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Monterey, California



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THESIS

SURVEY OF UNITED STATES COMMERCIAL
SATELLITES IN GEOSYNCHRONOUS
EARTH ORBIT

by

Lawrence D. Hunt
and
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September, 1994

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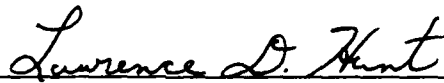
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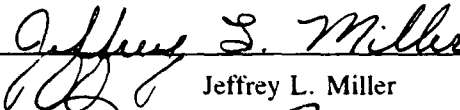
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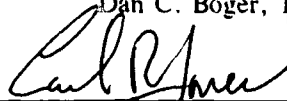


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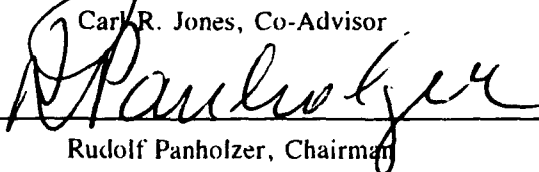
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ABSTRACT

This thesis examines the domestic commercial satellite options available for telecommunication and remote sensing services. The study provides a single source, comprehensive examination of the available commercial U.S. geosynchronous telecommunications satellites as well as the remote sensing spacecraft which may be utilized for commercial purposes. A general satellite communications technology overview is provided as background material for the more detailed satellite compendium. The following telecommunications operators are included with their respective domestic communications satellites: Alascom, Alpha Lyracom Pan American, AT&T, Comsat, GE Americom, GTE Spacenet, Hughes and Intelsat. Satellite evolution, overview, key design features, and performance parameters are catalogued. Additionally, each satellite's communications payload is examined in detail. Emerging technologies in the remote sensing field are presented. The current GOES and NOAA satellite systems are surveyed with an emphasis on each satellite's capabilities and operational status.

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I. INTRODUCTION

A. BACKGROUND

There are hundreds of space-borne platforms occupying orbital slots in Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO). Add to this burgeoning inventory the large constellations of communications satellites that are slated to be launched in the next seven years, such as the Mega Leo System (1066 individual satellites) and the Iridium System (66 individual satellites), and in a short period of time LEO and GEO slots will become limited. The heightened launch schedule required to put these large systems in orbit will also pose significant problems in the areas of excessive accumulation of space debris and will increase the probability of on-orbit collisions of space vehicles.

In order to limit the projected operational satellite inventories, reduce the redundancy of satellite missions, and reduce the cost of military and private satellite missions, the efficient utilization of the current inventory of space-borne sensors is necessary. This alternative could be accomplished by the purchasing of services from commercial satellites already on-station or satellites that are about to be launched. If an organization was interested in taking this approach it would want to compare various satellite parameters such as satellite services available, satellite capabilities, performance characteristics, and design life. This type of design and operational performance data on the current inventory of commercial satellites would be a valuable tool in a cost-risk analysis study to determine the feasibility of purchasing services vice launching a new satellite to perform the mission.

B. OBJECTIVES

The objective of this thesis is to provide useful data to institutions (military, civil, or commercial) for developing cost-risk studies of satellite systems. Additionally, individuals requiring technical data on a specific domestic satellite in geosynchronous Earth orbit would have a detailed reference guide superior to present surveys.

This paper will address the key design features, performance parameters, and services offered by the current inventory of domestic commercial satellites in Geosynchronous Earth Orbit. In addition, the satellites providing meteorological data to the National Oceanic and Atmospheric Administration (NOAA) will be described.

C. ORGANIZATION

This thesis is organized into eight chapters.

Chapter II, The Commercialization Of Space In The United States, describes the various commercial space industries in the United States and provides a brief chronology of their evolution. It also suggests specific areas for Federal support to stimulate private ventures in commercial space industries. An examination of possible emerging commercial space industries is included to highlight potential opportunities in the commercial exploitation of space.

Chapter III, Communications Satellite Technology, describes how communications satellites operate. Technological innovations used in current operational domestic satellites are also described.

Chapter IV, United States Commercial Communications Satellites, presents detailed technical descriptions on current domestic satellite communications systems. This section is formatted in alphabetical order according to the satellite vendor and provides a technical summary of each system owned and operated by that company. These summaries

include a background to the satellite vendor, an overview of the satellites in the system, orbital parameters of the satellites, satellite capacity, services available from the satellite system, design life of the satellites, and performance parameters.

Chapter V, Remote Sensing Technology, describes remote sensing technology and delves into the commercial opportunities available in the evolving remote sensing industry. Additionally, a brief overview of the equipment used on remote sensing satellites is presented.

Chapter VI, National Oceanic And Atmospheric Administration System, presents an overview of NOAA and details the current polar orbiting and geostationary operational environmental satellites (GOES) of the NOAA system. Additionally, the capabilities and orbital parameters of each of these satellites is examined.

Chapter VII, Summary And Recommendations, presents a summary of the findings of this study.

II. THE COMMERCIALIZATION OF SPACE IN THE UNITED STATES

A. THE UNITED STATES SPACE PROGRAM IN THE 1990s

The utilization of space is important to national security, technological growth, and economic stimulation of private industries in the United States. Since its inception in the late 1950s, the U.S. space program has been on the cutting edge of advanced technologies and scientific research. Three generations of scientists, aerospace engineers, and manufacturers have worked diligently to establish the United States as the premier authority in the space arena. But, they did so in a national security context where there was little concern for costs or markets. Now that Russia is no longer considered a threat to national security, many of the National Aeronautics and Space Administration's (NASA) projects have become the focus of Congressional scrutiny as the current administration seeks to trim the federal deficit.

Today, the United States has a space program that provides only a minor interactive role to the U.S. public. Many of its projects are scrapped before completion due to cost overruns and dwindling budgets. In substance, NASA has lost the commanding constituency that it nurtured in the late 1960s at the zenith of the Apollo program. The 1990s will be characterized as an era of declining federal budgets for DoD and NASA. Many federally backed programs are already beginning to feel the pinch of budgetary cutbacks as political and military leaders tout the decade of doing more with less. With civil appropriations dwindling and defense technology programs being slashed, the health of the U.S. space industry is a growing concern.

B. TEMPORARY SETBACKS

The summer of 1993 was a particularly debilitating period for NASA. First the Titan 4 blew up. Then two NASA satellites (Landsat 6 and the Mars Observer) mysteriously failed on the same afternoon. Meanwhile, the Advanced Solid Rocket Motor Project (ASRM) and the Strategic Defense Initiative (SDI) program were terminated in the House of Representatives and the Senate. This costly string of disasters drives home the need for restructuring the space program to guide it safely into the next century. How can this best be accomplished? The most efficient method for achieving this goal would be to transition government-funded space activities to the private sector. In stimulating commercial space ventures, the Federal government will be able to reduce federal budgets for space projects, foster technological growth, and help retain United States' leadership in the space arena.

C. UNITED STATES NATIONAL SPACE POLICY

The National Space Policy is a culmination of a series of presidential policies aimed at a fundamental redefinition of the traditional role of the Federal government towards space. The National Space Policy states:

The U.S. Government will provide a climate conducive to expanded private sector investment and involvement in space activities, with due regard to public safety and national security. (Fuhs, 1993, p. 184)

To facilitate this commercial space policy, the United States needs to pay more attention to international space commerce or risk losing more business to foreign competition. Issues of fair trade and technology protection are critical now, especially for the space transportation and spacecraft construction industries, which will face stiff competition in the years to come. With Europe's Arianespace consolidating its leadership role, Japan developing a new rocket, and both

Russia and China aggressively marketing their respective expendable launch vehicles (ELVs), a new era in the aerospace marketplace is dawning. The United States commercial launch vehicle industry, in particular, faces a critical junction in its evolution.

D. CHRONOLOGY OF THE COMMERCIAL LAUNCH VEHICLE INDUSTRY

The Delta launch by McDonnell Douglas in August of 1989 was the first commercial rocket launched in the United States. Prior to that, all space launches were considered to be federally sponsored.

1. The Role Of The Federal Government In Commercial Launches

The Air Force and NASA traditionally purchased launchers from the launch industry and managed the launchings for themselves and for other customers. These customers included foreign governments, other government agencies, and domestic and foreign commercial ventures. The United States' launch vehicle industry, therefore, relied heavily on the government for business and research and development (R&D) funding.

2. The Impact Of The Shuttle Program On The Launch Industry

In 1982 the U.S. space launch monopoly was shattered when the European consortium, Arianespace, began commercial launches. In 1983 the United States decided to launch all government payloads on the space shuttle and in 1984 Congress passed the Commercial Space Launch Act which focussed on commercializing expendable launch vehicles. Unfortunately, the shuttle launch price was heavily subsidized and set too low for ELVs to compete against it. Additionally, since all government payloads were to be launched by shuttles, there was very little business available for the ELVs. These two factors

led several launch contractors to close down their ELV production lines and to lay off their respective workforces. The Air Force was successful in ordering ten Titan 4s as backups for the shuttles.

3. Space Policy During the Reagan and Bush Era

In January 1986, the Challenger accident, coupled with the Titan 4, Atlas, and Delta launch failures, altered U.S. launch policy. The Reagan administration directed that no commercial payloads, either domestic or foreign, could be carried by shuttles except for national security and foreign policy reasons. In addition, NASA was prohibited from providing ELV services. This policy went into effect in August of 1986. Suddenly, the private ELV providers no longer had to worry about competition from the lower priced shuttles or NASA competition at all. In essence, this policy provided a liferaft to the U.S. commercial ELV industry. (Chow, 1993, pp. 8-9)

In compliance with National and Department of Defense (DoD) Space Policy Directives, the Air Force increased its Titan 4 order from 10 to 23 rockets in 1987, thus ensuring the viability of Martin Marietta's Titan Program. Additionally, the Air Force's signing of the Medium Launch Vehicle contracts, MLV-1 in 1987 and MLV-2 in 1988, allowed the Delta and Atlas production lines to remain open. Without the 1986 changes in United States' space policy and subsequent Air Force purchases, both McDonnell Douglas and General Dynamics would most likely have terminated their respective production lines and abandoned the industry. (Chow, 1993, pp. 9-10)

4. Key Issues For The Clinton Administration

Space policy is modified with every change-of-command in the White House. As of yet, the Clinton Administration has not made any alterations to current United States space policy with regards to commercial space enterprises. However, if a launch policy is implemented with provisions that are not

supportive of the commercial industry, one or more of the major launch vendors could conceivably be forced out of the marketplace. The U.S. launch industry can survive on government business alone, although the launch cost to the government could be considerably higher than if the launch business was competitive with that of foreign companies. A competitive domestic launch industry that is capable of providing launch services on a global scale can also have the effect of deterring other countries from developing their own space launch vehicles, thus discouraging additional competition from newcomers attempting to enter the market. Another big bonus resulting from low priced commercial launches is that if countries can purchase this service from the United States then they would not need to build their own space vehicles. This could be extremely conducive towards effectively slowing the rate of missile proliferation in third world countries.

A serious issue confronting the space transportation industry is the lack of fair pricing arrangements that put government-subsidized launch programs in non-market economies on equal footing with unsubsidized launchers. Currently, the U.S. share of the global launch business has slipped from a dominant position to approximately 40 percent of the market, largely because of the 1980's decisions to rely more heavily on the space shuttle than expendable launch vehicles. (Seitz, 1993, p. 16)

5. Open Competition In The International Market

Today's launch industry is dominated by Europe's Arianespace, based out of Evry, France, which is owned by 52 European aerospace companies, banks, and national agencies. The Ariane rocket, the only ELV in current use that was designed specifically for launching satellites, controls approximately 60 percent of the market. The remainder is effectively divided between the Atlas rocket, built by General

Dynamics, and the Delta, built by McDonnell Douglas. Martin Marietta's Titan 4 has suffered some temporary setbacks on the launch pad and is currently not involved in open competition with the other firms. The new competitors entering the scene are China's Great Wall Corporation sporting the Long March Rocket and Russia with the Proton. (Dorfman, 1993, pp. 15-16)

6. Projected Requirements

Projections of commercial satellite launch vehicle requirements indicate that most, if not all, commercial communications satellite launch needs could be met by 20,000-pound, low earth orbit (LEO) ELVs. The United States could control this market with the right launcher. The proposed National Launch System could provide such a launch vehicle if investments in that technology are initiated. Once the 20,000-pound lift capability is developed, the United States could build upon that core capability in subsequent upgrades to extend to even greater weight capacities. This approach would produce the quickest and most cost-effective product development of launch vehicle technology. (Dorfman, 1993, pp. 15-16)

The bottom line is that the United States has a single launch industry that serves the needs of both the government and commercial customers. Since the government is the primary customer, there is a natural tendency for the launch industry to fixate on government requirements vice the requirements of commercial consumers. The inherent philosophy is that even without commercial business the industry can remain viable on government contracts alone. This may be an accurate assessment of the situation, however the government should recognize that a noncompetitive launch industry will eventually force higher launch fees as the domestic launch industry becomes more monopolized.

7. Short-Term Challenges

To keep the commercial launch industry healthy, there are several challenges that must be met. First, there is the need to reduce launch costs. In the past, the United States space launch program was tailored towards military needs and thus concentrated on high performance. Foreign competitors such as the European Space Agency and Japan, however, catered to commercial applications and cost per launch during their launcher development programs.

The second challenge is to upgrade the United States launch infrastructure. Our current infrastructure contains a large inventory of 1950s vintage equipment. Several items are so old that obtaining replacement parts is a major problem. So far, mostly through meticulous maintenance practices by technicians and ground crews, there have been no major mishaps. However, obsolete equipment will eventually degrade launch reliability. Most satellites cost considerably more than a launch vehicle. The reliability record of the launch provider is a critical factor in a customer's decision on the selection of a launch vendor. A deteriorating reliability record could inevitably cause the United States to lose commercial launch business. (Chow, 1993, pp. 17-18)

The final area of concern relates to foreign competition. Since every foreign launch industry is subsidized by its government, the United States government will have to continue to do the same if its industry is to survive in the global market. The U.S. launch industry could benefit by an increased government launch demand, tax incentives, and R&D funding support. These stimulants would have the net effect of reducing costs in launcher manufacturing and processing.

E. THE U.S. COMMERCIAL COMMUNICATIONS SATELLITE INDUSTRY

In contrast to the U.S. launch industry, the U.S. satellite communications industry is already flourishing. This industry generates some five billion dollars a year from the transmission of radio and television broadcasts, telephone conversations, electronic mail, and business data. Future satellite communication from geosynchronous orbit presents opportunities for advances in communication technology through the development of large communication platforms, higher frequency systems, and in dynamic and directed techniques such as beam switching. All of these new technologies give rise to potential opportunities for future commercial exploitation. Moreover, satellite communications opportunities exist in the development and marketing of new services: direct audio broadcasting; the provision of satellite communications services to automobiles, trucks, emergency service units, and aircraft; the use of low orbiting satellites to provide electronic mailman service to remote areas; and to provide for the location and tracking of simple, low-cost transmitters mounted on commercial rail, maritime, and trucking fleets. (Shahrokhi, Chao, and Harwell, 1988, pp. 3-5)

F. OPPORTUNITIES IN NAVIGATION THROUGH THE USE OF SATELLITES

Another field which has shown potential for commercial exploitation is navigation. Navigation and geodesy are valuable offshoots of space technology. Accurate navigation is becoming increasingly important for optimizing traffic flows (aircraft/shipping) and minimizing fuel consumption through traffic sequencing. Additionally, reliable position determination is essential for a variety of economic activities including seabed mining, offshore drilling, geodynamics research, and plate tectonics studies. Although some scientific studies require extremely accurate geodetic measurements using satellite laser radar or very long baseline

interferometry, most economic activities use satellite navigation based on doppler measurements. While much of the work in this area is undertaken on the federal level, there is an increasing necessity to stimulate satellite position determination operations in the commercial sector and to involve private firms in the research and development in such a way as to facilitate future commercial ventures in satellite-assisted navigation.

G. SPACE-BASED MATERIALS PROCESSING

One of the more lucrative ideas for future commercial space ventures is space-based materials processing. In the future, items such as drugs, alloys, and crystals will be manufactured in space through the use of orbiting space facilities. On the Earth, gravity influences every physical process to some extent. When two metals of different densities are mixed to form an alloy, gravity causes nonuniformity so that by-products are not as strong or durable as they should theoretically be. In a microgravity environment, this effect is eliminated, allowing superior alloys to be manufactured. At some point in time private industry should be able to exploit the space environment to refine the manufacture of heavy alloys such as lead, steel polymers, and other complex three dimensional structures. Currently, with the high cost of space transport, it is likely that only products of extremely high value per pound (i.e., pharmaceuticals and crystals) will be attempted initially. (Shahrokhi, Chao, and Harwell, 1988, p. 13)

A critical advantage of manufacturing in space is that container walls and molds are not necessary. Crystals can be grown without contacting an adjacent surface and thus will not contract the impurities associated with that contact. Numerous genetic engineering, fermentation, culturing, and separation technologies are now being used in ground-based biological

processing. Unfortunately, these processes are hampered by thermal convection, sedimentation, gravity-driven flows, and turbulence. In space these problems can be circumvented and the processing of biological materials to obtain specific cell types, hormones, antigens, proteins, and other organic substances with a higher level of purity can be accomplished. (Shahrokhi, Chao, and Harwell, 1988, p. 14)

Electrophoretic chambers for the processing of pharmaceuticals will eventually be flown in established orbiting space facilities. These facilities could also provide a subsidiary business for the space-based manufacturing industry. For example, rental service on these facilities could be leased to scientists in developing countries that do not have the capability of setting up their own experimental facilities. Clearly, the advantages that this industry could create in the health care field and clinical medicine are of enormous potential.

H. THE AMERICAN SATELLITE PRODUCTION INDUSTRY

The U.S. satellite production industry is the dominant world supplier of satellites, accounting for 70 percent of all commercial sales in 1992. This trend might not continue. Many other countries have expressed an increasing desire to subsidize their internal satellite production facilities to catch up to the United States. (Seitz, 1993, p. 16)

The American satellite industry includes satellite service providers, manufacturers of space systems, and launch providers. This industry employs thousands of Americans and returns billions of dollars to the economy each year. To ensure the continued growth of this industry several important issues must be addressed. These include adequate spectrum allocations, the development of technologies and standards that will harmonize satellite and terrestrial technologies, and timely

and responsive regulatory licensing procedures. (Stern, 1993, p. 15)

In September of 1993, the United States relaxed its stringent rules for exporting communications satellite parts and will do the same for whole remote sensing spacecraft and their components by the end of 1994. This change in policy will allow American satellite manufacturers to sell commercial spacecraft abroad with far less red tape. Spy satellites on the other hand will remain under tight government control. The decision essentially takes communications satellites out of the politically charged atmosphere surrounding licensing decisions on hardware with military applications. (Lawler, 1993, pp. 4-21)

Many countries have targeted the aerospace industry for development and often encourage teaming or combining private firms to create a national leader in the industry. Europe has encouraged the creation of Airbus Industrie, Eurocopter, Deutsche Aerospace, and Arianespace to name a few. The United States, on the other side of the spectrum, discourages the teaming of firms and pooling of resources because of aged antitrust policies. As a result, domestic manufacturers will be confronted with foreign competitors that are encouraged to combine resources with the intent of dislodging American products from the global marketplace. In this context obsolete United States antitrust laws which were originally designed to protect American businesses in the domestic market are now working to our detriment in the international arena. (Fuqua, 1993, p. 16)

I. SUMMARY

The successful promotion of space in commercial circles hinges upon continued investment and space policies conducive to entrepreneurial, space-related ventures at the federal level. To maintain the space industrial base and stimulate space industries, the financial health of fledgling space companies must be safeguarded. If the government establishes policies that shift greater financial risks to the private sector, the industry's health is sure to dissipate as the increased cost of a particular project becomes too risky to attempt. Therefore, future space policies must be designed with heavy emphasis on the promotion of industrial growth and the minimization of over-regulation. Additionally, tax incentives, antitrust law modifications, and the loosening of regulations on technology transfer from government to private industry would all provide a positive stimulus for long term sustainability in the global forum.

Continued investments in space technology, by the Department of Defense and NASA and additional long term contracts by government agencies to purchase space-related products from industry, are critical ingredients in the expansion of the domestic market. The most important priority, however, should be to reduce basic infrastructure costs, especially the costs associated with the transportation of payloads into low Earth orbit. The initiation of these processes could serve to have a positive effect upon the inducement of private investment in established and emerging technologies in space-related enterprises.

The commercial opportunities associated with space technology are as numerous as they are lucrative. The next decade will be characterized by a wave of emerging space industries in the United States ranging from cost-effective space transport to exotic forms of materials processing in space. The United States has always been the leading pioneer

in aerospace technology. It is now time to extend that vision to the private sector so that domestic businesses can remain competitive in the international arena. The scientific, economic, and political benefits generated by a strong domestic space industry will provide ample justification for federal expenditures and policies conducive to commercial space exploitation.

III. COMMUNICATIONS SATELLITES

A. INTRODUCTION

This chapter describes and explains the fundamentals of communications satellite systems. It addresses the technologies utilized in both the space-based platform and the ground segment.

B. DOMESTIC COMMERCIAL COMMUNICATIONS SATELLITE INDUSTRY

The Federal Communications Commission (FCC) has licensed seven communications carriers to provide domestic geosynchronous satellite communication services to the United States and its territories. These carriers are Alascom, Alpha Lyracom, AT&T, Comsat, GE Americom, GTE Spacenet, and Hughes. This license authorizes the carriers to provide fixed and mobile services for private and government subscribers.

Geostationary communications satellites typically operate at the C-band (4-6 GHz), the Ku-band (11-14 GHz), or operate at both bands (hybrid satellite).

C. MULTIPLE ACCESS METHODS

In satellite communications, information is transmitted by modulating data signals onto electromagnetic carriers at C-band or Ku-band. Satellite communications systems handle numerous uplink and downlink signals simultaneously. A particular earth station may need to transmit information to a number of different receiving stations. Similarly, a given earth station may be required to receive the transmissions of several different transmitting stations. Since all the uplink carriers must access through a common satellite to complete their downlink transmissions, the overall system operation has

been referred to as multiple-access communications. (Gagliardi, 1991, pp. 26-27)

Multiple accessing must allow a receiver to separate the desired carrier while rejecting the unwanted carriers. This separability is achieved by requiring the carriers to conform to a specific multiple-access format. This multiple-access format is simply a method of carrier-wave multiplexing which allows many carriers to remain separable after channel transmission, even when emitted from remotely located stations. Satellite systems typically have both uplink multiple accessing and downlink multiple accessing. The uplink accessing format must allow different Earth stations to transmit to a given satellite at the same time while downlink accessing must allow a ground receiver to separate out undesired carriers. (Gagliardi, 1991, pp. 26-27)

In a transponding satellite, the uplink and downlink multiple-accessing format is the same with all uplink carriers passing through the satellite to complete the downlink. By contrast, in processing satellites, the uplink format may be revised at the satellite prior to the downlink transmission. (Gagliardi, 1991, pp. 26-27)

The three most common forms of multiple-accessing formats are code division multiple access (CDMA), frequency division multiple access (FDMA), and time division multiple access (TDMA). (Gagliardi, 1991, p. 28)

1. Code Division Multiple Access

With the code division multiple access method, several different earth stations use the same carrier frequency and associated bandwidth, simultaneously. To achieve this powerful means of multiple access, CDMA utilizes a technique within the broad field of spread-spectrum communications. The application of code division multiple access is essentially limited to digital transmissions and requires a larger

bandwidth than would be needed for direct transmission of the message. (Pritchard, 1986, p. 270)

Uplink stations, in a CDMA satellite system, are identified by unique and separable address codes within the carrier waveform. No frequency or time separation is required. Therefore, each uplink station may use the entire bandwidth and transmit through the satellite at any time. Carrier separation is achieved at the receiving Earth station by identifying the carrier with the proper address code. These address codes are normally in the form of periodic binary sequences that change the frequency state of the carrier or modulate the carrier directly. (Gagliardi, 1991, p. 289)

Each bit of the digital message is transmitted as a sequence of bits which occurs as the original information bit stream is convolved with a predetermined code sequence at a slightly higher bit rate. By knowing the encoding sequence, the receiver is capable of reconstructing the original message under an extremely adverse signal-to-noise ratio. In the event that several stations transmit simultaneously, using different encoding sequences, then any receiving station interprets the undesired coded message traffic as noise within the tolerable noise power budget. (Pritchard, 1986, p. 271)

2. FDMA (Frequency Division Multiple Access)

FDMA has been utilized since the inception of satellite communications. With this multiple access method, each earth station, which shares the transponder capacity, transmits one or more carriers to the satellite transponder at a different frequency. Each carrier is assigned a separate frequency band in the transponder bandwidth, along with a guard band to avoid interference between adjacent carriers. Once the satellite transponder receives the carriers in its bandwidth it amplifies and retransmits them back to Earth. (Gagliardi, 1991, pp. 250-252)

There are two generic types of FDMA systems, both of which may use analog and digital transmission techniques. The first of these FDMA systems accommodates multiple channels per carrier (MCPC) while the other system employs single channel per carrier (SCPC) techniques. (Gagliardi, 1991, p. 252)

a. MCPC (Multiple Channels Per Carrier)

The first multiple access technique to be employed in satellite communications was the analog MCPC system. This type of system was an outgrowth of the frequency division multiplex (FDM) hierarchy developed for terrestrial multiplex systems. Initially, in the multiple channels per carrier access method, individual voiceband channels are single-side-band modulated on frequency division multiplex carriers to form FDM baseband assemblies. The voiceband channels from the terrestrial telephony system are connected at an earth station with FDM multiplex equipment which is used to create FDM baseband signals in accordance with a preassigned frequency plan. At each earth station, the FDM basebands are frequency modulated on preassigned carriers and transmitted through the satellite in a preassigned portion of the transponder bandwidth. The receiving stations then demodulate each received carrier and using FDM multiplex equipment, strip off only the channels assigned to that particular earth station. (Pritchard, 1986, p. 247)

The analog multiple channels per carrier method provided excellent voice quality and service for many years, however it tends to be inflexible in redistributing traffic demands. Additionally, its high per channel hardware requirements prevents it from becoming more cost effective as the number of channels increases. Because analog MCPC employs multiple-carrier operation, this system is subject to the penalties caused by the nonlinear performance of the transponder. Therefore, in multiple access operation, such a system does not always achieve the highest capacity. For high

density point-to-point communications links however, the system can achieve competitively high transponder capacities. (Pritchard, 1986, p. 247)

The digital MCPC system is used for the transmission of digitally encoded baseband signals. The operational requirements of this system are similar to those used in analog FDM/FM transmission, requiring only basic frequency coordination typical of FDMA systems and no network clock synchronization. The baseband information for each carrier typically consists of multiple PCM-TDM bit streams. These multiplexed signals are modulated in digital carriers, normally employing four-phase coherent PSK which are compatible with FDM/FDMA carriers sharing the same transponder. The use of digital time division multiplex baseband permits the potential use of digital speech processing to provide a significant enhancement of voice channel capacity by taking advantage of silence intervals in multichannel speech telephony using speech interpolation techniques. The digital baseband coding of individual channels may use any one of several methods, although the predominant technique is PCM. (Pritchard, 1986, p. 251)

b. SCPC (Single Channel Per Carrier)

In the single channel per carrier multiple access method each uplink carrier is assigned its own transponder channel. No multiplexing is involved except within the transponder bandwidth, where frequency division is used to channelize individual carriers, each supporting the information from a single channel. The terrestrial system connects to the earth station SCPC equipment on a channel-by-channel basis. Associated with each incoming signal is a channel unit, which contains all of the equipment required to convert the voice or data signal into a PSK modulated RF carrier. This carrier is then transmitted over the satellite transpond-

er channel using only that station's assigned segment of the transponder bandwidth. (Pritchard, 1986, pp. 252-253)

In operation, a pair of channel frequencies is selected, one for the uplink and one for the downlink. On the receiving end, the channel unit associated with each carrier frequency contains all the equipment required to demodulate the radio frequency carrier and deliver the signal to the terrestrial end links. (Pritchard, 1986, p. 253)

Several uplink carriers may be transmitted from a given earth station or each uplink carrier may originate from a separate earth station. Additionally, the frequency band selection may be fixed or assigned on demand. With fixed frequency operation, each carrier is given a dedicated frequency band for the uplink which may not be utilized by any other carrier. In demand assigned multiple access (DAMA), frequency bands are shared by several carriers, with a particular band assigned at the time of need, depending on availability. DAMA systems are able to serve a larger number of carriers if the usage time of each is relatively low, but may require a more complex ground routing system. (Gagliardi, 1991, p. 217)

3. TDMA (Time Division Multiple Access)

The TDMA system operates on a time division basis. Each earth station sharing a satellite transponder uses the same center frequency for transmission on a time division basis. Therefore, each earth station has the use of the entire transmission bandwidth for a limited period of time to transmit traffic bursts in a periodic TDMA frame. The satellite transponder receives one traffic burst at a time, which it amplifies and retransmits. Consequently, each receiving earth station may receive the entire traffic burst and extract only the data intended for it. (Gagliardi, 1991, p. 252)

Each uplink earth station is assigned set time intervals to relay data through the satellite. During this interval, that particular earth station has exclusive use of the given transponder, therefore no intermodulation or carrier suppression occurs and the transponder amplifier may be operated at saturation to achieve maximum output power. This access method requires precise earth station synchronization to prevent adjacent earth station interference. Each downlink earth station desiring to receive data from a particular uplink earth station must gate into the satellite signal during the proper time interval. This timing sequence, known as network synchronization, means that all earth stations, both in the uplink and downlink, must be part of the synchronized network. (Gagliardi, 1991, p. 252) The TDMA method does not have the problem of many carriers trying to pass through a particular satellite at the same time, thereby avoiding the intermodulation problem of FDMA. However, TDMA systems do require communications concepts which are relatively complex while FDMA systems involve basic frequency tuning for accessing and providing essentially independent channel on/off operation. Additionally, TDMA time intervals must be relatively short to accommodate numerous users, therefore requiring burst type transmissions, and the time intervals of all users must be properly and accurately synchronized. This requires several levels of timing control. (Gagliardi, 1991 p. 251)

D. COMMUNICATIONS PAYLOAD

A communications satellite is an orbiting signal repeater which receives, amplifies, and retransmits a signal. The communications platform is the assembly of equipment designed to perform this operation on the signals arriving at the satellite.

The communications payload may be broken down into two segments, the transponder chains and the antennas. The spacecraft transponder chain comprises all of the communications hardware except for the antennas and feed networks.

1. Transponders

A satellite transponder chain may be divided by function into two sections, the receiver and transmitter. The precise dividing point is dependent on the particular design. Typically, the receiver includes everything from the point where the input signal enters from the receiver antenna feeder to the point prior to its entry into the power amplifier. (Williamson, 1990, p. 144)

a. Receiver Section

The signal strength of the carrier reaching a communications satellite is weak due to the distance it travels: 36,000 km for a geostationary satellite. This is a result of the beam spreading phenomenon, which is highly dependent on distance. For example, the signal reaching a geosynchronous satellite from an earth station with an antenna beamwidth of one degree is approximately 630 km wide. The spreading of the beam reduces the radiated power density by the ratio of the area of the beam at the height to the area of the earth station antenna, a ratio of about 10,000,000,000 to 1. Therefore, highly sensitive, low noise receivers are required. A satellite front end typically functions as either a single conversion or double conversion receiver. (Williamson, 1990, pp. 144-146)

A single conversion payload utilizes a single frequency from the higher uplink frequency to the lower downlink frequency. In operation, the antenna feeder network passes the uplink signal to an input filter, which limits the bandwidth of the signal into the transponder. This prevents interference from other communications systems and harmonics or spurious noise generated by components of the transponder

itself. This filtered signal is then boosted in power by a low noise amplifier (LNA). LNAs are designed to deliver a high signal-to-noise ratio, which is essential at this early stage since any noise generated here will be carried through the remainder of the transponder. There are two types of LNAs commonly used in communications satellites, bipolar transistors and field effect transistors (FETs). Bipolar transistors operate up to about 2 GHz while FETs are normally used between 2 and 20 GHz. Typically, each type of amplifier provides about 10 dB of gain. (Williamson, 1990, pp. 147-149)

The next device in the receiver section is the downconverter, which reduces the frequency of the uplink to the lower downlink frequency. The downconverter consists of a mixer and an oscillator. The oscillator generates a stable frequency which is combined with the uplink frequency in the mixer. The output of the mixer is tuned to the difference of its two input frequencies, thus providing the downlink frequency. (Williamson, 1990, p. 150)

The final stage of the receiver section involves further amplification and filtering. A preamplifier boosts the strength of the mixer output and passes this amplified signal through a channel filter. The channel filter has a narrower bandpass than the input filter and it is this channel filter which defines the usable bandwidth of the transponder. After filtering, the signal is further amplified by a driver amplifier. The drive amplifier amplifies the downlink signal to a level acceptable to the main high power amplifier. (Williamson, 1990, p. 151)

Double conversion transponders differ from single conversion transponders in that the former downconverts the receive frequency to a frequency lower than the transmit frequency for preamplification and filtering. After preamplification and filtering the signal is upconverted to the

appropriate downlink frequency. Double conversion transponders are typically utilized in satellites operating at Ka-band (20/30 GHz) where the frequencies are too high to be conveniently handled by conventional intermediate transponder components. (Williamson, 1990, p. 152)

b. Transmitter Section

The purpose of the power amplifier is to increase signal power for transmission. The power amplifier is the final amplifier stage and has various bandwidths such as 27, 36, 43, 54, 72, or 241 MHz. The bandwidths used are dependent on the access method chosen and services provided. Generally, satellite power amplifiers are either traveling wave tube amplifiers (TWTAs) or solid state power amplifiers (SSPA). (Gordon, 1993, p. 160)

(1) *Traveling Wave Tube Amplifier (TWTAs)*. TWTAs were once the dominant power amplifiers for communication satellites and are still widely used. These satellite power amplifiers utilize vacuum tubes with an electron beam which interacts with the traveling RF wave. They deliver significant power, up to approximately 50 watts, which is higher than that delivered by SSPAs. TWTAs have efficiencies in the range of 50 percent and operate over a wide bandwidth, typically from 40 to 80 MHz. Compared to SSPAs, TWTAs are heavier and tend to have shorter operational lives. (Gordon, 1993, pp. 160-161)

A TWTAs is a specially designed vacuum tube device which makes special use of a stream of electrons. This electron beam is generated by an electron gun, consisting of a heated cathode and focusing electrodes. The stream of electrons travels along the axis of the tube, constrained by focusing magnets, until it reaches the collector. Surrounding this electron beam is a helix, capable of propagating a slow electromagnetic wave. The input RF signal enters one end of the helix, and the RF output comes out the other end. While

the RF wave travels along the helix wire itself at close to the speed of light, the helical path in which it must travel causes wave propagation along the axis of the tube to be at a much lower axial velocity. Typically, in low power TWTAs this may be one-tenth of the speed of light while, in higher power tubes it is about two to three times greater. (Gordon, 1993, pp. 162-163)

High voltages accelerate the electrons in the electron beam to a velocity approaching the axial phase velocity of the RF wave. TWTAs are designed to ensure that the axial velocity of the RF wave is slightly lower than the velocity of the electron beam. In regions where the electric (E) field lines are in the direction of electron travel, electrons are decelerated, and where the field is in the opposite direction they are accelerated. The interaction is such that the electrons in the electron stream receive a periodic velocity modulation approximately in phase with the electric (E) field of the RF wave. (Williamson, 1990, p. 164)

Amplification in TWTAs is a result a phenomenon known as bunching, where alternate regions of electrons, in the electron beam, are accelerated and decelerated. While all of the electrons are physically moving in the same direction, the critical motion is that of the electron bunches with respect to the RF field. Some of the electrons are decelerated by the electric (E) field into lagging bunches and some of the electrons are accelerated to form leading bunches. The electrons which are accelerated to form the leading bunch move forward into the next deceleration field and as a bunch lose energy by deceleration. As a result a majority of the electrons are decelerated and the resulting loss of velocity corresponds to a loss of kinetic energy by the electron beam. This kinetic energy, which is lost by the electron beam, is transferred to the RF wave, where it manifests itself as an

increase in amplitude in the RF wave. (Williamson, 1990, pp. 164-165)

(2) *Solid State Power Amplifier (SSPA)*. The solid state power amplifier consists of several cascaded amplifier stages, with a typical gain of 10 dB per stage. Gallium arsenide field effect transistors (GaAs FETs) are frequently used for SSPAs. Normally, the last stage of an SSPA is formed by several matched amplifiers which are summed by a power combiner. The maximum output power of the amplifier is generated in this final stage. (Gordon, 1993, p. 162)

Reliability and long service life are inherent benefits which may be achieved in using solid state power amplifiers (SSPAs). The low voltage operation associated with the SSPA, compared to the TWTAs, simplifies the electrical power system requirements and reduces the likelihood of voltage break-down and arc-over failures. SSPAs generally have a lower mass than comparable TWTAs, which make them attractive to payload engineers. Additionally, SSPAs tend to operate more linearly, which increases transponder capacity. However, the efficiency of SSPAs, at approximately thirty percent, tends to be lower than that of TWTAs. (Gordon, 1993, p. 161)

2. Antennas

Space and weight restrictions are strict for satellite launch vehicles. As a result, antenna diameters of no more than three meters can readily be accommodated and then only if partially stowed during the launch phase. Larger antenna diameters would require folding or deflating during the launch. Antenna mass is also a significant consideration for satellite launch. Therefore, current satellite-borne reflectors are generally constructed in a sandwich form, consisting of an aluminum honeycomb core with face sheets on either side. Carbon fiber is often employed in the manufacture of these sheets because of its high strength to mass ratio and thermal

stability. However, kapton blankets are usually required to wrap the rear of the reflector, antenna support structure, and primary feeds to reduce thermal extremes. (Evans, 1987, p. 204)

Satellite antennas fall into four main types: helix, horn, reflector, and array. The most frequently used is the high performance reflector configurations, which generate highly directional focused beams. At frequencies up to C-band all four types of antennas may be used for spacecraft applications. For frequencies above C-band the choice is usually confined to reflector antennas.

Helical antennas produce reasonable directivity but generate larger sidelobes than parabolic reflectors. Helical antennas are usually small compared with other antenna types and produce circularly polarized fields. (Gagliardi, 1991, p. 101)

Horn antennas are frequently used as primary radiators in reflector systems and occasionally as complete radiators when wide beamwidths are required. At geostationary Earth orbit, a horn antenna with a beam angle of about 18 degrees will provide earth coverage beams. There are two types of horn antennas commonly used in satellite communications, the pyramidal horn and the conical horn. The pyramidal horn antenna is easily designed because it is an extension of a rectangular waveguide. Circular horn antennas, which are the natural extension of circular waveguides, are frequently used to exploit their higher mode propagation. Horn antennas are generally used to produce linearly polarized fields. The main disadvantage is that it is difficult to obtain a beamwidth of less than 10 degrees and a gain greater than about 23 dB when using a horn antenna. (Pritchard, 1986, pp. 322-323)

Two types of reflector antennas can be identified depending on the position of the feed. One design has the feed mounted at the focus of a symmetric parabolic reflector, so that all parallel rays are reflected from the dish into the feedhorn. The major disadvantage of this type of reflector is the blockage of the useful reflector surface which occurs as a result of the feed and its support structure. The other type of reflector is the offset-fed design, in which the feed horn is placed away from the principal axis of the antenna reflector.

There are two types of antenna arrays, phased arrays and slot arrays. Phased array antennas consist of several radiating elements which can be electrically coupled to form a particular beam pattern. Phased antenna arrays are usually designed to produce beam shapes which are more complex than would be attainable with the other antenna types. The more elements in the array, the larger the pattern gain and the narrower the beamwidth. By properly selecting the phase shifts between the array elements, the direction of the beam can be controlled. Slot array antennas may be formed from slots cut into waveguide walls. Slot array antennas generally produce simpler beam shapes than do phased array antennas. (Williamson, 1990, p. 172)

E. LINK BUDGETS

An essential aspect relating to the design or evaluation of a communications satellite system is the link budget analysis. The link budget analysis provides a means of determining signal strength values at critical nodes throughout the transmission path. Determining the link budget for the downlink is very similar to that of the uplink. This process involves summing up all of the gains and losses along the path.

1. Effective Isotropically Radiated Power (EIRP)

The first item calculated in a link budget is the EIRP, which is expressed in dBW or dBm. The EIRP is utilized to quantify the performance of the transmitting system, including both the satellite and the earth station transmitters. When calculating the link budget for an uplink, it is the earth station EIRP which is considered, while it is the satellite EIRP when calculating the downlink. There are essentially three elements included in this system: the transmitter itself, an antenna, and a transmission line. When using the dB power notation in dBW the equation used to calculate the EIRP is:

$$\text{EIRP(dBW)} = P_t + G_a - L_t$$

where:

P_t = the RF output power of the transmitter in dB

G_a = the gain/loss of the antenna in dB

L_t = the transmission line loss in dB

If this calculation is made using dBW, then dBW must be used throughout the link budget calculation. Conversely, if dBm is used to determine EIRP then dBm must be used throughout. (Freeman, 1991, pp. 33-34)

2. Free Space Path Loss (FSPL)

The power radiated to or from a satellite is dissipated due to the distance between the antennas. Free space path loss may be calculated using the equation:

$$\text{FSL} = 20 \cdot \log(10) \cdot (\text{wavelength} / (4 \cdot \pi \cdot \text{radius}))$$

This is a major source of loss in geostationary satellites. (Freeman, 1991, p. 369)

Often there is an elevation angle associated with the satellite which increases the given distance to the satellite and must be accounted for. When this is the case, the actual distance involved may be determined by referring any number of texts which have graphs that indicate the range to satellite

in nautical miles for various elevation angles. (Freeman, 1991, p. 374)

3. Isotropic Receive Level (IRL)

The IRL is the RF signal level impinging on the far-end receive antenna as if it were an isotropic antenna. To obtain the IRL, the EIRP and FSPL are algebraically summed as follows:

$$\text{IRL(dBW)} = \text{EIRP(dBW)} + \text{FSL(dB)}$$

It should be noted that although this calculation will provide a good indication of the isotropic receive level, the actual value will be slightly different unless several additional losses are taken into account. Among these losses are pointing losses, polarization loss, radome losses, gaseous absorption loss, and excess attenuation due to rainfall. (Freeman, 1991, pp. 369-370)

4. Gain-to-Noise Ratio (G/T)

The G/T ratio is next algebraically added to the IRL value. The G/T ratio is the receiving system figure of merit which qualifies the receiving system sensitivity. G/T may be expressed by the following identity:

$$G/T = G(\text{dB}) - 10 \log T$$

where:

G = the receiving system antenna gain

T = the receiving system noise temperature

(Freeman, 1991, p. 376)

5. Boltzmann's Constant

All satellite communications receivers have a thermal noise of spectral density kT watts/Hz associated with them. Boltzmann's constant is an absolute reference value for noise and is represented by $-228.6 \text{ dBW/Hz} \cdot \text{K}$. This is the constant of proportionality between the molecular kinetic energy and temperature. The units of the constant describe the level of noise contained in every 1 Hz of bandwidth for every 1 degree

kelvin (K) of temperature in terms of power (dBW). (Freeman, 1991, p. 374)

F. EARTH STATIONS

In satellite communications systems, earth stations perform two satellite link functions. First, earth stations provide a means of monitoring and controlling satellite operations through telemetry, tracking and control (TT&C). Earth stations also provide a source for the communications link itself.

The functions of telemetry, tracking, and control are normally integrated into a single subsystem which is separate from the main communications network. Telemetry provides a means of retrieving the measurements made at a distance. Tracking is the plotting of satellite movement and control is the means by which satellite control is maintained. TT&C is generally provided by a dedicated earth station which may or may not be co-located with a communications uplink station. The size of the TT&C station is dependent on uplink performance requirements which are dominated by reliability. Therefore, most TT&C earth station antennas are at least 10 meters in diameter. (Williamson, 1990, p. 197)

The type of earth station used to provide the source of the communications link depends on the quantity and type of communications traffic which is to be carried. Small earth stations, with antenna diameters of only 3 to 5 meters, can provide uplinks for routes with low traffic requirements. However, for communications trunk routes, large earth stations with antenna diameters in the range of 30 meters are the norm. These larger earth stations are known as gateway stations and are used to handle routes such as transatlantic links. The earth station hardware required for a satellite downlink is somewhat more varied than that for an uplink because of the

diversity of satellite communications applications. (Williamson, 1990, p. 197)

Most earth stations are required to provide both an uplink and downlink for the satellite however, there are some special applications which require only transmit or receive operation. As an example, earth stations which operate as television broadcast satellite uplinks, operate in the transmit mode only while satellite television reception terminals operate only in receive. (Williamson, 1990, p. 197)

IV. INVENTORY OF COMMERCIAL COMMUNICATIONS SATELLITES

This chapter presents a detailed technical summary of domestic communications satellites which are currently operational in geosynchronous Earth orbit. The chapter is formatted in alphabetical order according to the satellite vendor and provides a systems summary of each satellite owned and operated by that company. These summaries include a background of the satellite vendor, an overview of the satellites in the system, orbital parameters of the satellites, satellite capacity, services available from the satellite system, and performance parameters.

A. ALASCOM INCORPORATED

Alascom Incorporated provides commercial and government communications services within Alaska and between Alaska and locations in Hawaii and the 48 contiguous states. Additionally, Alascom provides full long distance telecommunications services to every community in Alaska of 25 or more people. The company was founded in 1971 and currently has approximately 750 employees. Alascom, whose parent company is Pacific Telecom Incorporated operates at over 350 locations in Alaska. (The World Satellite Directory, 1993, pp. 16-17)

In addition to the satellite services, Alascom also operates an elaborate terrestrial network of microwave facilities. The network extends along the length of the 800 mile Alaska pipeline. It connects Fairbanks to Homer and the Canadian border. It also connects Anchorage to Seattle though Canada. (The World Satellite Directory, 1993, p. 17)

1. Aurora 2 Satellite

a. Evolution of the Aurora 2 Satellite

The first Alascom satellite, Aurora 1, was launched in 1982 as RCA Satcom 5. It was subsequently acquired by Alascom. This was the first of the RCA (now GE) Advanced Satcom C-band satellites to carry solid state power amplifiers (SSPAs). In 1990 Aurora 1 customers had to be moved to GE Americom's Satcom C1 because of service interruptions that resulted from attitude control problems in Aurora 1. Aurora 1 was retired in March 1991. (Interavia Space Directory, 1992, p. 402)

Following GE Americom's 1987 aquisition of RCA Americom, GE Americom embarked on an aggressive program to replace the aging C-band satellite fleet. Between 1990 and 1992 GE Americom launched four replacement 3000-class C-band satellites, Satcom C1, C3, C4, and C5. In May 1991 Satcom C5, which was later re-designated Aurora 2, was launched to replace Satcom 5. Ownership of Satcom C5 has since been transfered to Alascom Incorporated who now operates it as Aurora 2. (Jane's Space Directory, 1993, p. 372)

Aurora 2 became operational in July 1991 to provide successor capacity for Aurora 1. Initially, Alascom owned fourteen transponders on the Aurora 2 with the balance of the capacity owned and operated by GE Americom. The majority of GE Americom's transponders were used to provide successor capacity for its digital audio transmission service (DATS). The remainder of GE Americom's transponders were used to provide telecommunications sevices to the federal government. Shortly after becoming operational, full ownership of Aurora 2 was transferred to Alascom Incorporated. (Long, 1991, p. 641)

b. Satellite Overview

Aurora 2 is a C-band communications satellite which provides 24 broadcast quality TV channels or their equivalent to CONUS, Alaska, and Hawaii. The principal uses of Aurora 2 are telephony, TV networking, and data transmissions. This linearly polarized satellite uses frequency reuse methods. (International Satellite Directory, 1992, p. 9-218)

Figure 1 is a graphic illustration of the Aurora 2 satellite. (Long, 1991, p. 641)

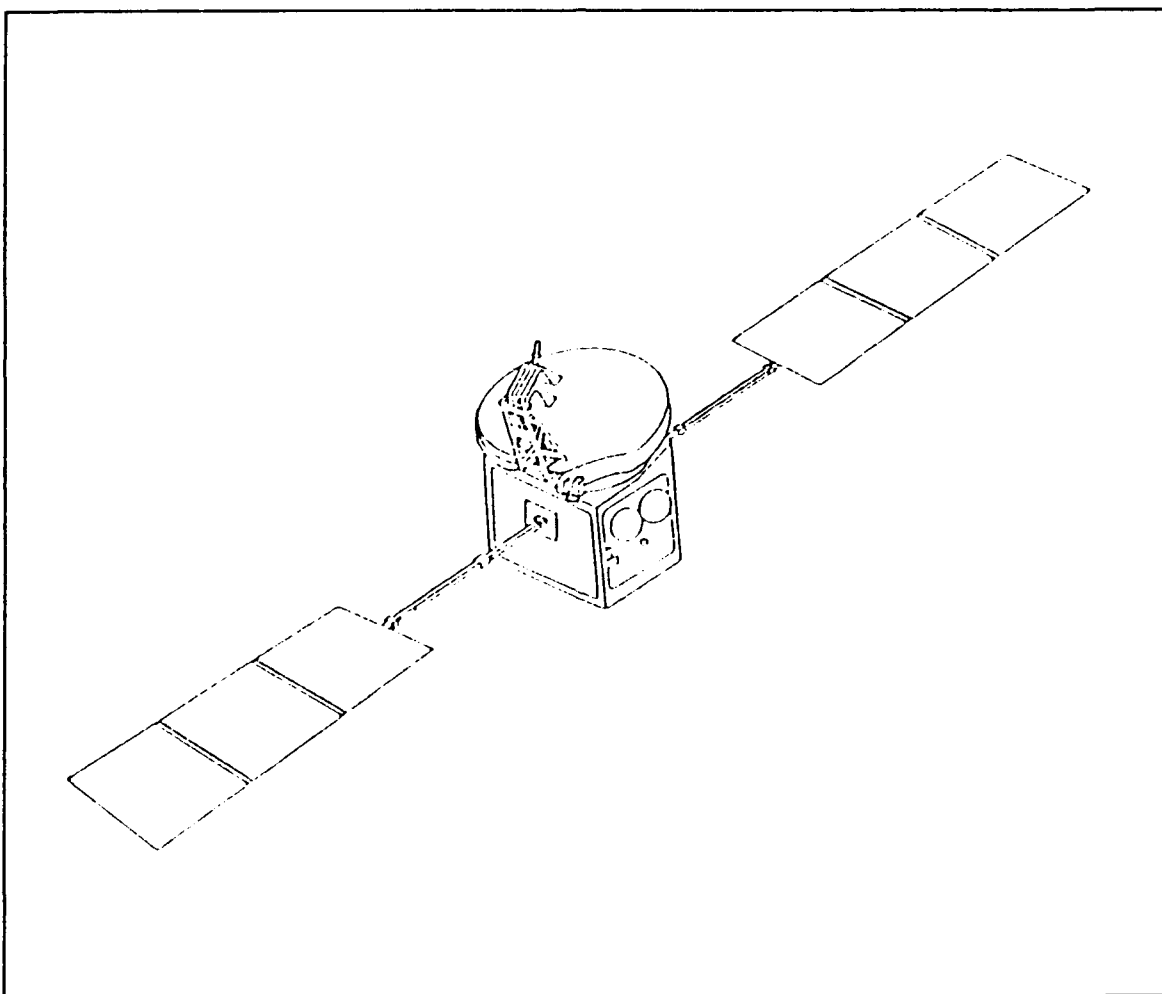


Figure 1. The Aurora 2 Satellite

c. Orbital Parameters

(1) *Orbit.* Aurora 2 is currently in geosynchronous equatorial orbit. The spacecraft is located at 139 degrees west longitude. Stationkeeping accuracy for the Aurora 2 is rated at plus or minus 0.1 degrees in latitude and longitude. (Interavia Space Directory, 1992, p. 402)

(2) *Orbital History of the Satellite.* Aurora 2 was launched as Satcom C5 from Cape Canaveral, Florida, by a Delta II on May 29, 1991. (Long, 1991, p. 641)

d. Key Design Features

(1) *Configuration.* Aurora 2 is a C-band communications satellite whose uplink frequencies range from 5.925 to 6.425 GHz and downlink frequencies range from 3.700 to 4.200 GHz. The satellite is comprised of twenty-four transponders, each with a bandwidth of 36 MHz. There are an additional eight transponders carried onboard Aurora 2 which provide backup on the order of an eight-for-six redundancy scheme. Aurora 2 uses orthogonal linear (vertical/horizontal) polarization. Twelve of the transponders operate on horizontally polarized channels while the other twelve operate on vertically polarized channels. (Long, 1987, p. 433)

(2) *Physical Characteristics.* Aurora 2 utilizes a GE Astro Space 3000 series platform. This three axis stabilized, box shaped platform is 1.63 meters long, 1.32 meters wide, and 0.99 meters high. Pitch stabilization is provided by a 6000 rpm momentum wheel while magnetic torquing provides stabilization in roll and yaw. The spacecraft has a launch mass of 1338 kg with an on orbit mass of approximately 736 kg. (Interavia Space Directory, 1991, p. 402)

The electronics units, batteries, propulsion, and attitude control system (ACS), equipment are mounted on six aluminium honeycomb structural panels. Transponders and housekeeping elements are mounted on four panels, two each on the north and south sides. Additional housekeeping equipment is mounted on the anti-Earth panel. (Interavia Space Directory, 1991, p. 402)

The Aurora 2 spacecraft carries a twin silicon solar power array which consists of three panels per side. With a total array surface area of 12.9 square meters, the electrical power system delivers 1,718 watts at the beginning of life (BOL) and 1,100 watts at the end of life (EOL). Two nickel hydrogen batteries are used to supply electrical power during periods of eclipse. (Interavia Space Directory, 1992, p. 402)

(3) *Capacity.* The Aurora 2 satellite can carry twenty-four broadcast quality television channels or their equivalent. (International Satellite Directory, 1993, p. 12-196)

(4) *Design Life.* The design life for Aurora 2 is 12 years. (Interavia Space Directory, 1992, p. 402)

e. Transmitters/Receivers

The Aurora 2 C-band satellite transmitter operates between 3.700 and 4.200 GHz. The twenty-four transponders carried on Aurora 2 use solid state power amplifiers (SSPAs) to generate their output power. These solid state power amplifiers generate 10 watts of output power and have bandwidths of 36 MHz. (The World Satellite Directory, 1993, p. 18)

The minimum beam edge EIRPs for the different operating regions of Aurora 2 are: 34 dBW (CONUS), 34dBW (Alaska), and 26 dBW (Hawaii). (Long, 1987, p. 433)

The GE Americom C-band Satcom satellite receivers operate on signals between 5.9250 and 6.425 GHz. (International Satellite Directory, 1993, pp. 12-196 - 12-198)

f. Antenna Farm

The Aurora 2 C-band communications satellite antenna package is comprised of two antennas. One of the communications antennas is used for horizontally polarized signals, during both transmit and receive operation, and the other antenna is used for vertically polarized signals. Each of the two communications antennas carried on-board Aurora 2 has separate feed horns for the CONUS, Alaska, and Hawaii coverage regions. The antenna pointing accuracy is less than plus or minus 0.1 degrees. (Long, 1991, p. 638)

In addition to the C-band communications antennas there are also antennas which propagate the telemetry beacons and the command beacon. There are two telemetry beacons; one operates at 3.7005 MHz on horizontally polarized signals and the other operates at 4.1995 MHz on vertically polarized signals. The command beacon operates at 6.4235 MHz and is horizontally polarized. (International Satellite Directory, 1993, p. 12-196)

Figure 2 depicts the footprint of the Aurora 2 satellite in its current operating location. (International Satellite Directory, 1992, p. 9-219)

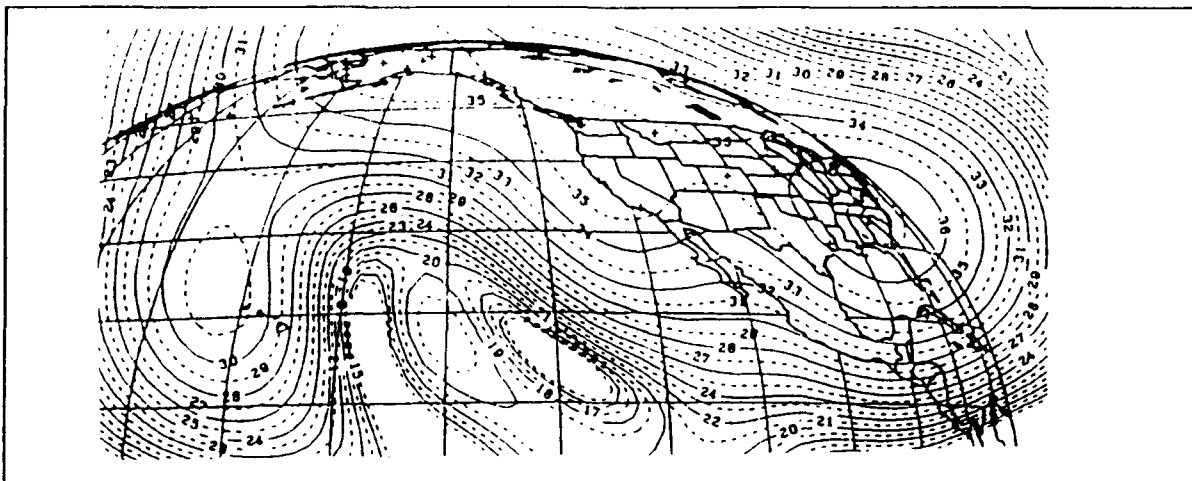


Figure 2. The Footprint of the Aurora 2 Satellite

g. Performance Characteristics

(1) *Satellite Services.* The Aurora 2 satellite provides FSS service to Alaska, CONUS, and Hawaii. A variety of services are available from Alascom. Occasional use transponder services available include partial transponder capacity and subcarrier channels. Full-band broadcast 1.5 Mbps video-conferencing and program audio facilities for dedicated and occasional use are also available. Aurora 2 provides dedicated and dial-up data services and dedicated voice services. Finally, marine VHF and single-sideband communications services are also available. Programming carried by this satellite includes Digital Audio Transmission Service (DATS) radio and Alaska TV plus other traffic in TDMA and SCPC formats. (World Satellite Directory, 1993, p. 17)

(2) *Performance Parameters.* Table 1 lists the performance parameters of Aurora 2. (The World Satellite Directory, 1993, p. 18)

TABLE 1. AURORA 2 PERFORMANCE PARAMETERS

Satellite Name	Aurora II
Longitude	139° W.L.
Launch Vehicle	Delta II
Manufacturer and Model	GE Astrospace
Date of Launch	May 1991
Frequency Band(s) Transmit Receive	C band 3.700-4.200 GHz 5.925-6.425 GHz
Transponders Number Bandwidth Polarization	24 36 MHz Linear (frequency re-used by horizontal and vertical cross-polarization)
Power Output SSPA	10 watt
Antenna Coverage (Beam Edge EIRP) Alaska Conus and Alaska Puerto Rico Virgin Islands Hawaii	39 dBW 36 dBW 28 dBW 27 dBW 29 dBW
Primary Power Watts EOL	1,100
Stabilization Type	3-axis
Mass (Kg. in Orbit)	736
Design Life (Years)	12

B. ALPHA LYRACOM PAN AMERICAN SATELLITE CORPORATION

The Pan American Satellite Corporation was established in 1984. Its original, primary operational goal was to provide western hemisphere satellite capacity for the Caribbean Region, Latin America, and links between the two with the United States. Later, it built upon this vision and broadened its plans to serve all of Western Europe. This corporation was one of several that emerged in the early 1980s which attempted to compete against Intelsat in response to changing U.S. telecommunications policies towards Intelsat's monopoly in international communications. (Stanyard, 1987, p. 256)

In 1985 PanAmSat was granted an FCC lisenace and acquired the partially-completed ASC-3 satellite from RCA Astro Electronics. This satellite was originally intended as a ground spare for the American Satellite Corporation's ASC System, however the company elected not to exercise its option to purchase the spacecraft. The ASC-3 was renamed PAS-1 shortly after its acquisition by PanAmSat and was launched in 1988. With PAS-1, PanAmSat became the world's first operator of a privately-owned transoceanic international satellite system. (PanAmSat Service Overview, 1991, pp. 1-2)

The success of the PAS-1 satellite has prompted PanAmSat to build upon this initial capability and pursue a global satellite system. In 1991 PanAmSat negotiated a deal to purchase three additional satellites (PAS-2/PAS-3/PAS-4). These satellites are of the HS-601 model design, unlike the PAS-1 which is a GE 3000 model satellite. This next generation of PAS satellites is slated to be launched into geosynchronous orbit between June 1994 and June 1995. The PAS-2 is scheduled to provide Pacific Ocean Region coverage, the PAS-3 will provide Atlantic Ocean Region coverage, and the PAS-4 is planned for Indian Ocean Region coverage. (Overview of PanAmSat's Global Satellite System, 1992, pp. 1-2)

1. PAS 1 Satellite

a. Evolution of the PAS 1 Satellite

The PanAmSat-1 (PAS-1) was purchased from RCA Astro Electronics in 1985 when the American Satellite Corporation failed to exercise its option to acquire the spacecraft. The PAS-1 was successfully launched in June of 1988. It currently provides coverage of Europe, North America, Latin America, and the Caribbean Region. Through the use of PAS-1, PanAmSat provides video, data, facsimile, voice, electronic mail, and a host of other vital telecommunications services in a single all-digital network. Additionally, PAS-1's power promotes the use of low-cost VSAT terminals located directly on customer premises. (Alpha Lyracom Data Services, 1992, pp. 1-2)

b. Satellite Overview

The PAS-1 is a hybrid, three-axis stabilized, dual band (C-band and Ku-band) communications satellites with frequency reuse of C-band. Each satellite has twenty-four operational transponders. At C-band (6/4 GHz) there are twelve narrowband 36 MHz transponders which utilize 8.5 watt solid state power amplifiers. At Ku-band (14/11 GHz) there are six wideband 72 MHz transponders which use 16 watt TWTAs for power amplification. PAS-1's transponders are leased to communications companies, television networks, foreign governments, and other businesses with large telecommunications requirements. (Long, 1991, p. 447)

The PAS-1 satellite is equipped with three parabolic dish type antennas. A pair of offset-fed reflectors are used at C-band whereas a single reflector is employed at Ku-band. The primary function of this satellite at C-band is to provide telecommunications services to customers in Latin America and the Caribbean through the use of four spot beams. At Ku-band three of the Ku-band transponders are connected to a Ku-band spot beam which is centered over Western Europe. The other three transponders are linked to a Ku-band spot beam

which is centered over the contiguous United States. All six transponders can be accessed from either Europe or the United States via a common uplink. Figure 3 is a graphical depiction of the PAS-1 satellite. (Long, 1991, pp. 447-448)

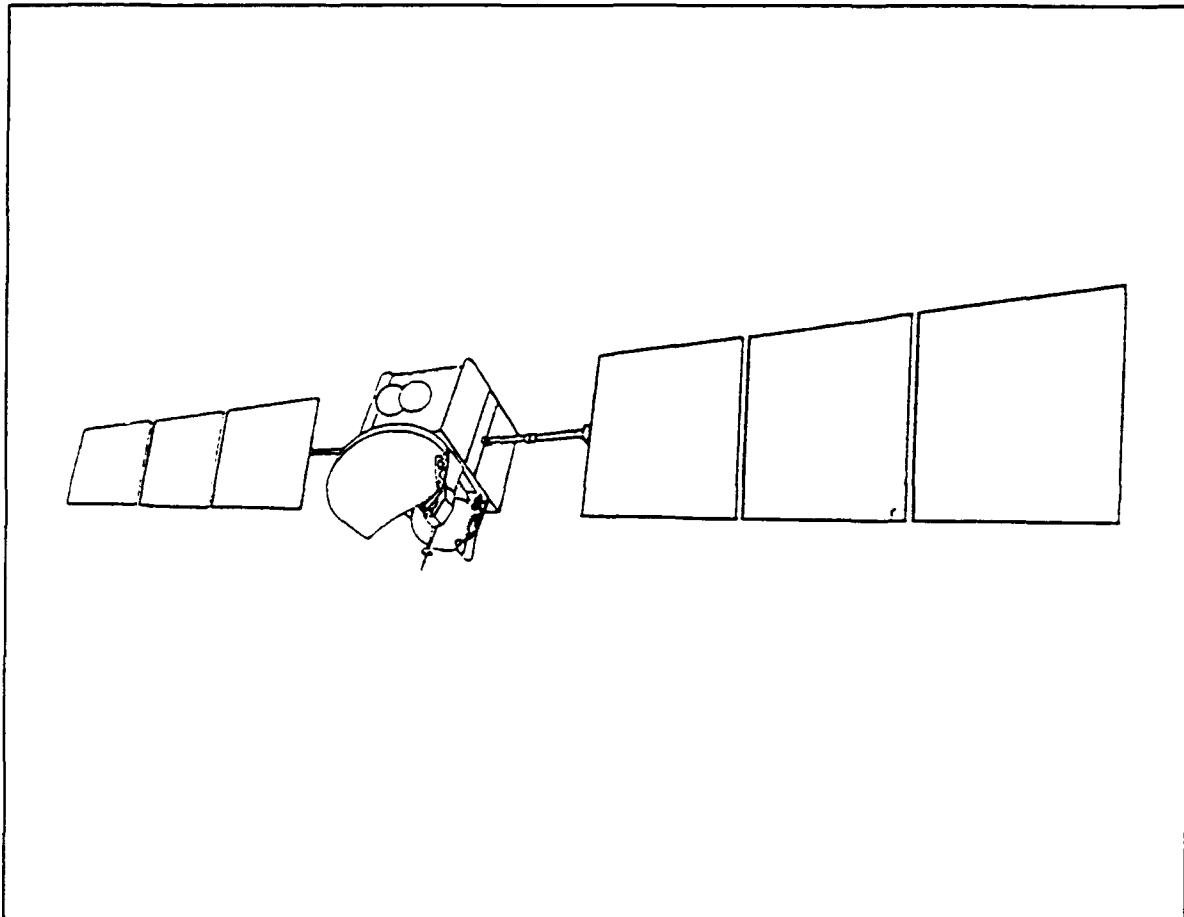


Figure 3. The PAS-1 Satellite

c. Orbital Parameters

(1) *Orbit.* The PAS-1 satellite is in a geosynchronous equatorial orbit. Stationkeeping for the satellite is rated at plus or minus 0.05 degrees in latitude and longitude. PAS-1 is located at position 45 degrees west longitude. (PAS-1 Technical Overview, 1992, p. 1)

(2) *Orbital History of the PAS-1.* PAS-1 was launched on June 28, 1988 by Ariane 401 from Kourou, French Guiana. (Jane's Space Directory, 1993, p. 368)

d. Key Design Features

(1) *Configuration.* The PAS-1 satellite has a GE-3000 satellite bus. A total of twenty-four operational transponders which provide 1500 MHz of usable bandwidth are equipped on each satellite. Of that total, twelve transponders are narrow C-band and six are wide C-band transponders (4 GHz). These C-band transponders utilize 8.5 watt SSPAs and 16 watt TWTAs, respectively. Additionally, at C-band frequency reuse is achieved through the use of orthogonal linear polarization. At Ku-band this satellite features six wideband (11 GHz) transponders which utilize 16 watt TWTAs. Frequency reuse is achieved at Ku-band also through the use of orthogonal linear polarization. The twelve narrow C-band transponders are channelized at 36 MHz. All other transponders are channelized at 72 MHz. (Interavia, 1992, p. 369)

(2) *Physical Characteristics.* The PAS-1 satellite is of the GE Astro 3000 model design. It is a three-axis stabilized box-shaped platform with dimensions of 1.63 meters x 1.32 meters x 1.9 meters. Additionally, it has a 15.8 meter solar array span and is 1.9 meters in height. The satellite employs three parabolic antenna reflectors. The satellite mass is 1220 kilograms at launch and 708 kilograms on-station at the beginning of life. Three-axis stabilization is applied via momentum wheels and a hydrazine reaction

control system. The satellite is also equipped with twin silicon solar arrays of three panels each as well as nickel hydrogen batteries which provide electric power to the satellite on the order of 1400 watts at the beginning of life and 1200 watts at the end of life. (Interavia, 1992, p. 403)

(3) *Capacity.* The PAS-1 has the capacity to accomodate one color TV signal or 3600 two-way voice channels per 36 MHz of bandwidth. This capacity is doubled for a 72 MHz transponder channel. In the digital mode 60 Mb/s is the maximum transmission rate for digital information at 36 MHz bandwidth and 120 Mb/s is the maximum transmission rate at 72 MHz bandwidth. (Martin, 1986, p. 140)

(4) *Design Life.* The original design life for the PAS-1 satellite was eleven years (Jane's Space Directory, 1993, p. 368). Conservation of fuel on the satellite has extended the PAS-1's life expectancy to 13.25 years from its launch date. (PAS-1 Technical Overview, 1992, p. 1)

e. Transmitters/Receivers

(1) *C-Band Operation.* At C-band (6/4 GHz) there are six 72 MHz wideband transponders and twelve 36 MHz narrowband transponders. For the narrowband transponders there are seven power amplifiers (SSPAs) for each of two groups of six transponders which provides 7-for-6 redundancy within each group. For wideband transponders there are four TWTAs for each of two groups of three transponders which provides for 4-for-3 redundancy in each group. Redundant communications receivers are provided on a 4-for-2 basis. The 72 MHz transponders utilize 16 watt TWTAs while the 36 MHz transponders are powered by 8.5 watt SSPAs. Frequency reuse is accomplished through horizontal and vertical cross-polarization. The uplink frequency ranges from 5.925 to 6.425 GHz and the downlink frequency ranges from 3.702 to 4.178 GHz. PAS-1's C-band coverage is primarily used for communications between the

United States and Latin America. (PAS-1 Technical Overview, 1992, p. 1)

(2) *Ku-Band Operation.* At Ku-band (14/11 GHz) there are six 72 MHz transponders on each satellite which are powered by 16 watt TWTAs. Ku-band transponders are horizontally polarized on the downlink and vertically polarized on the uplink. The uplink frequency ranges from 14.00 to 14.50 GHz and the downlink frequency ranges from 11.464 to 11.936 GHz. Ku-band coverage is mainly used for communication links between the United States and Europe. Combined C-band and Ku-band coverage are used for communication links between the United States, the Caribbean Region, Latin America, and Europe as required. (Falworth, 1988, pp. 1-3)

f. Antenna Farm

The antenna subsystem of the PAS-1 satellite is comprised of three separate antennas for the communications payload. All antennas are fixed on the earth-facing side of the spacecraft's body. At C-band there are two parabolic antennas which are approximately four feet by five feet sharing the same physical aperture with an embedded grid for one of two orthogonal linear polarizations. A high degree of polarization purity is achieved at C-band through the utilization of these grids embedded in each of the reflectors which are transparent to the opposite sense of polarity. (Falworth, 1988, pp. 1-3)

At C-band, transponder outputs are fed to four output multiplexers and the power divider network which chooses the power requirements among PAS-1's feed horn antenna array to achieve the required coverage. Six feed horns are employed for each polarization and are arranged geometrically on the spacecraft's Earth-oriented structure. They are phased to provide the correct antenna patterns for eastern or western zone coverage which depends on the spacecraft's orbital position. Each reflector antenna is composed of a thermally-stable

sandwich structure of a 0.006 cm thick kevlar epoxy honeycomb core bonded to kevlar cloth covers. (Falworth, 1988, pp. 1-3)

Spot beam coverage at C-band consists of two uplink and four downlink beams. The downlink coverages include a central beam, a southern beam, a Latin beam, and a northern beam. The central beam is focused on Peru, but also covers Bolivia, Ecuador, and important business hubs in Southern Brazil. The southern beam is centered on Chile and Argentina, while also providing coverage for Uruguay and Paraguay. The Latin beam is a broad area coverage beam which extends from Florida to the southern tip of South America. The northern beam is centered on the Colombia/Venezuela border. This beam provides coverage of Mexico, Central America, and the Caribbean. (Morgan, 1990, pp. 17-18)

At Ku-band there is one fixed parabolic antenna which utilizes horizontal polarization on the downlink and vertical polarization on the uplink. In Ku-band operation a power divider combines two sets of output multiplexers to split the power into a four-horn feed array which provides correct antenna patterns for continental United States coverage. The antenna reflector has the same physical construction as the C-band reflector. (Falworth, 1988, pp. 1-2)

Spot beam coverage at Ku-band consists of three transponders that serve Europe (the Europe beam); and three transponders which serve North America (the CONUS beam). Either beam can be accessed from both sides of the Atlantic via a common uplink beam. (Morgan, 1990, pp. 17-18)

Figure 4 provides a consolidated representation of PAS-1's regional and spot beam coverage.

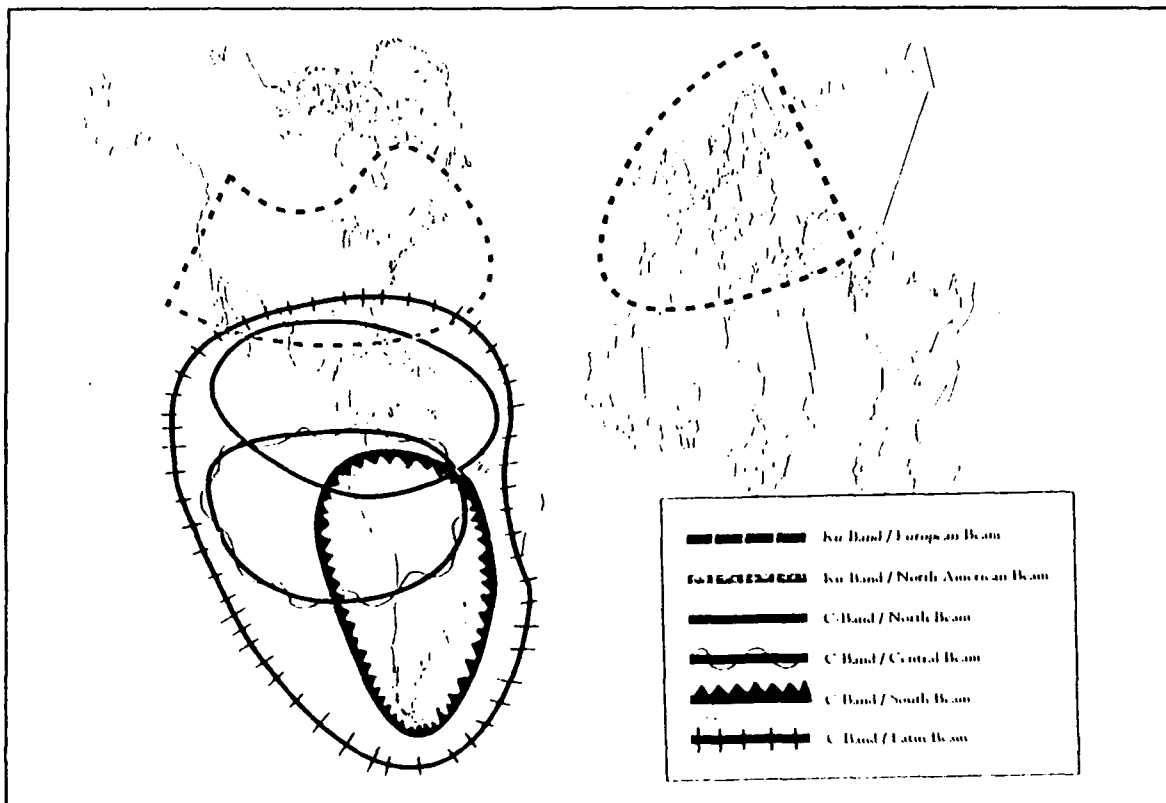


Figure 4. PAS-1 Regional and Spot Beam Coverage

g. Performance Characteristics

(1) *Satellite Services.* The PAS-1 was designed to provide high quality satellite communications including voice, data, telex, facsimile, broadcast, and television signals to very small domestic and international terminals. Signals are transmitted at both C-band and Ku-band from the PAS-1. Additionally, enhanced services such as video teleconferencing, private voice, and data transfers are also key service features of the satellite. (Falworth, 1988, p. 2)

The PAS-1 has the capability to accomodate a variety of different network architectures, including data broadcasting networks, point-to-point networks, and hub-based VSAT networks. A point-to-point network is one in which every facility has unlimited access to every other facility. These networks can be employed through a mesh architecture with direct satellite links between all points, a star design in which all points communicate through a central point, or a combination of the two. Hub-based VSAT networks use a centralized hub facility to communicate with several very small aperture terminals. Individual and shared hub systems can readily utilize PAS-1's high-powered beams. Additionally, these services can be established for the first time between North America and Europe via PAS-1's Ku-band common uplink beam. (Alpha Lyracom Data Services, 1992, pp. 1-2)

(2) *Performance Parameters.* The PAS-1's reliability rating for communications services is 99.99 percent (PAS-1 Technical Overview, 1992, p. 1). EIRP levels for regional and spot beam coverage are as follows:

South beam coverage ranges from 18.5 dBW to 38.5 dBW.

Europe beam coverage ranges from 37.5 dBW to 47.5 dBW.

CONUS beam coverage ranges from 35.5 dBW to 45.5 dBW.

Latin beam coverage ranges from 19.5 dBW to 37.5 dBW.

North beam coverage ranges from 22.0 dBW to 40.0 dBW.

Central beam coverage ranges from 20.0 dBW to 41.0 dBW.

Figures 5, 6, 7, 8, 9, and 10 depict EIRP signal performance parameters graphically for the various regional and spot beams of the PAS-1 satellite. (Long, 1991, pp. 453-455)

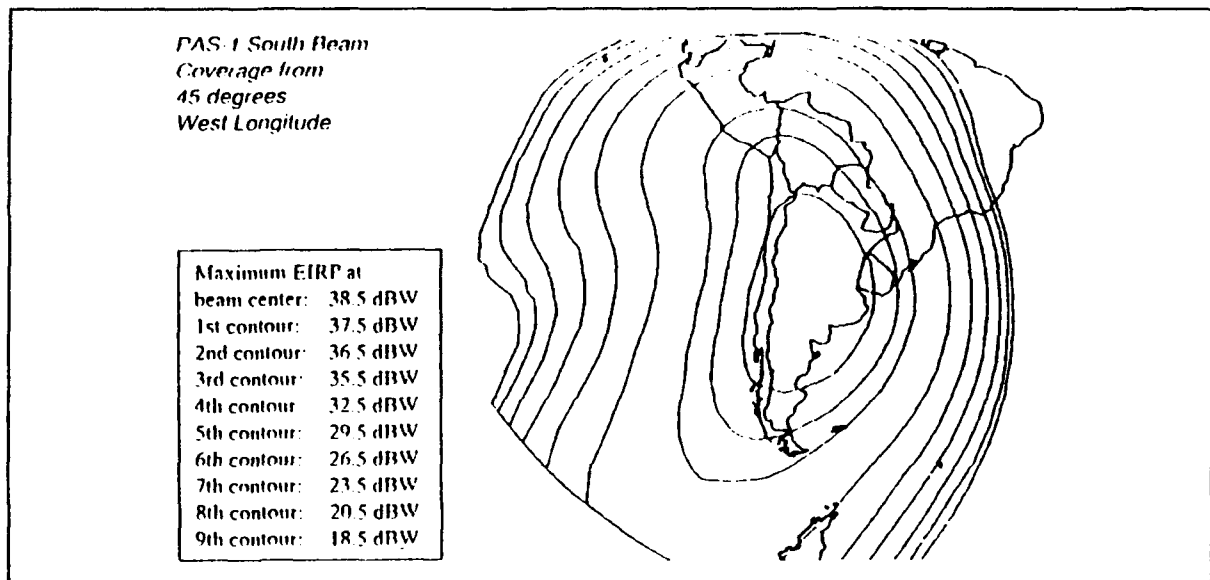


Figure 5. PAS-1 South Beam Coverage

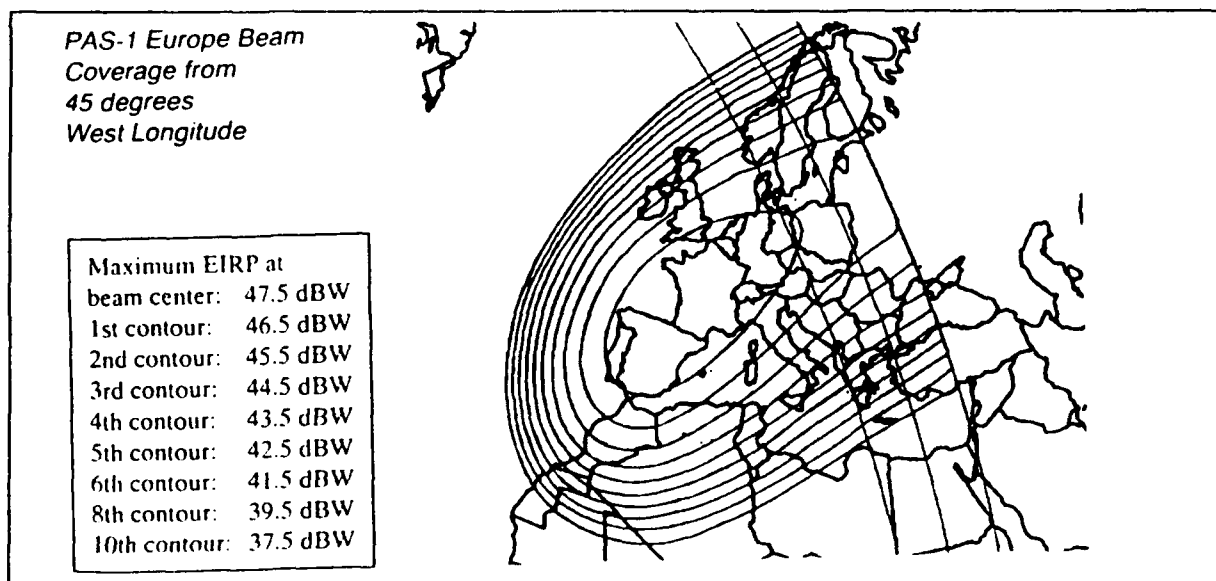


Figure 6. PAS-1 Europe Beam Coverage

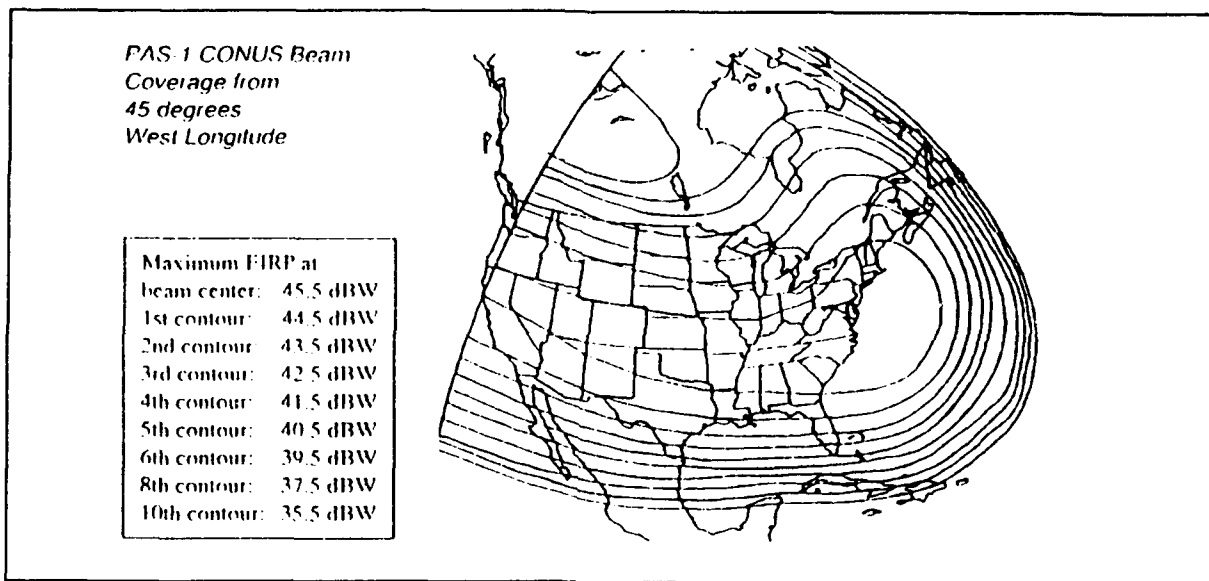


Figure 7. PAS-1 CONUS Beam Coverage

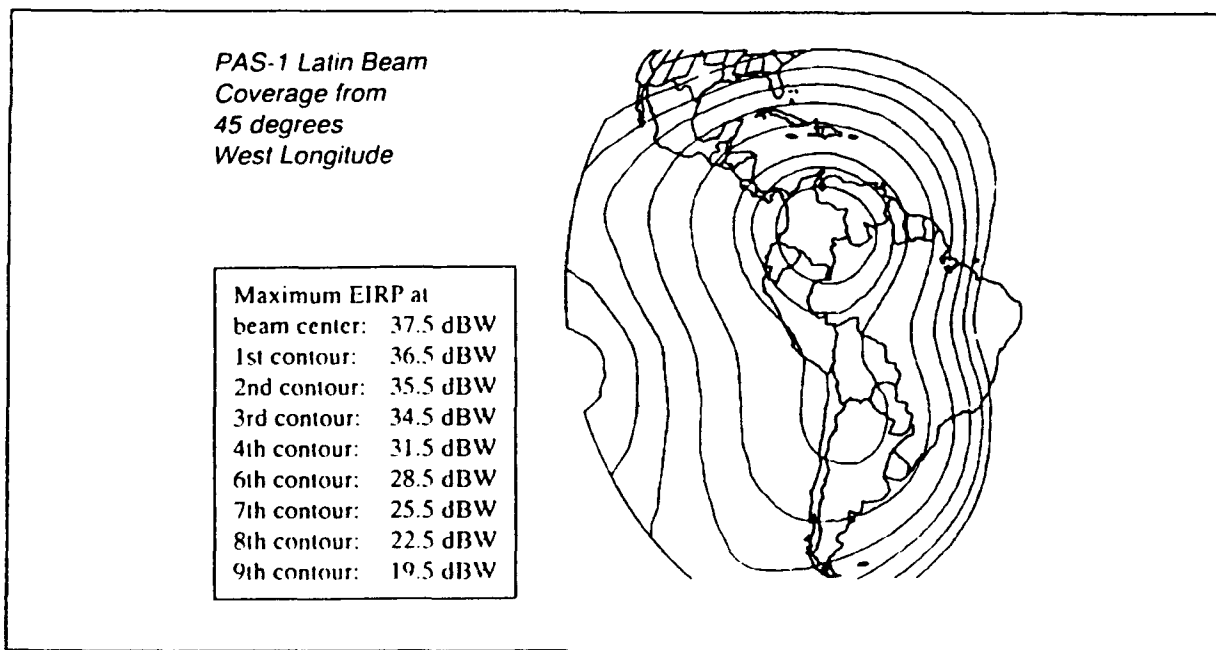


Figure 8. PAS-1 Latin Beam Coverage

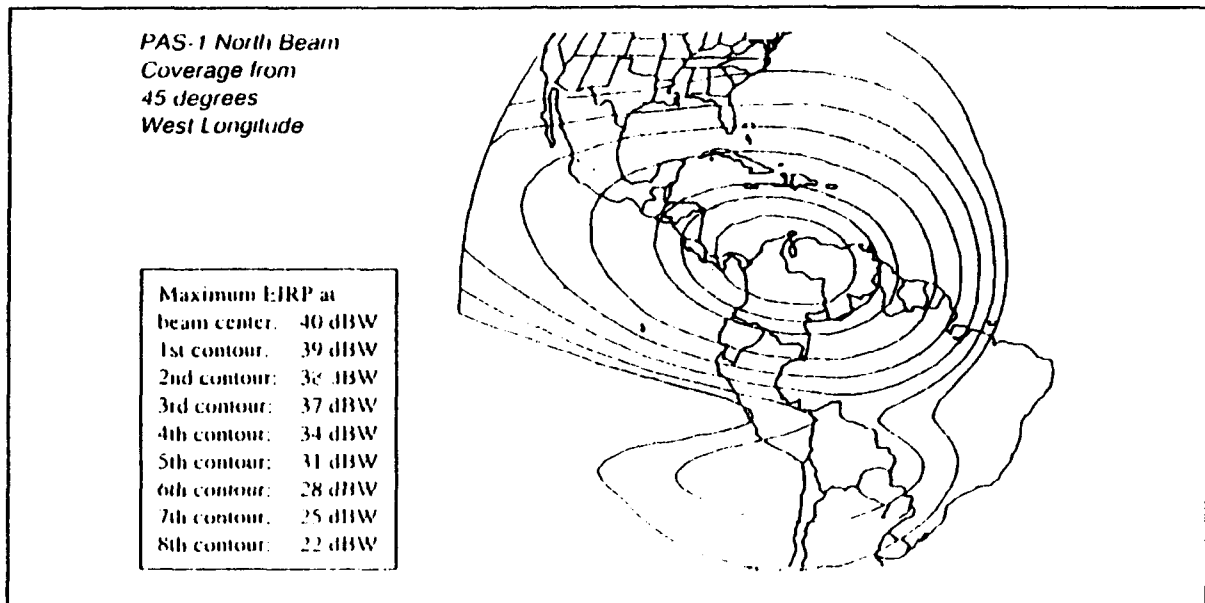


Figure 9. PAS-1 North Beam Coverage

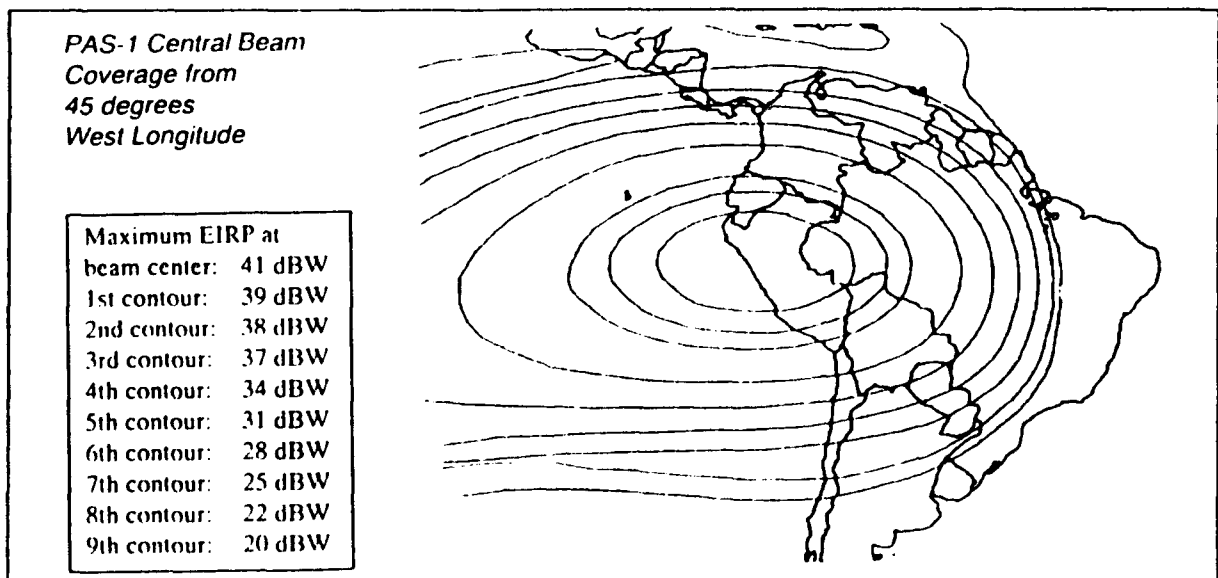


Figure 10. PAS-1 Cental Beam Coverage

2. Next Generation PAS Series (PAS 2/3/4)

a. Evolution of the PAS Series

In 1990 the Alpha Lyracom Pan American Satellite Corporation filed an application with the FCC to construct, launch, and operate an additional three PAS series satellites. These satellites were designed to augment the capabilities of the PAS-1 and expand the company's network into a global satellite system. This proposal was subsequently approved by the FCC, and the Hughes Corporation was contracted to build three HS-601 satellites to serve as the buses for the PAS-2, PAS-3, and PAS-4. Firm launch windows were contracted with Arianespace in 1992 with all three satellites scheduled for deployment between the beginning of 1994 and the summer of 1995. (Overview of PanAmSat's Global Satellite System, 1992, p. 1)

The future PanAmSat (PAS) system can best be described as a satellite network comprised of a series of customized, high-powered satellites strategically positioned in geosynchronous orbit for complete global coverage. PAS-2 was the first satellite launched. It was launched in June of 1994. Additionally, PAS-2 is designed to serve the Asia-Pacific Region in an area that stretches from Bangladesh to the west coast of the United States and from Russia to New Zealand. In addition to this regional coverage, the PAS-2 will also incorporate spot beam coverage over China, New Zealand, Australia, and North-East Asia. The PAS-3 will essentially be the follow-on to the PAS-1. It will be launched sometime between December 1994 and February 1995 and will cover the Atlantic Ocean Region for services within and between the Americas and Europe as well as Africa. The PAS-4, the final satellite of the system, is currently slated to be launched between March 1995 and June 1995. It will serve the Indian Ocean Region with coverage from Europe to Japan, including Central and Eastern Europe, Africa, Russia, the Middle East,

South Asia, South-East Asia, China, and Australia. (PanAmSat Global Satellite System, 1992, p. 4)

b. Satellite Overview

The PAS-2, PAS-3, and PAS-4 satellites are hybrid, three-axis stabilized, dual band (C-band and Ku-band), cross-strappable communications satellites with full frequency reuse at both C-band and Ku-band. Each satellite has thirty-two operational transponders channelized at 54 MHz bandwidth. These satellites will utilize the HS-601 satellite bus which was chosen for its exceptional operating power, permitting the achievement of very high EIRP on the ground. Additionally, the HS-601 employs a state-of-the-art beam-shaping technology which optimizes the distribution of power within each downlink beam. (PanAmSat Global Satellite System, 1992, pp. 1-4)

The PAS satellites are all equipped with five square antennas. Two communications antennas operate at C-band; two communications antennas operate at Ku-band; and one antenna provides telemetry, tracking, and control of the satellite. The primary functions of these satellites is to provide business TV, data transmission services, and voice services to Latin America and the United States at C-band and to Europe, Africa, China, and Asia at Ku-band (Long, 1991, p. 437). Figure 11 is a graphic depiction of the next generation PAS series satellite. (PanAmSat Global Satellite System, 1992, pp. 2-4)

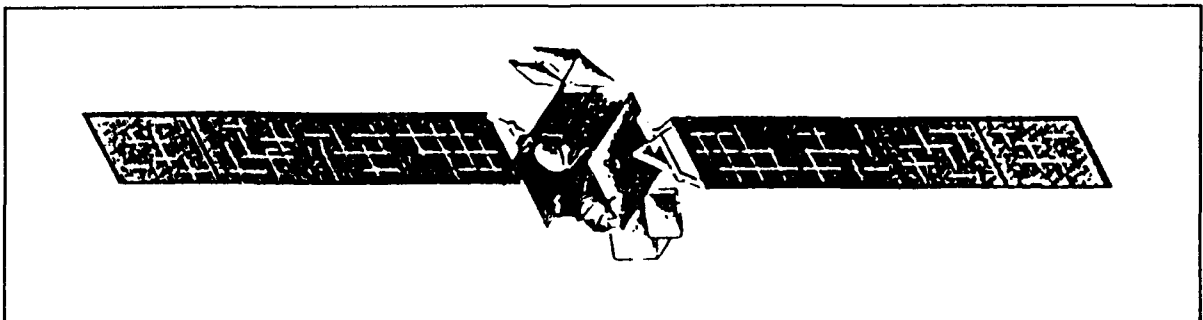


Figure 11. PAS Series Satellite

c. Orbital Parameters

(1) *Orbit.* The PAS series of satellites will all be placed in geosynchronous equatorial orbits between June 1994 and June 1995. Stationkeeping for each satellite is projected to be plus or minus 0.05 degrees in latitude and longitude. PAS-2 will be located at position 192 degrees west longitude. PAS-3 will be located at position 43 degrees west longitude. PAS-4 will be located at position 72 degrees east longitude. (Overview of PanAmSat's Global Satellite System, 1992, p. 1)

(2) *Orbital History of the Series.* PAS-2 was launched in June 1994. The PAS-3 is scheduled to be launched between December 1994 and February 1995. The PAS-4 is slated for launch between March 1995 and June 1995. All PAS satellites are scheduled to be launched via Ariane launch vehicles from Kourou, French Guiana. (Overview of PanAmSat Global Satellite System, 1992, p. 1)

d. Key Design Features

(1) *Configuration.* The next generation PAS series satellites employs the HS-601 satellite bus design. A total of thirty-two operational transponders will be equipped on each satellite. Of that total sixteen transponders will be channelized at 54 MHz C-band and sixteen will be channelized at 54 MHz Ku-band. These C-band transponders utilize 34 watt SSPAs. Additionally, at C-band full frequency reuse is achieved through the use of linear polarization. At Ku-band this satellite features sixteen wideband transponders which utilize 63 watt TWTAs. Full frequency reuse is achieved at Ku-band also through the use of linear polarization. All transponders make use of linearizers which permit lower backoff within the transponder during multi-carrier operation. This translates into a higher achievable throughput on each transponder. (PanAmSat Global Satellite System, 1992, pp. 3-4)

(2) *Physical Characteristics.* The PAS series of communications satellites are of the HS 601 model design. It is a three-axis stabilized box-shaped platform with dimensions of 2.70 meters x 3.60 meters x 3.1 meters. Additionally, when the solar arrays are deployed the satellite has a span width of 26.5 meters. The satellite employs five square antenna reflectors. The satellite mass is 2968 kilograms at launch. Three-axis stabilization is applied via gimballed momentum wheels. The satellite is also equipped with twin silicon solar arrays of three panels each as well as nickel hydrogen batteries which provide electric power to the satellite. (Morgan, 1990, p. 29)

(3) *Capacity.* The PAS-2, PAS-3, and PAS-4 satellites will have four times the capacity as the PAS-1. Each of these satellites will be able to accomodate four color TV signals or 14,400 two-way voice channels per 54 MHz of bandwidth. In the digital mode 240 Mb/s is the maximum transmission rate for digital information at 54 MHz bandwidth. (Overview of PanAmSat Global Satellite System, 1992, pp. 1-2)

(4) *Design Life.* The design life for the next generation PanAmSat satellites is fifteen years. (Global Satellite System Fact Sheet, 1992, p.1)

e. Transmitters/Receivers

(1) *C-Band Operation.* At C-band (6/4 GHz) there are sixteen 54 MHz wideband transponders. For these wideband transponders there are ten 34 watt SSPAs for each set of eight transponders which provides for 10-for-8 redundancy in each group. Redundant communications receivers are provided on a 4-for-2 basis. Frequency reuse is accomplished through horizontal and vertical cross-polarization. The uplink frequency ranges from 5.975 to 6.385 GHz and the downlink frequency ranges from 3.720 to 4.168 GHz. Two communications antennas operate at C-band. At C-band the primary functions of these

satellites is to provide business TV, data transmission services, and voice services to Latin America and the United States. (PanAmSat Global Satellite System, 1992, pp. 1-4)

(2) *Ku-Band Operation.* At Ku-band (14/12 GHz) there are sixteen 54 MHz transponders on each satellite which are powered by 63 watt TWTAs. Ku-band transponders are horizontally polarized on the downlink and vertically polarized on the uplink. The uplink frequency ranges from 14.050 to 14.440 GHz and the downlink frequency ranges from 11.750 to 12.700 GHz. Ku-band coverage is mainly used to provide business TV, data transmission services, and voice services to Europe, Africa, China, and Asia (Long, 1991, p. 437). Additionally, all Ku-band and C-band transponders employ advanced linearizers in order to diminish the disruptive interference between the various carriers when sharing the same transponder. (PanAmSat Global Satellite System, 1992, pp. 1-4)

f. Antenna Farm

The antenna subsystem of the next generation PAS satellites is comprised of five separate antennas; two square-shaped antennas provide communications services at C-band; two operate at Ku-band; and there is one antenna which is utilized for telemetry, tracking, and control of the satellite. Each satellite will have three uplink beams and five downlink beams at both C-band and Ku-band (PanAmSat Global Satellite System, 1992, p. 3). The beam shaping technology employed by these satellites allows the satellite's footprints to be more precise than the PAS-1 satellite's footprints. This design ensures that power is not wasted over unpopulated areas such as the ocean by allowing the transponder power to be tailored to a specific area with supplemental "hot spot" coverage over strategic population centers. (Overview of PanAmSat's Global Satellite System, 1992, pp. 2-5)

The PAS-2 is specifically designed to serve the Asia-Pacific Region in an area that stretches from Bangladesh to the west coast of the United States and from Russia to New Zealand. In addition to this regional coverage, the PAS-2 will also incorporate spot beam coverage over China, New Zealand, Australia, and North-East Asia. PAS-3 will cover the Atlantic Ocean Region for services within and between the Americas and Europe as well as Africa. The PAS-4 will serve the Indian Ocean Region with coverage from Europe to Japan, including Central and Eastern Europe, Africa, Russia, the Middle East, South Asia, South-East Asia, China, and Australia. (PanAmSat Global Satellite System, 1992, p. 4)

Figures 12, 13, and 14 depict the coverage areas of the PAS-2, PAS-3, and PAS-4 respectively.

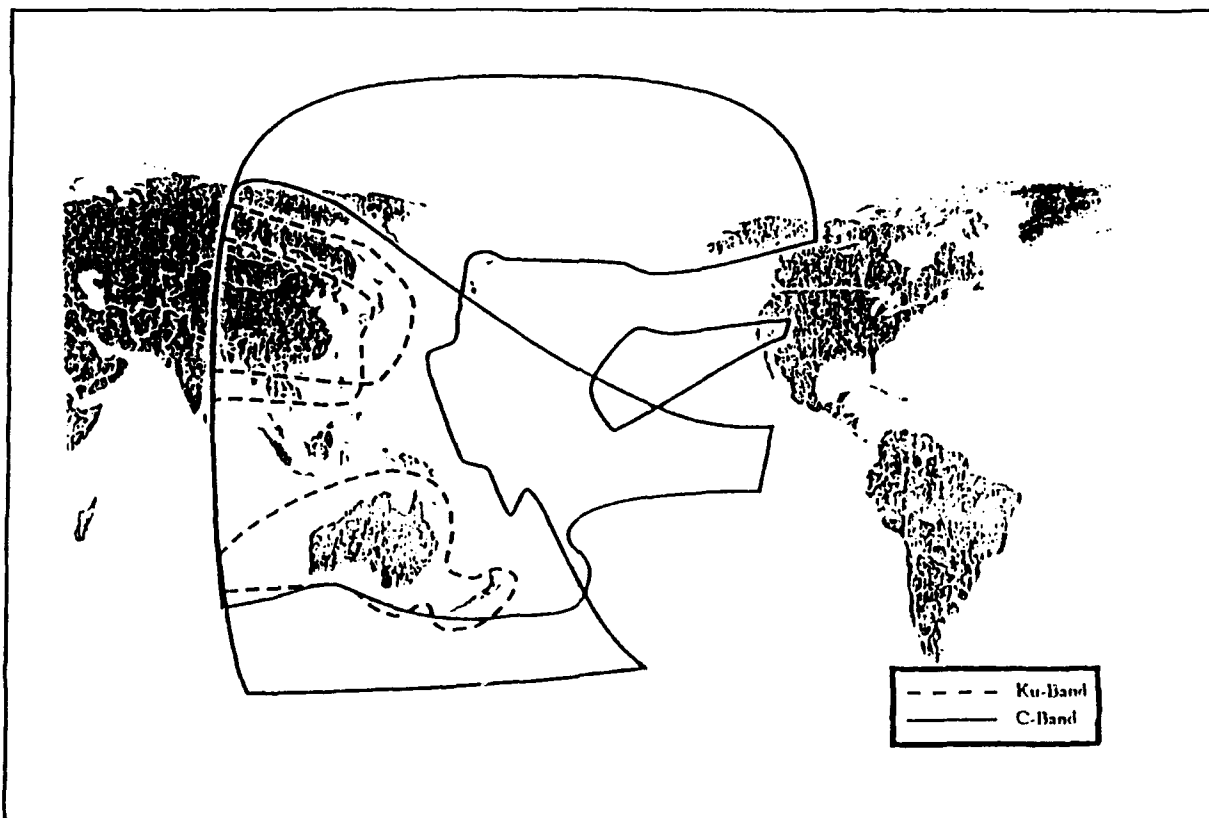


Figure 12. PAS-2 Footprint

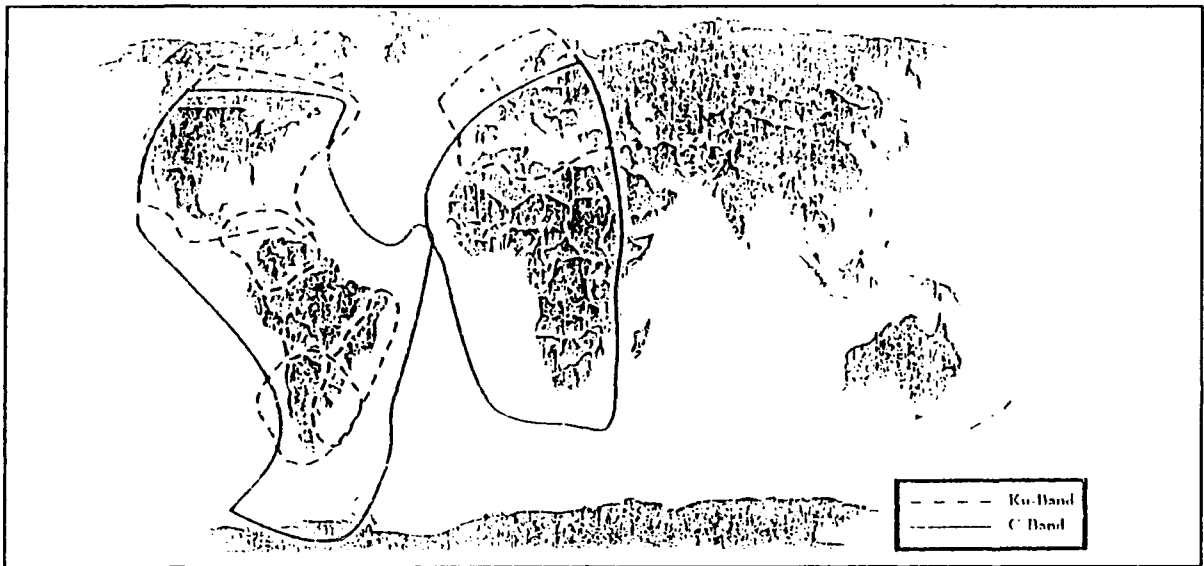


Figure 13. PAS-3 Footprint

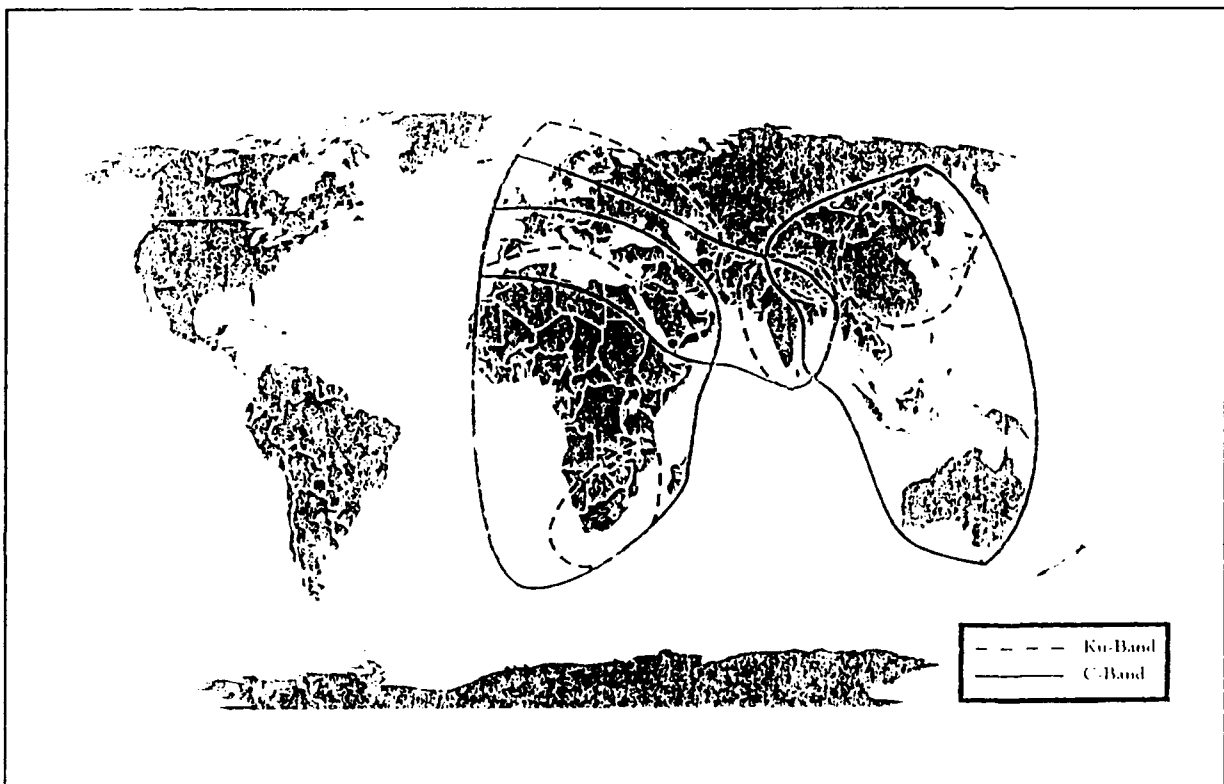


Figure 14. PAS-4 Footprint

g. Performance Characteristics

(1) *Satellite Services.* The PAS satellites will accomodate a variety of communications services including single channel per carrier (SCPC), VSAT, one-way and two-way voice services, and a host of other business features. Digital voice circuits ranging from a standard voice only service at 32 kb/s to digital data circuits at 64 kb/s highlight the digital features of the next generation PAS satellites (PanAmSat's Global Satellite System, 1992, p. 10). The PAS series satellites will be configured for maximum power and sensitivity in order to accomodate small on-premise earth stations. (Overview of PanAmSat's Global Satellite System, 1992, p. 4)

Broadcast services will be available on the next generation PAS satellites on a full-time, part-time, or occasional basis for applications such as satellite news-gathering, broadcast television, special events, and program distribution. In addition to two-way data networks, a full spectrum of bandwidth options for one-way data broadcasting will be facilitated by the PAS satellites. One-way data broadcasting is used for weather information services, sports information, stock and financial quotations, and domestic and international news wire services. (PanAmSat Global Satellite System, 1992, pp. 6-11)

(2) *Performance Parameters.* Tables 2 and 3 provide a comprehensive listing of performance parameters of the PAS-3 and PAS-4 satellites. (Long, 1991, pp. 440, 673)

TABLE 2. PAS-3 PERFORMANCE PARAMETERS

PAS-3 Beams	Gain	EIRP G/T
C-Band Transmit North Spot	32.3 dBi	40.7 dBW
C-Band Transmit South Spot	33.8 dBi	42.2 dBW
C-Band Transmit Latin Beam	27.5 dBi	37.5 dBW
C-Band Receive Spot Beam	31.6 dBi	1.8 dB/K
C-Band Receive Latin Beam	27.2 dBi	-1.6 dB/K
Ku-Band Transmit CONUS Beam	35.1 dBi	50.1 dBW
Ku-Band Transmit Europe Beam	34.9 dBi	49.9 dBW
Ku-Band Receive Atlantic Beam	33.4 dBi	2.4 dB/K
Ku-Band Receive CONUS Beam	37.4 dBi	6.4 dB/K
Ku-Band Receive Europe Beam	35.9 dBi	4.9 dB/K
Ku-Band Receive South American Beam	29.7 dBi	1.2 dB/K
C-Band Transmit African Beam	31.8 dBi	40.2 dBW
C-Band Receive African Beam	31.9 dBi	2.1 dB/K

TABLE 3. PAS-4 PERFORMANCE PARAMETERS

PAS 4 Beams	EIRP
C-Band Japan/China (includes Beijing and Shanghai)	42.0 dBW
C-Band Malay (includes Philippines, Thailand, Korea, Vietnam, Singapore and Hong Kong)	40.9 dBW
C-Band Southern (includes Australia, New Zealand, and Tasmania)	37.7 dBW
C-Band Pacific (includes Guam, American Samoa, and Territories)	38.9 dBW
Ku-Band Japan/China (includes Japan and North East China)	51.7 dBW
Ku-Band Malay (includes Philippines, Thailand, Korea, Vietnam, Singapore and Hong Kong)	50.5 dBW
Ku-Band United States (includes West Coast, Alaska, and Hawaii)	54.8 dBW
Ku-Band Southern (includes Australia, New Zealand, and Tasmania)	45.4 dBW

(3) *Flexibility.* The flexibility of the PAS satellites allows for access to both the C-band and Ku-band beams from most locations within the overall footprint of the satellites. Additionally, all beams can be accessed from most points within the satellite's footprint for complete region-wide connectivity. Full cross-strapping capability allows for Ku-band to C-band and C-band to Ku-band operation. (Overview of PanAmSat's Global Satellite System, 1992, p. 4)

C. AT&T SATELLITE COMMUNICATIONS

AT&T, one of the premier domestic commercial satellite vendors, holds the distinction of being the first commercial satellite vendor in the world to build and operate its own spacecraft. The TELSTAR 1 and TELSTAR 2 satellites, launched in 1962 and 1963 respectively, heralded the dawning of the commercial telecommunications industry. In 1983 AT&T updated its satellite inventory with the TELSTAR 3 series. This system represents the current operational satellite network of AT&T. It is comprised of a three satellite constellation in geosynchronous orbit. Through this system AT&T provides satellite-based long-distance communications services under the SKYNET brand. Additional services include one-way and two-way analog and digital data, image and voice transmission.

(Jane's Space Directory, 1993, pp. 369-370)

1. Telstar 3 Series (Telstar 301(3A)/302(3C)/303(3D))

a. Evolution of the Telstar 3 Series

The Federal Communications Commission Domsat decision opened up the U.S. domestic market for satellite operations in 1972. This ruling enabled GTE, RCA, and Western Union to develop their own domestic satellite systems. AT&T was prohibited from developing their own systems for a three year period after this decision because AT&T was considered a dominant monopoly and the FCC wanted to buy some time for emerging companies in the growing communications satellite

industry before they faced full-scale competition from AT&T. As a direct consequence of these policy decisions, AT&T had to rent capacity on COMSAT's Comstar system. In December of 1980, the FCC finally authorized the launching of AT&T's Telstar 3 satellite system. This allowed AT&T to terminate its utilization of the Comstar system by 1986. The first Telstar 3 satellite, Telstar 301, was launched in 1983. Telstar 302 and Telstar 303 were launched in 1984 and 1985 respectively. (Stanyard, 1987, p. 289)

b. Satellite Overview

The three satellites comprising the Telstar 3 system are utilized to provide radio, TV, voice, and high speed data transmission services within CONUS, Alaska, Hawaii, the U.S. Virgin Islands, and Puerto Rico. In support of these spacecraft, AT&T utilizes eight 20 meter and one 15.5 meter earth stations. Additionally, a host of 10 meter earth stations are used with the system for network TV, private line, governmental, and experimental uses. (Stanyard, 1987, pp. 289-290)

Each satellite in the Telstar 3 constellation operates solely in the C-band and has twenty-four transponders with a usable bandwidth of 36 MHz. Due to their ten year design life, Telstar 301 and Telstar 302 will be near the end of their useful lives by late 1994. Figure 15 provides a graphic depiction of a Telstar 3 satellite. (Stanyard, 1987, pp. 289-290)

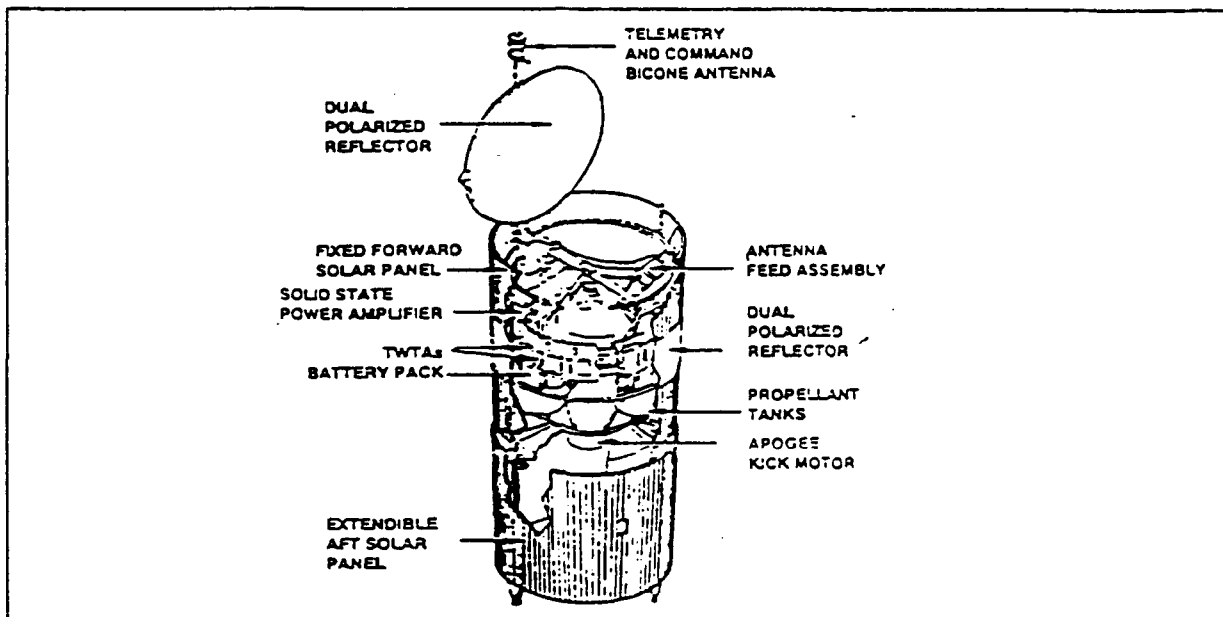


Figure 15. The Telstar 3 Satellite

c. Orbital Parameters

(1) *Orbit.* All Telstar 3 satellites are in geostationary orbit with a stationkeeping accuracy of plus or minus 0.05 degrees in latitude and longitude. Telstar 301 is located at position 96 degrees west longitude. Telstar 302 is located at position 85 degrees west longitude. Telstar 303 is located at position 125 degrees west longitude. (Interavia, 1992, p. 404)

(2) *Orbital History of the Series.* Telstar 301 was launched July 29, 1983 by a Delta rocket from Cape Canaveral. Telstar 302 was launched August 30, 1984 by Shuttle STS-41D. Telstar 303 was launched June 17, 1985 by Shuttle STS-51G. (Interavia, 1992, p. 404)

d. Key Design Features

(1) *Configuration.* Each satellite has twenty-four transponders operating at C-band (6/4 GHz). All transponders are channelized at 36 MHz bandwidth. In addition Telstar 3 satellites have eighteen 5.5 watt solid state power amplifiers (SSPAs) and twelve 5.5 watt traveling wave tube amplifiers (TWTAs). The thirty amplifiers are configured via a switching matrix to provide one backup amplifier for each set of four primary amplifiers. Signals are processed through the use of orthogonal linear polarization. (AT&T Telstar 3 Systems Summary Chart, 1992, p. 1)

(2) *Physical Characteristics.* Telstar 3 satellites are of the Hughes HS-376 model satellite bus design. These satellites are cylindrical in shape and spin stabilized. Fully deployed, the satellite is 2.2 meters in diameter and 6.8 meters in height. Each Telstar 3 has a mass of 625 kilograms on-station at the beginning of life. Also, they are powered by 15,588 silicon cells attached externally to the satellite body which provides 800 watts of power at beginning of life and 670 watts at end of life. (Interavia, 1992, p. 404)

(3) *Capacity.* Telstar 3 satellites have the capacity to accomodate 21,600 simultaneous long-distance telephone calls. The solid state power amplifiers combined with advanced signal transmission techniques provide a four-fold increase in satellite capacity in comparison to conventional traveling wave tube amplifiers. Telstar 3 satellites are used to link ABC, CBS, the Hughes TV network, and indepen-

dent TV producers with affiliated TV stations all over the country. Additionally, each Telstar 3 transponder is capable of handling up to 900 voice circuits using FDM/FM modulation techniques or 2,689 compressed voice circuits if 90 Mb/s 160 AM is the modulation mode. (Long, 1991, pp. 511-513)

(4) *Design Life.* The design life for each Telstar 3 satellite is ten years. (Interavia, 1992, p. 404)

e. Transmitters/Receivers

The C-band communications subsystem of each Telstar 3 satellite is comprised of twenty-four transponders. Twelve transponders receive horizontally polarized signals and twelve transponders transmit vertically polarized signals. Each transponder has a usable bandwidth of 36 MHz with the center frequencies of co-polarized channels spaced at 40 MHz intervals. Adjacent cross-polarized channels are offset by 20 MHz intervals. Uplink signals are received in the 5925 MHz to 6425 MHz band, translated to the 3700 MHz to 4200 MHz band, separated into the individual 36 MHz channels, amplified, recombined, and then downlinked on the opposite polarization. (AT&T, 1992, p. 16)

f. Antenna Farm

Each Telstar 3 satellite is comprised of two different types of antennas for communications links; a parabolic communications antenna is positioned forward of the fixed forward solar panel; and a bicone antenna is colocated with the parabolic antenna. The parabolic antenna is the essential part of the communications payload whereas the bicone antenna is utilized for telemetry, tracking, and control. Figures 16, 17, and 18 depict the footprints of Telstar 301, 302, and 303 respectively.

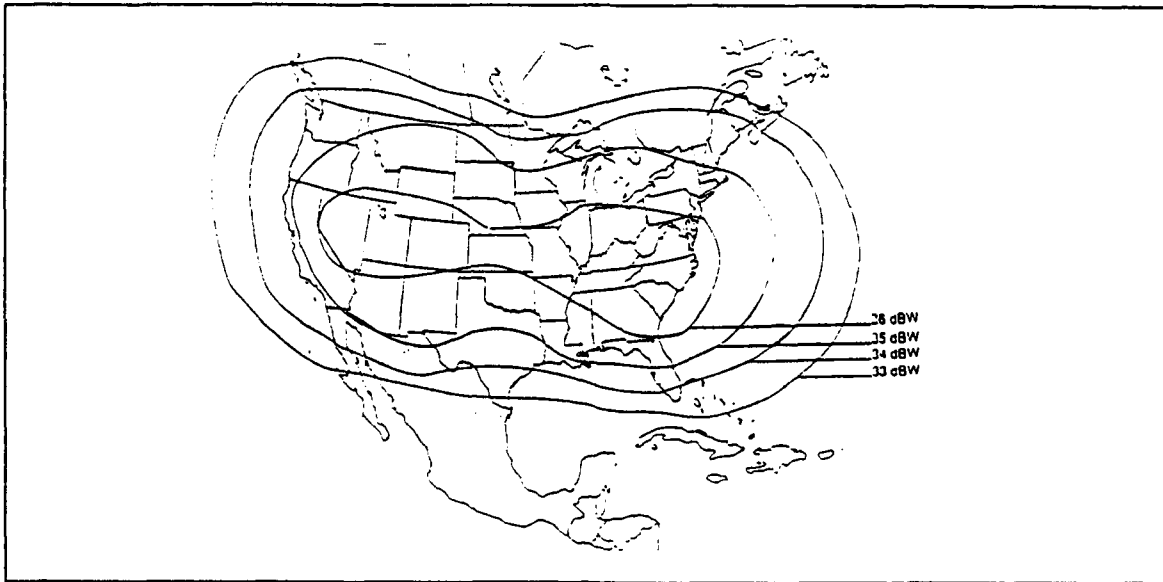


Figure 16. Telstar 301 Satellite Footprint

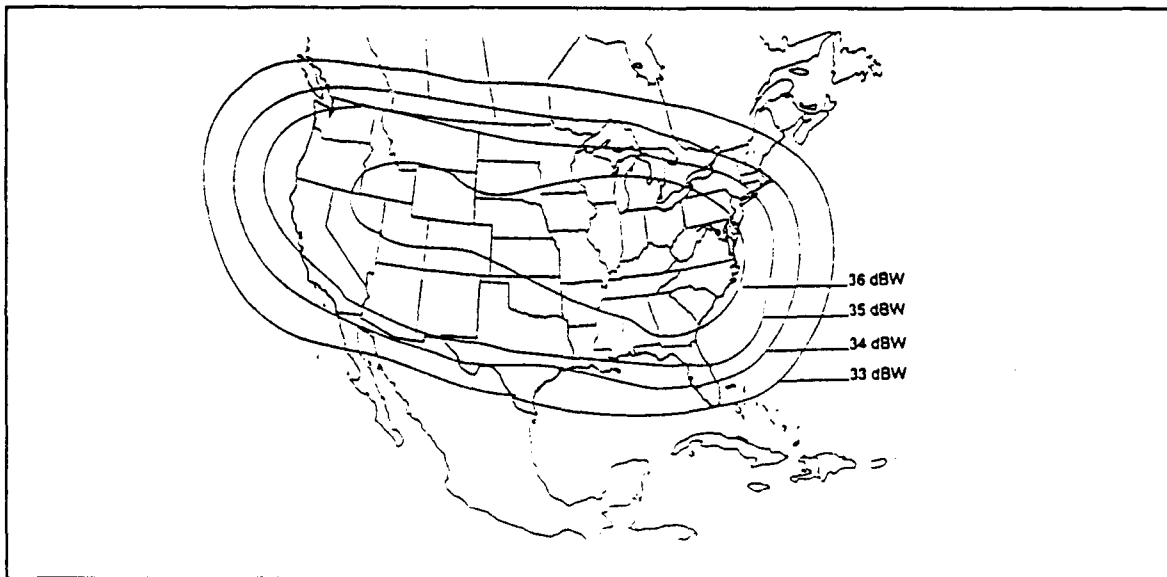


Figure 17. Telstar 302 Satellite Footprint

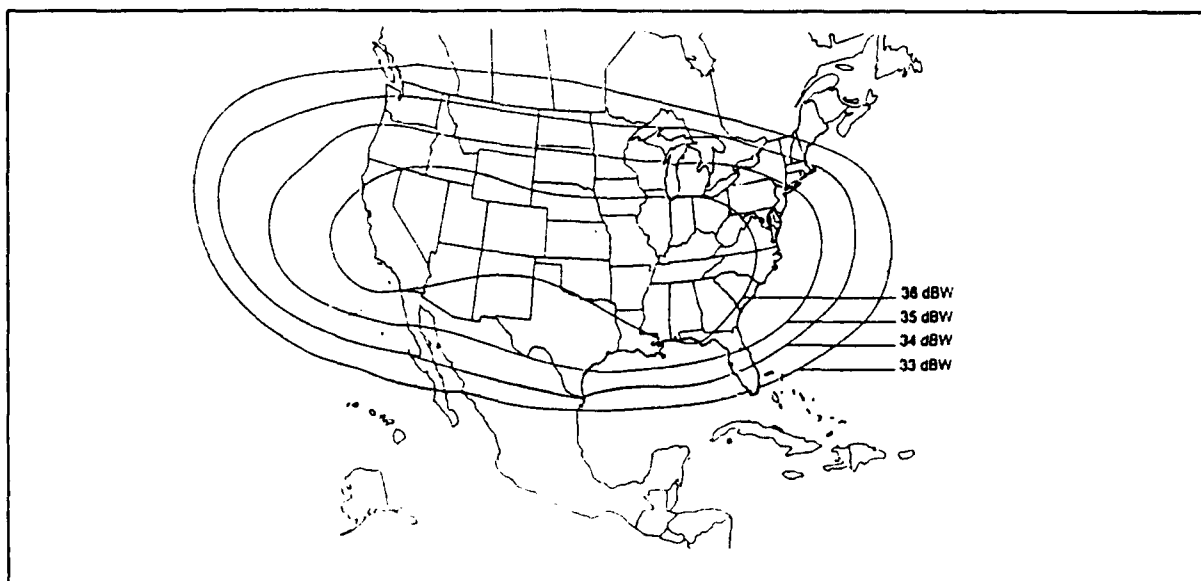


Figure 18. Telstar 303 Satellite Footprint

g. Performance Characteristics

(1) *Satellite Services.* AT&T provides communications services under the Skynet brand that includes both one-way and two-way analog and digital data, image, and voice transmission via the Telstar 3 System. Skynet Transponder Services provide C-band transponders on a full or part-time basis. Full-time transponders are available on a monthly basis or under multi-year fixed terms at various levels of protection. Part-time service is available on a half-hour basis or under bulk usage contracts for peak or off-peak hours. Skynet Television Services are also available on a full or part-time basis. This service is basically a two-way, non-simultaneous system that distributes broadcast-quality programming to widely separated stations. Skynet Digital Services allows

users to transmit and receive a mix of C-band data, video, and voice signals at a variety of speeds, ranging from 56 Kb/s to multiples of 1544 Kb/s. (World Satellite Directory, 1993, pp. 20-22)

(2) *Performance Parameters.* For all Telstar 3 satellites, nominal signal power EIRP for CONUS is 35 dBW and fringe signal power EIRP for CONUS is 33 dBW. Nominal signal power EIRP for Alaska, Hawaii, or Puerto Rico spot beams is 34 dBW. The maximum transmit power of Telstar 3 satellites is 5.5 watts. Nominal G/T for CONUS is -3.0 dB/K. Additionally, minimum transponder gain is 95.5 dB. (Long, 1991, pp. 511-514)

2. Telstar 4 Series (Telstar 401/402)

a. Evolution of the Telstar 4 Series

In October of 1987 AT&T submitted a proposal to the FCC to build three hybrid Telstar 4 satellites. One of the satellites would be launched in the third quarter of FY 1993, one would be launched in the fourth quarter of FY 1994, and the third would be held as a ground spare. Proposals were submitted to AT&T by various satellite manufacturers in October 1988 to build the largest United States domestic communications satellite to date. In July 1989 General Electric Astro Space was awarded the contract to build the three satellites. (Jane's Space Directory, 1993, p. 370)

The Telstar 401 and 402 satellites are slated to replace Telstar 301 and 302 respectively. These satellites should reach the end of their design lives by 1994. The Telstar 4 series technology builds upon the basic communications technology of the Telstar 3 series. In addition to providing C-band capacity, AT&T will enter the Ku-band market with the TELSTAR 4 System. The TELSTAR 4 System will provide two unique capabilities over its predecessor that will enable a variety of new services to its customers. These capabilities are cross-strapping between C-band and Ku-band frequencies and

the ability to control transponder output power in a manner that will permit ground controlled configuration of the satellites to accomodate customer requests for new services. (AT&T FCC Application, 1987, pp. 5-13)

b. Satellite Overview

The Telstar 4 series is a three-axis stabilized, multi-frequency, hybrid communications satellite. This series will provide voice, video, and data transmission and distribution services at C-band and Ku-band to the United States, Puerto Rico, and the United States Virgin Islands. These satellites are comprised of two independent cross-strappable communication subsystems operating at C-band (6/4 GHz) and Ku-band (14/12 GHz). The TELSTAR system makes new services possible because of the higher power transmission capability that results from power sharing and the paralleling of working and standby transponder amplifiers. A maximum of six Ku-band transponders on each satellite are capable of being operated in a power range of from 60 to 120 watts. Similarly, up to six C-band transponders are capable of being operated between 10 and 20 watts. Figure 19 is a graphic depiction of the Telstar 4 satellite. (AT&T FCC Application, 1987, pp. 13-20)

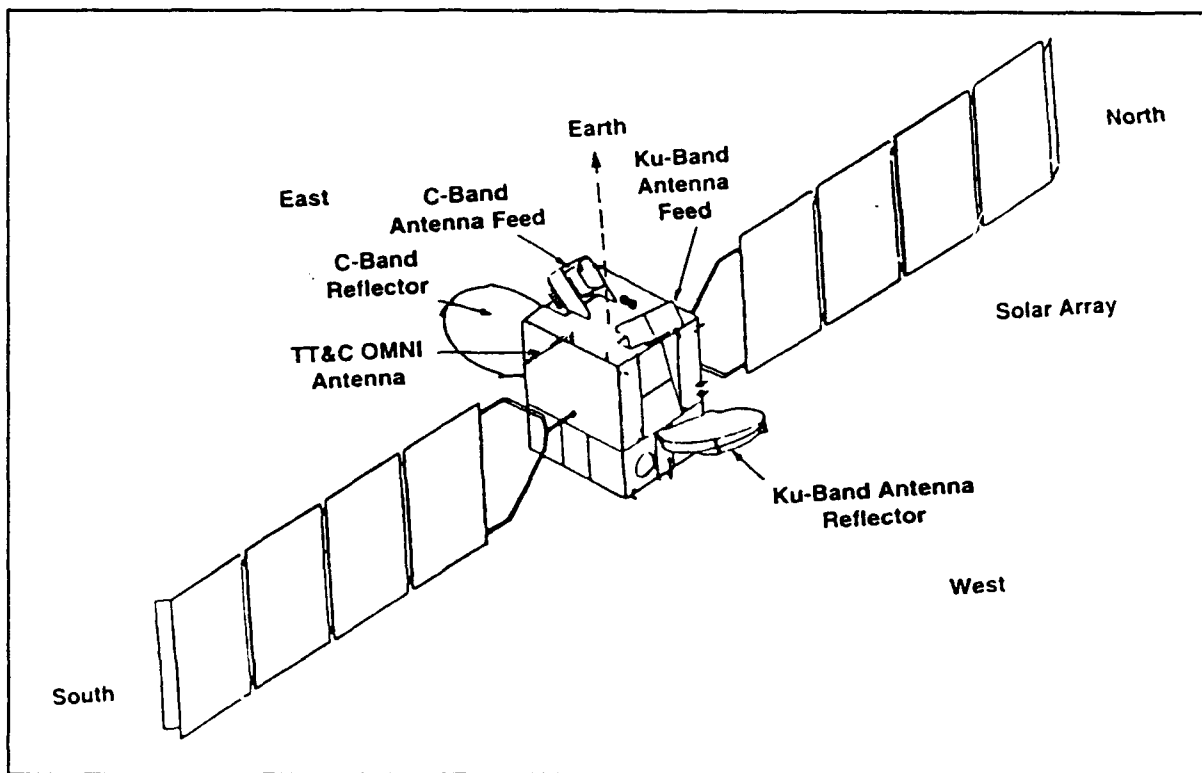


Figure 19. The Telstar 4 Satellite

A unique feature of the Telstar 4 spacecraft design is the inclusion of AT&T's interference-fighting capability at both C-band and Ku-band. The Anti-Intrusion Defeater and Locator (AIDAL) capability uses receive spot beams to minimize and eliminate interfering uplinks. This device not only reduces uplink interference but also has the capability to locate the interferer. (AT&T, 1992, p. 7)

c. Orbital Parameters

(1) *Orbit.* Telstar 401 is in a geostationary equatorial orbit at 97 degrees west longitude. Telstar 402 will be in a geostationary equatorial orbit at 89 degrees west longitude. Both satellites will have stationkeeping to plus or minus 0.05 degrees N-S and E-W. (Jane's Space Directory, 1993, p. 370)

(2) *Orbital History.* Telstar 401 was launched in December 1993. Telstar 402 is currently scheduled to be launched in April 1994. (AT&T, 1992, p. 3)

d. Key Design Features

(1) *Configuration.* Each Telstar 4 satellite has twenty-four 36 MHz C-band transponders which operate at 12 watts (SSPA) nominal RF output power and sixteen 54 MHz Ku-band transponders which operate at 60 watts (TWTA) nominal RF output power. Each of the upper eight 54 MHz transponders may be individually reconfigured under ground control into two 27 MHz transponders operating at 60 watts nominal RF output power, permitting up to sixteen 27 MHz transponders in the upper half of the Ku-band for a total of 24 Ku-band transponders. (AT&T, 1992, p. 6)

The Telstar 4 design also allows for C-band operation at up to 23 watt nominal RF output power level on all C-band transponders and Ku-band operation at a 120 watt nominal RF output power level on up to twelve transponders. Additionally, selected 27 MHz and 54 MHz transponders can implement the 23 watt C-band power level by combining 60 watt primary TWTAs with spare TWTAs. (AT&T, 1992, p. 6)

(2) *Physical Characteristics.* The satellite has a rectangular body with a height of 13.4 feet and an overall length of 80.4 feet. The solar array area is 552.2 square feet. The dry weight of the satellite is 3450 pounds. The satellite weighs approximately 4212 pounds in orbit at the

beginning of life. Telstar 4 satellites are equipped with sun-tracking solar arrays and two nickel hydrogen batteries. Prime power at beginning of life is 6.8 kilowatts. The spacecraft is three axis-stabilized, and antenna pointing accuracy is rated at plus or minus 0.15 degrees. (AT&T, 1992, p. 3)

(3) *Capacity.* The C-band capacity of the TELSTAR 4 system will be used primarily to replace the 48 transponders currently in use aboard Telstar 301 and Telstar 302. AT&T projects that the 48 C-band transponders of the TELSTAR 4 system will be almost fully utilized when existing video, data, and MTS/WATS traffic is transferred to the new system. In addition to the 48 C-band transponders the 401 and 402 will also have 48 Ku-band transponders. Ku-band is expected to be the area of strongest growth for AT&T satellite services in the next decade, particularly for VSAT networks. (AT&T FCC Application, 1987, pp. 23-29)

(4) *Design Life.* The design life for each Telstar 4 satellite is 12 years. (Jane's Space Directory, 1993, p. 370)

e. Transmitters/Receivers

(1) *C-Band Operation.* The C-band communications subsystem of each Telstar 4 satellite is comprised of twenty-four transponders. Twelve transponders receive horizontally polarized signals and transmit vertically polarized signals. Each transponder has a usable bandwidth of 36 MHz with the center frequencies of co-polarized channels spaced at 40 MHz intervals. Adjacent cross-polarized channels are offset by 20 MHz intervals. Uplink signals are received in the 5925 MHz to 6425 MHz band and then translated to the 3700 MHz to 4200 MHz band. These signals are next separated into the individual 36 MHz channels, amplified, recombined, and then transmitted on the opposite polarization. (AT&T, 1992, p. 16)

(2) *Ku-band Operation.* The Ku-band subsystem consists of sixteen 54 MHz transponders. Eight transponders receive horizontally polarized signals and transmit vertically polarized signals while the other eight receive vertically polarized signals and transmit horizontally polarized signals. These transponders have a usable bandwidth of 54 MHz with center frequencies spaced at 60 MHz intervals in the lower half of the band and 62 MHz intervals in the upper half of the band. Each of the upper eight 54 MHz transponders may be individually reconfigured to two 27 MHz transponders for a total of twenty-four transponders at Ku-band. Efficient use of power resources is achieved by allowing independent 27 MHz transponder operation because intermodulation does not occur. Uplink signals in the 14.0 GHz to 14.5 GHz band are received by the satellite, translated to the 4 GHz band, separated into their individual channels, amplified, upconverted, recombined, and then transmitted at 11.7 GHz to 12.2 GHz on the opposite polarization. (AT&T, 1992, pp. 16-17)

f. Antenna Farm

The antenna farm of the Telstar 4 series is comprised of three different types of antennas. For operation at C-band there is a single parabolic dish antenna. For operation at Ku-band there is a single parabolic dish antenna. For telemetry, tracking, and control there is one omnidirectional antenna. Figures 20 and 21 are graphic depictions of the C-band and Ku-band coverage of Telstar 401. Figure 22 and Figure 23 are projected depictions of the C-band and Ku-band coverage of Telstar 402.

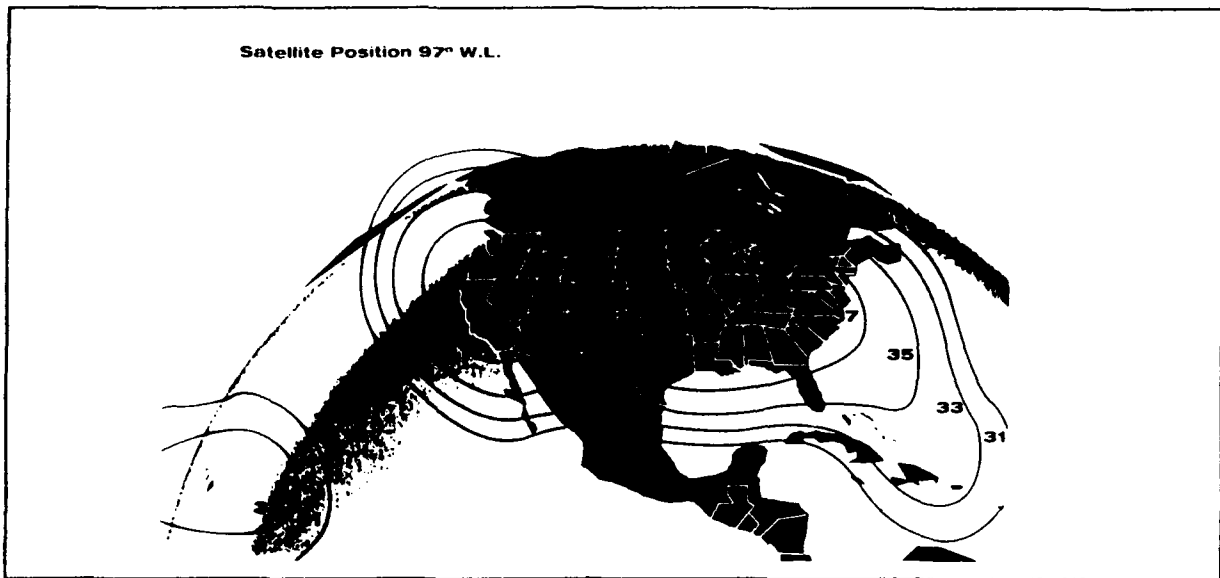


Figure 20. Telstar 401 C-band Footprint

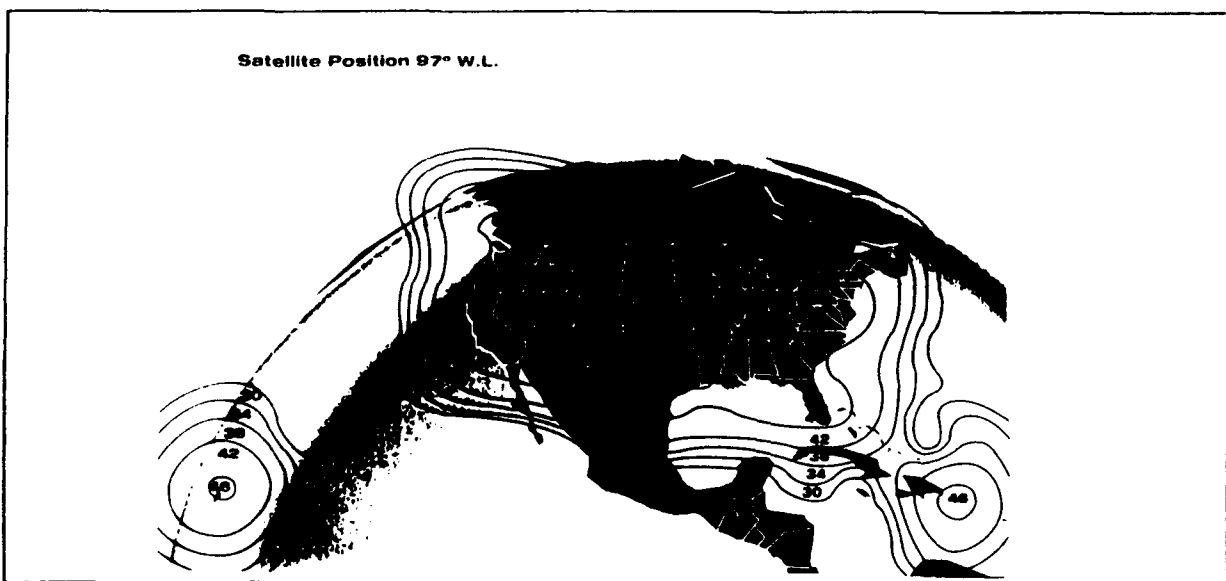


Figure 21. Telstar 401 Ku-band Footprint

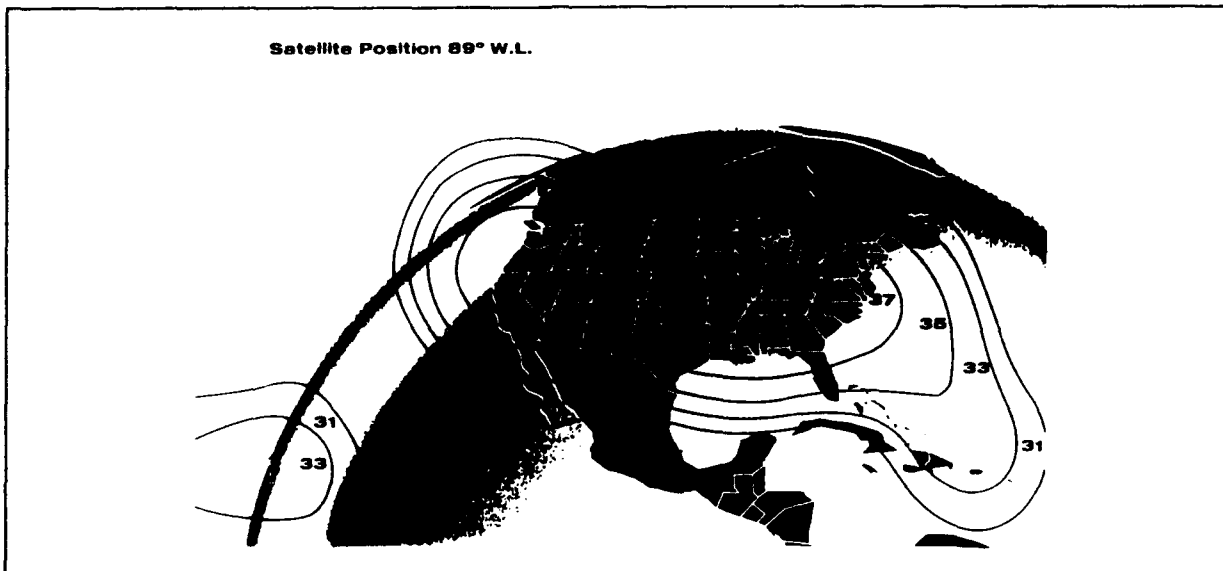


Figure 22. Telstar 402 C-band Footprint

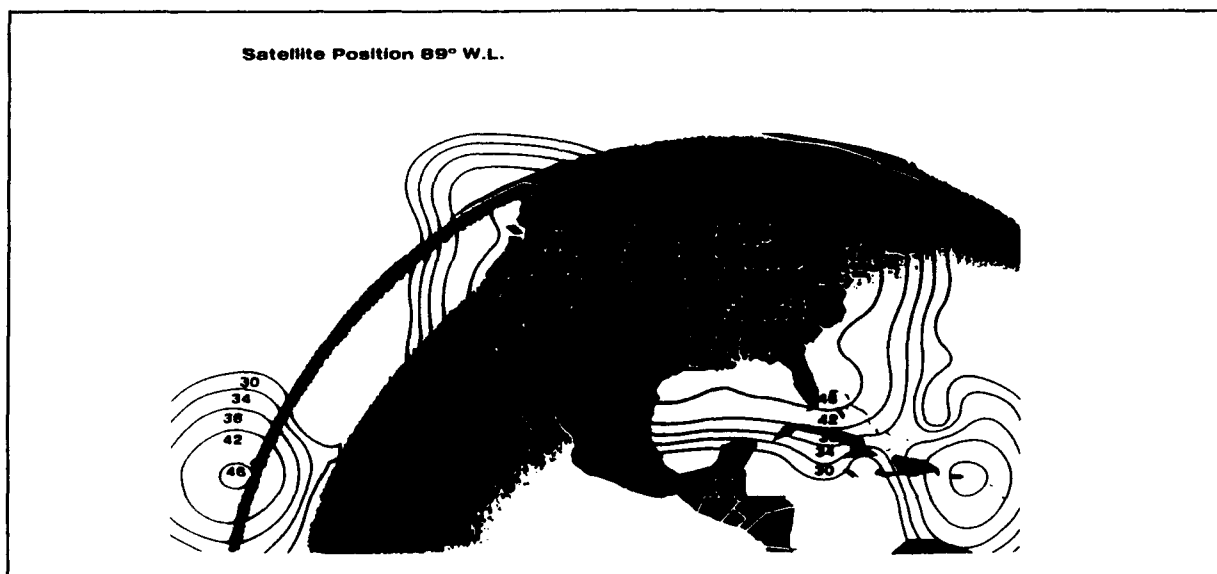


Figure 23. Telstar 402 Ku-band Footprint

g. Performance Characteristics

(1) *Satellite Services.* Telstar 4 satellites have the capability to provide all the same services as the Telstar 3 satellites and are designed to accomodate evolving digital technologies and the analog video technologies of the near future. In particular they can easily accomodate advancements in high-definition television and compressed digital video services. Additionally, SKYNET Video Conferencing Service will be available on Telstar 4 satellites at either C-band or Ku-band. (AT&T FCC Application, 1987, pp. 21-22)

(2) *Performance Parameters.* The hybrid design of the Telstar 4 satellite provides twice as much bandwidth capability as a Telstar 3 satellite. With their variable bandwidth option, AT&T can adjust the mix of 27 MHz and 54 MHz transponders at Ku-band whenever they need to in order to meet customer specifications. Additionally, Telstar 4 satellites can operate at differing, adjustable downlink EIRP levels with their variable power option by redirecting power from transponders operating in a lower power mode to transponders operating in a higher power mode. Tables 4 and 5 illustrate minimum EIRP and G/T levels by coverage region for Telstar 4 satellites. (AT&T, 1992, pp. 8-21)

TABLE 4. TELSTAR 4 MINIMUM EIRP BY COVERAGE REGION

Minimum EIRP at EOL
CONUS plus Caribbean Coverage

Coverage Region	C-Band EIRP	54 MHz	27 MHz
	12/23 Watt HPA	Ku-Band EIRP 60/120 Watt HPA	Ku-Band EIRP 60/120 Watt HPA
CONUS	35.2/38.0	44.3/47.1	44.1/46.9
Major Alaskan Cities	31.0/33.8	40.3/43.1	40.1/42.9
Hawaii	33.0/35.8	44.3/47.1	44.1/46.9
Puerto Rico/Virgin Island	31.0/33.8	44.3/47.1	44.1/46.9

TABLE 5. TELSTAR 4 MINIMUM G/T BY COVERAGE REGION

Minimum G/T at EOL
CONUS plus Caribbean Coverage

Coverage Region	C-Band G/T (dB/K)	Ku-Band G/T (dB/K)
CONUS	-1	-1
Major Alaskan Cities	-6	-3
Hawaii	-2	-1
Puerto Rico/Virgin Island	-2	-1

(3) *Flexibility.* AT&T's communication network reliability can be increased through the use of cross-strapping with Telstar 4 satellites. This is accomplished by permitting alternate transmission paths in the event of propagation degradation or interference. Cross-strapping has the added benefit of making it possible to simultaneously serve markets that currently use Ku-band and C-band downlinks regardless of the uplink frequency band. (AT&T, 1992, p. 9)

The variable power option, discussed in the previous section, allows AT&T to custom tailor the power level of each transponder in a Telstar 4 satellite to meet the requirements of a particular customer. This can be accomplished at any time while the satellite is in orbit and gives AT&T the unique capability to accomodate a customer's changing future needs while also maintaining peak transponder power efficiency on the satellite. (AT&T, 1992, p. 20)

D. COMSAT CORPORATION

The Communications Satellite Corporation, COMSAT, was established in 1963. It is a private, shareholder-owned corporation that represents the United States constituency in the INTELSAT organization and the INMARSAT organization. Currently, COMSAT owns approximately twenty-two percent of INTELSAT and twenty-five percent of INMARSAT. Through the use of the INTELSAT and INMARSAT network system, the COMSAT Corporation furnishes international telecommunications and maritime communications services between the United States and overseas point locations. COMSAT provides a variety of voice, data, facsimile, and video services to domestic and international service carriers as well as to the broadcast, maritime, and aeronautical communities. (World Satellite Directory, 1993, p. 24)

The COMSAT General Corporation, a subsidiary of COMSAT, was established in 1973 as a satellite operator. It currently

manages seven domestic satellites in geosynchronous orbit. These satellites are of the Comstar, Marisat, and SBS series. COMSAT utilizes the Comstar satellites to provide general video services. The SBS satellites are used for occasional-use TV broadcasting. The Marisat satellites are primarily used as an on-orbit contingency system for the INMARSAT Corporation and the United States Navy. (World Satellite Directory, 1993, p. 25)

1. Comstar Series (Comstar D2/D4)

a. Evolution of the Comstar Series

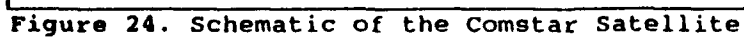
The Comstar satellites were some of the first domestic communications satellites to be placed into orbit. The Comstar System was initially comprised of a series of four C-band communications spacecraft: the Comstar D1, the Comstar D2, the Comstar D3, and the Comstar D4. These vehicles were purchased by the Comsat Corporation from Hughes in the early 1970s when the FCC approved Comsat's application for the satellite system. (Yenne, 1987, pp. 34-36)

The Comstar satellites were designed to provide telecommunication services between the contiguous United States, Alaska, Hawaii, and Puerto Rico. The first satellite of the series, the Comstar D1, was launched in 1976. By 1981 three additional Comstars had been successfully placed into geostationary Earth orbit (Stanyard, 1987, p. 97). General Telephone and Electronics (GTE) and AT&T were the principal users of this system when it was first activated. However, with the launch of the GSTAR and Spacenet satellites for GTE and the Telstar 3 satellites for AT&T, these customers no longer required the services of the Comstar system. Today, only the Comstar D2 and Comstar D4 are in an operational status. Comsat has moved both of these satellites to inclined geostationary orbits to further extend their operational lives. (Yenne, 1987, pp. 34-36)

b. Satellite Overview

The Comstar D2 and Comstar D4 satellites are cylindrical, spin-stabilized (Earth-oriented, despun communication platforms with a spinning body section), C-band only communication satellites. Each satellite has twenty-four operational transponders channelized at 34 MHz bandwidth (Long, 1987, p. 282). The satellite employs a beam-shaping technology which optimizes C-band coverage over CONUS, Hawaii and Puerto Rico. The Comstars utilize linear polarization, and frequency reuse is achieved via horizontal and vertical cross-polarization. (Martin, 1986, p. 125)

The Comstar satellites are all equipped with two parabolic antennas which occupy the same aperture. These communications antennas operate solely at C-band to provide CONUS telecommunications services to Comsat's clientele. These satellites are similar in design to the Intelsat IVA satellite. During the launch phase, Comstar satellites are compact cylinders. On station, the antenna unfolds from one end of the satellite and a cylindrical solar array is deployed axially from the opposite end of the satellite. Silicon solar cells cover the main cylindrical body of the satellite except for a mirrored band that serves as a thermal radiator. The primary functions of these satellites is to provide TV, business telephone services, data transmission services, video teleconferencing, and other voice services to the United States at C-band (Jane's Space Directory, 1993, p. 370). Figure 24 is a schematic of a Comstar satellite (Yenne, 1987, p. 34). Figure 25 is a graphic depiction of a Comstar satellite. (Martin, 1986, p. 125)



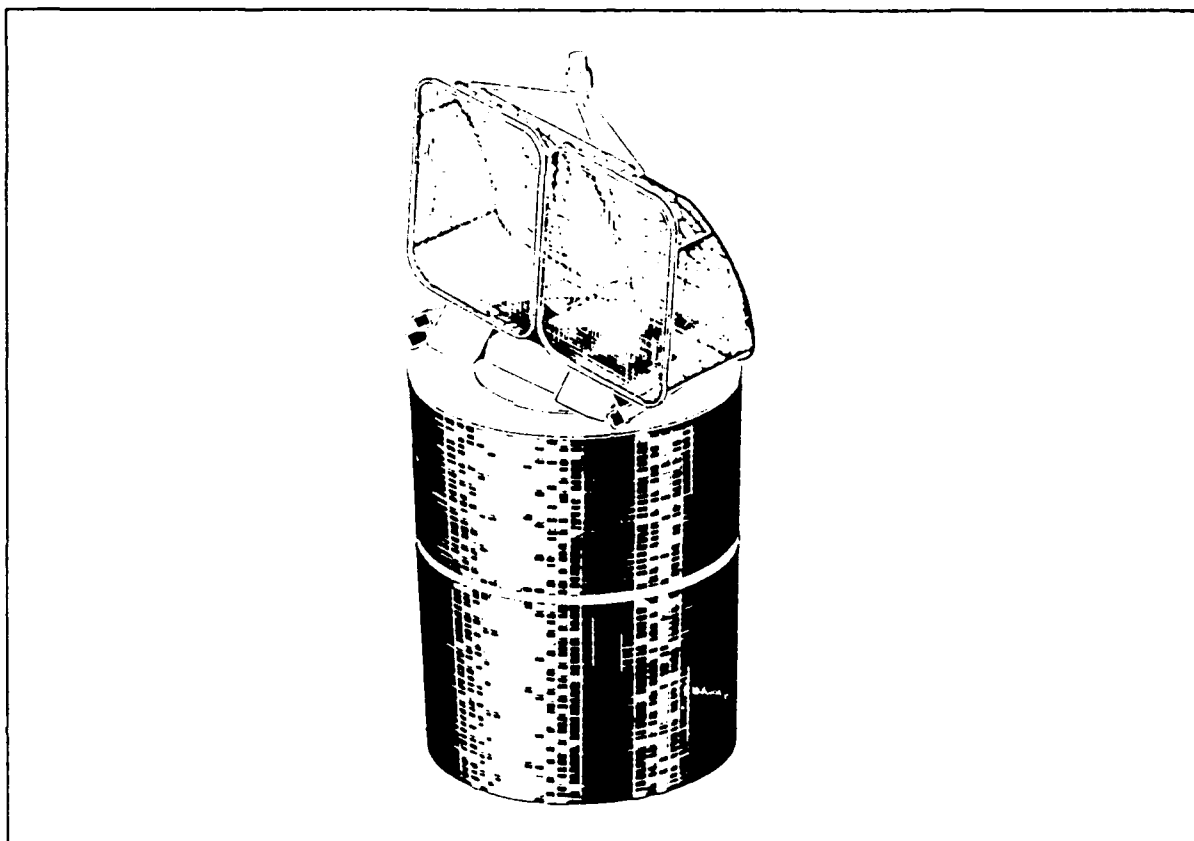


Figure 25. The Comstar Satellite

c. Orbital Parameters

(1) *Orbit.* The Comstar D2 and Comstar D4 satellites are both in an inclined geostationary orbit. Stationkeeping for each satellite is rated at plus or minus 0.5 degrees in latitude and longitude. Comstar D2 is located at position 76 degrees west longitude and is inclined at 7.1 degrees. Comstar D4 is located at position 76 degrees west longitude and is inclined at 5.5 degrees. (Interavia, 1992, pp. 404-405)

(2) *Orbital History of the Series.* The Comstar D2 was launched on July 22, 1976 by an Atlas Centaur from Cape Canaveral. The Comstar D4 was launched on February 21, 1981 by an Atlas Centaur from Cape Canaveral, also. (Interavia, 1992, pp. 404-405)

d. Key Design Features

(1) *Configuration.* The Comstar satellites utilize a Hughes HS-351 satellite bus design. A total of twenty-four operational C-band transponders are equipped on each satellite. These transponders are channelized at 34 MHz and altogether provide a total usable bandwidth of 616 MHz (Brown, 1981, p. 100). The transponders make use of linear polarization, and frequency reuse is achieved through horizontal and vertical cross-polarization. (World Satellite Directory, 1993, p. 26)

(2) *Physical Characteristics.* The Comstar D2 and Comstar D4 are cylindrical platforms which are spin stabilized at 56 rpm via four hydrazine thrusters. The satellites are identical, with dimensions of 2.4 meters in diameter and 6.1 meters in height when the satellite is fully deployed (Stanyard, 1987, p. 97). The satellites employ a despun communications platform comprised of two offset parabolic antenna reflectors for C-band operation. The satellite mass is 1516 kilograms at launch and 911 kilograms on-station at the beginning of life. Additionally, each satellite is equipped with silicon solar cells mounted along the cylindrical surface of the satellite body. Nickel cadmium batteries provide electric power to the satellite on the order of 610 watts at the end of life. (Jane's Space Directory, 1993, p. 370)

(3) *Capacity.* Each of the Comstar satellites can accomodate one color TV signal, 1200 simultaneous one-way voice channels, or 45 MB/s data transmission per transponder (Martin, 1986, p. 125). The total nominal capacity of a

Comstar spacecraft is 15,000 simultaneous two-way voice circuits, 18,000 one-way voice circuits, or 24 color TV signals. (Long, 1987, p. 282)

(4) *Design Life.* The design life for the Comstar D2 and the Comstar D4 is ten years. However, both of these satellites have exceeded their original design lives and are currently operational. (Interavia, 1992, pp. 404-405)

e. Transmitters/Receivers

At C-band (6/4 GHz) there are twenty-four 34 MHz transponders. There is one 5 watt TWTAs provided for each horizontally-polarized transponder (Conus, Hawaii, and Puerto Rico coverage) and one 5.5 watt TWTAs for each vertically-polarized transponder (Conus, Alaska, and Conus/Alaska coverage). There is no redundancy available in this configuration. The two C-band antennas (transmit and receive) are both parabolic, co-located dishes that utilize linear dual polarization. The transmit frequency ranges from 3.700 to 4.200 GHz and the receive frequency band ranges from 5.925 to 6.425 GHz. (Martin, 1986, p. 125)

f. Antenna Farm

Each Comstar satellite has two communications antennas. The C-band array is comprised of two offset parabolic antennas which occupy the same aperture. Each antenna reflector is 127 cm x 178 cm and is capable of handling twelve channels each (Jane's Space Directory, 1993, p. 370). The antenna platform is despun and Earth-oriented. Linear polarization is the mode used by Comstar satellites for signal processing and frequency reuse is achieved through horizontal and vertical cross-polarization. (World Satellite Directory, 1993, p. 26). The Comstar satellites provide C-band spot beam coverage for Conus, Alaska, Hawaii, and Puerto Rico. Figure 26 is a depiction of the footprints of the Comstar D2 and Comstar D4 satellites. (Martin, 1986, p. 135)

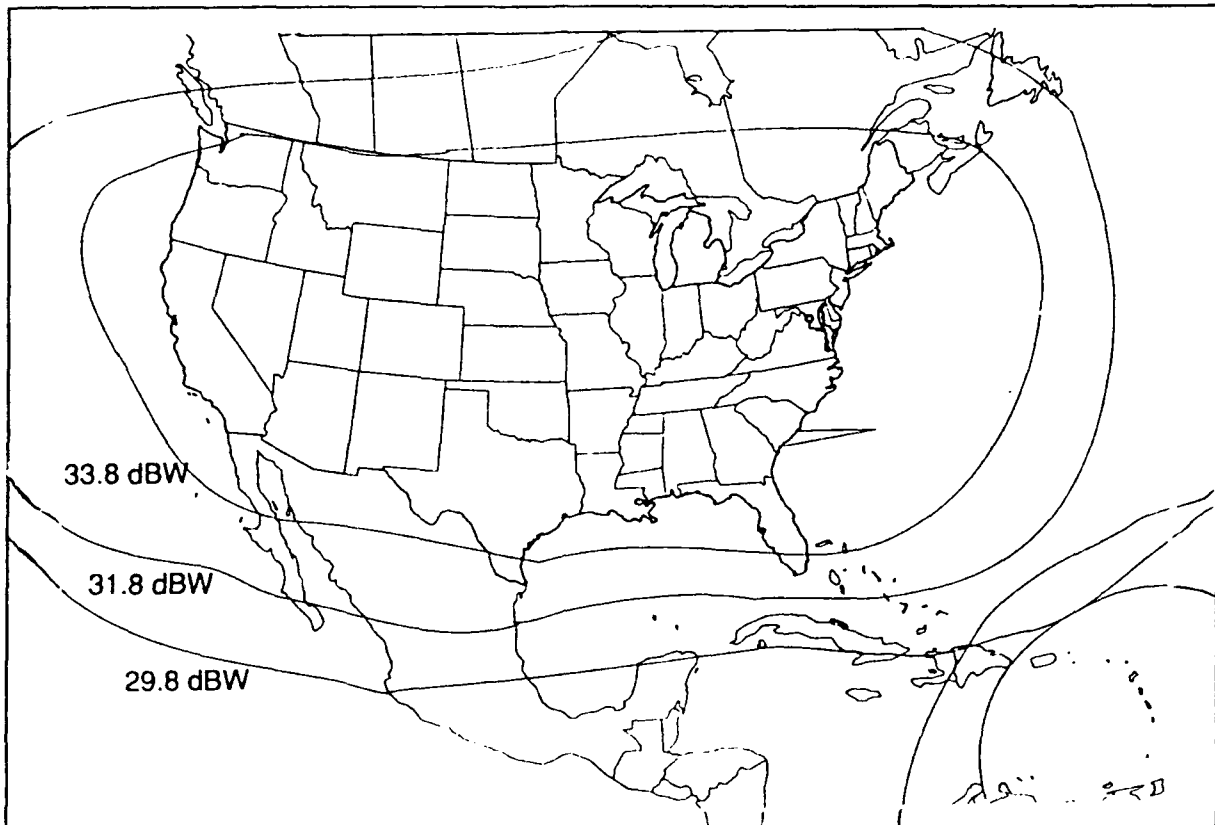


Figure 26. Comstar D2 and Comstar D4 Satellite Footprints

g. Performance Characteristics

(1) *Satellite Services.* The Comstar satellites are currently used to provide voice, data and television services for the contiguous United States, Hawaii, Alaska, and Puerto Rico. However, the role of the Comstar D4 will be changing very shortly. In 1993 the Comsat Corporation announced that the Comstar D4 will be moved over China as part of a joint venture with Hong Kong's Satellite Communications Asia Corporation. This satellite is scheduled to be transferred in 1994 to provide China and Asia coverage for the previously mentioned telecommunications services. (Jane's Space Directory, 1993, p. 370)

(2) *Performance Parameters.* The total usable bandwidth provided by the twenty-four operational transponders of each Comstar satellite is 616 MHz (Brown, 1981, p. 100). The bandwidth of a single transponder is 34 MHz. The minimum specified available EIRP for CONUS, Hawaii, Alaska, or Puerto Rico coverage is 33.0 dBW. The combined specified EIRP for CONUS and Alaska coverage is 31.0 dBW. The typical EIRPs for these coverages are 36.0 dBW and 34.0 dBW, respectively. The minimum saturation flux density for CONUS coverage is -81.7 dBW per square meter (Brown, 1981, p. 121). The specified minimum G/T for CONUS coverage is -8.8 dB/K. The typical minimum G/T for this coverage is -4.5 dB/K. (Martin, 1986, p. 125)

2. Marisat Series (Marisat 1/2/3)

a. Evolution of the Marisat Series

The Marisat satellites were initially developed to provide maritime communications services between ships and shore stations. The three satellites of this series are the Marisat 1, Marisat 2, and Marisat 3. All of these satellites were designed and manufactured by the Hughes Aircraft Corporation. The most significant feature of the Marisat series is their capability to provide global common-carrier service to ships of all nations. During the late 1970s the primary user of this system was the United States Navy. The Navy used the Marisat satellites to fill the gap in naval communications coverage during the period spanning from the end of life (EOL) of Tacsat and LES 6 up to the time that FLTSATCOM became operational. For this reason Marisat satellites are commonly referred to as the Gapfiller System or Gapsat. (Martin, 1986, p. 149)

The Marisat 1 was launched in 1976. It was positioned in geostationary Earth orbit over the Atlantic. Marisat 2 was launched four months later and placed in a similar orbit over the Pacific. Marisat 3 complemented the system in the fall of 1976 and was placed in orbit over the Indian Ocean. After extensive use by the Navy for UHF communications services and utilization by recognized United States and Canadian mobile satellite service carriers, the Marisat satellites were repositioned into inclined orbits to conserve fuel. Between 1983 and 1985 all three of these spacecraft were designated as in-orbit spares for the INMARSAT system. (Yenne, 1987, p. 102)

b. Satellite Overview

The Marisat satellites are hybrid, spin-stabilized cylindrical platforms (with a de-spun antenna section), dual band (C-band and L-band) communication satellites. Each satellite has five operational transponders. One transponder operates at C-band, one transponder operates at L-band, and three channels are devoted to UHF communications. The Marisat satellites are basically a derivative of the Anik A satellite. The support and structural subsystems of the Marisat series are identical to those of the Anik A. The one difference between the two is that the solar array diameter of the Marisat satellites is approximately thirteen percent larger than that of the Anik A. (Martin, 1986, p. 149)

The Marisat satellites are all equipped with nine communications antennas. Three helices supported by truncated cones form a UHF array with a thirty degree beamwidth. At C-band there are two earth coverage horns, one for receiving and one for transmitting. For L-band operation, there are four smaller cone-helix antennas that form a twenty degree beamwidth. Figure 27 is a graphical representation of a Marisat satellite. (Martin, 1986, p. 149)

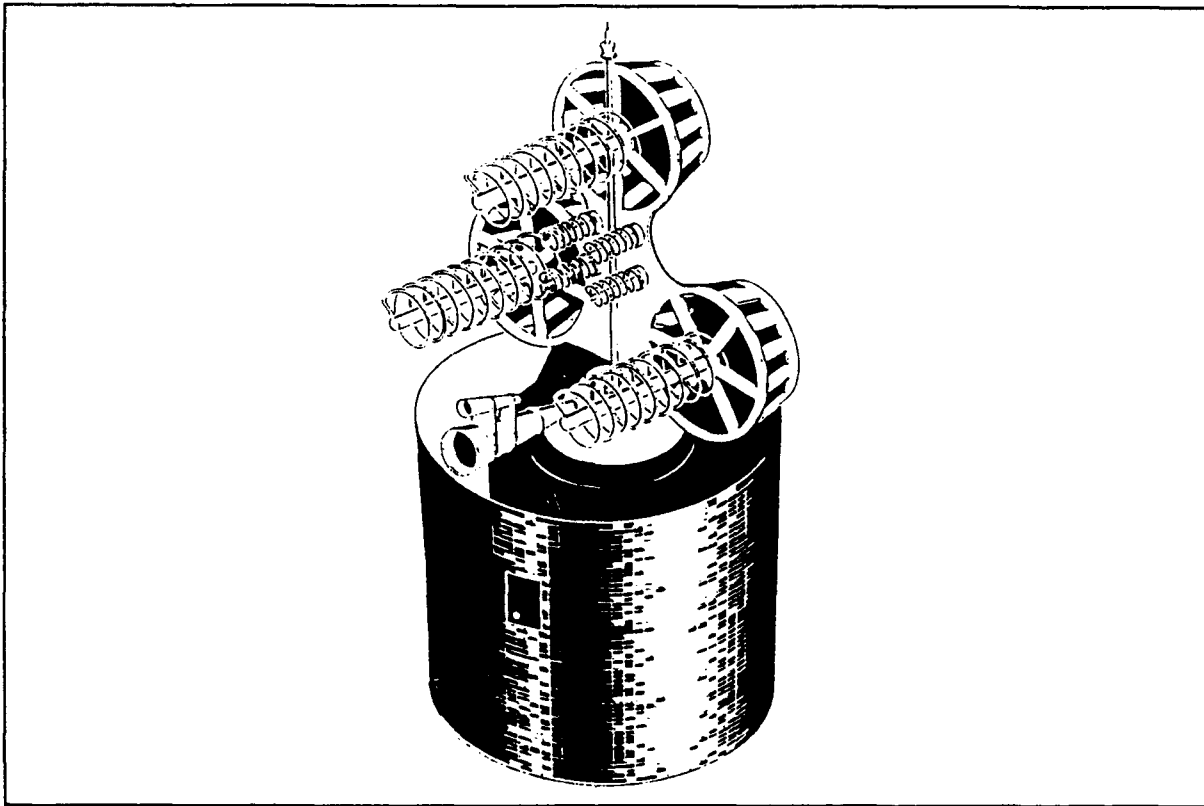


Figure 27. The Marisat Satellite

c. Orbital Parameters

(1) *Orbit.* The Marisat satellites are all positioned in inclined geostationary Earth orbits. Stationkeeping for each satellite is rated at plus or minus 0.5 degrees in latitude and longitude. Marisat 1 is located at position 106 degrees west longitude with an inclination of 9.6 degrees. Marisat 2 is located at position 72.5 degrees east longitude with an inclination of 8.8 degrees. Marisat 3 is located at position 176.5 degrees east longitude with an inclination of 10.1 degrees. (Interavia, 1992, pp. 404-405)

(2) *Orbital History of the Series.* Marisat 1 was launched on February 19, 1976 by a Delta from Cape Canaveral. In 1983 Marisat 1 became designated as an in-orbit spare for the INMARSAT system. Marisat 2 was launched on June 10, 1976 by a Delta from Cape Canaveral. In 1985 it was designated as an in-orbit spare for the INMARSAT system. The Marisat 3 was launched on October 14, 1976 by a Delta from Cape Canaveral. This satellite was designated as an in-orbit spare for the INMARSAT system in 1983. (Interavia, 1992, pp. 404-405)

d. Key Design Features

(1) *Configuration.* The Marisat satellites utilize a Hughes HS-333 satellite bus design. A total of five operational transponders are equipped on each satellite. Of that total, three transponders are utilized for UHF communications services; one transponder is used for L-band communications between the satellites and ships; and one transponder is utilized for C-band services between the satellites and shore stations. Circular polarization is employed on all bands, however, at saturation at C-band the transmitter will operate using linear polarization. At UHF there is one 500 KHz channel and two 25 KHz channels available. For commercial use there is one 4 MHz channel available at C-band and one 4 MHz channel available at L-band. (Martin, 1986, pp. 149-150)

(2) *Physical Characteristics.* The Marisat satellites are of the Hughes HS-333 model design. It is a spin stabilized (at 100 plus or minus 15 rpm), cylindrical platform with a de-spun antenna subsystem. The dimensions of each satellite, when fully deployed, are 3.8 meters in height and 2.1 meters in diameter. The satellite employs nine communications antennas. Three of these antennas are helical shaped truncated cones which form a UHF array with twenty degrees of beamwidth. Four smaller cone-helix antennas are

employed for L-band operation. And two earth coverage horns are utilized for C-band communications services. The satellite mass is 655 kilograms at launch and 330 kilograms on-station at the beginning of life (Long, 1991, p. 516). The satellite is equipped with 7000 silicon solar cells around its body as well as nickel cadmium batteries which provide electric power to the satellite on the order of 335 watts at the beginning of life and 305 watts at the end of life. (Martin, 1986, pp. 149-150)

(3) *Capacity.* Each of the Marisat satellites is equipped with three UHF channels. Two of the UHF channels are channelized at 25 KHz bandwidth and one channel is channelized at 500 KHz. For commercial use there are two 4 MHz bandwidth channels, one for ship-to-shore communications and one for shore-to-ship communications. These channels use L-band frequencies between the satellite and ships, and C-band between the satellite and shore stations. (Martin, 1986, p. 149)

The capacity of the 25 KHz UHF channels are 2400 b/s per channel. The maximum capacity of the 500 KHz channel is five separate 2400 b/s links and seventeen 75 b/s links. The 4 MHz channel (L-band to C-band) can accommodate nine voice circuits or 110 teletype circuits. The 4 MHz channel (C-band to L-band) can provide one, five, or nine voice circuits and 44, 66, or 110 teletype circuits depending upon the EIRP setting. (Martin, 1986, p. 149)

(4) *Design Life.* The design life for the Marisat 1, Marisat 2, and Marisat 3 is five years. However, all three of these satellites have exceeded their design lives and are currently operational. (Interavia, 1992, p. 405)

e. Transmitters/Receivers

(1) *UHF Operation.* At UHF (400/225 MHz) there are three transponders. Two of these transponders are channelized at 25 KHz bandwidth and one is channelized at 500 KHz bandwidth. There is one redundant SSPA provided for each transponder. The SSPAs powering the C-band transponder can be commanded to one of two different power settings, 20 watts or 65 watts. The three cone-helix antennas provide approximately thirty degrees of beamwidth for UHF operation. One redundant receiver is provided for UHF operation. Additionally, the UHF antennas all utilize circular polarization for signal processing. The transmit frequency ranges from 248 MHz to 260 MHz. The receive frequency band ranges from 300 MHz to 312 MHz. (Martin, 1986, pp. 149-151)

(2) *L-Band Operation.* At L-band (1.6/1.4 GHz) there is one 4 MHz narrowband transponder. There is one redundant TWTA provided for this transponder. The TWTA powering the C-band transponder can be commanded to one of three different power settings, 7 watts, 30 watts, or 60 watts. The four cone-helix antennas provide approximately twenty degrees of beamwidth for L-band operation. One redundant receiver is provided for L-band operation. Additionally, the L-band antennas all utilize circular polarization for signal processing. The transmit frequency ranges from 1537 to 1541 MHz. The receive frequency band ranges from 1638.5 MHz to 1642.5 MHz. (Martin, 1986, pp. 149-151)

(3) *C-Band Operation.* At C-band (6/4 GHz) there is one 4 MHz narrowband transponder. There is one redundant TWTA provided for this transponder. The TWTA powering the C-band transponder is rated at five watts. The two C-band antennas (transmit and receive) are both conical horns with eighteen degrees of beamwidth. One redundant receiver is provided for C-band operation. Circular polarization is the

signal processing mode for the C-band antennas. The transmit frequency ranges from 4195 to 4199 MHz. The receive frequency band ranges from 6420 MHz to 6424 MHz. (Martin, 1986, pp. 149-151)

f. Antenna Farm

Each Marisat satellite has nine communications antennas. The UHF array is comprised of three helical-shaped truncated cones which provide for a thirty degree beamwidth. The L-band array consists of four smaller cone-helix type antennas which provide for a twenty degree beamwidth. At C-band two earth coverage antennas are employed, one for transmitting and one for receiving. These antennas provide for an eighteen degree beamwidth. The UHF antennas are 48 inches in length while the L-band antennas are 15 inches in length. Figure 28 is a depiction of the footprints of the Marisat satellites. (Martin, 1986, pp. 149-150)

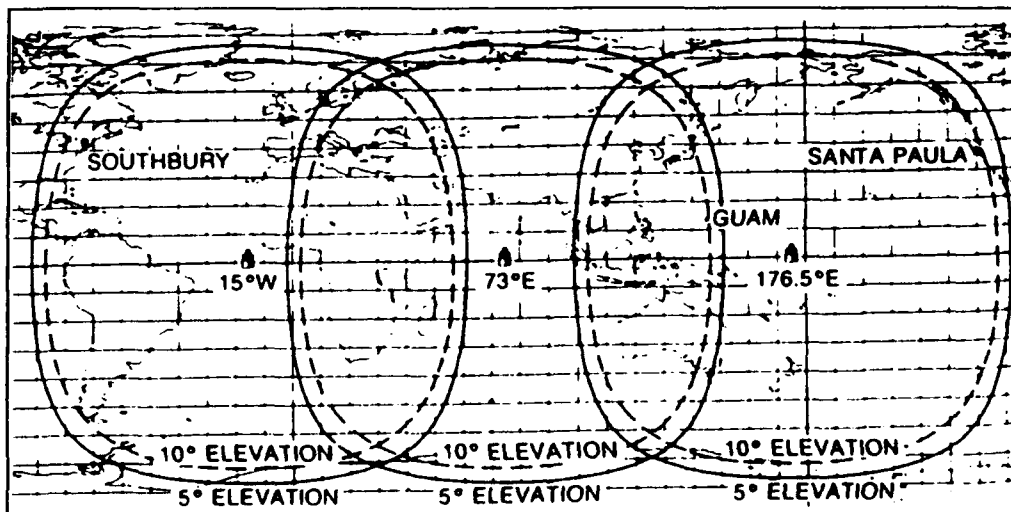


Figure 28. The Marisat Footprints

g. Performance Characteristics

(1) *Satellite Services.* The Marisat satellites were used extensively in the late 1970s and early 1980s to provide military and commercial maritime telecommunications services. These services included voice, teletype, high-speed data transmission (up to 4800 b/s), and facsimile service. The United States Navy utilized UHF frequencies between 240 MHz and 400 MHz on the Marisat satellites to cover a gap in satellite communications services that it experienced while waiting for FLTSATCOM to become operational in the early 1980s. Currently, all Marisat satellites are being utilized as in-orbit spares for the INMARSAT system. (Long, 1987, p. 191)

(2) *Performance Parameters.* The minimum signal power (EIRP) for the 500 KHz UHF channel is 28 dBW at the edge of the Earth for the 65 watt power setting. At the 20 watt power setting the minimum EIRP for the 25 KHz UHF channels is 23 dBW. At L-band the minimum EIRP for the 7 watt power setting is 20 dBW. For the 30 watt power setting (L-band) the minimum EIRP is 26 dBW. For the 60 watt power setting (L-band) the minimum EIRP is 29.5 dBW. At C-band the minimum EIRP is 18.8 dBW. The noise figures for UHF, L-band, and C-band are 4.2 dB, 4.9 dB, and 8.8 dB, respectively. The G/T at the edge of the earth for UHF, L-band, and C-band are -18 dB/K, -17 dB/K, and -25.4 dB/K, respectively. Minimum gain for UHF, L-band, and C-band is 12.1 dB, 14.4 dB, and 16 dB, respectively. (Martin, 1986, pp. 149-150)

(3) *Flexibility.* The Marisat satellites operate at three different frequency bands, UHF, L-band, and C-band. At UHF and L-band the power amplifiers have variable power settings which can be command-activated to boost performance at those frequencies. This is often utilized when the communication site is on the perimeter of the satellite's footprint.

As in-orbit spares the Marisat satellites ensure the continuity of the INMARSAT system.

3. SBS Series (SBS 2/3)

a. *Evolution of the Series*

The Satellite Business Systems (SBS) satellites were purchased by a partnership between IBM, Comsat, and Aetna Life. This consortium was established in 1975 and, shortly thereafter, contractual negotiations with the Hughes Corporation were finalized for the manufacture of three SBS spacecraft (SBS 1, SBS 2, and SBS 3). These satellites were subsequently constructed and launched between 1980 and 1982. The primary mission of the SBS satellites was to provide high speed digital data transmission capacity for business usage. During the early 1980s the demand for digital data capacity began to grow at a rapid rate in the commercial market. The SBS satellites were designed to be the first Ku-band domestic satellites to exploit this growing market. (Stanyard, 1987, pp. 248-250)

The SBS system turned out to be a bitter disappointment to its vendors through its first three years of operational service. From 1982 to 1985 the system posted annual deficits on the order of 100-140 million dollars. Due to financial constraints Comsat elected to sell its SBS interests to the MCI Corporation in 1985. In March of 1987 Comsat repurchased the three SBS satellites from their respective owners (Interavia, 1992, p. 405). Comsat's current SBS constellation is comprised of two satellites, the SBS 2 and the SBS 3. The SBS 1 is no longer operational. Both satellites have been placed in inclined geostationary orbits to extend their operational lives and are used extensively today to provide voice, television, and digital data transmission services for Comsat's customer base. (Stanyard, 1987, pp. 248-250)

b. Satellite Overview

The SBS 2 and SBS 3 satellites are cylindrical, spin-stabilized (Earth-oriented, despun communication platforms with a spinning body section), Ku-band only communication satellites. Each satellite has ten operational transponders and four spares channelized at 43 MHz bandwidth (Interavia, 1992, p. 405). These satellites utilize the HS-376 satellite bus design. Additionally, the HS-376 employs a beam-shaping technology which optimizes Ku-band spot beam coverage over CONUS and, in particular, the eastern portion of the United States. (Martin, 1986, p. 135)

The SBS satellites are all equipped with two parabolic antennas which occupy the same aperture. These communications antennas operate solely at Ku-band to provide CONUS telecommunications services to Comsat's clientele. These satellites are similar in design to the Anik C satellite. During the launch phase, SBS satellites are compact cylinders. On station, the antenna unfolds from one end of the satellite and a cylindrical solar array is deployed axially from the opposite end of the satellite. Silicon solar cells cover the main cylindrical body of the satellite except for a mirrored band that serves as a thermal radiator. The primary functions of these satellites is to provide TV, business telephone services, data transmission services, video teleconferencing, and other voice services to the United States at Ku-band (Long, 1987, p. 336). Figure 29 is a graphic depiction of the SBS 2 satellite. (Martin, 1986, p. 135)

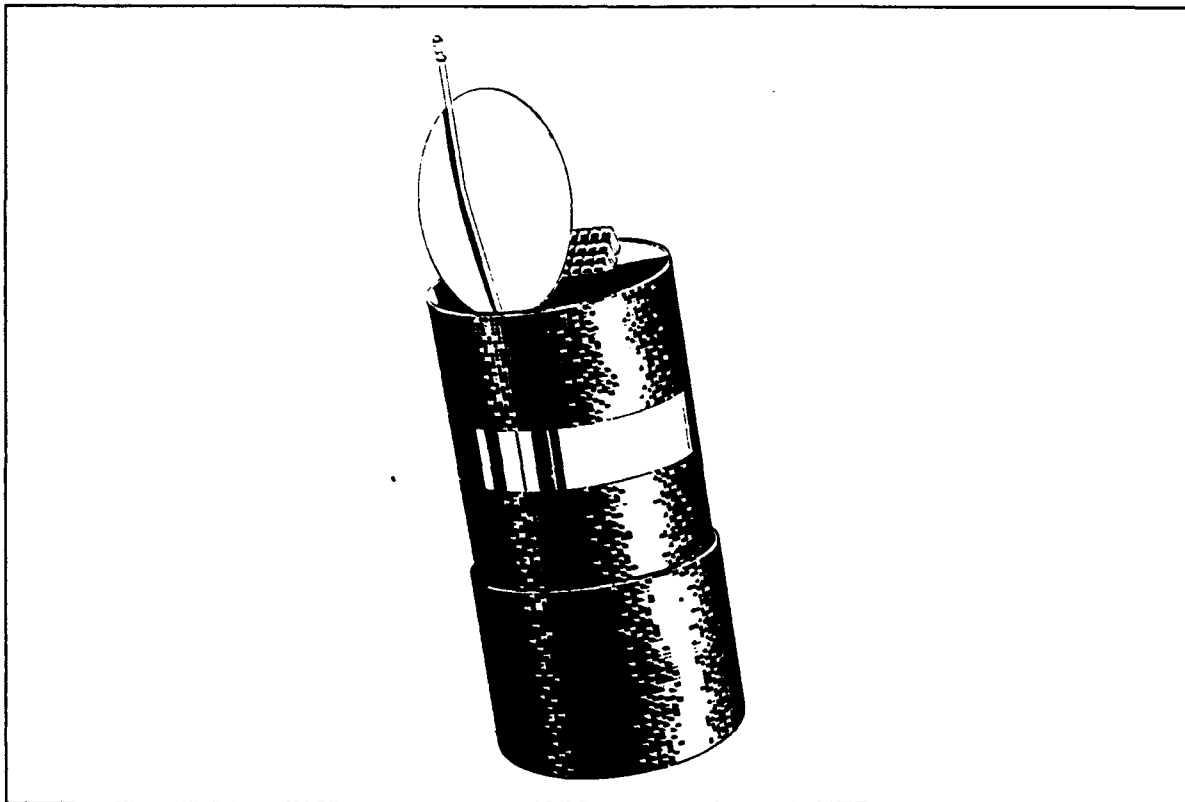


Figure 29. The SBS 2 Satellite

c. Orbital Parameters

(1) *Orbit.* The SBS series of satellites are all located in geostationary Earth orbit. Stationkeeping for each satellite is rated at plus or minus 0.5 degrees in latitude and longitude. SBS 2 is located at position 97 degrees west longitude with an inclination of 3.6 degrees. SBS 3 is located at position 95 degrees west longitude. (World Satellite Directory, 1993, p. 27)

(2) *Orbital History of the Series.* SBS 2 was launched on September 24, 1981 by a Delta from Cape Canaveral. The SBS 3 was launched on November 11, 1982 by a shuttle from Cape Canaveral. (World Satellite Directory, 1993, p. 27)

d. Key Design Features

(1) *Configuration.* A total of ten operational Ku-band transponders are equipped on each satellite. Four spare transponders are also installed on each satellite for redundancy purposes (Stanyard, 1987, p. 251). These transponders are channelized at 43 MHz and altogether provide a total usable bandwidth of 430 MHz. (Brown, 1981, p. 121)

(2) *Physical Characteristics.* The SBS 2 and SBS 3 satellites are cylindrical platforms which are spin-stabilized at 50 rpm via four hydrazine thrusters (Stanyard, 1987, p. 251). The satellites are identical with dimensions of 2.2 meters in diameter and 6.6 meters in height when the satellite is fully deployed. The satellites employ two parabolic antenna reflectors for Ku-band operation (Brown, 1981, p. 121). The satellite mass is 1060 kilograms at launch and 559 kilograms on-station at the beginning of life. Additionally, each satellite is equipped with 16,000 silicon solar cells mounted along the cylindrical surface of the satellite body. Nickel cadmium batteries provide electric power to the satellite on the order of 907 watts at the end of life. (World Satellite Directory, 1993, p. 27)

(3) *Capacity.* Each of the SBS satellites can accomodate ten color TV signals or 12,500 simultaneous two-way voice channels per transponder (Long, 1987, p. 336). Each transponder uses digital, demand assigned, TDMA links for all transmissions. The capacity of the links can be allocated by equipment at the premises of a user for various functions including voice circuits, video conferencing, and data and facsimile transmission. For multiple site customers, the total

network capacity can be allocated among various links to meet changing needs on a daily or long-term basis. (Martin, 1986, pp. 134-137)

(4) *Design Life.* The design life for the SBS 2 and the SBS 3 is five years. However, both of these satellites have exceeded their design lives and are currently operational. (Interavia, 1992, p. 405)

e. Transmitters/Receivers

At Ku-band (14/12 GHz) there are ten operational 43 MHz transponders and four spares. There is one TWTa provided for each transponder. The TWTa powering each Ku-band transponder is rated at twenty watts. The two Ku-band antennas (transmit and receive) are both parabolic co-located dishes that utilize linear orthogonal polarization. The transmit frequency ranges from 11.725 to 12.166 GHz and the receive frequency band ranges from 14.025 to 14.466 GHz. (Interavia, 1992, p. 405). Redundant receivers are provided on a 3-for-1 basis. There is only one operational receiver on each SBS satellite and three spares. (Martin, 1986, p. 135)

The SBS satellite communications system design is based upon quadrature phase shift keying (QPSK). This digital modulation technique is used in a TDMA system to link users in widespread geographical locations via a common transmission channel. Through the use of a QPSK modulated RF carrier signal, each transponder aboard an SBS satellite is capable of supporting approximately 50 Mb/s of digital communications. Additionally, each group of users that shares a transponder has access to the full bandwidth of the channel during their assigned timeslots. (Long, 1987, pp. 348-349)

f. Antenna Farm

Each SBS satellite has two communications antennas. The Ku-band array is comprised of two parabolic antennas which occupy the same aperture. Each antenna reflector is 72 inches in diameter. The antenna platform is despun and Earth-oriented. Orthogonal linear polarization is the mode used by SBS satellites for signal processing. The SBS satellites provide spot beam coverage for CONUS only. They are not attenuated for Alaska or Hawaii coverage. Additionally, the CONUS coverage of these satellites is weighted to emphasize the eastern region of the United States. Figure 30 is a depiction of the footprints of the SBS 2 and SBS 3 satellites. (Martin, 1986, p. 135)

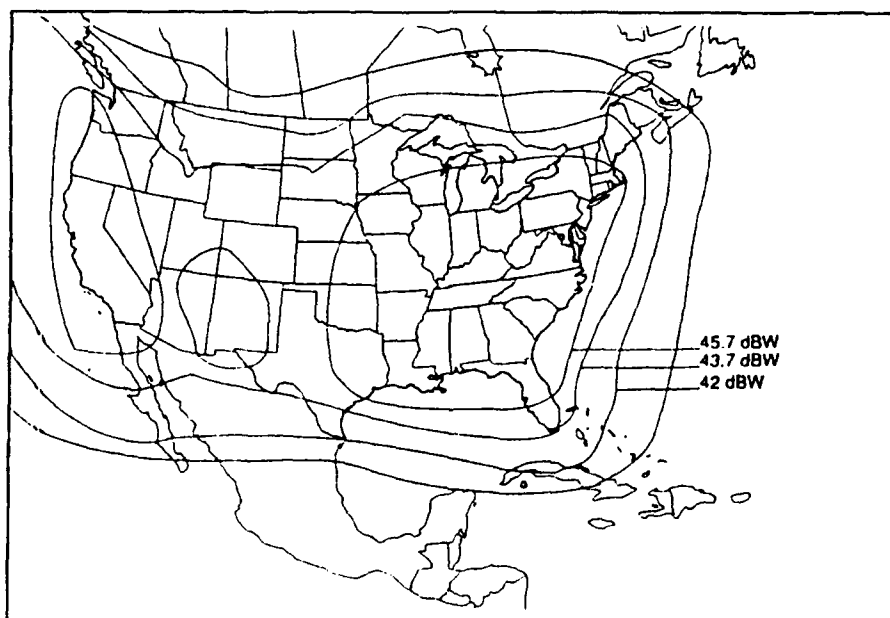


Figure 30. SBS 2 and SBS 3 Satellite Footprints

g. Performance Characteristics

(1) *Satellite Services.* The SBS 2 is primarily used to provide digital nonvideo telecommunications services. These services include high speed data transmission, facsimile service, electronic mail, and two-way business telephone conversations for CONUS coverage. The SBS 3 satellite on the other hand is mainly used for video type services. These include TV broadcasts, video teleconferencing, satellite news gathering services, and relaying video services. Additionally, the SBS 3 provides video programming to over 1500 hotels and motels nationwide. (Long, 1987, pp. 327-336)

(2) *Performance Parameters.* The total usable bandwidth provided by the ten operational transponders of each SBS satellite is 430 MHz. The bandwidth of a single transponder is 43 MHz. The RF power of each satellite is rated at 20 watts. Since the spot beam coverage over the eastern part of the United States is more powerful than over the rest of CONUS, performance parameters will be listed for both types. The minimum available EIRP for CONUS coverage is 37.0 dBW. The minimum EIRP over most of the eastern third of CONUS is 43.7 dBW. The minimum G/T for CONUS coverage is -5.5 dB/K. The minimum G/T over most of the eastern third of CONUS is +1.0 dB/K. The minimum saturation flux density for CONUS coverage is -80 dBW per square meter. The minimum saturation flux density over most of the eastern third of CONUS is -87 dBW per square meter. (Brown, 1981, p. 121)

(3) *Flexibility.* The SBS system utilizes digital, demand assigned TDMA links for all of its transmission services. Customers are largely served by means of sharing terminals with other customers in the same local area or via their own on-site terminals. SBS satellites have the capability to provide long-distance telephone service which is occasionally employed to accomodate residential customers.

Dedicated digital networks connecting multiple sites are the means by which the SBS system services its customers. The total network capacity can be allocated among various links in the SBS network to meet the changing needs of Comsat's customers on a long-term or daily basis as required. (Martin, 1986, p. 137)

E. GE AMERICOM

GE Americom was created in 1987 as a result of the acquisition of RCA Americom by General Electric. Subsequent to the GE acquisition, GE Americom began operations as part of the GE Communications and Service Group. Located in Princeton, New Jersey, the company provides service to both commercial and government customers through its fleet of Satcom satellites. GE Americom operates six Satcom series domestic communications satellites. Four of these Satcom series satellites operate at C-band and two operate at Ku-band. The company provides a host of services including: servicing cable TV, broadcast radio and TV, business information, and maintaining a supporting network of Earth stations, central terminal offices and TT&C facilities. Additionally, GE Americom installs, operates, and maintains dedicated Earth stations for government customers such as NASA, NOAA, and DoD. (Jane's Space Directory, 1993, p. 406)

In broadcasting, GE Americom is the leader in digital audio transmission services (DATS) for radio and a major player in the distribution of a wide range of broadcast video services. GE Americom satellites are widely used to distribute full-time and occasional video services, broadcast television and syndicated programming including network distribution for NBC. GE Americom is also a partner in Primestar which is a medium power direct-to-home satellite service. This service provides pay-per-view and superstation programming via the Ku-band to one meter home antennas over

Satcom K1. The company also distributes programming to: cable system headends throughout the United States via its C-band satellites. (GE American Communications, 1992, pp. 1-2)

In the business communications market, GE Americom supplies space segment services to private video and data communications networks and to video service users. GE American Communications provides a wide range of services to the government sector including private line voice, high-speed video and data, and a 50 Mb/s NASA data link for the Space Shuttle program. Internationally, the company provides connectivity with the Intelsat Atlantic Ocean Region (AOR) and Pacific Ocean Region (POR) as well as access to the PanAmSat satellite PAS-1. (GE American Communications, 1992, pp. 1-2)

GE Americom has FCC authorization to manufacture, launch, and operate two hybrid C-band/Ku-band satellites which are intended to provide successor capacity for GE Americom's current C-band and Ku-band customers. These two hybrid satellites are being constructed by Martin Marietta/GE Astro Space with the first satellite scheduled for a 1996 launch. Designated GE-1, the first of these hybrid satellites will replace Satcom K1 at 82 degrees west longitude and will provide more than twice the capacity of existing Ku-band satellites. (Jane's Space Directory, 1993, p. 372)

1. SATCOM Series (SATCOM 2R/C1/C3/C4)

a. Evolution of the Series

Following GE's 1987 acquisition of RCA Americom, GE Americom embarked on an aggressive program to replace the aging C-band satellite fleet. Of the original, on-orbit C-band satellites which GE Americom assumed ownership of, only Satcom 2R remains operational with its retirement expected in the near future. (Jane's Space Directory, 1993, p. 372)

Between 1990 and 1992 GE Americom launched four replacement 3000-class C-band satellites, Satcom C1, C3, C4, and C5. The first of these to be launched, Satcom C1, is currently operating as an on-orbit spare for the Satcom system. Next, in May 1991 Satcom C5 was launched to replace Satcom 5. Satcom C5 has since been transferred to and is operated by Alascom as Aurora 2. Satcom C4 was launched as a replacement for Satcom 4R in August 1992. Satcom 4R was launched in November 1984 by Telsat Canada and was originally designated Anik D2. This satellite was leased and subsequently redesignated Satcom 4R by GE Americom under a 1990 agreement. In April 1993, following the launch of Satcom C4, ownership of Satcom 4R reverted back to Telsat. Satcom C3 appeared in September 1992 to replace the retiring Satcom 1R. (Jane's Space Directory, 1993, p. 372)

b. Satellite Overview

The C-band Satcom satellites distribute programming to hotel/motel markets, and cable system headends. Satcom 2R provides service to CONUS and the Caribbean while Satcom C1, C3, and C4 provide services to CONUS, the Caribbean, Alaska and Hawaii (Long, 1991, pp. 475-640). The range of distributed cable entertainment services includes movies, news, sports, and variety programming. (GE Americom Communications, 1992, p. 2)

Telemetry, tracking, and control for the launch and transfer orbit phase of the C-band Satcom spacecraft is provided through the Astro Satellite Operations Control Center at East Windsor, New Jersey. GE Americom's own stations at Vernon Valley, New Jersey and South Mountain, California provide operational control. Telemetry data for Satcom C3 and C4 are encrypted to provide security of spacecraft functioning and stationkeeping. (Jane's Space Directory, 1993, p. 372)

Figure 31 is a graphic illustration of a RCA Satcom satellite. (Yenne, 1985, p. 129)

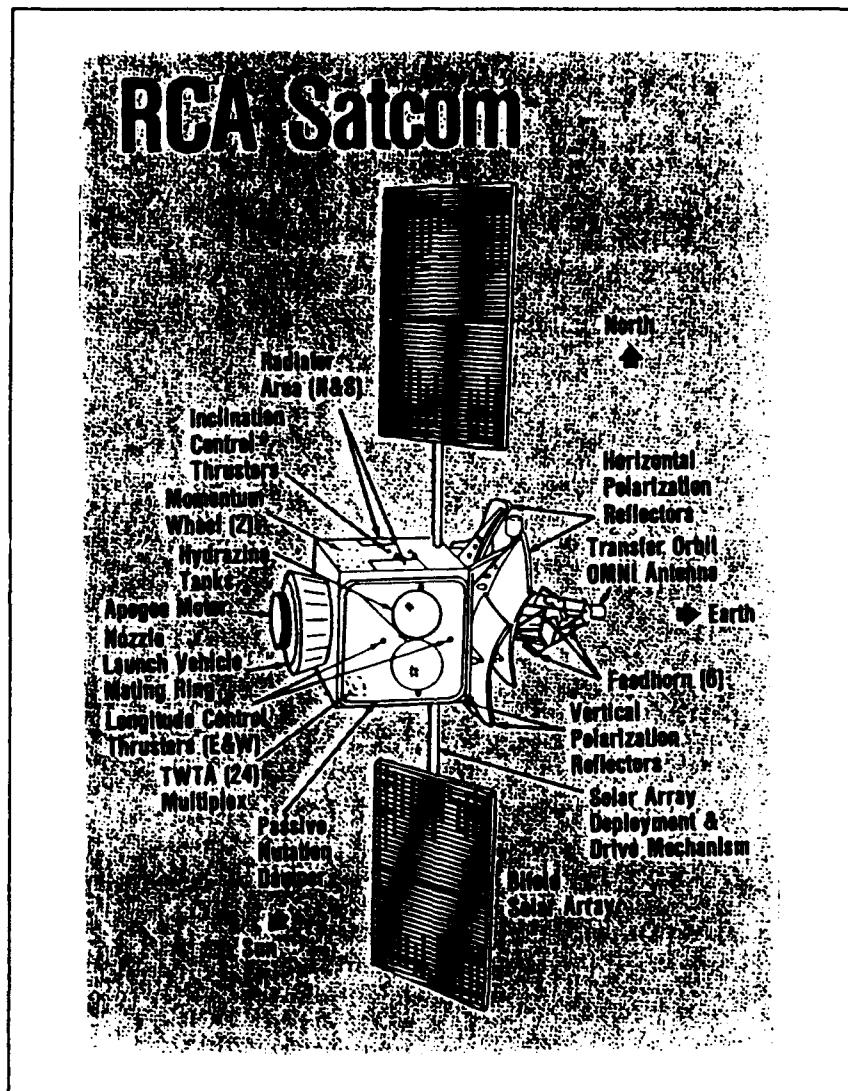


Figure 31. RCA Satcom Satellite

c. Orbital Parameters

(1) *Orbit.* All four C-band Satcom satellites are currently in geosynchronous equatorial Earth orbit. Stationkeeping for all satellites is rated at plus or minus 0.1 degrees in latitude and longitude. Satcom 2R is located at 72 degrees west longitude. Satcom C1 is located at 137 degrees west longitude. Satcom C3 is located at 131 degrees west longitude. Satcom C4 is located at 135 degrees west longitude. (The World Satellite Directory, 1993, p. 41)

(2) *Orbital History of the Series.* Satcom 2R was launched from Cape Canaveral, Florida, by Delta 3924 on September 8, 1983. Satcom C1 was launched from Kourou, French Guiana by Ariane 4 on November 20, 1990. Satcom C4 was launched from Cape Canaveral by Delta 7925 on August 31, 1992. Satcom C3 was launched from Kourou, by Ariane 4 on September 10, 1992. (Jane's Space Directory, 1993, p. 372)

d. Key Design Features

(1) *Configuration.* All four C-band Satcom satellites have twenty-four transponders with a bandwidth of 36 MHz. However, the redundancy schemes for the individual satellites vary. All C-band Satcom satellites use linear (vertical/horizontal) polarization. Satcom 2R and Satcom C1 utilize SSPAs to generate the required output power while Satcom C3 and C4 use TWTAs. (The World Satellite Directory, 1993, pp. 41-42)

(2) *Physical Characteristics.* All three C-band Satcom satellites utilize the GE 3000 series platform which is a three-axis-stabilized, box-shaped structure. Pitch stabilization for this platform is achieved via a 6000 rpm momentum wheel, while roll and yaw stabilization is provided by magnetic torquing (Jane's Space Directory, 1993, p. 372). Satcom 2R has a launch mass of 1120 kg, an on-station mass at the beginning of life (BOL) of 598 kg, and an end of life

(EOL) mass of 482 kg. Satcom C1 has a launch mass of 1169 kg and an on station BOL mass of 682 kg. Satcom C3 has a launch mass of 1375 kg and an on station BOL mass of 789 kg. Satcom C4 has a launch mass of 1402 kg and an on station BOL mass of 791 kg. The physical dimensions for C-band Satcom satellites are roughly 1.8 meters long, 1.6 meters in diameter, and 1.4 meters high. (Long, 1991, pp. 475-639)

System electrical power is provided by twin silicon solar arrays and nickel cadmium batteries for eclipse operation. Each of the two solar arrays are divided into three separate panels. The solar arrays on both the Satcom 2R and the Satcom C1 satellites provide about 1500 watts of power at BOL and approximately 1230 watts at EOL. Both spacecraft also carry three 24 ampere-hour nickel cadmium batteries. The BOL solar power supplied to Satcom C3 and C4 is 1950 watts while their EOL solar power is approximately 1400 watts. Both Satcom C3 and C4 carry two 50 ampere-hour nickel cadmium batteries. (Jane's Space Directory, 1993, p. 372)

(3) *Capacity.* The C-band Satcom satellites can carry up to twenty-four color TV channels. Satcom 2R which provides this service to CONUS and the Caribbean can carry up to 6000 one-way voice circuits, 64 Mb/s data, or two TV programs per repeater. Satcom C1, C3, and C4 provide services to CONUS, the Caribbean, Alaska and Hawaii. (Long, 1991, pp. 475-640)

(4) *Design Life.* The design life for Satcom 2R is 10 years with initial fuel capacity expected to be only 8.5 years (Long, 1987, p. 272). The design life for Satcom C1 is also 10 years. The design life for both Satcom C3 and C4 is 12 years. (The World Satellite Directory, 1993, p. 41)

e. Transmitters

The GE Americom C-band Satcom satellite transmitters operate between 3.700 and 4.200 GHz. Satcom 2R and C1 transponders use solid state power amplifiers (SSPAs) to generate their output power while the Satcom C3 and C4 satellites use traveling wave tube amplifiers (TWTAs). The SSPAs used by Satcom 2R and C1 each produce 8.5 watts of power and have bandwidths of 36 MHz. The more powerful TWTAs used by Satcom C3 and C4 produce 16 watts of output power. (The World Satellite Directory, 1993, pp. 41-42)

One transistor amplifier per transponder is used in the Satcom 2R satellite plus one spare for every six transponders. These transmitters deliver a CONUS beam edge EIRP of 39 dBW. The beam edge EIRP delivered by Satcom 2R for the Alaska operating region is 37 dBW while the Hawaii spot beam coverage is 26 dBW. (Martin, 1986, p. 131)

f. Receivers

The GE Americom C-band Satcom satellite receivers operate in the frequency band ranging from 5.9250 GHz to 6.4250 GHz. The receiver subsystem for Satcom 2R is comprised of four receivers, two of which are active and two of which are used as standbys. First stage amplification in the Satcom 2R receiver is achieved by field effect transistor (FET) preamplifiers with 3.5 dBW noise figures. (Martin, 1986, p. 131)

g. Antenna Farm

The GE Americom C-band Satcom satellite communications antenna package is comprised of two antennas. One of the communication antennas is used for horizontally polarized signals, during both transmit and receive operation, and the other is used for vertically polarized signals. Satcom C1 normally operates in the horizontal polarization mode, however it carries an on-board polarization switch. This polarization switch enables it to operate with vertically polarized signals

in any other C-band orbital slot in the GE Americom fleet if required for restoration purposes. (Long, 1991, p. 638)

Each of the two communication antennas carried on the C-band Satcom satellites has separate feed horns for the CONUS, Alaska, and Hawaii coverage regions. Satcom 2R uses seven feed horns for each polarization with 33 dB of isolation between the horizontally and vertically polarized signals. (Martin, 1986, pp. 131-132)

Figure 32 depicts the footprint of the Satcom 2R satellite in its current operating location. (International Satellite Directory, 1992, p. 9-210)

Figure 33 depicts the footprints of the Satcom C1 satellite in its current operating location. (Long, 1991, pp. 637-640)

Figure 34 depicts the footprints of Satcom C3, and C4 satellites in their current operating locations. (Long, 1991, pp. 637-640)

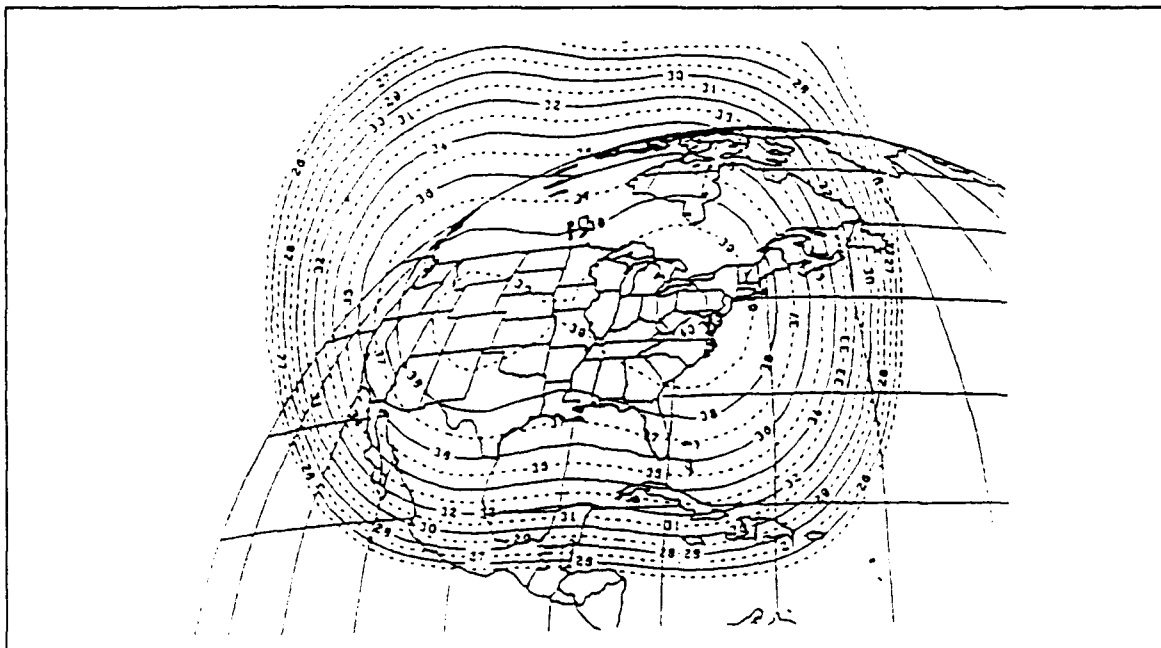


Figure 32. Beam Coverage of the Satcom 2R satellite

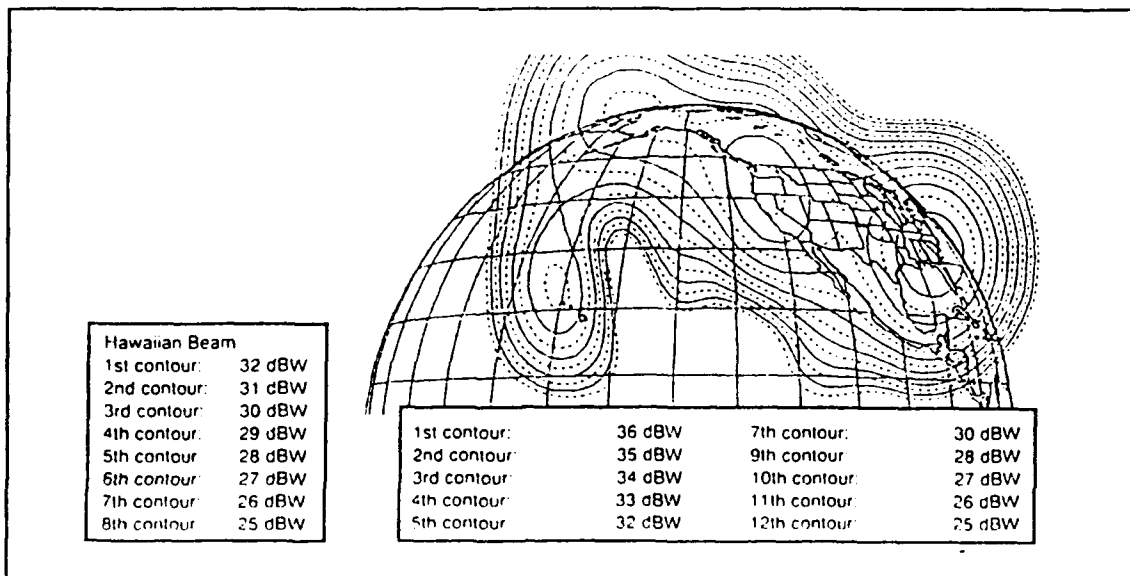


Figure 33 Beam Coverage of Satcom C1 Satellite

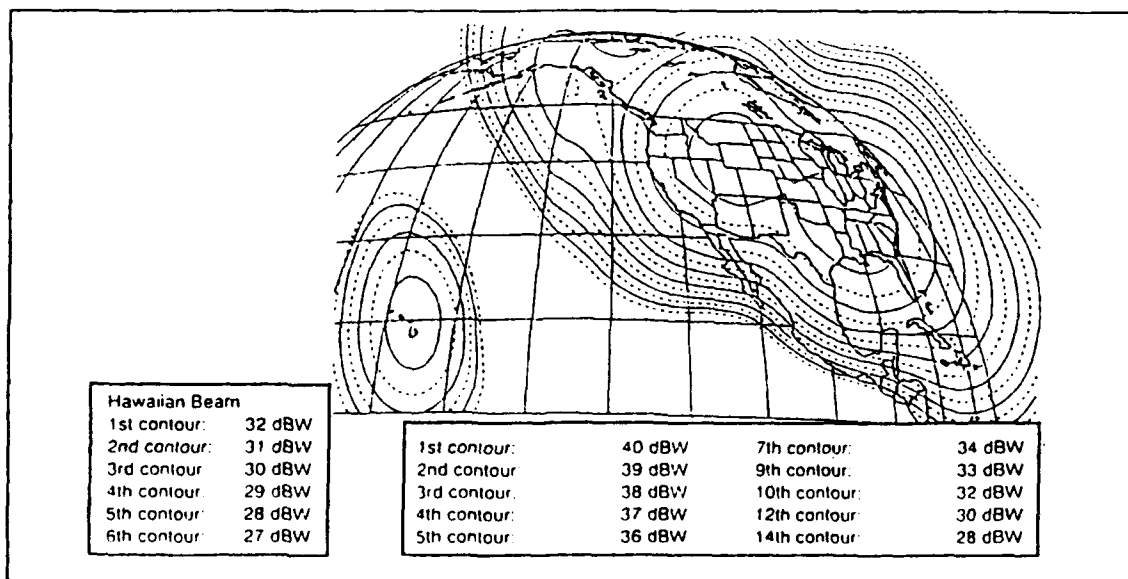


Figure 34 Beam Coverage of the Satcom C3 and C4 Satellites

h. Performance Characteristics

(1) *Satellite Services.* Satcom 2R is used for government video and data traffic, international video, broadcast services, and private networks in CONUS and the Caribbean. GE Americom uses this satellite to provide end-to-end customized networks for the United States government, including the National Aeronautics and Space Administration, the Department of Defense, and various civil agencies. Satcom C1 provides commercial video to three superstations of the Satellite Broadcast Networks: WBBM-TV (Chicago), WABC-TV (New York), and WXIA-TV (Atlanta). (Long, 1991, p. 475)

Satcom C1, which reaches approximately 15 million cable subscribers, provides coverage to CONUS, Hawaii, and Alaska. Satcom C1 services include TVRO entertainment, regional sports, and broadcast services. The specific video distribution services for regional sports networks includes the Sunshine Network (Florida), Home Sports Entertainment, Prime Sports Network-Rocky Mountain, Pacific Sports Network, Prime Sports Northwest, and Prime Ticket. The following six Netlink superstations are also carried on Satcom C1: WGN-TV, KUSA-TV, KCNC-TV, KMGH-TV, KWGN-TV, and KRMA-TV. (Long, 1991, p. 638)

Both Satcom C3 and Satcom C4 are dedicated to providing cable programming to the continental United States, Alaska, Hawaii, and the Caribbean. The programming carried on Satcom C3 includes: Arts & Entertainment, C-SPAN, Home Shopping Network, Jones Spacelink, Lifetime, Prime Network, QVC, The Family Channel, The Learning Channel, Viacom International, Viewer's Choice 1, Vision Interfaith Satellite Network, and The Weather Channel. Programming carried on Satcom C4 includes: C-SPAN 2, Home Shopping Network, Jones Spacelink, Lifetime, NUSTAR, QVC, Request TV 1 and 2, The Discovery Channel, The Family Channel, The Sci-Fi Channel, The

Travel Channel, Viacom International, Viewer's Choice 2, and WWOR. (Long, 1991, p. 636)

(2) *Performance Parameters.* The beam edge EIRPs for the different operating regions of Satcom C1 are: 36 dBW (CONUS), 33dBW (Alaska), and 32 dBW (Hawaii). The beam edge EIRPs for the different operating regions for both Satcom C3 and C4 are: 40 dBW (CONUS), 32 dBW (Alaska), and 32 dBW (Hawaii). (Long, 1991, pp. 636-640)

Table 6 lists the performance parameters of the Satcom R series. Note that Satcom 1R is no longer operational. Table 7 lists the performance parameters of the Satcom C series. (The World Satellite Directory, 1993, p. 42)

TABLE 6. SATCOM R SERIES PERFORMANCE PARAMETERS

Satellite Name	Satcom 1R, 2R
Longitude	131° W.L. (Satcom 1R) 72° W.L. (Satcom 2R)
Launch Vehicle	Delta 394
Manufacturer	GE Astrospace
Date of Launch	April 1983 (Satcom 1R) September 1983 (Satcom 2R)
Frequency Band(s) Transmit Receive	C band 3.700-4.200 GHz 5.300-6.400 GHz
Transponders Number Bandwidth Polarization	24 36 MHz Linear (vertical and horizontal)
Power Output SSPA	8.5 watts
Antenna Coverage (Beam Edge EIRP) Conus	36 dBW (Satcom 1R) 39 dBW (Satcom 2R)
Primary Power Watts ECL	1,227.9 (Satcom 1R) 1,193.2 (Satcom 2R)
Stabilization Type	3-axis
Mass (Kg. in Orbn)	480
Design Life (Years)	10

TABLE 7. SATCOM C SERIES PERFORMANCE PARAMETERS

Satellite Name	Satcom C-1, Satcom C-3*, Satcom C-4*, Satcom C-5 (see Alascom/Aurora II)
Longitude	137° W.L (Satcom C-1) 131° W.L (Satcom C-3) 135° W.L (Satcom C-4)
Launch Vehicles	Delta (Satcom C-1, C-2) Ariane (Satcom C-4)
Manufacturer	GE Astrospace
Date of Launch	November 1990 (Satcom C-1) September 1992 (Satcom C-3) August 1992 (Satcom C-4)
Frequency Band(s) Satcom C-1 Transmit Receive Satcom C-3 and Satcom C-4 Transmit Receive	C band 3.700-4.200 GHz 5.925-6.425 GHz 3.700-4.200 GHz 5.925-6.425 GHz
Transponders Number Bandwidth Polarization	24 36 MHz Linear (vertical and horizontal)
Power Output SSPA TWTA	8.5 watts (C-1) 16 watts (C-3 and C-4)
Antenna Coverage (Beam Edge EIRP) Satcom C-1 Conus Satcom C-1 and Satcom C-4 Conus	36 dBW 40 dBW
Primary Power Watts ECL	1,040 watts (C-1) 1,400 watts (C-3, C-4)
Stabilization Type	3-axis
Mass (Kg. In Orbit)	510 (C-1) 620 (C-3 and C-4)
Design Life (Years)	10 (C-1) 12 (C-3 and C-4)

2. SATCOM K-Band Series (K1/K2)

a. Evolution of the Series

GE Americom, which at the time was known as RCA Americom, entered into Ku-band satellite communications with its launch of Satcom K2 in 1985. The purpose for expanding into the Ku-band arena was to provide the United States broadcasting industry with medium power Ku-band capacity. This capacity removed the requirement for the national TV networks to maintain large terrestrial distribution systems to promulgate their programming to affiliate stations. (Stanyard, 1987, pp. 244-246)

A critical factor in their decision to proceed with the Satcom Ku-band concept was that RCA owned the NBC network. This arrangement made NBC the only major TV network to have instantaneous access to nearly every commercial TV station in the United States. As a result NBC had access to three times as many commercial TV stations as CBS or ABC. By putting this package together, GE Americom placed themselves in a dominant position in the broadcasting industry. This allowed them to bypass the traditional organizational arrangements in network broadcasting. Additionally, the Satcom Ku-band concept opened up the use of satellite news gathering services. Satellite news gathering allows news crews to instantaneously transmit footage back to their home station as well as to other stations nationally. (Stanyard, 1987, pp. 244-246)

Originally, GE Americom owned four Ku-band spacecraft, Satcom K-1, K-2, K-3, and K-4. Satcom K3, launched in September 1989, was to be operated by Crimson Satellite Associates, a GE Americom/Home Box Office partnership. Satcom K4 provided GE Americom with a ground spare. While Satcom K1 and K2 are still owned and operated by GE Americom, Satcom K3 and K4 were sold by the company in 1989. After the GE Americom/Home Box Office partnership dissolved, Satcom K3 was sold to SES and redesignated as the Astra 1B. Satcom K4 was

sold the same year to Intelsat and was subsequently launched in 1992 as Intelsat K. (Wilson, 1992, p. 406)

b. Satellite Overview

The Satcom K series are among the most powerful commercial Ku-band satellites in operation today. Their implementation allows very small aperture receive-only antennas to be used for both video and data services. Satcom K1 is used primarily by PrimeStar Partners L.P. to deliver its medium power Ku-band direct broadcast service throughout the United States. Satcom K2, which has the largest dedicated antenna base in commercial broadcast television, is used to distribute NBC programming to more than 200 affiliate stations as well as provide news gathering services for NBC and CONUS communications. (Long, 1991, pp. 485-486)

The two GE Americom Ku-band satellites have an outward appearance similar to that of the Satcom C series, however, internally the Ku-band satellites are quite different. The stabilization subsystem on the Ku-band spacecraft has been improved to provide greater pointing accuracy. The catalytic hydrazine thrusters of the Satcom C satellites have been replaced with electrothermal hydrazine thrusters to allow for more efficient stationkeeping maneuvers. Heat pipes have replaced heat spreaders on the north and south faces of the body, where the communications subsystem is mounted. This improves thermal control while reducing weight. Finally, the solar array on the Satcom K satellites has four panels per side, rather than three. This is due to the increased power requirements of the communication subsystem on the Ku-band compared to that of the C-band satellites (Martin, 1986, p. 132). Figure 35 is a graphic illustration of a Satcom Ku-band satellite. (Satellite News AH, 1987, p. 1)

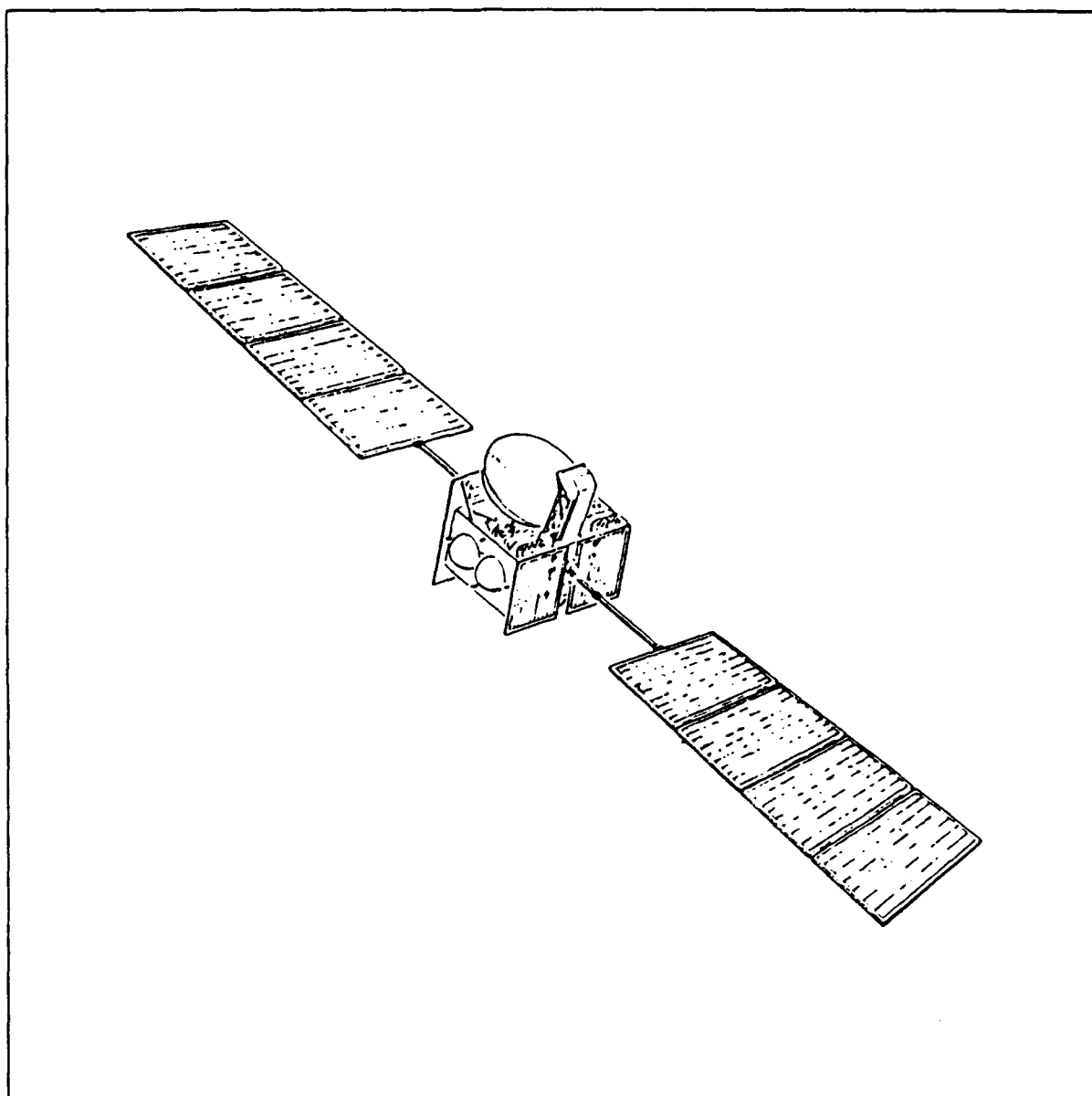


Figure 35. Satcom Ku-band satellite

c. Orbital Parameters

(1) *Orbit.* Currently, both the Satcom K1 and Satcom K2 spacecraft are in geosynchronous equatorial Earth orbit. Satcom K1 is located at 85 degrees west longitude. Satcom K2 is located at 81 degrees west longitude. Stationkeeping for both satellites is rated at plus or minus 0.1 degrees in latitude and longitude. (International Satellite Directory, 1992, p. 9-229)

(2) *Orbital History of the Series.* The first Satcom Ku-band satellite placed into orbit was Satcom K2. This spacecraft was launched from Launch Complex 39A, Eastern Range, Cape Canaveral, Florida on November 27, 1985 by Space Shuttle Atlantis. This was followed by the launch of Satcom K1 on January 12, 1986. Satcom K1 was also launched into orbit by space shuttle. (International Satellite Directory, 1992, pp. 9-226 - 9-229)

d. Key Design Features

(1) *Configuration.* Each Satcom K satellite is comprised of sixteen 54 MHz transponders operating at Ku-band. The transponders operate between 11.700 and 12.200 GHz on the downlink and between 14.000 and 14.500 GHz on the uplink. The downlink signals are horizontally polarized, while the uplink signals are vertically polarized. These satellites use 47 watt TWTAs to provide regional beams covering either the eastern or western regions of the contiguous United States. The separation between these regional beams is approximately a line from the western half of Minnesota to the western tip of Texas. Full CONUS beam coverage is also available. Within the communications subsystem, the transponders operate in two groups of eight. Additionally, there are three spares for each group of eight transponders. (Martin, 1986, pp. 132-134)

(2) *Physical Characteristics.* The GE Americom Ku-band satellites employ the GE Astro Space 4000 class platform. Spacecraft on-station mass is 1021 kg at the beginning of life with a dry mass of approximately 780 kg. The spacecraft are three-axis-stabilized by a high speed, 6000 rpm momentum wheel. Spacecraft pitch axis control is maintained by ground-controlled changes to momentum wheel velocity. Roll and yaw axes control, as well as nutation damping, is maintained by magnetic torquing. (Satellite News AH, 1987 p. 12)

The spacecraft electrical power system (EPS) provides sufficient power to meet the requirements of the spacecraft transponders and support systems. The EPS provides 3000 watts at the beginning of life with all transponders operating at saturation and a full 2650 watts after ten years. Backup power is provided by two parallel, 40 ampere-hour nickel hydrogen batteries. Each battery contains 22 cells, of which one cell in each battery may be shorted or open without degrading system performance. (Satellite News AH, 1987, p. 12)

(3) *Capacity.* The Satcom K series satellites have sixteen Ku-band transponders which operate from 14.000 to 14.500 GHz on the uplink and from 11.703 to 12.198 GHz on the down link. Channel bandwidth is 54 MHz and linear (horizontal/vertical) polarization is used. (International Satellite Directory, 1993, p. 12-288)

(4) *Design Life.* The design life for the Satcom K satellites is 10 years. (Long, 1991, p. 487)

e. Transmitters

The GE Americom Ku-band satellite transmitters operate between 11.703 and 12.198 GHz, with all downlink signals being horizontally polarized. The transmitters consist of sixteen 47 watt traveling wave tube amplifiers (TWTAs) which have a bandwidth of 54 MHz. The 47 watt TWTAs

deliver a maximum EIRP of over 50 dBW, giving customers the option of transmitting regional east and west beams or a full CONUS beam. The east beam provides for a minimum EIRP of 39 dBW, with most areas providing 45 to 47 dBW. The west beam delivers a minimum EIRP of 45 dBW, with most areas providing 46 to 48 dBW. The minimum EIRP delivered by the CONUS beam is 38 dBW, with more than ninety-five percent of the coverage being greater than 43 dBW. (Martin, 1986, pp. 132-133)

Channels are separated into two groups of eight transponders with each channel utilizing active frequency and polarization interleaving to permit simultaneous use. Each of the satellites has an additional three TWTAs per eight transponders for a total of six spare TWTAs carried on each satellite. Two sets of output multiplexers are combined through a power divider network to split the power fed into the feed horn arrays mounted on the spacecraft's Earth-oriented antenna structure. This provides the appropriate antenna pattern for continental United States coverage. (Satellite News AH, 1987, p. 13)

f. Receivers

The GE Americom Satcom K satellite receivers operate on vertically polarized signals between 14.000 and 14.500 GHz. The receiver subsystem for each satellite is comprised of four receivers, two are active and two are standbys. The first stage amplifier in the receiver is a thermoelectrically cooled FET preamplifier with a 2 dB noise figure. This marks the first time a thermoelectric cooler was used in a long-life communications satellite. (Martin, 1986, p. 133)

g. Antenna Farm

The GE Americom Satcom K series antenna package consists of two reflectors, one of which is used for horizontally polarized signals and one of which is used for vertically polarized signals. Each reflector has nine feed horns for east coverage and five feed horns for west coverage. All fourteen feed horns, which are arranged on the Earth-oriented spacecraft structure, are used for full CONUS coverage. Two sets of output multiplexers are combined through a power divider network to split the power into the feed horn array thus providing the desired antenna coverage pattern. (Satellite News AH, 1987, p. 12)

The antenna system is comprised of a single orthogonally-gridded, offset, parabolic elliptical aperture reflector antenna using a thermally stable Kevlar epoxy structure containing a honeycomb core. The antenna aperture and feed array are selected to optimize downlink communications performance. A reduced portion of the reflector utilizes orthogonal polarization, thus permitting independent optimization of the uplink antenna performance. (Satellite News AH, 1987, p. 13)

The Satcom K series attitude control system maintains spacecraft antenna alignments to within plus or minus 0.07 degrees in the north-south and east-west axes. Antenna-Earth orientation is maintained by an auxiliary control loop and rate gyros. These are activated for about forty minutes every two weeks to pulse modulate the stationkeeping control system thrusters. This provides compensation for antenna misalignments and disturbances created during stationkeeping maneuvers. (Satellite News AH, 1987, p. 13)

The Satcom K series command, ranging, and telemetry subsystem, operating at 14.0015 GHz, utilizes an omni-direc-

tional antenna through the launch phase and initial orbital operations. (Satellite News AH, 1987, p. 13)

Figure 36 depicts the footprint of Satcom K1 and Figure 37 depicts the footprint of Satcom K2. (International Satellite Directory, 1993, p. 12-289)

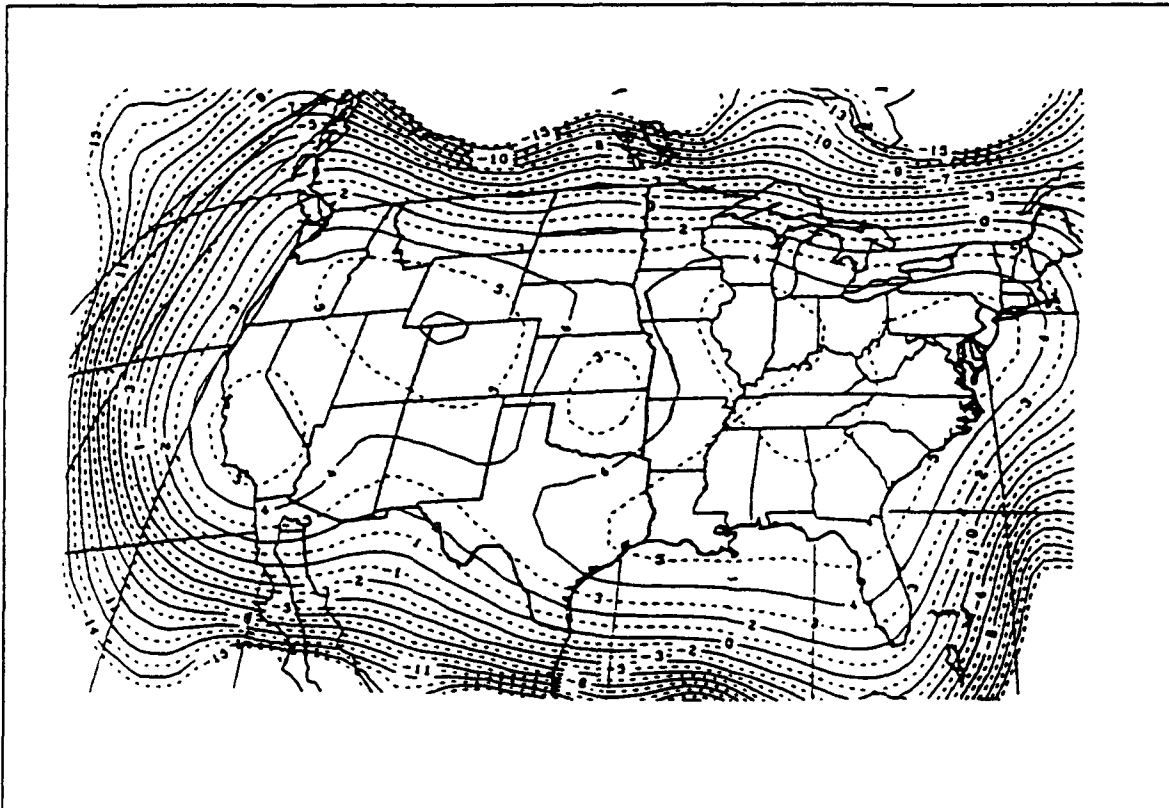


Figure 36. Satcom K2 Footprint

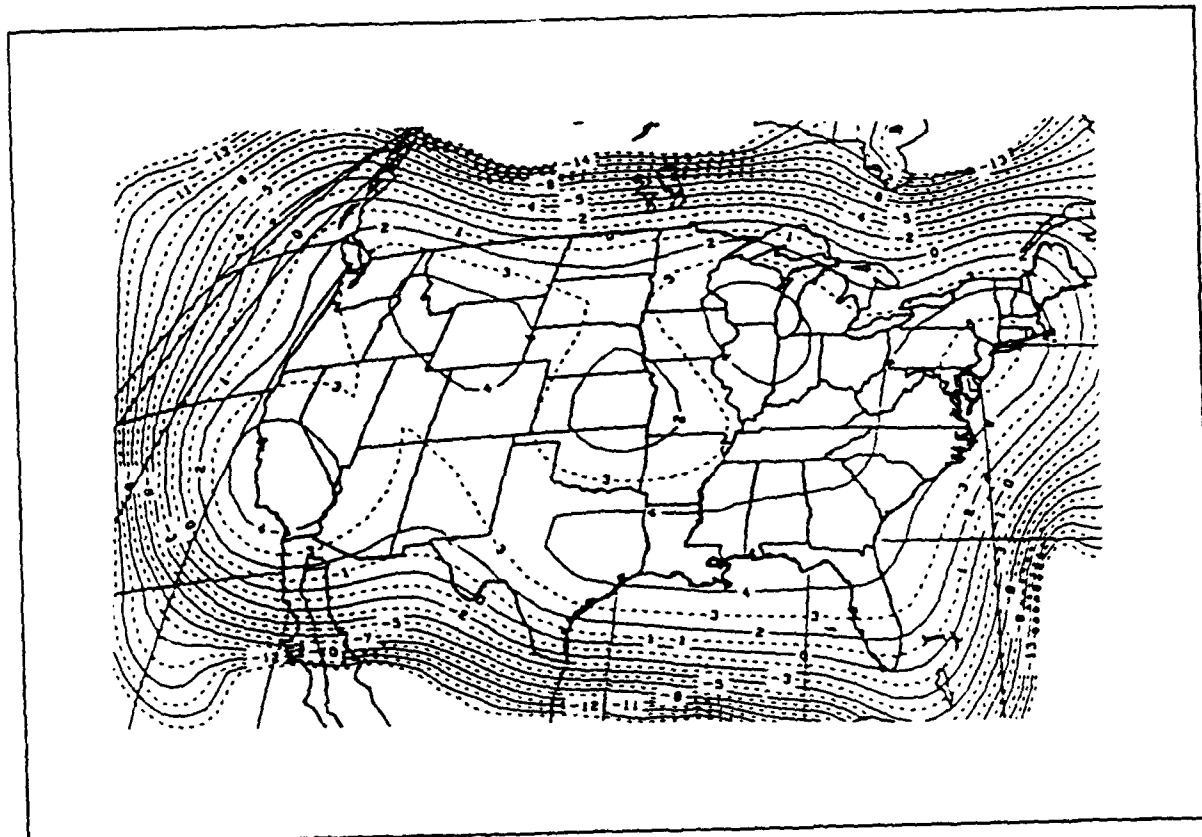


Figure 37. Satcom K2 Footprint

h. Performance Characteristics

(1) *Satellite Services.* Satcom K1 provides Direct Broadcast Satellite (DBS) and business video and data network services (GE American Communications, 1992, p. 5). Satcom K1 is primarily used by PrimeStar Partners L.P. to deliver its medium power Ku-band direct broadcast service throughout the United States to home antennas which are approximately one meter in diameter. The PrimeStar service offers three pay-per-view channels, seven superstations, and

TV Japan. The three pay-per-view channels are Request TV and Viewer's Choice I and II. The seven superstations are WTBS-TV (Atlanta), WGN-TV (Chicago), WPIX-TV and WWOR-TV (New York), WSBK-TV (Boston), KTLA-TV (Los Angeles), and KTVU-TV (San Francisco). TV Japan is a premium service providing Japanese news, entertainment, and cultural programming to Japanese citizens living in the United States. Finally, Satcom K1 also serves the commercial marketplace, with capacity used by customers such as Private Satellite Network, a business television system integrator, and various VSAT data networks. (Long, 1991, p. 485)

Satcom K2 provides network television and program distribution, business video/data networks, and private audio/data network services (GE American Communications, 1992, p. 5). Satcom K2 customers include NBC, NBC affiliated stations, CONUS Communications, and Cyclesat. This satellite also serves commercial customers such as Microspace, AT&T and various private VSAT data networks. (Long, 1991, pp. 485-486)

NBC uses multiple Satcom K2 transponders to distribute programming to over two hundred affiliated stations. Additionally, the Satcom K2 is used for satellite news gathering. The NBC network is fully automated, with NBC headquarters in New York remotely controlling satellite reception. CONUS Communications uses two Satcom K2 transponders for satellite news gathering, special events, and a daily news exchange among United States TV stations and cable systems. Cyclesat uses Satcom K2 transponders to allow advertising agencies to distribute advertisements directly to commercial TV and to provide satellite news gathering services. Microspace is a provider of private audio/data networks. AT&T uses Satcom K2 for its VSAT and business television services. (Long, 1991, pp. 485-486)

(2) *Performance Parameters.* Table 8 lists the performance parameters of the Satcom K series including launch, frequency bands, transponder data and coverage EIRP. (The World Satellite Directory, 1993, p. 43)

TABLE 8. PERFORMANCE PARAMETERS

Satellite Name	Satcom K-1 and Satcom K-2
Longitude	85° W.L (Satcom K-1) 81° W.L (Satcom K-2)
Launch Vehicle	STS
Manufacturer	GE Astrospace
Date of Launch	November 1985 (Satcom K-1) January 1986 (Satcom K-2)
Frequency Band(s) Transmit Receive	Ku band 11.700-12.200 GHz 14.000-14.500
Transponders Number Bandwidth Polarization	16 54 MHz Linear (vertical and horizontal)
Power Output TWTAs	47 watts
Antenna Coverage (Beam Edge EIRP) Conus	45 dBW
Primary Power Watts EOL	2,490
Stabilization Type	3-axis
Mass (Kg. in Orbit)	780
Design Life (Years)	10

(3) *Flexibility.* Each transponder has a variable power divider following the TWTA in the communications subsystem. This variable power divider can split the power to provide separate east and west spot beams, or it can supply the power to both to provide for full CONUS coverage. (Martin, 1991, p. 132)

F. GTE SPACENET CORPORATION

The GTE SPACENET Corporation was formed in 1983 by a merger which combined the Southern Pacific Satellite Company with the GTE Satellite Corporation. The GTE Satellite Corporation was formed in 1972, and its first major telecommunications project involved a teamed effort with AT&T to build and operate seven earth stations which became fully operational in 1976. In 1980 GTE's proposed GSTAR satellite system was authorized by the FCC. Meanwhile, the SPACENET satellite system of Southern Pacific had also received authorization from the FCC to proceed. GTE SPACENET currently operates a satellite constellation comprised of nine satellites in geosynchronous Earth orbit. Five of these satellites are C-band/Ku-band hybrid satellites (SPACENET series and ASC1) and four are Ku-band satellites (GSTAR series). (GSTAR System Summary, 1991, pp. 1-2)

The SPACENET and GSTAR satellite systems were started to provide long distance telephone service for GTE's clientele. Today, these satellite systems have been expanded to provide a variety of different services. Business television in various configurations, such as one-way video broadcast with two-way audio, stand-alone video transmission, and video overlay to data networks, are just a few of the options now available via this medium. Distance learning services and satellite news gathering services are also key features available on these satellite systems. For communications services, GTE's Skystar Network services features Interactive

Data Services, Metered Channel Services, and Broadcast Data Services. Interactive Data Services provide two-way digital communications services to customers that rely on centralized data processing. Metered Channel Services allow full-time or switched connectivity for high-speed communications, video, image, text, supporting data, and voice transmission. Broadcast Data Services provide for one-way transmission of information to multiple locations via the use of spread spectrum techniques. (Long, 1991, pp. 592-595)

1. GSTAR Series (GSTAR I/II/III/IV)

a. Evolution of the GSTAR Series

In 1980 the GTE Corporation received authorization from the FCC to build and operate the GSTAR satellite network. This network is currently comprised of four Ku-band communications satellites in geosynchronous Earth orbit. The GSTAR satellites hold the distinction of being the first domestic Ku-band satellites to offer wideband area coverage to all 50 states and high-powered spot beam coverage to either the eastern or western region of the continental United States. (World Satellite Directory, 1993, p. 54)

b. Satellite Overview

GSTAR satellites are three-axis stabilized, single frequency, communication satellites used to provide voice, video, and data transmission services at Ku-band frequencies (14/12 GHz). There are sixteen operational 54 MHz transponders allocated to each GSTAR satellite. Frequency reuse enables approximately 1000 MHz of useable bandwidth. Additionally, these satellites have a variety of different coverage options, which includes 50-state coverage and a ground-commandable east or west regional beam coverage. The regional beam coverage has the advantage of allowing higher traffic throughput, higher availability, and permits the use of smaller earth station antennas within the regional beam coverage than in the 50-

state coverage. Each satellite in the series employs two offset Ku-band antennas. Also, redundant receivers are provided on a 4-for-2 basis. Figure 38 is a graphic illustration of a GSTAR satellite. (GSTAR System Summary, 1991, pp. 1-3)

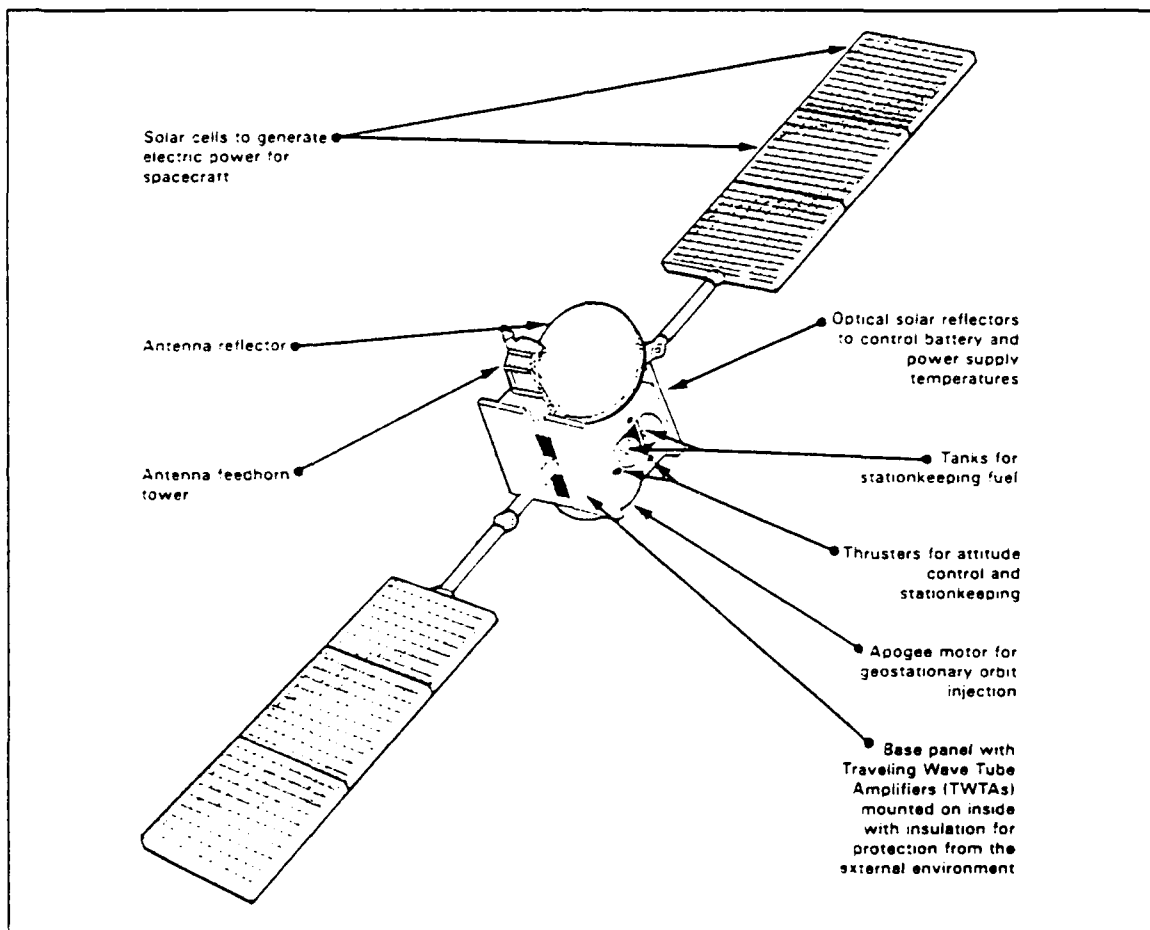


Figure 38. The GSTAR Satellite

c. Orbital Parameters

(1) *Orbit.* All GSTAR satellites are in a geosynchronous equatorial Earth orbit except GSTAR III. GSTAR III is in a 4.3 degree inclined geosynchronous Earth orbit. Stationkeeping for all satellites is rated at plus or minus 0.05 degrees in latitude and longitude. GSTAR I is located at position 103 degrees west longitude. GSTAR II is located at 125 degrees west longitude. GSTAR III is located at 93 degrees west longitude. GSTAR IV is located at 105 degrees west longitude. (World Satellite Directory, 1993, p. 54)

(2) *Orbital History of the Series.* GSTAR I was launched in May of 1985. GSTAR II was launched in March of 1986. GSTAR III was launched in September of 1988. GSTAR IV was launched in November of 1990. All satellites of this series were launched into orbit via Ariane launch vehicles. (World Satellite Directory, 1993, p. 54)

d. Key Design Features

(1) *Configuration.* Each GSTAR satellite has sixteen 54 MHz transponders operating at Ku-band. Fourteen transponders use 20 watt TWTAs to provide ground-commandable east or west regional, or CONUS coverage. The other two transponders provide 50-state coverage using 27 watt TWTAs. For the 50-state transponders, one spare 27 watt TWTA provides protection for the two operating TWTAs allowing 3-for-2 redundancy. For the remaining transponder channels, five spare 20 watt TWTAs provide protection for fourteen operating TWTAs allowing 19-for-14 redundancy. (GSTAR System Summary, 1991, pp. 2-4)

Each transponder can be operated in either the limiter or the linear mode. The linear mode is usually used for multi-carrier operation. The transponder is stabilized at peak saturation in the limiter mode for any value of flux density illumination within 15 dB of that required for linear

mode saturation at a given attenuator gain setting. The limiter mode is commonly used in single-carrier operations where uplink rain factors play a significant interference role. Additionally, the GSTAR III carries an L-band communications payload. (GSTAR System Summary, 1991, pp. 2-4)

(2) *Physical Characteristics.* GSTAR satellites are of the GE Astro 3000 model bus design. They are three-axis stabilized, box-shaped platforms with dimensions of 163 cm x 132 cm x 99 cm. Additionally, GSTAR satellites have a 14.33 meter solar array and two 1.58 meter parabolic offset antenna reflectors. The satellite mass is 1270 kilograms at launch and 759 kilograms on-station at the beginning of life. Three-axis stabilization is applied via momentum wheels and magnetic torquers. GSTARs are also equipped with twin silicon solar arrays of three panels each as well as nickel hydrogen batteries which provide electric power to the satellite on the order of 1750 watts at the beginning of life and a minimum of 1352 watts at the end of life. (Interavia, 1992, p. 407)

(3) *Capacity.* A typical GSTAR satellite has the capacity for 30,000 simultaneous telephone circuits or 16 TV channels (Long, 1987, p. 365). A full transponder on a GSTAR satellite is capable of handling a maximum of either 60 Mb/s or 90 Mb/s. The latter QPSK service utilizes the spot beam transponder (Stanyard, 1987, p. 154). Efficient use of the communications capacity on the GSTAR satellites is achieved through the use of digital transmission techniques. The customer inputs are effectively digitized prior to transmission through the system. A time division multiple access plan then takes those digitized signals and assimilates them into a burst mode transmission system. The transmission scheme is periodically reconfigured so that satellite capacity can be allocated in proportion to the traffic requirements of each earth station. (Long, 1991, p. 554)

(4) *Design Life.* The design life for GSTAR I, GSTAR II, and GSTAR IV is ten years. The design life for GSTAR III is six years. (GSTAR System Summary, 1991, p. 1)

e. Transmitters/Receivers

GSTAR satellites provide transmit/receive coverage at Ku-band (14/12 GHz) through shaped beams and switched channels. There are a total of sixteen channels per satellite; eight are horizontally polarized and eight are vertically polarized. The uplink frequency ranges from 14.0 to 14.5 GHz and the downlink frequency ranges from 11.7 to 12.2 GHz. Receive coverage is centered over CONUS. Through the use of two of the eight horizontally polarized transmit channels, added coverage of Alaska and Hawaii is also feasible. Transmit coverage may take place through dual-polarized CONUS, east or west half CONUS, or spot beams. The horizontally polarized spot beam is centered on the Northeastern United States while the vertically polarized spot beam is centered on California. In order to reduce rain depolarization both polarizations have been rotated twenty-six degrees clockwise when facing the Earth. (Long, 1991, pp. 502-503)

The GSTAR III satellite has a unique L-band communications subsystem that can receive signals from CONUS, Central America, and the Caribbean. The Geostar Corporation used this capacity (until it went bankrupt in 1991) to receive Radio Determination Satellite Service (RDSS) signals from Geostar units on the Earth. (Long, 1991, p. 502)

f. Antenna Farm

The antenna subsystem is comprised of two offset parabolic reflectors. GTE is able to achieve a high degree of polarization purity in the GSTAR series through the utilization of grids embedded in each of these reflectors which are transparent to the opposite sense of polarity. (Long, 1991, p. 554)

The various coverage patterns of the parabolic antennas have been detailed in the previous section. Figures 39, 40, 41, 42, and 43 depict the various spot beam coverages of each GSTAR satellite in the current operational system. (World Satellite Directory, 1993, pp. 44-48)

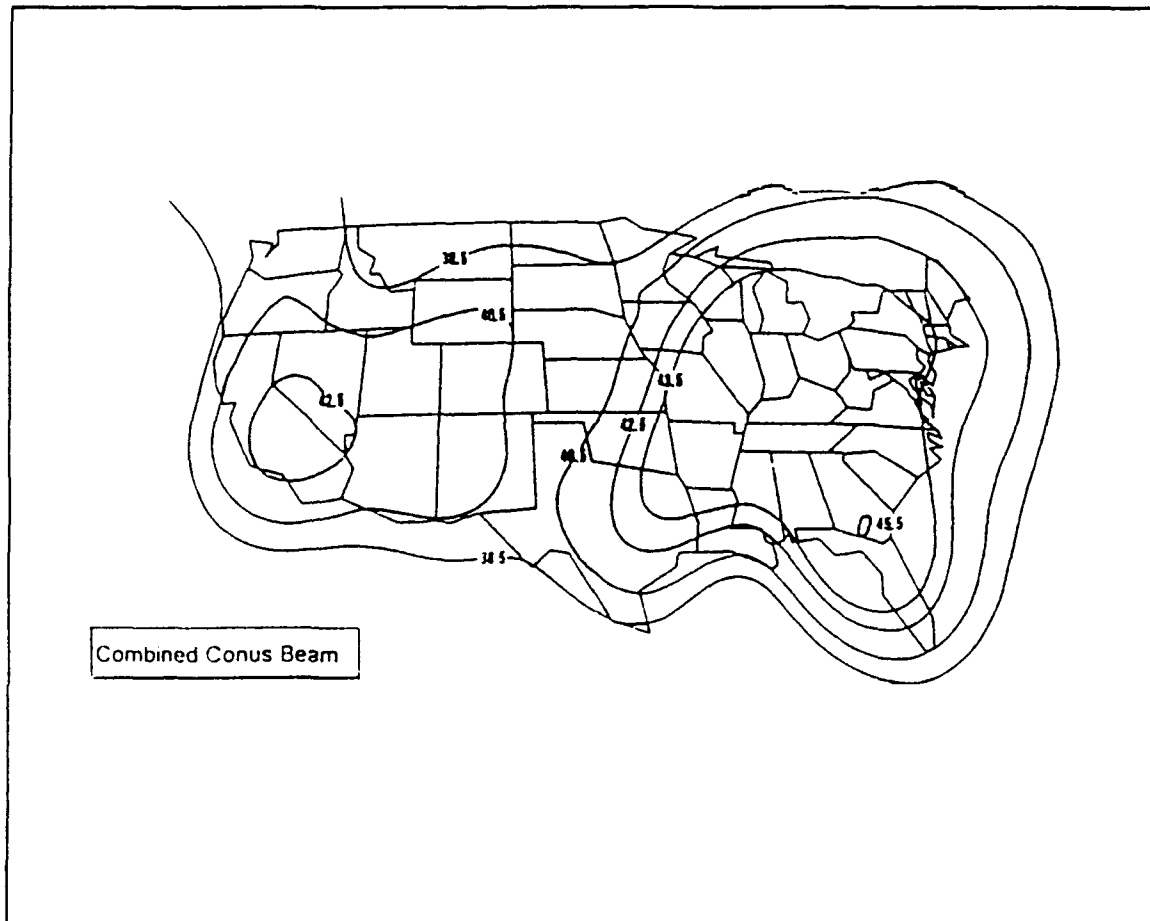


Figure 39. GSTAR I and II Combined Conus Beam Coverage

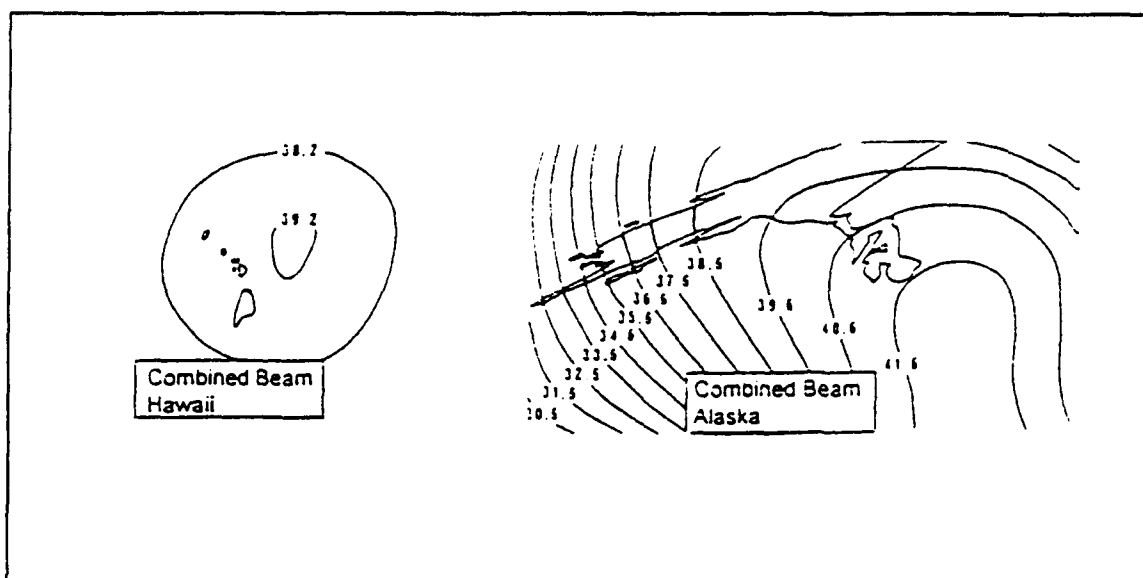


Figure 40. GSTAR I and II Combined Beam Alaska and Hawaii Coverage

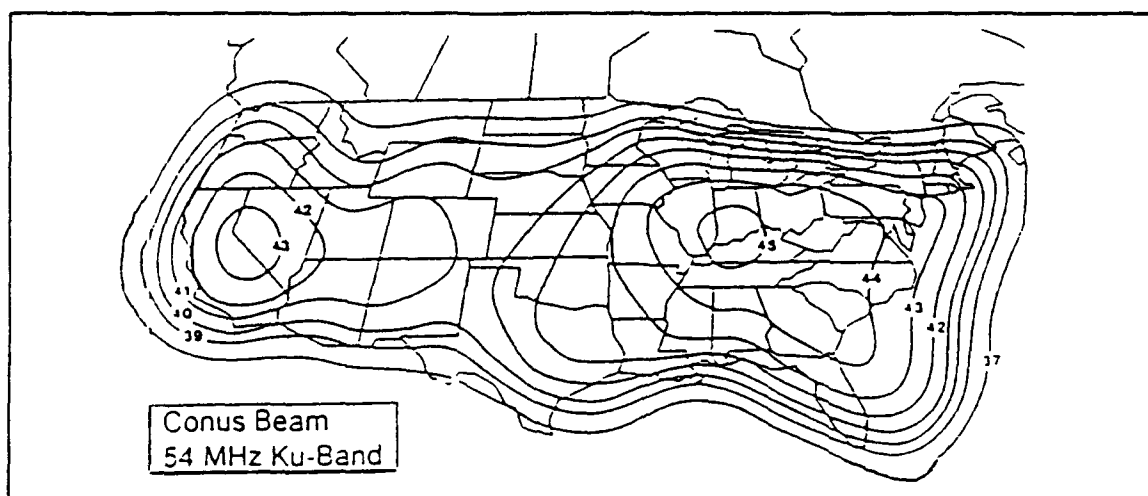


Figure 41. GSTAR III CONUS Beam Coverage

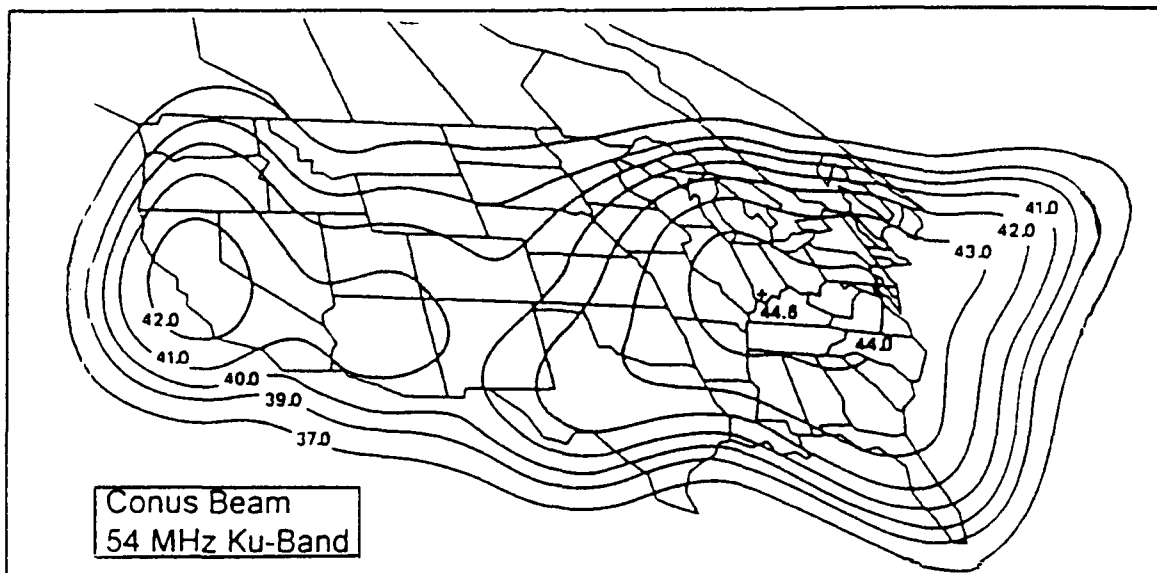


Figure 42. GSTAR IV CONUS Beam Coverage

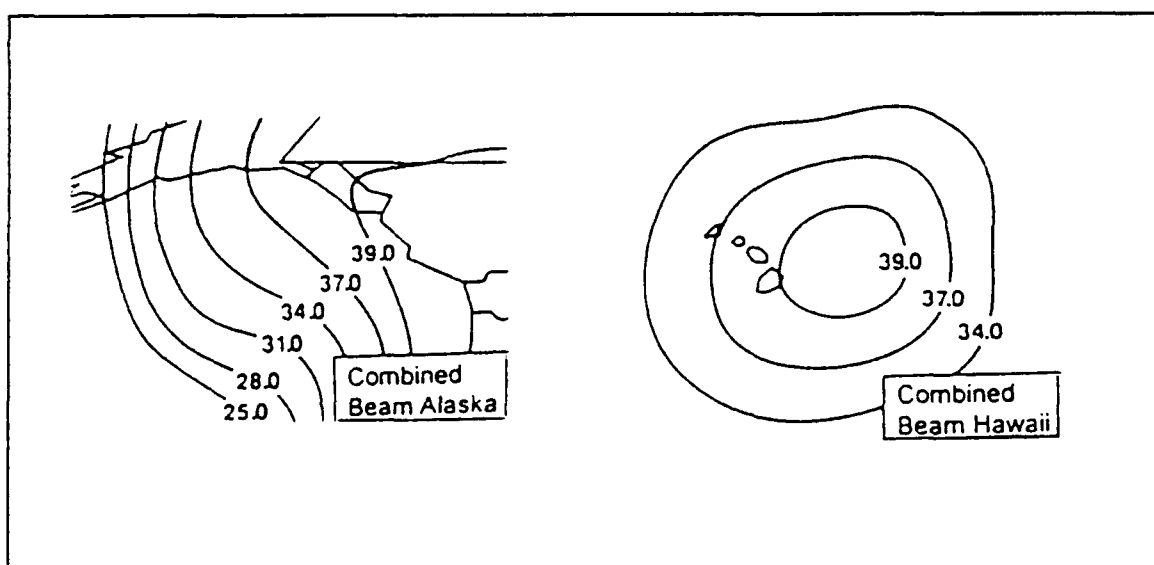


Figure 43. GSTAR IV Combined Beam Alaska and Hawaii Coverage

g. Performance Characteristics

(1) *Satellite Services.* The Skystar Network Services of GTE Spacenet accomodate the transmission of video and data to multi-site corporations and organizations throughout the United States. This set of services basically links very small aperture terminals (VSATs) which can be located on the user's premises with Ku-band transmission from the GSTAR constellation of satellites. Additionally, the Skystar system incorporates multipoint data services to transmit one-way digital data to many locations simultaneously as well as other forms of interactive data services. Two-way digital communication services are also provided for businesses that rely heavily on centralized data processing. Skystar Network Services utilize centralized earth station hubs to transmit data to their required network locations. Hub options range from compact types for networks consisting of 25-300 customer locations to large hubs for networks comprised of greater than 300 customer locations. (World Satellite Directory, 1993, pp. 45-46)

A proprietary voice system, known as the News Express Communicator, allows satellite news gathering customers to access any telephone in the world over the GSTAR II, GSTAR III, and GSTAR IV satellites. In addition to voice capability, the GSTAR system supports 1200 Baud rate data transmission. (World Satellite Directory, 1993, p. 46)

Lower rate channels routed through the GSTAR system are also offered by GTE SPACENET according to customer requirements. These are offered at three different bit rates, GDD-1 at a bit rate of 4.8 Kb/s, GDD-2 at a bit rate of 9.6 Kb/s, and GDD-3 at 56 Kb/s. These channels are designed for realtime computer-to-computer links, remote job entry, electronic mail, and fax transmissions. (Stanyard, 1987, p. 154)

(2) *Performance Parameters.* Tables 9, 10, 11, and 12 provide a comprehensive listing of EIRP and G/T performance parameters for each satellite in the GSTAR series according to type of beam coverage and location of the coverage.

TABLE 9. GSTAR I PERFORMANCE PARAMETERS

City	50-State EIRP (dBW) Transpd 1, 3	CONUS EIRP (dBW) Transpd 2, 4-16	G/T (dB/K) Transpd 1-16	SFD (dBW/m ²) Transpd 1-16
Atlanta	45.0	44.2	2.5	-95.6
Boston	43.3	43.1	2.3	-95.4
Buffalo	44.0	42.9	1.9	-95.0
Chicago	44.8	43.7	3.6	-96.7
Corpus Christi	40.4	40.5	-1.2	-91.9
Dallas	43.6	42.6	1.3	-94.4
Denver	41.6	40.8	0.4	-93.5
Houston	42.2	41.7	1.1	-94.2
Las Vegas	43.2	42.0	1.0	-94.1
Los Angeles	43.1	42.0	0.4	-93.5
Melbourne	43.9	43.0	1.8	-94.9
Miami	41.1	40.6	-0.5	-92.6
Minneapolis	40.8	41.4	0.1	-93.2
Nashville	44.9	44.4	2.3	-95.4
New York	43.7	43.8	2.8	-95.9
Phoenix	41.8	41.2	0.7	-93.8
Portland, ME	43.4	42.5	2.0	-95.1
San Francisco	42.6	42.0	0.4	-93.5
Seattle	41.2	39.8	0.0	-93.1
St. Louis	45.1	44.6	3.3	-96.4
Wash., D.C.	43.8	44.1	2.9	-96.0
Anchorage	39.3		-2.9	-90.2
Fairbanks	38.9		-3.8	-89.3
Honolulu	38.9		-2.8	-90.3
Nome	39.0		-3.0	-90.1

TABLE 10. GSTAR II PERFORMANCE PARAMETERS

City	50-State EIRP (dBW) Transpd 1, 3	CONUS EIRP (dBW) Transpd 2, 4-16	G/T (dB/K) Transpd 1-16	SFD (dBW/m ²) Transpd 1-16
Atlanta	45.8	44.8	2.1	-95.9
Boston	44.4	44.5	2.6	-96.5
Buffalo	44.3	43.7	3.1	-96.8
Chicago	45.1	44.6	2.6	-96.6
Corpus Christi	40.1	40.3	-2.1	-91.9
Dallas	45.3	44.1	1.0	-95.0
Denver	40.6	40.9	-0.2	-93.7
Houston	42.6	42.2	0.4	-94.4
Las Vegas	42.8	42.0	-0.7	-93.3
Los Angeles	42.4	41.9	0.1	-94.1
Melbourne	44.3	43.4	1.3	-95.2
Miami	41.2	41.1	-1.7	-92.4
Minneapolis	41.5	40.9	-0.6	-93.4
Nashville	45.8	44.8	2.6	-96.4
New York	44.4	44.7	2.4	-96.3
Phoenix	42.4	41.7	0.5	-94.4
Portland, ME	44.2	44.0	2.7	-96.4
San Francisco	43.2	43.3	0.7	-94.7
Seattle	41.1	38.5	-0.8	-93.2
St. Louis	46.0	45.3	2.5	-96.5
Wash., D.C.	44.6	44.8	2.0	-95.9
Anchorage	31.8		-12.3	-82.5
Fairbanks	34.9		-7.8	-86.9
Honolulu	37.2		-6.3	-88.5

TABLE 11. GSTAR III PERFORMANCE PARAMETERS

City	50-State EIRP (dBW) Transpd 1, 3	CONUS EIRP (dBW) Transpd 2, 4-16	G/T (dB/K) Transpd 1-16	SFD (dBW/m ²) Transpd 1-16
Atlanta	45.4	44.0	3.6	-97.2
Boston	42.0	40.1	0.6	-94.1
Buffalo	44.2	40.4	1.8	-95.6
Chicago	45.2	43.6	4.1	-97.5
Corpus Christi	38.8	38.5	-2.4	-91.1
Dallas	43.8	42.3	2.6	-96.0
Denver	40.8	40.6	1.3	-94.6
Houston	42.6	41.4	1.1	-94.5
Las Vegas	42.4	41.4	2.1	-95.5
Los Angeles	39.9	39.4	-0.8	-92.8
Melbourne	44.2	42.3	2.7	-96.3
Miami	40.2	38.8	-1.5	-93.1
Minneapolis	41.7	40.4	1.3	-94.6
Nashville	45.8	44.6	3.7	-97.3
New York	43.5	41.9	2.4	-95.7
Phoenix	39.6	39.2	0.3	-94.0
Portland, ME	40.9	38.3	-0.4	-93.0
San Francisco	42.4	41.4	1.4	-94.9
Seattle	40.5	38.4	0.5	-94.3
St. Louis	46.0	44.5	4.1	-97.3
Wash., D.C.	43.9	43.6	3.3	-96.5
Anchorage	36.2		-8.8	-85.2
Honolulu	36.5		-6.2	-87.8

TABLE 12. GSTAR IV PERFORMANCE PARAMETERS

City	50-State EIRP (dBW) Transpd 1, 3	CONUS EIRP (dBW) Transpd 2, 4-16	G/T (dB/K) Transpd 1-16	SFD (dBW/m ²) Transpd 1-16
Atlanta	45.2	44.0	2.6	-93.6
Boston	43.6	42.1	2.1	-93.2
Buffalo	44.1	42.1	3.0	-94.1
Chicago	45.6	43.4	3.3	-94.4
Corpus Christi	40.3	39.8	-0.5	-90.8
Dallas	44.4	42.9	1.5	-92.6
Denver	42.4	39.9	0.8	-91.8
Houston	42.3	41.5	1.5	-92.6
Las Vegas	42.7	41.5	1.2	-92.3
Los Angeles	42.6	41.6	1.5	-92.5
Melbourne	43.2	42.3	1.8	-92.8
Miami	40.2	40.0	-0.1	-91.0
Minneapolis	41.3	40.1	-0.8	-90.3
Nashville	45.6	44.2	3.0	-94.3
New York	44.0	42.8	3.1	-94.2
Phoenix	41.5	40.8	1.2	-92.4
Portland, ME	43.4	41.4	1.5	-92.6
San Francisco	42.6	41.4	1.0	-92.0
Seattle	41.6	39.5	1.1	-92.1
St. Louis	45.9	44.4	3.5	-94.6
Wash., D.C.	43.9	43.4	3.4	-94.5
Anchorage	38.9		-2.6	-89.4
Fairbanks	38.2		-5.2	-86.8
Honolulu	38.9		-4.0	-87.9
Nome	38.5		-2.8	-89.2

2. SPACENET Series (SPACENET II/III)

a. Evolution of the SPACENET Series

The SPACENET satellites were originally commissioned by the Southern Pacific Communications Company which was acquired by GTE SPACENET through a merger in 1983. The Southern Pacific Communications Company operated a network for dedicated long-distance telephone and data links in the later 1970s and early 1980s. This company owned a large portion of the terrestrial part of the network but had to lease all of the satellite portion. To replace the leased satellite capacity, Southern Pacific Communications contracted for the development of the SPACENET Communications Satellites (SPACENET I, SPACENET II, and SPACENET III). (Martin, 1986, pp. 140-141)

SPACENET I was launched in 1984 and was initially intended to carry primarily video traffic. In its first two years on station this satellite transmitted a variety of medical and religious TV programming which included the Hospital Satellite Network, Vanderbilt Medical TV, and American Christian TV. In the late 1980s and early 1990s the SPACENET I was utilized as part of GTE's Sprint Network. SPACENET II was also launched in 1984 and was intended mainly for business traffic. Additionally, SPACENET II is used for GTE's Sprint Service. SPACENET III was lost aboard its Ariane launcher in 1985 and was replaced by SPACENET IIIIR which is now referred to as SPACENET III. This satellite is primarily used for GTE's Sprint Network. (Stanyard, 1987, p. 263)

In 1992 the SPACENET I was sold to the Chinese government and moved to a new orbital position over Asia. The current SPACENET system is comprised of two satellites, SPACENET II and SPACENET III. (Seitz, 14-20 February 1994, p. 4)

b. Satellite Overview

The SPACENET II and SPACENET III are hybrid, three-axis-stabilized communication satellites with frequency reuse at C-band. Each satellite has twenty-four operational transponders providing approximately 1500 MHz of usable bandwidth. These satellites were designed for single-carrier and multi-carrier applications for both analog (SCPC/FM, FDM/FM, and TV/FM) and digital (SCPC/PSK, TDMA, and spread spectrum) modulation techniques. (Long, 1991, p. 621)

The SPACENET II and SPACENET III satellites are both equipped with three parabolic dish-type antennas. The primary functions of these satellites is to provide business TV, data transmission services, and voice services to CONUS, Hawaii, Alaska, and Puerto Rico. The SPACENET III is also capable of ground-commandable east or west regional beam coverage. The regional beam coverage has the advantage of allowing higher traffic throughput, higher availability, and permits the use of smaller earth station antennas within the regional beam coverage than in the 50-state coverage. Figure 44 is a graphic depiction of the SPACENET II satellite. (SPACENET and ASC System Summary, 1991, pp. 2-3)

c. Orbital Parameters

(1) *Orbit.* The SPACENET II and SPACENET III satellites are in geosynchronous equatorial Earth orbits. Stationkeeping for both satellites is rated at plus or minus 0.05 degrees in latitude and longitude. SPACENET II is located at position 69 degrees west longitude. SPACENET III is located at position 87 degrees west longitude. (SPACENET and ASC System Summary, 1991, pp. 1-2)

(2) *Orbital History of the Series.* SPACENET I was launched on May 23, 1984 by an Ariane from Kourou, French Guiana. In 1992 the SPACENET I was sold to the Chinese Government. SPACENET II was launched on November 10, 1984 by

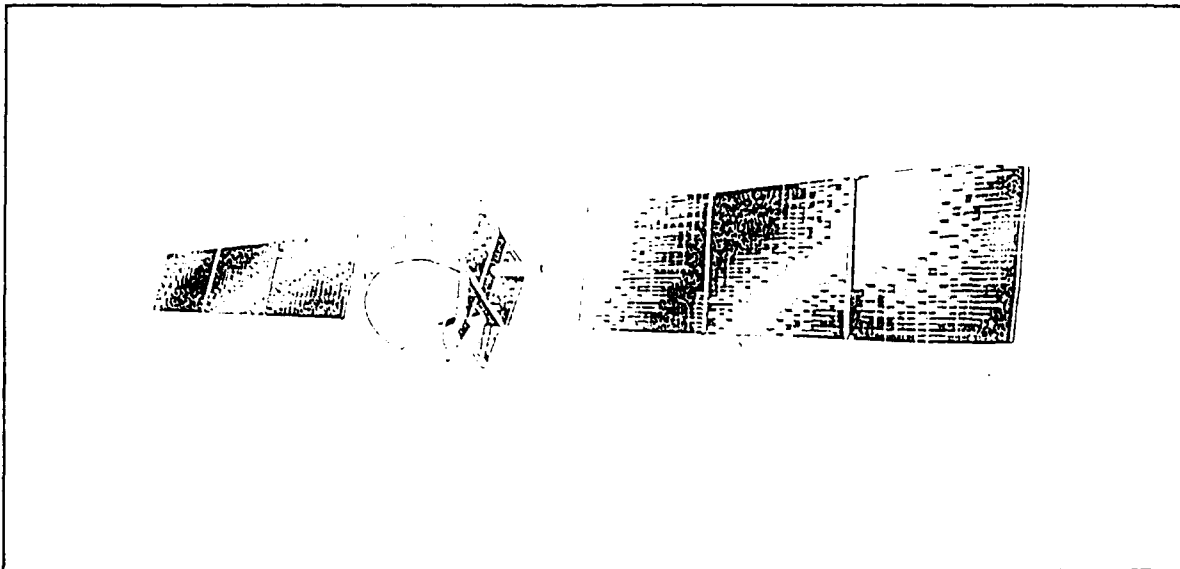


Figure 44. The SPACENET II Satellite

an Ariane from Kourou, French Guiana. SPACENET III was launched on March 11, 1988 by an Ariane from Kourou, French Guiana. (Interavia, 1992, pp. 407-408)

d. Key Design Features

(1) *Configuration.* Both the SPACENET II and the SPACENET III satellites have a GE-3000 satellite bus design. A total of twenty-four operational transponders, which provide 1500 MHz of usable bandwidth, are equipped on each satellite. Of that total, twelve transponders are narrow C-band and six are wide C-band transponders. These C-band transponders utilize 8.5 watt SSPAs and 16 watt TWTAs, respectively. The C-band configuration is identical on both satellites. At Ku-band both satellites feature six wideband (12 GHz) transponders which utilize 16 watt TWTAs. SPACENET III also has a two-channel L-band receive-only transponder that provides CONUS, Caribbean, and Central America Geostar position report-

ing service. However, this capability of the SPACENET III has not been used since 1991. (SPACENET and ASC Systems Summary, 1992, pp. 2-3)

The twelve narrow C-band transponders are channelized at 36 MHz. All other transponders are channelized at 72 MHz. (Interavia, 1992, p. 407)

(2) *Physical Characteristics.* The SPACENET II and SPACENET III are three-axis stabilized box-shaped platforms with dimensions of 1.63 m x 1.32 m x 2.54 m. Additionally, they have a 15.8 meter solar array span and are 1.9 meters in height (Long, 1991, p. 598). Each satellite employs three parabolic antenna reflectors. The satellite mass is 1195 kilograms at launch and 692 kilograms on-station at the beginning of life. Three-axis stabilization is applied via momentum wheels and magnetic torquers. Both satellites are also equipped with twin silicon solar arrays of three panels each as well as nickel hydrogen batteries. These batteries provide electric power to the satellite on the order of 1750 watts at the beginning of life and 1352 watts at the end of life. (Interavia, 1992, p. 407)

(3) *Capacity.* The SPACENET II and SPACENET III have the capacity to accomodate one color TV signal or 3600 two-way voice channels per 36 MHz of bandwidth. This capacity is doubled for a 72 MHz transponder channel. In the digital mode 60 Mb/s is the maximum transmission rate for digital information at 36 MHz bandwidth and 120 Mb/s is the maximum transmission rate at 72 MHz bandwidth. (Martin, 1986, p. 140)

(4) *Design Life.* The design life for the SPACENET II and the SPACENET III is ten years (SPACENET and ASC System Summary, 1991, p. 1). SPACENET II is expected to remain operational until 1997 while SPACENET III is predicted to remain operational until July of 1999. (Long, 1991, p. 561)

e. Transmitters/Receivers

(1) *C-Band Operation.* At C-band (6/4 GHz) there are six 72 MHz wideband transponders and twelve 36 MHz narrowband transponders. There are seven power amplifiers for each of the four groups of six transponders. This provides 7-for-6 redundancy within each group of transponders. Redundant communication receivers are provided on a 4-for-2 basis. The 72 MHz transponders utilize 16 watt TWTAs while the 36 MHz transponders are powered by 8.5 watt SSPAs. Frequency reuse at C-band is accomplished through horizontal and vertical cross-polarization. The uplink frequency ranges from 5.925 to 6.425 GHz and the downlink frequency ranges from 3.70 to 4.20 GHz. Receive coverage is centered over CONUS. (SPACENET and ASC System Summary, 1991, pp. 2-3)

(2) *Ku-Band Operation.* At Ku-band (14/12 GHz) there are six 72 MHz transponders on each satellite which are powered by 16 watt TWTAs. Ku-band transponders are linearly polarized and are thus unable to take advantage of frequency reuse. The uplink frequency ranges from 14.00 to 14.50 GHz and the downlink frequency ranges from 11.70 to 12.20 GHz. Receive coverage is also centered over CONUS. East and west regional beams are also employed at Ku-band. (SPACENET and ASC System Summary, 1991, pp. 1-3)

(3) *L-Band Operation.* The SPACENET III satellite has a unique L-band communications subsystem that can receive signals from CONUS, Central America, and the Caribbean. The Geostar Corporation used this capacity (until it went bankrupt in 1991) to receive Radio Determination Satellite Service (RDSS) signals from the Geostar surface units. (INTERAVIA, 1992, p. 407)

f. Antenna Farm

The antenna subsystem of the SPACENET II and the SPACENET III satellites is comprised of three separate antennas for the communications payload. All antennas are fixed on the Earth-facing side of the spacecraft's body. At C-band there are two parabolic antennas which are approximately four feet x five feet sharing the same physical aperture with an embedded grid for one of two orthogonal linear polarizations (Martin, 1986, pp. 140-141). GTE is able to achieve a high degree of polarization purity at C-band through the utilization of these grids embedded in each of the reflectors which are transparent to the opposite sense of polarity. C-band coverage is provided for CONUS, Alaska, Hawaii, and Puerto Rico. (Long, 1991, p. 554)

At Ku-band there is one fixed parabolic antenna which utilizes linear polarization. This antenna provides CONUS coverage only. The SPACENET III also has the ability to employ east and west regional beams with this antenna. Figures 45, 46, 47, 48, 49, 50, and 51 depict the footprints of the SPACENET II and SPACENET III satellites at C-band and Ku-band, respectively. (World Satellite Directory, 1993, pp. 48-50)

g. Performance Characteristics

(1) *Satellite Services.* SPACENET II and SPACENET III provide a variety of voice, facsimile, video teleconferencing, and low-speed data transmission services to its clientele. SPACENET II is utilized primarily for business traffic and GTE's Sprint Service (Stanyard, 1987, p. 263). Additionally, SPACENET II accommodates different forms of educational programming and video lease services. SPACENET III is also used for GTE's Sprint Service as well as for a host of other applications. This satellite supports GTE's Financial Broadcast Network which delivers financial news to radio is also used for GTE's Sprint Service as well as for a host of other applications. This satellite supports GTE's Financial

Broadcast Network which delivers financial news to radio WPIX, KTVT, and KTLA. Weather and voice information computer access are also novel features supported by this satellite. (Long, 1991, pp. 492-493)

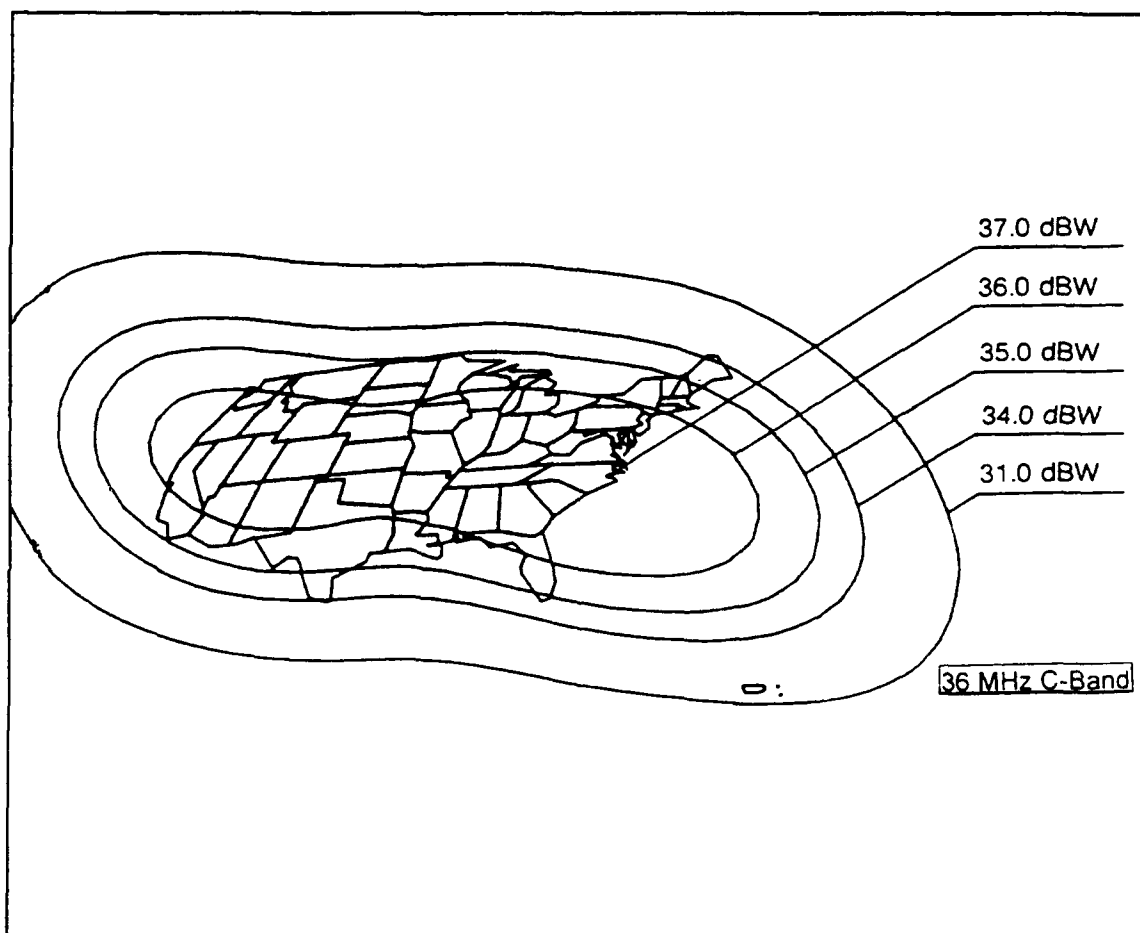


Figure 45 SPACENET II 36 MHz C-Band Coverage

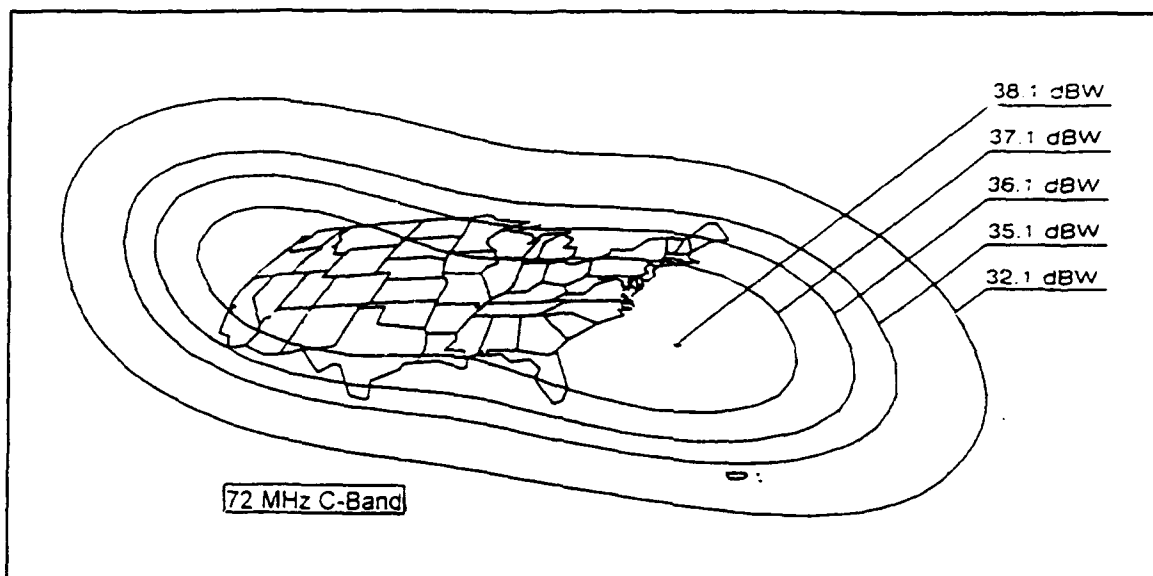


Figure 46 SPACENET II 72 MHz C-Band Coverage

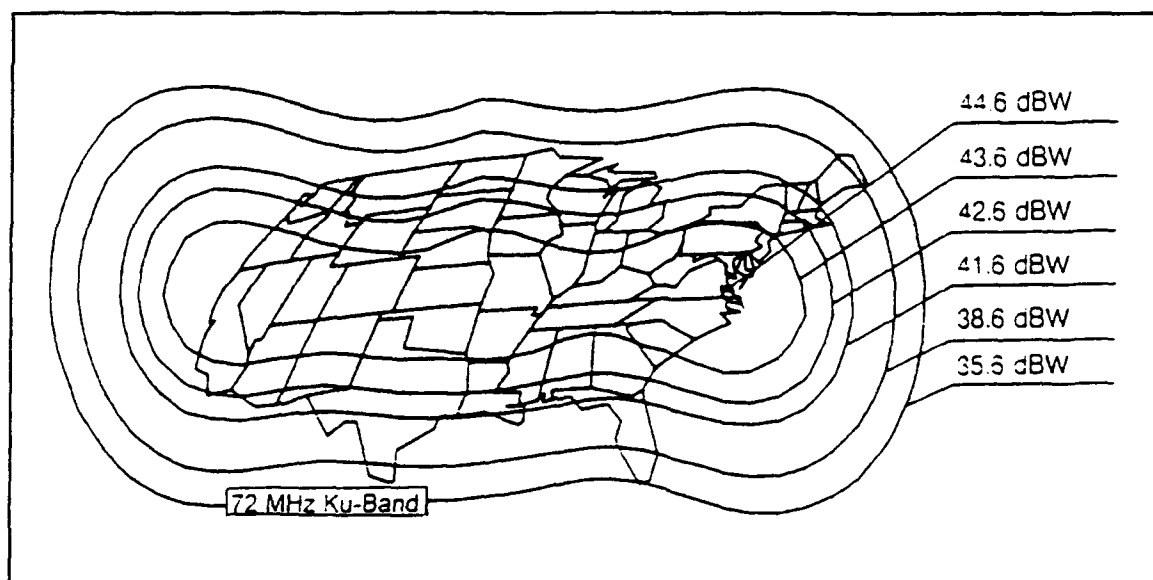


Figure 47 SPACENET II 72 MHz Ku-Band Coverage

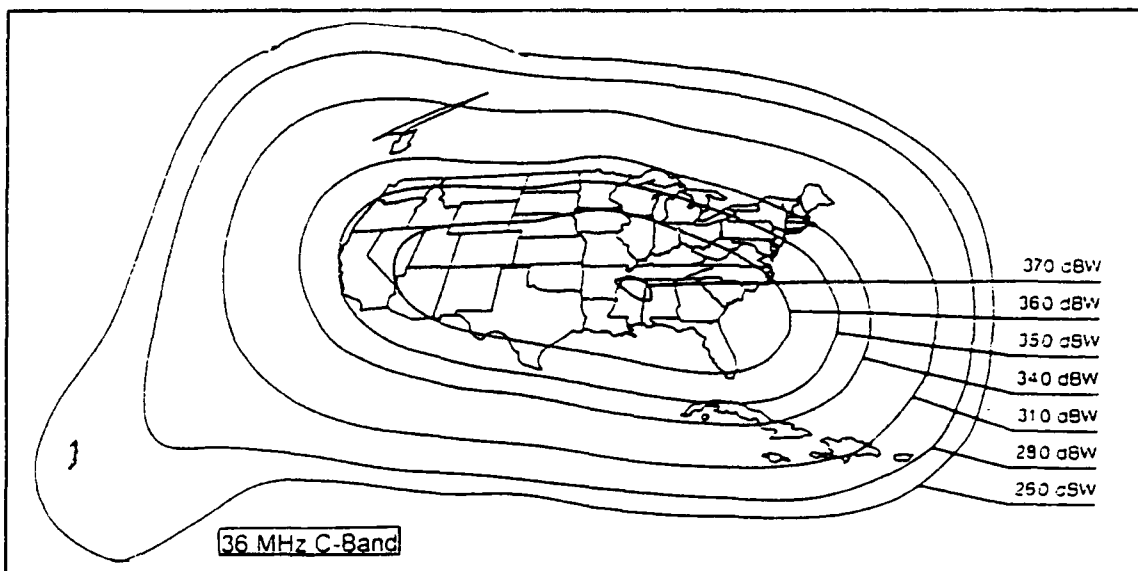


Figure 48 SPACENET III 36 MHz C-Band Coverage

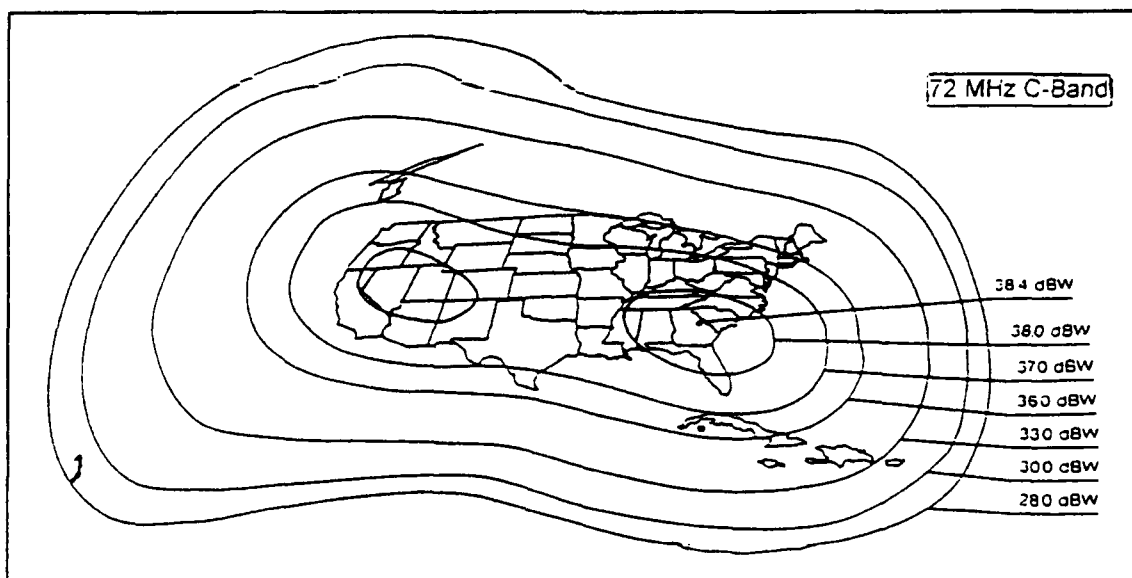


Figure 49 SPACENET III 72 MHz C-Band Coverage

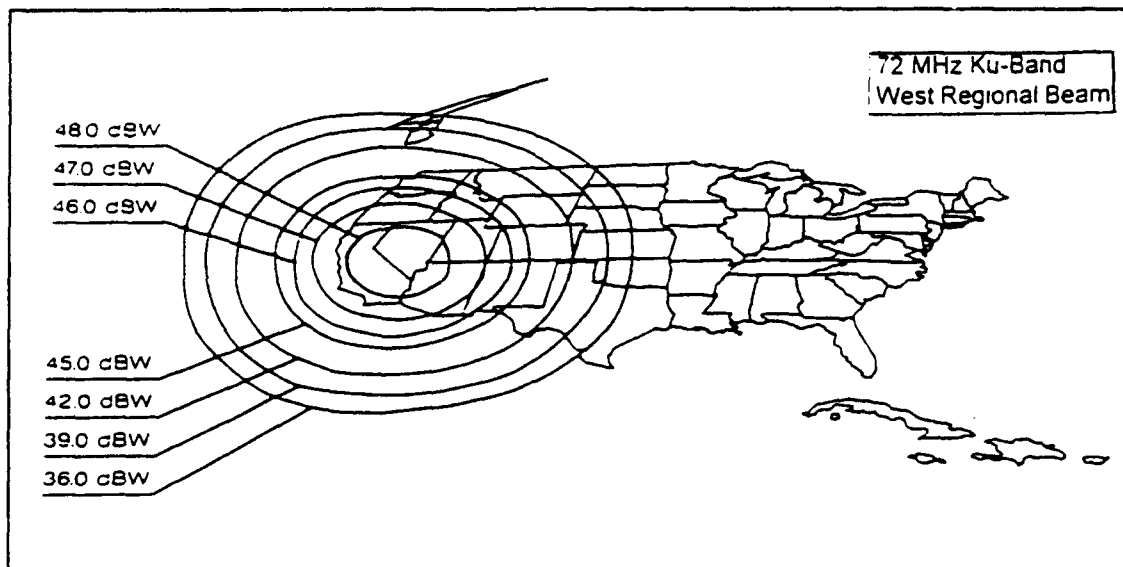


Figure 50 SPACENET III 72 MHz Ku-Band West Region Coverage

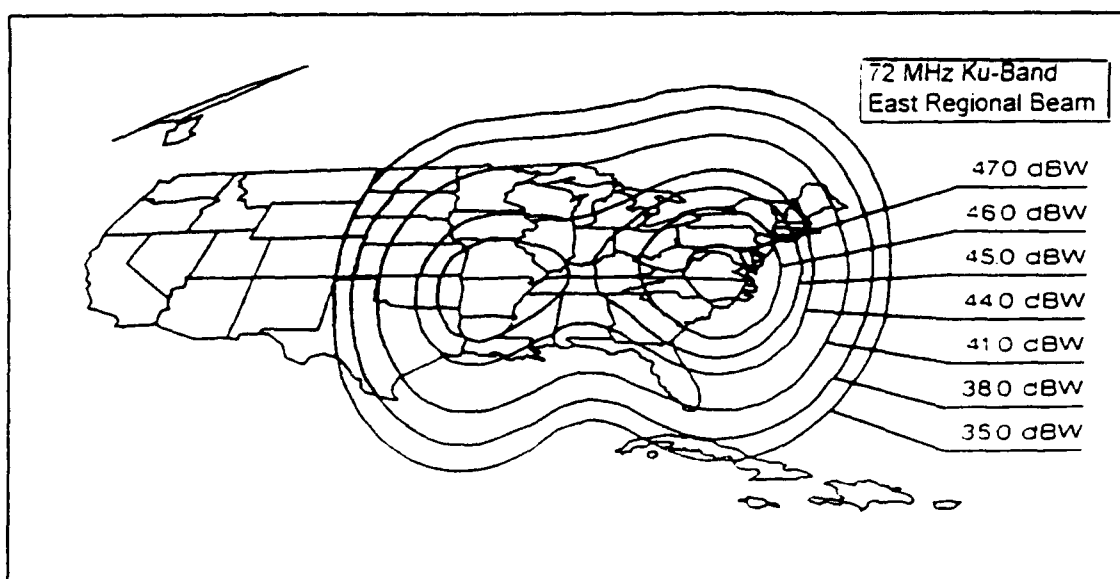


Figure 51 SPACENET III 72 MHz Ku-Band East Region Coverage

(2) *Performance Parameters.* Minimum EIRP within the intended coverage regions for both satellites at C-band are as follows:

CONUS coverage-	34.3 dBW for the 36 MHz channels
	39.8 dBW for the 72 MHz channels
Alaska coverage-	32.4 dBW for the 36 MHz channels
	36.0 dBW for the 72 MHz channels
Hawaii coverage-	26.7 dBW for the 36 MHz channels
	28.5 dBW for the 72 MHz channels
Puerto Rico coverage-	31.6 dBW for the 36 MHz channels
	34.3 dBW for the 72 MHz channels

Minimum EIRP within the intended coverage regions for both satellites at Ku-band are as follows:

CONUS coverage- 39.8 dBW for the 72 MHz channels.
SPACENET III East Regional Beam- 35.0 dBW.
SPACENET III West Regional Beam- 36.0 dBW. (SPACENET and ASC System Summary, 1991, pp. 15-43)

3. ASC Series (ASC-1/SPACENET IV(ASC-2))

a. Evolution of the ASC Series

The ASC series of communication satellites were originally purchased in 1983 by the American Satellite Company from RCA Astro Electronics. Prior to the purchase of this pair of satellites, the American Satellite Company provided general telecommunications services to its customers through its twenty percent partial ownership of the Westar III, Westar IV, and Westar V satellites. The ASC series was procured in order to provide capacity for the company's expanding customer base. A third ASC satellite, the ASC-3, was built as a ground spare for the system. When the American Satellite Company decided not to exercise its option for the purchase, ASC-3 was sold by RCA to the Alpha Lyracom Pan American Satellite Corporation and was renamed as the PAS-1 satellite (Interavia, 1992, p.

408). In 1991 the ASC series fell under GTE SPACENET ownership when the American Satellite Company merged with GTE SPACENET. It was also at that point that GTE SPACENET decided to rename the ASC-2 to SPACENET IV. (Stanyard, 1987, pp. 70-71)

There were significant difficulties in the early design phase of the ASC-1 satellite. Initially, the FCC was dissatisfied with the ASC-1 communications payload because dual polarization was not used in the Ku-band communications subsystem. Dual polarization is preferred by the FCC in order to preserve the Ku-band frequency spectrum. The single polarization plan was adopted for the ASC satellites in order to limit the weight and size of the satellite. (Stanyard, 1987, pp. 70-71)

These satellites have been providing interim video services for PBS over the past two years, however that business is slated to be transferred to AT&T's Telstar 401 when it becomes deployed and fully operational. At present GTE SPACENET is giving some consideration to selling SPACENET IV. Telesat Canada and the Chinese government have both made overtures towards negotiating a deal for the satellite. (Seitz, 14-20 February 1994, p. 4)

b. Satellite Overview

The ASC-1 and SPACENET IV are hybrid, three-axis stabilized, communication satellites with a frequency reuse capability of the C-band spectrum. Each satellite has twenty-four operational transponders providing approximately 1500 MHz of usable bandwidth. These satellites were designed for single-carrier and multi-carrier applications for both analog (SCPC/FM, FDM/FM, and TV/FM) and digital (SCPC/PSK, TDMA, and spread spectrum) modulation techniques. Additionally, these satellites incorporate a unique encryption security feature which prevents unauthorized access to the satellite command system. (Long, 1991, p. 621)

The ASC-1 and SPACENET IV satellites are both equipped with three parabolic dish type antennas. The primary functions of these satellites are to provide business TV, data transmission services, and voice services to CONUS, Hawaii, Alaska, and Puerto Rico. Figure 52 is a graphic depiction of the ASC-1 satellite. (SPACENET and ASC System Summary, 1991, pp. 2-3)

c. Orbital Parameters

(1) *Orbit.* The ASC-1 and SPACENET IV satellites are in geosynchronous equatorial Earth orbit. Stationkeeping for both satellites is rated at plus or minus 0.05 degrees in latitude and longitude. ASC-1 is located at position 128 degrees west longitude. SPACENET IV is located at position 101 degrees west longitude. (Interavia, 1992, p. 408)

(2) *Orbital History of the Series.* ASC-1 was launched on August 27, 1985 by STS-511. SPACENET IV was launched on April 13, 1991 by Delta 7925 from Cape Canaveral. (Interavia, 1992, p. 408)

d. Key Design Features

(1) *Configuration.* Both the ASC-1 and the SPACENET IV satellites have a GE-3000 satellite bus design. A total of twenty-four operational transponders which provide 1500 MHz of usable bandwidth are equipped on each satellite. Of that total twelve transponders are narrow C-band, and six are wide C-band transponders. These C-band transponders utilize 8.5 watt SSPAs and 16 watt TWTAs, respectively. The C-band configuration is identical on both satellites. At Ku-band the ASC-1 satellite features six wideband (12 GHz) transponders which utilize 16 watt TWTAs. SPACENET IV has four Ku-band transponders that use 16 watt TWTAs and two Ku-band transponders that use 30 watt TWTAs. (SPACENET and ASC Systems Summary, 1992, pp. 2-3)

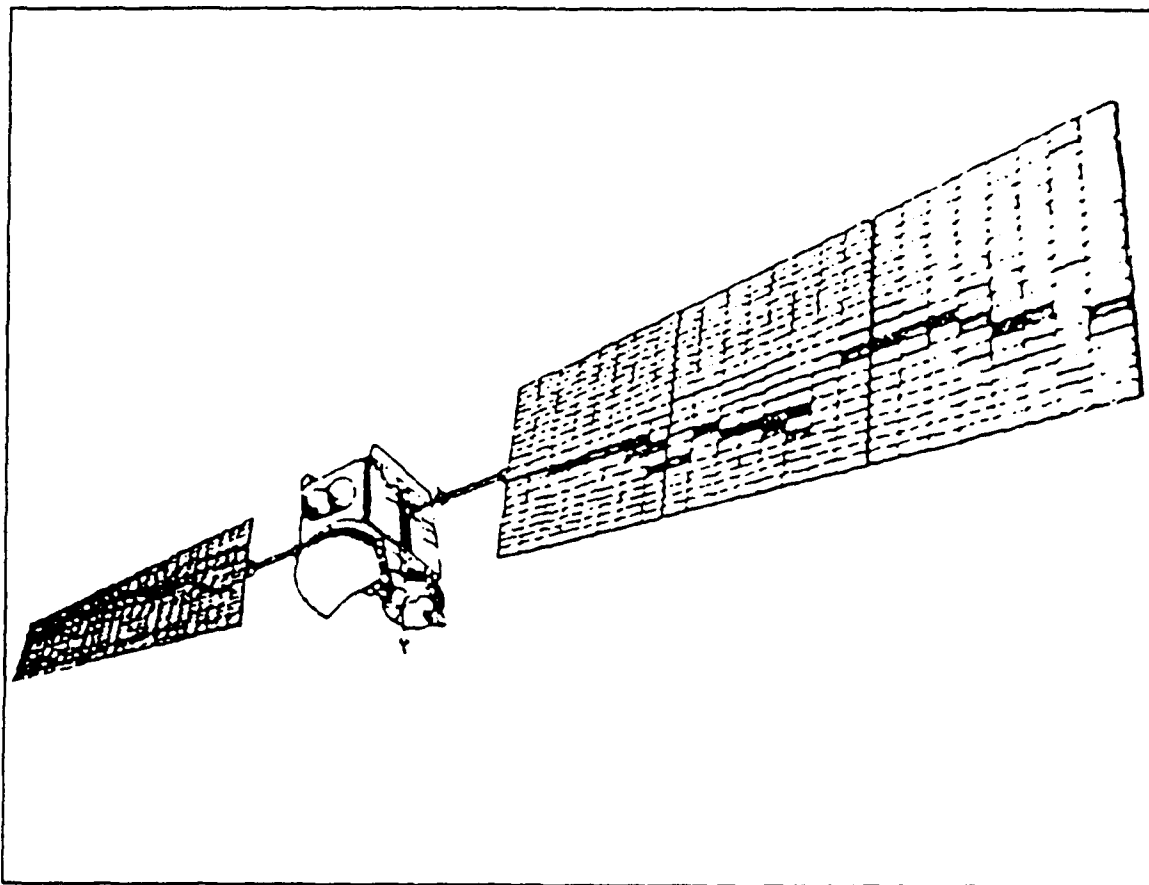


Figure 52 The ASC-1 Satellite

The twelve narrow C-band transponders are channelized at 36 MHz. All other transponders are channelized at 72 MHz. On SPACENET IV three of the Ku-band transponders are inoperative. They are channels 19, 21, and 23. (Interavia, 1992, p. 408)

(2) *Physical Characteristics.* The ASC-1 and SPACENET IV satellites are of the GE Astro 3000 model design. They are three-axis stabilized, box-shaped platforms with dimensions of 1.63 m x 1.32 m x 2.54 m. Additionally, they have a 15.0 meter solar array span and three parabolic fixed antenna reflectors. The satellite mass is 1195 kilograms at launch and 692 kilograms on-station at the beginning of life. Three-axis stabilization is applied via momentum wheels and magnetic torquers. Both satellites are also equipped with twin silicon solar arrays of three panels each as well as nickel hydrogen batteries which provide electric power to the satellite on the order of 1212 watts at the end of life. Additionally, each satellite is configured for 100 percent eclipse protection. (Interavia, 1992, p. 408)

(3) *Capacity.* The ASC-1 and SPACENET IV have the capacity to accomodate thirty-six color TV signals or 27,000 two-way voice channels. In the digital mode 2304 Mb/s is the maximum transmission rate for digital information. (Long, 1987, p. 412)

(4) *Design Life.* The design life for the ASC-1 and the SPACENET IV is ten years. (SPACENET and ASC System Summary, 1991, p. 1)

e. Transmitters/Receivers

(1) *C-Band Operation.* At C-band (6/4 GHz) there are six 72 MHz wideband transponders and twelve 36 MHz narrowband transponders. There are seven power amplifiers for each of four groups of six transponders which provides 7-for-6 redundancy within each group. Redundant communications receivers are provided on a 4-for-2 basis. The 72 MHz transponders utilize 16 watt TWTAs while the 36 MHz transponders are powered by 8.5 watt SSPAs. Frequency reuse is accomplished through horizontal and vertical cross-polarization. The uplink frequency ranges from 5.925 to 6.425 GHz, and the downlink

frequency ranges from 3.70 to 4.20 GHz. Receive coverage is centered over CONUS. (SPACENET and ASC System Summary, 1991, pp. 2-3)

(2) *Ku-Band Operation.* At Ku-band (14/12 GHz) there are six 72 MHz transponders on the ASC-1 which are powered by 16 watt TWTAs. On the SPACENET IV there are four 72 MHz Ku-band transponders using 16 watt TWTAs and two transponders using 30 watt TWTAs. Ku-band transponders are linearly polarized. The uplink frequency ranges from 14.00 to 14.50 GHz, and the downlink frequency ranges from 11.70 to 12.20 GHz. Receive coverage is also centered over CONUS. (SPACENET and ASC System Summary, 1991, pp. 1-3)

f. Antenna Farm

The antenna subsystem, of the ASC-1 and the SPACENET IV satellites, is comprised of three separate antennas for the communications payload. All antennas are fixed on the earth-facing side of the spacecraft's body. At C-band there are two parabolic antennas which are approximately four feet x five feet sharing the same physical aperture with an embedded grid for one of two orthogonal linear polarizations (Martin, 1986, p. 146). GTE is able to achieve a high degree of polarization purity at C-band through the utilization of these grids embedded in each of the reflectors which are transparent to the opposite sense of polarity. C-band coverage is provided for CONUS, Alaska, Hawaii, and Puerto Rico. (Long, 1991, p. 554)

At Ku-band there is one fixed parabolic antenna which utilizes linear polarization. This antenna provides CONUS coverage only. Figures 53 and 54 depict the footprints of the ASC-1 satellite at C-band and Ku-band, respectively. (Martin, 1986, p. 146)

g. Performance Characteristics

(1) *Satellite Services.* Through GTE's National Network, private lines for voice, facsimile, video teleconferencing communications, and low-speed data transmission to thirty-nine cities are provided via the ASC-1 and SPACENET IV satellites. Government and military networks use the GTE Government Services option for data, facsimile, video teleconferencing and voice transmission with these satellites. The ASC-1 relays private line, 56 Kb/s data, digitally secure voice channels, and wideband data for various military activities. Additionally, the ASC-1 and SPACENET IV have the capability to transmit such diverse information as global weather maps, Space Shuttle operational support data, and nuclear research data. (Long, 1991, pp. 621-622)

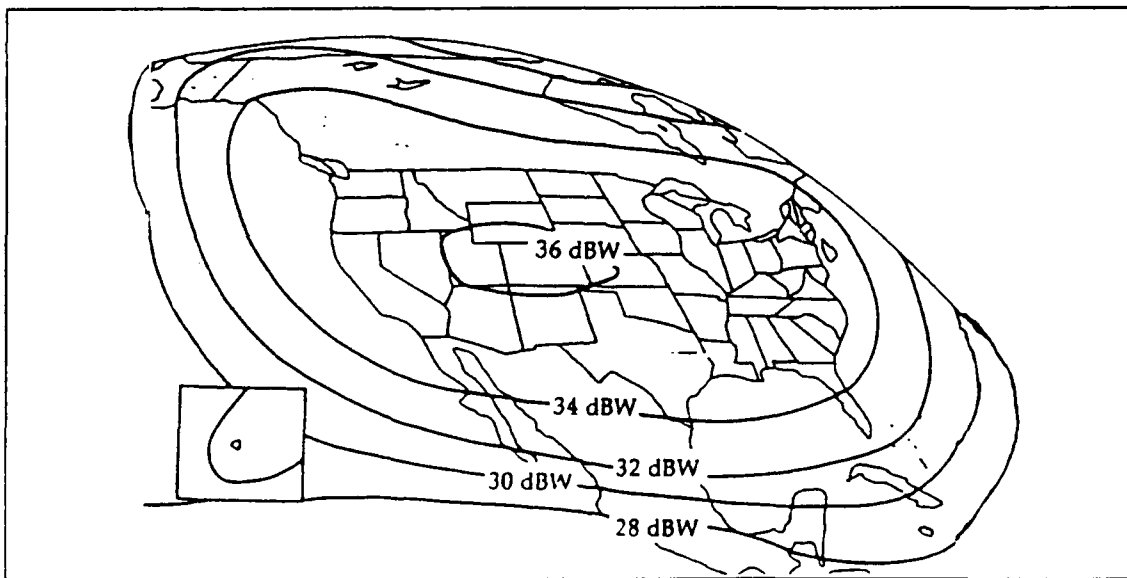


Figure 53 ASC-1 C-Band Footprint

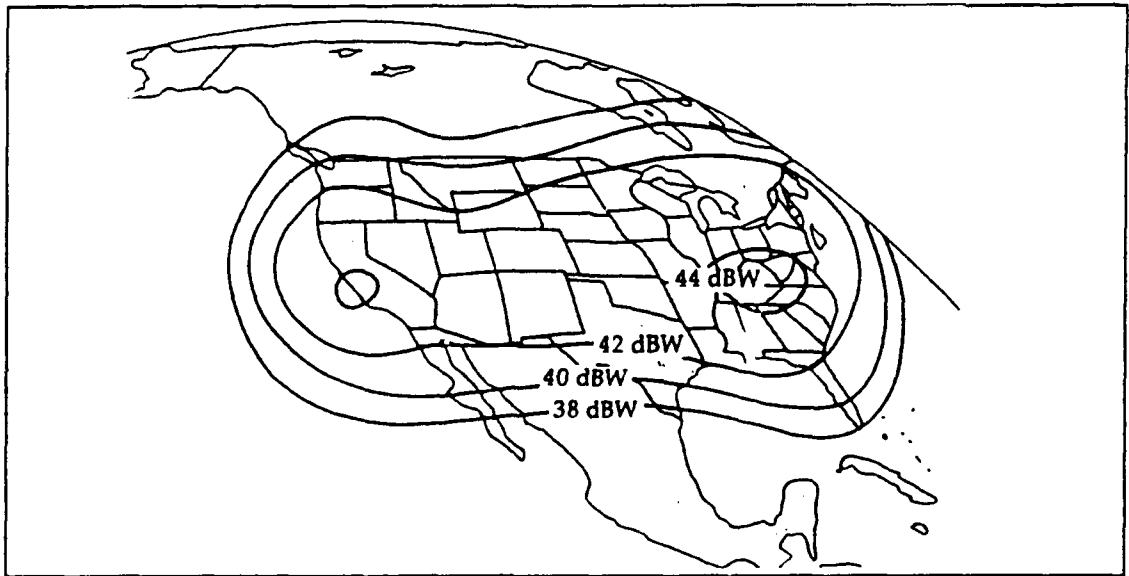


Figure 54 ASC-1 Ku-Band Footprint

(2) *Performance Parameters.* Minimum EIRP within the intended coverage regions for both satellites at C-band are as follows:

CONUS coverage-	34.0 dBW for the 36 MHz channels
	37.0 dBW for the 72 MHz channels
Alaska coverage-	31.0 dBW for the 36 MHz channels
	33.0 dBW for the 72 MHz channels
Hawaii coverage-	28.0 dBW for the 36 MHz channels
	30.0 dBW for the 72 MHz channels
Puerto Rico coverage-	27.0 dBW for the 36 MHz channels
	29.0 dBW for the 72 MHz channels

Minimum EIRP within the intended coverage regions for both satellites at Ku-band is as follows:

CONUS coverage-	42.0 dBW for the 72 MHz channels.

(Long, 1991, p. 623)

Gain to temperature ratios within the intended coverage regions for both satellites at C-band are as follows:

CONUS coverage G/T- -2.0 to -3.0 dB/K

Alaska/Hawaii G/T- -7.0 dB/K

Gain to temperature ratios within the intended coverage regions for both satellites at Ku-band is as follows:

CONUS coverage G/T- -3.0 dB/K. (Martin, 1986, p. 146)

Figures 55, 56, 57, 58, 59, 60, 61, 62, and 63 depict the EIRP performance level footprints of each transponder on the ASC-1 and SPACENET IV satellites for single carrier operation. For applications involving more than one carrier per transponder, GTE SPACENET will modify EIRP performance levels on a case-by-case basis. (SPACENET and ASC Systems Summary, 1991, pp. 3-48)

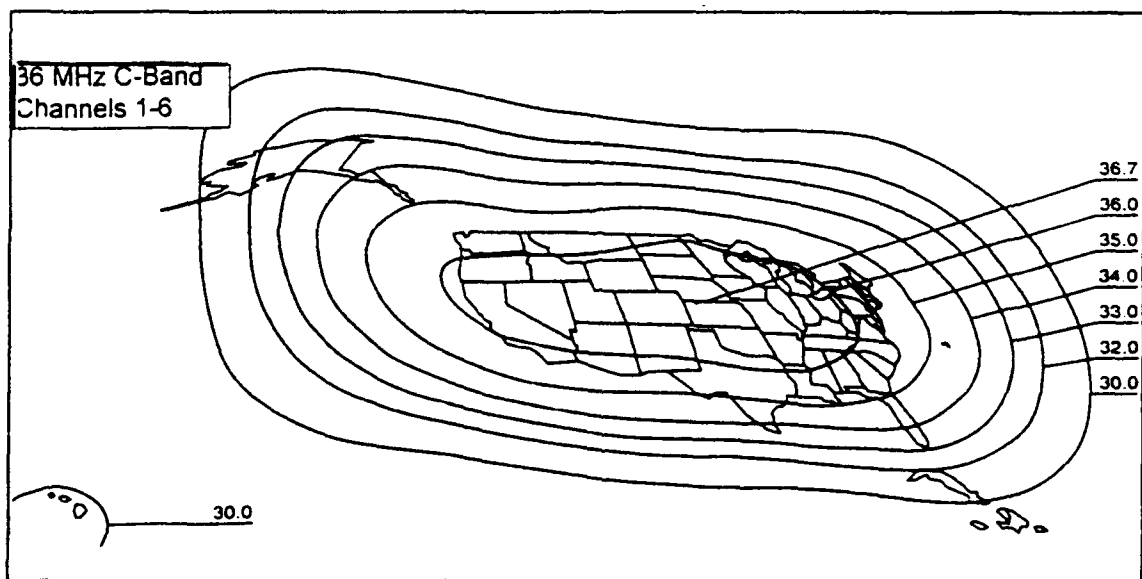


Figure 55 ASC-1 36 MHz C-Band EIRP (Channels 1-6)

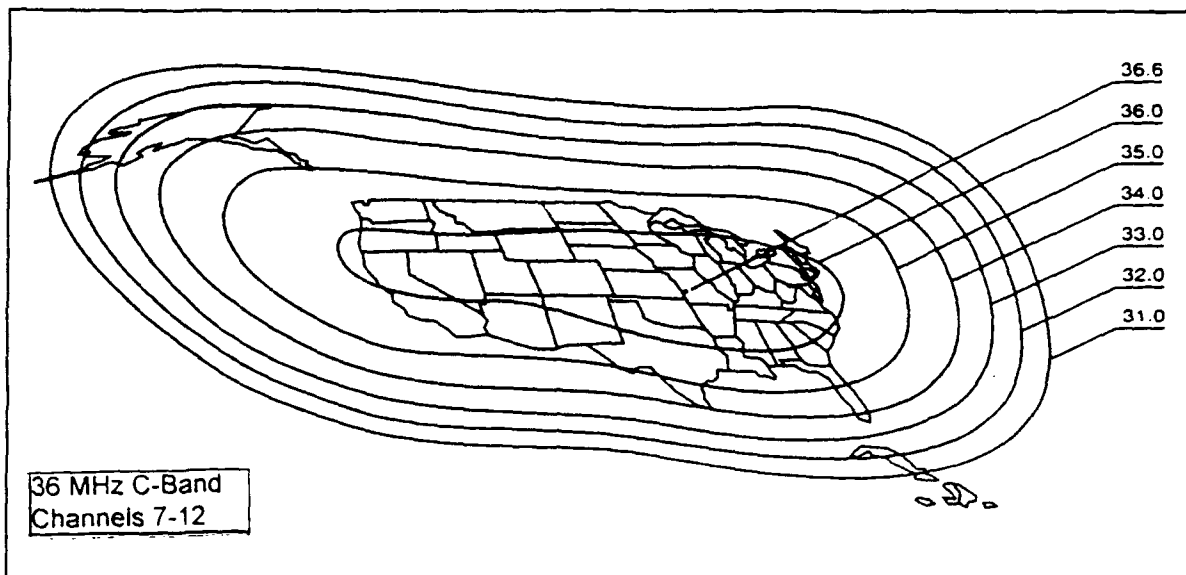


Figure 56. ASC-1 36 MHz C-Band EIRP (Channels 7-12)

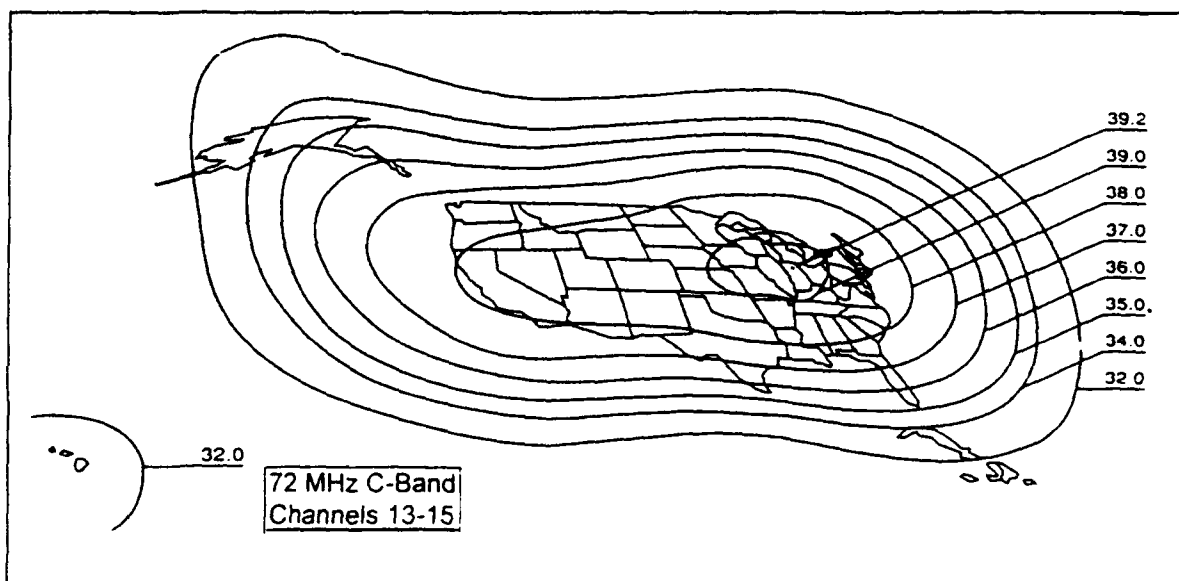


Figure 57. ASC-1 72 MHz C-Band EIRP (Channels 13-15)

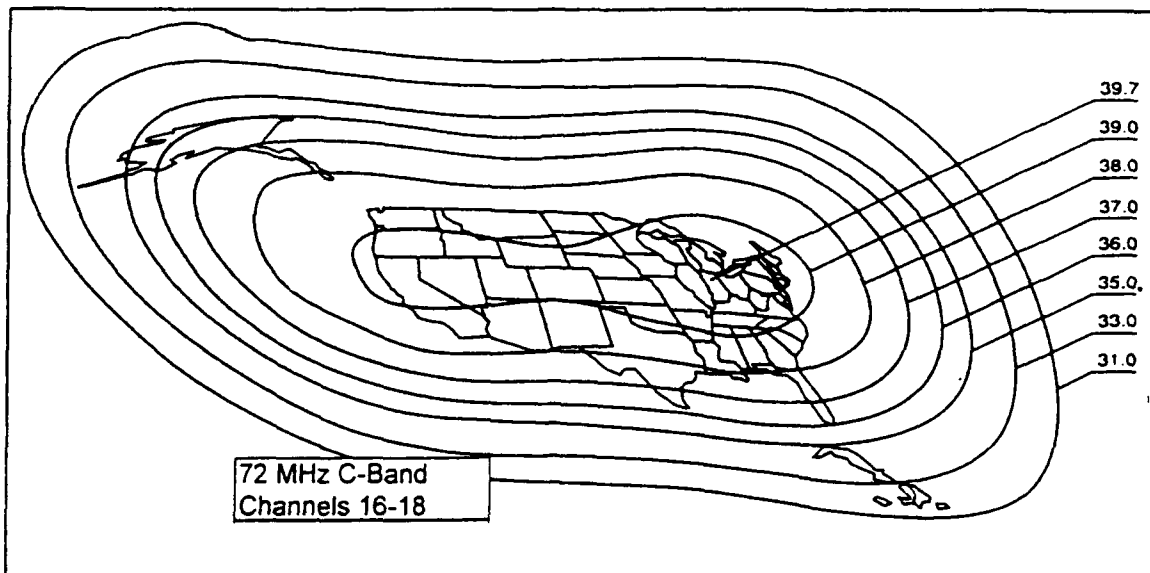


Figure 58. ASC-1 72 MHz C-Band EIRP (Channels 16-18)

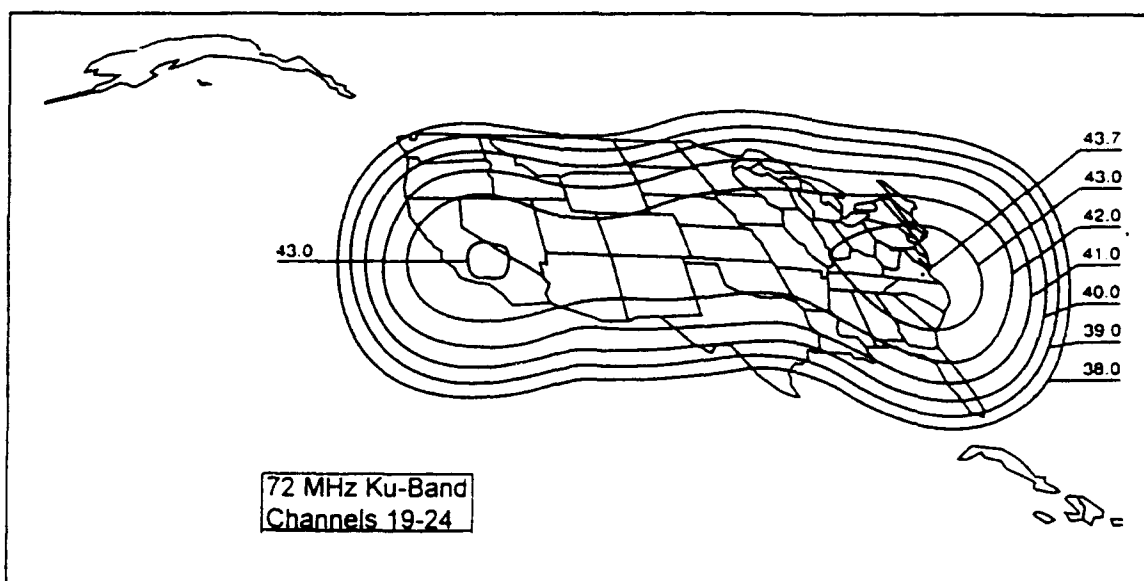


Figure 59. ASC-1 72 MHz Ku-Band EIRP (Channels 19-24)

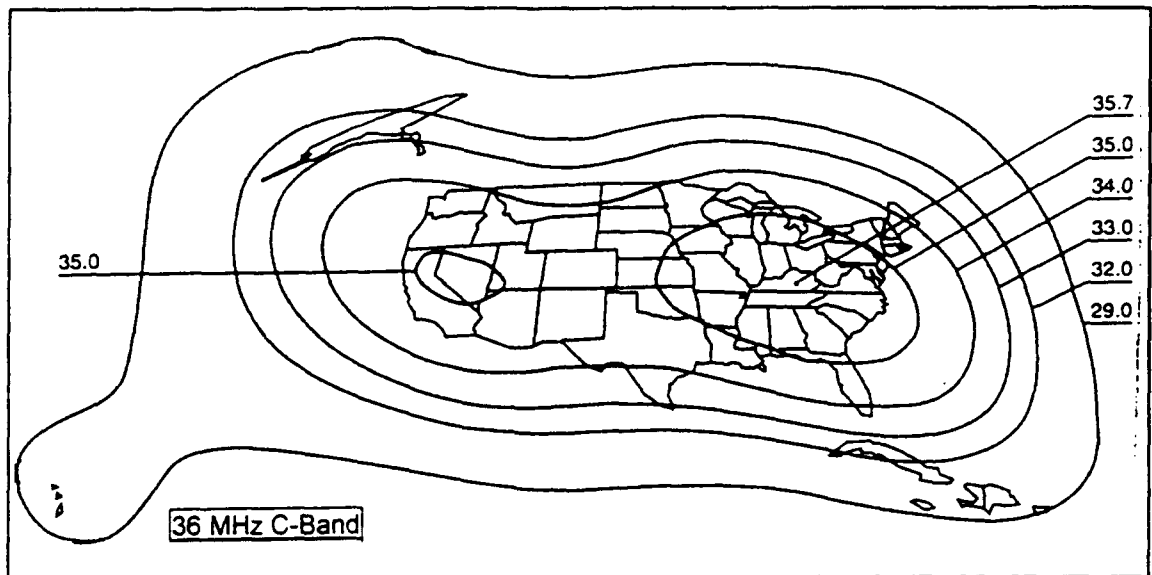


Figure 60. SPACENET IV 36 MHz C-Band EIRP

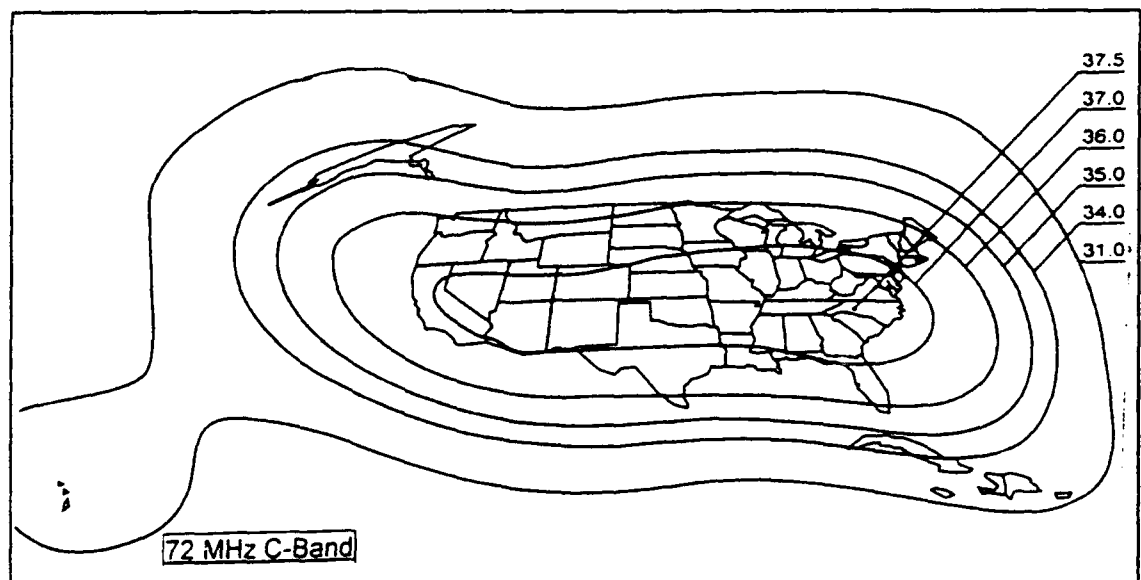


Figure 61. SPACENET IV 72 MHz C-Band EIRP

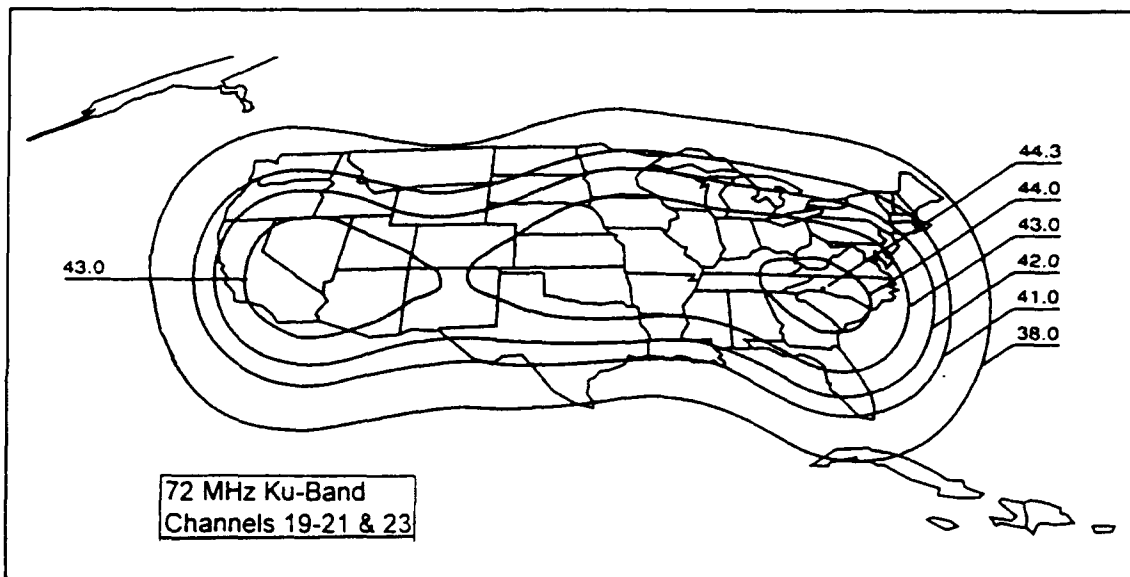


Figure 62. SPACENET IV 72 MHz Ku-Band EIRP(Channels 19-21, 23)

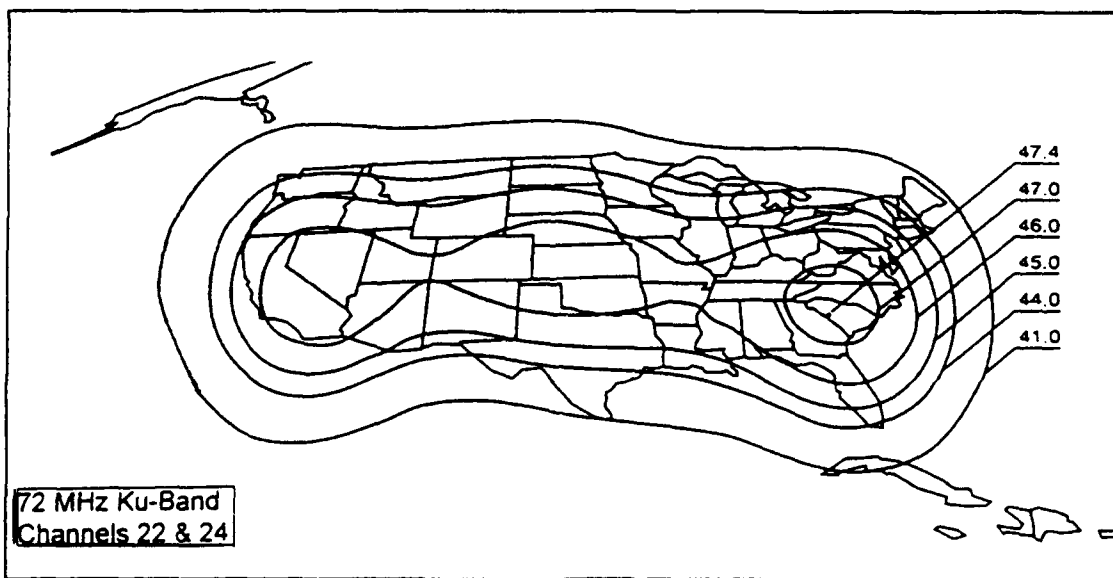


Figure 63. SPACENET IV 72 MHz Ku-Band EIRP (Channels 22, 24)

G. HUGHES COMMUNICATIONS INC.

Hughes Communications Inc. (HCI) is the world's largest private commercial satellite operator and the leading supplier of satellite communications services in the United States. Founded in 1979, Hughes Communications Inc. is a subsidiary of Hughes Aircraft Company. Hughes Communications Inc. owns and operates a domestic satellite fleet which operates in the C-band and the Ku-band. The fleet consists of five C-band Galaxy satellites, two dual-payload Galaxy satellites, and three Ku-band SBS satellites. The Galaxy and SBS satellite systems provide full and partial transponder point-to-point and point-to-multipoint C-band and Ku-band services. The fleet of Hughes satellites provides video, voice, and data communications for domestic and international customers. Additionally, HCI provides international television transmission services, participates in a mobile satellite communications joint venture, and supports DirecTV, which is North America's first high-power direct broadcast entertainment distribution system. In addition to its commercial communications services, HCI provides military communications services to the United States armed forces.

1. Galaxy I Series (Galaxy IR/II/III/V/VI)

Hughes Communications Inc. began satellite operations with the launches of its three initial C-band (6/4 GHz) Galaxy I series satellites during 1983 and 1984. This series of satellites provides point-to-point and point-to-multipoint C-band services for domestic and transborder communications. Telecommunications services are also available to subscribers in CONUS, Alaska, Hawaii, Canada, Mexico, and the Caribbean Basin. The C-band services provided by the Galaxy I series satellites include: cable video, broadcast video, compressed video, video timesharing service, international television service, and audio/data services. The Galaxy I series satellites are based on either the Hughes HS-376 or stretched HS-

376 spacecraft design. (Fleet Technical Description, 1992, pp. 1-2)

a. Evolution of the Series

Hughes Communications Inc. began its satellite operations with the launch of Galaxy I on June 28, 1983. The Galaxy I transponders were sold outright to carry cable TV channels. Galaxy II and Galaxy III were the next C-band spacecraft of this series to be launched. Launched in 1983 and 1984 respectively, Galaxy II and Galaxy III were initially orbited to provide voice, data, and other telecommunications services to such customers as MCI and Equatorial Communications. Galaxy VI, launched in October 1990, was the next in the series to be orbited. Galaxy V was launched in March 1992 to replace Westar 5. The first intended replacement satellite for Galaxy I was lost as a result of a launch failure in August 1992. Finally, Galaxy IR was successfully orbited in February 1994 as a replacement for Galaxy I. The transfer of customers from Galaxy I to Galaxy IR was completed on March 7, 1994.

b. Satellite Overview

The Galaxy I series of satellites are cylindrical, spin-stabilized (Earth-oriented, despun communications platform with a spinning body section), C-band only, communications satellites. Each C-band satellite provides twenty-four transponders for signal transmission. The bandwidth of these transponders is 36 MHz. Half of the twenty-four channels are horizontally polarized, and the other half are vertically polarized. The polarized signals are received by the satellite, filtered, downconverted, amplified and transmitted back to Earth at the opposite polarization. (Fleet Technical Description, 1992, p. 6)

services provided by Galaxy V are primarily related to television broadcasting (International Satellite Directory, 1993, pp. 12-207 - 12-258). Figure 64 is a graphic depiction of the Galaxy I series satellite. (Fleet Technical Description, 1992, p. 4)

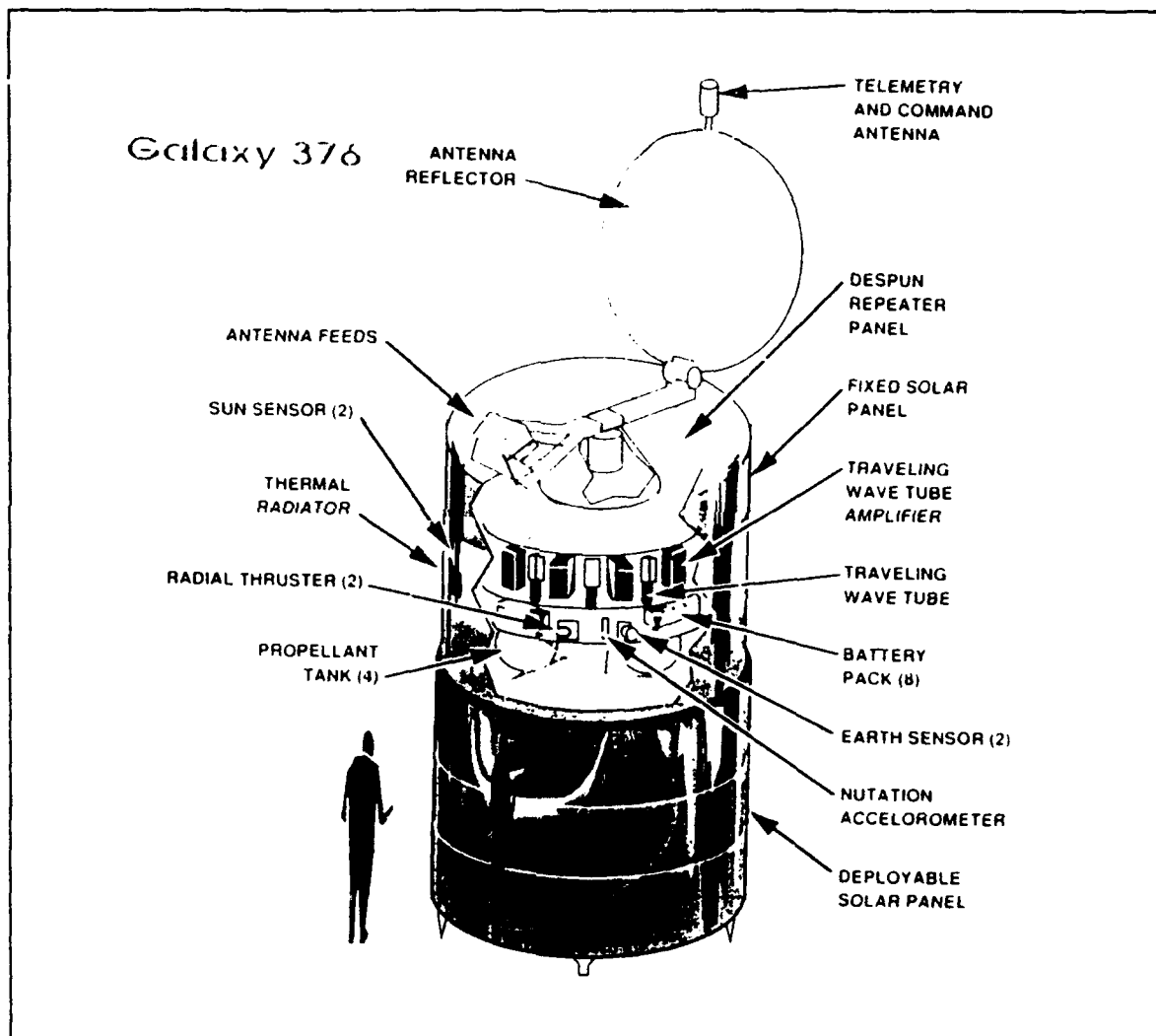


Figure 64 A Galaxy I Series Satellite

c. Orbital Parameters

(1) *Orbit.* The Galaxy series of satellites are located in a geostationary Earth orbit. Galaxy II is located at 74 degrees west longitude. Galaxy III is located at 93.5 degrees west longitude. Galaxy V is located at 125 degrees west longitude. Galaxy VI is located at 99 degrees west longitude. Galaxy IR is located at 133 degrees west longitude. Through the use of hydrazine propulsion thrusters, each satellite in this series is maintained on station to within plus or minus 0.1 degrees in both east-west and north-south directions. (Fleet Technical Description, 1992, pp. 1-5)

(2) *Orbital History of the Series.* Galaxy II was launched on September 22, 1983 by Delta 3920/PAM from Cape Canaveral. Galaxy III was launched on September 21, 1984 by Delta 3920/PAM from Cape Canaveral. Galaxy VI was launched on October 12, 1990 by Ariane 3 from Kourou, French Guiana. Galaxy V was launched on March 14, 1992 by Atlas 1 from Cape Canaveral. The last satellite in the series, Galaxy IR, was launched on February 19, 1994 by Delta II from Cape Canaveral (Hughes Communications News Release, 1994, p. 1).

d. Key Design Features

(1) *Configuration.* All Galaxy I series satellites utilize a Hughes HS-376 satellite bus. Each of these spacecraft provide twenty-four C-band transponders for signal transmission. (Fleet Technical Description, 1992, p. 6)

(2) *Physical Characteristics.* The Hughes HS-376 model design is a cylindrical platform which is spin-stabilized at 50 to 60 revolutions per minute (RPM) via four hydrazine thrusters. The physical size of the Galaxy satellites has increased with successive satellite generations to provide greater solar panel surface area. The earlier HS 376 satellites (Galaxy II, Galaxy III, and Galaxy VI) are approxi-

mately 9 feet 3 inches high in the stowed configuration, while 21 feet 8 inches high when fully extended. The stretched HS 376 models (Galaxy V and Galaxy IR) are 10 feet 2 inches high in the stowed configuration and 24 feet 7 inches high when fully extended. All HS 376 satellites are 7 feet 1 inch in diameter. (Fleet Technical Description, 1992, p. 4)

The Galaxy II, Galaxy III, and Galaxy V satellites had an on-orbit mass (BOL) of 637 kilograms. Galaxy VI had an on-orbit mass of 652 kilograms. Galaxy IR has a launch weight of 1088 kilograms, with an on-orbit mass (EOL) of 499 kilograms. (International Satellite Directory, 1992, pp. 9-78 - 9-91)

Each satellite contains a solar cell/battery power subsystem which provides sufficient power for full operation during both eclipse and non-eclipse periods.

(3) *Capacity.* The early Galaxy I satellites can accomodate 1000 simultaneous two-way voice channels or one color TV signal per transponder (Martin, 1986, p. 138).

(4) *Design Life.* The design life for all Galaxy I series satellites is 10 years. (World Satellite directory, 1993, p. 10)

e. Transmitters/Receivers

The Galaxy I series C-band (6/4 GHz) transmitters operate in the frequency range of 3702 to 4198 MHz. Each C-band satellite provides 24 transponders for signal transmission. Half of the twenty-four 36 MHz channels are horizontally polarized, while the other half are vertically polarized. In this polarization scheme transponders which downlink in the horizontal polarization will uplink in the vertical polarization. Transponders which downlink in the vertical polarization will uplink in the horizontal polarization. (Fleet Technical Description, 1992, p. 6)

While each of the Galaxy I series satellites provides twenty-four transponders, the power transmitted varies from one spacecraft to another. The Galaxy II and Galaxy III transponders transmit nine watts of power. The Galaxy VI transponders transmit at ten watts. The Galaxy V and Galaxy IR transponders transmit at sixteen watts. (Hughes Communications News, 1994, p. 1)

Amplifier redundancy improvements have been an integral part of the evolution of the Galaxy satellites. The early Galaxy spacecraft such as Galaxy I, II, III, and VI, have a total of 30 TWTAs that are separated into six groups of five. This allows for one spare TWTAs for every four essential TWTAs, providing a 5-for-4 redundancy scheme. The Galaxy V and IR satellites are configured in a ring redundancy arrangement which allows each transponder to have access to at least two spare amplifiers in the event that its own main amplifier fails. (Fleet Technical Description, 1992, p. 6)

The Galaxy I series satellites also utilize C-band 4.198 and 4.199 GHz telemetry beacons. (International Satellite Directory, 1993, p. 12-300)

The Galaxy I series C-band (6/4 GHz) receivers operate in the frequency range of 5927 to 6423 MHz. Each of these satellites have primary receivers dedicated to specific polarizations plus two spare receivers. In the event that one of the primary receivers fail, either of the two spare receivers can be used as a replacement. This particular receiver configuration results in a 4-for-2 redundancy scheme. (Fleet Technical Description, 1992, p. 6)

f. Antenna Farm

The transmit and receive beams are produced by a shared co-located aperture grid antenna with dual, orthogonal linear polarized reflectors. The two paraboloids which utilize polarizing grids are 72 inches in diameter. The front surface is horizontally polarized and the rear surface is

vertically polarized. Seperate microwave feeder networks are utilized to produce the different polarizations. (Yenne, 1987, p. 72)

Figures 65, 66, 67, 68, and 69 depict the footprints of the Galaxy II, Galaxy III, Galaxy V, Galaxy VI, and Galaxy IR satellites respectively. (Fleet Technical Description, 1992, p. 2)

g. Performance Characteristics

(1) *Satellite Services.* The Galaxy I series satellites are used to provide digital video, voice, and data communications for domestic and international customers. These telecommunication services are available to CONUS, Alaska, Hawaii, and Caribbean Basin. The Galaxy I series satellites provide full and partial transponder point-to-point and point-to-multipoint C-band services. (International Satellite Directory, 1993, pp. 12-276 - 12-300)

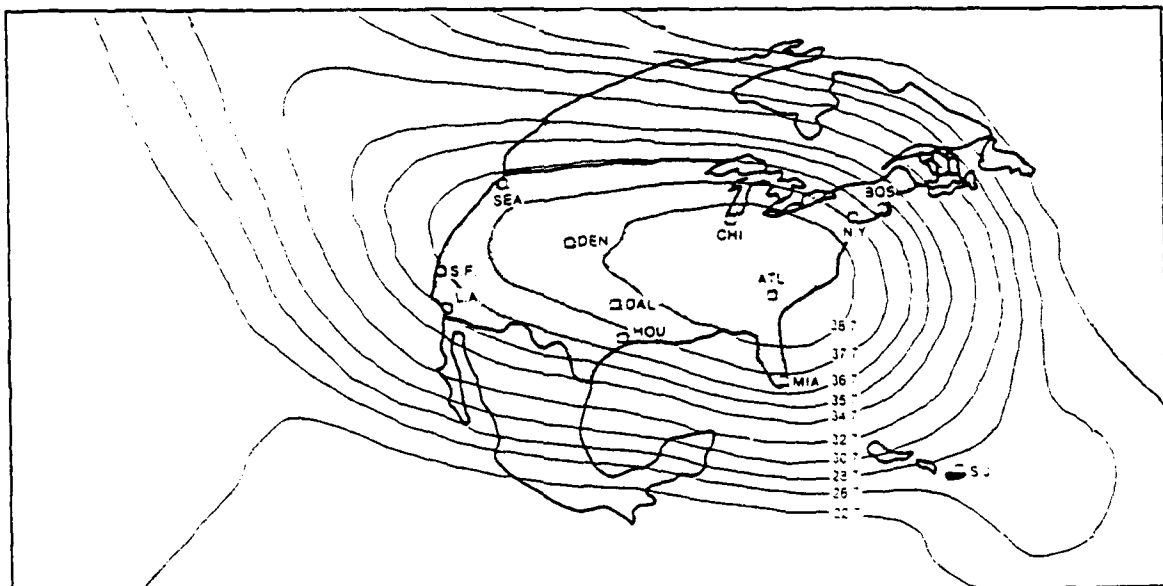


Figure 65 Galaxy II Satellite Footprint

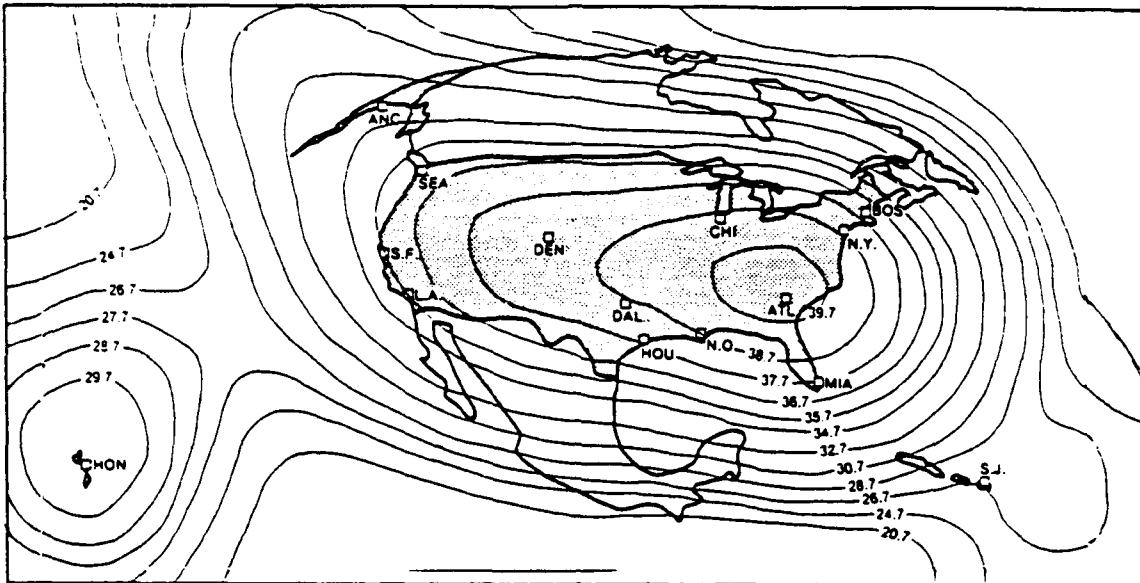


Figure 66 Galaxy III Satellite Footprint

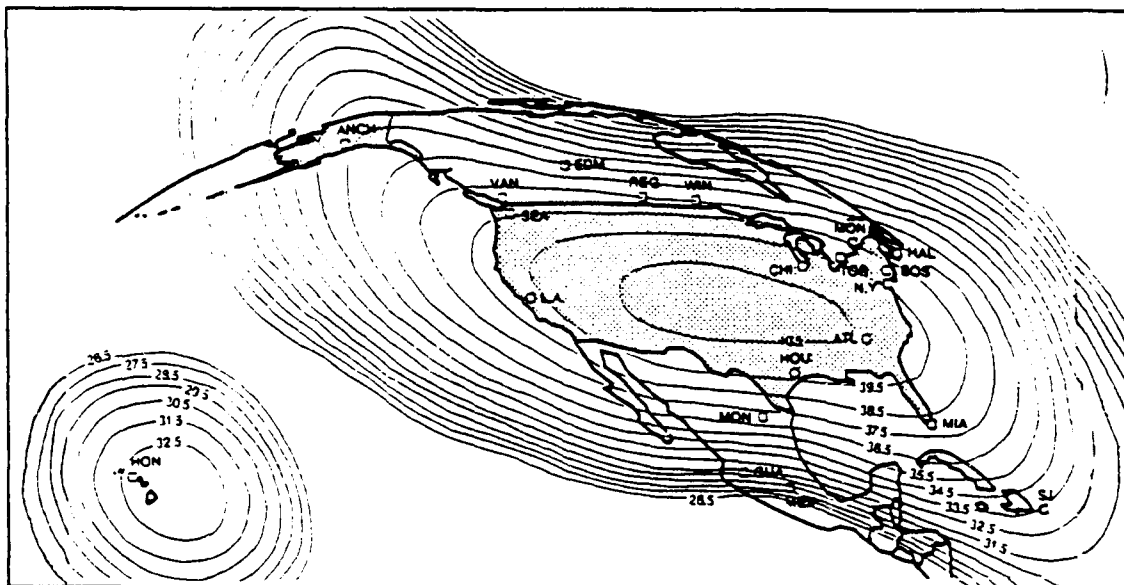


Figure 67 Galaxy V Satellite Footprint

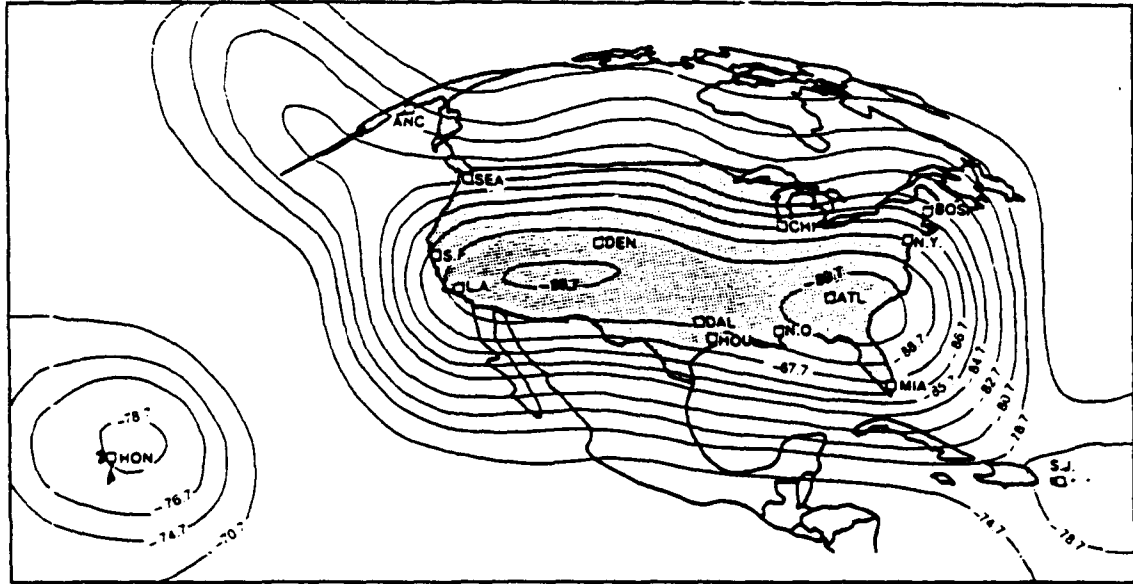


Figure 68 Galaxy VI Satellite Footprint

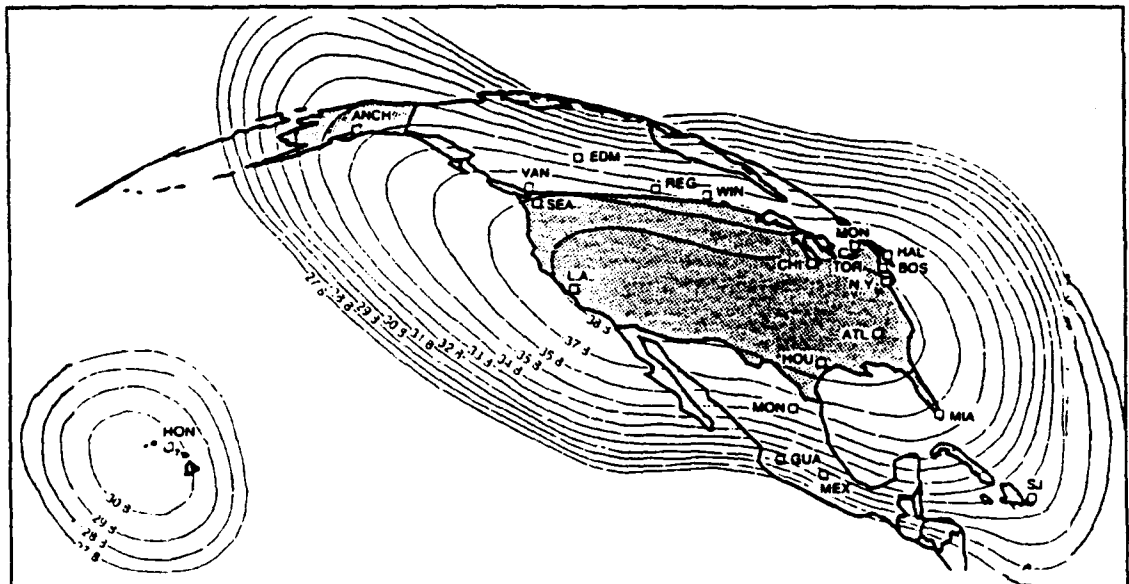


Figure 69 Galaxy IR Satellite Footprint

(2) Performance Parameters. Table 13 lists the performance parameters of the Galaxy I series satellites, including launch, frequency bands, transponder data, and coverage EIRP. (The World Satellite Directory, 1993, p. 68)

TABLE 13. PERFORMANCE PARAMETERS

Satellite Name	Galaxy I, Galaxy II, Galaxy III, Galaxy V, Galaxy VI
Longitude	133° W L (Galaxy I) 74° W L (Galaxy II) 93.5° W L (Galaxy III) 125° W L (Galaxy V) 99° W L (Galaxy VI)
Launch Vehicle	Delta (Galaxy I, II, III, VI) Atlas (Galaxy V) Ariane (Galaxy VI)
Manufacturer and Model	Hughes HS 376
Date of Launch	June 1983 (Galaxy I) September 1983 (Galaxy II) September 1984 (Galaxy III) October 1990 (Galaxy V) March 1992 (Galaxy VI)
Frequency Band(s) Galaxy I, II, III Transmit Receive Galaxy V and VI Transmit Receive	C band 5 945-6 405 GHz 3 720-4 180 GHz 5 925-6 425 GHz 3 700-4 200 GHz
Transponders Number Bandwidth Polarization	24 36 MHz Linear (frequency re-used by horizontal and vertical cross-polarization)
Power Output TWTA	9 watts (Galaxy I, II, III) 16 watts (Galaxy V) 10.2 watts (VI)
Antenna Coverage (Beam Edge EIRP) Galaxy I, II, III Conus Galaxy V Conus Galaxy VI Conus	34 dBW 37 dBW 34.5-39 dBW
Primary Power Watts EOL	741 (Galaxy I, II, III) 950.2 (Galaxy V, VI)
Stabilization Type	Spin
Maneuvering in Orbit	654 (Galaxy I, II) 604 (Galaxy V) 783 (Galaxy VI)
Design Life (Years)	10

2. Galaxy 4 Series (Galaxy IV/VII)

The Hughes Communications dual-payload Galaxy IV and Galaxy VII satellites are the newest generation of spacecraft developed by the Hughes Aircraft Company. Built on the HS 601 platform, they provide full and partial transponder point-to-point and point-to-multipoint C-band and Ku-band services. These hybrid satellites are used for domestic and transborder telecommunications, with services available to subscribers in the continental United States, Alaska, Hawaii, the Caribbean Basin, and parts of Mexico and Canada. (Fleet Technical Description, 1992, pp. 3-10)

a. Evolution of the Series

The first of the Hughes Communications dual-payload (C-band/Ku-band) satellites was Galaxy VII. This hybrid Galaxy spacecraft was used to replace two earlier Hughes Communications satellites. Galaxy VII provided a C-band substitute for Galaxy VI and a Ku-band substitute for SBS 4. Launched in October 1992, Galaxy VII successfully completed all deployment and communications payload testing and began full-time communications service on December 31, 1992 (Satellite News ED, 1994, p.11). Galaxy IV, which was launched in June 1993, was the permanent replacement for Westar IV. (World Satellite Directory, 1993, p. 62)

Galaxy IIIR, which is expected to be the next satellite in this series, is currently scheduled for launch in late 1995 to replace Galaxy III. (Hughes Communications Facts, 1994, p. 1)

b. Satellite Overview

The Galaxy IV series of satellites are three-axis-stabilized spacecraft developed by Hughes Aircraft Company. Stability is achieved through the use of magnetic torquers and an internal momentum wheel. Providing both C-band and Ku-band telecommunication services, these hybrid satellites offer a variety of services to subscribers in CONUS, Alaska, Hawaii,

and the Caribbean Basin. (Fleet Technical Description, 1992, p. 1)

The C-band payload provides twenty-four 36 MHz channels, half of which are horizontally polarized, while the other half are vertically polarized. The Ku-band payload includes sixteen 27 MHz channels and eight 54 MHz channels. (Fleet Technical Description, 1992, p. 10)

Figure 70 is a graphic depiction of a Galaxy IV series satellite. (Fleet Technical Description, 1992, p. 9)

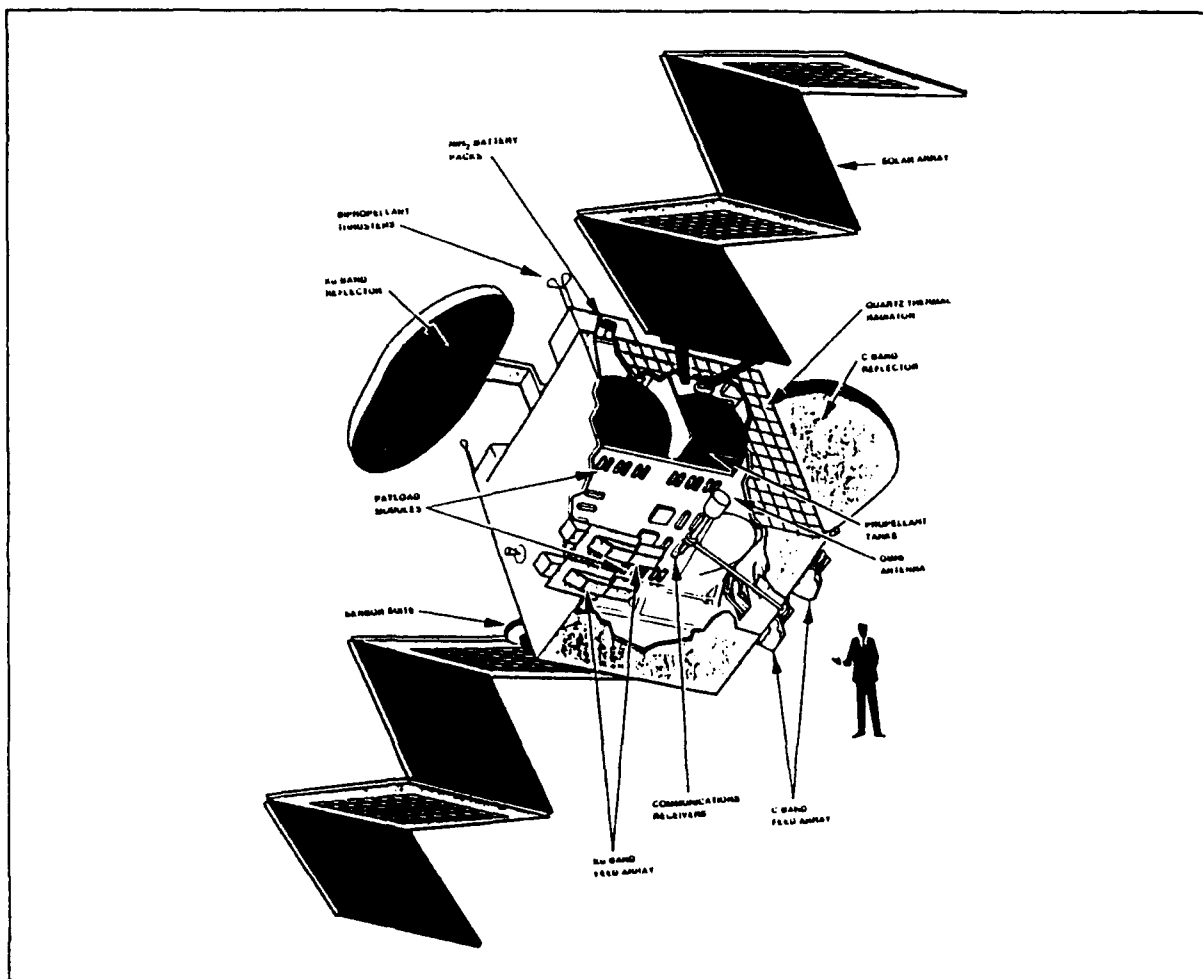


Figure 70 A Galaxy IV Series Satellite

c. Orbital Parameters

(1) *Orbit.* The Galaxy IV and Galaxy VII satellites are currently in a geostationary Earth orbit. Galaxy IV is located at 99 degrees west longitude. Galaxy VII is located at 91 degrees west longitude. Through the use of an integrated bipropellant propulsion system, both of these Galaxy HS 601 spacecraft are maintained on-station to within plus or minus 0.1 degrees in both east-west and north-south directions. (Fleet Technical Description, 1992, p. 8)

(2) *Orbital History of the Series.* Galaxy IV was launched on June 24, 1993 by Ariane 4 from Kourou, French Guiana (Satellite News ED, 1994, p. 11). Galaxy VII was launched on October 27, 1992 by Ariane 4 from Kourou. (Interavia Space Directory, 1992, pp. 409-410)

d. Key Design Features

(1) *Configuration.* These dual-payload Galaxy satellites provide twenty-four C-band and twenty-four Ku-band transponders for signal transmission. The C-band payload includes twenty-four 36 MHz channels, half of which are horizontally polarized on the downlink, with the other half being vertically polarized. The Ku-band payload includes sixteen 27 MHz channels and eight 54 MHz channels. Cross-strapping between the C-band and Ku-band payloads allows up to two channels to be converted from a C-band uplink to a Ku-band downlink simultaneously, with the same number of Ku-band uplink channels converted to C-band downlink channels. (Fleet Technical Description, 1992, p. 10)

Amplifier redundancy is provided for both payloads by two 15-for-12 amplifier redundancy rings. This arrangement allows every transponder to access two spare amplifiers. (Fleet Technical Description, 1992, p. 10)

(2) *Physical Characteristics.* The hybrid Galaxy IV series satellites are of the Hughes HS-601 model design. They are three-axis stabilized platforms which are designed to provide more power than the previous generations of Galaxy and SBS satellites. Spacecraft stability is achieved through the use of an internal momentum wheel which rotates at approximately 4500 rpm. (Fleet Technical Description, 1992, p. 8)

The physical size of the Galaxy IV satellites is 9 feet by 11.6 feet by 10 feet in the stowed configuration. The on-orbit dimensions, following solar array extension and antenna deployment, is approximately 24 feet across and 86 feet long. (Fleet Technical Description, 1992, p. 8)

The Galaxy IV and Galaxy VII satellites had a launch mass of 2725 kilograms, with an on-orbit mass (EOL) of 1320 kilograms. (Interavia Space Directory, 1992, p. 409)

Both satellites contain a solar cell/battery power subsystem which provide sufficient power for full operation during both eclipse and non-eclipse periods. The twin solar wings generate up to 6 kW. Each of the two solar wings have a 24.7 meter span and consists of four 2.16 meter by 2.54 meter panels. NiH2 batteries are utilized for eclipse periods. (Interavia Space Directory, 1992, p. 410)

(3) *Capacity.* The capacity of the links can be allocated by equipment at the premises of a user for various functions including voice circuits, video conferencing, and data and facsimile transmission. For multiple site customers, the total network capacity can be allocated among various links to meet changing needs on a daily or long-term basis.

(4) *Design Life.* The design life for the Galaxy IV and Galaxy VII satellites is 12 years. (World Satellite directory, 1993, p. 69)

e. Transmitters/Receivers

The Galaxy IV and Galaxy VII series C-band (6/4 GHz) transmitters operate in the frequency range of 5925 to 6425 MHz (World Satellite Directory, 1993, p. 69). The C-band payload provides twenty-four 16 watt SSPA transponders for signal transmission. Half of the twenty-four 36 MHz channels are horizontally polarized, while the other half are vertically polarized. In this polarization scheme transponders which downlink in the horizontal polarization will uplink in the vertical polarization. Transponders which downlink in the vertical polarization will uplink in the horizontal polarization. (Fleet Technical Description, 1992, p. 10)

The Galaxy IV and Galaxy VII series Ku-band transmitters operate in the frequency range of 14.000 to 14.500 GHz (World Satellite Directory, 1993, p. 69). The Ku-band payload provides twenty-four 50 watt TWTA transponders for signal transmission. The Ku-band payload includes sixteen vertical downlink polarized 27 MHz channels and eight horizontal downlink polarized 54 MHz channels. Cross-strapping with C-band is available on two transponders (Fleet Technical Description, 1992, p. 10)

Amplifier redundancy is provided for both the C-band and Ku-band payloads by two 15-for-12 amplifier redundancy rings. This amplifier arrangement allows each transponder to access two spare amplifiers. (Fleet Technical Description, 1992, p. 10)

The Galaxy IV series satellites also utilize C-band 4.198 and 4.199 GHz telemetry beacons. (International Satellite Directory, 1993, p. 9-88)

Galaxy IV series C-band receivers operate on frequencies from 3.700 to 4.200 GHz, while the Ku-band receivers operate on frequencies from 11.700 to 12.200 GHz. (World Satellite Directory, 1993, p. 69)

Each payload has primary receivers dedicated to either horizontally or vertically polarized signals. Two spare receivers are available for use in the event of a receiver failure. This configuration results in a 4-for-2 receiver redundancy scheme. (Fleet Technical Description, 1992, p. 10)

f. Antenna Farm

The Galaxy IV and VII satellites utilize a separate offset-fed parabolic reflector for each C-band and Ku-band antenna. The dual linear parabolic reflectors are designed to function with both horizontally and vertically polarized signals.

Figures 71 and 72 depict the footprints of the Galaxy IV and Galaxy VII satellites respectively. (Fleet Technical Description, 1992, p. 2)

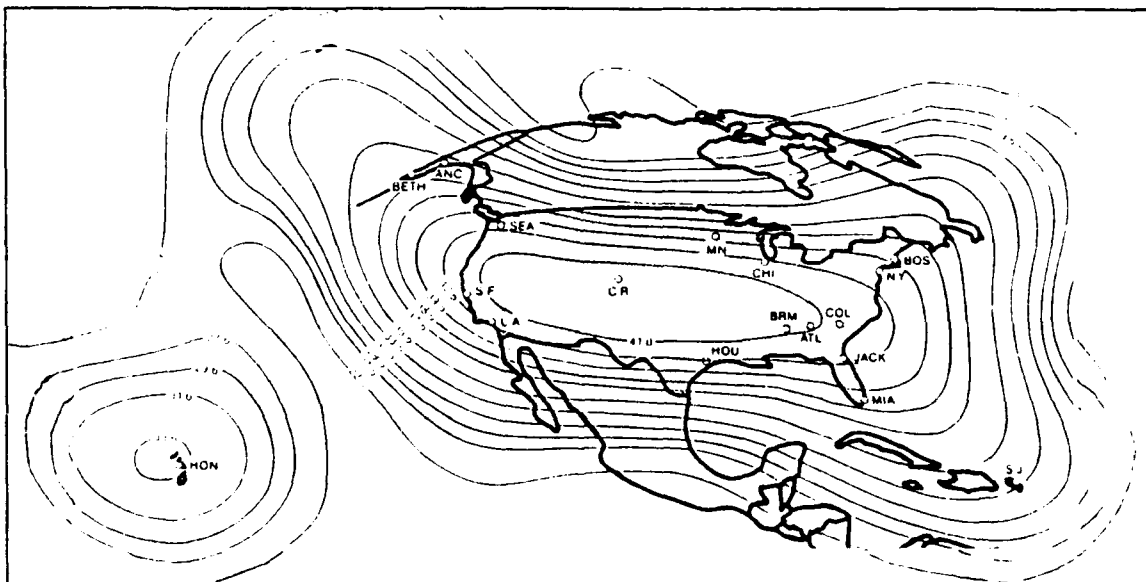


Figure 71 Galaxy IV Satellite Footprint

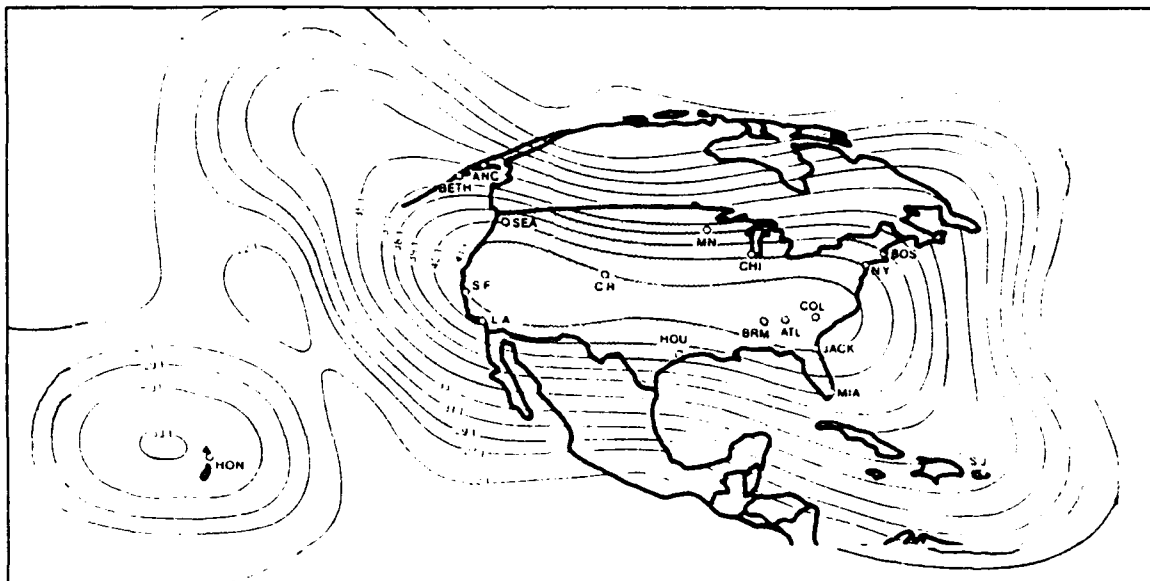


Figure 72 Galaxy VII Satellite Footprint

g. Performance Characteristics

(1) *Satellite Services.* The Galaxy IV and Galaxy VII satellites are used for C-band and Ku-band broadcast video, audio, single channel per carrier (SCPC), and VSAT telecommunications services on an on-request basis. The SCPC capacity is used for audio services which are available for the distribution of regional and national radio, and data network programming. Although both satellites provide coverage to CONUS, Alaska, Hawaii, and Puerto Rico, the type of service offered by Galaxy IV is FSS, while the type of service offered by Galaxy VII is BSS. (International Satellite Directory, 1993, pp. 12-127 - 12-276)

(2) *Performance Parameters.* Table 14 lists the performance parameters of the Galaxy IV and Galaxy VII satellites, including launch, frequency bands, transponder data and coverage EIRP. (The World Satellite Directory, 1993, p. 69)

TABLE 14. PERFORMANCE PARAMETERS

Satellite Name	Galaxy IV (replaces Westar IV)*, Galaxy VII (replaces Westar III and SBS 4)
Longitude	99° W.L. (Galaxy IV) 91° W.L. (Galaxy VII)
Launch Vehicle	Ariane
Manufacturer and Model	Hughes HS 601
Date of Launch	January 1993 October 1992
Frequency Band(s) C-Band Transmit Receive Ku-Band Transmit Receive	C band, Ku band 5 925-6 425 GHz 3 700-4 200 GHz 14 000-14 500 GHz 11 700-12 200 GHz
Transponders C-Band Number Bandwidth Polarization Ku-Band Number Bandwidth Polarization	 24 36 MHz Linear 24 16 27 MHz, 8 54 MHz Linear
Power Output C-Band TWTA Ku-Band TWTA	 16 watts 50 watts
Antenna Coverage (Beam Edge EIRP) C-Band Conus Ku-Band Conus	 37 0 dBW 45 0 dBW (Galaxy VII, Galaxy IV)
Stabilization Type	Body stabilized
Design Life (Years)	12

(3) *Flexibility.* A cross-connection exists between the C-band and Ku-band payloads which allows up to two channels to be converted from a C-band uplink to a Ku-band downlink simultaneously, with the same number of Ku-band uplink channels converted to C-band downlink channels. (Fleet Technical Description, 1992, p. 10)

3. SBS Series (SBS 4/5)

a. Evolution of the Series

The SBS 4 and SBS 5 satellites are Ku-band communication satellites purchased by IBM's Satellite Transponder Leasing Corporation subsidiary to augment the capabilities of the SBS 1, SBS 2, and SBS 3 satellites. These satellites were purchased from the Hughes Corporation in the mid 1980s and are identical in design to the earlier SBS spacecraft. The SBS 4 went into operation in 1984 and the SBS 5 became operational in 1988. In 1990 IBM sold these satellites to the Hughes Communications Corporation which uses them primarily to provide VSAT services for data networks and video broadcasting. Currently, SBS 4 is being used as an in-orbit spare and Hughes is considering putting it up for sale. (Jane's Space Directory, 1993, pp. 376-377)

b. Satellite Overview

The SBS 4 and SBS 5 satellites are cylindrical, spin-stabilized (Earth-oriented, despun communications platform with a spinning body section), Ku-band communication satellites. The SBS 4 and SBS 5 satellites both have ten operational transponders and six spares channelized at 43 MHz bandwidth. Additionally, the SBS 5 has four 110 MHz wideband Ku-band transponders installed for redundancy purposes. These satellites utilize the HS-376 satellite bus. Additionally, the HS-376 employs a beam-shaping technology which optimizes Ku-band spot beam coverage over CONUS. The SBS 5 also provides

spot beam coverage for Alaska and Hawaii. (Martin, 1986, p. 135)

The SBS satellites are equipped with two parabolic antennas which occupy the same aperture. These communication antennas operate solely at Ku-band to provide telecommunication services to customers in CONUS, Alaska, and Hawaii. These satellites are similar in design to the Anik C satellite. During the launch phase, SBS satellites are compact cylinders. On station, the antenna unfolds from one end of the satellite and a cylindrical solar array is deployed axially from the opposite end of the satellite. Silicon solar cells cover the main cylindrical body of the satellite except for a mirrored band that serves as a thermal radiator. The primary functions of these satellites is to provide TV, business telephone services, data transmission services, video teleconferencing, and other voice services to the United States at Ku-band (Long, 1987, p. 336). Figure 73 is a graphic depiction of the SBS 4 satellite. (Martin, 1986, p. 135)

c. Orbital Parameters

(1) *Orbit.* The SBS series of satellites are located in a geostationary orbit. Stationkeeping for each satellite is rated at plus or minus 0.5 degrees in latitude and longitude. SBS 4 was initially located at 91 degrees west longitude, however in January of 1993 it was moved to 77 degrees west longitude. SBS 5 is located at 123 degrees west longitude. (Jane's Space Directory, 1993, pp. 376-377)

(2) *Orbital History of the Series.* SBS 4 was launched on August 30, 1984 by STS-41D/PAM-D from Cape Canaveral. SBS 5 was launched on September 08, 1988 by Ariane V25 from Kourou, French Guiana. (Jane's Space Directory, 1993, pp. 376-377)

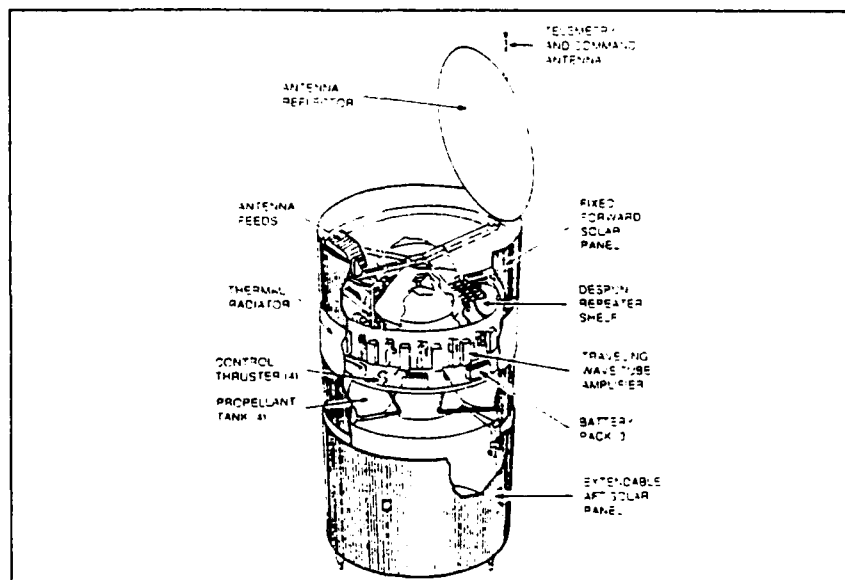


Figure 73 SBS 4 Satellite

d. Key Design Features

(1) *Configuration.* Both of the SBS satellites utilize a Hughes HS-376 satellite bus. A total of ten operational Ku-band 43 MHz transponders are equipped on each satellite. Four spare transponders are also installed on each satellite for redundancy purposes (Stanyard, 1987, p. 251). Additionally, the SBS 5 has four wideband 110 MHz transponders and two backup 110 MHz transponders. These are utilized extensively for Alaska and Hawaii coverage. (Interavia, 1992, p. 411)

(2) *Physical Characteristics.* The SBS 4 and SBS 5 satellites are of the Hughes HS-376 model design. They are cylindrical platforms which are spin stabilized at 50 rpm via four hydrazine thrusters (Stanyard, 1987, p. 251). The satellites are identical with dimensions of 2.2 meters in diameter and 6.6 meters in height when the satellite is fully deployed. The satellites employ two parabolic antenna reflectors for Ku-band operation (Brown, 1981, p. 121). The SBS 4 satellite mass is 1117 kilograms at launch and 571 kilograms on-station at the beginning of life. The SBS 5 satellite mass is 1241 kilograms at launch and 725 kilograms on-station at the beginning of life. Additionally, each satellite is equipped with 16,000 silicon solar cells mounted along the cylindrical surface of the satellite body. Two nickel cadmium batteries provide electric power to the satellites on the order of 1200 watts at the beginning of life and 1150 watts at the end of life. (Interavia, 1992, p. 411)

(3) *Capacity.* The SBS 4 satellite can accommodate ten color TV signals or 12,500 simultaneous two-way voice channels per transponder (Long, 1987, p. 336). The SBS 5 can accommodate twenty-two color TV signals or 25,000 simultaneous two-way voice channels per transponder (Long, 1991, p. 607). Each transponder uses digital, demand-assigned, TDMA links for all transmissions. The capacity of the links can be allocated by equipment at the premises of a user for various functions including voice circuits, video conferencing, and data and facsimile transmission. For multiple site customers, the total network capacity can be allocated among various links to meet changing needs on a daily or long-term basis. (Martin, 1986, pp. 134-137)

(4) *Design Life.* The design life for the SBS 4 and the SBS 5 is ten years. (Jane's Space Directory, 1993, pp. 376-377)

e. Transmitters/Receivers

At Ku-band (14/12 GHz) there are ten operational horizontal downlink polarized 43 MHz transponders and four spares for each satellite. There is one TWTA provided for each transponder. The TWTA powering each Ku-band transponder is rated at twenty watts. Additionally, SBS 5 has four vertical downlink polarized 110 MHz transponders (SBS 5 Technical Summary, 1992, p. 1). A high power option is available on the SBS 5. On this spacecraft four 110 MHz and four 43 MHz transponders can be commanded to switch from twenty watts to forty watts of transmitting power. This is accomplished through the operation of two twenty watt TWTAs in parallel. The forty watt power setting is essential for the accomodation of the high power requirements of VSAT customers. (Long, 1991. pp. 500-606)

The two Ku-band antennas (transmit and receive) are both parabolic colocated dishes that utilize linear orthogonal polarization. The transmit frequency ranges from 11.720 to 12.160 GHz and the receive frequency band ranges from 14.000 to 14.460 GHz. (Interavia, 1992, p. 411). Redundant receivers are provided on a 3-for-1 basis. There is only one operational receiver on each SBS satellite plus three spares. (Martin, 1986, p. 135)

The SBS 4 utilizes a 14-for-10 amplifier ring redundancy arrangement (SBS 4 Technical Summary, 1992, p. 1). The SBS 5 on the other hand utilizes a 24-for-14 amplifier ring redundancy arrangement. In the case of the SBS 4 arrangement each transponder has access to at least one spare TWTA in the event that its main amplifier fails. SBS 5 has access to at least two spares for this same malfunction. In this polarization scheme transponders which downlink using horizontal polarization will uplink using vertical polarization. Likewise, transponders which downlink using vertical polariza-

tion will uplink using horizontal polarization. (SBS 5 Technical Summary, 1992, pp. 1-2)

The SBS satellite communications system design is based upon quadrature phase shift keying (QPSK). This digital modulation technique is used in a TDMA system to link users in widespread geographical locations via a common transmission channel. Through the use of a QPSK modulated RF carrier signal, each transponder aboard an SBS satellite is capable of supporting approximately 50 Mb/s of digital communications. Additionally, each group of users that share a transponder have access to the full bandwidth of the channel during their assigned timeslots. (Long, 1987, pp. 348-349)

f. Antenna Farm

Each SBS satellite has two communications antennas. The Ku-band array is comprised of two parabolic antennas which occupy the same aperture. Each antenna reflector is 72 inches in diameter. The antenna platform is despun and Earth-oriented. Orthogonal linear polarization is the mode used by SBS satellites for signal processing. The SBS 4 provides spot beam coverage for CONUS only. The SBS 5 provides spot beam coverage for CONUS, Alaska, and Hawaii. A unique feature of the SBS 4 satellite is that five transponders can be switched by ground command to east or west spot beam coverage. Figures 74 and 75 depict the footprints of the SBS 4 and SBS 5 satellites. (Long, 1987, pp. 311-405)

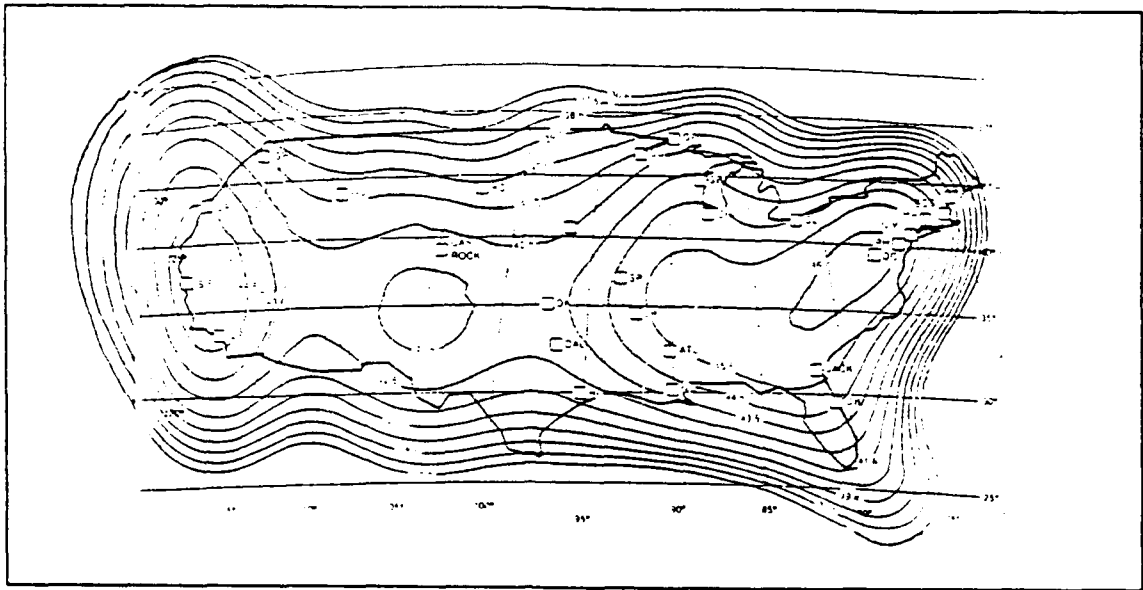


Figure 74 SBS 4 Satellite Footprint

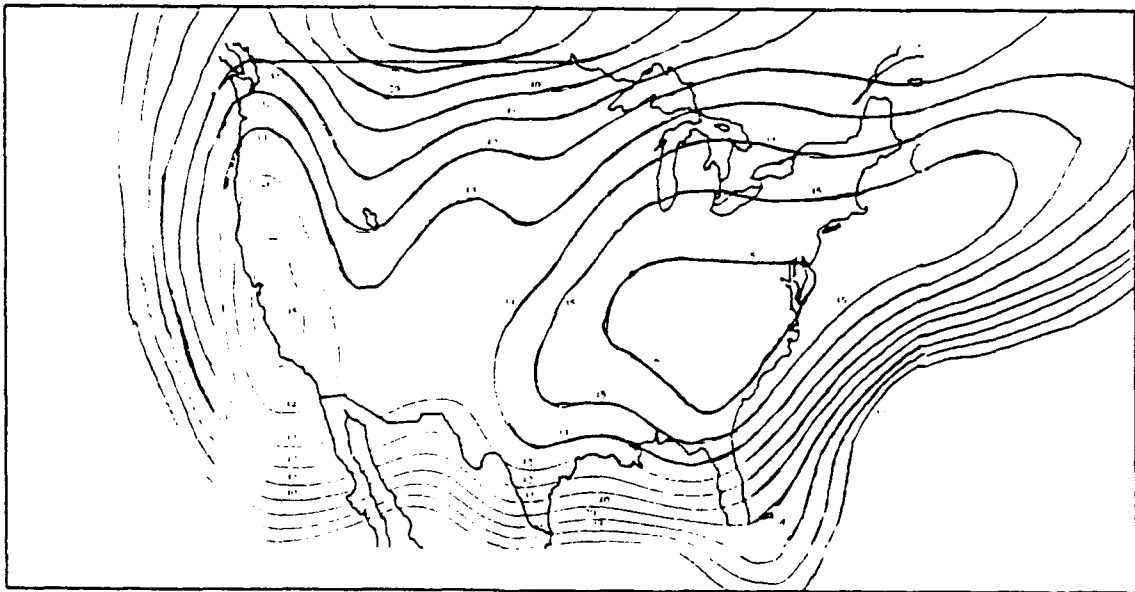


Figure 75 SBS 5 Satellite Footprint

g. Performance Characteristics

(1) *Satellite Services.* The SBS 4 and 5 are used to provide digital video and nonvideo telecommunications services. These services include high speed data transmission, facsimile service, electronic mail, two-way business telephone conversations, video teleconferencing, and VSAT services. Additionally, the SBS 5 provides scheduled use capacity to television stations and networks for satellite news gathering services. The SBS 5 is used extensively by corporate-owned VSAT networks for business information services and employee training. The SBS 4 satellite provides CONUS coverage whereas the SBS 5 satellite is equipped with wideband transponders to provide services for Alaska and Hawaii as well as CONUS. (Long, 1991, pp. 500-607)

(2) *Performance Parameters.* The total usable bandwidth provided by the ten operational 43 MHz transponders of each SBS satellite is 430 MHz. The total usable bandwidth provided by the four 110 MHz transponders of the SBS 5 is 440 MHz. The RF power of each satellite is rated at 20 watts. However, the SBS 5 has a high power option which is rated at 40 watts. (Long, 1991, pp. 500-608)

For the SBS 4 the minimum EIRP for CONUS coverage at the outer contour of the satellite's footprint is 38.0 dBW and the maximum EIRP at the beam center is between 47.0 and 49.0 dBW. The maximum EIRP for the east and west spot beams ranges from 50.0 dBW to 52.0 dBW. The minimum saturation flux density for the SBS 4 is -80.6 dBW per square meter. (International Satellite Directory, 1993, pp. 12-281-12-282)

The minimum CONUS EIRP for SBS 5 is 39.0 dBW. The maximum CONUS EIRP at the beam center is between 47.0 dBW and 49.0 dBW. The maximum EIRP for the Alaska spot beam is 53.0 dBW. The minimum saturation flux density for the SBS 5 is -82 dBW per square meter. (Long, 1991, pp. 500-607)

(3) *Flexibility.* The SBS 5 incorporates a high power option in which four of the 43 MHz transponders and four of the 110 MHz transponders can be switched from twenty watts of transmitting power to forty watts of transmitting power. This is accomplished by paralleling a pair of TWTAs. This provides the flexibility necessary to accommodate VSAT customers for high speed data and video services in the growing VSAT arena. (Long, 1991, p. 606)

4. SBS Series (SBS 6)

a. Evolution of the Series

The FCC granted permission on July 25, 1985 to the Satellite Business Systems Consortium to build, launch, and operate a second generation SBS satellite, the SBS 6. The SBS 6 was the last operational satellite designed to augment the SBS constellation of geosynchronous spacecraft. In 1986 the INTELSAT Corporation had an option to purchase this satellite from IBM; however, INTELSAT failed to exercise the option. The Hughes Communications Corporation eventually made the purchase, following its acquisition of the SBS 4 and SBS 5 satellites. The SBS 6 was initially utilized as a ground spare for the SBS system. It was subsequently launched in 1990 to replace the SBS 1 when it reached the end of its useful life. (Long, 1987, pp. 261-262)

b. Satellite Overview

The SBS 6 satellite is a second generation SBS satellite. It is very similar in appearance to previous SBS satellites. The major differences in the SBS 6 are that it is significantly larger (diameter of SBS 6 is 67 percent larger and height is 42 percent greater than other SBS satellites) than prior models and provides up to three times the capacity of a first generation SBS satellite. (Martin, 1986, pp. 136-137)

The SBS 6 is a cylindrical, spin-stabilized (Earth-oriented, despun communications platform with a spinning body section), Ku-band only, communication satellite. The SBS 6 satellite has nineteen operational transponders channelized at 43 MHz bandwidth. Dual polarization is employed to enable frequency reuse. This satellite utilizes the HS-393 satellite bus. Additionally, the HS-393 employs a beam-shaping technology which optimizes Ku-band spot beam coverage over CONUS, Alaska, and Hawaii. (Long, 1987, pp. 261-262)

The SBS 6 is equipped with one parabolic antenna. This communications antenna operates solely at Ku-band to provide telecommunication services to customers in CONUS, Alaska, and Hawaii. During the launch phase SBS satellites are compact cylinders. On station, the antenna unfolds from one end of the satellite, and a cylindrical solar array is deployed axially from the opposite end of the satellite. Silicon solar cells cover the main cylindrical body of the satellite except for a mirrored band that serves as a thermal radiator. The primary functions of this satellite are to provide TV, business telephone services, data transmission services, video teleconferencing, and other voice services to the United States at Ku-band (Long, 1987, pp. 261-262).

c. Orbital Parameters

(1) *Orbit.* The SBS 6 satellite is located in a geostationary orbit. Stationkeeping for this satellite is rated at plus or minus 0.5 degrees in latitude and longitude. SBS 6 is located at 99 degrees west longitude. (Jane's Space Directory, 1993, pp. 376-377)

(2) *Orbital History of the Series.* SBS 6 was launched on October 12, 1990 by an Ariane 4 from Kourou, French Guiana. (Jane's Space Directory, 1993, pp. 376-377)

d. Key Design Features

(1) *Configuration.* The SBS 6 satellite utilizes a Hughes HS-393 satellite bus. A total of nineteen operational Ku-band 43 MHz transponders are installed on this satellite. Frequency reuse is achieved through dual linear polarization. Ten of these use horizontal linear polarization while nine transponders utilize vertical linear polarization. The antenna coverage pattern is similar to that of the SBS 5 in that the satellite provides CONUS coverage as well as coverage to Alaska and Hawaii. (Long, 1991, pp. 527-528)

(2) *Physical Characteristics.* The SBS 6 is a cylindrical platform which is spin stabilized at approximately 50 rpm via six 22 Newton hydrazine thrusters (Interavia, 1992, p. 411). The satellite has dimensions of 3.6 meters in diameter and 10.0 meters in height when it is fully deployed. The satellite employs one 2.4 meter diameter parabolic antenna reflector for Ku-band operation. The SBS 6 satellite mass is 2478 kilograms at launch and 1514 kilograms on-station at the beginning of life. The dry mass of the satellite is 1138 kilograms. Additionally, the satellite is equipped with silicon solar cells mounted along the cylindrical surface of the satellite body. Two nickel hydrogen batteries provide electric power to the satellite on the order of 2262 watts at the end of life. (Long, 1991, p. 528)

(3) *Capacity.* SBS 6 can accomodate nineteen color TV signals or 25,000 simultaneous two-way voice channels per transponder (Long, 1987, p. 261). Each transponder uses digital, demand-assigned, TDMA links for all transmissions. The capacity of the links can be allocated by equipment at the premises of a user for various functions including voice circuits, video conferencing, and data and facsimile transmission. For multiple site customers, the total network capacity

can be allocated among various links to meet changing needs on a daily or long-term basis. (Martin, 1986, pp. 134-137)

(4) *Design Life.* The design life for the SBS 6 satellite is ten years (Jane's Space Directory, 1993, pp. 376-377). However, it is projected that the satellite will have an operational lifetime of 15.6 years (Long, 1991, p. 528).

e. Transmitters/Receivers

At Ku-band (14/12 GHz) there are nineteen operational 43 MHz transponders. Ten transponders are horizontally polarized and nine transponders are vertically polarized. This dual linear polarization scheme allows for frequency reuse. Output power is provided to each transponder by TWTAs. The TWTAs powering each Ku-band transponder is rated at forty-one watts. The SBS 6 utilizes a 30-for-19 amplifier ring redundancy scheme. This arrangement allows each transponder to have access to at least two spare TWTAs in the event that the main amplifier powering it fails. (SBS 6 Technical Summary, 1992, pp. 1-2)

The Ku-band antenna is a parabolic dish that utilizes dual linear polarization. The transmit frequency ranges from 11.720 to 12.160 GHz and the receive frequency band ranges from 14.000 to 14.460 GHz. (Interavia, 1992, p. 411). There are a total of four receivers on the SBS 6. Two are always operational and two are in a standby mode for redundancy purposes. (Martin, 1986, p. 137)

The SBS satellite communications system design is based upon quadrature phase shift keying (QPSK). This digital modulation technique is used in a TDMA system to link users in widespread geographical locations via a common transmission channel. Through the use of a QPSK modulated RF carrier signal each transponder aboard an SBS satellite is capable of supporting approximately 50 Mb/s of digital communications. Additionally, each group of users that share a transponder has

access to the full bandwidth of the channel during their assigned timeslots. (Long, 1987, pp. 348-349)

f. Antenna Farm

The SBS 6 satellite has one communications antenna. The Ku-band antenna reflector is 2.4 meters in diameter. The antenna platform is despun and Earth-oriented. Dual linear polarization is the mode used by the SBS 6 for signal processing. Nineteen operational Ku-band transponders comprise the communications payload of the SBS 6. Transponders, which uplink in the vertical polarization, downlink in the horizontal polarization. Alternatively, transponders which downlink in the vertical polarization, uplink in the horizontal polarization. Like the SBS 5, the SBS 6 provides spot beam coverage for CONUS, Alaska, and Hawaii. Figure 76 depicts the footprint of the SBS 6 satellite. (SBS 6 Technical Summary, 1992, pp. 1-3)

g. Performance Characteristics

(1) *Satellite Services.* The SBS 6 is used to provide digital video and nonvideo telecommunications services. These services include high speed data transmission, facsimile service, electronic mail, two-way business telephone conversations, video teleconferencing, and VSAT services. Additionally, the SBS 6 provides scheduled use capacity to television stations and networks for various types of television programming. Corporate-owned VSAT networks constitute the major users of the SBS 6's information services. Data transmission services provided to VSATs operate via digital, demand assigned, TDMA links (Martin, 1986, p. 137).

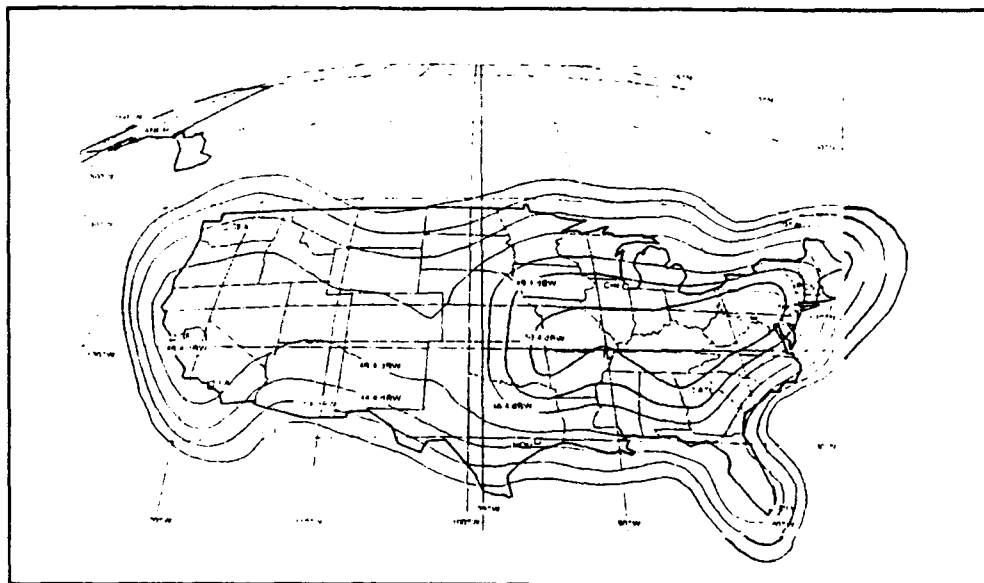


Figure 76 SBS 6 Satellite Footprint

(2) *Performance Parameters.* The total usable bandwidth provided by the nineteen operational 43 MHz transponders of the SBS 6 satellite is 817 MHz. The RF power of each satellite is rated at 41 watts. For the SBS 6 the minimum EIRP for CONUS coverage at the outer contour of the satellite's footprint is 40.4 dBW and the maximum EIRP at the beam center is between 49.4 and 50.4 dBW. The maximum EIRP for the east and west spot beams ranges from 47.4 dBW to 50.4 dBW. The minimum saturation flux density for the SBS 6 is negative 90.0 dBW per square meter. (SBS 6 Technical Summary, 1992, pp. 1-3)

H. INTELSAT CORPORATION

The International Telecommunications Satellite Organization (INTELSAT) is a cooperative of 128 member nations that collectively owns and operates a global commercial satellite system. Since its inception in the early 1960s, INTELSAT has procured and launched more than 50 communications satellites. The current INTELSAT satellite system is comprised of 20 operational satellites in geosynchronous orbit. Global telecommunications and international television services are provided by seven Atlantic Ocean Region (AOR) satellites, four Pacific Ocean Region (POR) satellites, and four Indian Ocean Region (IOR) satellites. Additionally, there are five satellites undergoing orbital testing which should go into service by 1995. Through this telecommunications network INTELSAT links more than 180 countries, territories, and dependencies via approximately 1000 earth stations worldwide (Carver and Cotner, 1992, pp. 1-9).

Earth stations accessing Intelsat data are owned and operated by a host of telecommunications organizations. There are currently thirteen categories of earth station standards in use. Coordination and control of communications services are the responsibility of the Satellite Control Center (SCC) and the Intelsat Operations Center (IOC). Handling more than 100 TV transmissions, antenna verifications, and other tests daily, the IOC is the nerve center for the communications network. TT&C services and pointing data for transmissions to Earth are provided by the SCC. As of 1992 there were six stations located and operated throughout the world. (Interavia 1992-1993, p. 371)

1. INTELSAT V Series (501/502/503/504/505/506/507/508)

a. *Evolution Of The INTELSAT V Series*

In response to ever-expanding requirements for space segment capacity, Intelsat embarked upon the Intelsat V program in 1976. Prior to this time the Intelsat system was a C-band only telecommunications network. The Intelsat V system provided Intelsat with its first generation of hybrid satellites, allowing Intelsat to establish a strong, marketable Ku-band capability. (Alper and Pelton, 1984, pp. 80-81).

b. *Satellite Overview*

The first Intelsat V, Intelsat 501, was built by Ford Aerospace. It was launched in 1980 and like all satellites of this series, it utilizes fourfold frequency reuse. These satellites employ both spatially separated beams and dual polarization within the 500-MHz available bandwidth at C-band and Ku-band. The Intelsat V series was the first generation of Intelsat satellites to operate in the 14/11 GHz Ku-band. Intelsat V satellites along with the modified Intelsat VA series of satellites are currently the workhorses of the Intelsat system, but are both nearing the end of their operational life. (Miller, 1993, p. 3)

In addition to a full payload of C-band and Ku-band transponders, Intelsat V satellites 505 through 508 carry a Maritime Communications Subsystem (MCS). The MCS operates at frequencies in C-band (4/6 GHz) and L-band (1.5/1.7 GHz) to link satellite shore stations with ships at sea as part of the International Maritime Satellite Organization (Inmarsat) system. Figure 77 is an illustration of an Intelsat V satellite. (Agrawal, 1986, p. 38)

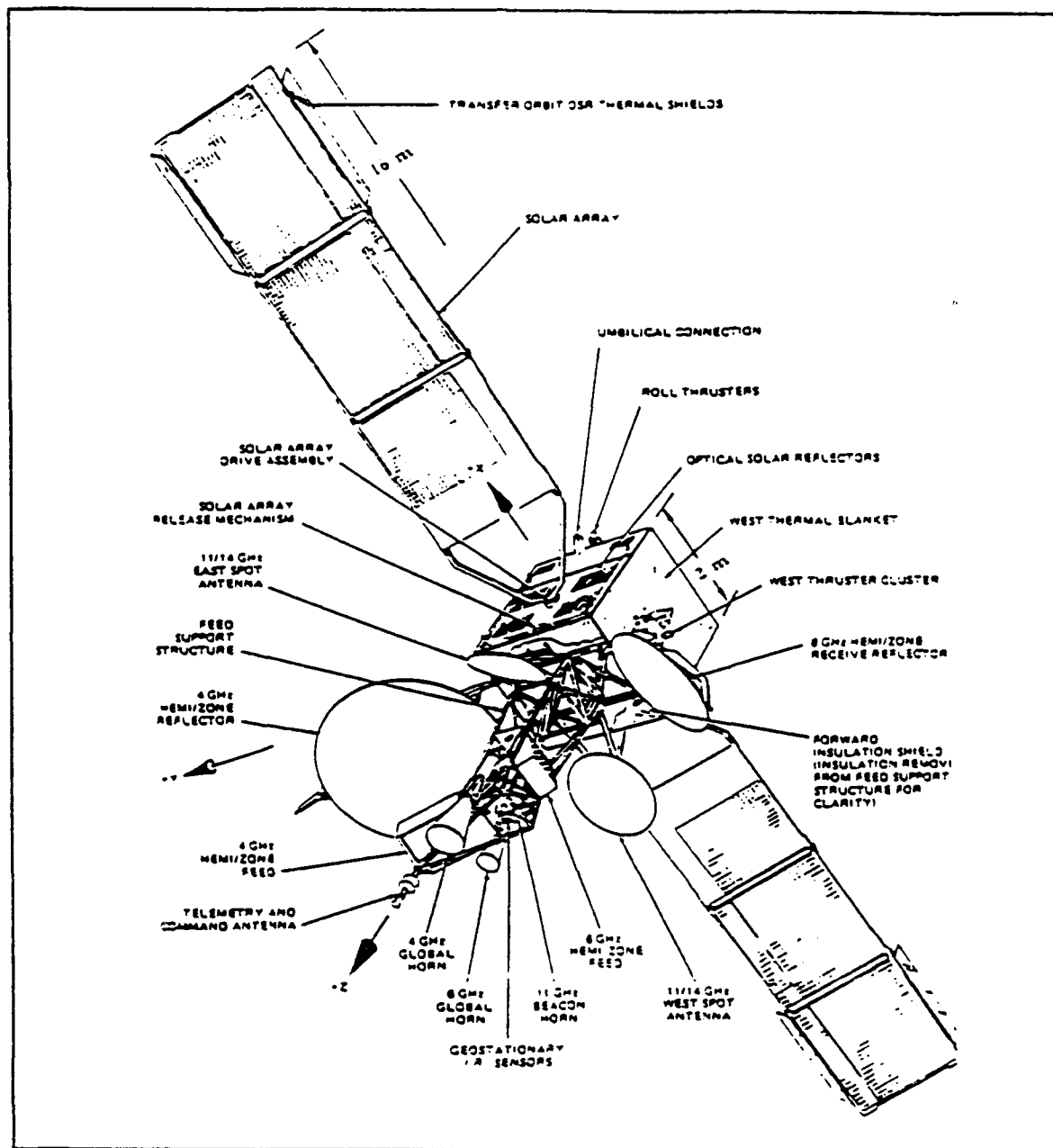


Figure 77 Intelsat V Satellite

c. Orbital Parameters

(1) *Orbit.* All Intelsat V satellites are currently in inclined geosynchronous Earth orbits. Spacecraft stationkeeping accuracy is rated at plus or minus 0.1 degrees east/west and north/south. Satellites 501 through 506 were placed in orbit by Atlas/Centaur launchers and satellites 507 and 508 were orbited by Ariane. Intelsat 502 which was the first of the series to be placed in orbit is located at 21.5 degrees west longitude. Intelsat 501 is located at 91.5 degrees west longitude. Intelsat 503 is located at 177 degrees west longitude. Intelsat 504 is located at 40.5 degrees west longitude. Intelsat 505 is located at 66 degrees east longitude. The last of the Intesat V series to be launched by Atlas/Centaur, Intelsat 506, is located at 50 degrees west longitude. As for the satellites launched by Ariane, 507 is located at 57 degrees east longitude and 508 is located at 180 degrees east longitude. (The World Satellite Directory, 1993, p. 148)

(2) *Orbital History.* The first Intelsat V to be launched was Intelsat 502 on December 6, 1980. The second launch of an Intelsat V was on May 23, 1981 with the launch of Intelsat 501. On December 16, 1981 Intelsat 503 was launched. Next, Intelsat 504 was launched on March 5, 1982. Intelsat 505 and 506 were launched on September 28, 1982 and May 19, 1983 respectively. These were followed by the launch of Intelsat 507 on October 19, 1983 and Intelsat 508 on March 5, 1984. (Janes Space Directory, 1994, p. 340)

d. Key Design Features

(1) *Configuration.* The INTELSAT V satellites operate on both vertical and horizontal polarizations. The zone and spot beams are cross-polarized to allow simultaneous east and west signal pattern transmission by both beams. Each Intelsat V is comprised of twenty-seven transponders, twenty-

one operating at C-band (6/4 GHz) and six operating at Ku-band (14/11 GHz). The C-band is comprised of twenty-one transponders, sixteen have 72 MHz or 77 MHz bandwidths and five have 36 MHz or 41 MHz bandwidths. Of the six Ku-band transponders two each have bandwidths of 72 MHz, 77 MHz, and 241 MHz. (Martin, 1988, pp. 52-54)

The satellites equipped with the MCS are Intelsat 505 through 508. The maritime subsystem makes use of some of the global beam equipment of the basic communications payload along with some additional equipment which was added on. In the shore-to-ship link, one double-conversion repeater with a 7.5 MHz bandwidth is utilized. The ship-to-shore link uses a single-conversion repeater with a bandwidth of 8 MHz. (Martin, 1986, pp. 55-56)

(2) *Physical Characteristics.* The Intelsat V spacecraft are three-axis stabilized and have a box-shaped bus. The spacecraft on-station mass is approximately 1188 kilograms. Spacecraft height is 6.4 meters. The Intelsat V series solar panels have a wingspan of 15.6 meters and contain 17,568 solar cells. The total power produced by the solar array is 1,742 watts. Additionally, these satellites carry NiH₂ batteries which provide power during eclipse periods. (Wilson, 1992, p. 372)

(3) *Capacity.* The nominal capacity in a typically configured Intelsat V satellite is approximately 12,000 two-way voice circuits plus two television channels (Miller, 1993, p. 3). Satellites 505 through 508, which carry MCS, provide for 30 voice circuits in the high power mode or 15 voice circuits in the low power mode. (Martin, 1988, p. 56)

(4) *Design Life.* The design life for the Intelsat V series of satellites is seven years. (Wilson, 1992, p. 372)

e. Transmitters

Each Intelsat V satellite carries twenty-seven transponders, twenty-one of which operate in the C-band while the other six operate in the Ku-band. Transponder connectivity is achieved via a switching matrix. (Martin, 1988, pp. 52-54)

The C-band (6/4 GHz) transmit section operates between 3704 MHz and 4198 MHz. One 8.5 watt TWTA per transponder provides the global beam (with one spare per transponder available). For the hemispheric beam one 8.5 watt TWTA per transponder is used (with one spare per two transponders available). One 4.5 watt TWTA per transponder provides for the zonal beam (with one spare available for every two transponders). (Martin, 1988, p. 54)

The Ku-band (14/11 GHz) transmitter section operates from 10.954 to 11.191 GHz and from 11.459 to 11.698 GHz. One 10 watt TWTA per transponder generates the Ku-band spot beams. One-for-one redundancy is used for the 241 MHz transponders and one-for-two redundancy is used for the 72 and 77 MHz transponders. (Martin, 1988, p. 54)

The MCS payloads, which are for lease to Inmarsat, are each capable of providing the equivalent of thirty telephone circuits. The L-band frequencies used are 1.6365-1.644 for the uplink and 1.535-1.5425 GHz for the downlink with an EIRP of 33 dBW. One active L-band transistor amplifier is used to provide 70 or 35 watts, and one is available as a spare. For C-band, 6.4175-6.425 GHz is used for the uplink while 4.1925-4.200 GHz is used for the downlink with an EIRP of 21.0 dBW. At C-band one active 4.5 watt TWTA is used and one is available for use as a spare. (Martin, 1988, p. 56)

f. Receivers

(1) *C-Band Receivers.* The Intelsat V C-band receiver section is comprised of five active receivers plus six spares. Satellites 501 through 504 in this series use bipolar preamplifiers while 505 through 508 carry field effect transistor (FET) preamplifiers. At 6/4 GHz the frequency plan runs from 5929 to 6423 MHz. (Martin, 1988, p. 54)

(2) *Ku-Band Receivers.* The Ku-band receiver section has two active receivers and two spares. Tunnel diode preamplifiers are used on satellites 501 through 506 and FET preamplifiers are carried on 507 and 508. At 14/11 GHz the frequency plan runs from 14.004 to 14.498 GHz. (Martin, 1988, p. 54)

g. Antenna Farm

On the Earth-viewing face of the Intelsat V body is an antenna tower on which are mounted both the communications and TT&C antennas. The tower is approximately 15 feet tall and is constructed of graphite fiber/epoxy. The antenna payload offers several beam coverage patterns which have been designed to meet specific traffic requirements. The telemetry beacons operate at 3.9475/3.9525 GHz and 11.200/11.450 GHz, while the command beacon typically operates at 3.9475 or 1.1196 GHz. (Martin, 1988, pp. 52-55)

At C-band each Intelsat V satellite carries global, hemispheric, zone and spot beam antennas. The global beams can relay signals to any point within the 42 percent of the Earth's surface which is in view of the satellite's position in orbit. There are two C-band Earth coverage horns, one for transmit the other for receive. Some C-band transponders may be switched to high gain spot beam antennas which provide for a nominally higher EIRP. (Long, 1991, pp. 139-141)

East and west hemispheric beams may relay signals to the eastern or western hemispheres relative to the satellite's position in orbit. The C-band frequency range is effectively doubled through the spatial isolation of the east and west hemispheric beams. Two zone beams relay signals to locations northeast and northwest of the spacecraft's orbital position. Due to the cross-polarization of the zone and hemispheric beams, they may transmit east and west signal patterns simultaneously. Again, the C-band frequency range is effectively doubled through the use of spatial isolation of the east and west zone beams. (Long, 1991, pp. 139-141)

There are two reflectors which generate the two hemispheric beams and the two smaller zone beams, each having 88 feed horns. The transmit reflector is 96 inches in diameter while the receive reflector is 61 inches in diameter. The zone beams each overlap a portion of a hemispheric beam and are separated by orthogonal polarization. (Martin, 1988, p. 55)

At Ku-band, medium power signals are relayed to designated regions via steerable east and west spot beam antennas. These beams are cross-polarized, therefore both may transmit into the same region simultaneously (Long, 1991, pp. 139-141). There are two Ku-band reflectors, one east and one west, with the east beam being 1.8 degrees and the west beam being 1.6 degrees. Each of these reflectors generates one beam for transmit and one for receive. (Martin, 1988, p. 55)

The C-band and Ku-band transponders on Intelsat V satellites are cross-strappable to allow their signals to be uplinked using one frequency band and then downlinked by the other. Signal routing is controlled by a switching matrix which is energized by command signals from Earth. (Long, 1991, pp. 139-141)

Intelsat V spacecraft 505 through 508 carry the Maritime Communications System (MCS) which uses C-band and L-band frequencies. Therefore, an additional L-band antenna is carried on these spacecraft. The L-band antenna used for this application is a one quad helix array with a beamwidth of 18 degrees to provide global coverage. This L-band antenna is steerable to within plus or minus two degrees east/west and employs circular polarization. The MCS payload uses frequencies in the top C-band transponder and an L-band transponder to link shore stations with ships at sea as part of the Inmarsat system. (Long, 1991, pp. 139-141)

Intelsat V satellites which no longer have the ability to make station-keeping maneuvers may have their operational life extended by a proprietary technique known as the Comsat Maneuver. This maneuver consists of subtle changes in the physical orientation of the spacecraft controlled by ground stations. The Comsat Maneuver ensures that the antenna pattern always remains centered on the desired coverage area. (Long, 1991, pp. 139-141)

h. Performance Characteristics

(1) *Satellite Services.* The Intelsat V series of satellites are capable of providing international video services, Intelsat Business Services (IBS), Intelsat services, and digital television services. The Intelsat V series satellites may carry up to 12,000 two-way telephone circuits as well as two television channels. Intelsat 505 through 508 provide maritime communications services for Imarsat. (Long, 1991, pp. 139-142)

(2) *Performance Parameters.* The Intelsat V hemispheric and zone beam antenna patterns are a full 3 dB higher than the respective footprints of Intelsat IVA satellites. The beam-edge EIRP levels of Intelsat V hemispheric and zone beams are typically 29 dBW at saturation. Global

beam transponders carried by the Intelsat V satellites also operate at EIRP levels which are higher than global beam transponders on Intelsat IV and IVA spacecraft. The typical Intelsat V global beam edge EIRP levels average approximately 23.5 dBW compared with 22 dBW for older Intelsat spacecraft. (Long, 1987, pp. 61-62)

Table 15 lists the performance parameters of the Intelsat V series including launch, frequencies, transmitter and coverage data. (The World Satellite Directory, 1993, p. 148)

2. INTELSAT VA Series (510/511/512/513/515)

a. Evolution Of The INTELSAT VA Series

A modification of the Intelsat V series, Intelsat VA's development began in late 1979. As with previous Intelsat upgrades the primary objective of Intelsat VA was to increase satellite capacity and keep ahead of traffic growth in the Atlantic operating region. Intelsat VA was developed by the Ford Aerospace Communications Corporation (currently Loral Space Systems). (Martin, 1986, p. 57)

The Intelsat VA series may be broken down into two separate models, the Intelsat VA and the Intelsat VA (IBS). Three spacecraft were manufactured using the first model design (Intelsat VA). These three spacecraft are designated as Intelsat 510, 511, and 512 (or F10, F11, and F12, respectively). The remaining two spacecraft are of the second model type, Intelsat VA (IBS). These two satellites are designated as Intelsat 513 and 515 (or F13 and F15, respectively). The two Intelsat VA (IBS) satellites operate as part of the Intelsat International Business Service (IBS) which is a digital communications network used by multinational businesses to link locations around the world. (Long, 1987, pp. 62-65)

TABLE 15. INTELSAT V PERFORMANCE PARAMETERS

Satellite Name	INTELSAT 501, INTELSAT 502, INTELSAT 503, INTELSAT 504 INTELSAT 505, INTELSAT 506 INTELSAT 507, INTELSAT 508
Longitude	91.50° E.L. INTELSAT 501 (Inclined) 21.50° W.L. INTELSAT 502 (Inclined) 177° W.L. INTELSAT 503 (Inclined) 40.5° W.L. INTELSAT 504 (Inclined) 66° E.L. INTELSAT 505 (Inclined) 50° W.L. INTELSAT 506 (Inclined) 57° E.L. INTELSAT 507 (Inclined) 180° E.L. INTELSAT 508 (Inclined)
Launch Vehicle (s)	Atlas/Centaur (501 to 506) Ariane (507 to 508)
Manufacturer	Ford Aerospace
Date of Launch	May 1981 (INTELSAT 501) December 1980 (INTELSAT 502) December 1981 (INTELSAT 503) March 1982 (INTELSAT 504) May 1983 (INTELSAT 505) May 1983 (INTELSAT 506) October 1983 (INTELSAT 507) March 1984 (INTELSAT 508)
Frequency Band(s) Global Transmit Receive	C. Ku 3.955-4.200 GHz 6.180-6.425 GHz
Transponders Global Number Bandwidth Polarization	5 Maximum 36, 41, and 72 MHz Circular
Power Output Global TWTA	8.5 and 4.5 watts
Antenna Coverage (EIRP Beam Edge)	23.5 and 26.5 dBW (Global)
Primary Power Watts EOL	1300
Stabilization Type	3-Axis
Mass (Kg. in Orbit)	1020 to 1090
Design Life (Years)	7

b. Satellite Overview

Externally, Intelsat VA appears to be identical to Intelsat V; internally however, there are considerable differences. Several changes were incorporated into the Intelsat VA to improve performance, reliability, and communications capacity. With the addition of two steerable 4-GHz zone beams, the Intelsat VA has an average communications capacity of 15,000 two-way circuits and two television channels. This represents an increase of approximately three thousand two-way bearer circuits over the Intelsat V series. Several weight-saving measures were taken to compensate for the additional communications hardware. Additionally, the internal arrangement of the communications hardware was modified to provide thermal balance. (Long, 1991, pp. 141-143)

The Intelsat VA (IBS) is an Intelsat VA with CONUS coverage capability at Ku-band and an additional switching capability which allows the 11 GHz downlink frequency bands of the Intelsat VA to be switched to higher frequency bands around 12 GHz. In these bands, which are not shared with terrestrial microwave systems, earth stations can be sited with minimal coordination difficulties. This ability allows International Business Service to be provided close to the customer's premises. (Long, 1987, pp. 62-65)

Figure 78 is an illustration of an Intelsat VA satellite. (Satellite News BK, 1988, p. 1)

c. Orbital Parameters

(1) *Orbit.* All five Intelsat VA spacecraft are currently in a geosynchronous equatorial (0.2 degrees of inclination or less) Earth orbit. Intelsat 510, 511, and 512 were orbited by Atlas-Centaur while the two Intelsat VA (IBS) satellites, 513 and 515, were launched on Ariane 2. The first Intelsat VA launched (Intelsat 510) is located at 186.0 degrees west longitude. Intelsat 511 is located over the Pacific Ocean at 183.0 degrees west longitude. Intelsat 512

is located over the eastern Atlantic Ocean at 1.0 degrees west longitude. The two Intelsat VA (IBS) satellites, 513 and 515, are located at 53.0 degrees west and 18.0 degrees west longitude, respectively. Spacecraft stationkeeping error is rated at plus or minus 0.1 degree east/west and north/south. (International Satellite Directory, 1993, pp. 12-176 - 12-374)

(2) *Orbital History.* The first Intelsat VA to be orbited was Intelsat 510 on March 22, 1985. The second Intelsat VA, 511, was launched on June 29, 1985. Next, Intelsat 512 was launched on September 28, 1985. The first Intelsat VA (IBS) (Intelsat 513) was launched on May 17, 1988.

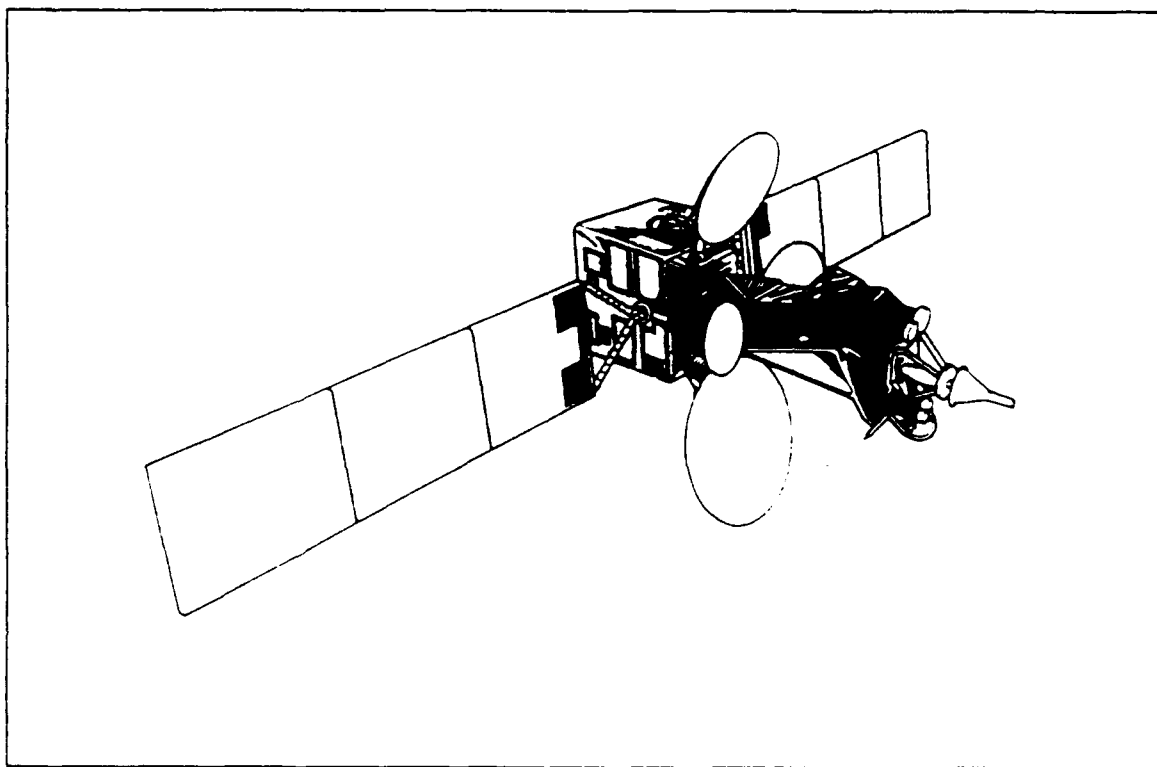


Figure 78 Intelsat VA Satellite

Intelsat 514 was lost during an Ariane launch vehicle failure in May 1986 (Martin, 1988, p. 57). The last of the series (Intelsat 515) was launched on January 26, 1989. (International Satellite Directory, 1993, pp. 12-176 - 12-374)

d. Key Design Features

(1) *Configuration.* Each Intelsat VA is comprised of thirty-two transponders, twenty-six of which are C-band, while the other six are Ku-band. The Intelsat VA uses circular polarization at C-band and linear polarization at Ku-band. (International Satellite Directory, 1992, p. 9-148)

At C-band there are sixteen transponders which have a bandwidth of 72 MHz and ten which have a bandwidth of 36 MHz. At Ku-band, four of the transponders operate with bandwidths of 72 MHz, while the other two use 241 MHz bandwidths. (International Satellite Directory, 1992, p. 9-148)

(2) *Physical Characteristics.* Intelsat VA satellites are stabilized via three-axis stabilization. The spacecraft has a launch weight of approximately 2013.6 kilograms and weighs approximately 1074.8 kilograms in orbit. The satellite height is 6.4 meters with a wingspan of 15.9 meters with the solar panels deployed. Additionally, Intelsat VA satellites use NiH₂ batteries to provide electrical power during periods of eclipse. The electrical power system is designed to provide 1354 watts after seven years. (International Satellite Directory, 1993, pp. 12-176 - 12-374)

(3) *Capacity.* The nominal capacity in a typically configured Intelsat VA or Intelsat VA (IBS) satellite is approximately 15,000 two way voice circuits plus two television channels. Intelsat satellites 510, 511, and 512 have a total bandwidth of 2,250 MHz while the Intelsat VA (IBS) satellites have a total bandwidth of 2,750 MHz. (Long, 1991, p. 142)

(4) *Design Life.* The design life for all Intelsat VA satellites is seven years. (International Satellite Directory, 1993, pp. 12-176 - 12-374)

e. Transmitters

(1) *C-Band Operation.* At C-band (6/4 GHz) an Intelsat VA transmitter operates from 3704 to 4200 MHz. The C-band global transmit beam operates from 3.955 to 4.200 GHz and uses one 8.5 watt TWT per transponder plus one spare per transponder. The C-band hemispheric beam operates from 3.700 to 4.077 GHz for transmit and uses one 8.5 watt TWT per transponder plus one spare per every two transponders. The zonal beam also operates from 3.700 to 4.077 GHz for transmit and uses one 4.5 watt TWT per transponder plus one spare per every two transponders. The C-band spot beam which is used for transmit only operates from 3.955 to 4.200 GHz. (International Satellite Directory, 1993, p. 2-34)

(2) *Ku-Band Operation.* At Ku-band (14/11 GHz), the Intelsat VA transmitter section operates from 10.95 to 11.70 GHz. The Intelsat VA (IBS) transmitter also operates from 11.70 to 11.95 GHz and 12.50 to 12.75 GHz. At Ku-band the Intelsat VA transmitter operates for spot beams only. It uses one 10 watt TWT per transponder with a one-for-one redundancy for the 241 MHz repeaters and a one-for-two redundancy for the 72 and 77 MHz repeaters. (International Satellite Directory, 1993, pp. 2-34)

f. Receivers

(1) *C-Band Receivers.* At C-band (6/4 GHz) the frequency plan runs from 5929 to 6423 MHz. Initial receive signal amplification is achieved via FET preamplifiers. The C-band receiver section is comprised of six active receivers and six spares. (Martin, 1988, p. 57)

(2) *Ku-Band Receivers.* At Ku-band (14/11 GHz) the frequency plan runs from 14.004 to 14.498 GHz. The Ku-band receiver section consists of two active receivers and two spares. (Martin, 1988, p. 57)

g. Antenna Farm

At C-band, each Intelsat VA has two Earth coverage horns, one for transmit and one for receive. The transmit horn, whose beamwidth is 18 degrees, provides a minimum gain of 16.5 dB. The receive horn has a beamwidth of 22 degrees and provides a minimum gain of 14.5 dB. Two C-band reflectors are used to generate two hemispheric beams, with a minimum gain of 21.5 dB, and two smaller zone beams, with a minimum gain of 24.5 dB. The diameter of the transmit reflector is 96 inches and the diameter of the receive reflector is 61 inches, each with 88 feed horns. The zone beams overlap a portion of one of the hemispheric beams and are separated by orthogonal polarizations. (Martin, 1988, p. 57)

At Ku-band there are two reflectors each generating one beam for transmit and one for receive. The east beamwidth is 1.8 x 3.2 degrees with a minimum gain of 33 dB. The west beam is 1.6 degrees with a minimum gain of 36 dB. Both beams are steerable and utilize linear polarization. (Martin, 1988 p. 57)

Antenna pointing accuracy is rated at plus or minus 0.2 degrees in pitch and roll. Antenna pointing accuracy in yaw channel is rated at plus or minus 0.4 degrees. (Martin, 1988, p. 57)

Figure 79 depicts the footprints of the three INTELSAT VA satellites (510, 511, and 512) and the two Intelsat VA (IBS) satellites (513 and 515). (The World Satellite Directory, 1993, pp. 142-143)

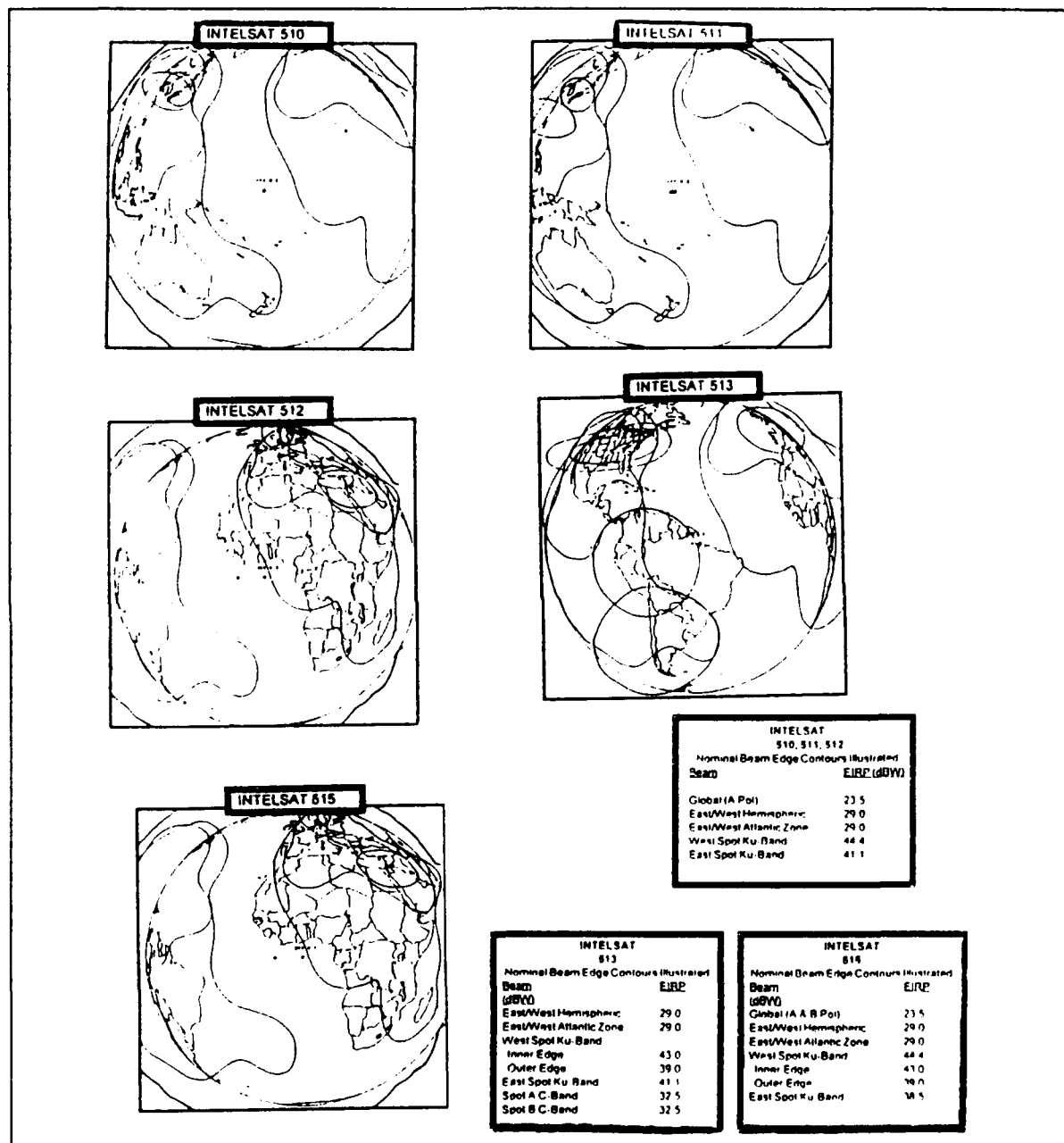


Figure 79 INTELSAT VA and VA (IBS) Footprints

h. Performance Characteristics

(1) *Satellite Services.* The Intelsat VA series of communication satellites takes advantage of several methods of multiple access (FDMA, SCPC/FDMA, and TDMA) in order to provide voice, video, and data transmission and distribution services at C-band and Ku-band. (Meyers, 1989, pp. 319-324)

The two Intelsat VA (IBS) satellites operate as part of the Intelsat International Business Service (IBS) which is a digital communications network used by multinational businesses to link locations around the world. These satellites use the 11.7 to 11.95 GHz spectrum allocated for fixed satellite services (FSS) in North America and the 12.5 to 12.75 GHz satellite business band established for business services in Europe. (Long, 1987, p. 65)

(2) *Performance Parameters.* The Intelsat VA satellites carry 14 percent greater telecommunications traffic than Intelsat V satellites. The nominal EIRP at the center of the global beams is 26.5 dBW with an average beam edge EIRP of 23.5 dBW. The beam edge EIRP levels of Intelsat VA hemispheric and zone beams are typically 29 dBW at saturation. The typical Intelsat VA spot beam edge EIRP levels average approximately 23.5 dBW. (Long, 1987, pp. 62-65)

The minimum C-band G/T ratios are as follows: -16.0 dB/K for the global beam, -9.0 dB/K for the hemispheric beams, and -6.0 dB/K for the zone beams. The minimum Ku-band G/T ratios are + 1.0 dB/K for the east spot beam and +4.3 dB/K for the west spot beam. (Martin, 1988, p. 57)

Table 16 lists the performance parameters of the Intelsat VA series including launch, frequencies, transmitter data, and coverage data. (The World Satellite Directory, 1993, p. 149)

TABLE 16. INTELSAT VA PERFORMANCE PARAMETERS

Satellite Name	INTELSAT 510. INTELSAT 511, INTELSAT 512 INTELSAT 513, INTELSAT 515
Longitude	174° W.L INTELSAT 510 177° E.L INTELSAT 511 1° W.L INTELSAT 512 53° W.L INTELSAT 513 18° W.L INTELSAT 515
Frequency Band(s) Global and C-Band (Tx only) Transmit Receive	C, Ku; 3.955-4.200 GHz 6.180-6.425 GHz
Transponders Global or C-Band Spot Number Bandwidth Polarization Ku-Band Spot Number Bandwidth Polarization	5 Maximum per Beam 36, 41 and 72 MHz Circular 3 per Beam 72, 77, and 241 MHz Linear
Power Output Global or C-Band Spot TWTA Ku-Band Spot TWTA	8.5 and 4.5 watts 8.5 and 4.5 watts
Antenna Coverage (EIRP Beam Edge) Global	23.5 and 26.5 dBW
Primary Power Watts EOL	1300
Stabilization Type	3-Axis
Mass (Kg. In Orbit)	1160
Design Life (Years)	7

3. INTELSAT VI Series (601/602/603/604/605)

a. Evolution of the INTELSAT VI Series

In 1980 industry proposals were requested for a new generation of satellite with three times the capacity of Intelsat V. Competition between international consortia was led by Hughes and Ford Aerospace. In April 1982 Intelsat contracted with the Hughes Space and Communications Group for the Intelsat VI as a follow-on to the Intelsat V/VA. Initially, five Intelsat VI satellites were to be supplied, with the first launch to take place in 1986. An option existed for an additional six spacecraft. (Alper and Pelton, 1984, pp. 80-81) However, this option was not exercised, rather Intelsat chose to pursue the Intelsat VII generation which was more economical and 30% lighter (Wilson, 1992, pp. 372-375).

b. Satellite Overview

Intelsat VI, built by Hughes and first launched in 1989, provides global, hemispheric, and zone coverage at C-band with spot beam transponders at Ku-band. By overlaying two zone beams, Intelsat VI is able to achieve six-fold frequency reuse, giving it a capacity of 24,000 circuits plus three television channels. Additional technological innovations include an onboard switch for TDMA networks which allows traffic bursts from sending earth stations to be routed to more than one satellite beam. Intelsat VI marks the first use of solid-state power amplifiers in the Intelsat system. The SSPAs provide power to the zone beams at C-band. Making use of the expanded frequency assignments, transponders operate at 5.85 to 5.925 GHz on the uplink and 3.625 to 3.70 GHz on the downlink. Finally, some Intelsat VI satellites include encrypted, secure command which provides protection against unauthorized seizure of control. Figure 80 is an illustration of Intelsat VI. (Agrawal, 1986, p. 42)

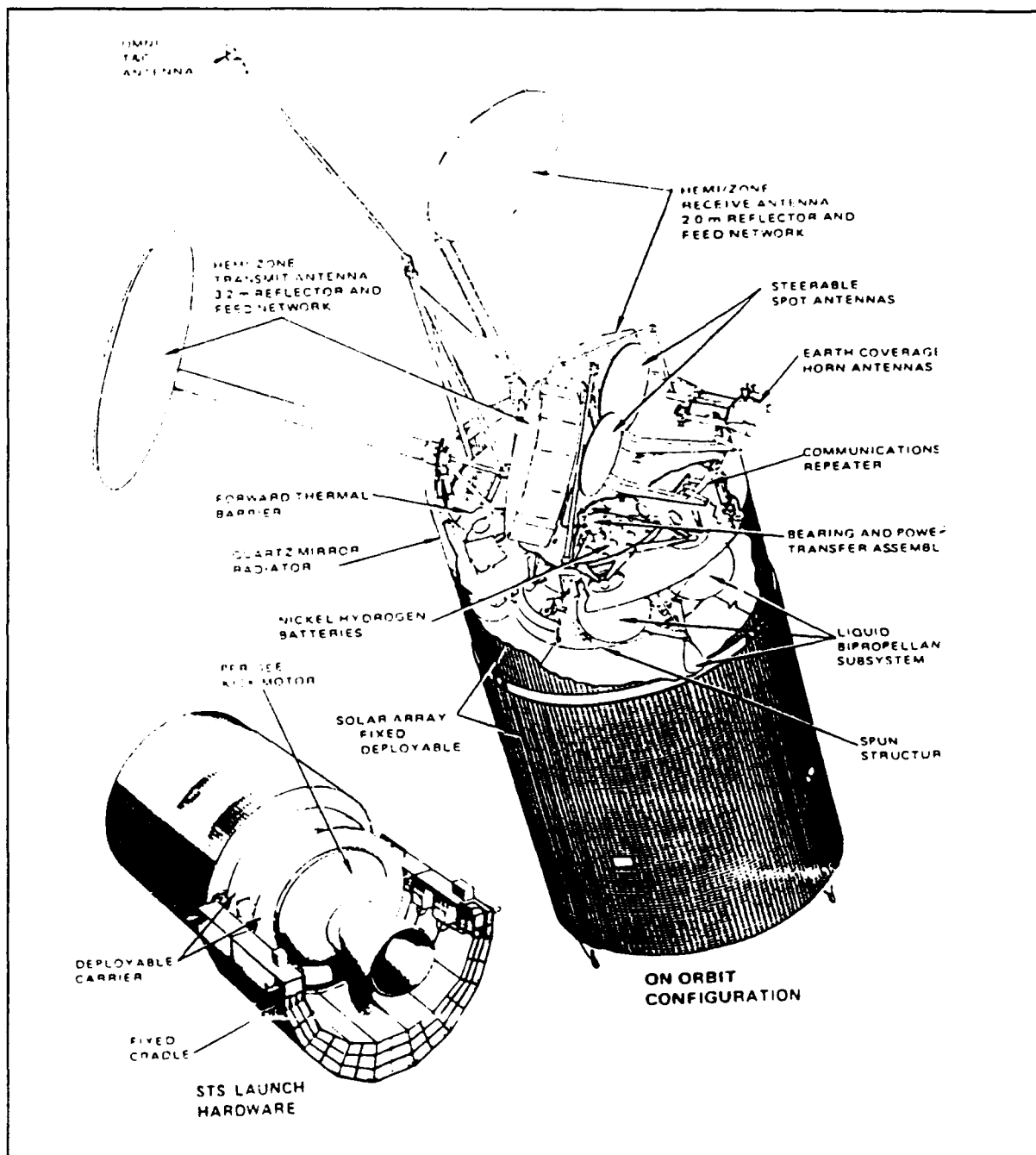


Figure 80 Intelsat VI Satellite

c. Orbital Parameters

(1) *Orbit.* Originally designed for launch by Shuttle or Ariane 4, the first Intelsat VI spacecraft (602) was launched by Ariane on October 27, 1989. Intelsat 602 is currently in a geosynchronous equatorial Earth orbit located at 63 degrees east longitude. The spacecraft is the primary Atlantic satellite, taking over regular operations on April 28, 1990 from Intelsat 501. Intelsat 601 is located at 27.5 degrees west longitude. Intelsat 603, which is in an inclined orbit, is located at 34.5 degrees east longitude. Intelsat 604 is located at 60 degrees east longitude. Intelsat 605 is located at 24.5 degrees east longitude. As with Intelsat 602 all five Intelsat VI spacecraft are currently in geosynchronous Earth orbit. (Wilson, 1992, pp. 372-375)

(2) *Orbital History.* The first Intelsat VI to be launched was 602 which was put into orbit on October 27, 1989. The second Intelsat VI (603) was launched March 14, 1990 by Titan 3 however, it was stranded in LEO. Subsequently, 603 received a shuttle reboost in May 1992. Next, 604 was launched by Titan on June 23, 1990. This was followed by the launch of 605 on August 14, 1991 and 601 on October 29, 1991, both of which were launched by Ariane. (Wilson, 1992, pp. 372-375)

d. Key Design Features

(1) *Configuration.* Intelsat VI satellites operate on both vertical and horizontal polarizations. Each Intelsat VI is comprised of forty-eight transponders, thirty-eight operating at C-band and ten operating at Ku-band. For the C-band channels on Intesat 605: twenty six are 72 MHz wide, twelve are 36 MHz wide, and two are 41 MHz wide. For the Ku-band channels on the same satellite: six are 72 MHz wide, two are 77 MHz wide, and two are 150 MHz wide. All transponders utilize dual polarization. (Long, 1991, p. 311)

(2) *Physical Characteristics.* Each Intelsat VI satellite is spin-stabilized at 30 rpm. The spacecraft weighs approximately 2546 kilograms in orbit with a dry mass of 1896 kilograms. Intelsat VI satellites have the greatest mass of any commercial communications spacecraft in orbit to date. Following deployment, the solar panels aboard the Intelsat VI are extended and five communications antennas are unfurled. The spacecraft height is 11.8 meters. Each Intelat VI has a drum mounted solar array which provides up to 2600 watts of power. Additionally, two NiH2 batteries provide power during eclipse mode. (Long, 1991, pp. 27-149)

(3) *Capacity.* With two and a half times the capacity of the Intelsat V series, Intelsat VI satellites are some of the most capable communications satellites to date. The increase was achieved by adding two more sets of zone beam transponders (southeast and southwest) and two additional hemispheric beam transponders (Long, 1991, p. 146). The capacity of Intelsat VI is 24,000 circuits and three television channels. The five satellites which make up the Intelsat VI series provide the equivalent combined capacity of up to 120,000 simultaneous two-way telephone circuits using digital modulation techniques and three TV channels. (Wilson, 1992, p. 372)

(4) *Design Life.* The design life for all Intelsat VI satellites is 13 years. (Wilson, 1992 p. 372)

e. Transmitters

Each Intelsat VI satellite carries forty-eight transponders, thirty-eight of which operate in the C-band while the other ten operate in the Ku-band. Transponder connectivity is achieved by utilizing an advanced static switch matrix. (Long, 1991, pp. 146-149)

A large increase in capacity was achieved in the Intelsat VI series by adding two more sets of zone beam transponders and two additional hemispheric beam transponders. The additional hemispheric transponders operate in the 3.6 to 3.7 GHz frequency spectrum assigned for fixed satellite service by the 1979 World Administration Radio Conference (WARC). (Long, 1991, pp. 146-149)

Intelsat VI utilizes a number of TWTAs at Ku-band for its steerable spot beams. There are eight 20 watt TWTAs which operate at 14.0-14.5, 10.95-11.2, and 11.45-11.70 GHz plus three backups. There are an additional two 40-watt TWTAs which operate at these frequencies plus one spare. The bandwidth of these dual polarization amplifiers is 72 MHz and they provide a minimum EIRP of 45 dBW. (Wilson, 1992, p. 372)

At C-band Intelsat VI utilizes six 16 watt TWTAs at 5.85-6.42 and 3.62-4.20 GHz plus two spares. These C-band amplifiers which are used to provide hemispherical and zonal beams have a minimum EIRP of 30 dBW. The bandwidth of these dual polarization TWTAs is 72 MHz. (Wilson, 1992, p. 372)

Intelsat VI marks the first of the Intelsat series to use solid state power amplifiers, which power the zone beams at C-band (Carver, 1992, p. 6). Each Intelsat VI has a total of thirty-two 10-watt SSPAs plus an additional ten SSPA spares used for redundancy at 5.85-6.42 GHz and 3.62-4.20 GHz. These C-band SSPAs are used for hemispherical and zonal beams and have a bandwidth of 72 MHz. The minimum EIRP for these dual polarization amplifiers is 30 dBW. (Wilson, 1992, p. 372)

f. Receivers

(1) *C-Band Receivers.* The Intelsat VI C-band receiver section is comprised of eight active receivers plus eight spares (Martin, 1986, p. 60). At C-band, the frequency plan runs from 6258 to 6425 MHz (The World Space directory, 1993, pp. 143-150).

(2) *Ku-Band Receivers.* The Ku-band receiver section has two active receivers plus two spares (Martin, 1986, p. 60). At Ku-band, the frequency plan runs from 14.00 to 14.50 GHz. (The World Space directory, 1993, pp. 143-150)

g. Antenna Farm

Intelsat VI provides global, hemispheric, and zonal coverage at C-band similar to the Intelsat V and Intelsat VA series except that two zone beams are overlaid on each hemispheric beam, providing sixfold frequency reuse. The Intelsat VI C-band hemi/zone antenna system consists of two large antenna dishes and associated feed networks. Each antenna simultaneously provides two fixed beams for hemispheric coverage, and four isolated beams for zone coverage. The zonal beams can be reconfigured in orbit to match the desired ocean region coverage. Intelsat VI also carries C-band Earth coverage horn antennas and a pair of C-band omnidirectional antennas for telemetry, command, and ranging. (International Satellite Directory, 1993, p. 2-35)

Antenna pointing error is less than plus or minus 0.05 degrees in beacon tracking mode and plus or minus 0.10 degrees with Earth/Sun sensors.

Each of the Intelsat VI satellites carries two Ku-band spot beam antennas which are steerable in orbit and used for enhanced coverage and connectivity. This enhanced spot beam coverage includes all locations both north and south of the equator which are visible from the satellite's orbital

position. Additionally, spot beam coverage has been expanded so that the size of the west spot beam is the same as that of the east spot beam. One of the steerable Ku-band spot beam antennas is 1.1 meters in diameter and the other one is 1.0 meters in diameter. (Wilson, 1992, p. 373)

Finally, there are both C-band and Ku-band telemetry beacon antennas aboard the Intelsat VI. The C-band telemetry beacons operate at 3.9475/3.9480 and 3.9520/3.9525 GHz. The Ku-band telemetry beacons operate at 11.198 GHz and 11.459 GHz. (Long, 1991, p. 311)

Figure 81 depicts the footprints of all five Intelsat VI satellites for zone, hemisphere, and global coverage regions. (The World Satellite Directory, 1993, pp. 143-144)

h. Performance Characteristics

(1) *Satellite Services.* Intelsat VI satellites provide both C-band and Ku-band telecommunications services to the Atlantic Ocean Region as well as the Indian Ocean Region. The Intelsat VI satellites were the first commercial telecommunications satellites to provide satellite switched time division multiple access (SS/TDMA). This enables flexible interconnection of beams according to specific traffic requirements allowing traffic bursts from sending earth stations to be routed to more than one satellite beam. Intelsat VI has advanced digital circuit multiplication equipment (DCME) which may handle up to 120,000 telephone calls and three color television channels. (Wilson, 1992, p. 373)

Intelsat VI makes partial use of the expanded frequency assignments available to fixed satellite service as a result of the 1979 World Administrative Radio Conference. These transponders operate at 5.85 to 5.925 GHz on the uplink and 3.625 to 3.70 GHz on the downlink. The last

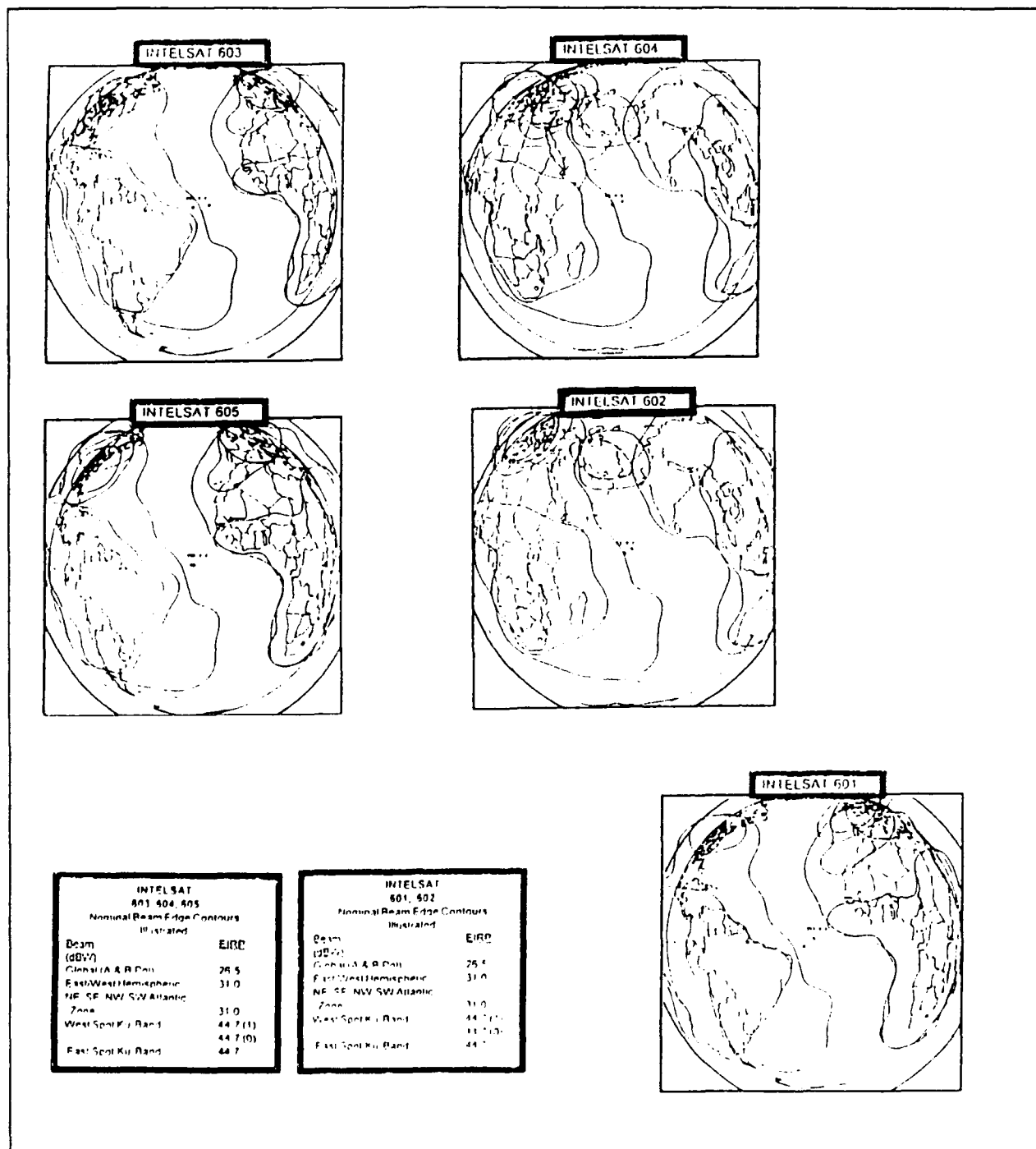


Figure 81 INTELSAT VI Footprints

two satellites in this series provide encrypted, secure command based on a United States Government approved algorithm. This feature will render the satellite immune to unauthorized control. (Carver and Cotner, 1992, p. 6)

(2) *Performance Parameters.* Table 17 lists the performance parameters of the Intelsat VI series including launch, frequencies, transmitter and coverage data. (The World Satellite Directory, 1993, p. 150)

4. Intelsat K

a. Evolution of the Intelsat K

In 1989 a number of Intelsat signatories, led by the United States, identified a shortfall in Intelsat's capacity to provide Ku-band transatlantic TV services. Therefore, in order to remain competitive in this market it was decided that Intelsat would purchase an existing communications satellite to offset this shortfall. The fact that this satellite was already designed and in its initial construction phase at the time Intelsat purchased it represents a change in the procurement policy of Intelsat. Prior to this purchase Intelsat sent out detailed requests for proposals (RFPs) for new satellites and subsequently monitored closely every aspect of their design. (Herridge and Thompson, 1993, pp. 151-152)

The satellite which was acquired for this purpose was a Satcom K4 which was in the early stages of construction at the GE/Astro facility in New Jersey. Upon acquisition of this satellite, Intelsat changed its designation to Intelsat K and modified its Ku-band payload. Successfully launched in June 1992, Intelsat K is currently providing TV broadcast services in the Atlantic Ocean Region. (Herridge and Thompson, 1993, pp. 151-152)

TABLE 17. INTELSAT VI PERFORMANCE PARAMETERS

Satellite Name:	INTELSAT 601, INTELSAT 602, INTELSAT 603 INTELSAT 604, INTELSAT 605
Longitude	27.50° W.L. INTELSAT 601 63° E.L. INTELSAT 602 34.50° E.L. INTELSAT 603 (Inclined) 60° E.L. INTELSAT 604 24.50° E.L. INTELSAT 605
Launch Vehicle	Ariane (601, 602, and 605) Titan (603 and 604)
Manufacturer	Hughes Aircraft Company
Date of Launch	October 1991 (INTELSAT 601) October 1989 (INTELSAT 602) March 1990 (INTELSAT 603) June 1990 (INTELSAT 604) August 1991 (INTELSAT 605)
Frequency Band(s) Global Transmit Receive Spot Transmit Receive	C; Ku 4.033-4.200 GHz 6.258-6.425 GHz 10.95-11.70 GHz 14.00-14.50 GHz
Transponders Global Number Bandwidth Polarization Spot Number Bandwidth Polarization	 4 Maximum per beam 36 and 41 MHz Circular 5 per Beam 72.77 and 150 MHz Linear
Power Output Global TWTA Spot TWTA	 10 and 13.5 watts 20 and 40 watts
Antenna Coverage Area (EIRP Beam Edge) Global Spot	 26.5 and 23.5 dBW 41.7, 44.7, and 47.7 dBW
Primary Power Watts EOL	2252
Stabilization Type	Spin
Mass (Kg. In Orbit)	2546
Design Life (Years)	13

b. Satellite Overview

Built by GE/Astro, the Intelsat K platform is a standard GE 5000 production bus. The satellite currently provides for transatlantic TV distribution and business services to North America, Europe, and South America. Specifically, Intelsat K has three distinct coverage regions for downlink and two coverage regions for uplink. For the downlink one region provides coverage for the major population centers in North America and one region provides coverage to Europe as far east as Italy. A downlink only coverage of Latin America provides coverage to the major urban centers of Venezuela, Columbia, Ecuador, Peru, Brazil, Argentina, and Chile. Uplink coverage is only provided for North America and Europe. (Herridge and Thompson, 1993, pp. 158-159)

Intelsat's first exclusive Ku-band satellite (and the first not to be designed by the organization), Intelsat K, operates in colocation with Intelsat 502 (operating at C-band) over the Atlantic Ocean Region (Interavia, 1992, p. 371). The communications payload on Intelsat K is remarkably different from any other Intelsat payload. Most notably, this satellite contains no C-band capability. Additionally, the Ku-band channelization plan is completely different from that of other Intelsat spacecraft. Although not designed and developed by the organization, Intelsat was able to define some aspects of the spacecraft within the mass, power, and size constraints imposed by the original Satcom 4 configuration. Figure 82 is an illustration of Intelsat K. (Herridge and Thompson, 1993, pp. 151-161)

c. Orbital Parameters

General Dynamics was awarded the launch contract for Intelsat K over Arianespace and China Great Wall Industries. The satellite was launched on June 10, 1992 from Cape Canaveral, on the first of the Atlas IIA vehicles (Wilson, 1992, p. 373). The spacecraft is currently in a geosynchro-

nous equatorial Earth orbit colocated at 338.5 degrees east longitude with Intelsat 502. Intelsat K is expected to have an orbital manoeuvre life of 13 years. On-orbit attitude control is provided by three-axis stabilization with hydrazine thrusters used for stationkeeping. (Herridge and Thompson, 1993, pp. 151-152)

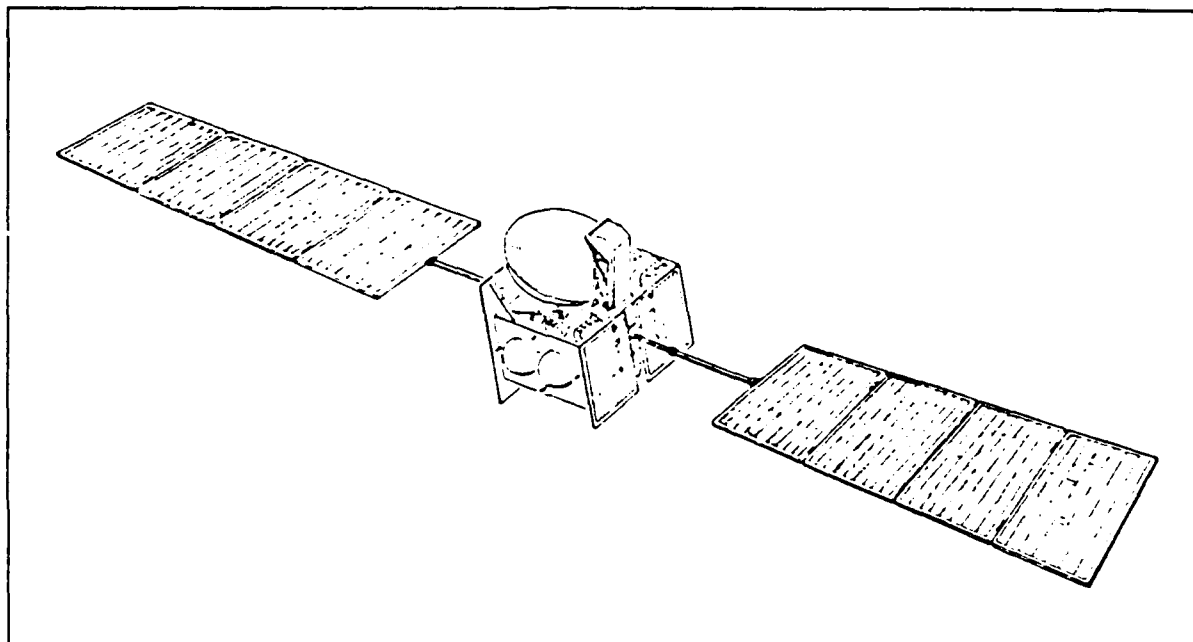


Figure 82 The Intelsat K Satellite

d. Key Design Features

(1) *Configuration.* Intelsat K operates on both vertical and horizontal polarizations. The satellite operates with two bands of eight transponders. Each of the sixteen Ku-band transponders has a bandwidth of 54 MHz. Certain transponders may use a different beam for receive and transmit while other transponders must use the same receive and transmit beam. The allowed transponder connectivities are

somewhat complex but this connectivity arrangement provides for significant flexibility. Combining the beams allows Intelsat K to broadcast to both sides of the Atlantic simultaneously using only one uplink beam channel, selectable from either a North American or European uplink. Additional flexibility is available by selecting which downlink frequency band to operate on. Three 250 MHz bands are available with the Intelsat K: 11.50-11.70 GHz, 11.70-11.95 GHz, and 12.50-12.75 GHz. (Herridge and Thompson, 1993, pp. 155-158)

(2) *Physical Characteristics.* Intelsat K is three-axis stabilized with a box-shaped bus and central cylinder. The spacecraft weighs approximately 1512 kilograms in orbit with a dry mass of 1219 kilograms. Spacecraft height is 2.6 meters. The wingspan is 23.8 meters and the two solar panels consist of eight sections providing a total area of 34.7 square meters. Intelsat K is equipped with sun-tracking solar arrays and NiH₂ batteries which provide 3804 watts of total electrical power. (Wilson, 1992, p. 373)

(3) *Capacity.* Approximately 13,200 bearer circuits or 32 TV channels are available with the Intelsat K. The high EIRP and gain are designed for use with small earth stations, less than one meter for receive only. (Wilson, 1992, p. 373).

(4) *Design Life.* The design life for the satellite is 10 years with stationkeeping propellant available for 13 years. (Herridge and Thompson, 1993, pp. 151-152)

e. Transmitters

The power amplifier arrangement for the Intelsat K is comprised of a driver amplifier followed by a high power amplifier. The driver amplifiers are arranged in two groups that provide amplification in the 11.45-12.75 GHz downlink bands. One group, which includes limiters, operates on the horizontally polarized signals as well as the South American

signals. The other group, which does not contain limiters, operates on the vertically polarized signals. (Herridge and Thompson, 1993, p. 159)

The Ku-band high power amplifiers used on the Intelsat K are 60 watt TWTAs. These TWTAs comprise traveling wave tubes and an electronic power conditioner. The electronic power conditioner is a high voltage power supply designed for integration with the 60 watt TWTAs which also provides the power for the receivers. (Herridge and Thompson, 1993, p. 159)

f. Receivers

The receiver section of the Intelsat K is comprised mainly of low noise amplifiers (LNAs) and downconverters. Preamplification for the received signal is achieved via the four 14.00-14.50 GHz LNAs. Normally, only two LNAs are utilized at any one time with the other two providing redundancy. (Herridge and Thompson, 1993, pp. 158-159)

Following preamplification by the LNAs the signals are further amplified and stepped down to the appropriate transmit frequency by a series of downconverters. Since the satellite operates at three separate downlink frequencies there are three separate types of downconverters. All three types of downconverters utilize local oscillators operating on different center frequencies to step down the received signal to the proper transmit frequency. The first downconverter is arranged in a four-for-two redundancy scheme. It steps down uplink signals in the range of 14.25-14.50 GHz to provide downlink frequencies in the range of 11.45-11.70 GHz. The second type of downconverter, which is arranged in a two-for-one redundancy scheme, steps down the uplink signals in the range of 14.00-14.25 GHz to 12.50-12.75 GHz for the downlink. The final type of downconverter also utilizes a two-for-one redundancy scheme and steps down the uplink signals in the

range of 14.00-14.25 GHz to 11.70-11.95 GHz for the downlink. (Herridge and Thompson, 1993, pp. 158-159)

g. Antenna Farm

The Intelsat K antenna farm consists of two separate antenna systems. Horizontal and vertical east-west coverage for North America and Europe is provided by a deployed, parabolic-gridded, dual-offset reflector illuminated by four offset feed arrays. Vertical polarization coverage for South America comes from an offset fed elliptical parabolic reflector array of four horns. (Herridge and Thompson, 1993, pp. 151-152)

The east-west coverage horizontal and vertical gridded reflectors are 2.13 meters in diameter. The North America horizontal and vertical polarized arrays consist of fourteen horns with the horizontally polarized horns operating in transmit and receive bands while the vertically polarized feed arrays each consist of twenty-three horns. As with the North American arrays, the European horizontally polarized horns operate in the transmit and receive bands while the vertically polarized horns operate in the transmit band only. (Herridge and Thompson, 1993, pp. 151-152)

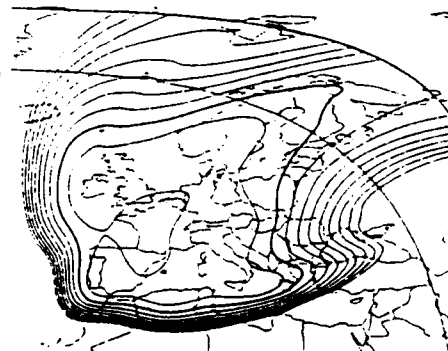
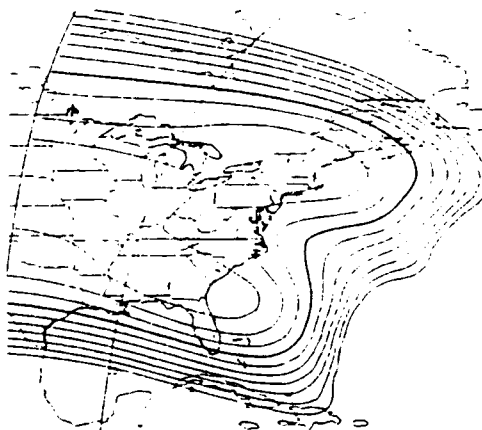
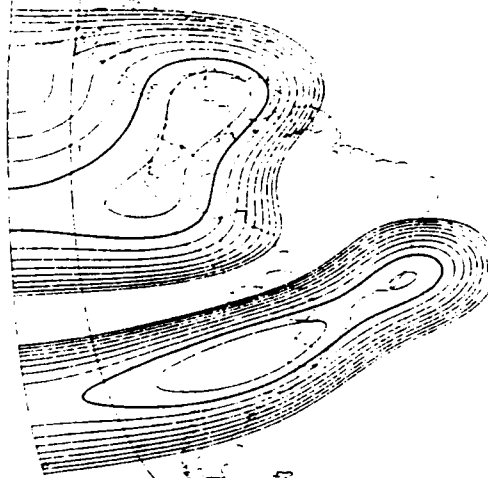
The elliptical parabolic reflector for South America is a 0.91 meter by 0.79 meter antenna which is illuminated by a feed array of four horns operating on the vertical polarization. The antenna configuration utilized for South America has a transmit capability only. (Herridge and Thompson, 1993, pp. 151-152)

Figure 83 depicts the footprints of Intelsat K, highlighting a typical beam coverage pattern for each antenna.

**INTELSAT-K South American
Downlink Beam from 338.5
degrees East (21.5 degrees West)**

1st contour:	46.0/43.7 dBW
2nd contour:	45.0/42.7 dBW
3rd contour:	44.0/41.7 dBW
4th contour:	43.0/40.7 dBW
5th contour:	42.0/39.7 dBW
6th contour:	41.0/38.7 dBW
7th contour:	40.0/37.7 dBW
8th contour:	39.0/36.7 dBW
9th contour:	38.0/35.7 dBW
10th contour:	37.0/34.7 dBW

South Am. only/
or combined with
North Am. beam



North American Downlink Beam

1st contour:	50 dBW	6th contour:	45 dBW
2nd contour:	49 dBW	7th contour:	44 dBW
3rd contour:	48 dBW	8th contour:	43 dBW
4th contour:	47 dBW	9th contour:	42 dBW
5th contour:	46 dBW	10th contour:	41 dBW

European Downlink Beam

1st contour:	48 dBW	6th contour:	43 dBW
2nd contour:	47 dBW	7th contour:	42 dBW
3rd contour:	46 dBW	8th contour:	41 dBW
4th contour:	45 dBW	9th contour:	40 dBW
5th contour:	44 dBW	10th contour:	39 dBW

Figure 83 Intelsat K Footprints

h. Performance Characteristics

(1) *Satellite Services.* The Intelsat K is currently being utilized to provide Ku-band transatlantic TV distribution and business services to North America and Europe, with downlink-only coverage of South America. The capacity of this satellite is approximately 13,200 bearer circuits or 32 TV channels. (Herridge and Thompson, 1993, p. 151)

(2) *Performance Parameters.* Table 18 lists the performance parameters of Intelsat K, including frequency data, transponder data, and antenna coverage. (Herridge and Thompson, 1993, p. 151)

TABLE 18. INTELSAT K PERFORMANCE PARAMETERS

Satellite Name:	INTELSAT K
Longitude	21.5° W.L.
Launch Vehicle	Atlas Centaur
Manufacturer and Model	GE Astro series 5000
Date of Launch	June, 1992
Frequency Band(s) Transmit Receive	Ku 14.00-14.50 GHz 11.45-11.70 GHz 11.70-11.95 GHz (North and South America) 12.50-12.75 (Europe Only)
Transponders Number Bandwidth Polarization	16 54 MHz 8 linear horizontal, 8 linear vertical
Power Output TWTA	60 watts, 11-for-8 redundancy
Antenna Coverage (EIRP) North America Europe Key South American Cities	47-50 dBW

5. Intelsat VII Series (Intelsat 701/702/703/704/705/709)

a. Evolution Of The Intelsat VII Series

The planning process for the Intelsat VII series began in 1985. In June of 1988 Ford Aerospace was selected as the preferred contractor and after detailed contractual negotiations, Intelsat signed a contract in October of 1988 to purchase six Intelsat VII series satellites. The Intelsat VIIs were designed to be smaller than the Intelsat VI series, but with increased flexibility to serve a variety of geographic locations through an increased set of antenna beams interconnected by switching matrices. The satellite design also emphasizes high performance to increase the usefulness of smaller earth stations and higher orbital reliability and lifetimes than previous Intelsat vehicles. (Thompson, Silk, and Herridge, 1992, pp. 1-16)

At present all of the Intelsat satellites covering the POR belong to the Intelsat V and Intelsat VA families. These satellites first appeared over the Pacific Ocean during the later half of 1985 and were manufactured with a design life of seven to twelve years. The Intelsat VII series was primarily designed as the follow-on to the Intelsat Vs and VAs which are rapidly approaching their end of useful life design limitations. (Carver and Cotner, 1992, pp. 3-4)

b. Satellite Overview

The Intelsat VII series is a three-axis controlled, multifrequency, communications satellite providing voice, video, and data transmission and distribution services at C-band and Ku-band. Although it is primarily a POR satellite, Intelsat VIIs are projected to have some utility in the AOR and IOR as well. They consist of two independent cross-strappable communications systems operating at C-band (6/4 GHz) and Ku-band (14/11 GHz). Antenna beam shape and polarization control are employed at C-band to achieve up to four times frequency reuse which provides up to 2 GHz of operating

bandwidth. At Ku-band, the Intelsat VII employs three independently steerable spot antennas to achieve two times frequency reuse in that band. The Ku-band and C-band spot antennas are mechanically steerable over the entire Earth surface while the remaining six antennas are fixed. Figure 84 is a graphic depiction of the Intelsat VII satellite. (Loral Space Systems, 1990, pp. 1-14)

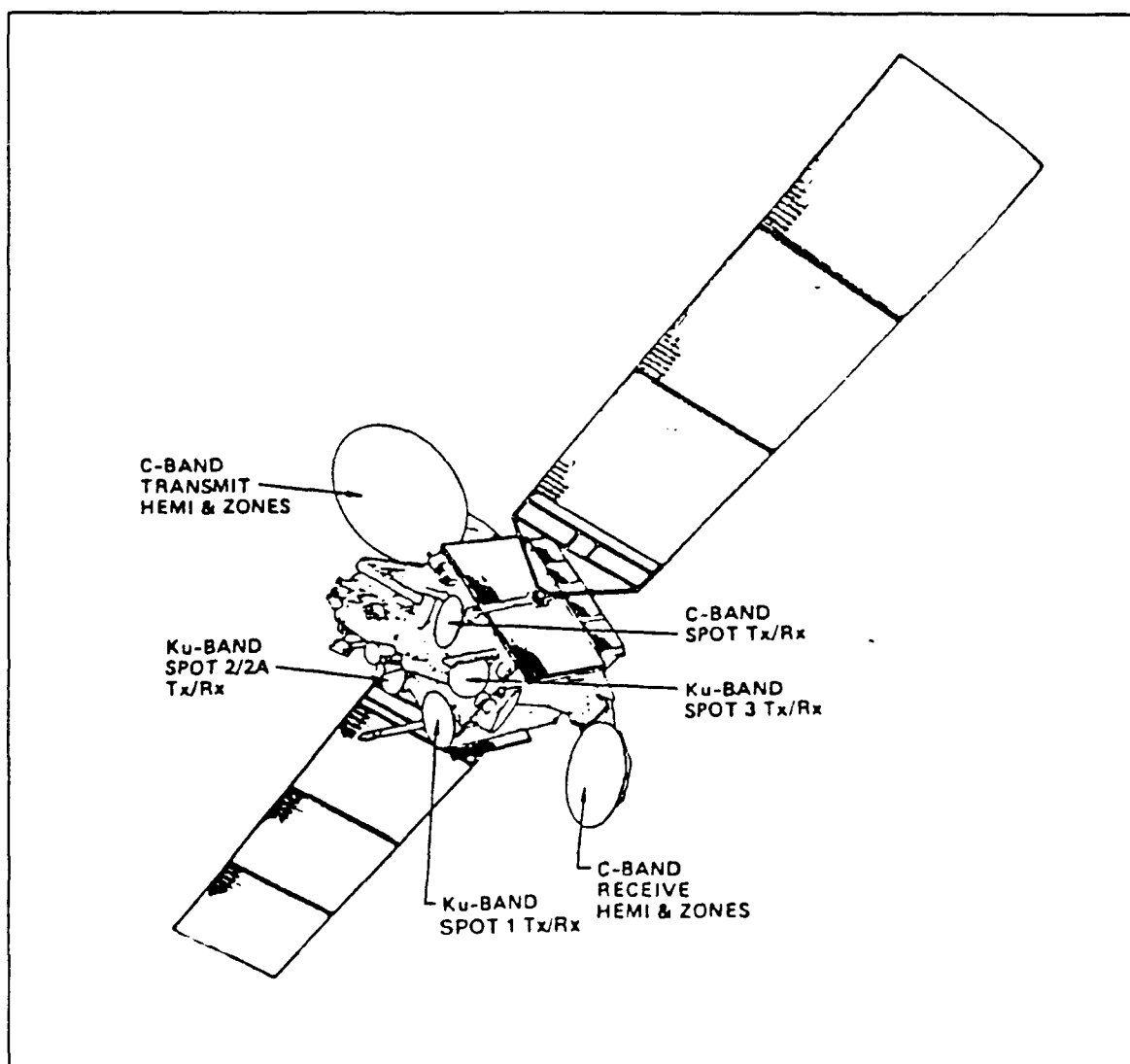


Figure 84 Intelsat VII Satellite

c. Orbital Parameters

(1) *Orbit.* All Intelsat VII spacecraft will be placed in a geosynchronous equatorial Earth orbit with station-keeping to plus or minus 0.05 degrees east/west and north/south. Intelsat 701, the first of the series, is currently located at 174 degrees east longitude. Intelsat 702 is located at 1 degree west longitude. Intelsat 703 will eventually be orbited at position 177 degrees east longitude. The orbital slots for Intelsat 704, 705, and 709 are still to be determined. (Jane's Space Directory, 1994, pp. 338-339)

(2) *Orbital History.* Intelsat 701 was launched on October 22, 1993 from Kourou, French Guiana via an Ariane. Intelsat 702 was launched on June 17, 1994 from Kourou, via an Ariane. Intelsat 703 will be launched in October of 1994 via an Atlas 2AS. Intelsat 704 is scheduled to be launched in December 1994 via an Atlas 2AS. Intelsat 705 is currently scheduled to be launched in February 1995 via an Atlas 2AS. Intelsat 709 is tentatively scheduled to be launched in February 1996 via an Ariane. (Jane's Space Directory, 1994, pp. 338-339)

d. Key Design Features

(1) *Configuration.* Each Intelsat VII has thirty-six transponders, twenty-six operating at C-band and ten operating at Ku-band. At C-band, there are thirty uplink channels combined into twenty-six downlink channels with 34 MHz to 77 MHz bandwidth, single conversion, dual-beam and dual-polarization frequency reuse. At Ku-band there are twelve uplink channels combined into ten downlink channels with 34 MHz to 112 MHz bandwidths, double conversion, dual-beam frequency reuse. (Jeffcoat and Cotner, 1992, pp. 5-6)

(2) *Physical Characteristics.* The satellite has a rectangular body with dimensions: 8.8 by 8.6 by 7.9 feet. Additionally, it has a 71.7 foot solar array wingspan. The satellite body plus the antennas gives the satellite a height of 15.3 feet and a width of 26.1 feet when the solar sails are fully deployed. The satellite weighs approximately 4200 pounds in orbit at beginning of life and 3200 pounds without fuel. Intelsat VIIs are equipped with sun-tracking solar arrays and NiH₂ batteries which provide 3970 watts minimum after 10.9 years. Three-axis stabilization is applied via momentum wheels and magnetic torquers. Antenna pointing accuracy is rated at plus or minus 0.25 degrees. (Ford Aerospace, 1989, pp. 1-2)

(3) *Capacity.* Compared with the Intelsat V series, Intelsat VII spacecraft will yield significantly higher usable capacity in orbit. Due to its efficient utilization of bandwidth, the Intelsat VII has an average capacity of 18,000 simultaneous two-way telephone circuits plus three TV channels. Each Intelsat VII will also have the potential capacity for up to 90,000 simultaneous two-way telephone circuits using digital circuit multiplication equipment. The higher power and improved communications parameters will make it possible to derive greater capacity for operation with smaller earth stations than previous Intelsat satellites. Thus, Intelsat VIIs will promote and increase the use of smaller, low-cost earth stations. (Ford Aerospace, 1989, pp. 1-2)

(4) *Design Life.* High capacity propellant storage tanks and third generation C-band solid-state power amplifiers offer the potential for reliable service for up to 17 years. (Seitz, 1993, p. 16)

e. Transmitters

(1) *C-band Transmitters.* At 6/4 GHz bandwidth the allocated frequency plan runs from 3704 to 4198 MHz. For global and spot beam coverage: there are six 16 watt solid-state power amplifiers for four 36-MHz bandwidth repeaters and three 30 watt solid-state power amplifiers for two 41 MHz bandwidth repeaters. For hemispheric beam coverage, there are seven 30/20 watt solid-state power amplifiers for five repeaters (beam 1 and beam 2). For zone beam coverage, there are seven 16/10 watt solid-state amplifiers for five repeaters (zone 1 and zone 2). (Loral Space Systems Summary, 1990, pp. 5-2 - 5-11)

(2) *Ku-Band Transmitters.* At Ku-band, the frequency plan consists of: 10.954 to 11.191 GHz for band A, 11.458 to 11.694 GHz for band B, 11.704 to 11.941 GHz for band C, and 12.504 to 12.741 GHz for band D. Repeaters (1,2), (3,4) and (5,6) are independently switchable to bands A or C on one of spots 1 and 2, to bands A or D on the other spot beam, and to bands A, C, or D on spot 3. Repeaters (7-9) and (10-12) are always set to band B. Additionally, there are seven 35 watt TWTAs for five repeaters interconnected with eight 50 watt TWTAs for five repeaters to form fifteen-for-ten redundancy. (Loral Space Systems Summary, 1990, pp. 5-11 - 5-13)

f. Receivers

(1) *C-Band Receivers.* At C-band, the frequency plan runs from 5929 to 6423 MHz. There are six receivers with four active for global and spot beams, and six receivers with four active for hemispheric and zone beams. (Loral Space Systems, 1990, pp. 5-10 - 5-11)

(2) *Ku-Band Receivers.* At 14/11 GHz, the frequency plan runs from 14.004 to 14.494 GHz. There are five receivers with three active. (Loral Space Systems, 1990, pp. 5-11 - 5-13)

g. Antenna Farm

The main function of Intelsat VII's antennas are to provide shaped uplink and downlink beams for transmission and reception of telecommunications signals in the operating frequency bands. To increase the communication capacity of the satellite, frequency reuse is applied with polarization. Polarization uses the principle that electromagnetic waves generally can be made to vibrate uniformly in one of several planes or directions of polarization. This technique enables a single range of frequencies to be re-used by arranging to transmit and receive with different polarization than was initially applied. (Welti, 1983, pp. XI-1 - XI-3)

The Intelsat VII is comprised of eight different types of communications and telemetry control antennas. These antennas are:

- 1) C-band global antenna
- 2) C-band hemi/zone antennas
- 3) C-band spot antenna
- 4) C-band beacon antenna
- 5) Ku-band spot antennas
- 6) Ku-band beacon antenna
- 7) Omni TT&C antennas
- 8) Telemetry directional antenna

Figure 85 illustrates the physical positioning of these antennas on the satellite.

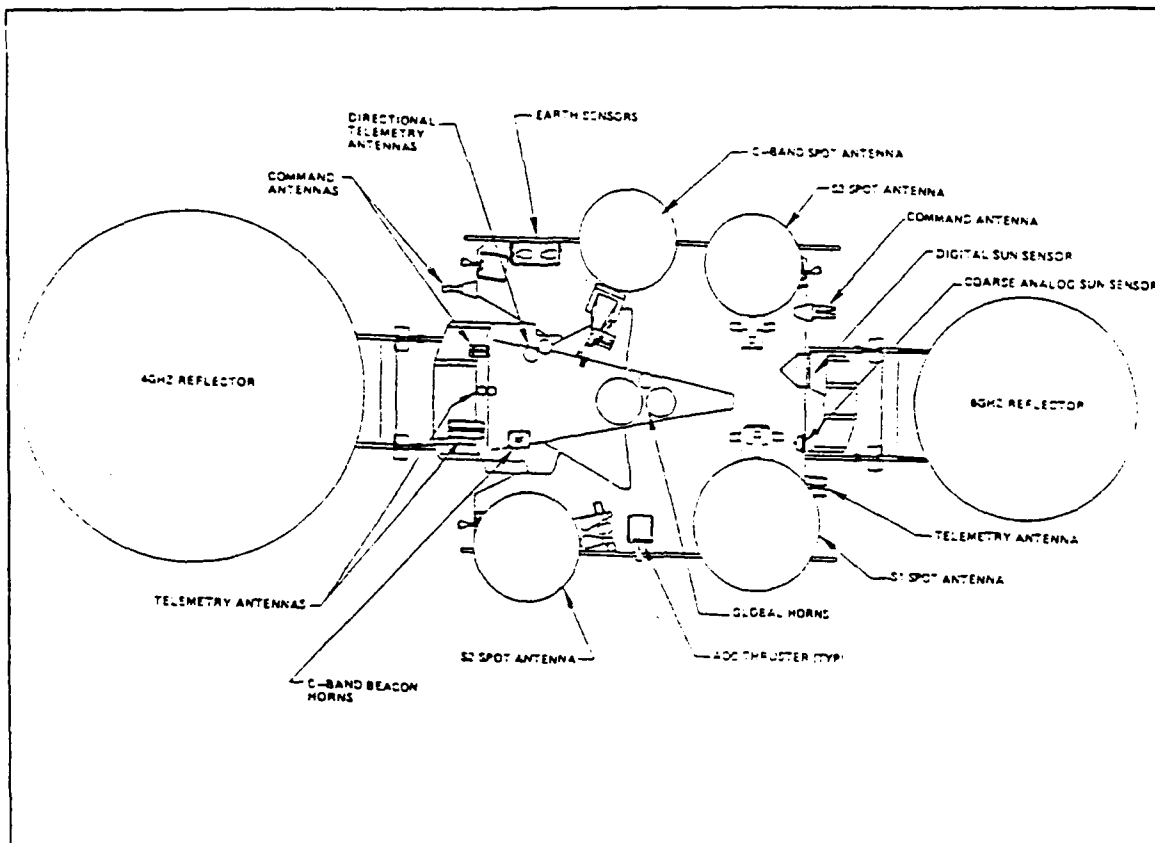


Figure 85 Intelsat VII Antenna Farm

(1) *C-Band Hemispheric/Zone Antennas.* The C-band communications antenna subsystem performs all the functions for 4 GHz transmission and 6 GHz reception of circularly polarized communications signals. This antenna subsystem consists of two deployable parabolic offset reflectors, one for the receive band and the other for the transmit band. The receive antenna reflector diameter is 1.57 meters while the diameter of the transmit antenna is 2.44 meters. Each reflector is illuminated by a multibeam feed cluster. (Loral Space Systems, 1990, pp. 4-1 - 4-2)

The antennas provide shaped hemi and zone coverage of the Earth. The hemispherical coverage and zone coverage beams are generated simultaneously, employing orthogonal polarization. An optimization procedure is used which minimizes the composite coverage areas while maximizing the separation between the adjacent regions via satellite biasing adjustments. The antenna serves four zones and two hemispheres. In addition, there is frequency reuse among the zones and among the hemis. For the receive antenna, a switching scheme is provided so that either the northwest, southeast or both zones simultaneously can be accessed. A similar scheme is employed for the northeast-southwest pair. There is full switch redundancy in both cases. The switching for the transmit antenna is done on a channel by channel basis in the transponders. (Loral Space Systems, 1990, pp. 4-1 - 4-3)

(2) *Spot Beam Antennas.* Both the C-band and Ku-band spot beam antennas are designed to provide communications coverage to high traffic areas using narrow beams capable of being mechanically steered by command from the ground. Each of the three Ku-band spot beam antennas are one meter in diameter, parabolic, offset-feed reflectors illuminated by a conical corrugated feed horn. The feed horn is actuated with the reflector during operation to provide constant pattern shape regardless of beam pointing position. This feature also improves isolation between the three Ku-band spot beam coverages (Thompson, Silk, and Herridge, 1992, pp. 4-2 - 4-4).

The steerable C-band spot beam antenna is very similar to its Ku-band analog in both size and function. Additionally, it shares transponders on a channel by channel switchable basis with the global coverage antenna and uses a very high performance dual-polarized transmit/receive feed. (Thompson, Silk, and Herridge, 1992, pp 4-1 - 4-4)

(3) *Earth Coverage Antennas.* The primary function of the Earth coverage antennas is to provide television distribution services on a continuous basis. The two C-band Earth coverage antennas are circularly-polarized conical horns. The basic design for the two antennas is identical, except that the higher gain transmit antenna covers an eighteen degree field of view, while the receive antenna covers a twenty-two degree field of view. The transmit antenna is mounted on a single-axis gimbal that enables the antenna beam to be steered up to plus or minus two degrees in the pitch direction to reposition the beam towards the Earth's center whenever the spacecraft is pitched in the east-west direction. The wider beam receive antenna is fixed mounted on the spacecraft. (Loral Space Systems, 1990, pp. 4-1 - 4-4)

(4) *Beacon Antennas.* The 4 GHz and 11 GHz beacon antennas utilize the same design concept as the Earth coverage antennas. These transmit antennas are circularly polarized, dual-mode, conical horns which cover a twenty-two degree field of view. Their primary function is to provide tracking and propagation loss data to ground stations via their respective transponders. Additionally, both beacon transmitters can be commanded on and off independently. (Thompson, Silk, and Herridge, 1992, pp. 4-3 - 4-4)

Figure 86 depicts a footprint of Intelsat 701 highlighting a typical beam coverage pattern for each antenna.

h. Performance Characteristics

(1) *Satellite Services.* The Intelsat VII series of communication satellite takes advantage of several methods of multiple access (FDMA, SCPC/FDMA, and SS-TDMA) in order to provide voice, video, and data transmission and distribution services at C-band and Ku-band. (Loral Space Systems, 1990, pp. 1-4 - 1-5)

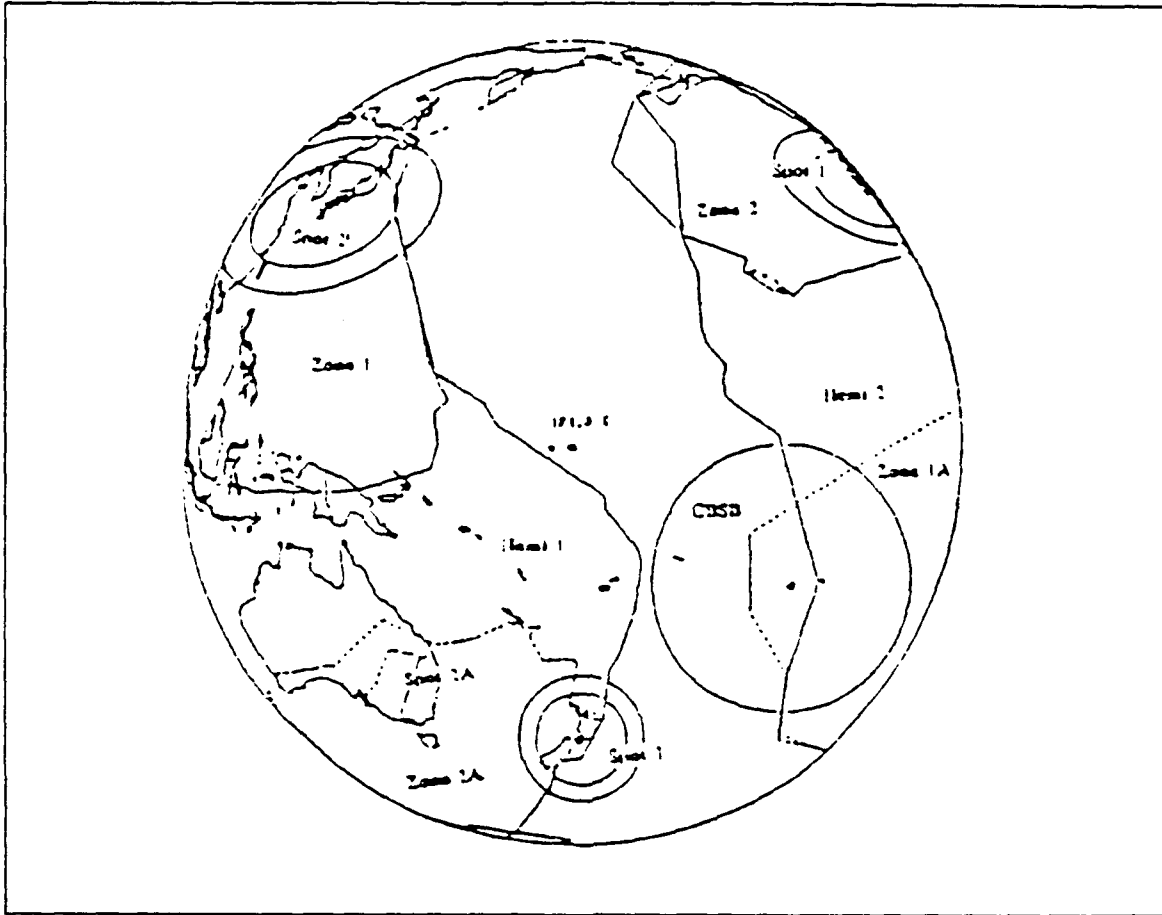


Figure 86 Intelsat 701 Footprint

(2) *Performance Parameters.* Specified EIRP ranges on the low side from 26 dBW for a C-band global channel up to 47.8 dBW for one of the Ku-band spot beams. Gain to noise temperature ratio, G/T, ranges from -11.95 dB/K for a C-band global channel to +5.53 dB/K for one of the Ku-band spot beams. Minimum antenna gain ranges from +10.7 dB for a beacon antenna to +34.92 dB for a Ku-band spot beam. Table 19 lists the performance parameters for each individual Intelsat VII antenna. (Loral Space Systems, 1990, pp. 1-4 - 1-5)

TABLE 19. KEY PAYLOAD PERFORMANCE PARAMETERS

Coverage	Channel Number	Minimum EIRP (dBW)	Minimum G/T at Maximum SFD (dB/K)
C-band Spot A	9	35.18	-4.87
C-band Spot B	9	33.22	-4.87
C-band Spot A&B	10-11	33.09	-4.87
C-band Spot A&B	12	36.17	-4.87
Global A	9	27.98	-11.95
Global B	9	26.09	-11.95
Global A, Global B	12	29.01	-11.95
Global A, Global B	10-11	25.94	-11.95
Hemispheric 1	1-9	32.61	-8.36
Hemispheric 2	1-9	32.64	-6.31
Zone 1	1-9	32.67	-5.52
Zone 1 extension (Z1A)	1-9	34.10	-8.35
Zone 2	1-9	32.78	-3.52
Zone 2 extension (Z2A)	1-9	32.55	-6.98
Spot 1, inner coverage	1-12		5.53
POR		46.79	
AOR		48.55	
Spot 1, outer coverage	1-12		2.83
POR		44.59	
AOR		46.35	
Spot 2, inner coverage	1-12		2.77
POR		46.53	
AOR		44.77	
Spot 2, outer coverage	1-12		-0.53
POR		43.43	
AOR		41.67	
Enhanced Spot 2 inner cov	1-12	44.33	0.69
Enhanced Spot 2 outer cov	1-12	41.63	-2.61
Spot 3 inner coverage	1-9	46.85\47.79	5.27
35 W/50 W	10-12	47.30\47.95	5.27
Spot 3 outer coverage	1-9	45.05\45.99	2.86
35 W/50 W	10-12	45.50\46.15	2.86

(3) *Flexibility.* Payload configuration flexibility is a key feature of the Intelsat VII satellite. The steerable spot beams in both C-band and Ku-band allow transmission of high power signals in both bands to any point on the Earth. A total bandwidth of 149 MHz can be transmitted in the C-band spot beam and 445 MHz in each of the three Ku-band spots. Each hemi and zone beam carries a total of 329 MHz of bandwidth with 36 MHz of that coverage transferrable to the C-band spot or global beam. (Loral Space Systems, 1990, pp. 1-5)

I. SUMMARY

This compendium represents the current inventory of geosynchronous, domestic commercial satellites to date. Although the Intelsat Corporation is considered to be an international consortium, twenty-eight percent of the corporation is owned by the United States. Because of this factor, Intelsat satellites were included in the survey. This chapter provides an in-depth systems summary with an emphasis on the capabilities and performance characteristics unique to each satellite. It is interesting to note that currently only communications satellites have been placed into geosynchronous orbit by domestic commercial corporations. This monopoly by the satellite communications industry on geosynchronous orbital slots will likely end within the next three years. This is because of the growing commercial interest in remote sensing, imagery from space-based platforms, and navigation via satellite assistance.

V. REMOTE SENSING TECHNOLOGY

A. OVERVIEW

Remote sensing is the science of obtaining atmospheric, surface, and oceanic data about the Earth from space through the use of space-based observational systems. The advent of this technology can be traced back to April of 1960 with the launch of the first meteorological satellite, TIROS-1 by the United States. Since then, many meteorological satellites have been launched worldwide providing meteorologists, oceanographers, and hydrologists with observational data from state of the art satellite systems.

Observational data obtained through the use of space-based platforms holds several unique advantages over data collected from other resources. Due to its high vantage point and large field of view, a satellite can provide a constant supply of data on remote regions of the Earth that are predominantly inaccessible via conventional means. Secondly, since the atmosphere can be broadly scanned by a satellite, large-scale weather systems can be detected with a single view. This provides a tremendous advantage over ground-based observations where the parameters of a weather front would have to be determined by piecing together information from a number of different sources. Additionally, satellite data is more timely than data obtained via terrestrial resources, thus enhancing the value of the information to the user. (Cornillon, 1982, pp. 2-6)

B. THE ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation is of primary importance in the field of remote sensing. The three primary regions of the electromagnetic spectrum which are utilized by remote sensing

satellites are the visible region, the infrared region, and the microwave region.

1. The Visible Radiation Band

The visible portion of the electromagnetic spectrum encompasses a window that ranges from approximately 0.4 micrometers to 0.75 micrometers. Blue light is the shortest wavelength of light that can be seen by the human eye and is made up of waves that are approximately 0.4 micrometers long. Red light, on the other hand, is the longest wavelength of light that can be seen and is comprised of waves that are approximately 0.75 micrometers long. Brightness can be defined as the relative intensity of light and is determined by the amplitude of the waves. Bright light will have large amplitude waves, whereas dim light will have small amplitude waves. (Cornillon, 1982, p. 7)

Visible light is one of the most important bands of the electromagnetic spectrum for remote sensing purposes because it propagates through a clean (limited aerosols), dry (limited clouds and rain) atmosphere with little attenuation. On a hazy or overcast day there are a great deal more absorbers and scatterers in the atmosphere and the light can be significantly affected as it passes through the atmosphere. (Cornillon, 1982, p. 7)

Another important feature of visible radiation is its ability to penetrate water. This makes the visible spectrum extremely important towards hydrology and oceanography studies. Of the three spectral regions, light (specifically blue light) penetrates water the best. In the thermal and microwave regions there is very little ability for water penetration. It is interesting to note that blue light has the ability to propagate twenty to thirty meters of clear ocean water before being significantly attenuated. (Cornillon, 1982, p. 7)

2. The Infrared Radiation Band

The infrared region of the spectrum is another important region to remote sensing. It is called infrared because it is below the visible red region. Infrared radiation can not be seen by the human eye, however instruments can record this radiation photographically or electronically. From this form it can be easily converted to an image that can be seen by the human eye or into numbers that can be quantitatively interpreted. The infrared region is subdivided into two well-defined segments, the near-infrared and the thermal infrared regions. (Cornillon, 1982, p. 9)

a. The Near-Infrared Region

The near-infrared region corresponds to the band of high reflectance for most vegetation. As an example, plants reflect a great deal more energy in the near-infrared than in the visible portion of the spectrum. Additionally, with the exception of clouds, the atmosphere is transparent to near-infrared radiation (an absorption window). The wavelengths bounding this region of the spectrum range from about 0.8 micrometers to 1.5 micrometers. As with visible radiation, most radiation leaving the Earth in this region is reflected solar radiation. (Cornillon, 1982, p. 9)

b. The Thermal Infrared Region

Thermal radiation is of significance to remote sensing because it is comprised chiefly of radiation emitted by the Earth and the atmosphere. Solar radiation does not make a significant contribution in this band. The thermal infrared band stretches from 4 micrometers to 0.3 millimeters. Source (water, land, clouds, snow, etc.) temperature and emissivity determines the intensity of the emitted radiation. From the intensity level measurement of the infrared radiation, the temperature of the source can be calculated with a high degree of accuracy. (Cornillon, 1982, p. 9)

The atmosphere is transparent to thermal infrared radiation within two narrow absorption windows. They are the 3 micrometer to 5 micrometer band and the 9.5 micrometer to 13.5 micrometer band. Except for these two bands, nearly all thermal infrared radiation is absorbed by the atmosphere as it travels upward towards the satellite. In the 9.5 micrometer to 13.5 micrometer window, atmospheric humidity affects radiation extensively. This represents one of the most significant problems with the use of thermal infrared sensors in determining sea surface temperatures. Additionally, thermal infrared radiation does not have the ability to pass through clouds. However, on the positive side, since a large fraction of the radiation is emitted by the Earth, data collection can be accomplished outside of daylight hours. (Cornillon, 1982, p. 9)

3. The Microwave Radiation Band

The third region of the electromagnetic spectrum which is important in remote sensing is the microwave region. The microwave region ranges from about 0.3 millimeters to 20 centimeters. There are several important differences between sensing in the microwave region compared to sensing in the visible or infrared. The most important point is that most microwave radiation will penetrate clouds with little attenuation or reduction in signal strength. This means that a large portion of the microwave spectrum may be used under all weather conditions except for rain. Another advantage of microwave sensors is that the wavelengths used are comparable to the size of many surface irregularities such as sand grains and capillary waves. Thus, the intensity of the reflected radiation often carries information on the roughness of the surface. This proves to be quite valuable when studying oceanographic phenomena. (Cornillon, 1982, pp. 9-10)

C. METEOROLOGICAL SATELLITE INSTRUMENTATION

1. Electro-Optical Detection Devices

a. Imaging Sensors

Visible imagery is obtained by measuring only visible radiation (light) received by the satellite. These imagers portray a scene similar to what would appear to the naked eye. This imagery is typically depicted in black and white. As a satellite looks down towards the Earth, the light that it receives is actually sunlight reflected from various features beneath it. Those features which appear the brightest are those that are reflecting the sunlight towards the spacecraft most strongly. Examples of this would include clouds, ice, snow-covered land, and desert. Visible imagers are limited to periods of daylight. There is one exception to this rule; on rare occasions bright moonlight provides sufficient illumination that very sensitive radiometers can detect it. (World Meteorological Organization, 1982, pp. 22-26)

Infrared imagery is derived in general from thermal radiation (heat) which is emitted by the objects towards which the satellite is pointing. Generally, the hotter the object, the greater amount of thermal radiation it emits. An infrared image is therefore a representation of the temperature of a small cross-sectional area. Color depiction on graphic displays for infrared imagery is usually portrayed in black and white. Common practice is to assign darker shades of grey to areas exhibiting higher thermal radiation levels. Thus, cold cloudy regions appear bright white whereas heated land surfaces appear almost black. The major advantage of infrared imagery over visible imagery is that infrared images do not need sunlight to illuminate the area being imaged. This enables the infrared imager to operate at night or at high latitudes in the winter months where a visible imager would be

relatively ineffective. (World Meteorological Organization, 1982, pp. 22-26)

(1) *Return Beam Vidicon Camera.* The Return Beam Vidicon Camera is a device that is currently used only in the Landsat series of environmental satellites. This camera is similar to photographic equipment in that it images an entire scene at one instant in time. With this device, detected radiance is converted to an electronic signal. The primary advantages of the system are that it generates an electronic output and it provides for nondestructive detection. The main disadvantages of the system includes lack of multispectral registration and two-dimensional distortion in the generated imagery. (Cornillon, 1982, pp. 13-14)

(2) *Scanners.* Devices which generate an image by scanning the scene of interest are known as electro-optical scanners. These instruments use a rotating mirror which reflects radiation from different parts of an area into the detection system. Rotation of the mirror provides radiance data along a straight line. This accounts for the first dimension of the obtained imagery. By advancing the sensor perpendicular to the scanning direction the second dimension of the imagery is assimilated by the scanner. So, in summary the scanning motion of the mirror provides across the track information and the motion of the satellite provides along the track information. Multispectral scanners such as the Very High Resolution Radiometer (VHRR) and the Advanced Very High Resolution Radiometer (AVHRR) operate on this principle. (Cornillon, 1982, p. 14)

b. Nonimaging Sensors

Nonimaging sensors generally take the form of various derivatives of sounding devices known as radiometers. These devices make atmospheric temperature and humidity soundings by sampling the thermal and microwave radiation of

the different wavelengths passing upwards from the atmosphere into space. Just as sunlight is comprised of different colors and wavelengths, thermal and microwave radiation is composed of different wavelengths. Soundings utilize wavelengths absorbed in varying degrees by the atmosphere. This enables different layers of the atmosphere to be studied by exacting measurements of radiation at the various wavelengths. (World Meteorological Organization, 1982, pp. 22-26)

(1) *Radiometers.* A radiometer is a device that is used for measuring visible radiation (light) or thermal radiation (heat). A radiometer basically receives and measures radiation from a small cross-section of a full area for which the image is required. A scanning mechanism enables the satellite to view a large number of these small sections (pixels) in rapid succession and generate a measurement of the amount of radiation received from each section. This data is then relayed to a ground station where the radiation values received from the satellite are converted to brightness levels and displayed in their precise positions on a photographic or electronic display device. Image-producing radiometers of primary concern to meteorologists and oceanographers fall into two broad categories; visible and infrared. (Cornillon, 1982, p. 14)

(2) *Spectrometers.* Spectrometers are a form of radiometer that incorporates a dispersing element. The dispersing element is basically a ruled grating or prism which spreads the incoming radiation spatially as a function of wavelength. A number of radiometers located at different positions within the sensor is then used to detect the dispersed radiation. If only one radiometric device is utilized in the spectrometer then the dispersed beam is swept past the same radiometer repeatedly. (Cornillon, 1982, p. 13)

2. Microwave Technology

In the past it was difficult to obtain accurate temperature profiles through cloudy, overcast regions via conventional atmospheric sounding instruments. However, the use of artificially created microwave radiation has proven extremely useful in this area. Microwaves have the ability to penetrate through clouds, thus providing valuable information in cloud-covered regions. Additionally, microwave technology is proving useful in the determination of characteristics of the ocean surface.

The methodology of microwave sounding basically runs as follows: Microwaves are transmitted downward from the satellite and then reflected back to the satellite by the ocean surface. Through a comparison of signal strength and the properties of the outgoing and returning signals it is possible to obtain data relating to wave height, surface roughness, wind speed in the lower atmosphere, and ice pack measurements.

a. Imaging Microwave Sensors

(1) *Synthetic Aperture Radar.* The Synthetic Aperture Radar (SAR) is an active side-looking instrument which makes use of doppler and ranging information to construct a surface image. The resolution of the Synthetic Aperture Radar is nominally on the order of twenty-five meters. The motion of the satellite allows the SAR to synthesize the signal normally seen with a much larger antenna system. The radar emits many pulses each second. Each pulse illuminates a large surface area. Because of this the surface area reflects energy back to the spacecraft a number of times as the satellite passes overhead. Features not visible to the radar via ranging and doppler measurements can now be resolved by assimilating the multiple views of the target area captured by the satellite. (Cornillon, 1982, p. 16)

b. Nonimaging Microwave Sensors

(1) *Radar Altimeter.* An active device which is used to measure the distance from the spacecraft to the reflecting surface below is known as a radar altimeter. This sensor has a high degree of accuracy associated with its measurements. The round trip travel time of the emitted pulses from the satellite to the sea surface is the primary variable observed by the radar altimeter. This instrument was used on Seasat-1, GOES 3, and Skylab. Altimeter resolutions on those spacecraft were 10 cm, 30 cm, and 1m, respectively. (Cornillon, 1982, p. 15)

The functionality of a radar altimeter is fairly simplistic. The radar altimeter emits a traveling wave pulse in a direct line beneath the satellite to the Earth's surface and then looks for the return pulse. When the return pulse is received, an elapsed time calculation is made.

The radar altimeter has been used extensively in the oceanographic research community to determine wave heights and sea states. Sea states are determined by making a comparison of the shape of the returned pulse with that of the emitted pulse. Wave heights are calculated by measuring the broadening of the returned echo which is caused by increased surface wave actions. Wave height calculations from the radar altimeter have important applications to both commercial and military enterprises. Since this sensor provides unusually detailed information concerning wave patterns, it has proven invaluable towards optimally routing shipping and providing inputs to the correction of wave propagation errors. (Cornillon, 1982, p. 15)

(2) *Scatterometer.* The scatterometer is primarily used in the measurement of wind-induced surface stress. The scatterometer is an active device which uses round trip travel time and ranging to locate the reflected pulse spatially. It responds to the intensity of reflected radiation

at angles from as low as ten degrees to angles as high as eighty degrees. (Cornillon, 1982, p. 15)

In order to obtain directional information on surface winds, a pair of antennas are commonly employed to view the same location from different angles. One beam is emitted from some angle in the forward direction and one beam is emitted from an angle in the aft direction. As the satellite advances along its path, the area covered by the aft beam would cross whatever had been observed by the forward beam. This pulse wave ranging is repeated continuously by the sensor in order to resolve wind direction. (Cornillon, 1982, p. 15)

D. COMMERCIAL APPLICATIONS OF REMOTE SENSING

A budding U.S. commercial space industry is making its way into the market for remote sensing technology. The satellite-relayed weather maps and information presented on local news programs have dramatically improved forecasts and reduced human fatalities from hurricanes and other natural disasters. Remote sensing satellites can also detect air pollution (such as sources of acid rain) and measure ozone and other critical elements comprising the Earth's atmosphere. One important direction of experimental and future operational meteorological study will be the monitoring of slowly changing atmospheric variables and the implication of these changes for long-term weather patterns. Satellite sensors are currently being developed to recognize global albedo and the quantity and distribution of carbon dioxide, chlorofluorocarbons, and dust in the lower atmosphere. These components are affected by man's activities, and long-term changes may give rise to alterations in weather patterns. (Shahrokhi, Chao, and Harwell, 1988, pp. 8-10)

E. IMAGERY COLLECTION

1. Areas of Exploitation

From a commercial standpoint the most promising use of remote sensing satellites is in providing imagery of the Earth's surface. The information gathered from the five U.S. Landsat satellites, launched in the 1970s, and the SPOT satellite of France, has proven to be extremely valuable in the mapping of remote areas. They have revealed unknown lakes, islands, underwater shoals, and reefs. Additionally, they have been used to map routes for railroads, pipelines, and electric power lines. (Shahrokhi, Chao, and Harwell, 1988, pp. 11-13)

The most extensive commercial uses of Landsat and SPOT data, however, have been in mineral exploration and agriculture. By studying satellite images of known oil, gas, and mineral deposits, scientists have learned how to identify key features that might point to new deposits. Landsat's thematic mapper records the reflection of light off the Earth with a sensitivity to color far surpassing that of the human eye. Through digitally enhanced coloration, explorers can detect features that they would have missed if they were making terrestrial observations. In agriculture, satellite imagery is used chiefly for crop forecasting in order to estimate potential crop yields. (Shahrokhi, Chao, and Harwell, 1988, pp. 11-13)

2. Media Utilization

One of the more interesting applications for imagery collecting satellites is usage for media reporting. This concept has been termed MEDIASAT. Several news firms have already used Landsat and SPOT imagery to support lead stories. One notable use of remote sensing imagery for media purposes was for reporting on the nuclear disaster at Chernobyl in 1986. The Chernobyl coverage was particularly significant because it represented the first high visibility usage of satellite-based imagery for other than meteorological purpos-

es. This coverage provided the media with the ability to graphically portray the devastation caused by the accident. More importantly, the media were able to display activity in an otherwise inaccessible part of the Soviet Union at a time when there was limited information being provided by the Soviet government on the extent and nature of the accident. (Broadhurst, 1991, pp. 10-11)

3. Negative Aspects Of Commercial Imagery

The emergence of commercial-based imaging platforms has given rise to questions concerning the potential negative impact that they could have on national security and international treaties. The question arises as to whether the federal government should be allowed to control or prohibit the development and operation of domestic commercial imaging systems that have spatial resolution good enough to conduct surveillance over U.S. territories. The current U.S. policy authorizes the Department of Commerce to impose licensing restrictions on data from American owned and operated satellites. These restrictions are somewhat vague in the sense that they do not spell out precisely what is restricted, but they cite the importance of protecting national security and foreign policy. (Broadhurst, 1991, pp. 30-31)

The federal government may have the ability to restrict domestic firms from building imaging satellites for surveillance purposes; however, it can do nothing about foreign systems that can access U.S. territories. This poses a great concern towards national security interests. Military operations could be severely compromised if commercially available surveillance data from space-based imagers were readily available to the media. If this information was to go public, troop dispositions and movements could be revealed and misinterpreted thus endangering the safety of our servicemen and potentially heating international tensions. (Broadhurst, 1991, pp. 30-31)

F. THE LANDSAT SYSTEM

From 1972 until 1986 the Landsat satellites held a tight monopoly on space-based imaging. During most of that period, Landsat 1 through Landsat 5 were funded, developed, launched, and operated by the U.S. government. The Land Remote Sensing Commercialization Act of 1984 established the procedures for the transfer of the Landsat System from the federal to the private sector. The Earth Observation Satellite Company (EOSAT) was selected after competitive bid to commercially operate the Landsat System. Thus EOSAT was charged with satellite operation, selling collected data, and building any future satellites necessary to augment the Landsat System.

Although the U.S. National Space Policy calls for the continuity of "Landsat type" remote sensing data, that policy has not been completely implemented. The federal government committed to funding Landsat 6; however, this satellite malfunctioned shortly after launch on 05 October 1993. Technicians discovered that they were unable to communicate with the satellite and it has now been declared a total loss. EOSAT is now left with only Landsat 4 and Landsat 5 operational and both are nearing the end of their design lives. This places EOSAT in a very precarious position and could force the U.S. government to reexamine the pace of development of the Landsat 7, the next Landsat spacecraft.

Considering the fact that the planning and development of space-based systems usually begins at least ten years prior to the time they will become operational, it is highly likely that there will be a major gap in the Landsat system.

The entrance of the French into the remote sensing field in 1986 ended the U.S. monopoly in this area. The capabilities of the French SPOT system, as well as the French policy of cooperative government cost burden-sharing, have challenged the United States technically, politically, and commercially.

G. INNOVATIVE EMERGING TECHNOLOGIES

1. The Eyeglass System

The Eyeglass system is a series of small satellites, currently in the planning stage, which are designed to provide spy-satellite quality imagery for sale on the open commercial market. These satellites are being built by a triumvirate comprised of the Orbital Sciences Corporation, GDE Systems Incorporated, and the Itek Optical Systems Corporation. These companies have formed a separate commercial firm named Eyeglass which will construct, own, and operate the Eyeglass series of remote sensing imagery collectors. This system is of significant commercial importance because it is the first domestic enterprise to compete in the remote sensing imagery market with international corporations such as Spot Image of Toulouse, France. (Seitz, Nov 08-14 1993, p. 18)

The Eyeglass satellites are being manufactured to collect imagery with a resolution of 1 meter. This resolution would enable one to distinguish objects as small as a fireplug. Eyeglass satellites are projected to be able to provide images which could be useful for mapping purposes, environmental monitoring, resource management, and city planning. The satellites would use a small Seastar-class satellite bus design as the vehicle's frame. Itek is responsible for devising the electro-optical imaging sensors and GDE will handle the ground image processing. The first operational satellite is currently slated for a 1996 launch aboard either a Taurus or Pegasus rocket which are manufactured by the Orbital Sciences Corporation. (Seitz, Nov 08-14 1993, p. 18)

2. The Geostationary Environmental Monitor (GEM)

The Geostationary Environmental Monitor (GEM) is a low-cost weather observation program that is currently being developed by the Hughes Technology Corporation. The high-tech, fifty pound GEM sensor suite is designed to ride piggyback on geostationary communications satellites. While traveling on

the host spacecraft, the GEM sensors will relay weather, disaster warnings, and other environmental data to both civil and commercial users.

The technology for the GEM sensor system was initially developed under the Strategic Defense Initiative (SDI). In particular, the infrared sensor and solid-state gyroscope were direct derivatives of SDI's Brilliant Eyes Program. (The Brilliant Eyes Program was a constellation of small satellites that were being designed to detect ballistic missiles in flight). From their geostationary Earth orbit, the GEM sensor suite will be used to measure the visible portion of the electromagnetic spectrum to produce color imagery with a 1 kilometer resolution. GEM's infrared sensor will have the capability to gather imagery with a 5 kilometer resolution. By updating its database every minute, the GEM system would be able to identify rapidly moving fronts and growing weather patterns such as thunderstorms and hurricanes. This ability to update data on a minute-by-minute basis is unequaled by any other weather satellite currently in orbit or on the drawing board. (David, Sept 20-26 1993, p. 16)

The cost for a single GEM package is estimated by the Hughes Corporation to be less than twenty million dollars. A GEM market plan estimates that twenty-five million dollars in profit could be earned annually for each GEM on station. A prototype GEM sensor package is currently being planned for a 1995 launch aboard a Hughes-built HS-601 communications satellite. Projected usage of this initial GEM suite would include utilization as a weather watch by local TV stations nationwide, use by insurance adjusters to ascertain damages from natural disasters, and as a weather monitor to airlines and fishing fleets. It is also feasible that the Department of Defense and the United States Weather Service could make use of the GEM sensors in times of crisis or natural disasters. (David, Sept 20-26 1993, p. 16)

3. The Midcourse Space Experiment Satellite (MSX)

The Midcourse Space Experiment satellite (MSX) is a United States Department of Defense satellite designed primarily for identifying and tracking incoming ballistic missiles. Additionally, it has a secondary capability of monitoring global climate change. The satellite is currently being assembled by the Johns Hopkins Applied Physics Laboratory for the Ballistic Missile Defense Organization. The launch date of the satellite is tentatively scheduled for the fall of 1994.

The MSX satellite will be equipped with cryogenically cooled sensors to identify test firings of missiles. The trajectory path and exhaust plumes of these missiles will be monitored by a suite of advanced on-board sensors that can simultaneously scan in a wide range of visible, infrared, and ultraviolet wavelengths. An added feature of this sensor system is that it can track dummy warheads and debris ejected from the rockets as they travel through the atmosphere. The highlight of the MSX satellite though is that it can focus on missiles, objects, or celestial bodies in deep space via precision pointing maneuvers. (David, Jan 31-Feb 06 1994, p.17)

In conjunction with its military capabilities, the 2700 kilogram MSX satellite is projected to have the ability to probe the makeup and dynamics of the Earth's atmosphere. Some of the possible remote sensing missions that the satellite could be utilized for include: monitoring atmospheric changes caused by agricultural burnoffs, forest fires, and volcanic eruptions. Additionally, the sensors of the MSX are predicted to be sensitive enough to detect minute differences in carbon dioxide, ozone, and chloro-fluorocarbons in the atmosphere. (David, Jan 31-Feb 06 1994, p.17)

The MSX satellite holds enormous potential to fill a significant gap in global change research over the next five

years. NASA's Upper Atmosphere Research Satellite ended its global observation collection in 1993. The Earth observing platforms are currently not scheduled to be launched until late 1999. In the interim period the MSX could provide a continuous source of valuable atmospheric data to the global change research community.

4. Spy Satellites For Nuclear Weapons Detection

A new generation of spy satellites is currently being developed by the Los Alamos National Laboratory. This facility is affiliated with the Department of Energy and has been involved with the development of space-based instruments to monitor the nuclear activities of other nations since the early 1960s. The satellites that are currently under design are being constructed to detect and monitor the proliferation of nuclear weapons inside countries that refuse to cooperate with international inspectors. (Foley, Jan 31-Feb 06 1994, p. 6)

For several years nuclear weapons proliferation in North Korea and Iraq has been of great concern to intelligence agencies and nuclear inspectors. The Persian Gulf War demonstrated the need for the collection of information relating to a hostile power's nuclear weapons status. One of the critical studies that the Los Alamos Lab is currently undertaking is the determination of observables in nuclear weapons production. When this information is obtained, future spy satellites will be designed to detect those observables via an elaborate sensor array.

(1) *The Alexis Satellite.* The first of the Los Alamos new generation of spy satellites is the Alexis satellite. The Alexis is a very small surveillance satellite. It was launched in April 1993. Its purpose involves the measurement of electronic pulses in the upper atmosphere. It is comprised of a battery of X-ray telescopes and an electronic measuring device to facilitate its mission. This satellite was

damaged slightly during the launch phase and continues to have minor operational difficulties to this day. In accordance with the laboratory's nuclear monitoring requirements, the Alexis has been used to test a new type of sensor. When pointed away from the Earth, Alexis can assimilate astrophysical data. When the sensors are aimed at the Earth they can be utilized for nuclear arms control verification purposes. In addition to its nuclear detection capabilities, a collateral objective of the Alexis program is to prove that small, low cost satellite operations can be exploited. (Foley, Jan 31-Feb 06 1994, p. 6)

(2) *The FORTE Satellite.* The Fast On-Orbit Recording of Transient Events (FORTE) Satellite is slated as the next major undertaking of the Los Alamos National Laboratory. It will be a seven foot long satellite with a thirty foot diameter antenna subsystem extending from the satellite's body. Currently scheduled for a 1995 launch, this satellite will be used exclusively to detect electromagnetic pulses in the atmosphere. These pulses are ones which would be created by a nuclear explosion. (Foley, Jan 31-Feb 06 1994, p. 6)

International treaties have banned nuclear testing in the atmosphere. Even though a nuclear explosion in the atmosphere has not been recorded since the early 1970s, the United States continues to monitor for them. The FORTE sensor suite will provide a means to monitor treaty violations and identify proliferant nations who aspire to build nuclear arsenals by detecting nuclear bursts.

(3) *The MTI Satellite.* The Multispectral Thermal Imaging Spacecraft (MTI) is a joint project that is currently being undertaken between the Los Alamos National Laboratory and Sandia National Laboratories (also affiliated with the Department of Energy). This satellite is being planned for a 1996 or 1997 launch and will be used to image objects on Earth in several simultaneous spectral bands. It is projected that the technology currently under development for

this satellite will have various applications in monitoring for nuclear weapons. When this satellite becomes operational, Los Alamos plans to turn the sensor suite over to U.S. arms control agencies and intelligence agencies for the monitoring of nuclear weapons in proliferant nations. (Foley, Jan 31-Feb 06 1994, p. 6)

H. SURVEILLANCE APPLICATIONS

For over twenty years images of the Earth from space have been available from civil and commercial space-based sensors. This imagery has revolutionized the way we view our planet and its dynamic processes through remote sensing technology. Now, with the advent of high resolution imagery the scope of remote sensing has extended to surveillance applications. Recently, the quest to bring these applications to the commercial market has grown in emphasis. Space-based imaging is viewed by many in the government and scientific community as the next major area for broadening the scope of the remote sensing field.

I. THE STIMULATION OF COMMERCIAL DEVELOPMENT

In this era of dwindling federal budgets for space, the federal government is severely limited in what it can do with regard to risk-sharing with private industry. However, there are several policy alternatives that could be exercised to foster commercial growth in the remote sensing industry. The United States could initiate policy incentives to private businesses that would limit their operating costs and thus increase their profit margins. These incentives could take the form of: tax credits for remote sensing research, low cost loans for satellite purchases, contracts for data sales to government agencies, commercial product licenses for value-added products.

Today, the remote sensing industry is gradually gravitating towards imagery-type products in order to sustain revenues. Traditional applications in this field are being greatly

enhanced through value-added hardware and software to such a degree that value-added firms within the remote sensing industry show great promise for future growth. (Broadhurst, 1991, pp. 33-34)

VI. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION SYSTEM

A. ORGANIZATION BACKGROUND

The National Oceanic and Atmospheric Administration (NOAA) was established as a subsidiary to the United States Department of Commerce in 1970. The primary objectives of NOAA are to improve safety and enhance the quality of life by expanding the knowledge base of the Earth's environment. In order to meet these mission areas, NOAA maintains, manages, and operates two independent satellite systems through the National Environmental Satellite Service (NESS). NESS is a branch department of NOAA. With the use of these assets NOAA is actively engaged in providing and disseminating weather information, developing new weather forecasting techniques, providing satellite data on the effects of various human activities on the environment, geodetic research, employing satellite data to monitor environmental quality, and utilizing satellite imagery for coastal mapping and charting.

The two satellite systems operated by the National Environmental Satellite Service of NOAA are the polar orbiting system (the Advanced TIROS-N or NOAA satellites) and the geostationary operational environmental satellite system (GOES). The polar orbiters are instruments of quantitative value to meteorologists because they can provide raw data that can be inserted into mathematical and prediction models. The low earth orbits of these spacecraft make them the preferred platforms for performing atmospheric soundings and the collection of high resolution imagery. The GOES satellites are preferred for areas of study requiring large-scale visual data at rapid, regular intervals. (Hill, 1993, p. 40)

B. POLAR ORBITING SATELLITES

1. Mission

The primary mission of the NOAA satellites is to provide daily weather information for worldwide weather forecasting. Cloud cover information, data on solar energy fluxes, atmospheric soundings, and high resolution visible and infrared imaging of the Earth's atmosphere are gathered and processed through a global network of ground stations in conjunction with international weather organizations, such as the World Meteorological Organization. Additionally, NOAA series satellites provide extensive meteorological data to the Department of Defense (DOD). All NOAA satellites are launched by NASA and then transferred to NOAA control once they are established in low earth orbit. When controlled by NASA the NOAA satellites are designated by letter (i.e., NOAA-D); however when the satellite is transferred to NOAA control it is redesignated with a number (for example NOAA-D was redesignated NOAA-12).

2. Chronology of the TIROS-N Series

a. The TIROS-N Satellites

The polar orbiting Television Infrared Observation Satellites (TIROS-N) were introduced during the latter half of 1979. These spacecraft were designed and manufactured by RCA. They replaced the TIROS-M series, commonly referred to as the Improved TIROS Operational Satellite (ITOS) System. NOAA-6, launched on June 27, 1979, was the first operational TIROS-N satellite. The TIROS-N and ITOS systems provided overlapping coverage until July 16, 1979 when the last of the ITOS satellites, NOAA-5, was deactivated. (National Environmental Satellite Service, 1980, p. 3)

There were a total of three TIROS-N satellites launched by NASA for NOAA. The first, NOAA-6, was placed in a 450 nm morning orbit and provided eight years of operational

service to the system, thus greatly exceeding its design life of two years. This satellite was deactivated on March 31, 1987. NOAA-B was launched May 29, 1980. However, this satellite failed to achieve a usable orbit because of a booster engine anomaly. Because of this, NOAA-B was never integrated into the system and therefore did not get redesignated with a number. NOAA-7, the last of the TIROS-N satellites, was launched on June 23, 1981 in a 470 nm afternoon orbit. This satellite remained in operation until it was deactivated in June of 1986 after experiencing a failure in the power system. (Advanced TIROS-N Handbook, 1992, pp. 1-2)

b. TIROS-N Meteorological Instruments

The TIROS-N satellites carried four primary meteorological instruments: an Advanced Very High Resolution Radiometer (AVHRR); a Data Collection and Platform Location System; a TIROS Operational Vertical Sounder which consisted of three complementary sounding instruments; and a Space Environment Monitor. (National Environmental Satellite Service, 1980, pp. 3-4)

(1) *Advanced Very High Resolution Radiometer.* The TIROS-N satellites could produce day and night images with the AVHRR. Additionally, the AVHRR has the capability to distinguish areas of ice, snow, clouds, and it can give surface and cloud-top temperatures of atmospheric water vapor (Hill, 1992, pp. 50-51). Table 20 depicts the channel characteristics of the AVHRR and the primary uses associated with those channels (Hussey, 1979, p. 13).

TABLE 20. TIROS-N AVHRR CHANNEL CHARACTERISTICS

Channel	Resolution at Subpoint	Wavelength (μm)	Primary Use
1	1.1 km	0.55-0.90	Day Cloud/Surface Mapping
2	1.1 km	0.725-1.10	Surface Water Delineation
3	1.1 km	3.55-3.93	SST, Night Cloud Mapping
4	1.1 km	10.5-11.5	SST, Day/Night Cloud Mapping
5	1.1 km	11.5-12.5	SST

For points directly beneath the satellite, the resolution of the AVHRR allows for a pixel size of 1.1 km. This resolution decreases as the scan reaches to either side of the orbit path of the satellite. The image swath is 2400 km wide, and because of the large scanning angle the edges of the swath are extremely distorted. AVHRR data can be assimilated into 4000 km long strips at 1.1 km resolution for local area coverage or degraded to 5 km resolution for global mosaics. Full global coverage is possible twice per day because the ground track of the satellite is shifted west by 821 km for successive orbits. (Drury, 1990, p. 49)

(2) *TIROS Operational Vertical Sounder*. The TIROS Operational Vertical Sounder (TOVS) is comprised of the following three sounding devices: a high resolution infrared spectrometer (HIRS/2), a stratospheric sounding unit (SSU), and a microwave sounding unit (MSU). The HIRS/2 can sound for temperature, ozone content, or water vapor content via the use of twenty channels to detect absorption of infrared radiation. The HIRS/2 records data with a 17.4 km pixel resolution in 20 non-imaging channels directed at the H₂O, CO, and N₂O absorption bands (Drury, 1990, p. 50). The SSU utilizes three infrared channels to compute air temperature from the Earth's surface up to 50 km. This enables extremely accurate temperature soundings of the stratosphere. The MSU utilizes the

microwave portion of the electromagnetic spectrum to take atmospheric soundings (in particular, the water vapor and oxygen absorption regions at 5-6 mm) through clouds. (Hill, 1992, p. 51)

All data collected from TOVS are in a digital format. The data are available via both VHF and S-band data links. Users who receive the high resolution transmissions from the AVHRR find that the most efficient method of collecting TOVS data is to extract it from the AVHRR data stream. (Hussey, 1980, pp. 15-16)

Table 21 lists the characteristics of the TOVS instrument package (Hussey, 1979, p. 14).

TABLE 21. TIROS-N TOVS CHARACTERISTICS

Characteristic	Stratospheric Subsystem (SSU)	Tropospheric Subsystem (HIRS/2)	Microwave Subsystem (MSU)
Resolution at Subpoint	147 km	17 km	109 km
Field of View	10°	1.4°	7.5°
General Spectral Regions Used	15 μm CO ₂	15 μm CO ₂ 11 μm Window 9.7 μm O ₃ 6.7 μm H ₂ O 4.3 μm CO ₂ 3.7 μm Window 0.7 μm Visible	50-57 GHz O ₂
Number of Spectral Channels	3	20	4

(3) *ARGOS Data Collection System.* ARGOS, the on-board data collection system, has the capability to determine the position of platforms such as stationary surface platforms or free floating buoys and balloons via an inverse doppler technique. Additionally, ARGOS could retrieve the meteorological or oceanographic data assimilated by those devices. The ARGOS data collection system receives data from platforms at the UHF frequency of 401.65 MHz. The platforms transmit their data independently of any type of interrogation from the spacecraft. The transmissions are made continuously from the platforms and vary in length from 360 to 920 ms. The repetition interval for those transmissions varies between 40 to 200 seconds. As the spacecraft passes within range of a platform during its orbit, it receives and records the successive transmissions. Then, when the spacecraft gets in range of an appropriate ground station, it plays back the recorded data. The French Space Agency, the Centre National d'Etudes Spatiales (CNES) provides ARGOS instrumentation for TIROS-N satellites and also processes and disseminates the collected data from ARGOS. (Hill, 1992, p. 51)

(4) *Space Environment Monitor.* The Space Environment Monitor (SEM) measures alpha particle and electron flux density, solar proton flux, and the total particulate energy distribution at the satellite's altitude. This is accomplished via three detection devices which are incorporated within the instrument. These devices are: a high energy proton and alpha particle detector, a medium energy proton and electron detector, and a total energy detector. The high energy proton and alpha detector senses protons and alpha particles in the 370 Kev to 850 Mev energy band. The medium energy proton and electron detector senses protons, electrons, and ions in the 30 Kev to 60 Kev energy band. The total energy detector measures the intensity of particles in the 0.3 Kev to 20 Kev

energy band. The data gathered from these detectors are combined at ground stations with data collected from GOES satellites and are used to monitor the state of solar activity. This is important because solar activity has a marked impact on electrical power distribution as well as terrestrial communications. (Hussey, 1979, pp. 18-19)

c. The ATN Program

(1) Overview. In 1983 NOAA began to upgrade its polar orbiting satellite system with the Advanced TIROS-N (ATN) satellites. These satellites are very similar in appearance to the TIROS-N series and carry the same primary meteorological devices as the TIROS-N satellites. The main difference between the two is that the ATN satellites are 19 inches longer and carry additional instruments. Table 22 lists the physical characteristics of an ATN satellite. (Hill, 1993, p. 53)

TABLE 22. PHYSICAL CHARACTERISTICS OF ATN SATELLITES

Spacecraft Weight	2200 lb (total)
Payload Weight	850 lb
Spacecraft Size	165 in (length) 74 in (diameter)
Solar Array	7.8 ft x 16.1 ft (125 ft ²) 515 watts (EOL)
Power Requirements	475 watts (full operation) 40 watts (Reserved)
Attitude Control System	0.2 degrees in all axes 0.14 degrees determination
Orbit	833; 870 km normal, sun synchronous
Launch Vehicle	Atlas E/F
Lifetime	2 years planned
Communications Command Link	148.560 MHz Beacon: 136.770; 137.770 MHz S-Band: 1698; 1702.5; 1707 MHz APT: 137.50; 137.620 MHz DCS (uplink): 401.650 MHz Search and Rescue: 1544.5 MHz Search and Rescue: (uplink): 121.5; 243.0; 406 MHz

(2) *Orbital Parameters.* The Advanced TIROS-N system is normally comprised of two satellites in an inclined sun synchronous orbit. One satellite normally operates in a morning descending orbit at 450 nm, while the other satellite operates in an afternoon ascending orbit of 470 nm. Each satellite in the system will orbit the Earth with a period of approximately 102 minutes and provide coverage of the entire Earth four times per day. Orbital separation between the satellites is normally ninety degrees. (Jane's Space Directory, 1994, pp. 449-450)

(3) *Evolution of the ATN Program.* The main reason why the TIROS-N system evolved to the ATN program was because the ATN satellites can carry instruments involved in the international search and rescue program, COSPAS/SARSAT. This program involves constituents from the United States, Russia, France, and Canada. The goal of this humanitarian project is to reduce the time required to rescue air and maritime distress victims and to locate survivors who otherwise might not be found. COSPAS (a Russian acronym for Space System for the Rescue of Vehicles in Distress) is the search and rescue equipment package deployed on several Russian meteorological satellites, while SARSAT (Search and Rescue Satellite Aided Tracking) is the equipment suite carried on NOAA's ATN satellites as the U.S. contribution to the program. France and Canada join the cooperative by providing on-board instruments to augment the satellite suites. (Hill, 1993, pp. 53-54)

(4) *The COSPAS/SARSAT System.* The COSPAS/SARSAT system basically operates as follows: A constellation of approximately four satellites (2 NOAA ATNs equipped with SARSAT and 2 Russian meteorological satellites carrying COSPAS) in LEO continuously monitor the search and rescue frequencies, 121.5, 243.0, and 406.0 MHz. When a satellite in the system picks up a signal from an emergency position

indicating radio beacon or an emergency locator transmitter it passes the data to a network of international groundstations. At these stations the distress beacon position would be determined using doppler fixing techniques. The satellite's rapid motion (approximately 8 km per second) would produce a noticeable "up doppler" and "down doppler", inbound and outbound to the beacon respectively. The ground stations would then relay the satellite data to the appropriate cooperative nation where on-site search and rescue units could act on the information.

(5) *Additional Instrumentation.* ATN satellites also carry a Solar Backscatter Ultraviolet Spectral Radiometer (SBUV/2) and two instruments, the Earth Radiation Budget Experiment (ERBE), which are used to aid in determining the Earth's radiation budget. The SBUV/2 is basically a modified version of a device carried aboard Nimbus 7 which measures ultraviolet light backscattered by the atmosphere. The SBUV/2 is used to measure solar irradiance over the spectral range of 160 to 400 nanometers and also to make atmospheric measurements from which the total ozone concentration in the atmosphere can be calculated with a high degree of accuracy. (Advanced TIROS-N Handbook, 1992, pp. 1-10)

The ERBE is comprised of a scanning component and a non-scanning device. The scanner is a collection of three small telescopes which collect radiation emitted by the Earth and the atmosphere, radiation reflected from the Earth, and radiation which is both reflected and emitted from the Earth. The non-scanning component is comprised of five detectors. One detector monitors the Sun's energy while the other four monitor radiation from the Earth. This collection of telescopes and detectors help to determine the balance of incoming solar radiation with the radiation reflected, absorbed, and emitted by the Earth. This is important because

factors which alter this balance have a pronounced effect on the weather. (Hill, 1993, pp. 52-55)

Figure 87 is a schematic of an Advanced TIROS-N satellite. (Satellite News, Aug 1992, p. 1)

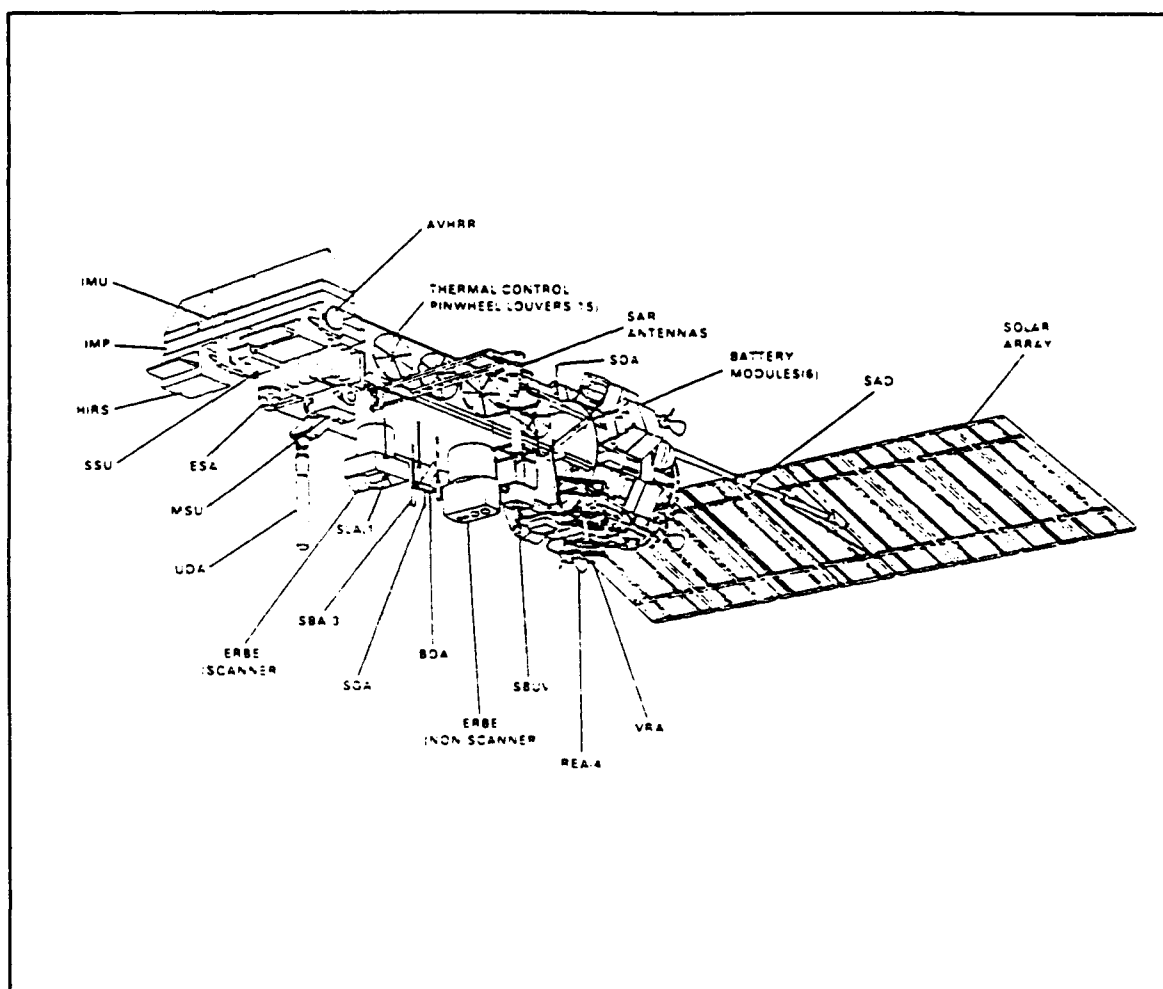


Figure 87 The Advanced TIROS-N Satellite

(6) NOAA-8. NOAA-8 (E) was the first of the Advanced TIROS-N (ATN) satellites to become operational. It was launched on March 28, 1983 and became fully operational on July 01, 1985 after recovering from a redundant crystal oscillator (RXO) failure. This satellite was placed in a 450 nm morning orbit and was the first NOAA satellite to carry a SAR package. NOAA-8 carried the entire instrument suite described previously, except for the SBUV/2 and the ERBE package. Dummies of those two instruments were carried on-board in order to balance the satellite's weight (Hill, 1993, p. 54). The satellite was lost on December 29, 1985 when it experienced a thermal runaway malfunction which destroyed the spacecraft's battery. (Advanced TIROS-N Handbook, 1992, p. 2)

(7) NOAA-9. NOAA-9 (F) was launched on December 12, 1986 into a 450 nm morning orbit. This was the first ATN satellite to carry the complete ATN sensor suite. This satellite remained operational for two years until it was replaced by NOAA-11 in 1988. When NOAA-9 was replaced by NOAA-11 it was placed in a standby status because its power system experienced a series of array shunt failures and battery malfunctions. (Jane's Space Directory, 1994, pp. 449-450)

(8) NOAA-10. NOAA-10 (G) was launched on September 24, 1988 into a 470 nm afternoon orbit with a 1:40 p.m. ascending node crossing time. NOAA-10 was equipped with the complete ATN sensor suite, except for the SBUV/2. The SRSAT processor/receiver on this satellite failed in 1988 and the ERBE scanner failed in 1989. The non-scanning ERBE solar monitor shutter is stuck in the open position, however it can still provide useful data. When NOAA-10 was replaced by NOAA-12 in 1991, it remained in orbit as a backup for NOAA-12. NOAA-10's meteorological instruments such as the AVHRR and SEM exhibit degraded operational performance, however it is projected that its sensor suite is adequate to serve as a

gapfiller should NOAA-12 experience a critical malfunction. (Jane's Space Directory, 1994, pp. 449-450)

3. The Current Operational Polar Orbiting System

a. NOAA-11

NOAA-11 (H) was launched on September 24, 1988 and was subsequently placed into a 470 nm afternoon orbit with a 1:40 p.m. ascending node crossing time. This satellite is transmitting data for local weather analysis directly to users around the world. A unique feature of the NOAA-11 was that it was modified for a zero to 80 degree sun angle. It also includes fixed and deployable sunshades on the Instrument Mounting Platform (IMP) as well as the capability for a deployable Medium Energy Proton and Electron Detector (MEPED). The increase in the maximum sun angle from 68 degrees (as in previous ATN satellites) to 80 degrees, allows an afternoon nodal crossing closer to noon which enhances data collection. (Advanced TIROS-N Handbook, 1992, p. 2)

Currently, the NOAA-11 is hobbled by a variety of technical problems and malfunctions, including the loss of three out of four stabilizing gyroscopes. The instrument suite carried on-board the spacecraft is still operating at full capacity, however the attitude control problems could cause NOAA to lose control of this satellite at any time. Because of this, NOAA-13 (ground designator: NOAA-I) was launched on August 9, 1993 to replace the NOAA-11. Unfortunately, on August 21, 1993, a short circuit interrupted the flow of electricity to the single large solar panel of the NOAA-13 and the powerless spacecraft was declared a total loss. (Harwood, Aug 30-Sept 05 1993, p. 11)

b. NOAA-12

NOAA-12 (D) was launched on May 14, 1991 and was subsequently placed into a 450 nm morning orbit to replace the aging NOAA-10. This satellite carries the complete ATN instrumentation, except for the SARSAT package, SBUV/2, and SSU. (Jane's Space Directory, 1994, p. 450)

An onboard information processor supplies all of NOAA-12's low-rate digital data and telemetry processing functions while the manipulated information rate processor performs the high-rate AVHRR data processing. Environmental data is stored on NOAA-12 via five onboard digital recorders. Three of these provide capacity for storage during one complete revolution and the other two are used as spares. (Satellite News, Aug 1992)

c. System Outlook

NOAA-12 is currently fully operational with no significant degradations as of June 1994. Both NOAA-11 and NOAA-12 continue to provide global environmental and meteorological data to support the national weather satellite system, World Weather Program, and the U.S. National Weather Service's experimental programs. However, both of these spacecraft have already surpassed their respective design lives (2 years) and cannot be counted on to provide adequate coverage for any period of time beyond 1994.

The loss of NOAA-13 (I) in August of 1993 will likely result in a 50 percent degradation of the polar orbiting system sometime during 1994. This is because NOAA-11 is very close to end of its useful life. NOAA-J (NOAA-14 when operational) is currently slated for a November 1994 launch and should provide the polar orbiting system with a badly needed replacement. NOAA-J, initially slated as the replacement spacecraft for NOAA-12, will now be utilized as the designated replacement for NOAA-11. So, from the time NOAA-11

is deactivated until the NOAA-J can be successfully launched, the polar orbiting system will be operating at 50 percent capacity.

C. GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES

1. Mission

The Geostationary Operational Environmental Satellite System (GOES) is normally comprised of a two satellite constellation of meteorological satellites orbiting the Earth in a geostationary orbit. These satellites provide for a wide variety of service-oriented environmental missions which include both scientific research and weather-related applications. The scientific research activities include: the continuous measurement of temperature and water-vapor content in the Earth's atmosphere; the monitoring of x-ray emissions from the sun; the measurement of the Earth's magnetic field; and the relay of distress signals from aircraft and ships. Weather-related applications include both day and night imaging of the visible and infrared spectral regions; monitoring for hurricanes and severe storms over the United States; providing for facsimile transmission of processed graphic and imaged data (WEFAX) to field stations; and the dissemination of data and analyzed environmental information to users in real time and near real time. (GOES GH Databook, 1986, pp. 1-5)

2. Chronology of the GOES Series

a. The GOES Satellites

The GOES satellites were introduced during the later part of 1975 with the launch of GOES 1. This system was the successor to NASA's Synchronous Meteorological Satellite (SMS) program which consisted of two satellites in geostationary Earth orbit, SMS 1 and SMS 2, launched in the mid 1970s. The SMS program was designed primarily to provide continuous

coverage of major storm systems, hurricanes, and forest fires taking place in the United States. The GOES system was basically built upon the core capabilities of SMS technology in geostationary observation techniques in order to provide NOAA with timely and continuous weather information over the United States.

To date, eight GOES spacecraft have been successfully launched and assimilated into the GOES system. Ford Aerospace (now Space Systems Loral) designed and constructed GOES 1-3 and GOES 8 (GOES I). Additionally, this company is currently producing the GOES-Next generation spacecraft (GOES I-M) which will support the GOES system into the twenty-first century. Hughes Aircraft has provided the instrumentation suite for the entire series and also built GOES 4-7. GOES satellites have a design life of five years and an operational life of five to eight years. When replaced by a new GOES spacecraft, these satellites are frequently repositioned in orbit to provide an on-orbit spare capability for the primary GOES satellites. Thus, in the event of a critical instrument or subsystem failure to that primary vehicle, an aged GOES spacecraft could be maneuvered to augment the primary satellite's instrument suite.

(1) *GOES 1*. The GOES 1 satellite was launched on October 16, 1975 by a Delta from Cape Canaveral. Initially, this satellite was positioned at 60 degrees east longitude over the Indian Ocean, however in 1979 it was moved to 135 degrees west longitude. In 1981 the satellite was used as an on-orbit spare and in 1982 it was reactivated to provide visible imagery when GOES 4's imaging system failed. GOES 1 was finally deactivated in the mid 1980s. (Jane's Space Directory, 1994, pp. 450-451)

(2) GOES 2. The GOES 2 satellite was launched on June 16, 1975 by a Delta from Cape Canaveral. Initially, it was positioned at 60 degrees east longitude over the Indian Ocean. This spacecraft was fully operational until January 1979 when the visible and infrared spin scan radiometer's (VISSR) primary encoder malfunctioned. The loss of this device rendered the satellite unable to provide imagery. In 1992, GOES 2 was repositioned to 60 degrees west longitude with an inclination of 9.4 degrees. In the later half of 1992, it was moved to 135 degrees west longitude to replace GOES 6 in supplying all non-imaging functions (SEM, DCS, and WEFAX) of the western GOES spacecraft. (Jane's Space Directory, 1994, pp. 450-451)

As of January 1994, GOES 2 was positioned at 135 degrees west longitude with an inclination of 10.9 degrees. The satellite batteries are currently unable to support eclipse power requirements. The communications subsystem was still operational, however there was some loss of redundancy. The onboard meteorological instruments are extremely degraded. In particular the VISSR is inoperable (neither scan drive functions due to failed encoder lamps). The three SEM instruments are semi-operational and the x-ray long sun channel is unreliable. (GOES 1993 Yearly Report, 1994, pp 3-4)

(3) GOES 3. The GOES 3 satellite was launched on June 16, 1978 by a Delta from Cape Canaveral. Initially, this satellite was positioned at 130 degrees west longitude. Essentially, GOES 3 was the replacement platform for the GOES 1. This satellite has operated in a degraded state for most of its operational life. The satellite's VISSR operated in a partially mission capable state from September 1979 to May 1980 when it failed completely. After 1980 GOES 3 had some use for various meteorological and scientific activities, includ-

ing use of the VHF downlink for the U.S. Air Force's Faraday Rotation experiment. In 1990 GOES 3 was repositioned to 176 degrees west longitude under an agreement with NASA and the Department of Commerce's National Telecommunications and Information Administration for use by over twenty-two Pacific island nations through the Pan-Pacific Educational and Cultural Experiments by Satellite (Peacesat) project. This project, established in 1971, provides two-way voice and data services to over 100 small earth stations in that region. (Jane's Space Directory, 1994, p. 451)

As of January 1994, GOES 3 was positioned at 175 degrees west longitude with an inclination of 9.8 degrees. Like GOES 2 the satellite batteries are unable to support eclipse power requirements. The communications subsystem was still operational with both S-band transponders still capable of providing operational support to the Peacesat project. The onboard meteorological instruments are extremely degraded. GOES 3 has the same problem with its VISSR as GOES 2. The VISSR is inoperable (neither scan drive functions due to failed encoder lamps). The three SEM instruments are still operational, however they were turned off for all of 1993. (GOES 1993 Yearly Report, 1994, pp 4-5)

(4) GOES 4. The GOES 4 satellite was launched on September 9, 1980 and initially positioned at 135 degrees west longitude. The imaging system of this satellite completely failed during 1982. After this loss the satellite was utilized primarily as an on-orbit standby transponder for data relay. In May 1985, GOES 4 was loaned to the European Space Agency (ESA) as a temporary substitute for Meteosat 1. To meet the requirements for this task, GOES 4 had to be moved to a position over the Atlantic Ocean (43 degrees west longitude) by June 1985. NOAA operated the spacecraft for ESA during this arrangement because ESA's ground equipment was incompatible

with the satellite. In August 1985, the spacecraft's data collection capabilities were inundated by unidentified UHF interference at 401.9 MHz as it was being moved back to its original position. After this malfunction, GOES 4 was returned to 43 degrees west longitude where it remained until November 1988 when it was boosted out of GEO and finally deactivated. (Jane's Space Directory, 1994, p. 451)

(5) GOES 5. The GOES 5 satellite was launched on May 22, 1981 and initially positioned at 75 degrees west longitude. This satellite was used to monitor the weather and storm fronts in the Eastern United States. The imaging system of this satellite failed on July 29, 1984 after two tungsten filament lamps malfunctioned on the device. After this loss the satellite was utilized primarily as an on-orbit transponder for data relay for the GOES 6 and GOES 7. In July 1990, GOES 5 was finally deactivated and is currently drifting back and forth between 145 degrees west longitude and 60 degrees west longitude. It is currently projected that this satellite will eventually settle at 105 degrees west longitude. (Jane's Space Directory, 1994, p. 451)

(6) GOES 6. The GOES 6 satellite was launched on April 28, 1983 and initially positioned at 135 degrees west longitude. This satellite was used to monitor the weather and storm fronts in the Western United States. When GOES 5 failed this satellite had to be alternately repositioned to 98 degrees west longitude to provide expanded coverage of the United States and 108 degrees west longitude to monitor for winter storms in the Pacific Northwest. GOES 6 essentially did the work of two geostationary satellites from 1984 to 1987. By 1989, all four of its encoder lamps had burned out and the satellite was reduced to data relay functions. From 1989 to 1992 it was used extensively in support of the non-imaging functions (WEFAX, DCS, and SEM) of the west spacecraft. In

1992 GOES 6 had depleted the last of its hydrazine supply and began to drift in a pattern similar to the GOES 5. (Jane's Space Directory, 1994, p. 451)

As of January 1994, GOES 6 was in free drift near 84 degrees west longitude with an inclination of 5.3 degrees. Despite its degraded state, GOES 6 continued to provide SEM data throughout all of 1993. The communications subsystem is currently still operational with full redundancy available. The satellite's imaging equipment (VAS) is inoperative due to failed scan drive encoder lamps. However, the SEM remains fully operational. (GOES 1993 Yearly Report, 1994, pp 5-6)

b. GOES Meteorological Instruments

GOES satellites carry three primary meteorological instruments: an imaging device, a data collection system which is identical to the that of the polar orbiting NOAA spacecraft, and a space environment monitor. For the earlier GOES satellites (GOES 1-3) the imaging function of the satellite was accomplished via the use of a visible and infrared spin scan radiometer (VISSR). GOES 4-8 utilize a visible and infrared spin scan radiometer atmospheric sounder (VAS) to accomplish this mission area. (GOES GH Handbook, 1986, p. 1)

(1) VISSR. The VISSR imaging subsystem images the Earth in the reflected visible light spectrum and in one spectral band of the thermal infrared region of the electromagnetic spectrum. The ground resolution of this instrument is 1 km in the visible and 7 km in the infrared. This data is downlinked to a special processing station in Wallops Island, Virginia, where it is reformatted, calibrated, and gridded. This processed data is then immediately uplinked to the transponders of satellites in the GOES system. The uplinked data is termed stretched VISSR data (SVISSR) and is available to users possessing a ground terminal capable of receiving and

demodulating the digital 1.7 GHz signal. (Davidoff, 1992, p. 14-3)

(2) VAS. The VAS is a more sophisticated version of the VISSR and is the imager that has been employed on GOES spacecraft since 1980. The VAS has three different operational modes; the VISSR mode, multispectral imaging mode, and Dwell Sounding mode. These functions gives the VAS additional capabilities over the basic VISSR. (GOES GH Handbook, 1986, pp. 1-10)

In the VISSR mode the VAS scans the Earth and collects images in the reflected visible light band and in the thermal infrared band (essentially operates as a VISSR). An image gathered in this mode consists of approximately 1,821 scan lines and requires less than twenty minutes to complete. It is important to note that the amount of power consumed in the VISSR mode of operation is much less than in the other modes because the subsystem processor is not used. (GOES GH Handbook, 1986, pp. 1-10)

In the multispectral imaging mode the VAS is processor controlled and can produce images in as many as five different infrared spectral bands. This represents a five-fold increase over the infrared imaging capability of the VISSR which was used on the GOES 1-3 satellites. This mode also allows for the production of two, three, or four separate images in the same amount of time that only one image could be produced via the VISSR. (GOES GH Handbook, 1986, p. 10)

In the dwell sounding mode the processor controlled VAS has the capability to image in all twelve infrared spectral bands as well as in the visible spectrum. The scan mirror is programmable and controlled by the processor which allows for multiple scans of the same latitude on Earth. This allows for extremely accurate temperature soundings which can be used to calculate atmospheric temperature

profiles over a given geographic region. Table 23 lists the technical characteristics of the VAS used by GOES spacecraft. (GOES GH Handbook, 1986, pp. 1-10)

TABLE 23. VAS CHARACTERISTICS

Size	1.5 m (length), 0.65 m (diameter)
Weight	69 kg (scanner), 14 kg (electronics module)
Structural Material	Beryllium
Optics	Ritchey-Chretien System 40.64 cm diameter primary mirror 291 cm focal length, 0.4 obscuration factor 1090 cm effective collecting aperture
Detectors	
Visible Spectrum	8 photomultiplier tubes coupled to focal plane by optical fibers IGFOV: 21x25 μ rad; spectral response 0.55 to 0.75 μ m
IR Spectrum	6 solid state detectors cooled to 90 K 2 HgCdTe; IGFOV: 192 μ rad square; spectral response 6.7-14.7 μ m 2 HgCdTe; IGFOV: 384 μ rad square; spectral response 6.7-14.7 μ m 2 InSb; IGFOV: 384 μ rad square; spectral response 3.9 to 4.5 μ m
Spectral Bands	Selectable filter inserted in IR optical path; 12 filters
Radiative Cooler	Servoed operating temperature -90 K Heat rejection capacity -16 mW; Min. temperature -82K
In-orbit Calibration	
Radiometric	Visible: optical aperture providing sun signal of 50% Earth albedo IR: temperature monitored blackbody, reflected onto detectors
Electronic	IR & visible: precision voltage ramp into individual amplifier chains
Onboard Processor	Selects and controls scan sector size and center position Controls scan mirror and filter wheel

(3) *Space Environment Monitor*. The SEM is utilized for three primary functions: sensing of energetic particles that make up the solar wind and radiation belts around the Earth, the measurement of magnetic field strength and direction adjacent to the satellite, and the assessment of solar x-ray flux. In order to accomplish these diverse tasks the SEM employs three independent subsystems and then correlates the data produced by them. These subsystems are: a magnetometer, a solar x-ray sensor, and an energetic particle sensor. (GOES GH Handbook, 1986, pp. 16-18)

The magnetometer is comprised of two detectors. These detectors are aligned parallel and perpendicular to the spacecraft's spin axis. The collected data from these detectors is processed, encoded, and transmitted to Earth in the form of telemetry data. The data collected from the detector oriented parallel to the vehicle's spin axis measures the magnetic field without further conversion. Data from the other detector must be processed via a phase sensitive device to determine the magnitude and direction angle of the magnetic field relative to the satellite. Table 24 is a listing of the technical parameters of the magnetometer. (GOES GH Handbook, 1986, pp. 1-16)

TABLE 24. MAGNETOMETER CHARACTERISTICS

Function	Monitor magnetic field at orbital attitude
Design	Z-axis parallel and transverse flux gate sensors on 3 ft boom, processing electronics inboard
Ranges	$\pm 50\gamma$ $\pm 100\gamma$ $\pm 200\gamma$ $\pm 400\gamma$ DC field -1200 to +1200 γ
Accuracy	1% or 1γ (whichever is greater)
In-flight calibration	$\pm 2\%$
Thermal control	Electric heater in sensor

The solar x-ray sensor measures the solar x-ray flux emitted from the full visible hemisphere of the sun in two spectral ranges. This is accomplished via the use of ion chamber detectors through a collimator which views the sun with each satellite orbit. The function of the collimator is to screen out energetic electrons and attenuate bremsstrahlung

and other undesired radiation. Additionally, the x-ray sensor has the capability to detect perturbations in the magnetic field. This is important because measurements of the magnetic field contribute to scientific research and improve the prediction of radio propagation. Table 25 is a listing of the technical aspects of the solar x-ray sensor. (GOES GH Handbook, 1986, pp. 1-16)

TABLE 25. SOLAR X-RAY SENSOR CHARACTERISTICS

Function	Provide data on solar X-ray activity to predict solar flares
Design	Collimator, two ion chambers, processing electronics, $\pm 27^\circ$ single axis positioner
Ranges	1 to 8 Å: 10^{-5} to 10^0 erg cm $^{-2}$ sec $^{-1}$ in 4 decades 0.5 to 3 Å: 10^{-6} to 10^{-1} erg cm $^{-2}$ sec $^{-1}$ in 4 decades.
Resolution	< 2% at > 20 x threshold
Field of view	48° azimuth, 22° elevation
In-flight calibration	$\pm 2\%$ overall

The energetic particle sensor is used for measuring the flux of energetic electrons, protons, and alpha particles in the vicinity of the satellite at numerous energy levels. This measurement is made by counting the numbers of impinging particles detected by solid state detectors over a designated period of time. The count is then transmitted to a ground station via spacecraft telemetry. Table 26 is a listing of the technical aspects of the energetic particle sensor. (GOES GH Handbook, 1986, pp. 1-16)

TABLE 26. ENERGETIC PARTICLE SENSOR CHARACTERISTICS

Function	Measure energetic particle flux at orbital altitude
Design	Telescope with 2 detectors and anticoincidence logic, done with 3 detectors, processing electronics, HEPAD
Ranges	Protons: 0.8 to 500 MeV.7 log ranges Alphas: 3.2 to 400 MeV.6 log ranges Electrons: ≥ 2 MeV.1 range HEPAD: $P > 370$ MeV.4 ranges $a > 640$ MeV.2 ranges Single events.5 channels
Resolution	LSB $< 7\%$ of count
Field of View	Telescope 70° (x 360°) Dome 130° (x 360°) HEPAD 68° (x 360°)
In-flight Calibration	Level sensor settings to $\pm 5\%$

c. GOES-Next Generation Program

(1) Overview. The next generation of GOES spacecraft has been termed the GOES-NEXT program. It is comprised of five satellites, GOES I-M. These satellites are being built by Loral Space Systems and will ensure improved geosynchronous Earth coverage into the next century. GOES I (now redesignated GOES 8) was launched on 13 April 1994. The remaining four spacecraft will be launched between 1994 and 2003.

GOES-NEXT satellites carry the same equipment package as previous GOES satellites, however several of the meteorological instruments have been upgraded. In particular, the imaging and sounding functions of the VAS can now be operated simultaneously and independently of each other in GOES-NEXT satellites. In previous GOES spacecraft only one or the other function could be performed by the dual function VAS. Additionally, the VAS on GOES-NEXT satellites has a higher resolution and more channels than its predecessor. A

search and rescue transponder is an added feature to GOES-NEXT satellites. (Bradley, 1989, pp. 1-3)

The satellite bus of GOES-NEXT vehicles is very different from earlier GOES spacecraft. GOES-NEXT satellites are box-shaped with all communications equipment and meteorological sensors physically located on one Earth-facing side. GOES-NEXT satellites also have a different stabilization system than its predecessors. They employ three-axis stabilization with momentum wheels, whereas previous GOES satellites were spin-stabilized. Figures 88 and 89 are illustrations of the GOES and GOES-NEXT satellites. (Bradley, 1989, pp. 1-6)

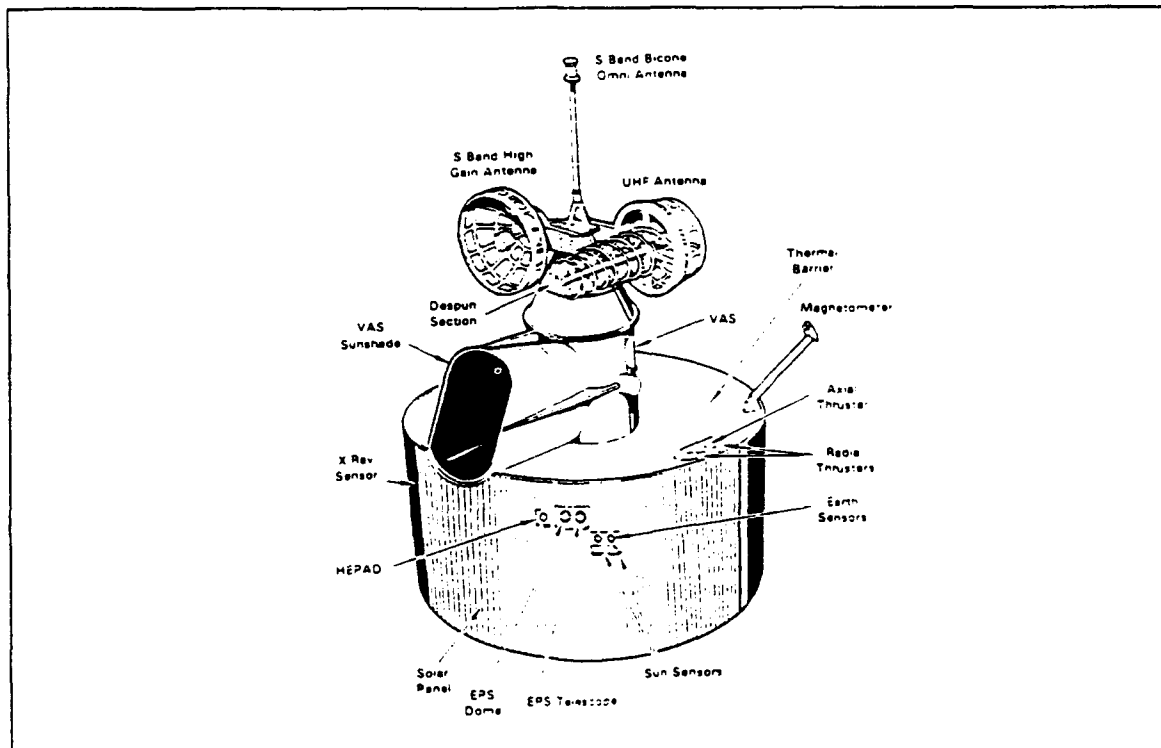


Figure 88 GOES Satellite

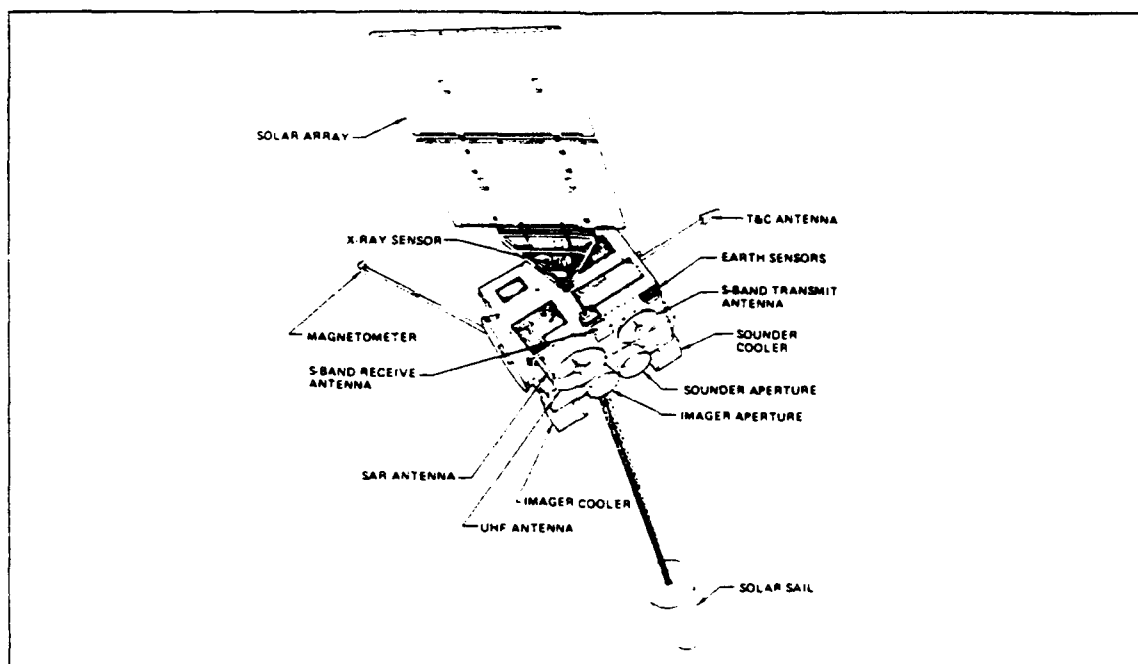


Figure 89 GOES-NEXT Satellite

(2) *Orbital Parameters.* The GOES-NEXT system will essentially transplant the current GOES system. This future system will normally be comprised of two operational GOES-NEXT satellites maintained at synchronous altitude, 19,312 nm above the Earth's surface. When established in orbit, these satellites will be designated as GOES East and GOES West. The GOES East satellite will be positioned over the equator at 75 degrees west longitude and the GOES West satellite will be located at 135 degrees west longitude. These satellites will have identical capabilities and will also possess the same on-orbit maneuvering ability as prior GOES satellites. (GOES GH Handbook, 1986, pp. 1-7)

3. The Current Operational GOES System

a. GOES 7 (GOES H)

The GOES 7 was launched on February 26, 1987 by a Delta from Cape Canaveral. Initially, this satellite was positioned at 80 degrees west longitude to function as the GOES-East spacecraft. In the winter of 1989 GOES 7 was repositioned to 98 degrees west longitude when the imaging system of the GOES 6 failed. In the spring of 1989 GOES 7 was maneuvered to 108 degrees west longitude for hurricane observation in the Atlantic. (Jane's Space Directory, 1994, pp. 448-449)

The GOES 7 is the last of the Hughes-designed spin-stabilized GOES satellites. The meteorological instrument package carried on-board this satellite is identical to that carried by its predecessors except for the COSPAS/SARSAT relay package which was added to the equipment loadout. The VAS system of GOES 7 can image in six infrared channels and 1 visible channel. The best image resolution is obtained from the visible channel at 900 meters. At infrared, there are two channels set between 3.7-7.3 um, two channels set between 6.7-14.7 um, and two channels set between 7.7-14.7 um. The best resolution that can be achieved at infrared is 6.9 kilometers. (Jane's Space Directory, 1994, pp. 448-449)

The field of view of the satellite's imager is 20 degrees E-W by 20 degrees N-S when the full Earth disk is centered. The time required to center the image on the VAS is approximately 20 minutes. Additionally, GOES 7 has the capability to provide two full Earth disk images each hour. The VAS is programmed to begin a new image at 30 minute intervals (on the hour and half hour). The ten minute intervals between images are used for ranging and WEFAX transmissions. The VAS onboard GOES 7 can also be programmed to a limited coverage mode during select periods set aside for

experimental services. In this mode specific latitudinal bands of varying N-S dimensions can be imaged for gathering data necessary for vertical atmospheric temperature profiles. (GOES GH Handbook, 1986, pp. 5-6)

GOES 7 is currently designated as the PRIME spacecraft in the GOES system. As of January 1994 it was located at 112 degrees west longitude with an inclination of 1.2 degrees. Throughout 1993, GOES 7 provided VAS imaging, VAS sounding data, East WEFAX, SEM data, and SAR support. Currently, all meteorological instruments onboard the satellite are fully operational except for the SEM. The SEM is semi-operational due to several channel failures in the magnetometer. The one major problem of GOES 7 is that it is running out of fuel. In January 1994 the spacecraft had only 20.7 pounds of hydrazine remaining. To conserve fuel, North-South stationkeeping for the satellite was terminated in June 1992. This is the reason for the inclined orbit of GOES 7. If GOES 7 is not maneuvered for stationkeeping this inclination will increase at the rate of 0.9 degrees per year. (GOES 1993 Yearly Report, 1994, pp. 6-7)

b. GOES 8 (GOES I)

GOES 8 is the first of the Loral-designed GOES NEXT generation satellites. It was successfully launched on April 13, 1994 via an Atlas I from Cape Canaveral. This satellite is currently located at 75 degrees west longitude and will function as the GOES-East spacecraft upon completion of orbital testing. GOES 8 carries the standard GOES NEXT instrument package described in the GOES NEXT overview section and has a design life of five years. (Jane's Space Directory, 1994, p. 449)

The spacecraft is configured as a compact, six-sided satellite bus which carries the meteorological instrument package, a continuous drive solar array attached to the south panel, a solar sail mounted off the north panel to offset solar pressure torque, a telemetry and command (T&C) antenna boom-mounted on the east panel for full omnidirectional coverage, and the SEM magnetometer on a boom opposite of the Earth-facing side. Additionally, all of the communication antennas, except the T&C, are fixed to the Earth-facing panel to ensure unobstructed coverage. The GOES 8 employs the solar sail and boom to balance the solar array. The solar array is comprised of two panels attached to a continuously rotating drive assembly. (Bradley, 1989, pp. 1-3) The primary feature of the GOES 8 is the improved VAS imager and atmospheric sounder. The imager is essentially comprised of five channels, four in the infrared band (3.8, 6.7, 10.5, and 12.0 μm) and one in the visible. The maximum imaging area for the GOES 8 measures 19 degrees in the N-S direction and 23 degrees in the E-W direction. The atmospheric sounder is composed of nineteen different channels, one in the visible and eighteen infrared channels. Both instruments sample the Earth's radiance via an independent two-axis scan system with an accompanying telescope. The most innovative facet of this upgraded VAS is that scan control and data collection for the two instruments are independent of one another. (Bradley, 1989, pp. 1-1 - 2-1)

c. System Outlook

Data from GOES satellites give meteorologists the unique ability to monitor and track hurricanes, tropical storms, and severe storm fronts from their original development stages through their final dissipation. At present, this is the only method available for constant surveillance of weather systems. Water droplets in thunderstorms must reach a certain size before they can be detected by radar. Because of

this, thunderstorms can be detected by GOES imagery long before a radar system can pinpoint them. GOES imagery also provides meteorologists with a method for estimating the amount of rainfall that clouds will produce. This is accomplished by studying the shape and texture of the clouds captured in GOES pictures. Rainfall estimates are extremely important as they provide insights as to where flash flooding may take place. (Hill, 1992, pp. 61-62)

Currently, the GOES 7 enables the U.S. weather service to pinpoint the location of a storm system within 6.2 to 12.4 miles. GOES-NEXT satellites will be able to geolocate storms to within 1.2 miles. (Werner, 24-30 Jan 1994, p. 22)

Although the GOES 7 is running out of fuel at 112 degrees west longitude, its meteorological instrument package is still in excellent shape. This is a big plus for the near future because that equipment can be used to augment the capabilities of the GOES-NEXT system by providing an in-orbit spare capacity. GOES 8 is currently involved with a six month checkout. It is slated to become operational in October 1994. The launch schedule for the four other GOES-NEXT satellites is tentatively slated as follows: GOES J (GOES 9)-April 1995, GOES K (GOES 10)-1998, GOES L (GOES 11)-1999, GOES M (GOES 12)-2003. (Werner, 24-30 Jan 1994, p. 22)

VII. SUMMARY AND CONCLUSIONS

A. SUMMARY

This study provided an up-to-date review of domestic commercial satellites located in geosynchronous Earth orbit. An extensive system summary catalogued the technical aspects, performance parameters, and operational capabilities for each of these space-borne assets. Additionally, the NOAA and GOES satellite systems providing meteorological data to NOAA were examined in detail with an emphasis on the capabilities and status of the current operational system.

There are many publications currently available which provide a brief synopsis of international and domestic satellites. These include various space directories (summarizing numerous spacecraft) and technical overviews from the individual commercial vendors (detailing specific satellites). Many of these publications were reviewed during the course of this project to provide insights into the capabilities of the satellites investigated. The scope of this thesis was to provide a single source, comprehensive examination of the current inventory of U.S. commercial communications and meteorological spacecraft.

It is hoped that this compendium, highlighting the technical aspects of domestic commercial satellites in geosynchronous Earth orbit, will prove to be a valuable tool to institutions (military, civil, and commercial) tasked with developing cost-risk analyses of purchasing services from satellite systems. Additionally, individuals requiring technical data on a specific satellite will have a ready reference for the key design features of a particular system.

B. CONCLUSIONS

The "Teal Group Mission Model", an annual report which forecasts future satellite launches, projects that approximately 792 new satellite payloads will be placed in orbit by the year 2002. The mission area breakdown is as follows: 525 commercial communications satellites, 100 military satellites, 61 scientific satellites, 45 Earth observation satellites, and 16 experimental satellites. A significant number of the commercial communications satellites will be small LEO communications satellites with a mass of less than 700 kilograms in orbit. This represents the growing trend of emerging communications vendors operating large constellations of LEO communications satellites. (Caceres, 1993, p. 26)

Over the course of the next eight years, communications traffic growth forecasts indicate the need for greater communications capacity than currently exists via space-borne assets. Satellite communication systems will continue to expand in response to these market conditions. Domestic and international entrepreneurial telecommunications providers are currently entering the communication satellite industry at unprecedented levels. This will cause the industry to become more competitive in terms of increasing the flexibility, reliability, and capacity of future satellite systems, while also providing cost effective services to the consumer.

As government regulatory measures relax in the commercialization of space, there will be a growing number of enterprises in fields ranging from remote sensing to space-based processing. In the next eight years a variety of domestic commercial remote sensing, Earth observation, and navigational satellites will be placed in orbit, thus breaking the communication satellite industry's dominance of space-based commercial enterprises.

GLOSSARY (OF TERMS)

Aperture: A cross sectional area of the antenna which is exposed to the satellite signal.

Attitude Control: The orientation of the satellite in relationship to the Earth and Sun.

Bandwidth: A measure of spectrum (frequency) use or capacity.

Beacon: A low-power carrier transmitted by a satellite which supplies the controlling engineers on the ground with a means of monitoring telemetry data, tracking the satellite, or conducting propagation experiments.

Beamwidth: The angle of conical shape of the beam the antenna projects. Large antennas have narrower beamwidths and can deliver higher levels of power.

C-Band: The band of frequencies between 4 and 8 GHz, with the 4 through 6 GHz frequencies being used primarily for satellite communications.

Cable Television (CATV): Most of the independent CATV companies have long since been purchased by national organizations that own multiple cable systems in rural and urban areas.

Code Division Multiple Access (CDMA): Process that shares time and frequency among many users by assigning to each an

orthogonal code patten that uniquely identifies each user's signal.

Channel: A frequency band in which a specific broadcast signal is transmitted. Channel frequencies are specified in the United States by the Federal Communications Commission (FCC). Television signals require a six megahertz frequency band to carry all of the necessary information.

Circular Polarization: This is a rotating corkscrew-like propagation pattern, which is commonly used by Intelsat satellites. Some satellites are capable of transmitting both right-hand rotating and left-hand rotating signals simultaneously on the same frequency, thereby doubling their capacity.

Co-location: Ability of multiple satellites to share the same approximate geostationary orbital assignment, usually due to the fact that different frequency bands are used.

Companding: A noise reduction technique which applies single compression at the transmitter and complementary expansion at the receiver.

CONUS: Contiguous United States, that is all of the states in the United States except for Alaska and Hawaii.

Demand Assigned Multiple Access (DAMA): A highly efficient means of instantaneously assigning telephony channels in a transponder according to immediate traffic demands.

Direct Broadcast Satellite (DBS): A service which uses satellites to broadcast multiple channels of television programming directly to home-mounted small dish antennas.

Downconverter: Converts the uplink signals from the uplink frequency range to the more readily used baseband or intermediate frequency range.

Downlink: The frequency range which is utilized by the satellite to retransmit signals down to Earth for reception.

Earth Station: The combination of antenna, low-noise amplifier (LNA), downconverter, and receiver electronics used to receive a signal transmitted by a satellite.

Eclipse: The period in which a satellite passes through the shadow cast by the Earth.

Edge of Coverage: Limit of a satellite's defined service coverage area, frequently defined as being 3 dB down from the signal level at beam center.

Equatorial Orbit: An orbit with a plane parallel to the Earth's equator where the inclination is 0 degrees.

Equivalent Isotropic Radiated Power (EIRP): Measure of the power radiated by an antenna in the direction of a receiver expressed as the equivalent power that would have to be radiated uniformly in all directions.

Footprint: A diagram of the satellite signal strength showing the EIRP contours of equal signal strength as they cover the Earth's surface.

Frequency Division Multiple Access (FDMA): The use of multiple carriers within the same transponder where each uplink has been assigned a frequency slot and bandwidth. This process shares a spectrum of frequencies among many users by assigning to each a subset of frequencies in which to transmit signals.

Frequency Reuse: A technique which maximizes the capacity of a communications satellite through the use of spatially isolated beam antennas and/or the use of dual polarities.

Geostationary Satellite: A satellite with an equatorial orbit 22,300 miles (36,000 km) above the Earth. The satellite revolves about the Earth in the same direction and with the same period as that of the Earth's rotation and thus appears stationary when viewed from the Earth.

Hybrid Satellite: A satellite which operates at both C-band and Ku-band.

IEEE: Institute of Electrical and Electronic Engineers, an international engineering society.

Inclination: The angle between the orbital plane of a satellite and the equatorial plane of the Earth.

Ka-Band: The band of frequencies ranging from 18 to 31 GHz.

Ku-Band: The band of frequencies ranging from 10.9 to 17 GHz.

L-Band: The band of frequencies ranging from 0.5 to 1.5 GHz. Also used to refer to the 950 to 1450 MHz band used for mobile communications.

Linear Polarization: A technique used by satellite engineers where the electric (E) field is propagated vertically or horizontally.

Master Antenna Television (MATV): An antenna system that serves a concentration of television sets such as in apartment buildings, hotels, or motels.

Multiple Access: The ability of more than one user to have access to a given transponder.

Multiplexing: Communications techniques which allow a number of simultaneous transmissions over a single circuit.

Pay-Per-View: A system of television services in which scrambled signals are distributed and then unscrambled at the homeowner's set with a decoder that responds upon payment of a fee for each program.

Receiver Sensitivity: Expressed in dBm, this parameter indicates how much power the detector must receive in order to achieve a specific base band performance, such as a specific bit-error rate or signal to noise ratio.

Single Channel Per Carrier (SCPC): A special high power audio service used to transmit a large number of signals over a single satellite transponder. Although fewer channels are handled, each signal is transmitted at a greater power level, thereby allowing much smaller receive-only antennas to be used at the earth station.

Satellite Master Antenna System (SMATV): The adding of an earth station to a MATV system to receive satellite programs.

Solid State Power Amplifier (SSPA): A VSLI solid state device that is gradually replacing traveling wave tube amplifiers (TWTAs) in satellite communications because of their lighter weight and greater reliability.

Spread-Spectrum Technique: A means of spreading a transmitted signal over extra bandwidth to permit redundancy in transmission and reception without interference from other signals using similar frequencies.

Spot Beam: A highly focused antenna pattern sent to a limited geographical area.

Spread Spectrum: The transmission of a signal over a very wide bandwidth. This technique produces low levels of interference between users and provides a reasonable level of security, in that the signals appear to be random noise to unauthorized earth stations.

Station Keeping: Orbital satellite adjustments conducted to maintain a particular orbital assignment.

Three Axis Stabilization: Type of spacecraft stabilization in which the body maintains a fixed attitude relative to the orbital track and the Earth's surface through the use of one or more momentum wheels.

Time Division Multiple Access (TDMA): Process that shares the time domain of a single carrier among many users by assigning to each user time intervals in which to transmit signal bursts.

Transponder: A microwave receiver, amplifier, and transmitter in a satellite which amplifies and changes the frequency of a signal from an earth station and retransmits it to Earth.

Television Receive Only (TVRO): These receive only terminals, which are typically small, privately owned systems, use reflectors and associated electronics equipment to receive and process television and audio communications for home use via satellite.

Very Small Aperture Terminal (VSAT): Small earth stations used in satellite communications, in the 1.2 to 2.4 meter range.

Waveguide: A metallic microwave conductor, typically rectangular in shape, used to carry microwave signals to and from antenna feeder networks.

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