# Satellite Communications

## Advances in electronic technology have contributed to growth in satellite communications.

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*I invite all nations to participate in a communications satellite system, in the interest of world peace and closer brotherhood among peoples of the world.*—JOHN F. KENNEDY, 24 July 1961

With these words, President Kennedy, in the early months of his Administration, took a considered step to accelerate the pace of the nation's space program. His words, contained in a "Policy Statement on Communications Satellites" (*1*), set in motion a train of events which would not only help the United States to regain space leadership but would benefit many nations in improved technology and commerce and provide a new means for international cooperation. His statement recognized the potential value of earth-orbiting platforms to provide communications services, established government policy to coordinate activities and carry out research and development, called for implementation by the private sector, and invited other nations to join in the effort.

President Kennedy's bold and prescient statement was based largely on prediction and promise but very little on the results of development or demonstrated technology. Some 16 years earlier, in 1945, Arthur Clarke had first foreseen the use of space stations in geostationary orbit for communicating to points on earth (*2*). Then Pierce of Bell Laboratories carried out a system analysis in 1954 (*3*). And in 1957 the first Sputnik demonstrated the possibility of the use of satellites for many applications. But by 1961, at the time of the Kennedy statement, the only relevant communications demonstrations had been the short-lived Courier IB satellite in 1000-kilometer orbit and the Echo I balloon in a 1600-km orbit, the former demonstrating active "store and forward" teletype transmission and the latter passive reflection of powerful microwave signals from one earth station to another. The effective demonstration of active microwave communications (Project Telstar and Project Relay) were still a year in the future. The first launch to a geostationary orbit (Project Syncom) would be made 2 years later (*4*).

One year after Kennedy's statement, the U.S. Congress passed the Communications Satellite Act of 1962 (*5*), which authorized the formation of a private corporation to carry out this country's interest in commercial satellite communications. As a consequence, the Communications Satellite Corporation (or COMSAT) was formed in 1963. Then in 1964, COMSAT joined together with communications entities of other nations to form an international body known as INTELSAT, the International Telecommunications Satellite Organization, to provide satellite communications on a global basis. In 1965 the world's first commercial satellite, INTELSAT I, known as "Early Bird," was launched and operational telecommunications service along a single path between the United States and Europe was inaugurated.

### Operational Progress

Today the INTELSAT system spans the globe. Early Bird has been supplanted by eight larger, more powerful satellites operating with 150 earth stations. The system shown in Fig. 1 provides communications along 500 paths located in 80 countries. The system carries 8000 full-time simultaneous two-way telephone conversations, telex, data, and facsimile traffic, plus television and leased transponders.

The growth rate of the INTELSAT system during its first decade of operation (Fig. 2) has been large. Growth stemmed not only from improvement in the existing service over previous means such as radio and cable but from the offering of entirely new services such as global television and wide-band data and to areas not previously served at all by existing means.

The reliability of system operations has increased over the past years, equaling or surpassing that of other modes. Individual links in the system operate at a reliability of 99.99 percent or more, with the total system reliability exceeding 99.9 percent (*6*).

### Technological Progress

In order for the operational capacity, quality, and reliability of the system to advance so rapidly, it was essential not only for the need to exist but for the technology to be available. The technologies necessary for satellite communications did indeed advance at a rapid rate.

In contrast to the case for many fields of aerospace and electronics system development in which 7 to 10 years frequently elapse from the development of a concept to the full deployment of an operational system, the progress in INTELSAT, which has seen the development of four generations of satellites in a decade, seems phenomenal. The Early Bird satellite, first of the series (Fig. 3), weighed only 38 kilograms. With limited power and bandwidth, its communications capacity could sustain about 240 two-way telephone circuits.

Great improvements were made in the three succeeding generations of satellites so that the INTELSAT IV series (*7*) currently in use represents an order-of-magnitude improvement in most operating parameters, for example, prime power and bandwidth, and thus in operating capacity. The most effective technique for increasing capacity through the first four generations of INTELSAT satellites came from increased effective radiated power from stabilized earth-pointing antennas. As shown in Fig. 4, the per circuit-year cost decreased by a factor of 30 in a decade.

The next generation of satellites, INTELSAT V, is now under contract. The first of this series, to be launched in 1979 (Fig. 5), will be the first body-stabilized spacecraft in the INTELSAT series (*8*). Its capacity will be greatly increased over that of previous generations, in part because of the increased primary power available and to a larger extent because of the increased communications band-

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width utilized. The INTELSAT V satellite will use not only the 6/4-gigahertz frequency band (6 Ghz is the receive band and 4 Ghz is the transmit band) used in earlier INTELSAT satellites but will inaugurate use of an additional 500-megahertz bandwidth available in the 14/11-Ghz band.

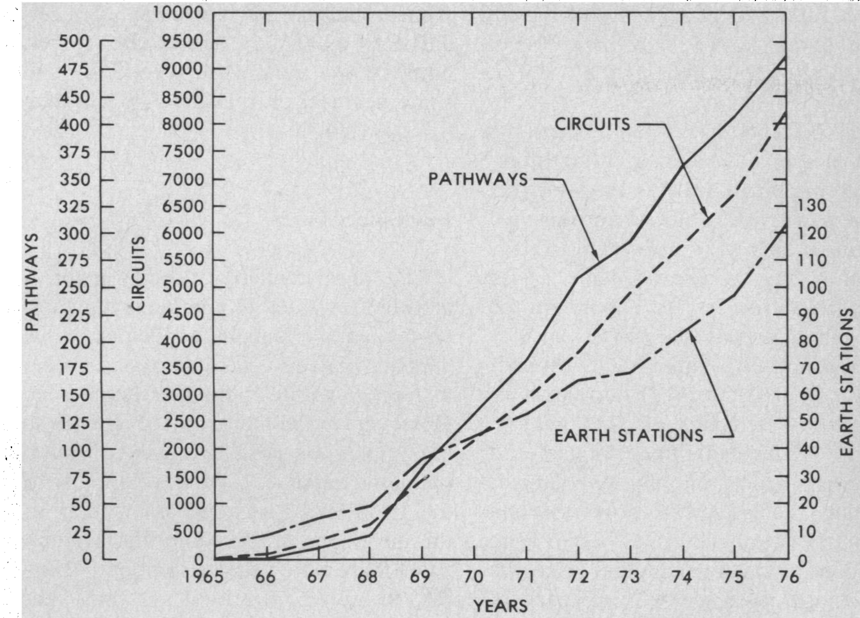
The distinguishing features of the INTELSAT V satellite are shown in Fig. 5. The body of the satellite, stabilized along three axes in space, is used as a platform on which to mount the large sun-oriented solar array and the complex of earth-oriented antennas. The INTELSAT V satellite is expected to carry projected global traffic through the mid-1980's. In this period the Space Shuttle may be introduced for launching satellites of all types including some of the INTELSAT V series.

Earth stations in INTELSAT are owned and operated by the individual participating countries. Since the purpose of the satellite system is to interconnect terrestrial systems of the various countries, the number of earth stations per country is small. Some countries operate in two ocean areas, and some of those with very large traffic streams have established diversity paths. Moreover, some islands or geographically separate areas require their own earth stations. Thus, the United States, for example, has two East Coast stations, two West Coast stations, and three island stations (in Puerto Rico, Hawaii, and Guam).

The first earth stations to enter the INTELSAT system were those built originally to operate experimentally with Telstar and Relay. With these small satellites and with Early Bird, very powerful and thus expensive earth stations with large antennas were required. Through its first 10 years, INTELSAT standardized on the use of such large antennas, generally with apertures of 30 meters, coupled with supercooled parametric amplifiers, to yield a ratio of antenna gain to system noise temperature ($G/T$) of 41.7 decibels per degree Kelvin (Fig. 6). Improvements in earth stations through the decade included the introduction of very-wide-band system elements such as high-power (up to 12 kilowatt) traveling wave tube (TWT) amplifiers and low-noise parametric amplifiers (capable of operation to 55°K without cryogenics). Cassegrainian antenna systems have been introduced with shaped surface reflectors yielding high gain-to-aperture efficiency. Other changes have been made so that today all amplification and signal-processing circuits (except the high-power amplifier) are based on the use of solid-state devices.

As the power of the satellites and the number of earth stations in the system increased, it became clear that for many applications smaller earth stations would be both suitable and cost-effective. In 1976, therefore, INTELSAT adopted a second earth station standard, smaller, less expensive, and tending to new sys-

Fig. 1. The INTELSAT system. The present global satellite communications system consists of eight satellites in orbit, four operational plus four spare satellites connecting 150 earth stations located in 80 countries over 500 paths.



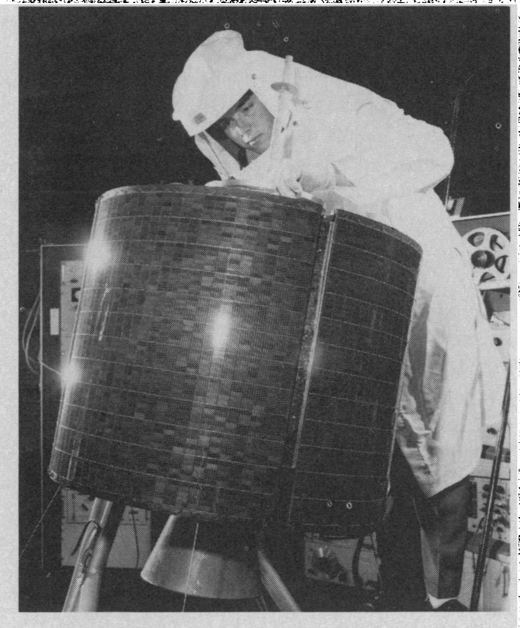
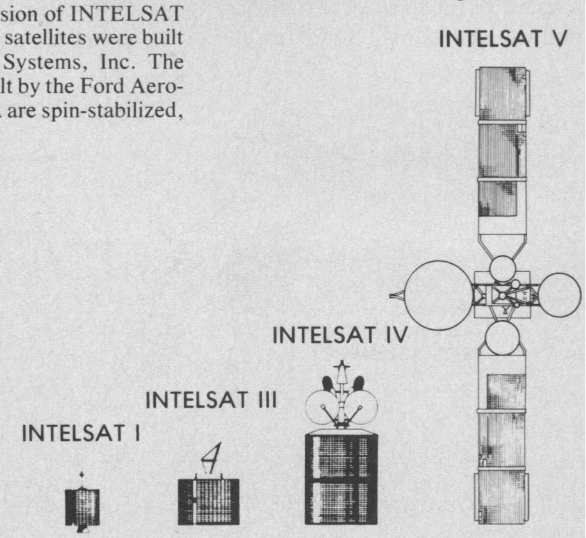



Fig. 2 (top left). Growth of the INTELSAT system. The number of earth stations, the communications paths connecting earth stations, and the traffic over these paths have each increased rapidly over the past decade. In many years each of these indexes of system growth increased by more than 50 percent. Fig. 3 (top right). The Early Bird satellite. Only one of these satellites was launched to provide initial transatlantic service. Early Bird proved the feasibility of the use of the geostationary orbit for commercial satellite communications. (Photo courtesy of Hughes Aircraft Company, Culver City, California) Fig. 4 (bottom). Technological progress in INTELSAT satellites. This table demonstrates the rapid technological progress in the series of INTELSAT satellites. Data are not shown for INTELSAT II, which saw service starting in 1967 with minor improvements over INTELSAT I, and INTELSAT IV-A, an improved version of INTELSAT IV, first launched in 1975 and currently in use. The INTELSAT I, II, IV, and IV-A satellites were built by Hughes Aircraft Company; INTELSAT III satellites were built by TRW Systems, Inc. The INTELSAT V satellite, now under construction for first launch in 1979, is being built by the Ford Aerospace and Communications Corporation. The INTELSAT satellites I through IV-A are spin-stabilized, whereas the INTELSAT V satellite will be body-stabilized along three axes.

tem applications. The new standard requires an aperture of about 11 m to provide a $G/T$ of 31.7 db/°K with room-temperature parametric amplifiers. These stations are expected to be used widely in the INTELSAT system in areas with low-to-moderate traffic requirements. They will be particularly useful to inaugurate service to new areas, to provide service to second ocean regions, to furnish diversity routing, and also to provide domestic service.

## Organizational and Economic Progress

Perhaps the most remarkable aspect of the global system is the institutional arrangements that make it possible. The INTELSAT system is an organization of 95 countries, all parties to an international agreement, equivalent to a treaty. The operating participants of INTELSAT are telecommunications entities in those countries—various government agencies, government-owned corporations, and private firms. The INTELSAT system carries on its activities through an international board of governors, a number of ad hoc and standing committees, a director-general with a full-time international staff, and a man-




| | INTELSAT I | INTELSAT III | INTELSAT IV | INTELSAT V |
|---|---|---|---|---|
| YEAR OF FIRST LAUNCH | 1965 | 1968 | 1971 | 1979 |
| PRIME CONTRACTOR | HUGHES | TRW | HUGHES | FORD AEROSPACE |
| DIMENSIONS | | | | |
| DIAMETER (m) | 0.72 | 1.42 | 2.38 | 2.0 |
| HEIGHT (m) | 0.60 | 1.04 | 5.28 | 15.7 |
| IN-ORBIT MASS (kg) | 38 | 152 | 700 | 967 |
| LAUNCH VEHICLE | THOR - DELTA | | ATLAS - CENTAUR | |
| PRIMARY POWER (WATTS) | 40 | 120 | 400 | 1200 |
| TOTAL BANDWIDTH (Mhz) | 50 | 500 | 500 | 2300 |
| CAPACITY (TELEPHONE CIRCUITS) | 240 | 1200 | 4000 | 12000 |
| DESIGN LIFETIME (YRS) | 1.5 | 5 | 7 | 7 |
| COST/CIRCUIT YEAR ($) | 32500 | 2000 | 1200 | 800 |

agement services contractor, a U.S. corporation (COMSAT).

One might doubt that such a complex international organization would work at all. It is truly remarkable that it works effectively and efficiently, and profitably too. As a technological organization it has made substantial progress in engineering development; as an operating entity it provides a reliable global telecommunications service with the capacity to operate effectively with national and bilateral systems; and as a commercial organization it has managed its affairs prudently and profitably.

The 11 original members of INTELSAT have grown to 95. The members and participants include nations of every political stripe and economic system. It is interesting to contemplate the diverse cultures tied together through a web of electromagnetic links. For example, one U.S. station at Etam, West Virginia, connects directly through an Atlantic INTELSAT IV-A satellite to 31 other earth stations located in such geographically and politically diverse locations as Asadābād, Iran; Cairo, Egypt; Cheia, Rumania; Lurín, Peru; Emeq Ha'ela, Israel; Lvov, U.S.S.R.; Nsele, Zaire; Pretoria, South Africa; Sintra, Portugal; and Tanum, Sweden.

The INTELSAT system keeps its books in a manner similar to any commercial organization (9). In principle, members of INTELSAT (countries) own investment shares in proportion to their current usage of the system. These shares range from 0.05 to 31 percent, the U.S. share. During its 12-year history (1965 through 1976), the total investment has been $650 million. With current annual operating revenues of $140 million, INTELSAT meets its financial goal of a 14 percent return on invested capital. Through technological progress and economies of scale, circuit charges have undergone a steady reduction from the unit charge (per half-circuit-year) of $32,000 in 1965 to $7,380 in 1977.

The total investment in all the earth stations of the network, owned not by the INTELSAT organization but by individual countries, is approximately that of the space segment, about $750 million. Cost analysis has indicated that the total annual half-circuit costs in the INTELSAT system, including earth station amortization and operating expenses and space segment charges, may be less than $10,000 (*10*).

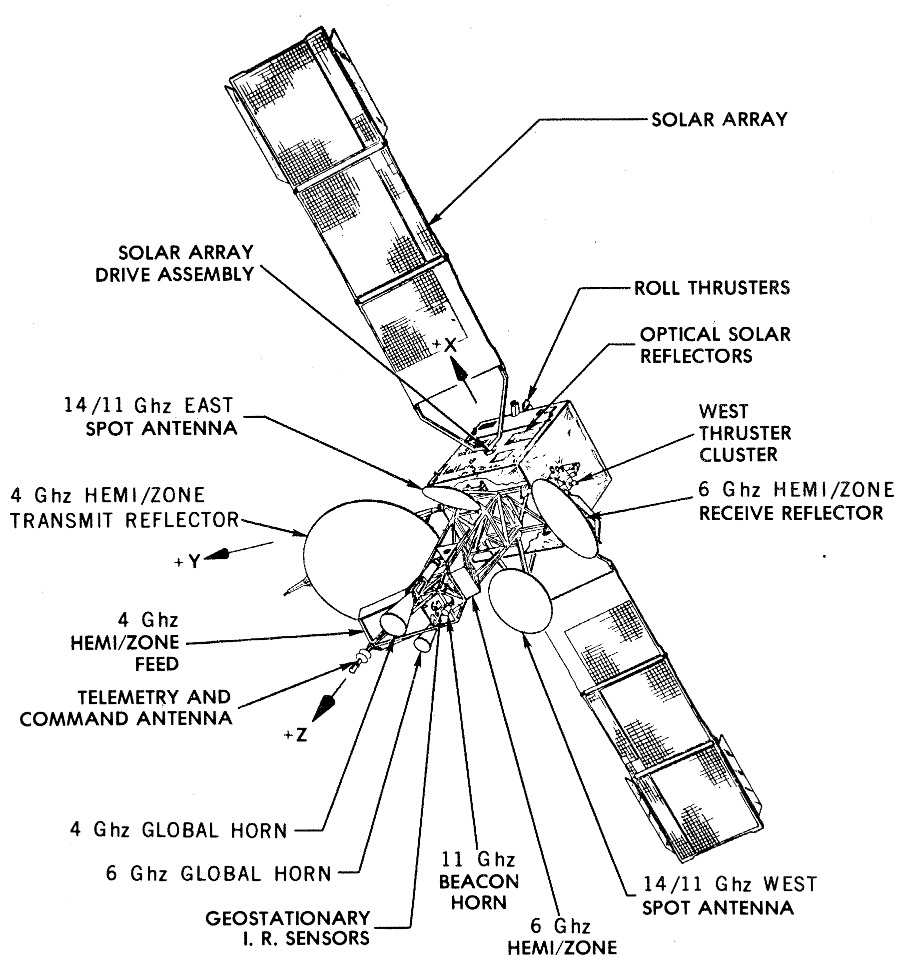



Fig. 5. The INTELSAT V satellite. The next-generation INTELSAT satellite will be body-stabilized. Like the earlier INTELSAT satellites, it will operate on the 6/4-Ghz band; it will inaugurate the use of the 14/11-Ghz band. The first launch will be in 1979 and the satellite will carry the projected traffic through the mid-1980's.

**Domestic Systems**

The same technologies that made it possible for satellite communications to span oceans is equally applicable to the crossing of geographical barriers or great distances within national boundaries. However, in the United States the sense of national purpose and unified action that gave impetus to the development of the INTELSAT system was lacking to the development of a domestic system. Also, there were existing competitive terrestrial communications systems. Actually, several possible routes might have been taken, either to provide domestic service through INTELSAT, or through a single existing organization or some new organization, or through competitive means. After a series of government studies and regulatory rulings lasting over a 5-year period, the United States finally adopted an "open skies" policy which led to the development of several competitive systems. While deliberations took place, some domestic service between remote areas was provided through INTELSAT between the contiguous 48 states and Alaska, Hawaii, and Puerto Rico, but these services are now being assumed by other domestic systems.

Without internal conflict, Canada established its own domestic system, TELESAT, with the launch of its first satellite, Anik, in 1972. At present, three satellites of the first generation are in orbit providing service to over 50 earth stations, many in small remote communities. Indonesia established a similar separate domestic system in August 1976.

Other countries, for example, Algeria, Brazil, Nigeria, and Norway, are leasing transponder capacity from INTELSAT for domestic service. Such services can be instituted quickly and operate efficiently since no capital investment is required for the satellites, and the country involved can concentrate on building and operating the earth stations.

The United States now has three separate domestic systems in operation. Western Union was the first of these, inaugurating service via its WESTAR satellites in 1974. Then RCA followed with SATCOM late in 1975, and, by July 1976, the COMSTAR system became operational with COMSAT General leasing satellite capacity to American Telephone & Telegraph and General Telephone & Electronics.

Domestic systems provide communications to regions, cities, and, in some cases, individual users. These services demonstrate the inherent flexibility of satellite communications since specially tailored earth stations are used to fit specific needs. The COMSTAR system is used with 30-meter stations to serve major regions of the United States by linking telephone networks much as in the global system. The WESTAR and SATCOM systems use 10-m stations for intercity communications and television distribution but may use 5-m stations to meet special customer needs.

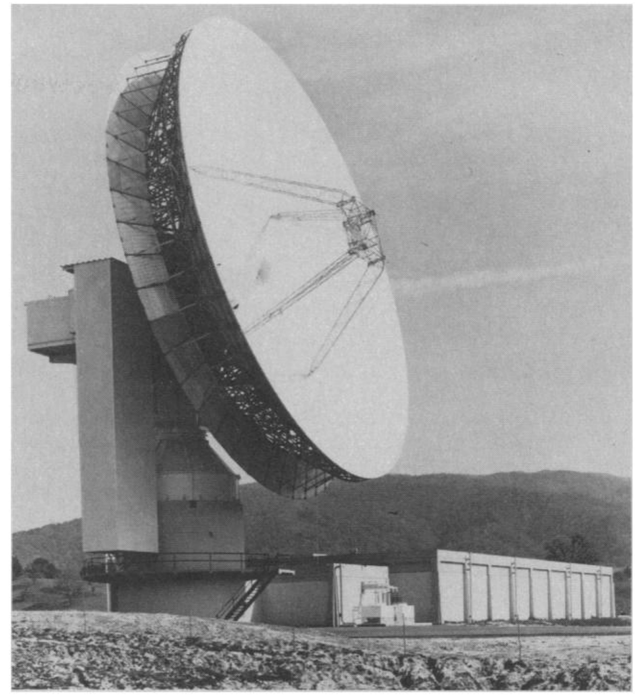


Fig. 6. Standard earth station (INTELSAT system). This parabolic dish antenna (29.5 m in diameter) is the dominant structure at the earth station for commercial satellite communications located at Jamesburg off the upper Carmel Valley in central California. The facility is capable of handling and processing all types of overseas communications: multichannel telephone, teletypewriter, facsimile, data, and both black-and-white and color television.

**Mobile Systems**

The use of mobile terminals is an important advantage that satellite communications has over all other modes of long-distance wide-band communications. Not surprisingly, a number of satellite systems to serve mobile platforms have been proposed, with one now fully operational. The MARISAT system, operated by the COMSAT General Corporation with several other U.S. carriers, provides three-ocean service to ships at sea. Starting in 1976, the MARISAT system (*11*) has been providing leased service to the U.S. Navy in the military very-high-frequency (VHF) band (225 to 400 Mhz) and commercial service at L band (1.5 Ghz). Thirty commercial ships flying flags of 12 nations were equipped for service with the MARISAT system at the start of 1977. This number is expected to grow to several hundred in the next few years. MARISAT provides two-way, ship-to-shore voice and telex service interconnected to the U.S. national and the international public-switched telephone networks. At present, the service cost is several dollars per minute, slightly more expensive than but still competitive with the much less serviceable and reliable high-frequency communications system which is the only other present mode of long-distance maritime communications.

What is spoken of as aeronautical, or more accurately, air traffic control communications is normally considered a governmental service. Plans for satellite systems to provide such service have been considered and proposed for a decade, but private investment capital was not forthcoming for a system dedicated to public service. However, in 1974, a tripartite organization was formed by the COMSAT General Corporation, the European Space Agency, and the Canadian Department of Transportation to develop AEROSAT, a satellite communications system to serve aircraft in international flight (*11*). The AEROSAT system would use the 136-Mhz VHF band as well as L-band frequencies close to the maritime band for this service. The U.S. customer for such service would be the Federal Aviation Administration. Difficulties in arrangements between all the parties involved have slowed progress so that, at this writing, it is difficult to predict a service date, but 1980 seems feasible.

**Electronics Contributions**

The technology on which progress in satellite communications has depended has come from two sources: (i) space technology, largely the product of the space program of the 1960's, heavily and continuously subsidized by the efforts of the National Aeronautics and Space Administration (NASA) and the Department of Defense, and (ii) communications technology, dependent largely on commercial development.

The developments in electronic devices and components stemming from line-of-sight microwave technology have contributed in many respects to the rapid technological progress made in satellite systems over the last decade. Several developments in electronics technology have been particularly important in contributing directly to progress in communications satellites. These include solid-state devices such as transistors, TWT amplifiers, and lightweight antennas and feed systems. Satellite electrical power systems have benefited from advances in silicon solar cells and lightweight, high-energy-density storage cells.

A typical satellite transponder is shown in Fig. 7. Early satellites, such as

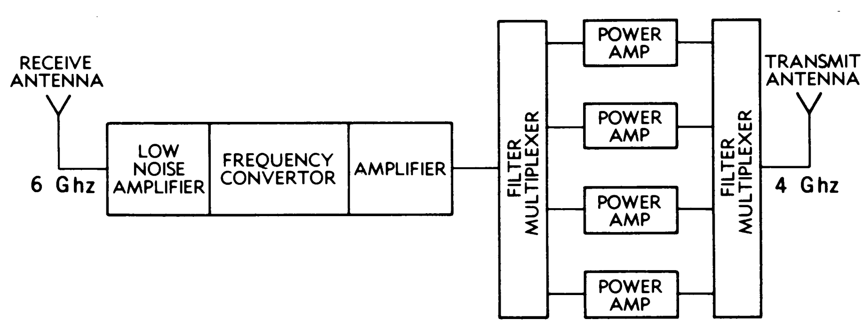
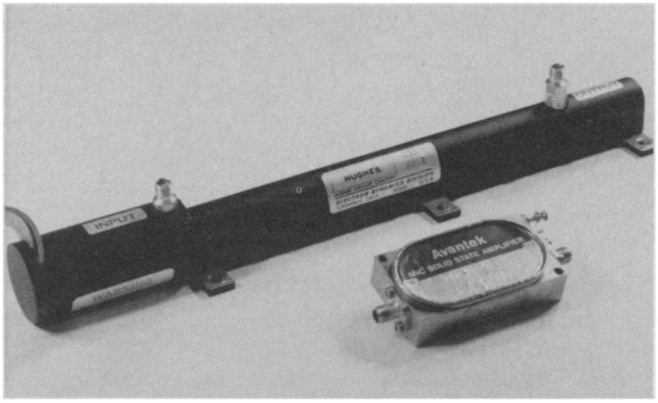



Fig. 7. Typical satellite communications transponder. A typical transponder includes a receiver incorporating a low-noise amplifier, frequency translation, and filter multiplexers; the output amplifiers raise the level of the output signal to approximately 5 to 10 watts.



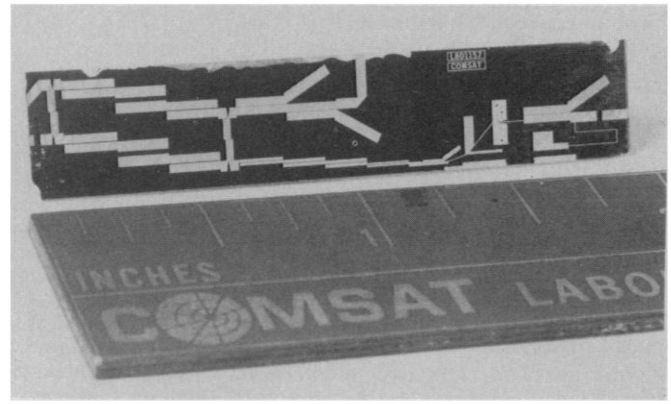




Fig. 8 (left). A modern traveling wave tube (TWT) amplifier and a solid-state amplifier. Future satellites will use solid-state amplifiers instead of TWT's, resulting in increased reliability, lighter weight, and improved transmission performance. Fig. 9 (right). Microwave integrated circuit (MIC) mixer. This MIC uses a thin quartz substrate coated with a layer of gold. The gold on one side is photoetched to a pattern which yields resonant circuits in the microwave frequencies. This modern form of construction affords the advantages of lighter weight and higher reliability, achieved as a result of a much simpler mechanical form.

INTELSAT II and III, used only two receivers and transmitters to amplify the two-way signal flow. The INTELSAT V satellite will include seven operating receivers and eight spares, along with 27 output amplifiers and 16 spares. There is a need for improved device and component reliability and conversion efficiency from primary to radio-frequency (RF) power as well as reduced weight, so that capacity can be increased. The TWT was first announced in 1947 (*12*), but it was not until the mid-1950's that it came into wide use in terrestrial microwave links. In the last decade, improvements in the TWT have resulted in an increase in the conversion efficiency from d-c to RF power from 20 to 40 percent (saturated operation) and the efficiency of the associated power supplies has improved from 60 to 87 percent. Permanent magnet-focusing based on the use of samarium cobalt magnets has further reduced the weight and improved the efficiency of these high-gain amplifiers. Figure 8 illustrates a modern TWT amplifier alongside a solid-state amplifier.

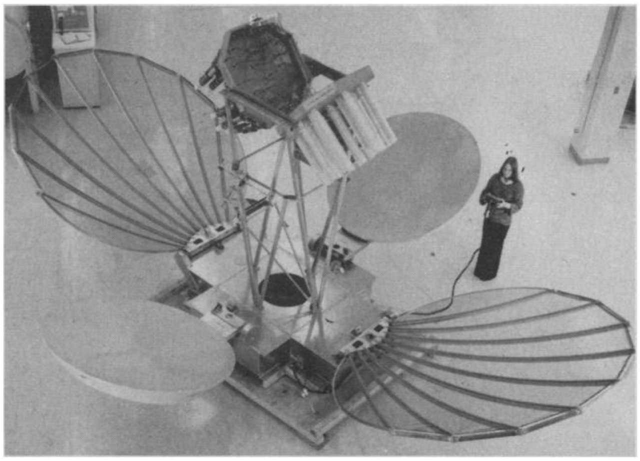
Future satellites are expected to make use of silicon power transistors to replace TWT's. These transistors operate at lower voltages (24 to 48 volts) with improved reliability, transmission performance, lighter weight, and very much longer lifetimes. At higher frequencies, IMPATT (impact avalanche and transit time) diodes can provide the power amplification that is required. Amplifiers based on the use of these devices have been built (*13*) at 11, 14, 20, and 30 Ghz, the bands assigned to space communications for future expansion.

Germanium tunnel diodes have been used as input amplifiers in the receivers of INTELSAT satellites. Low-noise transistor amplifiers, such as silicon bipolar or gallium arsenide field-effect transistors, are now replacing the tunnel diodes. These transistors can achieve a noise temperature about a third of that of the tunnel diode amplifier at the 6-Ghz receive band used in present INTELSAT satellites. For future satellites operating at higher-frequency receive bands, 14- and 20-Ghz low-loss mixers or a new invention, active medium propagation (AMP) amplifier (*14*), will probably be used. This AMP device developed at COMSAT Laboratories achieves low-noise gain through negative differential conductivity along a transmission line formed by a conductor deposited on a gallium arsenide substrate. This device has achieved a noise figure of 10.7 db at 16 Ghz.

To avoid interference to the input signal of the satellite caused by the retransmission of the signal back to earth, the receive and transmit frequencies must be separated. The amount of frequency separation is dependent upon the isolation that can be achieved by input filters and transmitting and receiving antennas. Typically an isolation that is 40 db more than the maximum direct gain between transponder input and output is required (that is, about 120 to 150 db). The frequency translation is obtained when the incoming signal is mixed with a locally generated signal. Coaxial lines, used as the mixers in INTELSAT IV, achieve a conversion loss of 7.5 db and weigh approximately 360 g. Designs in which microwave integrated circuits are used have realized less than a 4-db conversion loss and weigh about 75 g (*15*). The microwave integrated circuit (MIC) (Fig. 9) uses a thin quartz substrate coated with a layer of gold several micrometers thick.

Complex circuits are physically realizable through computer-aided design, and more stringent specifications, in terms of loss and gain variation within an operating band, are being achieved. The local oscillator part of the frequency translator must have a long-term frequency stability usually better than one part in a million per year and little jitter, to avoid adding noise to the amplified signal. In the standard approach a quartz crystal is used to control the oscillator frequency at 15 to 100 Mhz. Amplifiers drive a transistor multiplier to approximately 2 to 3 Ghz. To obtain higher frequencies, varactor frequency multipliers are used. Here again, improvement in the efficiency of the power conversion from d-c to RF and reduced noise are being realized with a transistor oscillator operating directly in the gigahertz range and stabilized by a highly selective microwave cavity.

Very dramatic advances have taken place in the art of antenna design. Early satellites, mentioned earlier, used simple radiators which spread the microwave energy over a wide solid angle very much larger than that subtended by the earth's disk. With the improvement in spacecraft materials along with more precise control of the spacecraft attitude, the beam width of antennas has been decreased and the energy concentrated toward the area of the earth being served. In addition to increasing the effective radiated power, the narrow beams permit the frequency bands assigned to the satellite to be reused. Figure 10 illustrates an antenna system which will generate the beam patterns specified for the INTELSAT V satellite. Separate beams directed at the Eastern and Western hemispheres use one polarization and zones coincident in the Eastern and Western hemispheres use the orthogonal polarization at 6 and 4 Ghz, thus realizing a fourfold reuse of these frequency bands. In addition, two beams at 14/11 Ghz will provide coverage in the



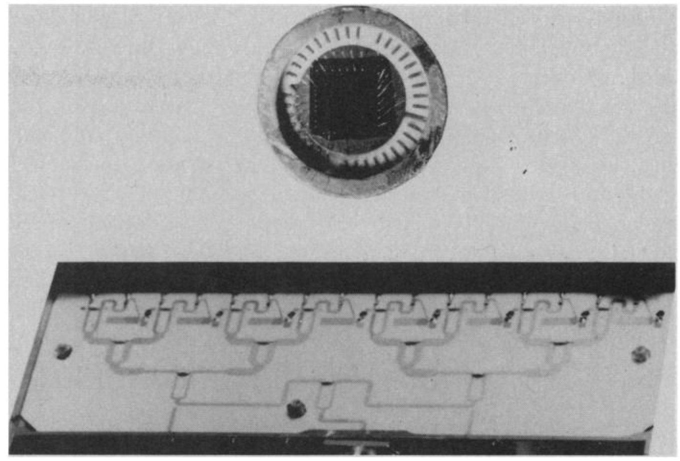


Fig. 10 (left). The INTELSAT V antenna model. This multibeam antenna model, constructed by Lockheed Missiles & Space Corporation under an INTELSAT research and development contract, will generate the beam patterns similar to that specified for INTELSAT V. The antenna system consists of two 3-m unfurlable offset-fed parabolic reflectors for the 4-Ghz coverage, one 6-Ghz offset-fed parabolic reflector, and one 14/11-Ghz offset-fed reflector. Fig. 11 (right). One section of a 16 by 16 MIC switch and the controlling LSI unit. This type switch will provide interconnection of the many narrow antenna beams that are expected to be used on future satellites.

areas with high traffic density in northwestern Europe and in northeastern United States and Canada. The total bandwidth available will be about 2300 Mhz (including guard bands between transponders). The use of lightweight material, exhibiting high strength and a low temperature coefficient, in which epoxy-filled carbon fibers form the major structural elements of the antenna and metallized Dacron mesh forms the reflecting surfaces has made such complex antenna systems feasible. Multielement feeds, such as those shown in Fig. 10, have been designed to achieve complex coverage.

Future satellites are expected to use a great number of very narrow beams, of the order of a few tenths of a degree, essentially one directed to each earth station. These beams must be interconnected. The interconnection is achieved through microwave switches operating at approximately the 4-Ghz band or, alternatively, at base-band frequencies. The microwave interconnection is effected by switches that use semiconductor diodes. These are controlled by an on-board microprocessor which cycles the connection of the receivers and transmitters to the several antenna ports so that all stations are cyclically interconnected to each other. Figure 11 shows one section of a 16 by 16 switch and the LSI (large-scale integration) unit controlling the MIC crossbar switch.

Further developments in microwave integrated circuits and transistor devices will allow a dramatic reduction in the size and weight of receivers which can demodulate digital transmissions, and, with the availability of large-scale integrated circuits for base-band processing, interconnection at the base-band signals is becoming feasible. This base-band processing will require that the system modulation be digital and the access to the satellite be by time interleaving. The interconnection at base-band also permits the processing of signals so that less power and bandwidth is consumed per bit of information. Thus, the combination of large-scale integrated circuits at lower frequencies with microwave integrated circuits at gigahertz frequencies will make possible very much more complicated satellites with capacities approaching 50,000 to 60,000 telephone circuits.

## System Trends

The rapid technological progress in electronics coupled with the impressive operational results and economic returns over the past decade have spawned new services, new systems, and new concepts for satellite communications. A number of experimental satellite programs will provide a good basis for further technological advancement, which will, in turn, provide new services and systems. The last U.S. experimental communications satellite was ATS-6, launched in 1974, which among other accomplishments demonstrated television broadcast to the Indian subcontinent. Other countries followed: Canada with the Communications Technology Satellite and France and Germany with Symphonie. Italy expects to launch the Sirio experimental satellite and Japan two experimental communications satellites in the next year; NASA has not pressed development work in communications satellites for several years but has recently considered resuming a major role and has been urged by several professional societies and the National Academy of Engineering to do so. It is likely that NASA will support extensive satellite communications experimentation in the flight test program for the Space Shuttle.

The Shuttle will open new avenues for the design of communications satellites. Shuttle-launched spacecraft can be much bigger and heavier than current designs with minimum cost penalty. Larger satellites in geostationary orbits can be used as stable platforms on which to erect a large and complex antenna array to promote the use of multiple frequencies and multiple beams—possibly multiple-service satellites as well.

Communications satellites of the future are likely to make use of the on-board processing mentioned above. The satellite will then carry out signal-processing functions including signal reshaping, switching or remultiplexing, or both, and compression. Operating at digital data rates above 100 megabits per second, these satellites will require very reliable digital logic and microwave integrated circuitry.

In addition to the 6/4- and 14/11-Ghz bands, where 500 Mhz of bandwidth is available in each band, the next decade will see the multiple reuse of these bands. For very-high-capacity links, the 30/20-Ghz band, where 3500 Mhz of bandwidth is available, will be coming into use.

Earth stations in future systems will be smaller, less costly, and closely adapted to the users' needs. Earth stations intended to serve cities, towns, villages, or individual users will be sized, configured, and located differently from those designed to serve countries. Earth stations to serve users in ships, aircraft, and land vehicles (land-mobile) will be designed differently and specifically for the use they serve (see Fig. 12).

Earth stations will be manufactured in large quantities to be economical. Those with antennas of 5 m or less are already priced below $100,000, and the cost of small receive-only stations is expected to approach $10,000 in the next decade.

The trend to digital transmission in satellite systems will in some cases precede the trend to digital transmission in terrestrial systems for the reason that the new satellite systems can employ new technology faster than older systems that involve replacement of existing plant facilities. Advances in solid-state technology, particularly the availability of reliable high-speed logic, have made the time domain easier to work in and more flexible than the frequency domain. The advantages of digital transmission techniques include efficiency and economy in switching, signaling, processing for compression and error control, modulation, and multiple access. Digital transmission methods will be used to carry traffic originating in digital form (for example, computer data and facsimile) but also to transmit more efficiently traffic originating in analog form (for example, voice and television). Domestic and special-purpose systems can be expected to use primarily digital transmission techniques. The TELESAT system of Canada introduced the first commercial operation of time division multiple access (TDMA), a digital technique that in-


Fig. 12. Small earth stations. An inherent advantage of satellite communications is the wide area coverage, including the ability to reach as close as desired to the ultimate user of the service provided. Smaller, inexpensive special-purpose earth stations are frequently required for such service. (A) An earth station equipped with a 10-m antenna used to provide domestic telephone and television service to a remote community in Alaska. Similar stations are now being used at some INTELSAT locations. (Photo courtesy of Scientific-Atlanta, Atlanta) (B) An antenna (5-m diameter) next to a Dow Jones printing plant used for high-resolution facsimile transmission of *The Wall Street Journal*. (C) An oil tanker with a mast-mounted 1.2-m antenna (inside the white radome) which provides a link to the shore communications networks via the MARISAT satellite. (Photo courtesy of COMSAT-General Corporation) (D) A 1.2-m antenna which can transmit and receive in the 14/12-Ghz band. This station was developed by COMSAT Laboratories for the demonstration of emergency communications with the American Red Cross.

volves transmission in short bursts and allows several earth stations to communicate sequentially on the same frequency. The second system to use TDMA was MARISAT, for ship-to-shore telex. Future systems, such as that proposed by Satellite Business Systems, a new company formed by COMSAT, International Business Machines, and Aetna to enter the U.S. domestic field, can be expected to be all digital.

The INTELSAT system, although probably best known for its introduction of international television, still derives over 90 percent of its revenue from telephone service. The future holds promise for as great an international market for data, including graphics—facsimile or "electronic mail"—and the evolving new field of "computer networking."

The U.S. domestic market for data transmitted by satellite is much larger than that for voice, since the public-switched telephone network in this country is already so extensive and efficient. For high-speed data the switched network is not now adequate, nor with its multiple cascaded links will it ever be as attractive as satellites from an error performance standpoint. In the United States, certainly, the television market represents an excellent prospect for satellite transmission. Also, new services such as video-voice teleconferencing may become practical on a large scale through domestic satellite systems. One can foresee the application of all these same service possibilities—voice, video, and data—to different degrees to mobile systems (maritime, aeronautical, and land-mobile).

Finally, satellite communications hold great promise for collective services, that is, service to great numbers of users, usually small, of a nature other than point to point. Satellites, because of the wide area covered, are ideal for providing multiple-origin or multiple-destination service. The former, generally known as "data collection systems," are applicable to the transmission of small quantities of data from numerous points of origin to a central delivery point for processing. The military services use such systems for warning, intelligence, and surveillance. Civil needs for meteorological, climatic, agricultural, geographic, and geological data are abundant. Most of these services are traditionally provided by government, but there are many possibilities for commercial applications.

Point-to-multipoint or distribution service may also be provided ideally by satellite. One such service, already established through domestic satellite systems, is television distribution—the satellite and the cable being a natural combination for the distribution of television. Over 40 cable television locations in the United States are now served through the RCA SATCOM system.

Another distribution service already being provided is high-resolution facsimile. *The Wall Street Journal* appearing on desks in New York and Miami is transmitted by satellite from the Dow Jones composing office in Chicopee, Massachusetts, to their printing plants in Brunswick, New Jersey, and Orlando, Florida, respectively. It is anticipated that additional "satellite" plants will be added across the country to make the *Journal* a truly national newspaper.

Distribution satellites providing both television and daily newspaper service across the country—and across the oceans—can certainly be said to have reached the "peoples of the world." Whether these services will help to bring "peace and closer brotherhood," as President Kennedy put it, has yet to be determined.

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