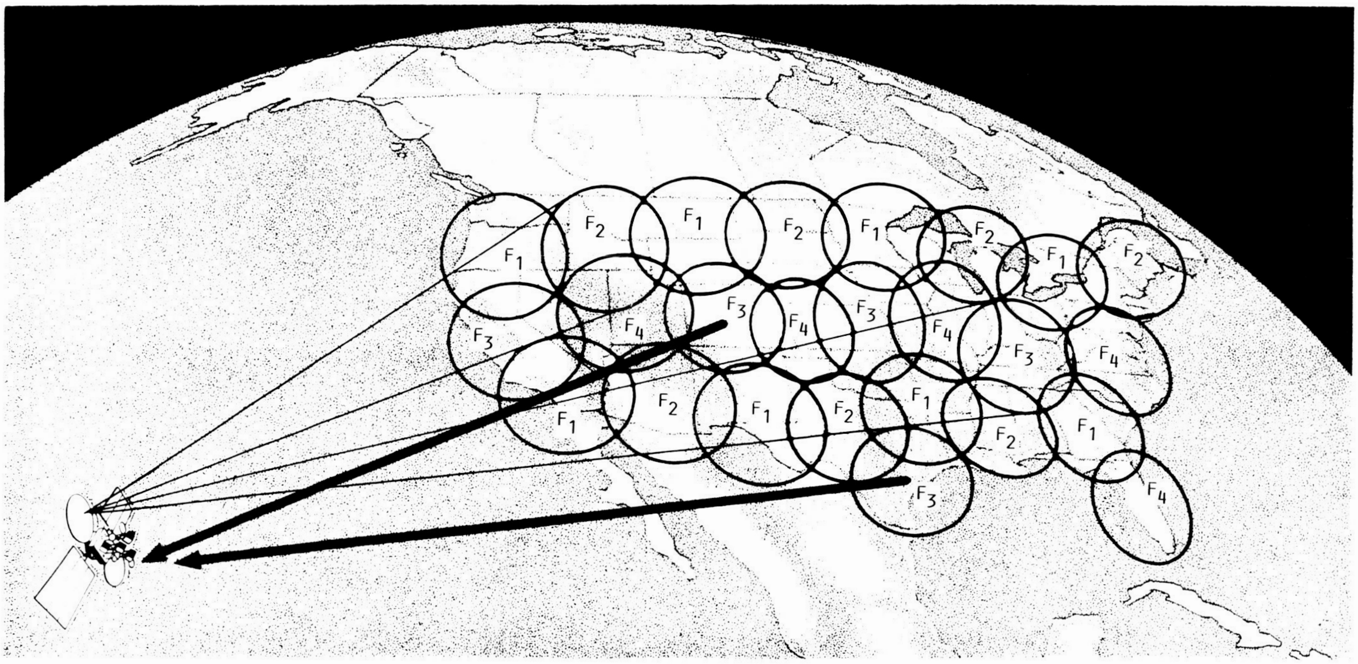


FIGURE 3.6. - MULTIPLE SPOT BEAM COVERAGE PATTERN USING FOUR FREQUENCY SUB-BANDS.

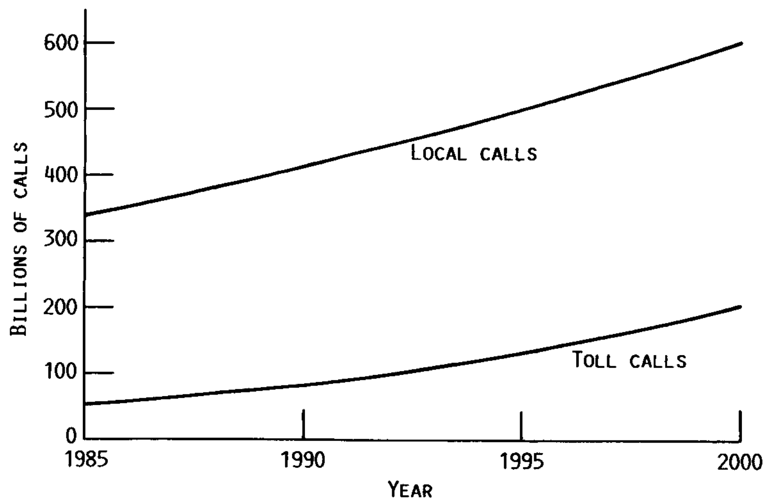


Figure 3.7. - Estimates of annual calls by year, 1985-2000.

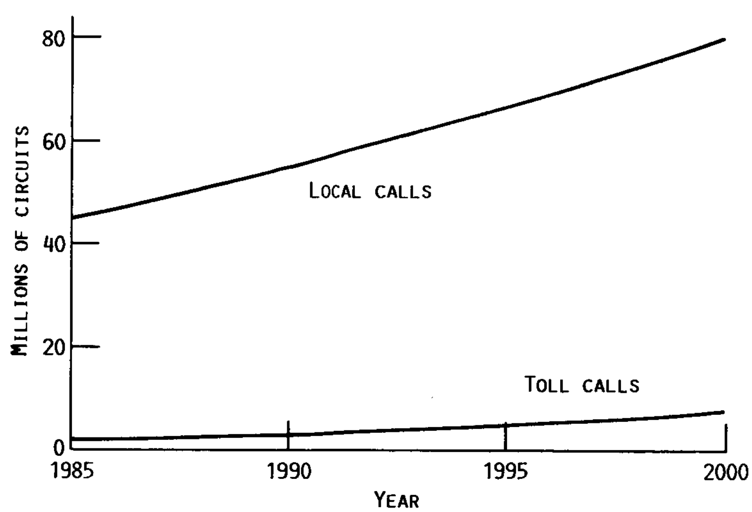


Figure 3.8. - Required number of circuits by year, 1985-2000.

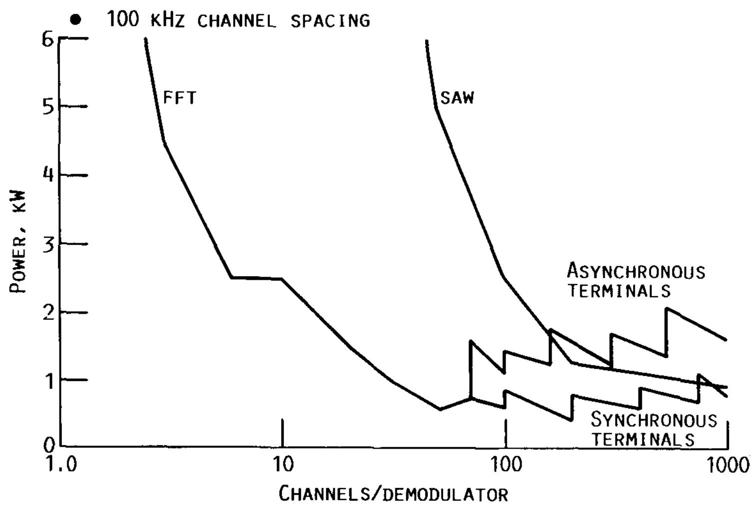


Figure 3.9. - Bulk demodulator power requirements for composite 1000 MHz bandwidth.

TRW

Cost item	Current AT&T (700 mi average distance)		Expected operational ACTS
	Switched access (small user)	Special access (larger user)	
Transmission (no fiber)	1	1	2
Switching	0.5	0.5	0
Access charges (two ends)	16.0	• 4 (metropolitan) • >>4 (remote) • Increasing with time	0.6
Billing	3.0	3.0	1.0
People Bell Labs ATT Comm + others	 1.0 5.0	 1.0 5.0	 0 2.0
Other operations, including advertising	3.0	3.0	3.0
Profit	2.5	2.5	2.5
Total	32.0	20.0+	11.1

26¢ average Fortune 500 cost (mix of on and off net)**

Figure 3.10. - Approximate long-haul cost for business user (cents per voice circuit minute).

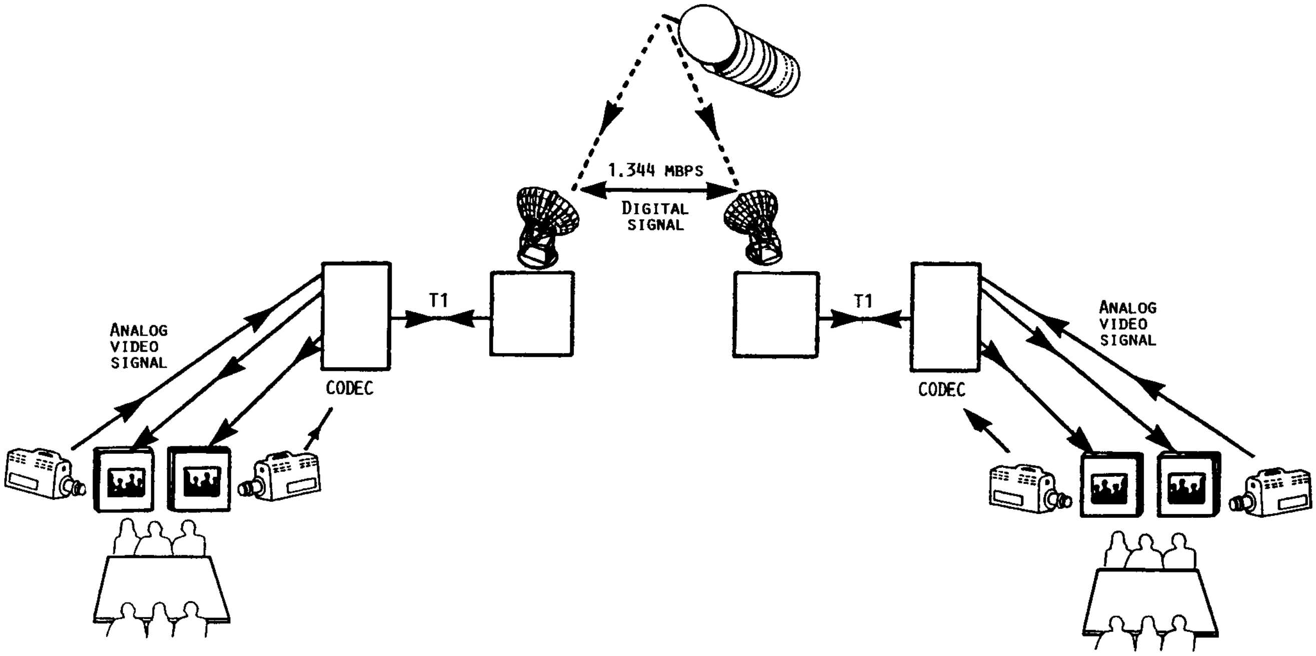


FIGURE 3.11. - POINT-TO-POINT DIGITAL INTERACTIVE VIDEOCONFERENCING.

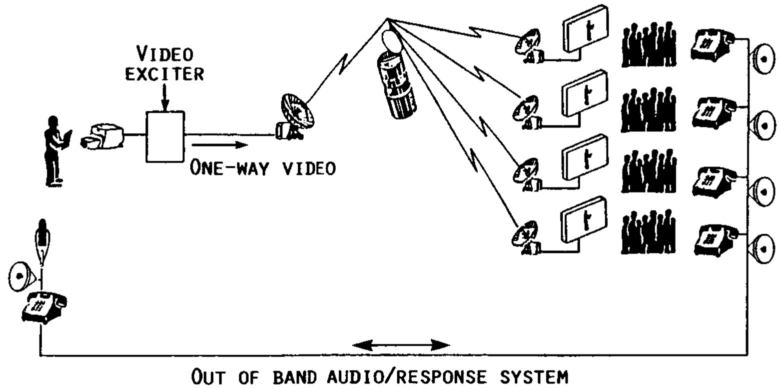


FIGURE 3.12. - VIDEO BROADCAST APPLICATION WITH AUDIO OUT OF BAND.

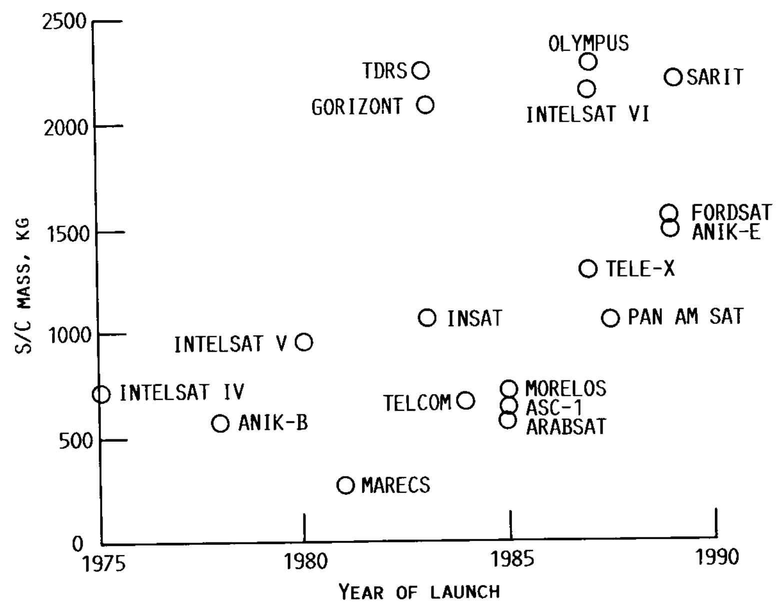


FIGURE 3.13. - SATELLITES INCREASING IN SIZE.

Ford Aerospace & Communications Corporation

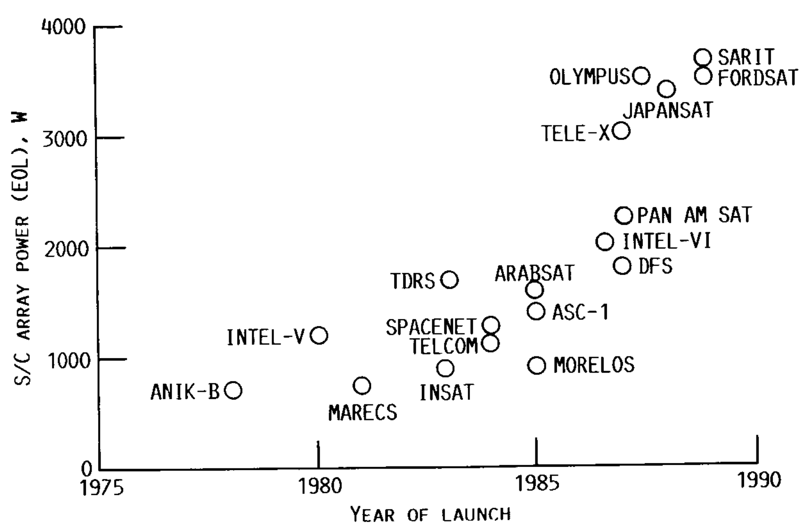


FIGURE 3.14. - SATELLITES INCREASING IN POWER.

Ford Aerospace & Communications Corporation

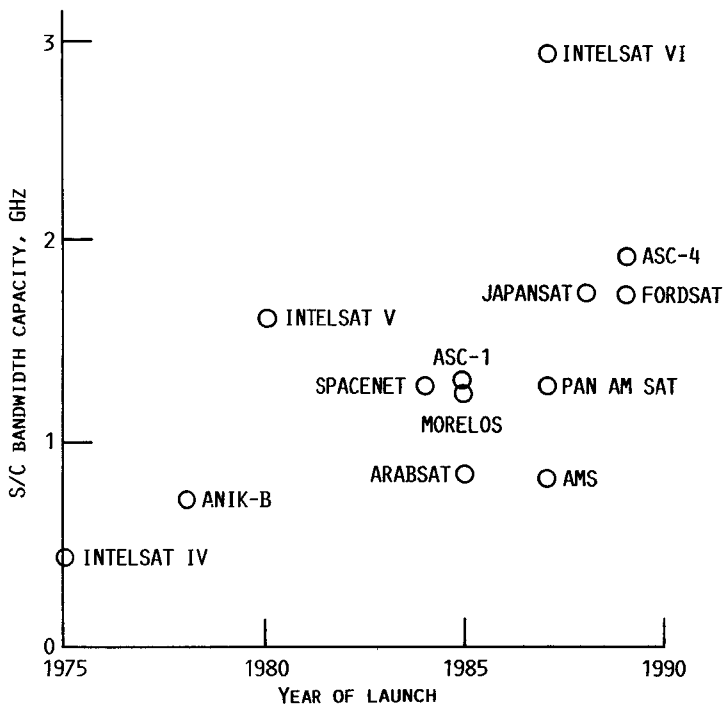
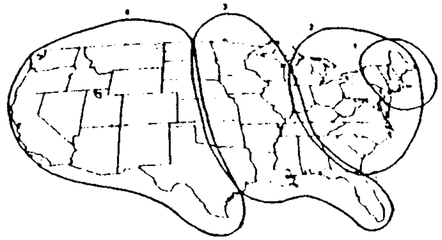
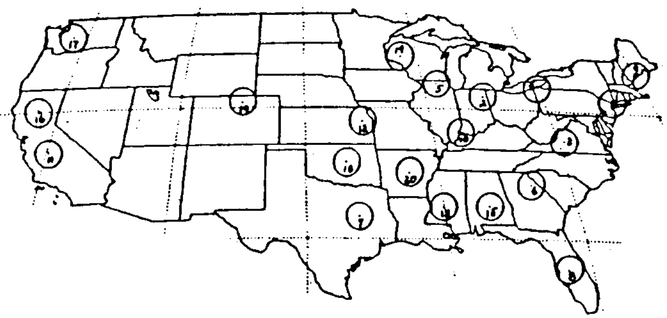


FIGURE 3.15. - SATELLITES INCREASING IN COMMUNICATIONS CAPACITY.

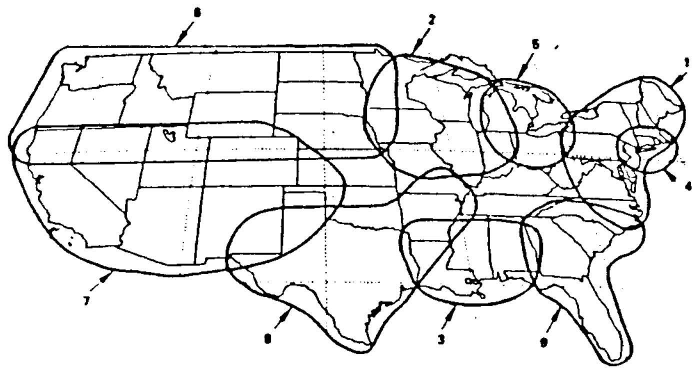
Ford Aerospace & Communications Corporation



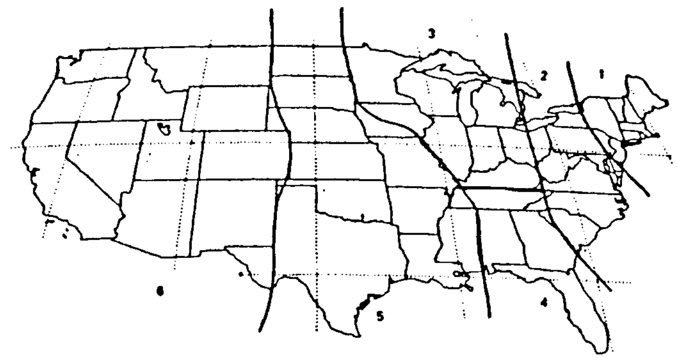
C-BAND: 48 CHANNELS OF 36 MHZ
(3.5 GB/S)



KA FIXED: 20 BEAM
38 CHANNELS OF 500 MHZ
(38 GB/S)



KU-BAND: 108 CHANNELS OF 36 MHZ
(7.8 GB/S)

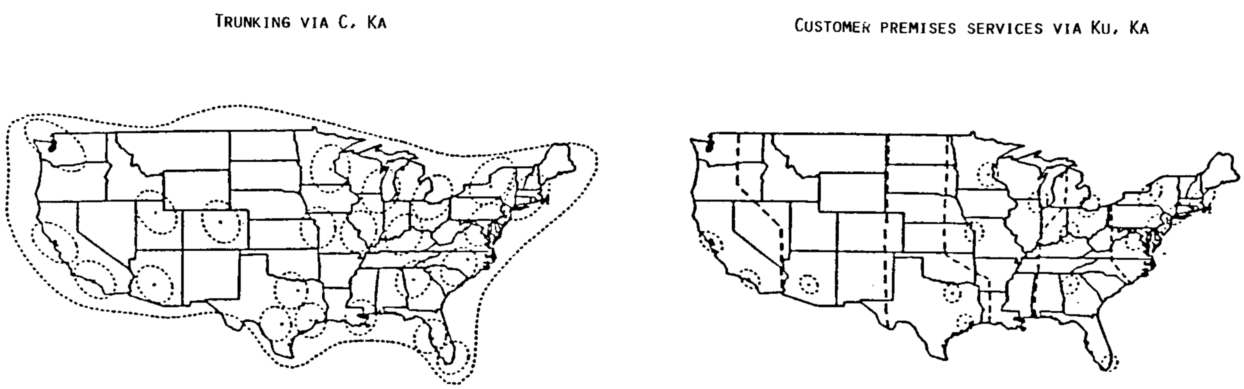


KA SCAN: 6 AREAS
18 CHANNELS OF 240 MHZ
14 CHANNELS OF 500 MHZ
(23 GB/S)

COMMUNICATIONS PAYLOAD OF
~2,261 KG
7,426 WATTS
72 GB/S

Ford Aerospace & Communications Corporation

FIGURE 3.16. - SCENARIO V - SERVICES ALLOCATION.



C-BAND

- 23 0.5° SPOT + CONUS
- 109 CHANNELS (36 MHZ)
- 60 MBPS/CHANNEL
- POWER:
  - 1 W/CHANNEL (SPOT)
  - 10 W/CHANNEL (CONUS)

KU-BAND

- 23 0.5° SPOT + CONUS
- 76 CHANNELS (36 MHZ)
- 60 MBPS/CHANNEL
- POWER:
  - 5 W/CHANNEL (SPOT)
  - 60 W/CHANNEL (CONUS)

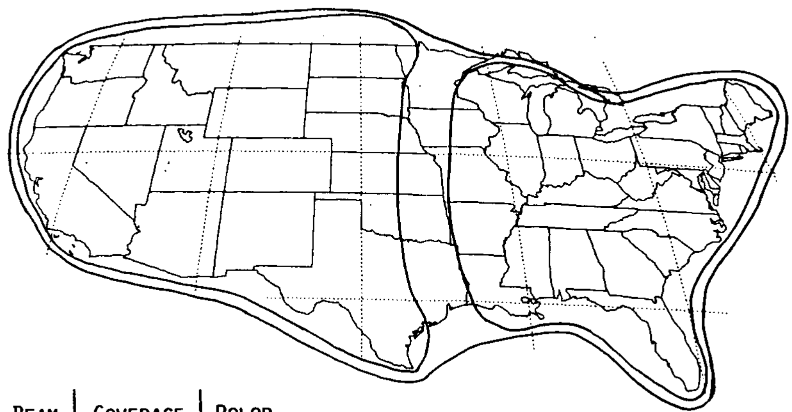
KA-BAND

- 17 0.25° FIXED SPOT
- 6 0.25° SCAN SPOT
- 326 CHANNELS (36 MHZ)
- POWER:
  - 4 W/CHANNEL (CLEAR)
  - 40 W/CHANNEL (RAIN)

SYSTEM CAPACITY 30.7 GBPS

RCA Astro-Electronics

FIGURE 3.17. - SCENARIO DESCRIPTION PAYLOAD CONCEPT 2 - FIXED SATELLITE SERVICE (CAPACITY 20% OF DEMAND).



Beam	Coverage	Polor.
1	Conus	V
2	West	H
3	East	H

Ford Aerospace & Communications Corporation

Figure 4.1. - Ku-band FSS Coverage.

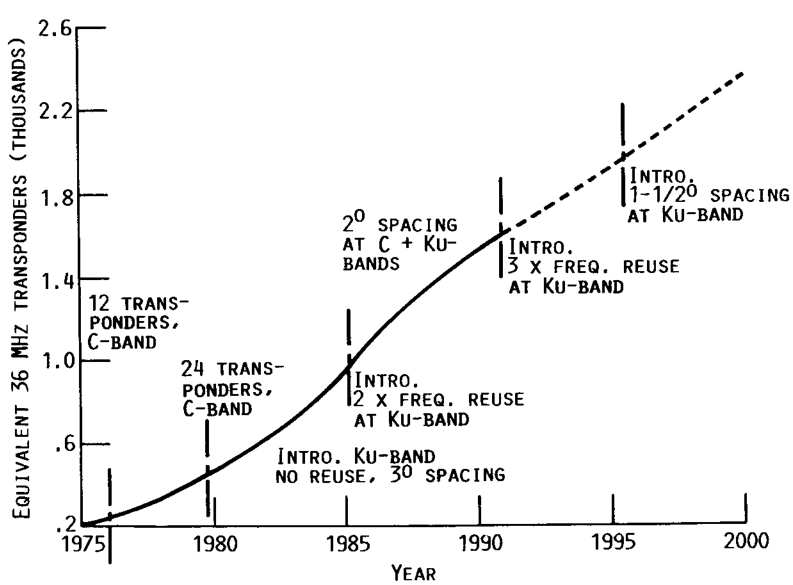


Figure 4.2. - Growth of U.S. arc capacity.

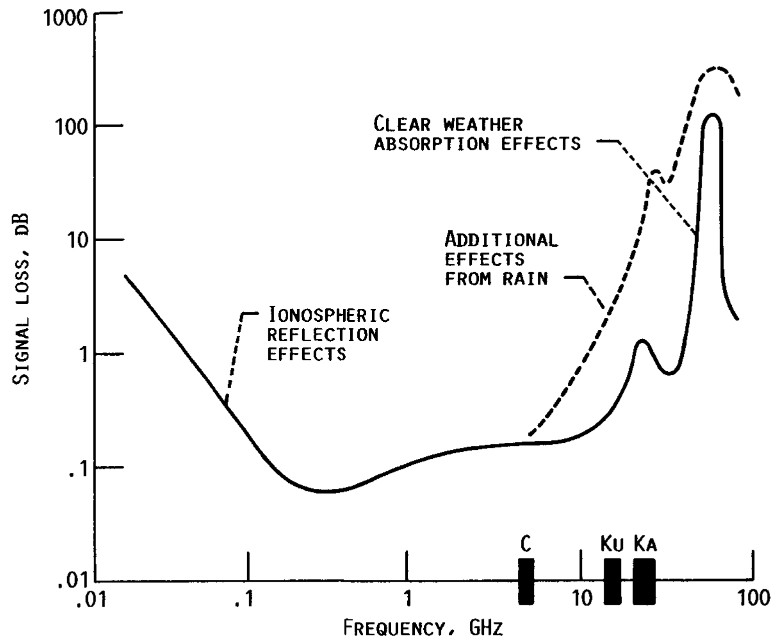


FIGURE 4.3. - RADIO SIGNAL ATTENUATION.

	EIRP (DBW)
A	53.5
B	51.5
C	49.5
D	47.5
E	45.5
F	41.5
G	37.5
H	35.5

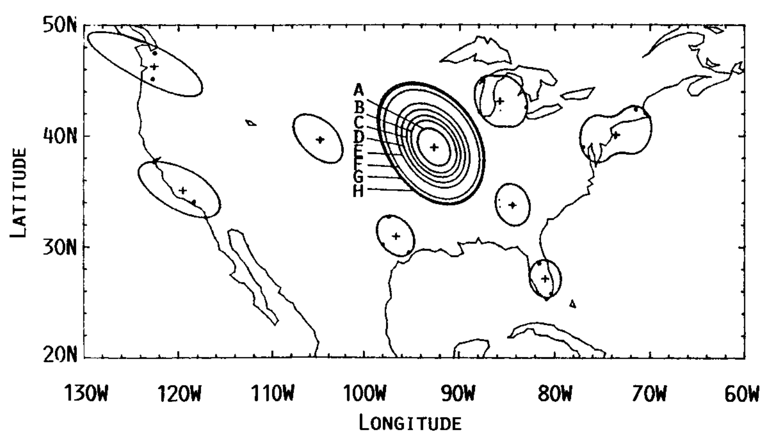


FIGURE 4.4. - SPOTBEAMS: SPACECRAFT AT 75 °W;
2 DB THROUGH 20 DB CONTOURS.

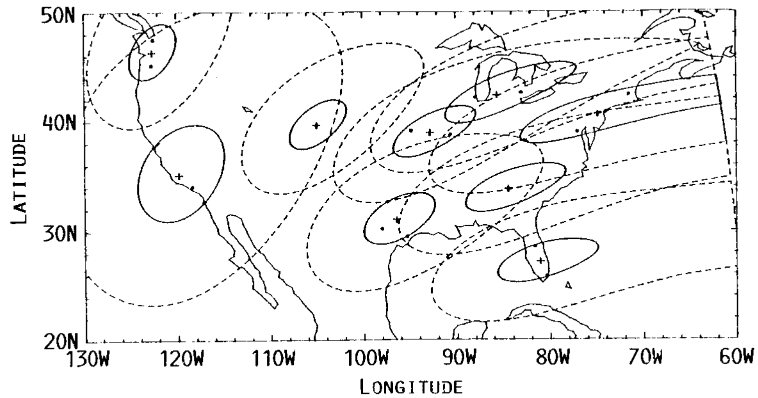


FIGURE 4.5. - SPOTBEAMS: SPACECRAFT AT 140 ^{O}W; 3 dB AND 30 dB CONTOURS.

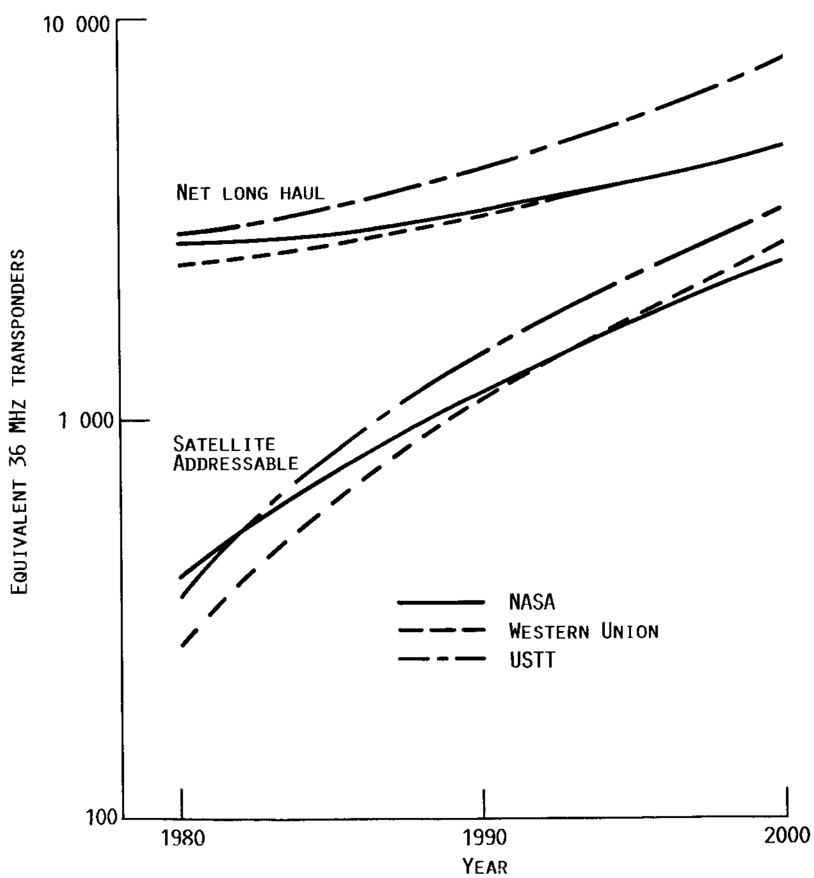


FIGURE 4.6. - COMPARISON OF NASA, WESTERN UNION, AND USTT TELECOMMUNICATIONS DEMAND FORECASTS.

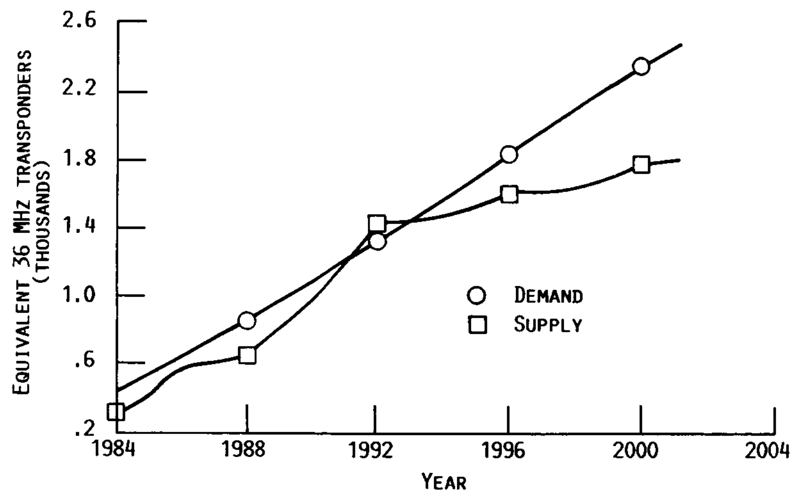


FIGURE 4.7. - SATELLITE ADRESSABLE TRANSPONDERS.

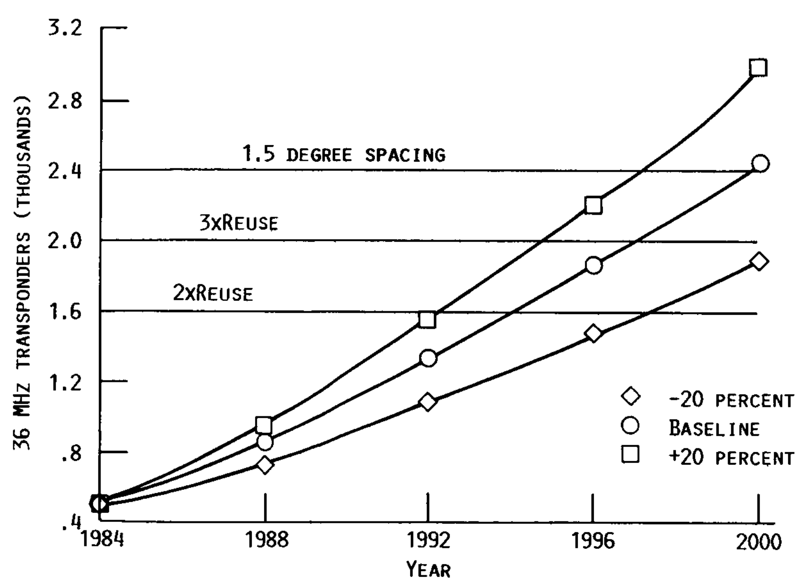
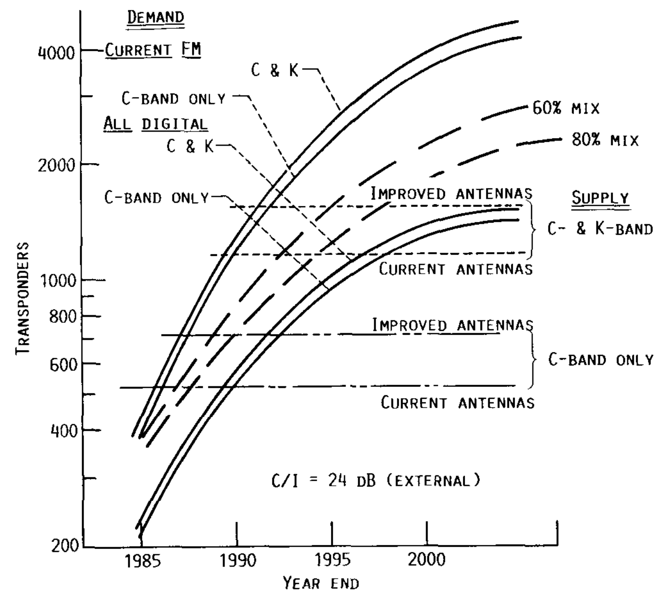


FIGURE 4.8. - SATELLITE ADDRESSABLE DEMAND WITH 20 PERCENT VARIATION.



U.S. ORBITAL ARC: TRANSPONDER SUPPLY/DEMAND

CONFIGURED U.S. DOMESTIC SATELLITE DEMAND (36-MHz TRANSPONDERS)

YEAR	C-BAND TRANSPONDERS		K-BAND TRANSPONDERS		COMBINATION OF C- AND K-BAND TRANSPONDERS[A]	
	CURRENT FM[B]	ALL-DIGITAL	CURRENT FM[B]	ALL-DIGITAL	CURRENT FM[B]	ALL-DIGITAL
1985	394	216	469	253	435	236
1990	1,171	544	1,358	639	1,273	596
1995	2,321	888	2,613	1,013	2,480	956
2000	3,592	1,310	4,210	1,490	3,929	1,408

[A]WEIGHTED AVERAGE (45 PERCENT C-BAND, 55 PERCENT K-BAND) RESULTING FROM A GREATER SUPPLY OF K-BAND TRANSPONDERS DUE TO ADDITIONAL ORBIT SLOTS WITH AVAILABLE CLOSER SATELLITE SPACING AT K-BAND.

[B]CURRENT MODULATION IS DEFINED AS FM APPLIED TO VOICE AND TV SERVICES; QPSK FOR DATA. THE TABLE DEPICTS THE CASE FOR AN EXTERNAL C/I OBJECTIVE OF 24 dB.

FIGURE 4.9. - COMSAT TRANSPONDER SUPPLY/DEMAND ESTIMATES.

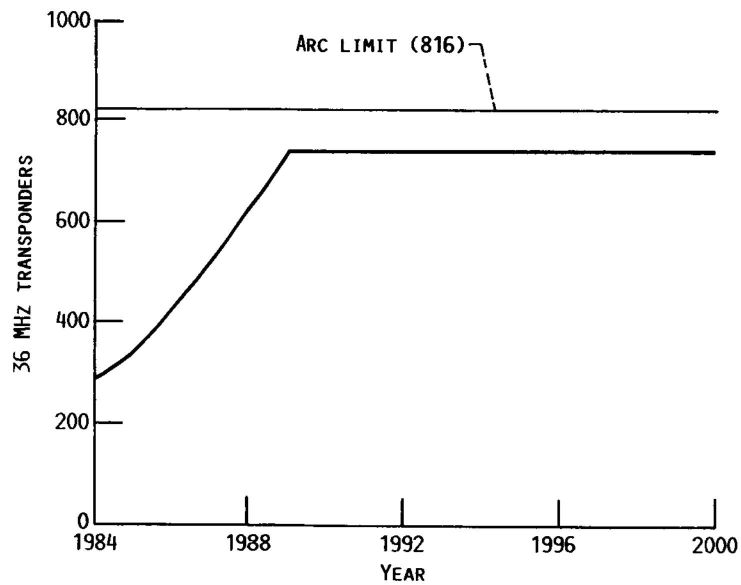


FIGURE 4.10. - C-BAND; LIMIT AND SUPPLY.

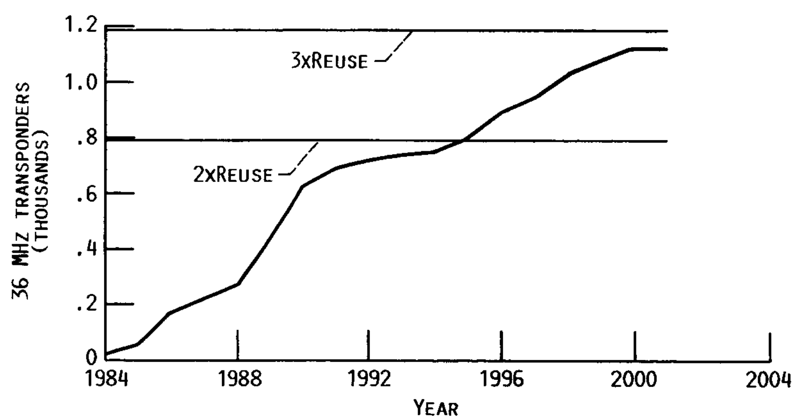
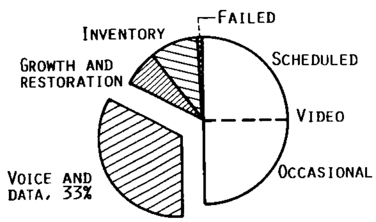
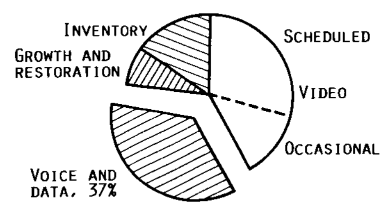


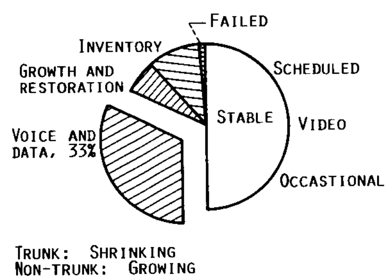
FIGURE 4.11. - KU-BAND; LIMIT AND SUPPLY.



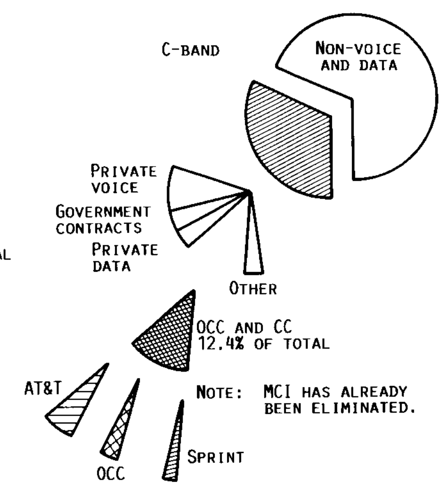
C-BAND TRANSPONDER USES
U.S. SATELLITES - JAN. '88



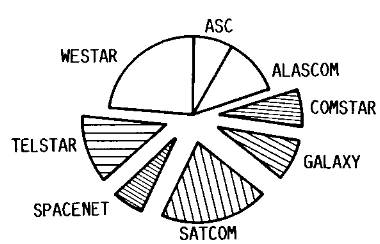
KU-BAND TRANSPONDER USES
U.S. SATELLITES - JAN. '88



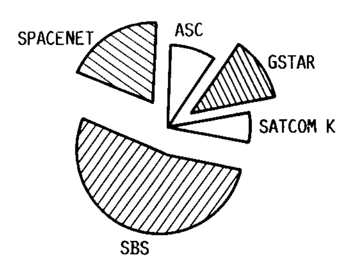
C-BAND TRANSPONDER USES
U.S. SATELLITES - JAN. '86



VOICE AND DATA TRANSPONDERS
U.S. SATELLITES - JAN. '86



C-BAND VOICE AND DATA TRANSPONDERS
BY SATELLITE FAMILY
U.S. SATELLITES - JAN. '86



KU-BAND VOICE AND DATA TRANSPONDERS
BY SATELLITE FAMILY
U.S. SATELLITES - JAN. '86

FIGURE 4.12. - TRANSPONDER USAGE.

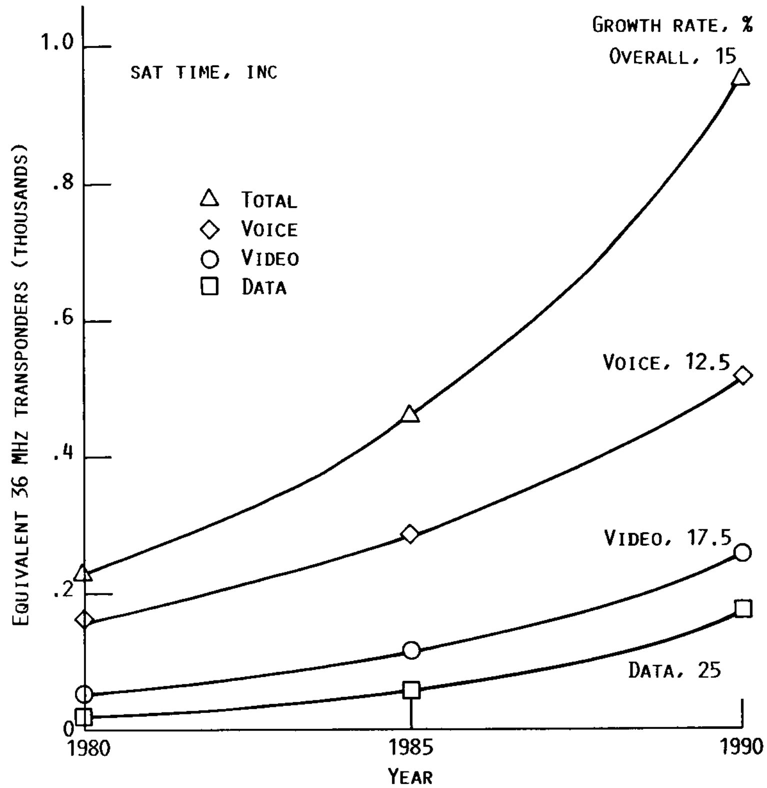


FIGURE 4.13. - TRENDS IN TRANSPONDER UTILIZATION.

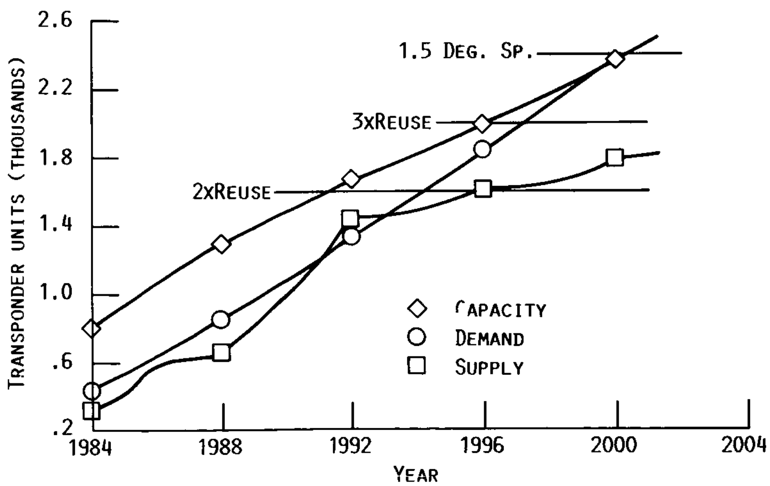


FIGURE 4.14. - DEMAND, SUPPLY, AND ARC CAPACITY; 36 MHZ TRANSPONDERS.

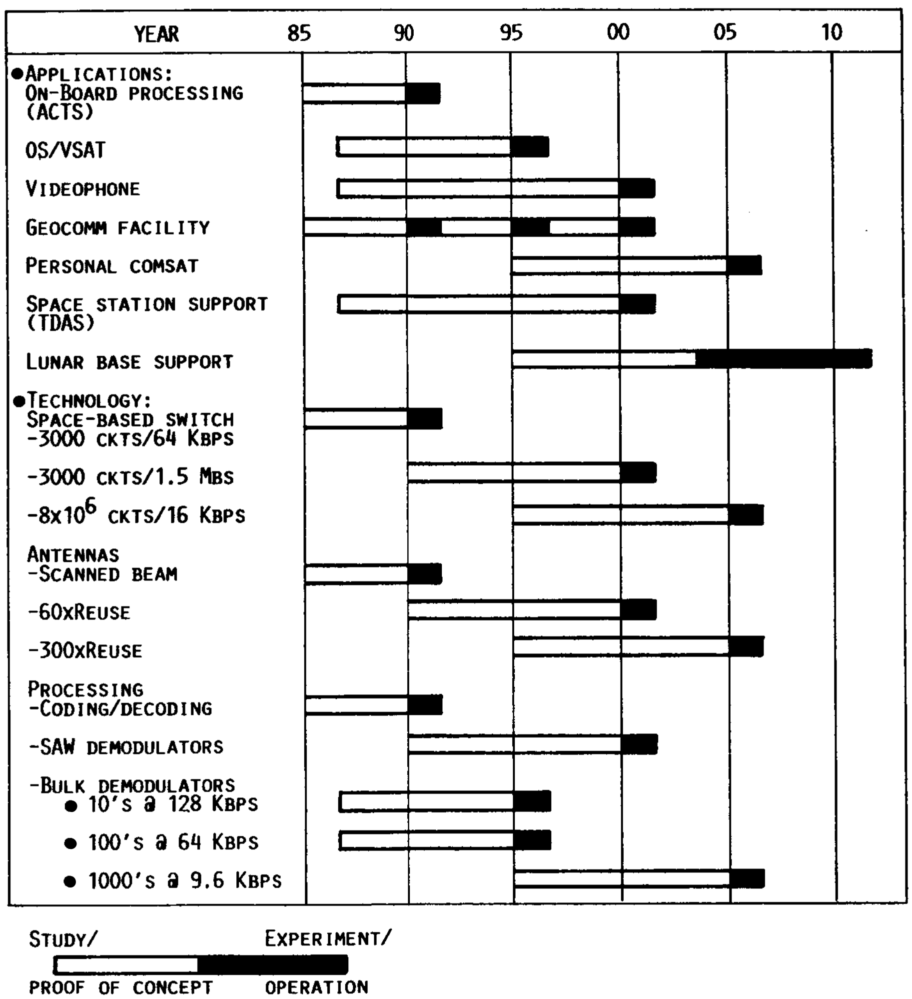


FIGURE 7.1. - ESTIMATED TECHNOLOGY AND APPLICATION TIMELINE.

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15. Supplementary Notes

16. Abstract

This document was prepared in response to a request by the Space Applications Advisory Committee (SAAC) for information relevant to the status and trends in satellite communications activities. This information was to be used to support that committee's efforts to conceive and recommend long range goals for NASA communications activities. Included in this document are assessments of: (1) The outlook for satellite communications (including current applications, some potential future applications, and impact of the changing environment such as optical fiber networks, the Integrated Services Digital Network (ISDN) standard, and the rapidly growing market for Very Small Aperture Terminals (VSAT).; (2) The restrictions imposed by our limited spectrum resource; (3) The technology needs indicated by the discussed future trends. Potential future systems discussed include: large and powerful satellites for providing personal communications; VSAT compatible satellites with onboard switching and having voice capability; large satellites which offer a pervasive T1 network service (primarily for videophone); and large geostationary communications facilities which support common use by several carriers. Also, discussion is included of NASA particular needs and possible future systems. Based on the mentioned system concepts, specific technology recommendations are provided for the time frames of now - 1993, 1994 - 2000, and 2000 - 2010.

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