Communication Satellites

Fifth Edition

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Contents

1. Experimental Satellites

Although the performance of communication satellites could be predicted theoretically, until 1962 or 1963 there was considerable doubt concerning whether their actual performance would match the theory. This was one of the basic motivations for the early communication satellite experiments. Two other important factors were the desire to prove the satellite hardware (since space technology in general was still in its infancy) and the need to test operational procedures and ground equipment. Whereas the first few experiments (SCORE, Courier, and Echo) were very brief beginnings, the Telstar, Relay, and Syncom satellites laid definite foundations for the first operational satellites.

Communication satellites have been in operational commercial and military service since 1965 and 1967, respectively. However, there was, and still is, the need for additional experimental satellites. These are used to prove new technologies for later introduction into operational satellites. Some satellites combine experimental objectives with preoperational demonstrations. Discussions of such satellites are included in this chapter if their emphasis is primarily experimental; those directly continued by operational satellites are described in later chapters.

SCORE

The first artificial communication satellite, called Project SCORE (Signal Communication by Orbiting Relay Equipment) [1–5], was launched in December 1958. The primary objective of the project was to demonstrate that an Atlas missile could be put into orbit. The secondary objective was to demonstrate a communications repeater.

The entire communication subsystem was developed in 6 months by modifying commercial equipment. Two redundant sets of equipment were mounted in the nose of the missile. Four antennas were mounted flush with the missile surface, two for transmission and two for reception. The subsystem was designed to operate for the expected 21-day orbital life of the missile. Because of the short lifetime, batteries alone were the power source; thus, the complexity of solar cells and rechargeable batteries was avoided. The details about SCORE are as follows.

Satellite

Communications equipment integral with Atlas launch vehicle

99 lb equipment

Silver-zinc batteries, 56 W maximum load

Capacity

One voice or six teletype channels

Real-time and store-dump modes

Transmitter

132 MHz, 8 W output

All vacuum tubes

Receiver

150 MHz, 10 dB noise figure

All transistors

Antenna

Four slots (two transmit, two receive)

–1 dB gain

Recorder

4 min capacity, 300–5000 Hz band

Life

Two weeks

Orbit

100 x 800 nmi, 32 deg inclination

Orbital history

Launched 18 December 1958, battery failed 30 December 1958

Decayed 21 January 1959

Atlas B launch vehicle

Management

Developed by ARPA; communications equipment built by Army Signal Research and Development Laboratory, Ft. Monmouth, New Jersey

Each half of the communication subsystem had a tape recorder with a 4 min capacity. Any of the four ground stations in the southern United States could command the satellite into a playback mode to transmit the stored message or into a record mode to receive and store a new message. A real-time mode was also available in which the recorder was bypassed. About 8 hr of actual operation occurred before the batteries failed. During this time, voice, single-channel teletype, and frequency-multiplexed six-channel teletype signals were transmitted to the satellite, recorded, stored, and later retransmitted. One of the signals handled in this manner was a Christmas message from President Eisenhower. In addition to the stored-mode transmissions, there were several real-time transmissions through the satellite.

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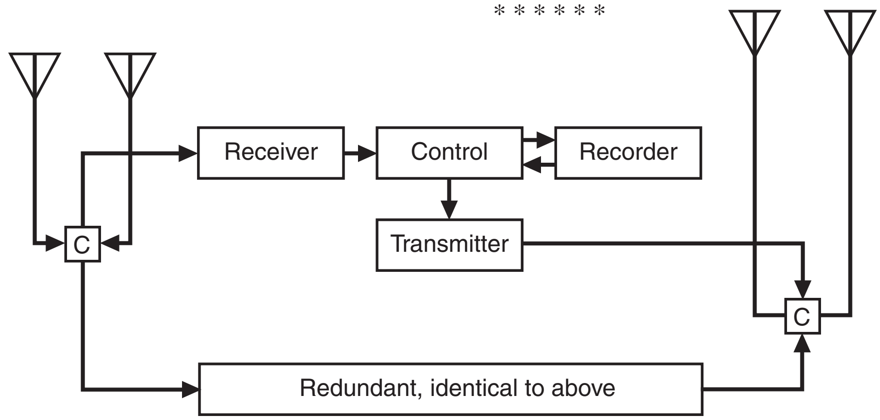

Fig. 1.1. SCORE communication subsystem.

1. S. P. Brown and G. F. Senn, “Project SCORE,” *Proceedings of the IRE*, Vol. 48, No. 4 (April 1960).

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3. M. I. Davis and G. N. Krassner, “SCORE—First Communication Satellite,” *Journal of the American Rocket Society*, Vol. 4 (May 1959).

4. S. P. Brown, “The ATLAS-SCORE Communication System,” *Proceedings of the 3rd National Convention on Military Electronics* (June 1959).

5. D. Davis, “The Talking Satellite. A Reminiscence of Project SCORE,” *Journal of the British Interplanetary Society*, Vol. 52, No. 7–8 (July–August 1999).

Echo

During the late 1950s and early 1960s, the relative merits of passive and active communication satellites were often discussed. Passive satellites merely reflect incident radiation, whereas active satellites have equipment that receives, processes (may be only amplification and frequency translation, or may include additional operations), and retransmits incident radiation. At the time of Project Echo, the main advantages given for passive satellites were

- very wide bandwidths
- multiple-access capability
- no chance for degradations caused by failures of satellite electronics

The disadvantages were

- lack of signal amplification
- relatively large orbit perturbations resulting from solar and atmospheric effects (because of the large surface-to-weight ratio)
- difficulty in maintaining the proper reflector shape

The progress in active satellites soon overshadowed the possible advantages of passive satellites, and interest in passive satellites ceased in the mid-1960s. In the mid-1970s, there was some interest in passive satellites concerning their use in a nuclear-war environment.

Project Echo [1–12] produced two large spherical passive satellites that were launched in 1960 and 1964. The details of Echo are as follows.

Satellite

Echo 1: sphere, 100 ft diam, 166 lb

Echo 2: sphere, 135 ft diam, 547 lb

Not stabilized, no onboard propulsion

Aluminized Mylar surface, maximum reflectivity 98% for frequencies up to 20 GHz

Frequencies

Echo 1: 960 and 2390 MHz

Echo 2: 162 MHz

Orbit

Echo 1: 820 x 911 nmi, 48.6 deg inclination (initial values)

Echo 2: 557 x 710 nmi, 85.5 deg inclination (initial values)

Orbital history

Unnumbered: launch vehicle failure 13 May 1960

Echo 1: launched 12 August 1960, decayed 25 May 1968

Echo 2: launched 25 January 1964, decayed 7 June 1969

Delta launch vehicle

Management

Developed by G. T. Schjeldahl Company (balloon), Grumman (dispenser) for NASA (National Aeronautics and Space Administration) Langley Research Center (Echo 1), NASA Goddard Space Flight Center (Echo 2).

Echo 1 was used for picture, data, and voice transmissions between a number of ground terminals in the United States. In addition, some transmissions from the United States were received in England. Numerous modulation methods were tested during the Echo 1 experiments, and valuable experience was gained in the preparation and operation of the terminals, especially in tracking the satellites. In addition to the communications experiments, Echo 1 was used for radar and optical measurements, and its orbital data were used to calculate atmospheric density.

Echo 2 had a slightly different design to provide a stiffer and longer lasting spherical surface. It was used very little for communications, although some one-way transmissions were made from England to the Soviet Union. It was primarily used in scientific investigations similar to those performed with Echo 1.

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1. *Space Communications and Navigation 1958–1964*, NASA SP-93 (1966).

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12. C. B. Waff, "Project Echo, Goldstone, and Holmdel: Satellite Communications as Viewed From the Ground Station," in *Beyond the Ionosphere: Fifty Years of Satellite Communication*, A. J. Butrica, ed., NASA History Office, Washington, D.C. (1997), ch. 5.

Courier

The objective of the Courier program [1–3] was to develop a satellite of higher capacity and longer life than SCORE, which could be used for communication tests and assessments of traffic handling techniques. The concept was similar to SCORE in that the primary operating mode was store-and-dump using onboard tape recorders. A real-time mode was also available. Unlike SCORE, Courier was a self-contained satellite and had both solar cells and rechargeable batteries for power supply. Except for the final amplifiers of the transmitters, the electronics were all solid state. The details of Courier are as follows.

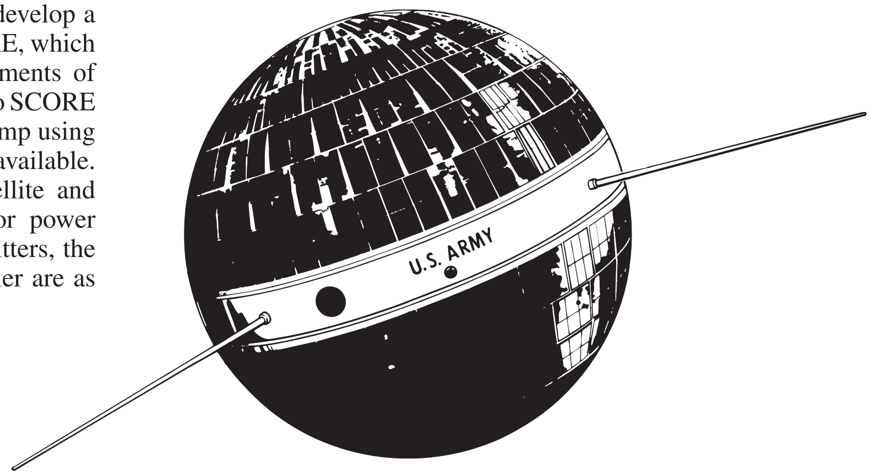

Fig. 1.2. Courier satellite.

Satellite
Sphere, 51 in. diam, 500 lb in orbit

Solar cells and NiCd batteries, 60 W

Capacity
Real time: one voice channel

Store-dump: 13.2 Mb/recorder digital, 4 min voice

Transmitter
1700–1800 MHz band

Two transmitters on, two standby

Solid state except output tubes

2 W output per transmitter

Receiver
1800–1900 MHz band

Two receivers on, two standby

All solid state

14 dB noise figure

Antenna
Two slots at antipodal points, used for both transmit and receive

–4 dB gain

Linear polarization

Recorder
Four digital: each 4 min at 55 kbps (13.2 Mb total)

One analog: 4 min capacity, 300–50,000 Hz

Life
One year

Orbit
525 x 654 nmi, 28 deg inclination (initial values)

Orbital history
Courier 1A: launch vehicle failure

Courier 1B: launched 4 October 1960, operated 17 days

Thor-Able Star launch vehicle

Management
Developed by Army Signal Research and Development Laboratory

The Courier communication subsystem had four receivers, two connected to each antenna. Signals received through the two antennas were summed in a baseband combiner. The satellite could support a single half-duplex voice circuit in the

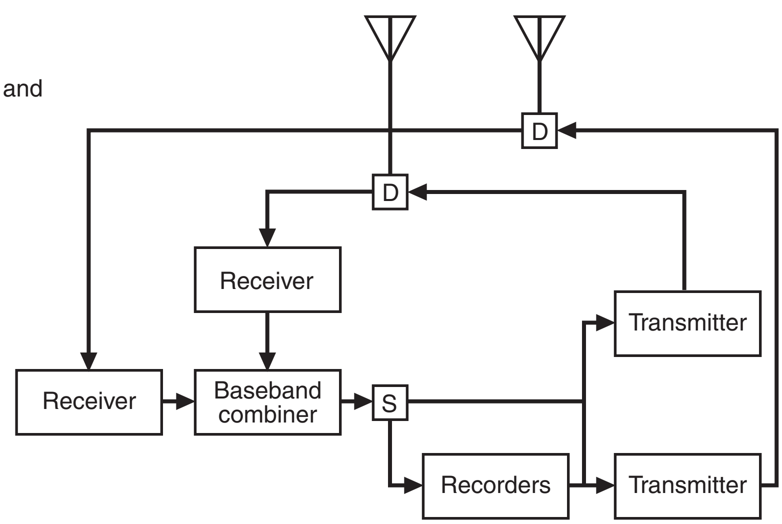

Fig. 1.3. Courier communication subsystem.

real-time mode. One analog and four digital recorders, each with a 4 min recording capability, were used for the store-and-dump mode. This allowed any ground terminal to use the satellite for transmission of four separate digital (multiplexed teletype) messages, one to each of four other terminals. Upon command, a recorded message (or the received signal in the real-time mode) would modulate two transmitters, one connected to each antenna. The satellite also had two spare transmitters. The two carrier frequencies were separated about 20 MHz. Various signal-combining techniques were used at the ground to make use of these two signals.

The first Courier launch was unsuccessful because of a booster failure. The second, in October 1960, was successful. Communication tests were performed by two ground terminals, located in New Jersey and Puerto Rico. The satellite performed satisfactorily until 17 days after the launch, when communications were stopped by a command system failure.

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West Ford

The West Ford concept [1–4] grew out of a 1958 summer study on secure, hard, reliable communications. The following conclusions were reached.

- Use satellites and microwave frequencies for long-distance communications.
- Put all active equipment on the ground for reliability.
- Use a belt of dipoles instead of a single satellite for hardness.

When the concept was defined openly, there was some adverse reaction because of the uncertain effects on optical and radio astronomy. After some time, the project was allowed to proceed under certain restrictions.

West Ford and Echo were the only two passive communication reflectors put into orbit. Echo could rightly be called a satellite, but the West Ford reflector consisted of 480 million copper dipoles. The length was chosen to correspond to a half wavelength of the 8 GHz transmission frequencies used in the program. Other West Ford details are as follows.

Satellite

480 million copper dipoles, each 0.72 in. long, 7×10^{-4} in. diam

88 lb dispenser plus dipoles; dipoles weighed 43 lb

Frequencies

7750, 8350 MHz

Orbit

1970 nmi nominal altitude

Nearly circular, nearly polar

Dispersion: 8 nmi cross-orbit, 16 nmi radially, 1300 ft average distance between dipoles

Orbital history

First: launched 21 October 1961, dispenser did not release dipoles

Second: launched 9 May 1963, fully dispersed August 1963

Atlas-Agena B launch vehicle

Management

Developed by MIT Lincoln Laboratory

The dipoles were dispensed from an orbiting container in May 1963. At first, all were concentrated in one portion of the orbit. During the first few weeks, voice and frequency shift keying (FSK) data up to 20 kbps were transmitted from Camp Parks (Pleasanton, California) to Millstone Hill (Westford, Massachusetts—the source of the project name). Four months later, when the belt was fully extended, the density was much lower, and only 100 bps data were transmitted. Because of this low capacity and the increasing performance of active satellites, no further experiments of this type were attempted. The last transmission of signals was accomplished in 1965, and a combination of measurements and analytic predictions indicated that all the dipoles would reenter the atmosphere before the end of the 1960s.

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Fig. 1.4. West Ford dipoles.

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2. I. I. Shapiro, "Last of the West Ford Dipoles," *Science*, Vol. 154 (16 December 1966).

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Telstar

The Telstar experiment [1–10] grew out of the Bell Systems' interest in overseas communication. Bell Telephone Laboratories was a major participant in communication experiments using Echo 1. The positive results of those experiments strengthened the interest in satellite communications generated by earlier analytical papers. Therefore, American Telephone and Telegraph Company (AT&T) decided to build an experimental active communication satellite. The objectives of the Telstar program were to

- look for the unexpected
- demonstrate transmission of various types of information via satellite
- build a large ground antenna and learn how to use it
- gain experience in satellite tracking and orbital predictions
- study Van Allen radiation belt effects
- face the design problems required for a spaceborne repeater

An active satellite was decided on because the required balloon size for television bandwidths was much beyond the state of the art. The choice of the Delta launch vehicle provided basic design constraints such as size, weight, and orbit. In accordance with the fifth objective, the satellite contained a number of sensors to make radiation measurements. The third objective was accomplished by the construction and use of a ground station at Andover, Maine.

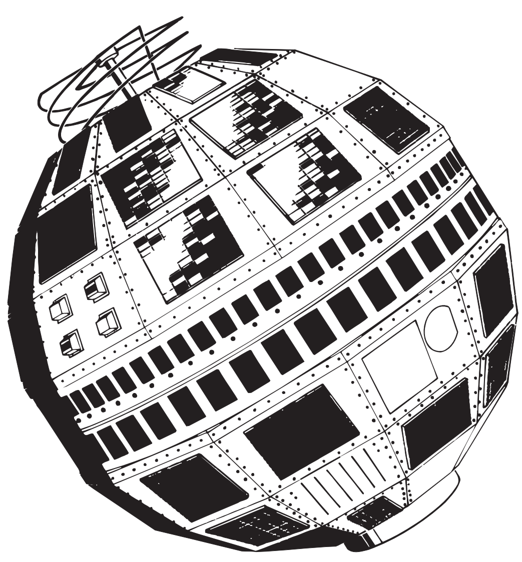

Fig. 1.5. Telstar satellite.

Two Telstar satellites were produced. The satellites were 34.5 in. diam spheres with solar cells covering most of the outer surface. The solar array output alone could not support operation of the communication subsystem, so batteries were used to supply the peak power requirements. The batteries were recharged during the periods when the satellite was not in view of the ground terminals and the communication subsystem was turned off. This subsystem had a single channel with a 50 MHz bandwidth. The program details are as follows.

Satellite

Sphere, 34.5 in. diam

170 lb in orbit (Telstar 1), 175 lb in orbit (Telstar 2)

Solar cells and NiCd batteries, 15 W

Spin-stabilized, 200 rpm

Configuration

One 50 MHz bandwidth double-conversion repeater

Capacity

600 one-way voice circuits or one TV channel

60 two-way voice circuits (tests limited to 12 circuits by ground equipment)

Transmitter

4170 MHz

All solid state except TWT (traveling wave tube)

TWT operated linear at 3.3 W (saturated power: 4.5 W)

Receiver

6390 MHz

All solid state

12.5 dB noise figure

Antenna

Transmit: 48 small ports equally spaced around satellite waist

Receive: 72 small ports

Uniform pattern around waist and ±30 deg from waist plane

Circular polarization

Telemetry and command

Telemetry: 136.05 MHz, 200 mW transmitter

Command: approximately 123 MHz

Four-element helical antenna

Life

Two-year goal

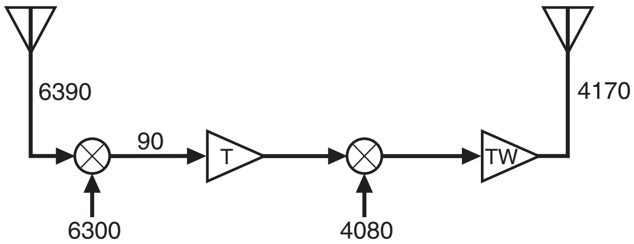

Fig. 1.6. Telstar communication subsystem.

Orbit

Telstar 1: 514 x 3051 nmi, 45 deg inclination

Telstar 2: 525 x 5830 nmi, 43 deg inclination

Orbital history

Telstar 1: launched 10 July 1962, operated until 23 November 1962, and 4 January to 21 February 1963

Telstar 2: launched 7 May 1963, operated until May 1965

Delta launch vehicle

Management

Developed by Bell Telephone Laboratories for AT&T

Telstar 1 was launched in June 1962. In the following 6 months, about 400 transmission sessions were conducted with multichannel telephone, telegraph, facsimile, and television signals. In addition, more than 250 technical tests and measurements had been performed. Stations in the United States, Britain, and France participated in these activities. In November 1962, the command subsystem on the satellite failed. The cause was later established as degradation of transistors due to Van Allen belt radiation. Various operations effected a recovery that allowed the satellite to be used for another month and a half early in 1963, after which the command subsystem failed again.

Telstar 2 was nearly identical to Telstar 1. The only significant design change was the use of radiation-resistant transistors in the command decoders. The Telstar 2 satellite orbit had a higher apogee than Telstar 1, which increased the time in view of the ground stations and decreased the time in the Van Allen belts. Telstar 2 was launched in May 1963 and operated successfully for 2 years.

* * * * * *

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Relay

The Relay program [1–9] was undertaken by NASA to perform active satellite communications and to measure Van Allen belt radiation and its effect on satellite electronics. Basic objectives were to transmit telephone and television signals across the Atlantic and to transmit telephone signals between North and South America. During the time the satellite was being developed, foreign governments were invited to participate in communications experiments. Primary ground stations were in Maine, England, and France—the same stations that conducted demonstrations with Telstar 1. Other ground stations were in California, New Jersey, Germany, Italy, Brazil, and Japan.

The Relay satellite had a more complex communication subsystem than Telstar, with two identical redundant repeaters. Either repeater could be connected to the common antennas by ground command. Each repeater had one 25 MHz channel and two 2 MHz channels. These channels allowed either one-way transmission of wideband (WB) signals or two-way transmission of narrowband (NB) signals. The communication subsystem block diagram is shown; the satellite details follow.

Satellite

Octagonal prism, 35 in. long, 29 in. diam, 53 in. overall length

172 lb in orbit

Solar cells and NiCd batteries, 45 W

Spin-stabilized, 150 rpm

Configuration

Two double-conversion repeaters (one on, one standby), each with one WB and two NB channels

Capacity

WB: 300 one-way voice circuits or one TV channel

NB: 12 two-way telephone circuits (limited by ground equipment, not satellite bandwidth)

Transmitter

4164.7, 4174.7 MHz (NB), 4169.7 MHz (WB)

All solid state except TWT

10 W output

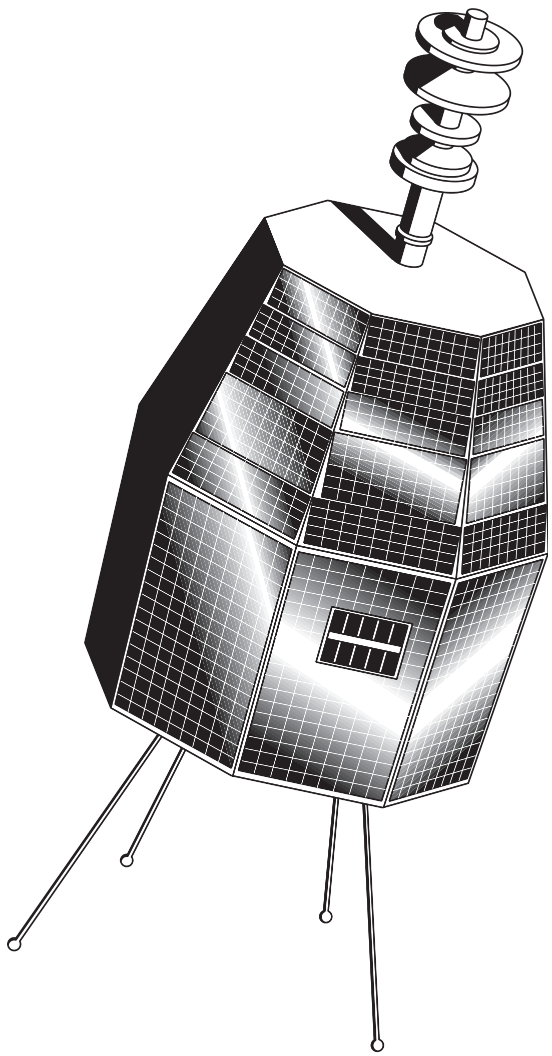

Fig. 1.7. Relay satellite.

Orbital history

Relay 1: launched 13 December 1962, operated until February 1965

Relay 2: launched 21 January 1964, operated until May 1965

Delta launch vehicle

Management

Developed by RCA for NASA Goddard Space Flight Center

Relay 1 was launched in December 1962. Radiation experiment data were obtained on the first day. That same day, difficulties with communications transponder No. 1 that caused excessive power consumption were noticed. The problem could not be fully corrected, and from January 1963 transponder No. 2 was used for almost all the communication experiments. Relay 1 operated until February 1965.

During 1963, several tests and demonstrations were conducted including telephone and television transmissions. Network TV broadcasts were transmitted from the United States to Europe and to Japan. Several times, both television and telephone transmissions were used for international medical consultations. In October 1964, television coverage of the Olympic Games was relayed from Japan to the United States by Syncom 3 and then from the United States to Europe by Relay 1.

Relay 2 was modified slightly to provide increased reliability and radiation resistance. Relay 2 was launched in January 1964 and was used in a variety of communications tests similar to those done with Relay 1. By July 1964, Relays 1 and 2 had been used for 112 public demonstrations of telephone and television transmission. Relay 2 was used until May 1965.

The Telstar and Relay programs were both considered successful. They demonstrated that the technology at that time could produce a useful, medium-altitude communication satellite. In addition, ground station technology was proven, and routine operation of ground stations was demonstrated. Measurements of communications parameters indicated no significant deviations from theoretically expected values. Finally, it was shown that satellite communication systems

Receiver

1723.3, 1726.7 MHz (NB), 1725 MHz (WB)

All solid state

14 dB noise figure

Antenna

Two biconical horns (one transmit, one receive)

Approximately 0 dB gain normal to spin axis

Circular polarization

Life

One year

Orbit

Relay 1: 712 x 4012 nmi, 47.5 deg inclination

Relay 2: 1130 x 4000 nmi, 46 deg inclination

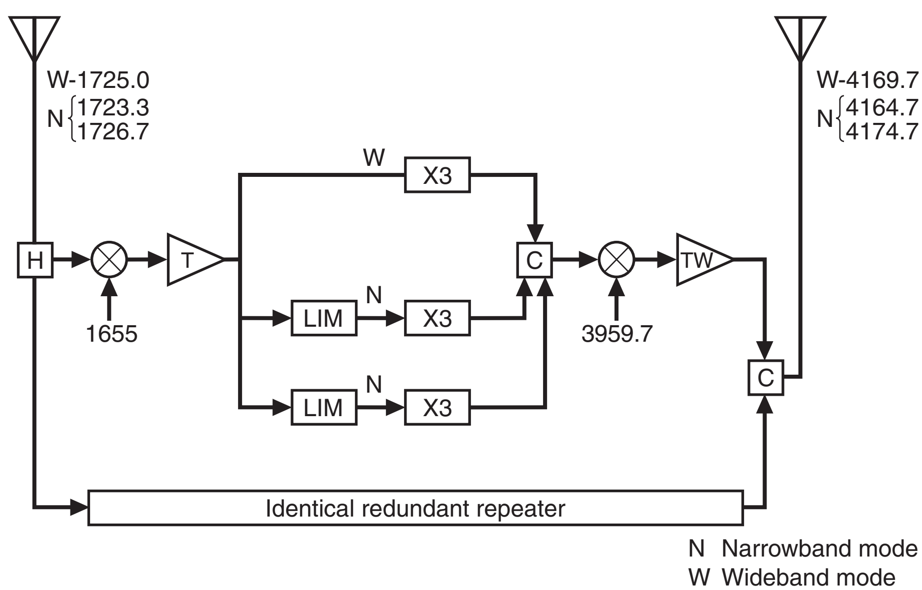

Fig. 1.8. Relay communication subsystem.

could share frequencies with terrestrial microwave systems without mutual interference.

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1. *Space Communications and Navigation 1958–1964,* NASA SP-93 (1966).

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a. S. Metzger and R. H. Pickard, "Relay" (See Ref. 5).

b. R. H. Pickard, "Relay 1 Spacecraft Performance."

c. R. Pickard, S. Roth, and J. Kiesling, "Relay, An Experimental Satellite for TV and Multichannel Telephony."

7. "Development of the Relay Communications Satellite," *Interavia*, Vol. 17 (June 1962).

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Syncom 1 to 3

In the early 1960s, both medium and synchronous altitude communication satellites were of interest to planners. NASA conducted experiments at both altitudes using the Relay and Syncom satellites. The Syncom program [1–12] had three major objectives:

- to place a satellite in synchronous orbit
- to demonstrate on-orbit stationkeeping
- to make engineering measurements on a synchronous altitude communication link

The Syncom satellite had a short cylindrical body that was spun about its axis to provide stabilization in orbit. The antennas were mounted beyond one end of the body and were collinear with the satellite axis. All the satellite equipment was contained within the body. This design formed the basis for several later synchronous altitude satellites. The communication subsystem had two receivers and two transmitters for redundancy; either receiver could be operated with either transmitter. The channelization was similar to Relay, with two 500 kHz channels for NB two-way communications and one 5 MHz channel for one-way WB transmissions. (These capabilities could not be used simultaneously.) The satellite details are as follows.

Satellite

Cylinder, 28 in. diam, 15 in. height

78 lb in orbit

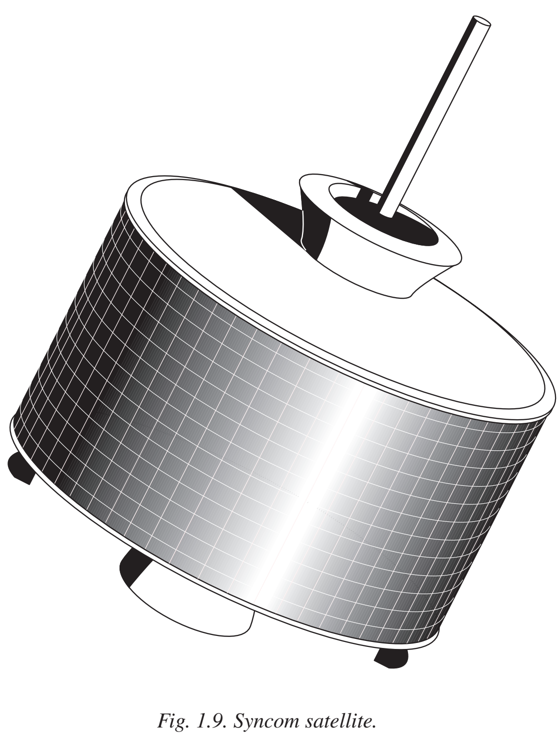

Fig. 1.9. Syncom satellite.

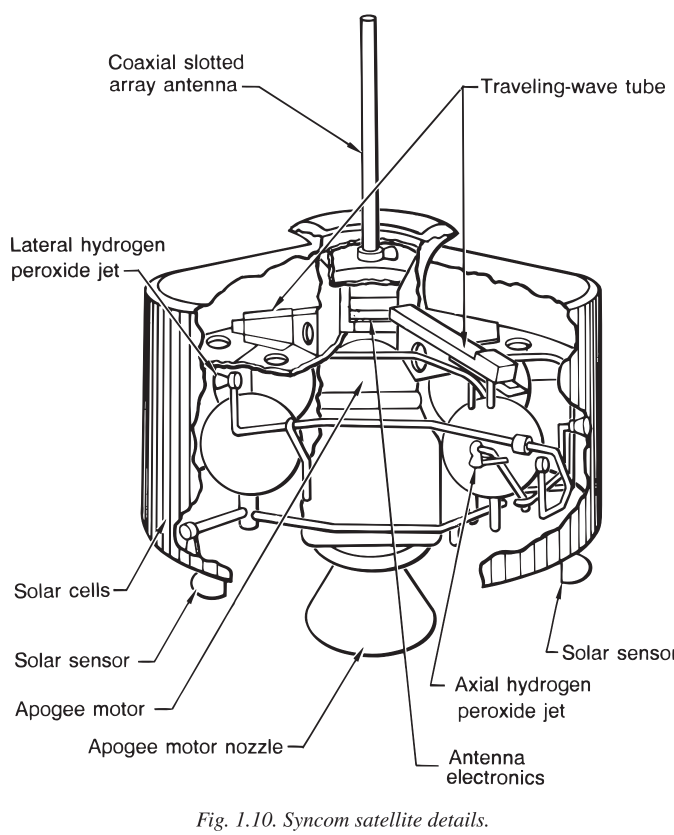

Fig. 1.10. Syncom satellite details.

Solar cells and NiCd batteries, 28 W initially, 19 W minimum after 1 year

Spin-stabilized

Solid rocket motor for apogee maneuver, cold gas propulsion for on-orbit use

Configuration

Syncom 1, 2: two 500 kHz bandwidth double-conversion repeaters or one 5 MHz bandwidth double conversion repeater

Syncom 3: one 5 MHz bandwidth and one switchable (50 kHz or 10 MHz) bandwidth double-conversion repeater (some references say 13 MHz instead of 10 MHz)

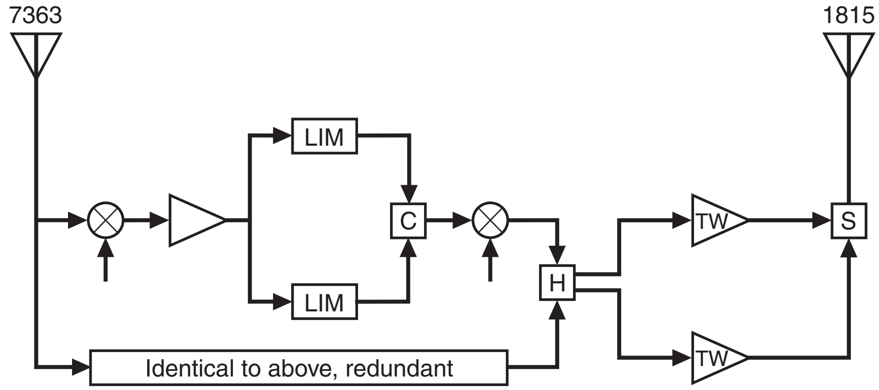

Fig. 1.11. Syncom communication subsystem.

Capacity

Several two-way voice circuits or one TV channel

Transmitter

1815 MHz

Two TWTs (one on, one standby)

2 W output

Receiver

7363 MHz

10 dB noise figure

Antenna

Transmit: three-element collinear slotted array, 6 dB gain, 23 x 360 deg beam

Receive: slotted dipole, 2 dB gain

Telemetry and command

Telemetry: 136 MHz, via four monopole antennas

Beacon: 1820 MHz

Command: 148 MHz, via four monopole antennas

Orbit

Syncom 1, 2: synchronous altitude, approximately 32 deg inclination

Syncom 3: synchronous equatorial

Orbital history

Syncom 1: launched 13 February 1963, all communications failed during orbital insertion

Syncom 2: launched 26 July 1963, operated through 1966, final turn off April 1969

Syncom 3: launched 19 August 1964, operated through 1966, final turn off April 1969

Delta launch vehicle

Management

Developed by Hughes Aircraft Company for NASA Goddard Space Flight Center

Syncom 1 was launched in February 1963. The intended orbit was at synchronous altitude with a 33 deg inclination. The satellite operated properly during the ascent, but all communication was lost when the apogee motor fired to inject the satellite into its final orbit. The cause of the failure was the rupturing of a tank of nitrogen that was part of the on-orbit control subsystem. Syncom 2 was successfully launched in July 1963. Like Syncom 1, it was not intended to achieve a stationary synchronous orbit because of the extra propellant weight and control complexity required to attain 0 deg inclination. NASA conducted a number of tests using this satellite, including voice, teletype, and facsimile. During its first year, in addition to engineering tests, 110 public demonstrations were conducted. Their purpose was to acquaint the public with communication satellites and to gain a broader-based, subjective appraisal of system performance.

Syncom 3 was launched in August 1964. By this time, launch vehicle technology had progressed to the point where a true synchronous equatorial (inclination <1 deg) orbit was possible. The only major change in the communication equipment was a channel, with greater bandwidth than Syncom 2, to be used for television transmissions.

The Department of Defense (DOD) also conducted a number of tests using Syncom 2 and 3. During 1965 and 1966, both were used extensively. Five ground stations and one shipborne terminal were in regular system use. Also, tests with aircraft terminals were conducted using the very high frequency (VHF) command and telemetry links. By February 1966, the Syncom 2 and 3 repeaters had a cumulative operational time of 27,000 hr. DOD use of Syncom diminished when the Initial Defense Communication Satellite Program (IDCSP) satellites became operational.

While the Syncom satellites were being developed and tested, an Advanced Syncom study was also being conducted. The Advanced Syncom program was sometimes called Syncom II, which, in some references, is difficult to distinguish from the second satellite of the original Syncom program (Syncom 2 in this report). The conceptual satellite was larger than Syncom, generated more prime power, had higher antenna gain, and had repeaters of two different designs. This program grew beyond an advanced communications experiment and became the Applications Technology Satellite (ATS) program.

* * * * * *

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Lincoln Experimental Satellites

The Massachusetts Institute of Technology (MIT) Lincoln Laboratory had been active for a long time in various aspects of military communications before the space age. With the early developments of space technology, Lincoln Laboratory began investigations of applications to military communications. The outcome of some of these investigations was the Lincoln Experimental Satellites (LES) series.

LES-1 to -7

Early work in ionospheric and tropospheric scatter communications at Lincoln Laboratory evolved into the West Ford orbital scatter program. At the conclusion of that program in 1963, Laboratory efforts were directed toward active communication satellite techniques [1–8]. The large West Ford ground stations were to be used in the new programs. In addition, smaller mobile terminals were to be developed. The basic goals of the program included demonstration of

- high-efficiency, all solid-state transmitters
- electronically despun antennas
- communications with small mobile terminals
- techniques for stationkeeping and attitude control

Experimental techniques were developed with a view toward eventual application in synchronous altitude military communication satellites.

LES-1 and -2 were essentially identical. They had small polyhedral bodies and were spin-stabilized. The primary experiment was an all solid-state X-band repeater and an eight-horn electronically switched antenna. The other experiments were in attitude sensing and control. The transmitter source was a crystal oscillator and multiplier chain that was used for upconversion of the signal from intermediate frequency (IF). The X-band power was 200 mW.

The eight horns were mounted so as to provide omnidirectional coverage. Sensors were used to determine the direction of the Earth and the satellite spin rate. Onboard logic then controlled switches to use the antenna most closely pointed toward the center of the Earth. Other details of LES-1 and -2 are as follows.

Satellite

26-sided polyhedron, approximately 24 in. in each dimension

82 lb in orbit

Solar cells, 25 W beginning of life, no batteries

Spin-stabilized with magnetic torquing, 180 rpm

Configuration

20 MHz bandwidth triple-conversion repeater

Transmitter

7750 MHz (continuous-wave beacon at 7740 MHz)

All solid state

200 mW output, 115 mW at antenna

Receiver

8350 MHz

16 dB noise figure

G/T: –37 dB/K, maximum

Antenna

Eight horns, electronically switched (only one used at a time)

Approximately 3 dB gain

Telemetry

Telemetry: 237.00 MHz, 0.8 W transmitter

Life

Two years

Orbit

1500 x 8000 nmi, 32 deg inclination

Orbital history

LES-1: launched 11 February 1965, launch vehicle failure left satellite in 1500 x 1500 nmi orbit and tumbling

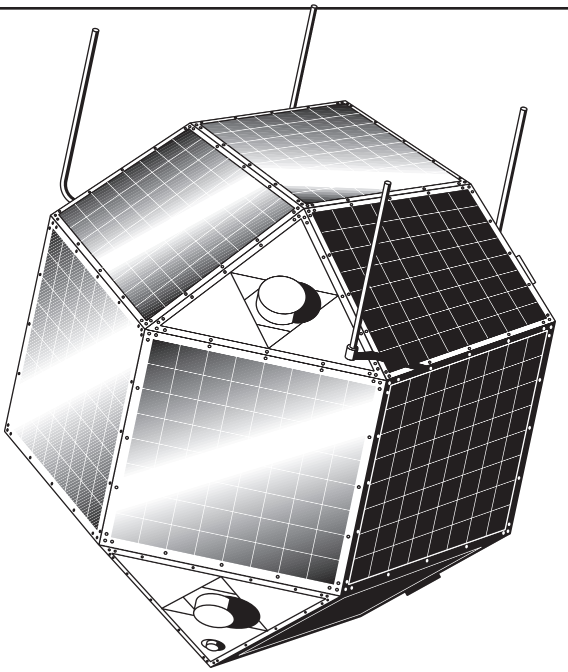

Fig. 1.12. LES-1 satellite.

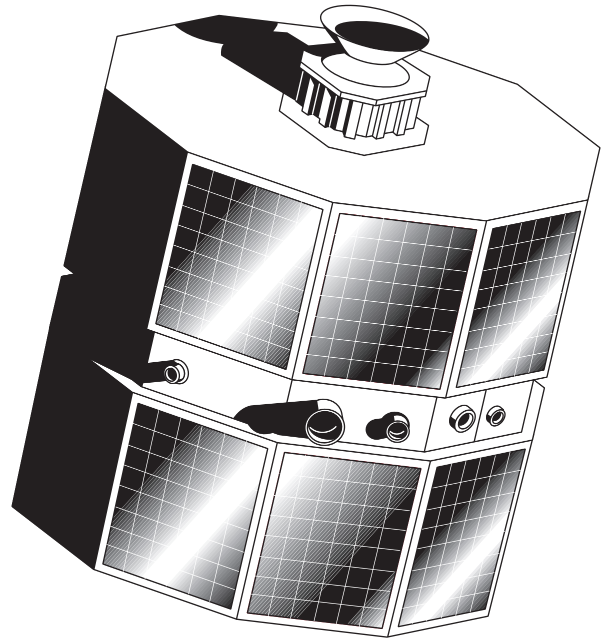

Fig. 1.13. LES-4 satellite.

LES-2: launched 6 May 1965, operated until September 1966, final turn off May 1967

Titan IIIA launch vehicle

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

LES-1 was launched in February 1965. A launch vehicle failure left the satellite in the wrong orbit. The results of limited tests conducted indicated that the repeater and the switched antennas were operating properly. The satellite then entered a tumbling mode that ended its usefulness. LES-2 was launched in May 1965 and operated as planned until it was turned off in September 1966.

LES-3 was not a communication satellite; its purpose was to transmit an ultrahigh frequency (UHF) signal for propagation measurements. LES-3 is described in a later chapter. The LES-4 satellite was similar to LES-1 and -2. The interior structure was the same, but the solar array was mounted on a cylindrical shell rather than on a polyhedral shell, the cylindrical array being more efficient for the synchronous equatorial orbit of LES-4. The satellite details are as follows.

Satellite

10-sided cylinder, 31 in. diam, 25 in. height

116 lb in orbit

Solar cells, 36 W initial minimum, no batteries

Spin-stabilized with magnetic torquing, 11 rpm

Configuration

20 MHz bandwidth triple-conversion repeater

Transmitter

7750 MHz (continuous-wave beacon at 7740 MHz)

All solid state

230 mW at antenna, 3 dBW EIRP

Receiver

8350 MHz

9 dB noise figure

G/T: –29 dB/K, maximum

Antenna

Transmit: eight horns electronically switched, 10 dB peak gain, circularly polarized, each horn covered about 26 x 45 deg of a 26 x 360 deg toroid

Receive: biconical horn, 26 x 360 deg, circularly polarized

Telemetry

237.00 MHz

Life

Three years

Orbit

Intended: synchronous equatorial

Actual: 105 x 18,200 nmi, 26 deg inclination

Orbital history

Launched 21 December 1965. Launch vehicle failure resulted in wrong orbit and orientation; decayed 1 August 1977.

Titan IIIC launch vehicle

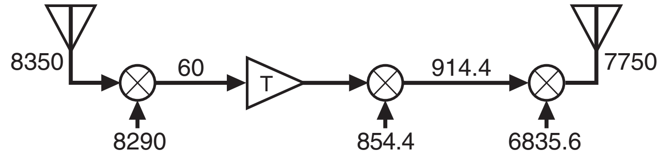

Fig. 1.14. LES-1, -2, and -4 communication subsystem.

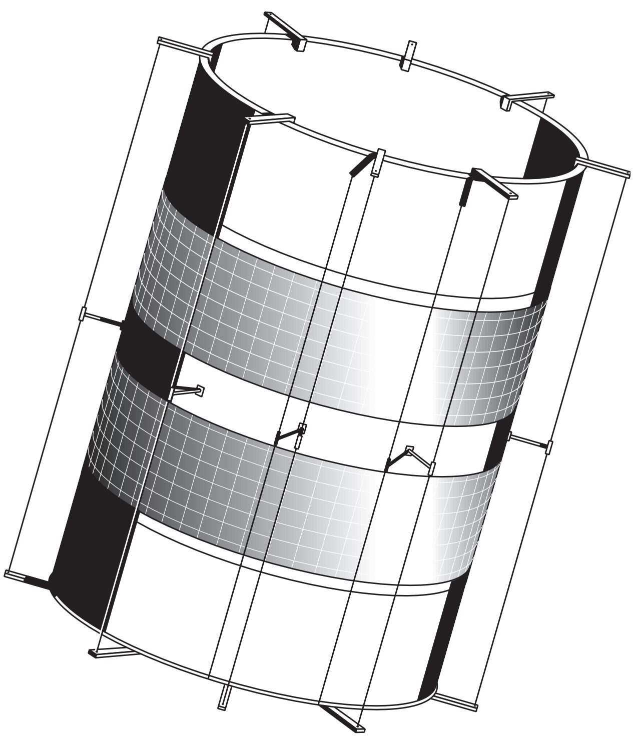

Fig. 1.15. LES-5 satellite.

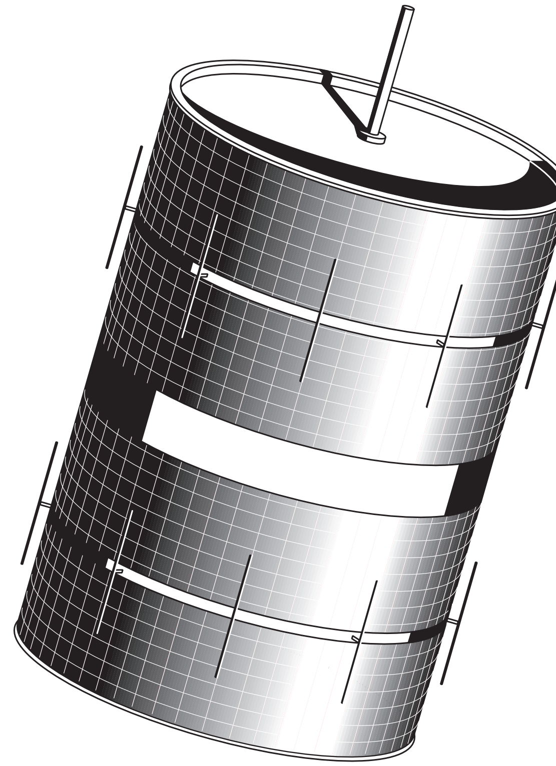

Fig. 1.16. LES-6 satellite.

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

The LES-4 repeater design was nearly the same as the LES-2 design, but improved components significantly lowered the receiver noise figure and increased the transmitter power. The LES-4 transmitting antenna comprised eight horns uniformly spaced in a plane normal to the satellite spin axis. Sun and Earth sensors and logic circuits controlled the switches to despin the antenna electronically. The difference in the antenna design from LES-2 was possible because LES-4 was intended for use in a synchronous equatorial orbit, where coverage could be limited to 26 deg in the north-south plane.

LES-3 and -4 were launched in December 1965. As the result of a launch vehicle malfunction, the satellites were placed in an elliptical synchronous transfer orbit. Originally, the orientation of LES-4 was such that only enough power was available for operation of the telemetry system. Five days after launch, the spin axis orientation had changed enough so that power was available for the operation of all the satellite systems. From that time, the LES-4 repeater and antenna operated as expected.

The LES-5 and -6 satellites had cylindrical shapes with equipment mounted on a platform near the center of the cylinder and normal to its axis. Both had multiple-element antennas mounted around the cylindrical surface. In addition to their communications equipment, the satellites carried solar cell degradation and radio frequency interference (RFI) experiments. LES-6 also had a prototype autonomous stationkeeping subsystem. The details of LES-5 are as follows.

Satellite

Cylinder, 48 in. diam, 64 in. height

230 lb in orbit, beginning of life

Solar cells, 136 W initial maximum, no batteries

Spin-stabilized with magnetic torquing, approximately 10 rpm

Configuration

Single 100 or 300 kHz bandwidth double-conversion repeater

Transmitter

228.2 MHz, beacon at 228.43 MHz

Solid state

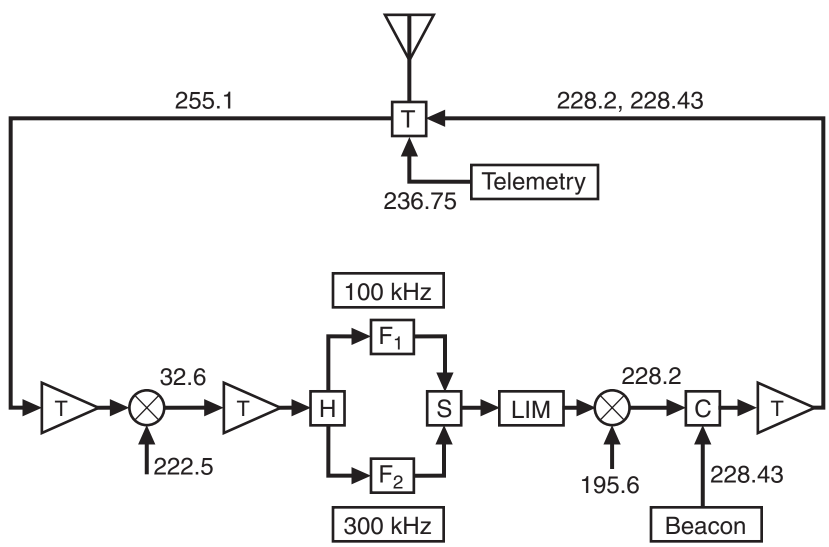

Fig. 1.17. LES-5 communication subsystem.

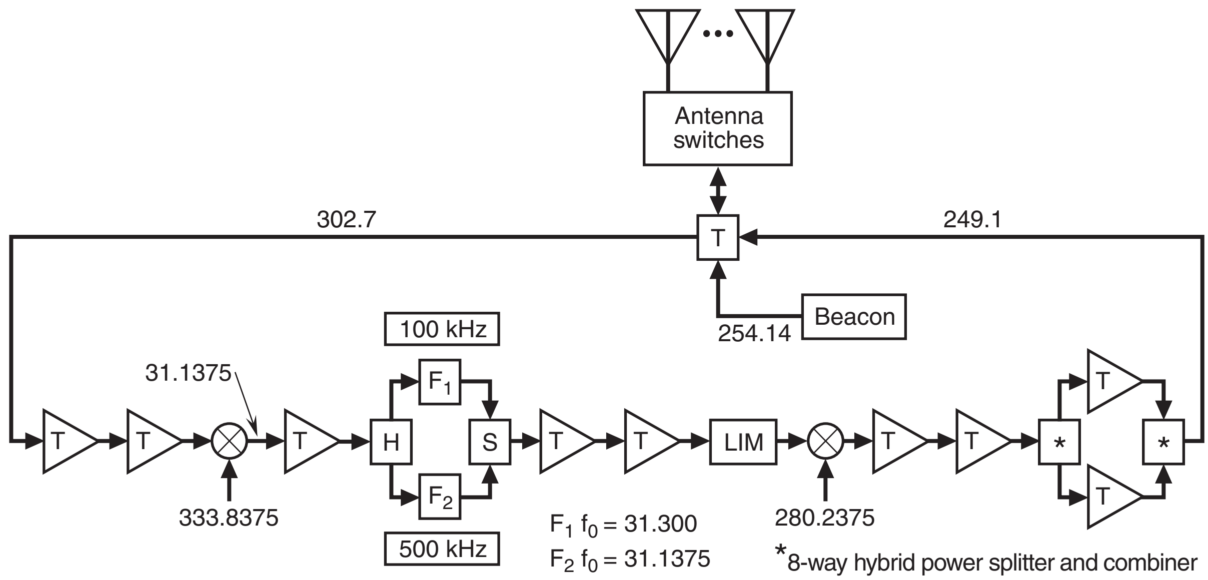

Fig. 1.18. LES-6 communication subsystem.

35 W output, 16.3 dBW EIRP beginning of life nominal in satellite's equatorial plane

Receiver

255.1 MHz

3.6 dB noise figure

G/T: –26 dB/K nominal in satellite's equatorial plane

Antenna

Eight dipoles parallel to satellite axis, 2.5 dB gain circularly polarized (electronic despin logic tested on satellite, but not used with antennas)

Telemetry

236.75 MHz

Life

Five years

Orbit

18,000 x 18,180 nmi (30 deg drift per day), 7 deg initial inclination

Orbital history

Launched 1 July 1967, operated until May 1971

Titan IIIC launch vehicle

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

The details of LES-6 are as follows.

Satellite

Cylinder, 48 in. diam, 66 in. height

398 lb in orbit, beginning of life

Solar cells, 220 W initial maximum, limited battery capacity

Spin-stabilized with magnetic torquing, approximately 8 rpm

Cold gas propulsion for on-orbit use

Configuration

Single 100 or 500 kHz bandwidth double-conversion repeater

Transmitter

249.1 MHz (500 kHz mode), 248.94 MHz (100 kHz mode), beacon at 254.14 MHz

Solid-state amplifiers

Variable output power, 120 W initial nominal (see text)

EIRP: 29.5 dBW at beginning of life, 21 dBW after 5 years

Receiver

302.7 MHz (500 kHz mode), 302.54 MHz (100 kHz mode)

3.6 dB noise figure

Antenna

Sixteen sets of dipoles and cavity-backed slots arranged in eight collinear pairs, circularly polarized

Electronically despun, 9.5 dB gain, 34 deg (north-south) x 54 deg (equatorial plane) beamwidth

Telemetry

236.755 MHz

Orbit

Synchronous altitude, 3 deg initial inclination

Orbital history

Launched 26 September 1968, operated until turned off in March 1976, still operable in 1978, 1983, and 1988 tests

Titan IIIC launch vehicle

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

LES-5 and -6 had all solid-state communications equipment that operated in the military UHF band. (This is called UHF, although the standard designation is VHF up to 300 MHz and UHF above that.) The LES-5 communication subsystem had a final amplifier of conventional design and had very good efficiency—68-percent direct current (dc) to radio frequency (RF). The LES-6 amplifier was an experimental design in that it was directly connected to the solar-array power bus without any intervening power converters. In this design, all power not required by other satellite systems was directly available to the transmitter, and the transmitter power varied with the available prime power. It was claimed that this design provided an extra 3 dB of transmitted power initially and 0.5 dB extra at the end of satellite life. In-orbit measurements indicated that transmitter power was in the range of 100 to 130 W. LES-5 did not have a despun antenna, but it was used to test some logic that was used in LES-6. The despun circuitry in LES-6 was based on LES-2 and -4 experience and used similar techniques involving Earth and sun sensors.

LES-5 was launched in July 1967 with three IDCSP satellites and was placed into a subsynchronous orbit similar to theirs. Both Lincoln Laboratory and the military services conducted a number of tests with LES-5. Aircraft, shipborne, and fixed and mobile ground terminals were all involved in the tests, which were considered very successful. LES-5 operated until May 1971.

LES-6 was launched in September 1968 and was used in tests similar to those conducted with LES-5. The satellite operated satisfactorily. The communication subsystem continued in active use, although by 1975 the effective radiated power (EIRP) had decreased 8 dB from its initial value. It was turned off early in 1976 to avoid any frequency conflict with the Marisat launched in February 1976.

The LES-7 satellite was intended to have an all-solid-state, 100 MHz bandwidth, single-conversion, X-band repeater and a multibeam antenna. Although the program was canceled before the satellite was built, a prototype antenna was built and tested. This antenna was a waveguide lens-type with a cluster of 19 feed horns and was capable of generating beam sizes as small as 3 deg and as large as Earth coverage.

* * * * * *

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8. W. W. Ward and F. W. Floyd, "Thirty Years of Space Communications Research and Development at Lincoln Laboratory," in *Beyond the Ionosphere: Fifty Years of Satellite Communication,* A. J. Butrica, ed., NASA History Office, Washington, D.C. (1997), ch. 8.

LES-8 and -9

LES-8 and -9 [1–8] were the latest in a series of experimental military communication satellites developed by the MIT Lincoln Laboratory. They were operating with a variety of fixed and mobile terminals with the use of both UHF and K-band (36–38 GHz) for uplinks and downlinks. A K-band crosslink between LES-8 and LES-9 was a significant part of the program. The communications electronics were all solid state. Two K-band receivers and transmitters were on each satellite, one used with a horn antenna and the other with an 18-in. parabolic reflector. The paraboloid worked with a steerable flat plate and a five-horn feed to provide a narrowbeam tracking antenna. This antenna was normally used for crosslink communications but was also used for uplink/downlink traffic. The satellites acquired the crosslink with initial pointing uncertainties greater than ±1 deg and maintained tracking to better than 0.1 deg at typical signal levels. The horn antenna was fixed and used only for uplinks and downlinks. The K-band transmitters used parallel Impatt diode amplifiers to produce an output power of 0.5 W. The crosslink bit rate was either 10 or 100 kbps, using phase shift keying (PSK) modulation. The K-band uplinks used both eight-tone FSK and differential quadriphase shift keying (DQPSK); the K-band downlinks used DPSK. All UHF transmissions used eight-tone FSK. For transmissions involving UHF links, which were primarily for relatively simple mobile terminals, the basic data rate was 75 bps. The K-band links handled selected information rates up to 19,200 bps, which was adequate for computer data or digitized voice. Except for an optional UHF frequency translation mode with a bandwidth of 500 kHz, all received uplinks were translated to intermediate frequencies and then demodulated. All signal routing was controlled by switches set by commands from the ground. The basic routings are shown in Fig. 1.20.

LES-8 and -9 were practically identical. Most of the electronic subsystems were contained in the satellite body, which is 46 in. long and about 44 in. across. The two radioisotope thermoelectric generators (RTGs) were mounted one upon the other on the back end of the satellite body. These RTGs provide all the electrical power used by the satellite; no solar cells were used. The UHF antenna was also attached to the back end of the satellite body. The K-band antennas and some electronics, plus Earth sensors, were mounted on the front end. The overall length of the satellite was about 10 ft. The satellite was three-axis-stabilized by a gimballed momentum wheel and 10 gas thrusters. The satellite details were as follows.

Satellite

Approximately 10 ft long

LES-9, 948 lb in orbit, beginning of life

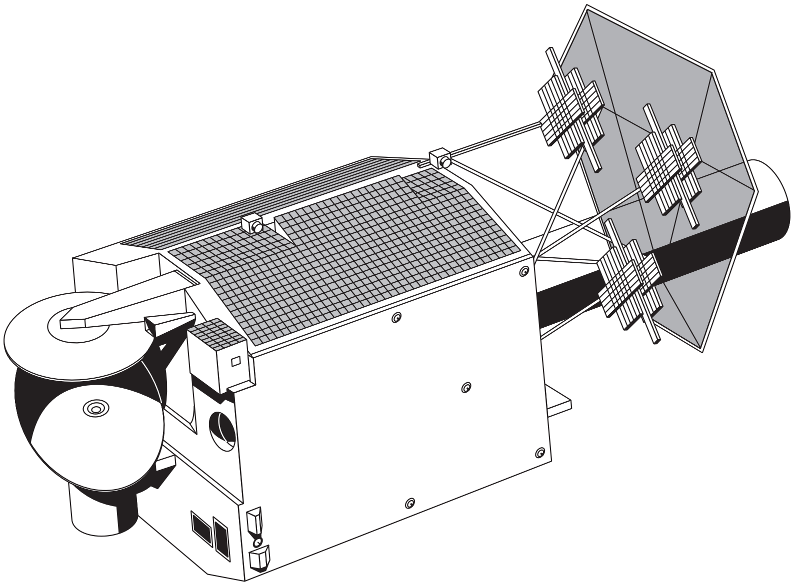

Fig. 1.19. LES-9 satellite.

LES-8, similar to LES 9

Two RTGs, 152 W each initially, 130 W each after 5 years (design goal was 145/125 W)

Three-axis stabilization using a gimballed momentum wheel, ±0.1 deg about pitch and roll axes, ±0.6 deg about yaw axis

Cold gas propulsion for on-orbit use

Transmitter

UHF: 240–400 MHz band, 32 W or 8 W output, EIRP 25 dBW (high power mode) or 18 dBW (low power mode)

K-band: 36 to 38 GHz band; 0.5 W output, 21 dBW EIRP (horn); 0.5 W output, 39 dBW EIRP (dish)

Receiver

UHF: 240–400 MHz band, system noise temperature approximately 1000 K, G/T –20 dB/K

K-band: 36–38 GHz band, system noise temperature 1400 K, G/T

≥–8 dB/K (horn), ≥10 dB/K (dish)

Antenna

UHF: three crossed dipoles on a ground plane, 35 deg beamwidth, approximately 8 dB gain (edge of Earth)

K-band: horn, 10 deg beamwidth, 24 dB gain (on axis); dish, 18 in. paraboloid, 1.15 deg beamwidth, 42.6 dB gain (on axis), steerable ±10 deg in elevation and 104 deg in azimuth by gimballed flat plate

Telemetry and command

Telemetry: 2240 MHz and 236.75 MHz (LES-8), 2250 MHz and 249.36 MHz (LES-9); alternate via K-band communications downlink or crosslink

Command: in 240–300 MHz band; alternate via UHF communications uplink or K-band communications uplink or crosslink

Orbit

Synchronous, 25 deg inclination, 40°W and 110°W longitude, later collocated near 106°W longitude

Orbital history

Launched 14 March 1976

Titan IIIC launch vehicle

In use (1989)

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

LES-8 and -9 were launched together on a Titan IIIC booster on 14 March 1976. The first tests showed that all important communications parameter values were in good agreement with the prelaunch measurements. Since then, the satellites were exercised in a variety of modes, both for detailed performance measurements and for functionally oriented demonstrations to prove the operability of the various links. These tests involved ground and mobile terminals developed by Lincoln Laboratory, the Air Force, and the Navy. The test results were all satisfactory and showed that the LES-8 and 9 communications features operationally useful. The satellites were still in good condition and being used in 1989.

* * * * * *

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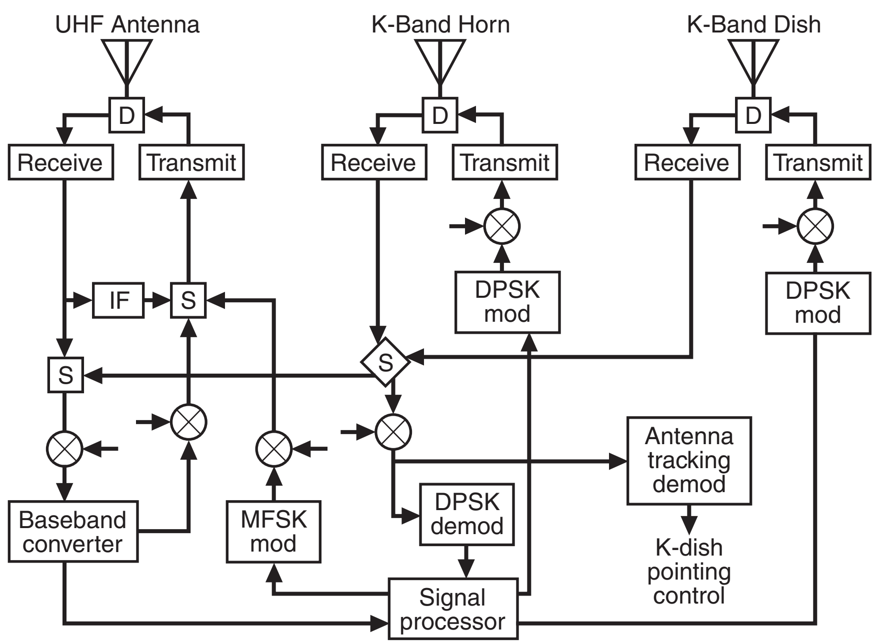

Fig. 1.20. LES-8 and LES-9 communication subsystem.

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Applications Technology Satellites

The ATS program evolved from the Advanced Syncom study. The ATS series continued some of the communications experiments planned for Advanced Syncom and also included meteorological, attitude control and stationkeeping, and space environment experiments. ATS 1 through 5 (called ATS B, A, C, D, and E before launch) constituted the first generation of the program; the second generation was the single ATS 6 (ATS F before launch) satellite.

ATS 1 to 5

The first objectives of the ATS program were to

- investigate and flight test technology common to a number of satellite applications
- investigate and flight test technology for the geosynchronous orbit
- conduct a gravity gradient experiment
- conduct flight test experiments for a number of types of satellite applications on each individual spacecraft

ATS 1 to 5 [1–9] had some basic similarities, which are summarized in Table 1.1. The main distinction between the designs of these satellites was that two used spin stabilization and three used gravity-gradient stabilization. Table 1.1 delineates the communications experiments in each satellite; block diagrams of the equipment associated with each experiment are shown graphically.

The C-band communications experiment was the only experiment common to all five satellites. The transmit and receive frequencies were in the satellite communication bands used by the Intelsat satellites. Three modes of operation were possible in each of the two repeaters, which could operate simultaneously. The frequency translation mode was used for WB data relay between two ground stations. In this mode, only one carrier was present, and the signal could occupy the entire 25 MHz repeater bandwidth. Several frequency division multiplexed, single-sideband modulated signals were received in the multiple access mode, and the composite signal was used to phase modulate the transmitter in the satellite. All the ground stations received the transmitted signal and selected the channels of interest from the recovered baseband, which contained all the channels in use. In this way, a number of ground stations could be connected simultaneously. The WB data mode was used for transmission of information generated by onboard meteorological cameras. Various types of antennas were used on ATS 1 to 5 with the C-band communications experiment. Details of the experiment are as follows.

Configuration

Two 25 MHz bandwidth repeaters

Capacity

1200 one-way voice circuits or one color TV channel

Transmitter

4120 and 4179 MHz

Two TWTs per repeater, used singly or together

4 W output per TWT, except 12 W at 4179 MHz on ATS 3

EIRP: ATS 1: 19.5, 22.0 dBW (1, 2 TWTs); ATS 3: 22.0, 25.0 dBW (1, 2 4W TWTs), 26.5 dBW (1 12 W TWT); ATS 5: 22.5, 25.0 dBW (1, 2 TWTs)

Receiver

6212 and 6301 MHz

Tunnel diode preamplifiers

6.2 dB noise figure

Antenna

ATS 1: Transmit: phased array, 16 sets of four collinear dipoles, 14 dB gain, 17 deg (north-south) x 21 deg (equatorial plane) beamwidth. Receive: six-element collinear array, 6 dB gain

ATS 2: Horn, 10.5 dB gain

ATS 3: Mechanically despun cylindrical reflector with linear feed on cylinder (and spin) axis, 18 dB gain, 17 deg beamwidth

ATS 4, 5: Receive: planar array, four slots in each of four waveguide sections, 16.3 dB gain, 23 deg beamwidth; transmit: similar array, 16.7 dB gain

The VHF experiment, which was on ATS 1 and 3, had the primary objective of evaluating communications between ground stations and aircraft. Other objectives were (1) to demonstrate the collection of meteorological data from remote terminals, (2) to communicate with ships, and (3) to evaluate the feasibility of a VHF navigation satellite. The VHF equipment on the two satellites was similar. The antenna was an eight-element, but with a common IF amplifier.

It was possible to operate only four transmitters to conserve prime power, or to equalize the phase shifters to generate a toroidal antenna pattern. On ATS 3 only, it was possible to receive a VHF signal and transmit it with the C-band transmitter. Details of the experiment are as follows.

Table 1.1. ATS 1 to 5 Characteristics

Characteristics	Satellite [a, b]				
	ATS 1 (B)	ATS 2 (A)	ATS 3 (C)	ATS 4 (D)	ATS 5 (E)
Cylinder					
Diameter (in.)	58	56	58	56	56
Height (in.)	54	72	54	72	72
Initial orbital weight (lb)	775	702	775	670	670
Solar cells and NiCd batteries (W initial)	175	130	175	130	130
Stabilization	Spin	Gravity gradient	Spin	Gravity gradient	Gravity gradient
Design life (yr)	3	3	3	3	3
Actual orbit	Sunchronous equatorial, 149°W, moved to 164°W in 1982, drifting by 1995	100 × 600 nmi	Synchronous equatorial, 105°W	130 × 480 nmi	Synchronous equatorial, 70°W, above synchronous orbit by 1995
Intended orbit		6000 nmi		Synchronous equatorial	
Launch date	7 Dec 1966	6 Apr 1967	8 Nov 1967	10 Aug 1968	12 Aug 1969
Decay date		2 Sep 1969		17 Oct 1968	
Launch vehicle	Atlas-Agena	Atlas-Agena	Atlas-Agena	Atlas-Centaur	Atlas-Centaur
Experiments					
C-band communications	Yes	Yes	Yes	Yes	Yes
VHF communications	Yes		Yes		
Millimeter wave propagation					Yes
L-band communications					Yes

[a]Alphabetic designations were used before launch, numeric after.
[b]Satellites were developed by Hughes Aircraft Company for NASA, operated by NASA.

Configuration
100 kHz bandwidth double-conversion repeater

Transmitter
135.6 MHz

ATS 1: 5 W per element, 40 W total, 22.5 dBW EIRP

ATS 3: 6.25 W per element, 50 W total, 25.2 dBW EIRP

Receiver
149.2 MHz

ATS 1: 4.5 dB noise figure

ATS 3: 4.0 dB noise figure

Antenna
Eight-element (dipoles) phased array

ATS 1: 9 dB gain

ATS 3: 10 dB gain

The millimeter-wave experiment on ATS 5 was designed to measure atmospheric effects on propagation. No repeater was included in the satellite. Rather, on both uplinks and downlinks, a carrier was phase-modulated by a sine wave. The modulation index was selected to equalize power at the carrier and the first two sideband frequencies. Measurements were made at two frequencies, one for the uplink and the other for the downlink. These measurements provided data on absorption, refraction, and fading characteristics. The use of the modulated sidebands provided data on the coherence properties of the atmosphere. Details of the experiment are as follows.

Transmitter
15.3 GHz

Solid state

200 mW output

Receiver
31.65 GHz

15 dB noise figure

Antenna
Two horns (one each for transmit and receive)

20 deg beamwidth, 19 dB gain

Modulation (uplinks and downlinks)
Phase modulation, 1.43 modulation index to provide approximately equal power in carrier and first sidebands

Modulation frequency: none, 100 kHz, 1 MHz, 10 MHz, or 50 MHz

The L-band (1550/1650 MHz) equipment on ATS 5 had a design similar to the C-band (4 and 6 GHz) communications equipment on all five ATS satellites. Its purpose was to investigate navigation and traffic control communications for aircraft. For these functions it may have been more suitable than VHF, where the available bandwidth is limited and propagation variations limit navigation accuracy. The L-band equipment could be operated as a repeater in the frequency translation mode. In the multiple access mode, as many as 10 single-sideband modulated signals were received at L-band and

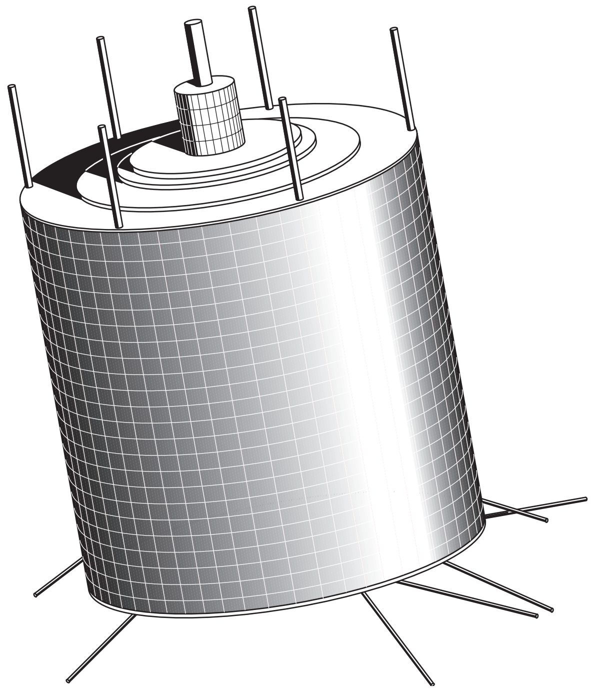

Fig. 1.21. ATS 1 satellite.

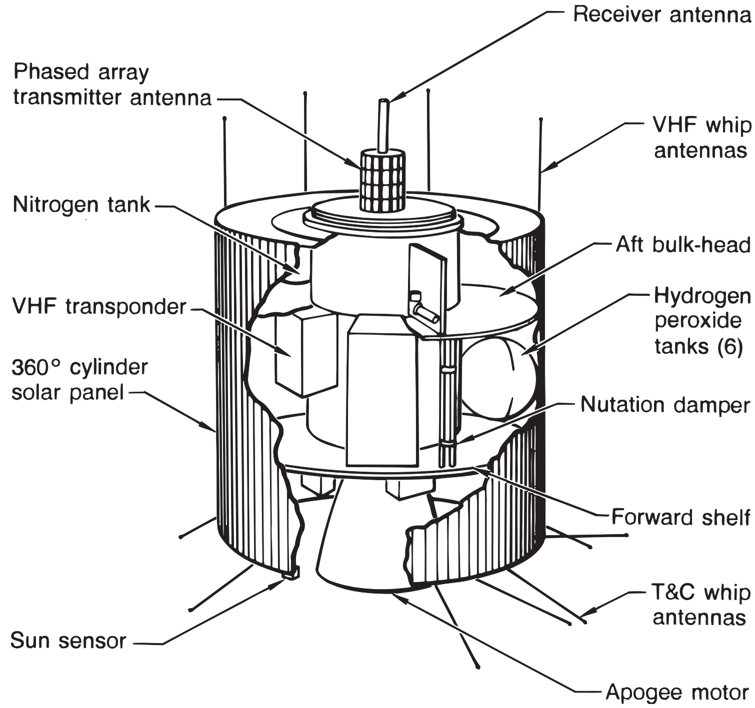

Fig. 1.23. ATS 1 satellite details.

combined into a composite signal that frequency modulated either the L-band or the C-band transmitter. An alternative frequency translation mode used the C-band receiver and the L-band transmitter. The transmitter could also be modulated by data from onboard experiments.

Configuration

25 MHz bandwidth repeater

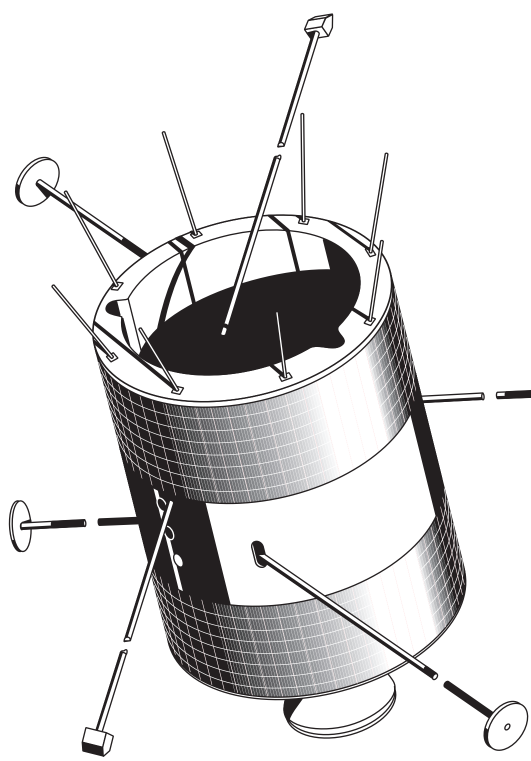

Fig. 1.22. ATS 4 satellite.

Transmitter

1550 MHz center frequency

Two TWTs used singly or together

12 W per TWT, 22.4 dBW EIRP (one TWT), 25.4 dBW EIRP (two TWTs)

Receiver

1651 MHz center frequency

8 dB noise figure

Antenna

17.2 dB gain

Of the five ATS launches, three satellites were successfully placed in orbit. ATS 2 and 4 did not achieve the desired orbit because of launch vehicle malfunctions, and few experimental data were obtained. The ATS 2 C-band repeaters operated 12 and 626 hr, and the ATS 4 repeaters operated only 9 and 30 hr. ATS 4 was in orbit only 2 months. ATS 2 was in orbit over 2 years but was deactivated after 6 months.

The experiments on both ATS 1 and ATS 3 were used extensively after the satellites were in orbit. Through March 1971, the four microwave communication repeaters on these satellites had accumulated about 35,000 hr of use. Tests were run in all modes, and numerous spacecraft parameters were measured. Various tests were run to determine the values of system noise, delay, frequency response, and intermodulation. In general, system performance was satisfactory according to commercial standards. The C-band communications equipment was also used a number of times for international television broadcasts of public interest.

Engineering performance measurements were also performed on the VHF equipment. System performance was evaluated for ground-satellite-aircraft links using equipment installed on several commercial aircraft. The U.S. Coast Guard performed tests using several shipborne terminals. In general, the results with both aircraft and ships were fair to good communications, and the quality of the satellite link was usually as good as, or better than, alternative communication links. The VHF equipment was also used for experiments in clock synchronization, navigation, and meteorological data collection and dissemination. Results were varied, often limited by available equipment or satellite design, but the experiments did provide a database and recommendations for future work. Since April 1971, the VHF repeater of ATS 1 was used regularly about 20 hr a week as a single channel international communication system called Project PEACESAT (Pan Pacific Education and Communication Experiments by Satellite). PEACESAT provided cultural and emergency communications to about 20 nations (mostly small island nations) of the Pacific basin. ATS 3 also provided communication services in the Pacific basin. Both ATS 1 and ATS 3 degraded in performance, but both continued in use for more than six times their 3-year design lives. In 1985, ATS 1 failed to respond to commands; therefore, it could no longer be kept at the correct location to serve all the Pacific basin users, even though its electronics remained usable. ATS 3 was still functioning properly into 1986.

ATS 5 was successfully placed into synchronous orbit. The satellite was to be spinning upon orbital injection and then despun, at which time the gravity-gradient stabilization would begin. During orbital injection, however, the satellite developed a spin about an axis normal to the intended spin axis. In this orientation, the satellite could not be despun. Because of the spinning condition, the satellite antennas pointed toward Earth only a small portion of each revolution. Hence, the communication experiments were operated with limited success in a pulsed type of operation synchronized with the periods of correct antenna orientation.

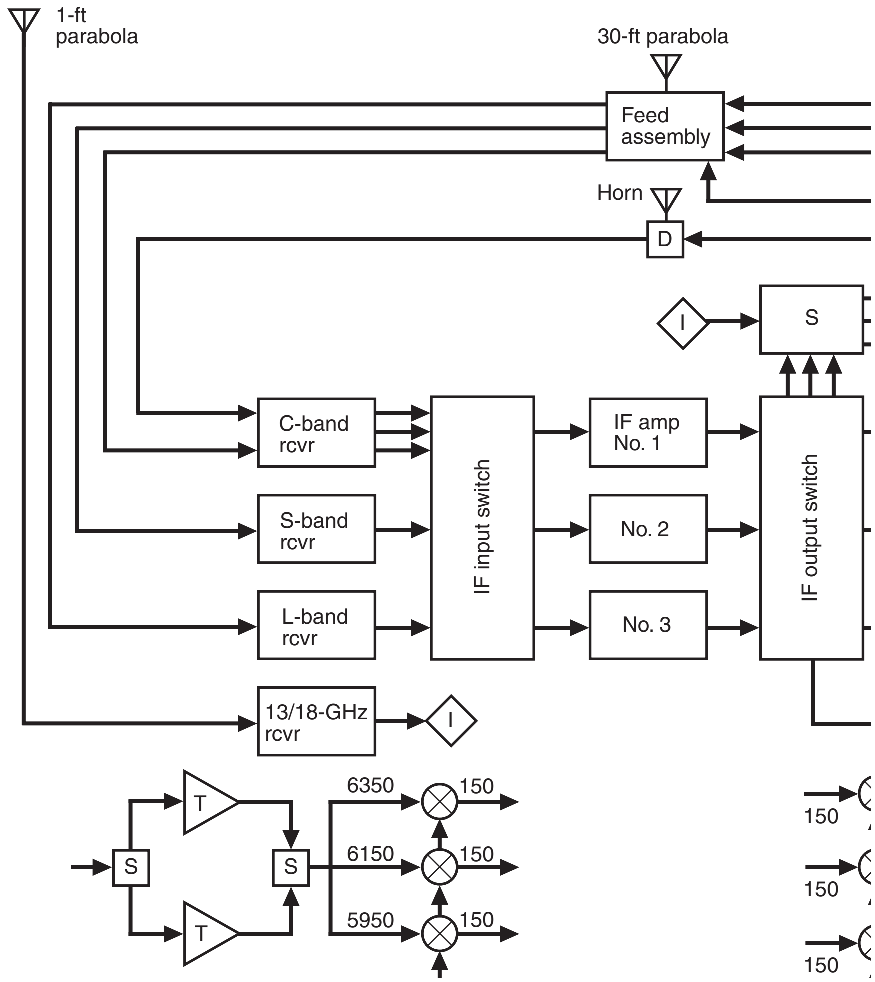

Fig. 1.24. ATS 1 to 5 communication subsystems.

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ATS 6

The ATS 6 satellite [1–28] was the second generation of the NASA Applications Technology Satellite program. Prior to launch, the satellite was designated ATS F. The program had included a second, very similar satellite called ATS G, but it was canceled for budgetary reasons. ATS 1 to 5, launched in 1966 through 1969, constituted the first generation. Eight of the experiments on ATS 6 were for communications and propagation studies that covered a frequency range from 860 MHz to 30 GHz.

ATS 6 consisted of a 30 ft diam parabolic antenna, an Earth-viewing module located at the focus of the parabola, two solar arrays, and the interconnecting structures. The antenna and the

Fig. 1.25. ATS 6 satellite.

solar arrays were deployed after the satellite was in orbit. All the communications experiments were located in a section of the Earth-viewing module. Feed horns for the large parabola were mounted on top of the module and other antennas on the bottom. General satellite characteristics are as follows.

Satellite

30 ft diam parabolic reflector, 6.5 ft diam hub section with copper-coated Dacron mesh supported by 48 aluminum ribs

Earth-viewing module at antenna focus with experiment sections and support subsystems, 54 x 54 x 65 in.

Two solar arrays (deployed in space), each half a cylinder, 54 in. radius, 94 in. long

Maximum height, 27 ft, 6 in., maximum span, 51 ft, 8 in.

Initial orbital weight 2970 lb

Power

Solar cells and NiCd batteries

645 W initial maximum

415 W minimum after 5 years

Stabilization

Three-axis-stabilized with inertia wheels, 0.1 deg pointing accuracy

Pointing to any location on Earth

Tracking of low-altitude satellite over ±11 deg from local vertical

Telemetry and command

Telemetry: 136.23, 137.11 MHz via two dipole antennas or main reflector; alternate path through C-band transmitter and horn antenna

Command: 148.26, 154.2 MHz via two dipole antennas or main reflector; alternate path through C-band receiver and horn antenna

Life

Two years (required), 5 years (goal)

Orbit

Synchronous equatorial; 94°W longitude until June 1975, 35°E longitude from July 1975 to July 1976, 140°W longitude until July 1979; moved out of synchronous orbit late 1979 or early 1980

Orbital history

Launched 30 May 1974

Titan IIIC launch vehicle

In use until turned off (July 1979)

Management

Developed by Fairchild for NASA

ATS 6 was launched in May 1974. It was originally positioned at 94°W longitude, where it was used with U.S. ground stations for 1 year. During June 1975, it was moved to 35°E longitude for the instructional television experiment broadcasts to India. At the same time, the NASA millimeter-wave experiment was used in conjunction with several European ground terminals. After the 1-year Indian experiment, in the fall of 1976, the satellite was slowly returned to the Western Hemisphere. During the transfer period, demonstrations of the social benefits possible with such a satellite were made in 27 countries. ATS 6 was then located at 140°W longitude and used in several experimental programs. It was turned off in the summer of 1979.

The position location and aircraft communication experiment (PLACE) was an extension of similar experiments conducted at ATS 1, 3, and 5. Like ATS 5, ATS 6 used frequencies near 1550 and 1650 MHz (L-band) for transmissions to and from aircraft. Both voice and digital data transmissions and a four-tone ranging system for aircraft position determination were part of the experimental program. The system was configured to permit multiple access voice from 100 aircraft in 10 kHz channels. At first, three ground terminals were used to simulate aircraft, with later experiments involving actual aircraft. The ranging signal operation had a transmission to all aircraft, with a coded data channel to designate one aircraft at a time to return the signal. All frequencies were coherently related to the ground station transmitter frequency so that range rate as well as range could be determined. Experiments included multiple aircraft tracking, determination of capacity limitations (ground equipment simulated most of the aircraft), determination of multipath effects, and evaluation of ground and aircraft terminals. Details of the experiment are as follows.

Configuration

Two-way link through ATS 6 between a ground terminal and aircraft for both voice and ranging functions

Transmitter (ATS 6 to aircraft link)

1550 MHz

40 W output, 40.3 or 51.0 dBW EIRP

Receiver (aircraft to ATS 6 link)

1650 MHz

G/T: –4.4 or –5.5 dB/K

Antenna
30 ft parabola, 28–29 dB gain with 0.8 x 7.5 deg fan beam, 38.5 dB gain with 1.5 deg pencil beam, circular polarization

Transmitter (ATS 6 to ground link)
One of 3750, 3950, or 4150 MHz

12 W output, 28 dBW EIRP on axis

Receiver (ground to ATS 6 link)
One of 5950, 6150, or 6350 MHz

G/T: –17 dB/K peak

Antenna
Horn, 16.3 to 16.5 dB gain, 13 x 20 deg beamwidth, linear polarization

The satellite instructional television experiment (SITE, or sometimes ITV) was a cooperative effort by NASA and the government of India. The basic objectives were to demonstrate the use of satellite television broadcasting for instructional purposes and to evaluate the various techniques and equipment. The television programs were prepared by the Indian government and transmitted at 6 GHz to ATS 6 from one of three ground stations in India. The satellite retransmitted the signals at 860 MHz. The 860 MHz signal was directly received in 2000 villages by community television receivers with simple 10 ft parabolic antennas. The signal was also received by regular television stations and rebroadcast to about 3000 villages in the standard VHF television band. The television signal had two audio channels with different dialects. (Operational systems may have as many as 14 audio channels to cover the major dialects and languages used in India.) The 1 year of SITE operation provided experience for development of a national television broadcast satellite system being planned by India. Details of the experiment are as follows.

Configuration
40 MHz bandwidth double-conversion repeater

Transmitter
860 MHz (3750 MHz used occasionally to monitor signals)

80 W output, 51.0 dBW EIRP peak

Receiver
5950 MHz

G/T: –17 dB/K peak

Antenna
Transmit: 30 ft parabola, 33 dB peak gain, 2.8 deg beamwidth, circular polarization

Receive: horn, 16.3 dB peak gain, 13 x 20 deg field of view, linear polarization (30 ft parabola might be used for receiving instead of horn, 48.4 dB peak gain, 0.4 deg beamwidth, +13.7 dB/K G/T)

The TRUST experiment (television relay using small terminals) was similar to SITE and used the same equipment in ATS 6. SITE was used in a year-long instructional program with evaluations of that program, whereas the main objectives of TRUST were hardware oriented. System performance was compared with design values, and ionospheric effects on system performance were measured. Considerable emphasis was placed on the small 860 MHz receiver. A program goal was to develop a terminal that would cost less than $200 in large-volume production. The experiment details are the same as given for SITE.

The health/education experiment (formerly the educational television experiment) was used to test satellite distribution of educational and medical programs. The educational programs were primarily for children, and the medical programs covered both professional education and consultation and general health care. The receiving terminals for the experiment were in areas where present television services are limited because of either geographical (Rocky Mountain states, Alaska) or social (Appalachia) factors. Two separate television channels could have been transmitted by ATS 6 using separate antenna beams (produced by two feed horns and the 30 ft reflector). Since a 1 deg beamwidth was used, transmission to the various geographic areas occurred at different times. The transmissions from ATS 6 were at 2570 and 2670 MHz (S-band). Some of the receiving terminals were equipped to provide an S-band return link through ATS 6. Details of the experiment are as follows.

Configuration
Forward link: two 30 to 40 MHz bandwidth repeaters for two FM-TV carriers with sound subcarriers plus separate telephone carriers

Return link: for telephone carriers

Transmitter
2570 and 2670 MHz (also C-band for monitoring)

15 W output, 53.0 dBW peak EIRP

Receiver
5950 MHz

G/T: –17 dB/K peak

Antenna
Transmit: 30 ft parabola, 41.5 dB peak gain, 1 deg beamwidth, circular polarization

Receive: horn, 16.3 dB peak gain, 13 x 20 deg field of view, linear polarization (30 ft parabola might be used for receiving instead of horn, 48.4 dB peak gain, 0.4 deg bandwidth, 13.7 dB/K G/T)

In the tracking and data relay satellite experiment, ATS 6 was used to relay commands and tracking signals to, and data and tracking signals from, GEOS-3 and Nimbus 6. The returned data were compared with data received from the spacecraft at a standard ground terminal. The orbit was computed from the range and range rate data obtained through ATS 6 and the uncertainty of the orbit determination compared with theoretical predictions. ATS 6 used S-band for communications with the spacecraft and C-band for communications with the ground. An array of feed horns under the 30 ft reflector was switched to allow the antenna beam to track the spacecraft along its orbit. The same equipment was also used to provide a communications relay between the ground and an Apollo spacecraft during the Apollo-Soyuz Test Project. Details of the experiment are as follows.

Configuration
Two 12 or 40 MHz bandwidth channels

Two-way link through ATS 6 between ground and a low-altitude satellite

Transmitter (ATS 6 to satellite link)

2063 MHz

20 W output, 48.0 dBW EIRP minimum

Receiver (satellite to ATS 6 link)

2253 MHz

G/T: 7.0 dB/K minimum

Antenna

30 ft parabola, 36.4 dB gain minimum, 13.2 deg overall field of view using switched feeds, circular polarization

Transmitter (ATS 6 to ground link)

3753 MHz primary (alternates 3953 or 4153 MHz)

12 W output, 28.0 dBW EIRP peak

Receiver (ground to ATS 6 link)

5938 MHz primary (alternates 6138 or 6338 MHz)

G/T: –17 dB/K peak

Antenna

Horn: 16.5 dB transmit gain (peak), 16.3 dB receive, 13 x 20 deg field of view, linear polarization

The frequencies from 5925 to 6425 MHz are shared by terrestrial and satellite communication services. The RFI experiment was used to determine the extent of interference between these two services. When the RFI experiment was operating, the entire 500 MHz bandwidth of interest was received by ATS 6 and retransmitted to a ground station. Data processing at the ground station was used to determine the power levels and geographic and frequency distribution of the terrestrial sources of noise. The minimum detectable noise source EIRP was 10 dBW, and the frequency resolution was 10 kHz. A portable ground station was used as a tracking beacon for ATS 6 and as a system calibration source. Details of the experiment follow.

Receiver

5925 to 6425 MHz

G/T: +17.0 dB/K (30 ft parabola) or –17.0 dB/K (horn) peak, minimum detectable ground source is 10 dBW EIRP

Antenna

30 ft parabola, 48.4 dB gain peak, 0.4 deg beamwidth, circular or linear polarization

Horn, 16.3 dB gain peak, 13 x 20 deg beamwidth, linear polarization

ATS 6 had two millimeter-wave experiments. The NASA experiment used a C-band uplink and 20 and 30 GHz downlinks, whereas the Communications Satellite (Comsat) Corporation experiment used 13 and 18 GHz uplinks and a C-band downlink. In the NASA experiment, the 20 and 30 GHz downlinks could have been unmodulated, modulated by an onboard tone generator, or modulated by a communication signal received on the C-band uplink. The continuous-wave propagation tests had sufficient power to accommodate fades as deep as 60 dB, whereas the communication mode was used with digital data rates up to 40 Mbps. A 4 GHz downlink was used with the millimeter-wave downlinks for comparisons. The objectives of the experiment were to measure the characteristics of the millimeter-wave links and to compare directly measured propagation effects with indirect measurements such as radiometric sky temperature, radar backscatter, and meteorological conditions. Details of the experiment follow.

Configuration

Propagation modes: continuous-wave or multitone downlinks

Communications mode: 40 MHz bandwidth repeater

Transmitter (propagation modes)

20.0 and 30.0 GHz

Continuous wave: 2 W output, 30 dBW peak EIRP

Multitone (nine tones): 0.06 W output/tone, 15 dBW peak EIRP/tone

Transmitter (communications mode)

20.15 and 30.15 GHz and one of 3750, 3950, or 4150 MHz

20.15 GHz: 2 W output, 40 dBW peak EIRP

30.15 GHz: 2 W output, 42 dBW peak EIRP

C-band: 12 W output, 28 dBW peak EIRP

Receiver (communications mode only)

One of 5950, 6150, or 6350 MHz

G/T: 13.7 dB/K (30 ft parabola), –17 dB/K (horn)

Antenna

Propagation mode: horn, 27 dB peak gain, 5 x 7 deg beamwidth, linear polarization

Communication mode:

- 20.15 GHz: 1.5 ft parabola, 37 dB gain, 2.4 deg beamwidth
- 30.15 GHz: 1.5 ft parabola, 39 dB gain, 1.6 deg beamwidth
- C-band transmit: horn, 16.5 dB gain, 13 x 20 deg beamwidth
- C-band receive: horn, 16.3 dB gain, 13 x 20 deg beamwidth or 30 ft parabola, 48.4 dB gain, 0.4 deg beamwidth

In the Comsat Corporation millimeter-wave experiment, 39 unmodulated uplinks were received by ATS 6 and retransmitted to a ground station on a C-band downlink. Fifteen stations scattered throughout the eastern part of the United States (>100 miles separation) each transmitted 13 and 18 GHz uplinks. Nine additional stations transmitting 18 GHz uplinks were placed in groups of three near (<25 miles separation) three dual-frequency stations. The experiment operated on a nearly continuous basis for about 1 year. The results are useful for determining the required weather margins for future communication links using frequencies near 13 or 18 GHz. Data from the three groups of stations, with smaller separations, were used to determine attenuation correlation and, hence, the uplink improvement possible with space diversity. Details of the experiment are as follows.

Configuration

Thirty-nine unmodulated uplink carriers received and retransmitted to a control ground terminal in a 30 MHz bandwidth

Transmitter

4150 MHz

0.2 to 1.3 mW output per carrier

–13 to –21 dBW EIRP per carrier

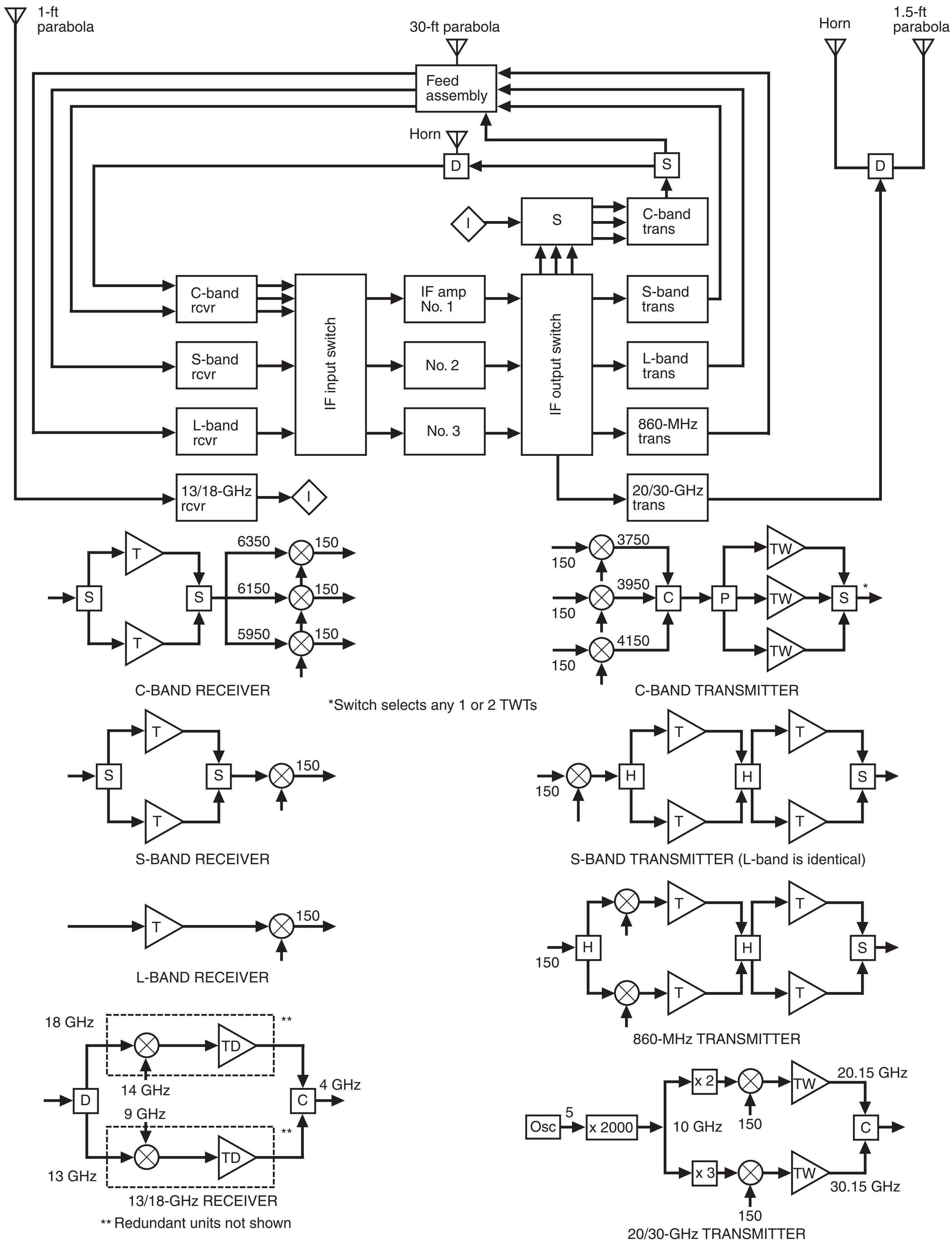
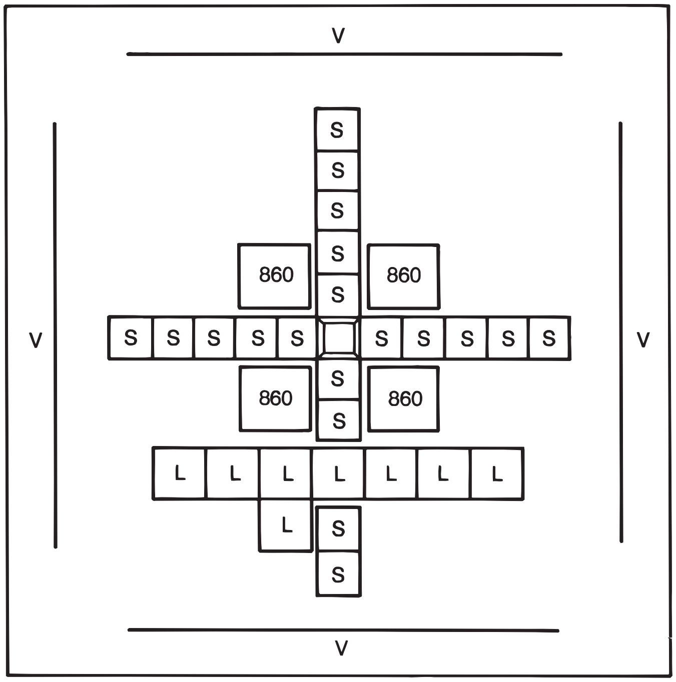


Fig. 1.26. ATS 6 communication subsystems.



Center	C-band horn surrounded by 4-horn S-band monopulse
S	S-band cavity backed crossed dipoles
L	L-band cavity backed crossed dipoles
860	860-MHz cavity backed crossed dipoles
V	VHF (130 to 150 MHz) dipoles

Fig. 1.27. Feed structure for the ATS 6 30 ft reflector.

Receiver

Fifteen carriers near 13.19 GHz and 24 near 17.79 GHz

10 dB noise figure

Antenna

Transmit: horn, 17 dB gain

Receive: 1 ft parabola, 26/28 dB peak gain (13/18 GHz), 4 x 8 deg beamwidth, linear polarization

The communications equipment on ATS 6 included four receivers (C-, S-, L-band, and 13/18 GHz), three IF amplifiers, and five transmitters (C-, S-, L-band, 860 MHz, and 20 and 30 GHz). The 13/18 GHz uplink was downconverted to C-band, amplified, and routed to the C-band transmitter. The other uplinks were amplified and filtered before downconversion to the 150 MHz intermediate frequency. Any receiver (except 13/18 GHz) could have been connected to any one of the three identical IF amplifiers, which could have provided either 12 or 40 MHz bandwidths. The IF outputs could have been connected to any of the transmitters. The transmitters included upconverters, driver amplifiers, and power amplifiers; most of these elements were redundant. The C-band and 20 GHz transmitters used TWTs, whereas the lower-frequency transmitters were all transistorized. The primary communication antenna was the 30 ft parabola. In addition, the satellite had a C-band horn and two small parabolas and a horn for the millimeter-wave experiments. The feed structure for the large reflector included 36 elements to provide efficient performance for the various frequencies and beam patterns used in the communications experiments. The arrangement of the feed elements on the top surface of the Earth-viewing module is shown.

* * * * * *

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Communications Technology Satellite

The Communications Technology Satellite (CTS), formerly called Cooperative Applications Satellite C (CAS-C), was a joint effort of the Canadian Department of Communications and NASA [1–22]. The main purpose of CTS was to demonstrate advanced spacecraft techniques that were applicable to higher-power transmissions in the 12 to 14 GHz band, including a high-power transmitter, a lightweight extendable solar array with an initial output above 1 kW, and a three-axis stabilization system to maintain accurate antenna pointing. Canada developed the satellite. NASA provided the primary experiment, which was a 200 W output, 50-percent efficient 12 GHz TWTA (traveling wave tube amplifier). NASA also had the responsibility for launching the satellite. The European Space Research Organization (ESRO), now known as ESA (European Space Agency), participated in the CTS program by supplying one of the TWTAs, a parametric amplifier, and some other items.

The satellite body was roughly a cylinder 6 ft in height and diameter, which was injected into a synchronous equatorial orbit in a spinning condition. Solar cells on the satellite body supplied power during this time. After it was despun, two 51 x 244 in. solar panels were deployed from opposite sides of the body. The solar panels rotated about their long axis to track the sun continually. The antennas were mounted on gimbals on the front (Earth-viewing) end of the body and required no deployment. Satellite details are as follows.

Satellite

Body 72 in. diam, 74 in. height with two solar arrays 51 in. wide and 20 ft, 4 in. long; total satellite span 52 ft, 9 in.

738 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 1360 W initially, approximately 930 W minimum during last year (1979)

Three-axis stabilization using a variable-speed momentum wheel, ±0.1 deg about pitch (north-south) and roll (velocity vector) axes, ±1.1 deg about yaw (radial) axis

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

Configuration

Two 85 MHz bandwidth single-conversion repeaters

Transmitter

11.843–11.928 GHz and 12.038 to 12.123 GHz

Normal configuration 20 W TWTA on low band and 200 W TWTA on high band, alternately both bands share the 20 W TWTA (at reduced capability)

Receiver

14.010–14.095 GHz and 14.205 to 14.290 GHz

Two preamplifier chains (one on, one standby)

Noise temperature:

Approximately 2000 K with tunnel diode preamplifier or approximately 1350 K with parametric amplifier

G/T: 6.4 dB/K on-axis with parametric amplifier

Antenna

Two 28 in. diam antennas, 36.2 dB gain on axis for transmit and receive, 2.5 deg beamwidth, steerable over ±7.25 deg linear polarization

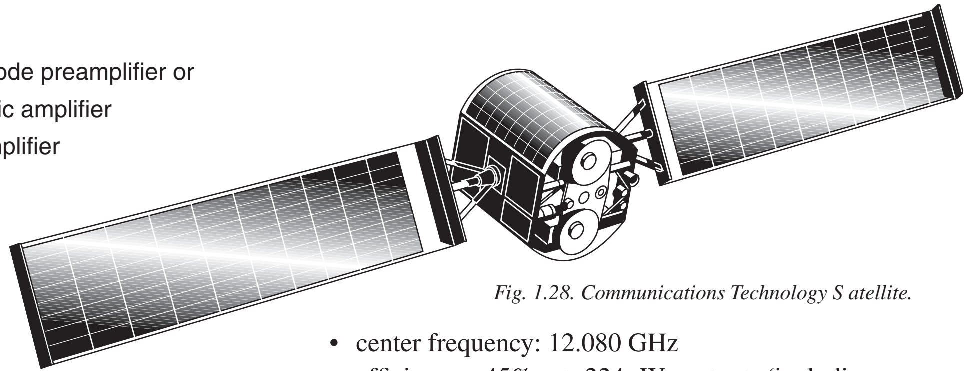

Fig. 1.28. Communications Technology S atellite.

Telemetry and command

Telemetry: 2277.5 MHz, 2 W transmitter

Beacon: 11.7 GHz, 200 mW transmitter

Command: 2097.2 MHz

Life

Two years

Orbit

Synchronous equatorial, 116°W longitude, (142°W last half of 1979) ±0.2°E-W stationkeeping, inclination ≤0.8 deg through mid-1979

Orbital history

Launched 17 January 1976

Delta 2914 launch vehicle

In use until turned off (November 1979)

Management

Developed by Canadian Department of Communications

The communication equipment included 20 and 200 W TWTAs. Two 85 MHz channels were available. Normally, one of the redundant 20 W TWTAs was the power amplifier for one channel as well as the low-level driver for the 200 W TWTA on the second channel. In a backup mode, the 200 W TWTA was bypassed, and the output of the 20 W TWTA was divided between the two channels. Some characteristics of the 200 W TWTA, as demonstrated during the first 6 months in orbit, were

- construction: coupled cavity, multistage depressed collector, conduction cooling
- RF output at saturation: 200 W continuous-wave minimum over the operating band, 240 W peak, 30 dB gain, 3 dB bandwidth ≥85 MHz
- center frequency: 12.080 GHz
- efficiency: 45% at 224 W output (including power supply)

The CTS had redundant receivers, one with a tunnel diode preamplifier and the other with a parametric amplifier. Both receiver chains were single conversion and had a tunnel diode amplifier (TDA) following the mixer. The receivers fed redundant field effect transistor amplifiers that provided the input signals for the TWTAs. The satellite had two narrowbeam antennas, one directed toward a control terminal and the other toward remote terminals. The two channels were used for two-way communications. The high-power TWTA was used for transmission to the remote terminals that used relatively small antennas.

Canada, NASA, and other U.S. Government agencies started conducting communication experiments with the CTS following its launch on 19 January 1976. Canada had its control terminal at Ottawa and remote terminals in the north. The capability of the CTS allowed the remote terminals to be relatively small, as indicated by the characteristics given in Table 1.2. The CTS could support several simultaneous links with these terminals. For example, the 8 ft terminal noted in Table 1.2 could receive a television signal transmitted with only a quarter of the total CTS power. In May 1976, the CTS was renamed Hermes in Canada. By mid-1978, 32 experimental programs had been completed or were in progress and seven more were planned. These experiments were in the fields of propagation, communications engineering, television broadcasting, education, medicine, government, and community affairs. Results were positive and encouraged further work. The operational viability of many of these projects was studied further using the 12 and 14 GHz channels on Anik B. In July 1979, CTS was moved to support satellite communications testing in Australia. CTS was used until November 1979, at which time it was turned off.

* * * * * *

Table 1.2. CTS Ground Terminals

Function	Diameter (ft)	Antenna Peak Gain (dB)	Antenna Beamwidth (deg)	Receiver Type and Noise Temperature (K)	GT (db/K)	Maximum Transmitter Power (W)
Control terminal						
Transmit and recieve TV and multiplexed voice signals	30	59	0.18	Uncooled paramp, 425	32.9	1000
Remote terminals						
TV transmission	10	50	0.54	TDA, 1150	19.5	1000
TV reception and two-way voice	8	48	0.67	TDA, 1150	16.5	1
Two-way voice	4	42	1.3	Mixer, 2660	7.8	1
Receive FM sound broadcast	2 equivalent	35	2 x 4	Mixer, 2660	0.8	

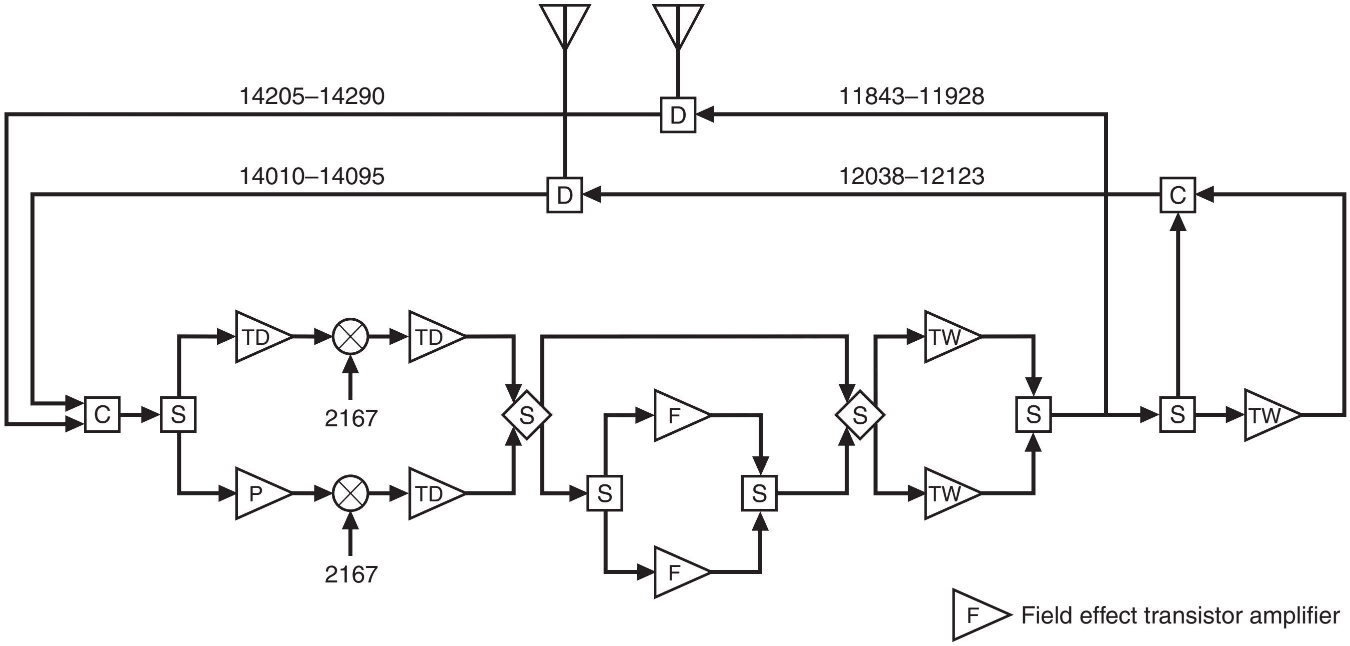

Fig. 1.29. CTS communication subsystem.

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Sirio

The Italian industrial research satellite (Sirio) [1–12] was developed for use in propagation and communication experiments at 11.6 and 17.4 GHz. These frequencies were selected prior to the 1971 World Administrative Radio Conference and, therefore, did not exactly coincide with the satellite communication frequency bands defined at the conference. A large part of the Italian aerospace industry participated in construction of the satellite under direction of the Italian National Research Council (CNR). Three ground stations in Italy plus stations in other European countries participated in the Sirio experiments.

The satellite had a cylindrical, spin-stabilized body with a despun antenna on one end. All the equipment was mounted on an internal platform. The payload was primarily for support of the three primary experiments: propagation, NB communications, and WB communications. Secondary experiments were for measurements of the natural environment at synchronous altitude.

In the propagation experiment, the 17.4 GHz uplink was amplitude-modulated at 386 MHz to produce two sidetones 772 MHz apart. In the satellite, they were converted to about 386 MHz with a separation of 20 kHz, and a calibrated reference signal was inserted between them. This combined signal was further converted to 266 MHz and used to amplitude-modulate the 11.6 GHz downlink carrier. The downlink carrier amplitude was controlled to provide a reference level. This combination of uplinks and downlinks allowed all measurements to be performed on the ground. The measurements made were absolute attenuation at 11.6 and 17.4 GHz, and relative attenuation and phase delay over frequency intervals of 772 MHz and 532 MHz. In addition, multiple ground receivers were used to measure space diversity improvement. Space diversity on the uplink was achieved by having two sidetones transmitted from different locations.

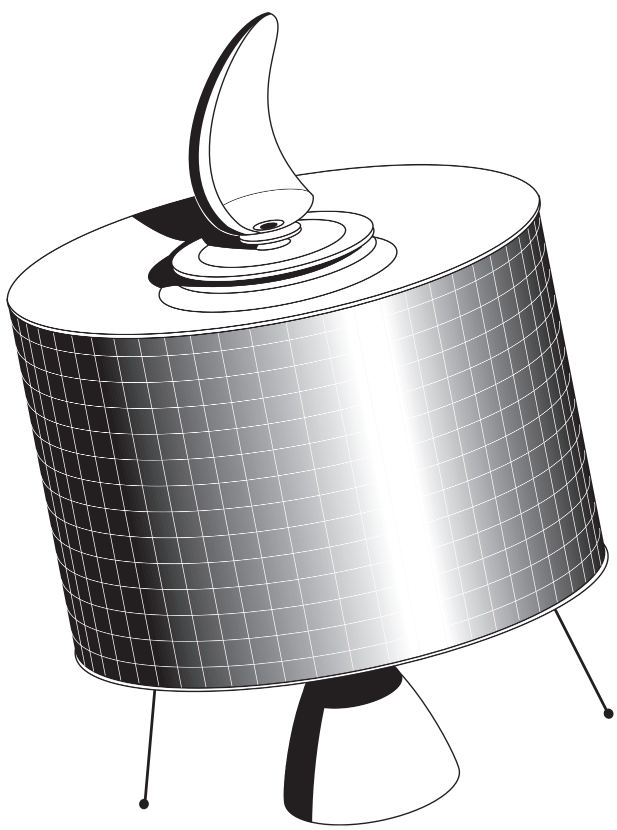

Fig. 1.30. Sirio satellite.

In the NB communication mode, as many as 12 biphase modulated carriers were transmitted to the satellite by frequency division multiplexing. The data rate on each carrier was 70 kbps, and the satellite bandwidth was 2.5 MHz. In the satellite, the combined signal was amplified at IF and then used to modulate the downlink carrier. The WB communication mode was similar, except that the satellite bandwidth was 35 MHz. The uplink transmission was a single television channel or high-rate digital data.

The satellite was operated in any one of the three modes. The satellite equipment was common for all the modes except for portions of the IF section. The transmitter output power was 10 W from either of two TWTAs. The equipment details are as follows.

Satellite

Cylinder, 56 in. diam, 34 in. height (78 in. overall)

480 lb in orbit, beginning of life

Solar cells, 135 W beginning of life, 100 W minimum after 2 years

Spin-stabilized, 90 rpm

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

Configuration

Communication experiment: 2.5 MHz bandwidth repeater with as many as twelve 70 kbps carriers, or 35 MHz bandwidth repeater with one TV channel

Propagation experiment: 40 kHz bandwidth repeater

Transmitter

11.597 GHz

10 W output TWTA (one on, one standby)

EIRP: propagation mode, 16 dBW; NB communication, 24 dBW; WB communication, 26 dBW; all at edge of coverage (all 5 dB higher in central 1 deg of beam)

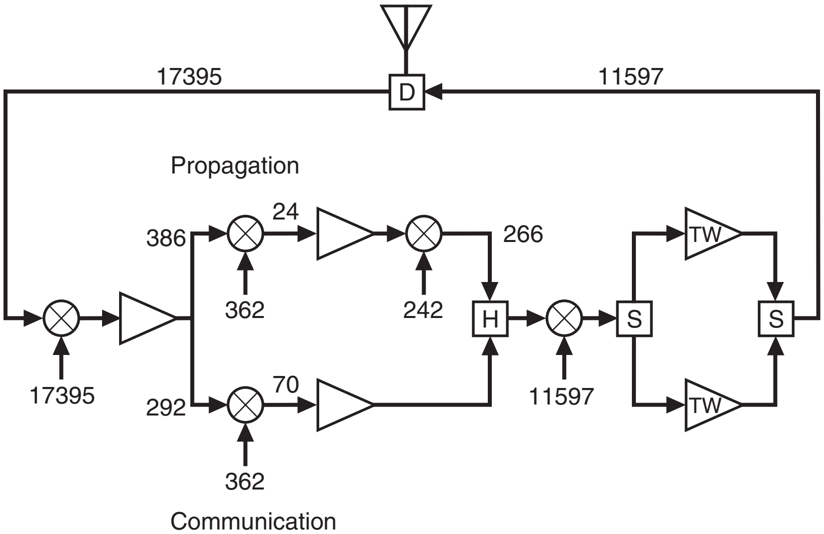

Fig. 1.31. Sirio communication subsytem.

Receiver

17.395 GHz

G/T: –16 dB/K (–10 dB/K over central 3 x 5 deg of beam)

Antenna

Fixed feed horn with mechanically despun reflector, >22.5/23.5 dB gain on axis (11.6/17.4 GHz), 6 x 10 deg beamwidth (6 deg is north-south beamwidth), beam center 6.5 deg above equatorial plane, steerable 3.5°W to 4.5°E of satellite nadir, circular polarization

Telemetry and command

Telemetry: 136.14 MHz, 6.5 W transmitter

Command: 148.26 MHz

Four quarter wave monopole antennas

Life

Two years

Orbit

Synchronous equatorial, 15°W longitude, later moved to 12°E longitude; moved to 65°E in early 1983; drifting in 1990s

Orbital history

Launched 25 August 1977, in use until 1985

Delta 2313 launch vehicle

Management

Developed by Italian aerospace industry for CNR (Consiglio Nazionale della Richerche)

The Sirio experiment was defined in 1968 and was originally scheduled to be launched in 1972. A number of delays occurred as the result of technical, political, and financial reasons. The satellite was launched 25 August 1977 and used in a variety of experiments. In 1983, it was moved to a position over the Indian Ocean for cooperative Chinese-Italian experiments, which lasted until October 1984. Sirio was turned off in 1985.

The Sirio 2 satellite was an ESA program. The satellite was primarily constructed with hardware left over from the basic Sirio program, but the payloads were different. Sirio 2 had an S-band transponder for distribution of meteorological data between ground sites, and a detector and retroreflector for a laser clock synchronization experiment.

The Sirio 2 program started in 1978. The satellite was launched together with a Marecs satellite on an Ariane launch vehicle in September 1982. A failure in the Ariane third stage resulted in the loss of both satellites.

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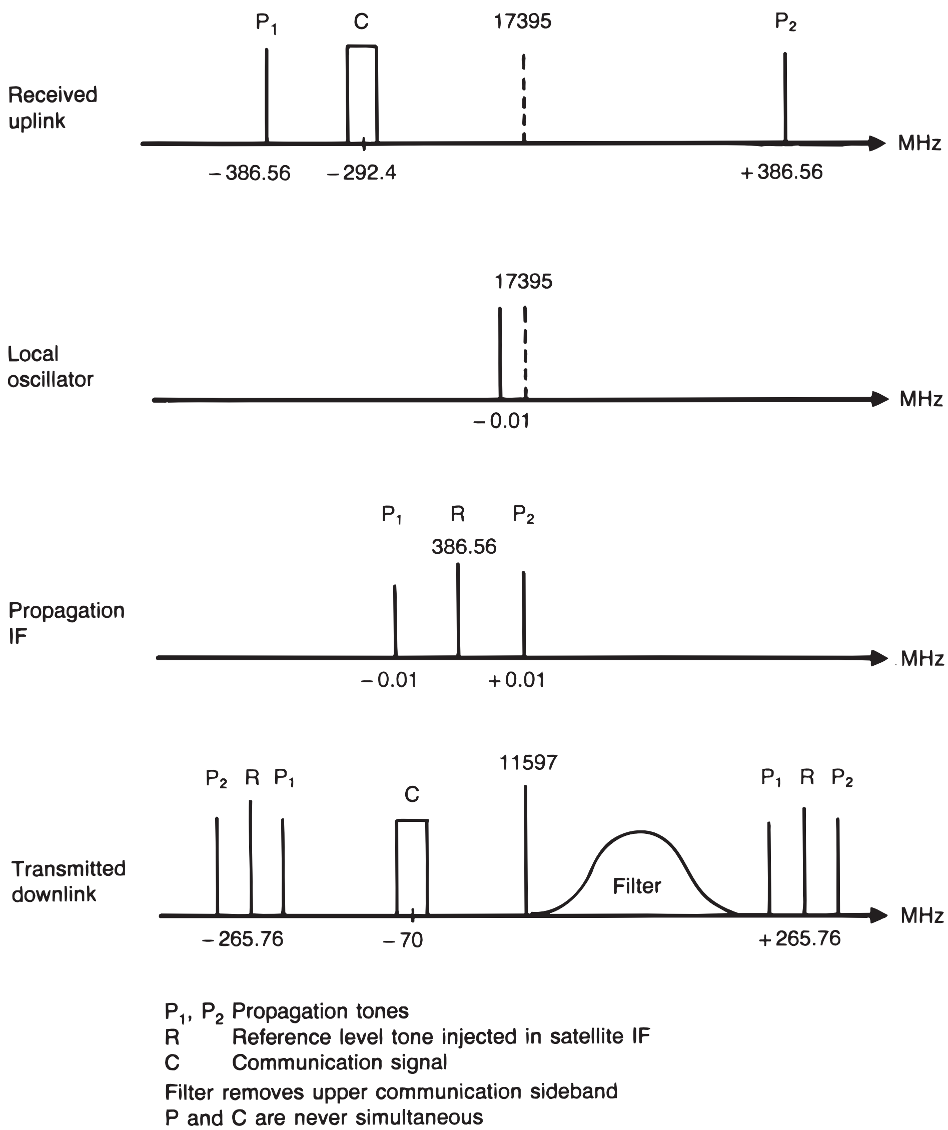

Fig. 1.32. RF spectra in the Sirio satellite.

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   b. A. Canciani, "System and Subsystem Design Criteria of the Sirio Satellite."

   c. G. Perrotta, "The SHF Experiment Onboard Equipment."

   d. S. Tirro, "The System Design of the SHF Experiment."

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Japanese Satellites

Japan built and launched several low-altitude satellites in the early 1970s, but its first communications and broadcasting satellites were built in the United States and launched by NASA. These are described in chapter 8. At the same time, Japan was developing smaller synchronous orbit satellites and a launch vehicle for them. The launch vehicle was the N rocket, which was based on the 1970 design of the U.S. Thor-Delta. An improved version, the N-2, was based on the mid-1970s Delta. The first synchronous orbit mission for this launch vehicle was the Engineering Test Satellite-II (ETS-II), described in chapter 9. The successor to ETS-II was the Experimental Communication Satellite (JECS), which was also launched by the N rocket. Japan continued the development and test of satellite bus and payload technologies and the demonstration of improved launch vehicles with a series of Engineering Test Satellites (ETS), also known by the name Kiku. This section describes the Engineering Test Satellites that have or had a communications or broadcasting payload. Three closely related satellites not numbered in the ETS series are also described: the Communications and Broadcasting Engineering Test Satellite (COMETS), the Optical Intersatellite (or Inter-orbit) Communications Engineering Test Satellite (OICETS), and the Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS).

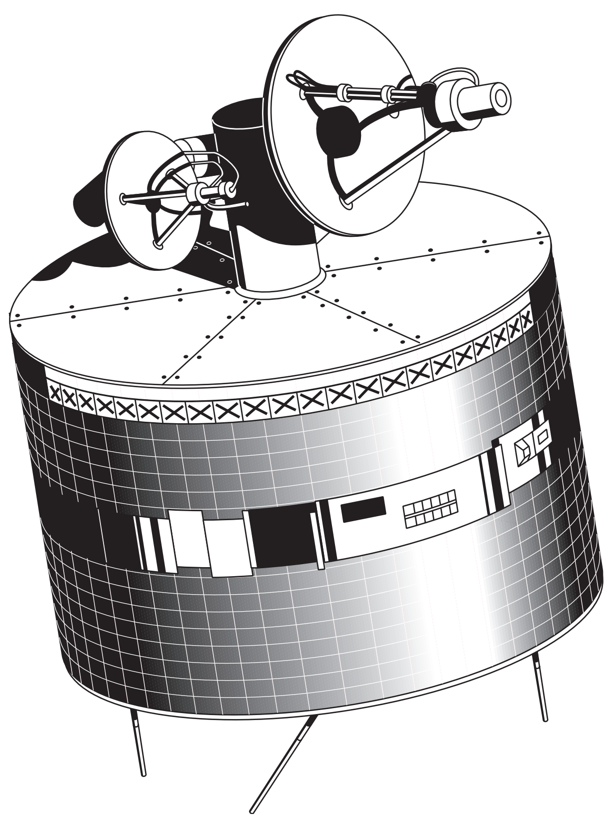

Fig. 1.33. Japanese Experimental Communication Satellite.

Japanese Experimental Communication Satellite

The objectives of the Japanese Experimental Communication Satellite (JECS) program [1–4] were to develop techniques for launch and on-orbit control of synchronous satellites, to make propagation measurements, and to conduct communications experiments. The satellites were launched on the Japanese N rocket. JECS was based on the Skynet I design, because the Skynet was sized to the Delta launch vehicle from which the N rocket was developed; both satellites were built by the same manufacturer. Like Skynet, JECS was spin-stabilized with a mechanically despun antenna. The solar array was mounted around the outside of the spinning body, and other subsystems were attached inside the spinning body on both sides of an equipment platform. The despun section had two parabolic antennas whose beamwidth was sized to cover Japan while minimizing radiation on adjacent nations. The larger antenna was for C-band (4 and 6 GHz), and the smaller was for K-band (31 and 34 GHz). There was also a 128-element C-band array mounted around the top end of the satellite body, which provided nearly onmidirectional coverage. The C-band equipment could be switched between the two C-band antennas. Technical details of the satellite are as follows.

Satellite

Cylinder, 55.7 in. diam, 37 in. height (64.8 in. overall)

Approximately 290 lb in orbit, beginning of life

Solar cells and NiCd batteries, 118 W maximum at beginning of life, 99 W minimum after 1 year

Spin-stabilized, 80–115 rpm

Configuration

Single transponder with selectable bandwidth of 10, 40, or 120 MHz, input and output independently switchable to either C-band or K-band

Transmitter

C-band: 4.08 GHz center frequency, redundant 5 W TWTAs (one on, one standby), 23 dBW EIRP

K-band: 31.65 GHz center frequency, single 2.5 W TWTA, 34 dBW EIRP

Receiver

C-band: 6.305 GHz center frequency, tunnel diode preamplifier, –12 dB/K G/T

K-band: 34.83 GHz center frequency, mixer followed by transistor amplifier, –5 dB/K G/T

Antenna

C-band: narrowbeam parabola, 22 in. diam, measured minimum gain with rotary joint loss 20.5/23.6 dB (transmit/receive), beamwidth approximately 9/6.5 deg

C-band: array composed of 128 cavity-backed crossed dipoles mounted in a band around the satellite body, pattern nearly uniform in array plane and ±45 deg from the plane

K-band: narrowbeam parabola, 12 in. diam, measured minimum gain with rotary joint loss 34.7/34.9 dB (transmit/receive), beamwidth approximately 2.5 deg

All antennas use circular polarization

The two narrowbeam antennas are despun together

Telemetry and command

Telemetry: approximately 136 MHz, via four monopole antennas

Beacon: 3.94 GHz, via either C-band parabola or array

Command: approximately 148 MHz, via 4 monopole antennas

Life

Approximately 1.5 years

Orbit

Synchronous equatorial, 145°E longitude planned, both satellites actually are drifting in near synchronous elliptical orbit

Orbital history

JECS A: launched 6 February 1979, destroyed by collision with launch vehicle third stage during apogee motor firing

JECS B: launched 22 February 1980, destroyed by apogee motor failure

Japanese N launch vehicle

Management

Developed by Mitsubishi (prime), Ford Aerospace and Communications Corporation (spacecraft and antennas), and Nippon Electric Company (transponder) for National Space Development Agency of Japan

The communication subsystem of the JECS had five basic sections, shown in Fig. 1.34: C- and K-band receivers (left), an intermediate frequency section (middle), and C- and K-band transmitters (right). The IF section handled only one signal at a time. By ground commands, either transmitter and either receiver could be connected to the IF section, giving a total of four possible configurations. The bandwidth of the IF section could be switched to 10, 40, or 120 MHz. The 10 MHz option was intended for range and range rate measurements and the wider bandwidths for the communications experiments.

JECS was launched in early February 1979 but was destroyed during apogee motor firing, apparently by a collision with the launch vehicle third stage. The spare JECS was launched a year later and was destroyed by a failure of the apogee motor.

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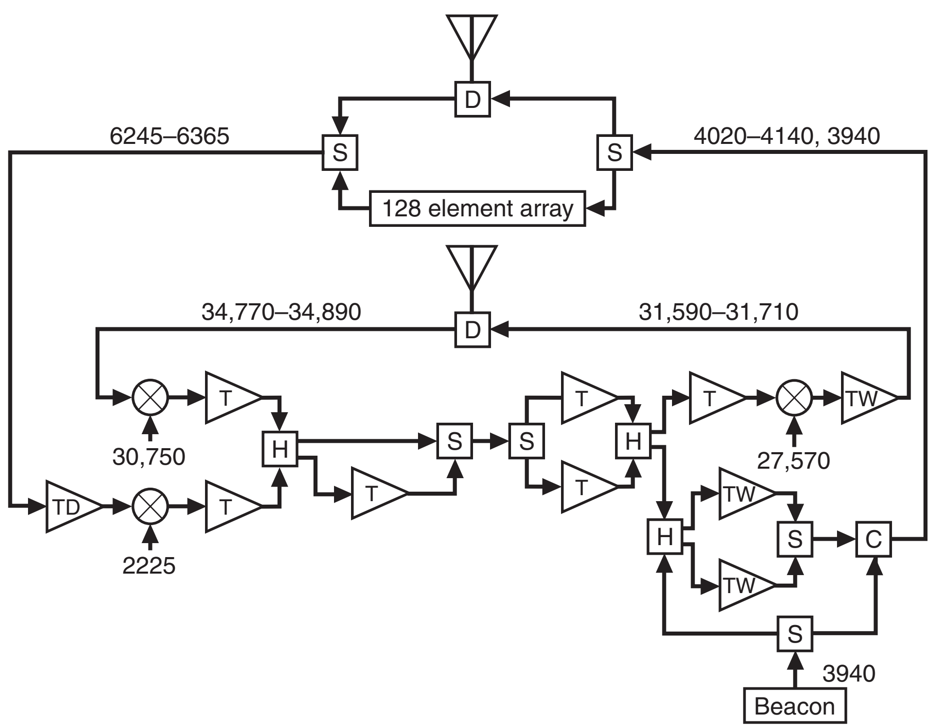

Fig. 1.34. JECS communication subsystem.

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Engineering Test Satellite V

The Japanese national space program has used Engineering Test Satellites (ETS) as a means of proving basic equipment and techniques for satellites, launch vehicles, and satellite control and operations. ETS-V [1–14] was the first of this series to incorporate a communications payload. The ETS-V satellite, also known as Kiku-V had four objectives:

- to serve as a test payload for the Japanese H-1 launch vehicle and high-energy upper stage
- to establish three-axis stabilization technology for synchronous orbit satellites
- to use in experiments in maritime communications with Japanese fishing vessels
- to use in experiments in aeronautical communication and navigation and air traffic control

The communications payload of ETS-V, which was used in satisfying the third and fourth objectives, was called the Aeronautical Maritime Experiment Transponder. It was the space segment of the Experimental Mobile Satellite System.

The ETS-V satellite body, the solar arrays, and the antennas are shown in Fig. 1.35. ETS-V was the first Japanese-built three-axis-stabilized satellite and served as a test of the stabilization subsystem as well as of the deployable, sun-tracking solar arrays. It was the first communication satellite of any nation to use GaAs solar cells, which were being produced in Japan. The satellite stabilization accuracy was equal to the state of the art achieved by other nations. The satellite and payload details are as follows.

Satellite

Rectangular body about 1.4 x 1.67 x 1.74 m, 3.47 m height to top of antenna, 9.7 m across tips of deployed solar arrays

1080 kg at launch, 529 kg in orbit, end of life

Solar cells and NiCd batteries, 1067 W maximum, beginning of life; 820 W minimum, end of life

Three-axis stabilized, ±0.08 deg 3σ (pitch and roll), ±0.45 deg 3σ (yaw)

Configuration

C/L-band for fixed to mobile terminals, 3 MHz bandwidth

L/C-band for mobiles to fixed, 3 MHz bandwidth

C/C-band for fixed to fixed, 3 MHz bandwidth

L/L-band for mobiles to mobiles, 300 kHz bandwidth

Transmitter

L: 1540.5–1543.5 MHz and 1545–1548 MHz

Two 25 W FET amplifiers

35.5 dBW per channel EIRP on axis

C: 5218.75–5241.25 MHz

Two 8 W FET amplifiers

25 dBW EIRP on axis

Receiver

L: 1642.5–1645.5 MHz and 1647 to 1650 MHz

FET preamps, 1.65 dB noise figure

–4 dB/K minimum G/T on axis

C: 5948.75–5971.25 MHz

FET preamps, 2.1 dB noise figure

–8 dB/K G/T on axis

Antenna

L: one 1.5 m diam parabolic reflector, offset fed by two helices to produce two beams, each with approximately 9 deg beamwidth and 25 dB on axis gain, circular polarization

C: one Earth coverage horn with approximately 20 dB on axis gain, circular polarization

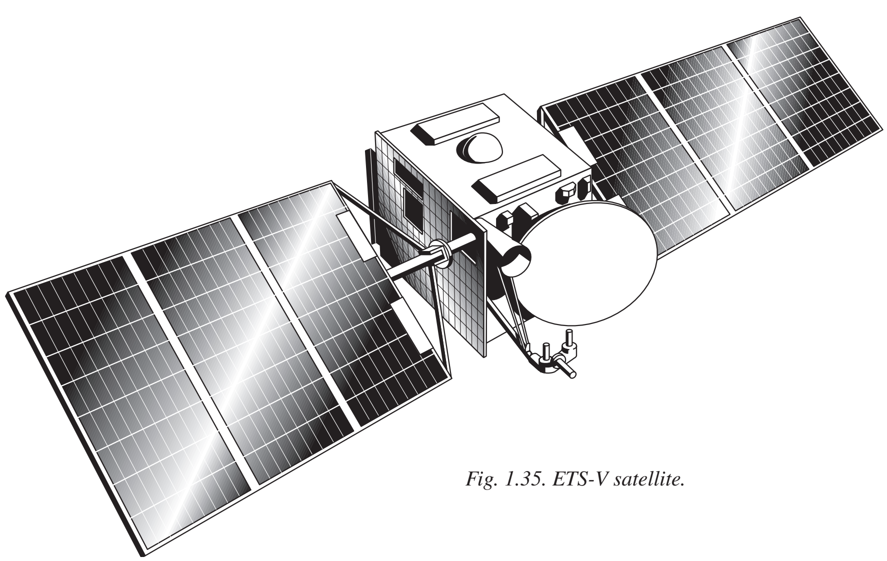

Fig. 1.35. ETS-V satellite.

Telemetry and command

Telemetry: in 2200–2290 MHz

Command: in 2025–2110 MHz

Life

Five years (1.5 year fuel load planned)

Orbit

Geostationary, 150°E longitude, stationkeeping to ±0.1° N-S and E-W

Orbital history

Launched 27 August 1987, still operating in 1992, moved above synchronous orbit after 1995

Japanese H-1 launch vehicle

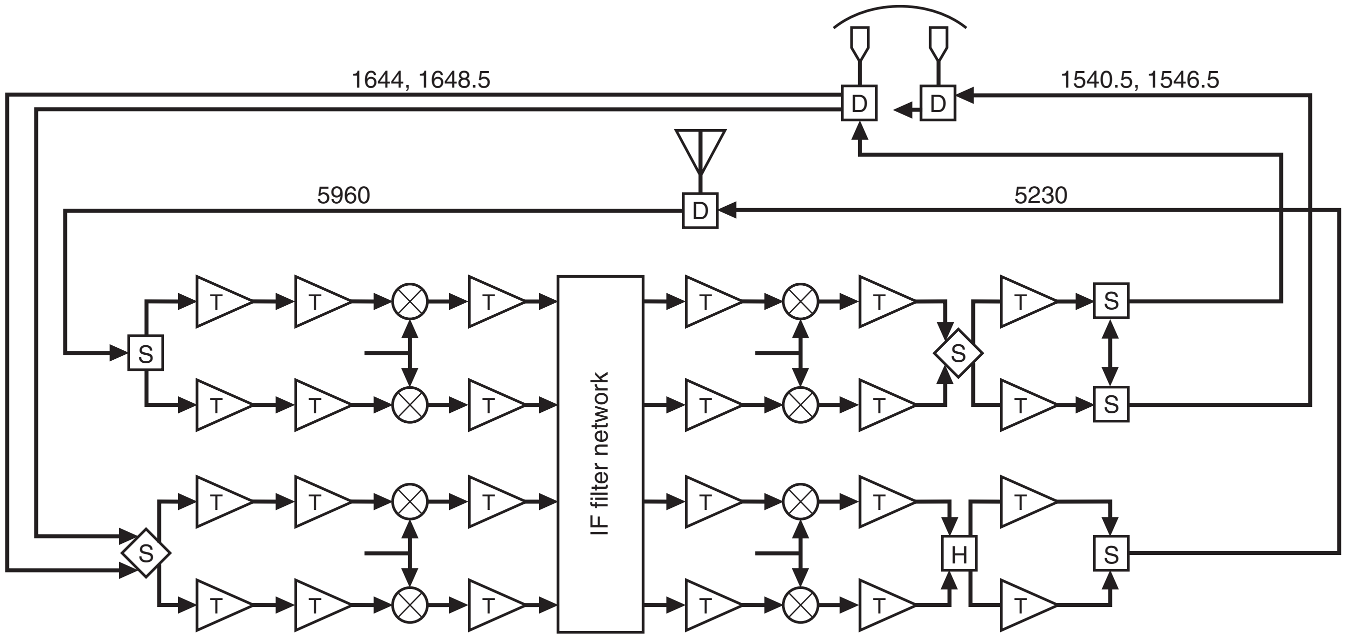

Fig. 1.36. ETS-V communication subsystem.

Management

Developed by Mitsubishi Electric Company (prime contractor) and NEC (communication subsystem) for NASDA, Ministry of Posts and Telecommunications, and Ministry of Transport

Operated by NASDA

The payload used C-band to communicate with fixed ground terminals in Japan and L-band to communicate with mobile terminals, that is, ships and airplanes. Both antennas as well as an S-band telemetry and command antenna can be seen on the satellite (Fig. 1.35). The L-band antenna generated two independent beams, which provided coverage of all Asian coastal waters and seas and about half of the Pacific Ocean. The two beams provided higher gain than a single beam with broader coverage; this gain was necessary to limit the antenna size required on the mobiles.

Because ETS-V was a test satellite, rather than an operational one, the communication subsystem had only partial redundancy. There were four paths through the subsystem, for communication between fixed terminals (C-band receiver/C-band transmit), from fixed to mobile terminals (C/L-band), from mobile to fixed terminals (L/C-band), and between mobile terminals (L/L-band). The path was determined by the uplink frequency, which caused the IF filter network to route the signal to the proper downlink. The IF filters were constructed with surface acoustic wave devices.

The ETS-V satellite development began in 1983. The satellite was launched in 1987. Initial testing showed that the satellite and the payload were operating properly. The primary mobile communications experiments were conducted between Earth stations in Japan and a ship and a 747 aircraft. Signal quality was measured in many conditions, and fading countermeasures were tested. Land mobile communications were conducted with vehicles and trains; three modulation formats were tried. The 1-1/2 year basic operational period of the satellite finished successfully in 1989.

Following the basic mobile communications experiments, several supplementary experiments have been conducted. One was a position location test using signals from a mobile station transmitted through both ETS-V and the Pacific Inmarsat. In another experiment, non-government organizations used the satellite for mobile communications demonstrations. In addition, Aussat conducted land mobile experiments through the southern L-band antenna beam. Other experiments were conducted while the satellite continued to operate. The experience gained through the ETS-V experiments will be applied in the future design of an operational mobile communications satellite system.

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Engineering Test Satellite VI

ETS-VI [1–38] was one of the Experimental Test Satellites (ETS) developed and launched by Japan. The project had three broad objectives. One was spacecraft technology: to develop and operate a three-axis-stabilized satellite weighing more than 4000 lb. Another was to verify the capability of the Japanese H-II launch vehicle by launching ETS-VI on the second flight of the H-II series. A third was to build, and demonstrate in orbit, several communications payloads incorporating new technologies appropriate to future operational missions.

The development aspect of the spacecraft technology objective was carried out both by the basic design features of ETS-VI and by several experiments. The spacecraft body was a rectangular box, with solar arrays, two large antenna reflectors, and one smaller antenna compartment, which deploy from it in orbit. The structure was made of composite materials. A bipropellant system was used for the apogee maneuver and in-orbit control, augmented by ion thrusters for north-south stationkeeping. A nickel-cadmium battery was the primary power storage, but ETS-VI also had a nickel-hydrogen battery. The latter was new for Japan, although common in other satellites, whereas the ion thrusters were a new technology for a 10-year life satellite. Other aspects of the ETS-VI attitude control and power used techniques new to Japan. In addition, the satellite carried a variety of sensors to measure the launch environment and the internal and external environments in orbit.

ETS-VI had six communications payloads. The largest was the fixed communications payload, to demonstrate high-capacity services between fixed-site ground terminals. The primary frequency bands were 20 and 30 GHz. Each was associated with one of the large reflectors, which form very narrow beams. Twelve of these beams were required to cover the main islands of Japan. To reduce the payload weight in order to accommodate other payloads, only four beams were implemented. Two of these pointed at Tokyo and Osaka, which are the largest metropolitan areas; the same frequencies were used independently in both beams. This frequency reuse, in addition to dual polarization frequency reuse, demonstrated techniques necessary for a very high capacity communications satellite. Being an experiment, this payload did not have as many 20 and 30 GHz transponders as the spectrum can support. However, it also had one transponder using the 4 and 6 GHz bands. This transponder shared the 30 GHz reflector and has one beam that covered most of Japan. Its purpose was to be an alternate to any of the 20 and 30 GHz transponders and beams, if the traffic exceeded their capacity or if they were temporarily unavailable due to attenuation caused by heavy rain.

The mobile communications payload shared the 20 GHz reflector and had five beams, which covered all of Japan plus the ocean areas to 200 miles offshore. The main demonstration with this payload was communications between small fishing vessels and shore stations. The one transmitter of this payload amplified the signals for all five beams, dividing its power automatically in proportion to the number of signals in each beam. This feature was important because the traffic patterns for mobile terminals are variable.

The fixed and mobile communications payloads were connected through an IF switch. This allowed signals from any of the uplink beams to be routed to any of the downlink beams. The switch was fast enough to route individual time division multiple access (TDMA) bursts to different beams. Within the fixed communications payload, the TDMA rate was as high as 200 Mbps; rates within the mobile communications payload were limited by its 5 MHz bandwidth. The IF switch was supplemented by a 20 GHz RF routing switch. Both switches shared an onboard controller, which communicated with the ground via separate 20 and 30 GHz control and status links.

Another payload was the S-band intersatellite link. Its performance was similar to that of the S-band multiple access portion of the U.S. Tracking and Data Relay Satellite (TDRS). The reason was that the Japanese planned to develop their own relay satellite compatible with the U.S. TDRS. The antenna used a 19-element phased array to form one transmit and two receive beams steerable to any satellite at altitudes up to 1000 km. In the satellite drawing in Fig. 1.37, the phased array is the flat hexagonal panel to one side of the antenna tower. These S-band intersatellite links were coupled with 20 and 30 GHz feeder links to and from the ground; together they provided two-way communications between ground stations and low orbit satellites. Transmissions were PSK with code division multiple access. Bit rates up to 1.5 Mbps were possible, but rates under 300 kbps were used most of the time.

Another intersatellite link payload used Ka-band: 23 GHz for a link from ETS-VI and 26 GHz for a return link. This payload was similar to one planned by the United States for the Advanced TDRS, and now in orbit on TDRS 8 to 10. Its purpose was to prepare for the Japanese relay satellite in a manner compatible with TDRS (and with the planned European relay satellite). Like the S-band intersatellite payload, this payload was coupled with 20 and 30 GHz feeder links between ETS-VI and the ground. Data rates up to about 10 Mbps will to be tested. Testing of both intersatellite payloads began with a ground-based user satellite simulator.

Another ETS-VI payload was for millimeter wave communications. The primary purpose of this payload was to demonstrate communications with very small Earth terminals, for example, as small as a 30 cm diameter antenna and 0.5 W transmitter. Another application was for an intersatellite link, which can be demonstrated with a ground-based simulator. This payload used 38 GHz for transmissions from ETS-VI and 43 GHz to ETS-VI. The data rate with small Earth terminals was 64 to 512 kbps; for intersatellite demonstrations it was 10 Mbps. The attenuation caused by rain is very high at these frequencies, but many of the applications postulated for the small Earth terminals do not require continuous communications and are able to tolerate outages during storms. The millimeter wave payload was small—a 16 in. antenna and a weight of 22 lb. It was mounted on the same platform as the Ka-band intersatellite payload. A single pointing mechanism steered the platform and provided the antenna pointing control for both payloads. These payloads were mounted on the side of the antenna tower opposite the S-band phased array. The millimeter-wave payload was also connected to the 20 and 30 GHz feeder links for communications with the primary experiment ground terminals.

ETS-VI also had an optical communications payload. The aim of this payload was to demonstrate technology for an intersatellite link. The payload had a 7.5 cm diameter telescope. The uplink used an argon laser, the downlink a GaAlAs diode laser. The data rate was 1 Mbps. The payload used a two-stage control loop. A charge-coupled device array detector provided coarse pointing information to the outer loop, which controlled a gimballed flat mirror. A quadrant detector provided fine pointing information to an inner loop, which controlled the fine pointing mechanism. Pointing accuracy while autotracking the uplink was expected to be 2 mrad (0.0001 deg).

Development of ETS-VI began in 1987. Structural and thermal tests of satellite engineering models were conducted in 1989 and 1990. Additional details are as follows.

Satellite

Rectangular body 2.0 x 3.0 x 2.8 m, 29.95 m across the deployed solar arrays, 7.85 m height of body plus antenna tower

3800 kg at launch, 2000 kg in intended orbit, beginning of life; 1906 kg dry

Sun-tracking solar arrays, NiCd battery (operations), NiH_2 battery (test), approximately 4720 W beginning of life, 4100 W minimum at summer solstice after 10 years

Three-axis-stabilized, ±0.05 deg accuracy in pitch and roll, ±0.15 deg accuracy in yaw

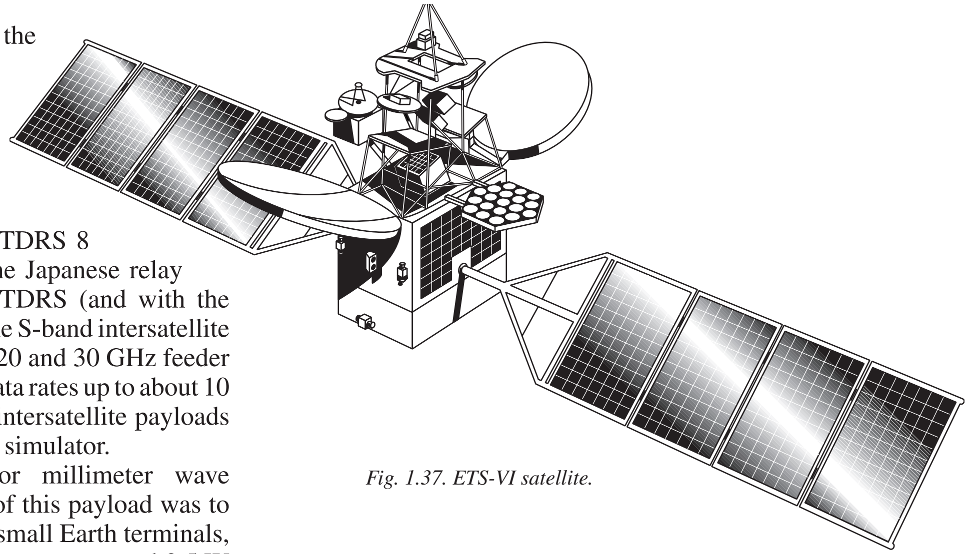

Fig. 1.37. ETS-VI satellite.

Liquid bipropellant propulsion for apogee maneuver, hydrazine monopropellant for on-orbit use, plus ion propulsion for north-south stationkeeping

Configuration

Fixed communications payload (FC): multiple 200 MHz bandwidth transponders at C band (4 and 6 GHz) and Ka-band (18 and 30 GHz) connecting multiple beams through an IF switch, dual-polarization and dual-beam frequency reuse

Mobile communications payload (MC): five beams connected through a single 5 MHz bandwidth S-band (2.5/2.6 GHz) transponder

S-band Intersatellite Link payload (S-ISL): one forward transponder with 5 MHz bandwidth, one return transponder with 5 MHz bandwidth

Ka-band Intersatellite Link payload (K-ISL): one forward transponder and one return transponder

Millimeter wave payload (MMW): one forward transponder and one return transponder

Optical payload (Opt): duplex communications, 1 Mbps data rate

S-ISL, K-ISL, and MMW are each connected with 30 GHz (uplink) and 20 GHz (downlink) feeder links through a 2 GHz IF switch network; the two transponders within each of these payloads can be connected to each other as an alternative to the feeder link connections

Transmitter

FC: 3.82 GHz (H polarization), 4.08 GHz (H), 17.885 GHz (V and H), 18.365 GHz (V)

7 W SSPAs at 4 GHz

K-ISL feeder: 19.938 GHz

S-ISL feeder: 20.1219, 20.2455 GHz

10 W TWTAs at 18 GHz, plus 4 W SSPA near 20 GHz for a downlink associated with the ISL and MMW payloads

MC: 2502.5 MHz

8 GaAs FET power amplifiers

100 W total output power flexibly shared among beams

S-ISL: 2108.4 MHz

0.9 W SSPA for each of 16 antenna elements

34.2 dBW minimum total EIRP

K-ISL: 23.3875 GHz

3 W SSPA

36.2 dBW minimum EIRP

MMW: 38.0 GHz

Two SSPAs, one 0.8 W, one 0.5 W, each with four parallel GaAs FETs in the final stage, one active, one spare

Opt: 0.83 micron

Two GaAlAs laser diodes, 14 mW average power, one active, one spare

Receiver

FC: 6.045 GHz (V polarization), 6.305 GHz (V), 27.685 GHz (V and H), 28.165 GHz (V), 30.805 GHz (V),

3.5 dB receiver noise figure at 6 GHz

K-ISL feeder: 29.772 GHz

S-ISL feeder: 29.8984 GHz

5 dB receiver noise figure with HEMT preamplifiers at 27 to 31 GHz, <7.4 dB system noise figure

MC: 2657.5 MHz

2.5 dB receiver noise figure

S-ISL: 2287.5 MHz

1.5 dB receiver noise figure

–4 dB/K minimum G/T

K-ISL: 25.8505 GHz (data), 25.298 (beacon)

5 dB receiver noise figure with HEMT preamplifier

6.4 dB/K minimum G/T

MMW: 43.0 GHz

5.2 dB receiver noise figure with HEMT preamplifier

Opt: 0.51 micron

Avalanche photodiode

Antenna

FC and MC: One 2.5 m diam reflector for 4, 6, and 27–31 GHz; one 4 and 6 GHz feed horn produces one beam with 33/35 dB gain at edge of coverage, linear polarization; about two dozen 27–31 GHz feed horns form four 0.3 deg beams with 48 dB gain at edge of coverage, dual linear polarizations; the two frequency bands share the antenna via a frequency selective surface; 0.015 deg antenna pointing accuracy at 27–31 GHz using a steerable subreflector. One 3.5 m diam reflector for 2 and 18 GHz; twelve 2 GHz feed horns produce five beams with 31 dB gain at edge of coverage, circular polarization; about two dozen 18 GHz feed horns form four 0.3 deg beams with 48 dB gain at edge of coverage, dual linear polarizations; the two frequency bands share the antenna via a frequency selective surface; 0.015 deg antenna pointing accuracy at 18 GHz using a steerable subreflector

S-ISL: 19-element phased array, elements arranged in a hexagonal pattern, 5.8 ft across corners; all 19 elements used to form two receive beams, 16 elements used to form one transmit beam; element gain ≥14.8/14.5 dB (receive/transmit); total gain >27.3/26.2 dB (receive/transmit); beams steerable ±10 deg, pointing error ≥1.1 deg; circular polarization

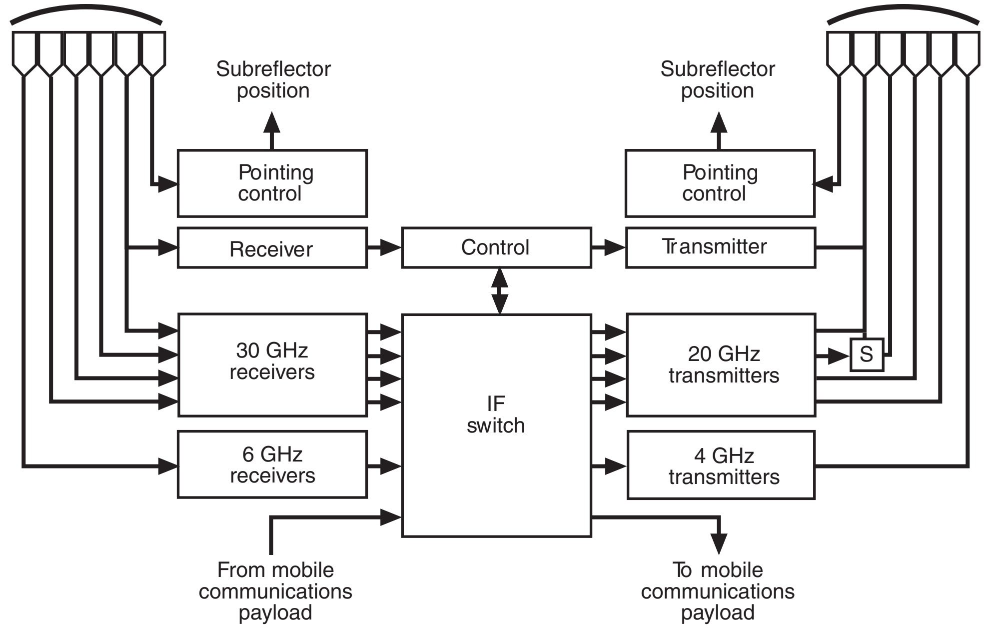

Fig. 1.38. ETS-VI fixed communications subsystem.

K-ISL: 80 cm diam parabola, >34.7/36.3 dB gain (transmit/receive), ±0.2 deg pointing accuracy with autotracking, steerable ±9.8 deg, circular polarization

MMW: 40 cm diam parabola, 37/41 dB gain (transmit/receive), mounted on same steerable platform as Ka-ISL antenna, circular polarization

Opt: 7.5 cm diam gimballed telescope, 30 or 60 mrad (1.7 or 3.4 mdeg) transmit beamwidth; two-stage pointing with autotrack, coarse pointing accuracy 32 mrad, fine pointing accuracy 2 mrad

Telemetry and command

Telemetry: in 2200–2290 MHz

Command: in 2025–2110 MHz

Life

Ten years (spacecraft), 2 to 3 years (payloads)

Orbit

Geostationary, stationkeeping to ±0.1° N-S and E-W intended, but see “Orbital history”

Orbital history

Launched 28 August 1994, did not reach intended orbit; initial orbit approximately 4200 x 20,800 nmi, 13 deg inclination; orbit for experimental use 4620 x 20,873 nmi, 13 deg inclination

Japanese H-II launch vehicle

Management

Developed for NASDA by Toshiba (spacecraft), NTT (FC and MC payloads), and others

ETS-VI was launched in August 1994. The launch vehicle operated as expected and delivered the satellite to a transfer orbit. However, because of a faulty valve, the satellite’s apogee motor produced only one-tenth of the design thrust, which left the satellite in an inclined, elliptical orbit. Since the satellite could not be moved to a circular, geostationary orbit, the initial orbit was modified slightly in November 1994 to a period of five orbits in 3 days, so that the satellite track, as

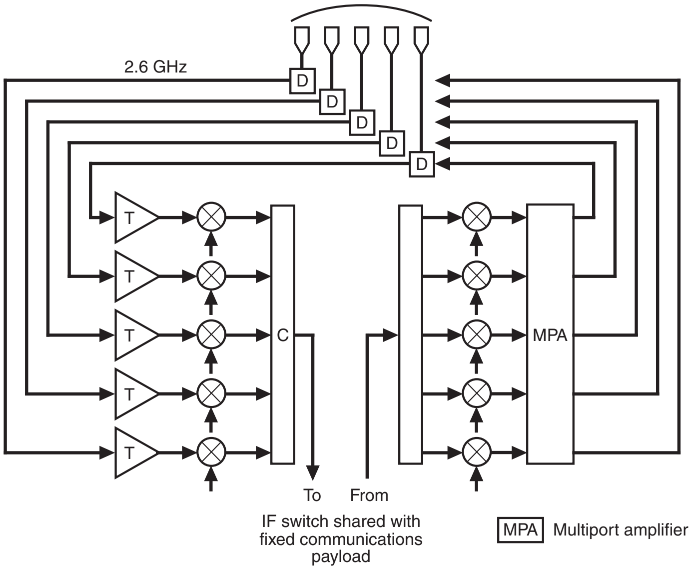

Fig. 1.39. ETS-VI mobile communications subsystem.

viewed from the ground, repeated every 3 days. New attitude control and solar-array pointing strategies were developed and implemented. These allowed use of the satellite, although with limitations on the portions of the orbit available for experiments. Furthermore, the radiation level in this orbit is much higher than in the intended geostationary orbit, which causes the solar array output to decrease faster.

Experiments with the satellite began late in 1994. All of the satellite bus technology experiments, except the apogee propulsion, were successful. Use of the communication subsystems showed that all equipment was functioning with performance levels close to those measured before launch. S-band mobile communications were demonstrated and propagation data were gathered. Performance of the S-band intersatellite link was measured, and the link was demonstrated with a simulated user at a ground station and then with NASA's Upper Atmosphere Research Satellite. Performance of the millimeter wave payload was measured and demonstrations and propagation measurements conducted using it. Acquisition and tracking of the optical uplink and downlink were demonstrated and atmospheric conditions measured in Japan. Optical acquisition, tracking, and bit error rate measurements were conducted with a NASA ground station in California. Communication experiments with ETS-VI continued into 1996.

* * * * * *

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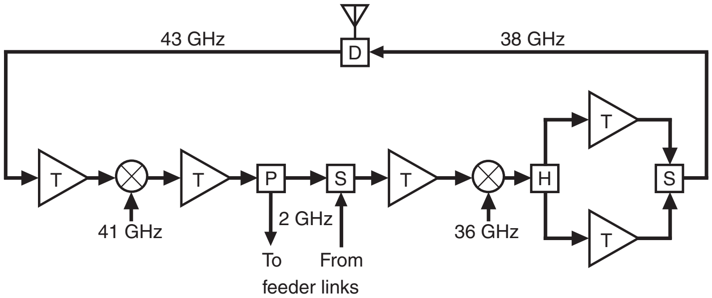

Fig. 1.40. ETS-VI millimeter wave subsystem.

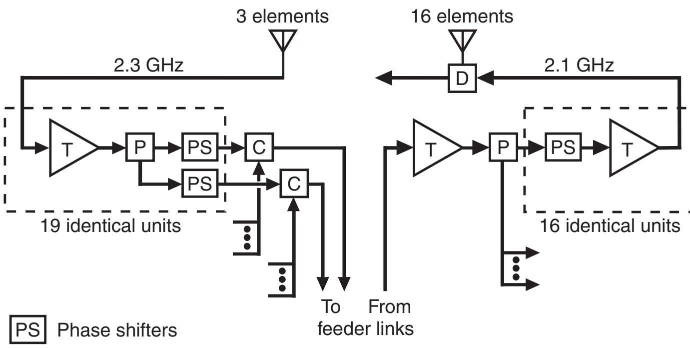

Fig. 1.41. ETS-VI S-band intersatellite link subsystem.

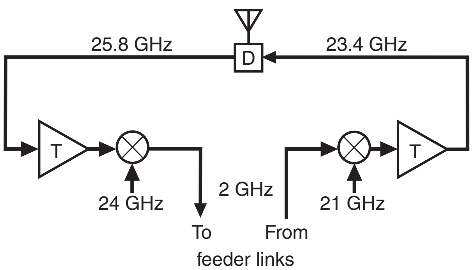

Fig. 1.42. ETS-VI Ka-band intersatellite link subsystem.

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Communications and Broadcast Engineering Test Satellite

The Communications and Broadcasting Engineering Test Satellite (COMETS) program [1–16] was conducted by the Japanese National Space Development Agency (NASDA) and by the Communications Research Laboratory of the Ministry of Posts and Telecommunications. COMETS, also known as Kakehashi, continued the efforts of the ETS-V and ETS-VI programs in the development of new technology and the conduct of experiments in three fields: data relay, broadcasting, and mobile communications. The COMETS program began in 1990. The satellite bus was derived from that of ETS-VI; it supports three payloads.

The purpose of the interorbit communications equipment was to demonstrate link acquisition and tracking, and data transfer between satellites in geosynchronous and low Earth orbits, and to evaluate orbit determination of the satellites by means of tracking data derived from the links. The Japanese advanced Earth observation satellite was to have been the primary low orbit satellite communicating with COMETS. The technology and experiments with this payload directly supported development of Japan's data relay satellite system, for which the first satellite was launched in 2002 (refer to chapter 8). This relay system is intended to be interoperable with those of NASA and the European Space Agency (ESA).

The interorbit communications payload had both S-band and Ka-band interorbit links coupled with K-band links between COMETS and the ground. The interorbit link frequencies were compliant with the interoperability agreement of NASDA, NASA, and ESA. The payload supported single forward (COMETS to low orbit) and return (low orbit to COMETS) channels in each frequency band. The return link data rate capability was 100 bps to 6 Mbps at S-band and 1 to 120 Mbps at Ka-band; the forward rate was 100 bps to 300 kbps at S-band and 100 kbps to 30 Mbps at Ka-band. Modulation formats included BPSK and QPSK. The acquisition and tracking experiments had a goal to demonstrate a tracking loss of no more than 0.5 dB at Ka-band with a 3.6 m diam antenna on COMETS.

The purpose of the satellite broadcasting equipment was to evaluate performance of the equipment on the satellite and to conduct broadcasting experiments. Several past and current Japanese satellites provide television broadcasting in the 12 GHz downlink band. This payload was the first evaluation of the 21 GHz satellite broadcasting band. (Although the allocated satellite broadcasting band is 21.4 to 22.0 GHz, the COMETS payload transmitted at 20.7 GHz.) The payload had two beams, one each for the southern and Tokyo areas of Japan; these two were representative of six beams that would cover all of Japan in an operational system. One broadcasting signal was transmitted in each of the two beams. The satellite power amplifier was a 200 W coupled cavity TWTA developed in Japan. Broadcasting experiments included comparisons of modulation and compression techniques and evaluation of the effects of atmospheric attenuation and cochannel interference between the two beams.

The purpose of the mobile communications equipment was to test mobile and personal communications equipment and techniques that could be implemented in a future system. Both K-band and millimeter wave frequencies were tested. These frequencies were chosen for the wide bandwidth available and the small size mobile terminals that can be built. The disadvantage was link outages because of the high atmospheric attenuation in rain; these outages were considered acceptable for personal communications, whereas they are not acceptable for many other communication links.

This payload had two antenna beams, one aimed at Tokyo and one aimed at the adjacent Nagoya area. Both had K-band capability; the Tokyo beam also had the millimeter wave capability. The two beams intentionally had adjacent footprints to allow evaluation of interference effects. Of the three beam and frequency combinations available, the payload supported any two simultaneously in either a frequency translation mode or a regenerative mode or both. The payload had an overall bandwidth of 36 MHz, split into three 500 kHz and three 6 MHz wide frequency translation channels plus an 800 kHz filter for the regenerative channel. The regenerative channel allowed up to eight 4.8 or 24 kbps FDMA uplinks; each of the eight were demodulated, then time-division-multiplexed for retransmission to the ground.

COMETS was about the same size and weight as ETS-VI. It had three large antennas, one for interorbit links, one for the broadcasting payload, and one for the data-relay feeder links and the mobile communications payload. Satellite and payload details available follow.

Satellite

Rectangular body 2 x 3 x 2.8 m, 7.87 m height including antenna tower, 30.9 m span across deployed solar arrays

3945 kg at launch, 2150 kg in orbit, beginning of life

Sun-tracking solar arrays with GaAs cells, NiH_2 batteries, >5300 W at end of life

Three-axis-stabilized, interorbit link antenna pointing to 0.16 deg (program track), ±0.043 deg (autotrack)

Liquid bipropellant propulsion for apogee maneuver, liquid monopropellant propulsion for on-orbit use, ion propulsion for north-south stationkeeping

Configuration

Interorbit communications (IO): 2 MHz bandwidth forward channel at S-band (2 GHz), 10 MHz bandwidth return channel at S-band (2.2 GHz), 30 MHz bandwidth forward channel at Ka-band (23 GHz), 150 MHz bandwidth return channel at Ka-band (26 GHz); K-band (20 and 30 GHz) feeder links with the ground

Broadcasting (Br): two 120 MHz bandwidth channels

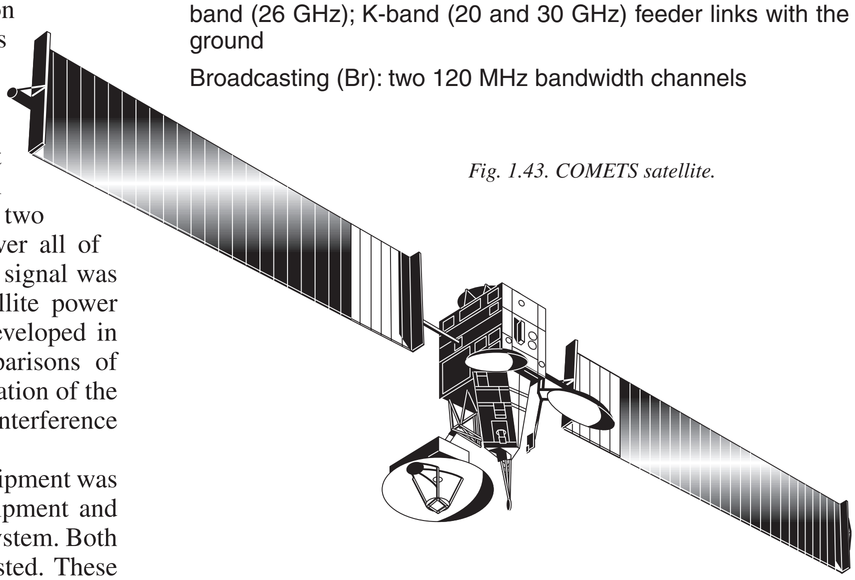

Fig. 1.43. COMETS satellite.

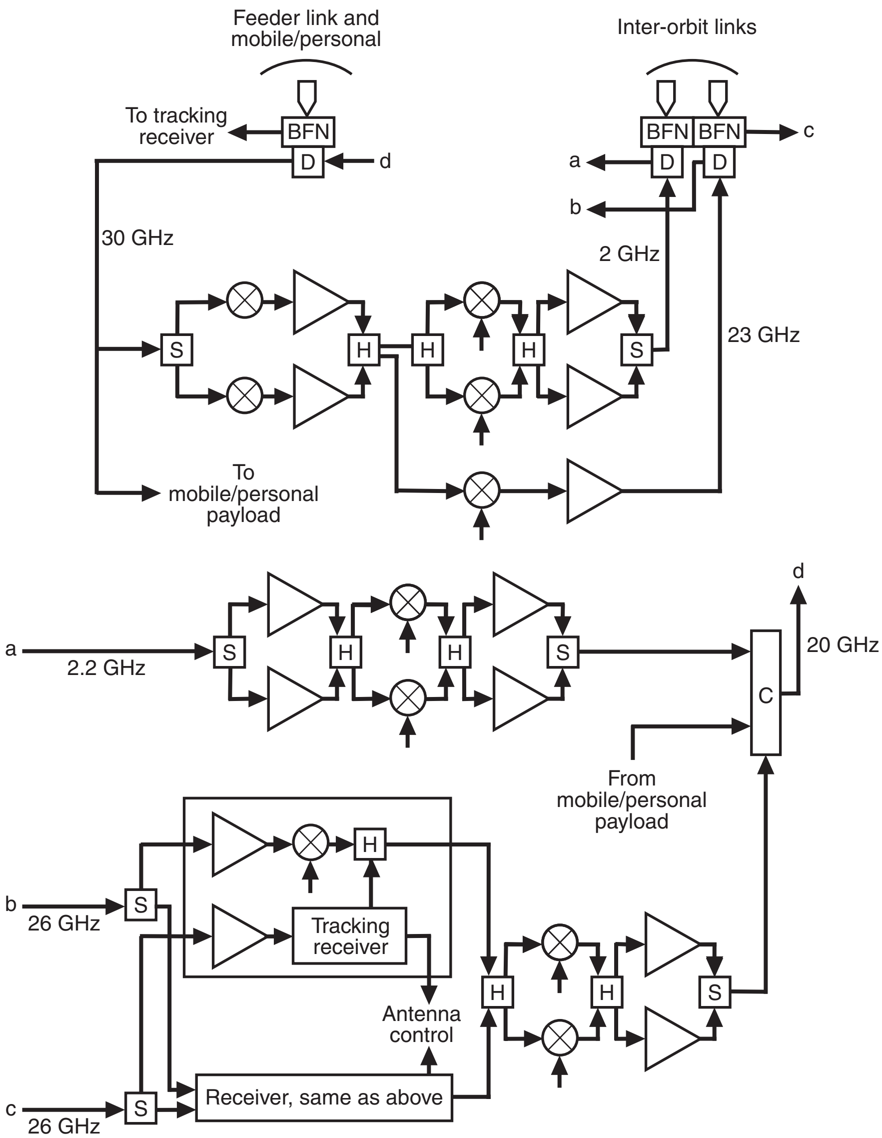

Fig. 1.44. COMETS interorbit communications subsystem.

Mobile and personal communications (MP): two K-band (20 and 30 GHz) beams and one mm-wave (44/47 GHz) beam, any two simultaneously, 36 MHz bandwidth (divided as described in text)

Transmitter

IO: S-band tuneable in 2025–2110 MHz, Ka-band tuneable in 23.19–23.55 GHz plus beacons at 23.3875 and 23.54 GHz; feeder link 20.37 GHz (for S-band), 19.685 GHz (for Ka-band)

One active, one spare SSPA (S-band), EIRP 38–43.5 dBW

One active, one spare SSPA (Ka-band), EIRP 48–56 dBW

TWTA for beacon (Ka-band), EIRP 27 dBW

Br: 20.7 GHz

Two active, one spare coupled-cavity TWTA, switchable to 200 W or 63 W

MP: 20.98–21.07 GHz (Ka-band), 43.75–43.78 GHz (millimeter)

Two 20 W SSPAs (K-band)

One 20 W TWTA (millimeter)

Receiver

IO: S-band tuneable in 2200–2290 MHz, Ka-band tuneable in 25.525–26.425 GHz; feeder link 30.18 GHz (for S-band), 29.785 GHz (for Ka-band)

G/T 7 dB/K minimum (S-band), 26 dB/K minimum
(Ka-band)

Br: 27.3 and 27.8 GHz

MP: 30.75–30.85 GHz (K-band), 46.87–46.9 (millimeter)

Two low-noise receivers (K-band)

One active, one spare HEMT LNA, 2.3 dB noise figure (millimeter)

Antenna

IO: 3.6 m diam reflector for S-band and Ka-band, four S-band feed horns surrounding a single multimode K-band horn, autotracking at Ka-band, steerable to 10 deg from nadir, switchable between two circular polarizations

K-band feeder links via MP antenna

Horn, approximately 20 deg beamwidth for beacon

Br: 2.3 m diam reflector with multiple feed horns, autotracking, maximum gain 50 dB, gain over coverage areas 44 dB, circular polarization

MP: 2.0 m diam reflector with multiple feeds, autotracking

Telemetry and command

Telemetry: in 2200–2290 MHz band

Command: in 2025–2110 MHz band

Life

Three years

Orbit

Geostationary, 121°E longitude intended, but see “Orbital history”

Orbital history

Launched 21 February 1998, did not reach intended orbit; initial orbit 246 x 1902 nmi at 30 deg inclination; orbit for experimental use 473 x 17,711 km, 30 deg inclination

Japanese H-2 launch vehicle

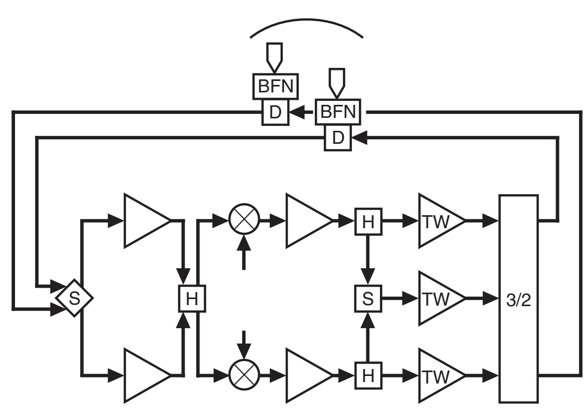

Fig. 1.45. COMETS broadcasting subsystem.

Management

NASDA; payload developments managed by NASDA and CRL

During the launch of COMETS, the second burn of the second stage of the launch vehicle was shorter than programmed. This left COMETS in a low orbit. By the end of May 1998, seven orbit adjustments had raised the satellite to an elliptical orbit with a ground track that repeated nine times in 2 days. Ground terminals were modified to accommodate the large angular motion of the satellite and Doppler shift caused by the unplanned orbit. Use of COMETS began in July 1998 and continued into 1999. Tests included evaluation of equipment on the satellite, communications demonstrations, and propagation measurements. Most use of COMETS was with ground terminals in Japan, but some use was made with ground terminals in Australia.

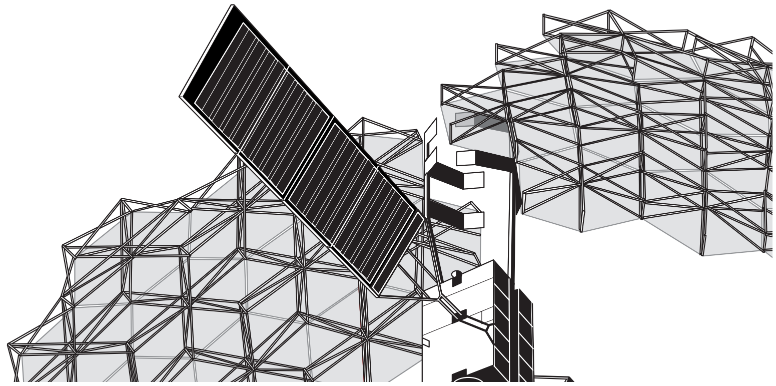

Fig. 1.46. COMETS mobile personal communications subsystem.

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Engineering Test Satellite VIII

The Engineering Test Satellite VIII (ETS-VIII) [1–20] is being developed by the Japanese National Space Development Agency (NASDA) to demonstrate the following technologies.

- Satellite bus suitable for a satellite in-orbit weight on the order of 6000 pounds (almost 50 percent larger than ETS-VI and COMETS)
- Very large deployable antenna reflector
- Communication subsystem that will enable voice- and low-speed communications with, and broadcasting to, hand-held terminals, and high-speed packet communications with terminals the size of a laptop computer
- Atomic clock and navigation signal generator on the satellite

The second and third technologies are the main mission of the project. The second technology provides the large reflector needed for the satellite to communicate with hand-held terminals, and the first technology provides the satellite bus capable of supporting the deployed reflector, and the high-power transmitter and other equipment that is part of the third technology. The fourth technology includes two Cesium clocks on the satellite and will be tested, in conjunction with the Global Positioning System and laser range finding from the ground, with a view toward a future satellite positioning system.

There are two large deployable reflectors on ETS-VIII. One is for transmitting, the other for receiving. Each reflector is composed of 14 hexagonal modules. Each module has a mesh surface with cables that control the surface of the mesh. Each module has six radial truss members that fold together for launch, so that an entire reflector occupies a cylinder 1 m diam by 3.4 m length.

Although the large reflectors with their phased-array feeds could generate many beams, only three beams will be used on ETS-VIII. Each of these beams will be pointed at a different part of Japan. In the transmitter, each feed network section divides the signal into 31 paths, each of which has an independent attenuator and phase shifter followed by an amplifier. The output of each path is combined with the corresponding path of the other section and applied to one of the 31 elements of the reflector feed array. In the receiver, the same signal path is used in the reverse direction.

Voice communications with mobile (hand-held, vehicular, and airborne) terminals will be at 5.6 kbps, and data communications at 32 kbps. Multiple access will be by means of TDMA on each of several carrier frequencies. Packet communications will be at rates up to 1024 kbps with rate one-half convolutional coding and up to 512 kbps without coding. An onboard packet processor will demodulate, route, and remodulate each packet. Mobile terminals will be able to communicate directly with other mobile terminals and with terrestrial networks via ETS-VIII base stations. The broadcasting will be six channels at selectable rates between 32 and 256 kbps.

Work on ETS-VIII began in 1996. Construction and testing of early models of critical portions of the satellite, including modules of the large reflectors, began in 1997. Engineering model testing of structural, thermal, and electrical models of the satellite, as well as a full size reflector, was completed by 2000. An in-orbit deployment test of a model of the large reflector, made of seven half-size modules, was conducted as part of an Ariane launch in December 2000. This test was named LDREX (Large Deployable Reflector Experiment). Some anomalies were observed and the design of the flight reflector was modified accordingly. Launch of LDREX-2 occurred in October 2006. Manufacturing of the protoflight model of the satellite began in 2000; launch was originally planned for 2002 but was delayed for years.

After launch and in-orbit testing, there will be two kinds of experiments using ETS-VIII. The first will be the basic experiments, carried out by the developers of the satellite. This work will include measurement of antenna characteristics; evaluation of onboard packet switches, modulators, and demodulators; sound and data transmissions to terminals the size of a cellular telephone; high-speed data transmissions and broadcasting; and evaluation of orbit determination, clock synchronization, and ground user position determination. The second set, the utilization experiments will be carried out by other organizations using the capabilities of the satellite as made available by JAXA (Japan Aerospace Exploration Agency), the successor to NASDA. Additional details follow.

Satellite

Rectangular body approximately 2.35 x 2.45 x 7.3 m including antennas, 40 m span across deployed solar arrays, 37 m span across deployed reflectors

5800 kg at launch, 2900 kg in orbit, beginning of life

Sun-tracking solar arrays, NiH_2 batteries, 7500 W at summer solstice after 3 years of life

Three-axis-stabilized, pointing accuracy ±0.05 deg (roll and pitch), ±0.15 deg (yaw)

Liquid bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

Communications (C): S-band communications with mobile terminals

Broadcasting (B): S-band broadcasting to mobile terminals

Feeder link (F): feeder link for communications and broadcasting

Transmitter

C and B: 2500–2505 MHz and 2535–2540 MHz

C and B share thirty-one solid-state amplifiers (one per phased-array feed element), twenty-three 10 W amplifiers and eight 20 W amplifiers

F: 20.8 GHz, two 8 W TWTAs

Receiver

C: 2655–2660 MHz

One low-noise amplifier per phased-array feed element

Minimum G/T 13.5 dB/K

F: 30.6 GHz, two low-noise amplifiers

Antenna

C, B: 31-element phased-array feeds (1 transmit, 1 receive) each producing three beams; each feed is a microstrip antenna inside a metal cup

Two deployed reflectors (1 transmit, 1 receive), each 16.7 x19.2 m with 13 m diam effective aperture, maximum root mean square surface deviations 0.094 in. (2.4 mm)

42 dB minimum gain over coverage area of each beam

Left-hand circular polarization

Telemetry and command

Telemetry: in 2200–2290 MHz band

Command: in 2025–2110 MHz band

Life

Satellite bus 10 years, mission life 3 years

Orbit

Geostationary, 146°E longitude, stationkeeping to ± 0.1 deg

Orbital history

Launched 18 December 2006

Japanese H-2A launch vehicle

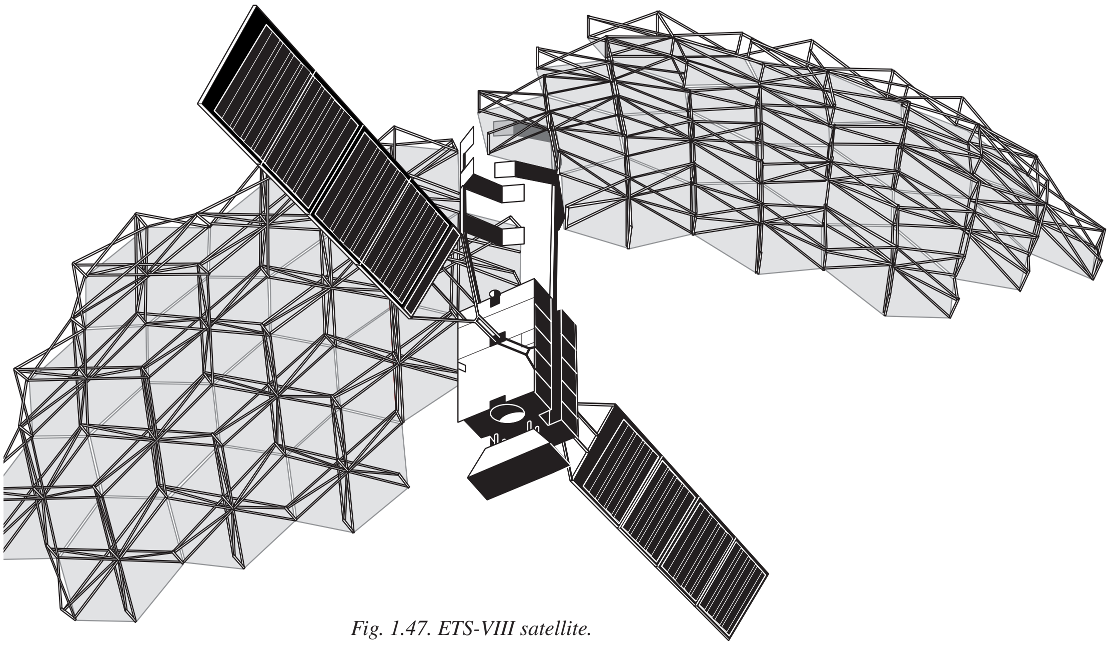

Fig. 1.47. ETS-VIII satellite.

Management

Developed by NASDA (JAXA since October 2003) in cooperation with Communications Research Laboratory (National Institute of Information and Communications Technology since April 2004) and Advanced Space Communications Research Laboratory, in cooperation with multiple Japanese companies

Operated by JAXA

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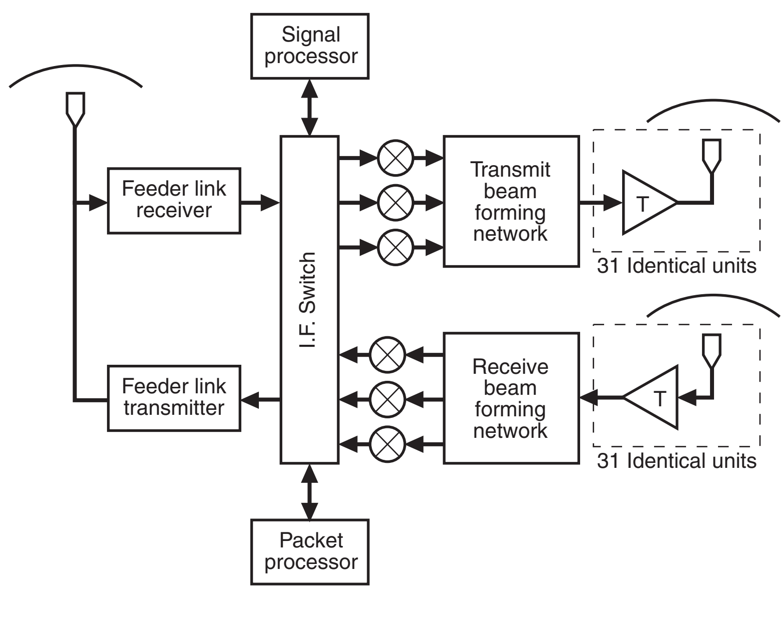

Fig. 1.48. ETS-VIII communication subsystem.

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Optical Inter-orbit Communications Engineering Test Satellite

The Optical Inter-orbit Communications Engineering Test Satellite (OICETS) [1–11] program was begun in 1993 when NASDA and the European Space Agency (ESA) signed an agreement of cooperation in optical communications in space. Their plan is to demonstrate acquisition, tracking, pointing, and communications on links between NASDA’s OICETS in low Earth orbit and ESA’s Artemis in geosynchronous orbit. In 1994 the agreement was broadened to include an intersatellite link at S-band. In 1996 they agreed Artemis would be launched by a Japanese launch vehicle. This launch was scheduled for 2001, to be followed by OICETS. However, because of delays in Japanese launch vehicle development, Artemis was launched in 2001 on a European Ariane. In 2004, OICETS was in storage and the launch had been delayed to 2005.

The major payload on OICETS is the Laser Utilizing Communications Experiment (LUCE); the secondary payload is a sensor to measure microvibrations over the frequency range 0.5 Hz to 1 kHz. One face of the rectangular OICETS body will always face Earth. The optical portion of LUCE includes the optical transmitter and receiver, fine pointing mechanisms, and the telescope (the optical antenna), all of which are mounted on a two-axis gimbal that is attached to the anti-Earth face of OICETS. The electronics portion of LUCE includes the gimbal and fine pointing control processors, test data generation and bit error rate measurement units, and command and telemetry interfaces with the satellite; this equipment is within the satellite body. The LUCE optical and electronics equipment weighs approximately 110 kg and 40 kg respectively and uses 220 W during communications. The optical equipment is on a two-axis gimbal with a range of 380 deg in azimuth and 120 deg in elevation. Fine pointing is accomplished through a pair of small single-axis mirrors with a range of 1 milliradian. The pointing accuracy for the optical beam will be better than ±2.6 microradians during communications.

In September 2003 the engineering model of LUCE was taken to an ESA ground station on the Canary Islands and successfully tested with Artemis. The ground station’s beacon was used to aid acquisition since LUCE was not designed to be operated from the ground. Nevertheless, at times of good atmospheric conditions, acquisition was accomplished without using that beacon. In space the acquisition sequence between Artemis and OICETS will be: first, Artemis scans a beacon and OICETS stares at a 0.4 deg field of view; second, OICETS detects the beacon and returns communication beam; and third, Artemis detects the beam from OICETS, stops its scan, turns on its communication beam, and turns off its beacon.

Testing of LUCE in orbit will include evaluation onboard equipment in the space environment, acquisition and tracking, interorbit communications, microvibration measurements, and optical communication link and ranging with Japanese ground stations.

The link from Artemis to LUCE will be at 2.048 Mbps with a pulse position modulation format. The return link will be at 49.37 Mbps with an on-off modulation format. The link from Artemis will originate at an ESA ground station in Belgium, which will receive the data sent from LUCE to Artemis; these links will be at 29 and 19 GHz. The OICETS microvibration

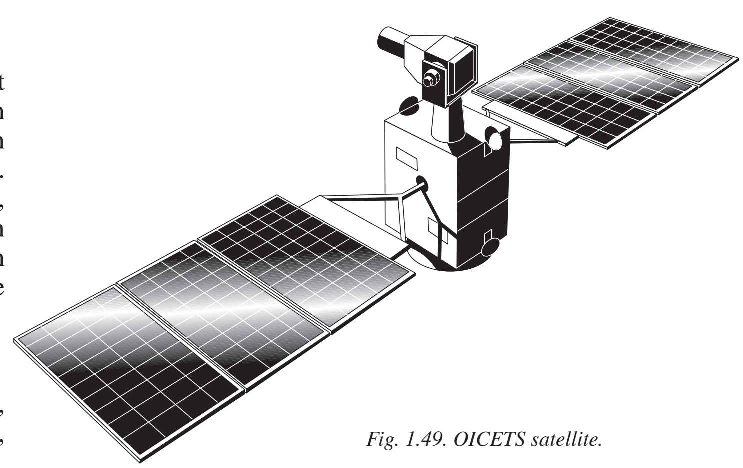

Fig. 1.49. OICETS satellite.

measurements and the communication bit error rates will be compared to determine if there is a correlation. OICETS S-band command and telemetry links will operate direct with ground stations and, at other times, through Artemis as a relay satellite, and also through the Japanese Data Relay Test Satellite (DRTS) launched in 2002. OICETS was launched in 2005 and renamed Kirari, meaning twindle or flash. Additional information about OICETS and LUCE follows.

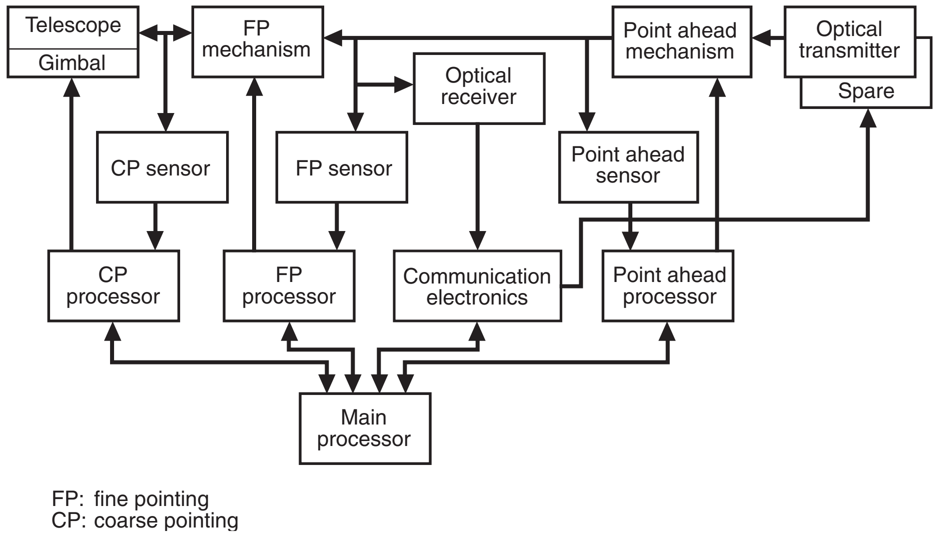

Fig. 1.50. OICETS laser communication subsystem.

Satellite

Rectangular body 0.78 x 1.1 x 1.5 m, span of deployed solar arrays 9.36 m, overall height include optical equipment 2.93 m

Approximately 570 kg at launch and in orbit

Solar arrays and Nickel Metal Hydride battery

Three-axis-stabilized

Transmitter

847 nm, 100 mW average power GaAlAs laser diode (one active, one spare)

Receiver

819 nm (data), 801 nm (acquisition beacon)

Charge-coupled device with 672 x 488 pixels for acquisition (0.4 deg field of view), quadrant silicon photodetector for tracking, silicon avalanche photodiode for communications

Antenna

26 cm diam center-fed Cassegrain telescope, left-hand circular polarization

Telemetry and command

Telemetry: in 2212–2228 MHz band

Command: in 2043–2045 MHz band (ground terminals to OICETS), in 2029–2059 MHz band (Artemis or DRTS to OICETS)

Life

Mission life about 1 year

Orbit

610 km altitude at beginning of life to 550 km at end of life, 97.8 deg inclination

Orbital history

Launched 24 August 2005

Dnepr launch vehicle

Management

NASDA, JAXA since October 2003

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Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS)

Japan has been making a strong promotion of an information technology society. The Gigabit Satellite concept received attention for several years, and there is now the i-Space project [1]. WINDS is part of i-Space, and is aimed at developing and demonstrating the space portion of the infrastructure for an information technology society [2-8]. The goal of WINDS is to establish both a domestic ultrahigh-speed internet network and ultrahigh-speed international internet access. The WINDS space infrastructure will be integrated with the terrestrial infrastructure and will contribute wide coverage, flexible reallocation of capacity, and relative immunity to outages caused by natural disasters.

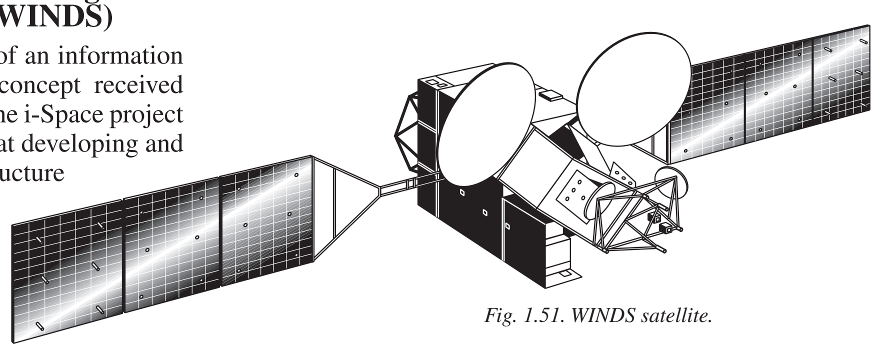

Fig. 1.51. WINDS satellite.

Numerical goals of WINDS include data rates of 155 Mbps to and 6 Mbps from homes equipped with 45 cm antennas up to 1.2 Gbps to and from offices equipped with 5 m antennas. WINDS will offer two types of communication services: moderate- to high-rate asynchronous transfer mode (ATM) links with processing and packet switching on the satellite, and ultrahigh-rate links without processing on the satellite. Processing on the satellite will be demodulation and decoding of uplinks to ATM cells, routing the cells, which can include copying cells for multicasting, and coding and modulating the downlinks. The processor has nine inputs; each can accept 14 frequency multiplexed links at 1.536 Mbps or one link at 6.144, 24.00, or 51.84 Mbps; 155 Mbps links are uplinked as three 51.84 Mbps signals. The processor has three outputs at 155 Mbps each. Information rates for the unprocessed links are 622 Mbps and 1.244 Gbps.

WINDS will communicate with ground terminals through two types of antennas. It has two multibeam antennas; one has nine fixed beams aimed at urban areas in Japan, Korea, and nearby parts of China; the other has 10 fixed beams aimed at urban areas from Hong Kong to the east coast of India to Indonesia. Any eight of these 19 beams may be selected and used simultaneously. The high gain of these antennas will be used with the 622 Mbps and 1.2 Gbps links. For downlinks these antennas are coupled to the output of a multiport high-power amplifier, which can flexibly distribute power among eight outputs to accommodate variations in demand for capacity and variations in weather attenuation in each of the eight selected downlink beams. WINDS also has active array antennas, one for receiving and one for transmitting; each will generate two beams, which can be scanned to any location on Earth with about 20 degrees or more elevation angle to the satellite. Scanning can be synchronized with the TDMA bursts used on the processed links.

The two primary reflectors for the multibeam antennas are clearly visible in the satellite in Fig. 1.51. The triangular structure on the Earth-viewing side of the body contains the feed horns and supports the subreflectors for these antennas. Frequency selective surfaces, which diplex the transmit and receive frequencies for these antennas, protrude from the triangular structure. The array antennas are in the rectangular unit next to the underside of the triangular structure.

Design work on WINDS began in 2001, and protoflight hardware was in development in 2003. As of September 2003 the projected launch date was 2005, but launch vehicle changes resulting from a November 2003 failure delayed the launch. Additional information follows.

Satellite

Rectangular body approximately 2 x 3 x 3 m, 8 m height of body plus antennas, 21.5 m span of deployed solar arrays

4850 kg at launch, approximately 2700 kg at beginning of life

Sun-tracking solar arrays, more than 5200 W over life

Three-axis stabilization

Configuration

See text

Transmitter

17.7–18.8 GHz

Multiport high-power amplifier with eight active and two spare 50 W TWTAs operated in linear region; total output power >280 W to multibeam antennas

128 solid-state PHEMT amplifiers each connected to one element of the active array, 1 W output each at 1 dB compression

EIRP>68 dBW (multibeam antenna), >55 dBW (active array)

Receiver

27.5–28.6 GHz

PHEMT low-noise amplifiers connected to multibeam antennas

128 PHEMT low-noise amplifiers each connected to one element of the active array

2.8 dB maximum noise figure

G/T >18 dB/K (multibeam antenna), >7 dB/K (active array)

Antenna

Two multibeam antennas, offset-fed Cassegrain geometry with 2.4 m diam main reflectors, frequency selective surface to diplex transmit and receive signals

Two active array antennas, 128 elements each, transmit aperture 69 x 54 cm, receive aperture 48 x 29 cm

Multibeam antennas have one linear polarization in each beam, adjacent beams are usually on opposite polarizations; array antennas use linear polarization

Life

5 years

Orbit

Geostationary, probably 143°E

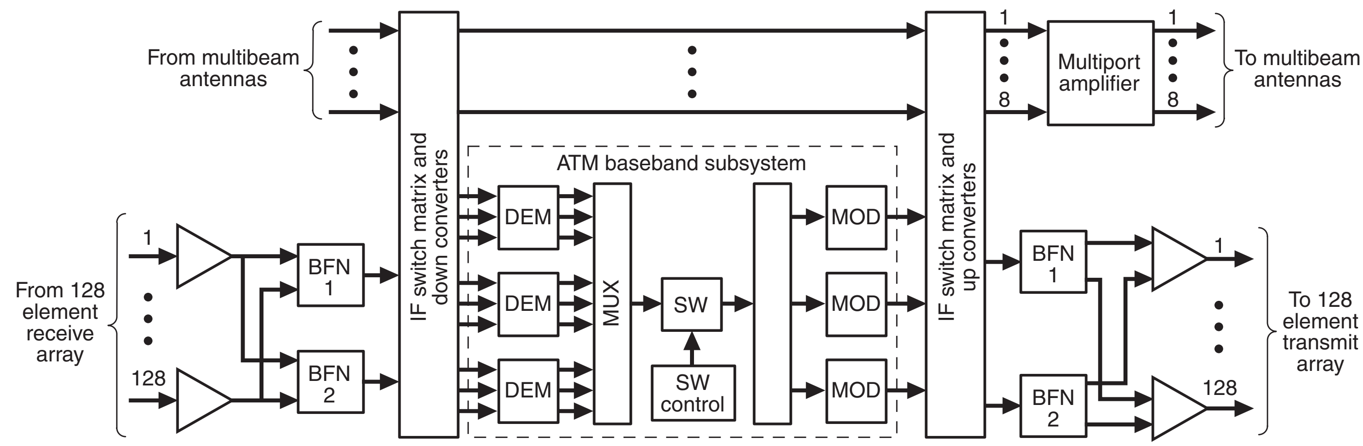

Fig. 1.52. WINDS communication subsystem.

Orbital history

Launch planned in April 2007 to March 2008 period

H-IIA launch vehicle

Management

JAXA (NASDA until October 2003) with National Institute of Information and Communications Technology (Communications Research Laboratory until April 2004)

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Advanced Communications Technology Satellite

In 1973, NASA greatly reduced its efforts in communications technology, primarily because of budget restrictions. Private industry supported some developments with short-term (e.g., a few years) potential for commercial success. However, private industry could not support the higher-risk, higher-potential developments, which require about a decade to bring to commercial usefulness. Because of this, and with urgings from many directions, NASA was able to resume its support of communications technology in 1978.

The major item in the new program is a high-capacity domestic communications satellite in the 30 and 20 GHz bands. This became known as the 30/20 GHz program [1–11]. Market analyses and system studies were carried out first. Then in 1980, several hardware developments were undertaken. These included a multibeam antenna with both fixed and scanned beams, a baseband processor, an IF switch matrix, a TWTA, and a low noise receiver. The initial phases of these developments were completed by 1984.

In 1983, NASA defined an Advanced Communications Technology Satellite (ACTS) [12–69], which incorporates the results of the hardware developments. ACTS demonstrated all the critical communication technologies necessary for high-capacity operational satellites in the 1990s, but on a reduced scale. An operational satellite will probably have six to 12 times the number of beams, channels, and total capacity as ACTS. (For various reasons, especially economics, operational satellites of this complexity were delayed and did not enter operation until 2005.) The ACTS program included the following tasks.

- Demonstration of the new technology items on the spacecraft (multibeam antenna, IF switch matrix, baseband processor, high-power TWTA, and low-noise receiver)
- TDMA (time division multiple access) network control and operations experiments

- Tests of ground terminal hardware
- Tests of error correction and power control to minimize degradations caused by atmospheric attenuation
- Propagation measurements

The ACTS support subsystems within the central body of the satellite and the deployed solar arrays were based on flight-proven designs. The two large reflectors were attached to the central body of the spacecraft and were deployed in orbit. The smaller subreflectors were mounted on a mast, extending forward of the central body, and did not require deployment. The feed arrays for the two antennas were mounted on the front face of the central body. Other communications equipment was mounted within the body. Satellite and communication subsystem details are as follows.

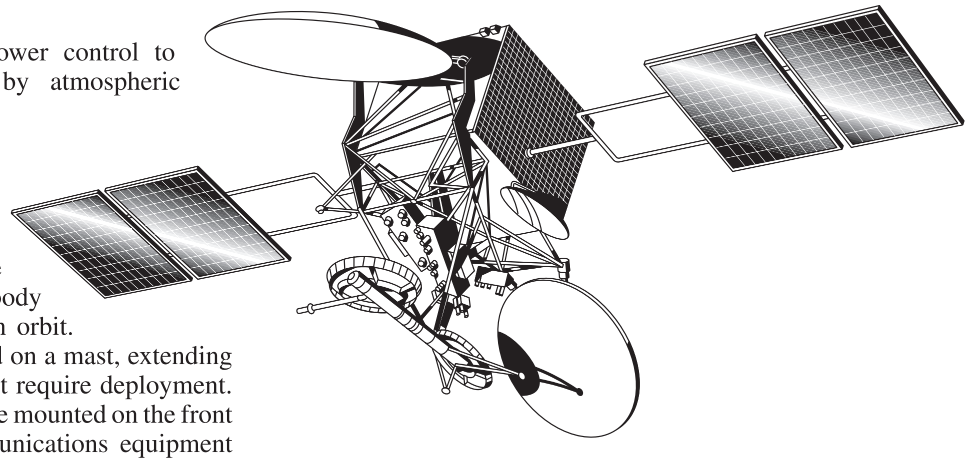

Fig. 1.53. Advanced communications technology satellite.

Satellite

Rectangular body 80 x 84 x 75 in., 47 ft across deployed solar arrays, 30 ft across deployed reflectors

3270 lb in orbit, beginning of life

Sun-tracking solar arrays, NiCd batteries, 1770 W maximum, beginning of life; 1400 W minimum after 4 years; only housekeeping loads are supported during eclipses

Three-axis-stabilized using momentum wheels, antenna pointing accuracy ±0.025 deg pitch and roll and ±0.15 deg yaw with autotrack, ±0.1 deg pitch and roll and ±0.25 deg yaw with Earth sensor; offset pointing to ±6 deg pitch, ±2 deg roll

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

Configuration

Three fixed beams, two scanned beams, and one steerable beam, interconnected by an IF switch matrix and a baseband processor

Capacity

900 MHz bandwidth for each of three switch matrix channels

110 Mbps or 2 x 27.5 Mbps for each of two baseband processor channels

Any combination of three channels simultaneously

Transmitter

19.2–20.2 GHz, center frequencies vary from 19.451–19.7 GHz depending on type of signal

Four 46 W TWTAs, three active, each switched to one fixed or scanned beam or to the mechanically steerable beam

EIRP: 59–60 dBW per fixed or scanned beam, 53 dBW on steerable beam

Propagation beacons to 20.185, 20.195, and 27.505 GHz; solid-state amplifiers, 0.18 W (20.185, 20.195 GHz), 0.08 W (27.5 GHz); EIRP over CONUS 17.5 dBW (20.185, 20.195 GHz), 14.2 dBW (27.5 GHz)

Receiver

29–30 GHz, center frequencies vary from 29.238–29.68 GHz depending on type of signal

Three active receivers plus one spare

HEMT preamplifiers

3.5 dB receiver noise figure

G/T: 15–18 dB/K (multibeam antenna), 11 dB/K (mechanically steered antenna)

Antenna

Two offset-fed Gregorian multibeam antennas with 3.3 m (20 GHz) and 2.2 m (30 GHz) diam main reflectors, 0.3 deg beamwidth, orthogonal linear polarizations used on each antenna; each reflector has 47 feed horns split between the two polarizations: three for the fixed spots, 13 for the isolated scanning positions, and 31 for the sector scan; 25 dB cross-polarization isolation between beams, 25 dB copolarization isolation between beams separated by more than one beamwidth

One 43 in. diam offset-fed parabolic steerable antenna; 44 dB gain (receive), 42 dB gain (transmit); 1 deg beamwidth; linear polarization; one feed horn each for transmit and receive, feed horns are coupled to beam-forming networks of multibeam antennas; antenna steerable ±10 deg in azimuth and elevation

One 6.5 x 11 in. offset-fed elliptical reflector with a single feed horn (20.185 GHz, vertical polarization; 20.195 GHz, horizontal polarization); one 7.5 x 13 in. offset-fed elliptical reflector with two feed horns (27.505 GHz, vertical polarization; commands, horizontal polarization)

Telemetry and command

Telemetry: 20.185 GHz–20.195 GHz, 200 mW transmitter via propagation beacon antenna; in 3.7–4.2 GHz band via omnidirectional antenna during launch, transfer orbit, and initialization

Command: in 29.5–30 GHz band, received via propagation beacon antenna; in 5.925–6.425 GHz band via omnidirectional antenna during launch, transfer orbit, and initialization

Life

Four years, estimated on-orbit fuel supply for 5 years

Orbit

Geostationary, 100°W, stationkeeping to ±0.05 deg north-south and east-west; north-south stationkeeping ended 1998, moved to 105.2°W in summer 2000

Orbital history

Launched 12 September 1993, in use until shut down 28 April 2004

Shuttle launch vehicle with transfer orbit stage

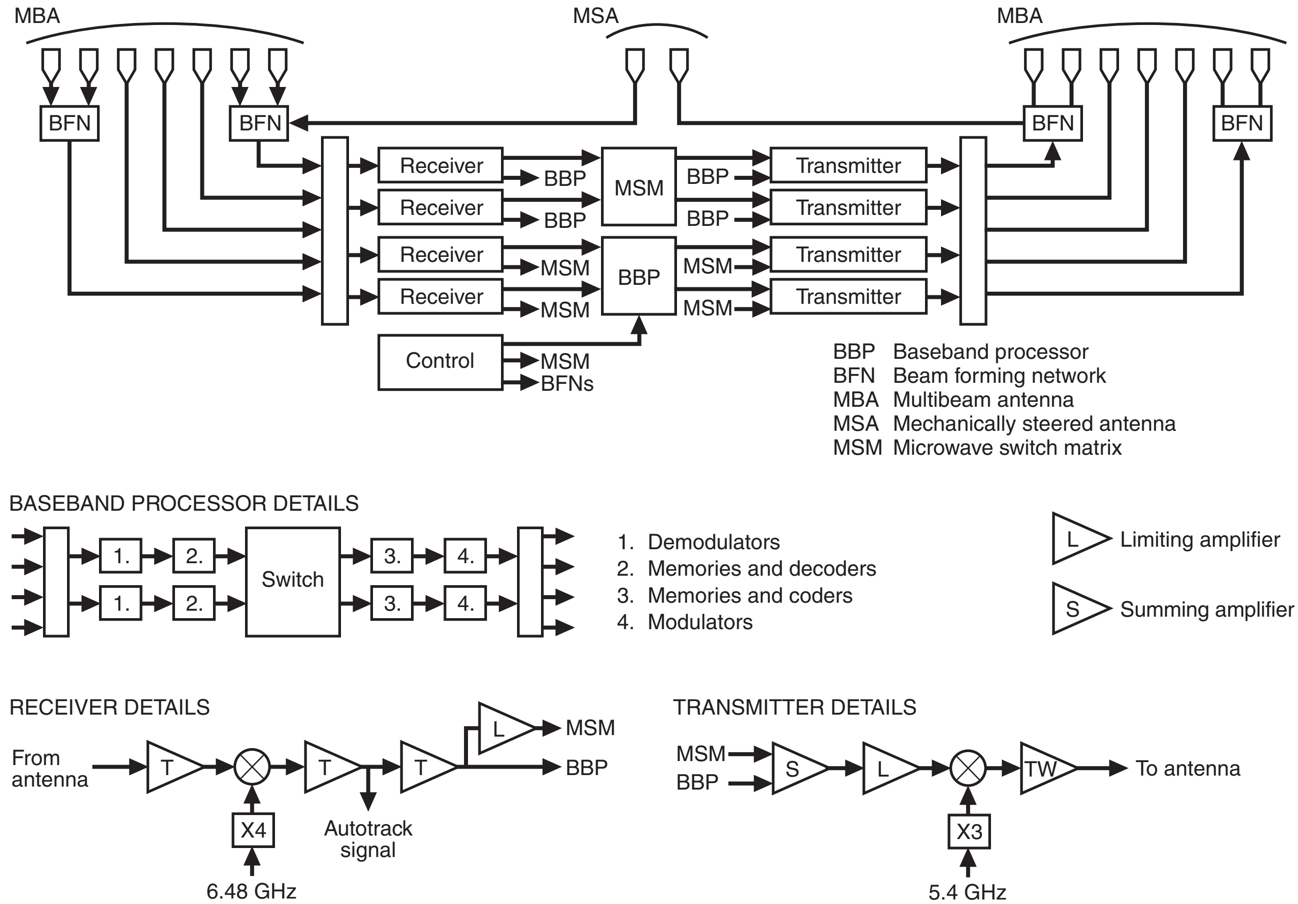

Fig. 1.54. ACTS communication subsystem.

Management

Developed by GE Astro-Space (formerly RCA) for NASA

Operated by GE Astro-Space, later Martin-Marrieta, later Lockheed Martin (spacecraft control); NASA (communications control)

The ACTS communication subsystem was composed of multibeam antennas and multimode electronics. The two large antennas, one for transmission and one for reception, each was able to form five beams. Three beams were fixed, pointed at Cleveland, Atlanta, and Tampa. The Cleveland uplink beam was used by the ACTS autotracking receiver to keep the antennas accurately pointed. The other two beams are scanning beams. Each scanned one contiguous area in the northeast United States and either six or seven specific metropolitan areas in other parts of the country. The scanning was controlled by beam-forming networks, which switch among the multiple feed horns for each scanning beam; the switching can be accomplished in one-half microsecond. Uplink and downlink scanning patterns were independent. A separate, mechanically steerable antenna formed a single beam that can be steered toward any point in the 50 states. This antenna was operated as part of the scanned beam capability.

The communications electronics were able to process signals from any three of the five beams, three fixed and two scanned. The electronics had two separate paths, corresponding to two operating modes for the communication links. The high-burst-rate mode was associated with the microwave switch matrix. This 4 x 4 matrix operated at an intermediate frequency slightly above 3 GHz and interconnected the four receivers and four transmitters. Only three were active at a time; the fourth was redundant. The microwave switch matrix was usually operated with the three fixed beams, but one or two could be replaced by scanned beams. Signals were typically serial minimum shift keyed (SMSK), but other modulation formats were tested. The original plans were for a data rate of 220 Mbps; as a result of experimenters' interests, transmissions were also at low rates and at 155 and 622 Mbps. The matrix switched in synchronism with TDMA burst transmissions from as many as 10 ground terminals; switching time is 100 ns. The TDMA frame length was 1 ms, and the burst switching pattern could be changed as often as once a minute. The switch could also be fixed in any one state, thereby providing three transponders of fixed connectivity for WB and FDMA experiments. Uplink power control was used to counter the effects of variable propagation losses.

The low burst rate mode was associated with the baseband processor portion of the communication subsystem. The processor accepted either one 110 Mbps (exact rate 110.592 Mbps) or two 27.5 Mbps (exact rate 27.648 Mbps) inputs from each scanned beam. The inputs were at approximately 3.3 GHz; the two lower rate inputs were at separate frequencies. During increased propagation losses, the data rate was reduced by a factor of four and rate 1⁄2 coding applied to produce symbol rates of 55 Msps or 13.75 Msps. The transmission format was TDMA with SMSK modulation. Uplink capacity could be demand assigned in increments of 64 kbps. The uplink rate and coding could switch from burst to burst. The input bursts were demodulated, and decoded if necessary; the resulting 64-bit words were routed through buffer memories to a data routing switch. The switch sent the 64-bit words through output buffer memories to two modulators. The downlink burst transmission rate was, independently in each beam, either 110 Mbps uncoded or 27 Mbps encoded to 55 Msps.

The satellite also had two propagation beacons at 20 GHz and one at 27.5 GHz. The 20 GHz beacons had telemetry subcarriers. All three beacons were used for power monitoring for power control or coding decisions for fade compensation on the main links, and for propagation research.

The ACTS satellite control center was in New Jersey, but command and telemetry links were routed via terrestrial lines between this center and NASA's master ground station in Cleveland. This station handled the satellite command and telemetry transmissions, controlled the communications payload and the network of users, and recorded system data. In operational orbit the telemetry and command links were in the 20 and 30 GHz bands; C-band (4 and 6 GHz) links were used during transfer orbit and as an operational backup. Many other ground terminals were provided by experimenters for both communications and propagation applications.

The ACTS contract was awarded in 1984. However, in that year and in most years until 1990, the programs had ups and downs in the budget process, even being completely eliminated and then restored. The satellite was launched in September 1993. On-orbit testing and experimental results indicated that the satellite remained in good condition throughout the first 4 years on orbit, meeting or exceeding performance specifications, other than some beam wander due to daily thermal distortions of the subreflector of one of the large antennas.

The experimental program, involving NASA, industry, universities, and DOD, began early in 1994. Experimenters designed, funded, and conducted their own experiments, while NASA helped with experiment planning, provided satellite time, and managed satellite operations. Experiments and demonstrations included performance measurements of various multiple-access methods and network protocols; T1 (1.544 Mbps) links to terminals with 4 ft antennas; transmissions to and from terminals with antennas as small as 14 in.; video, voice, and data transmissions to aircraft; 622 Mbps links for satellite-fiber interoperability and remote supercomputing; land mobile communications for both civil and Army uses; telemedicine, including remote image diagnostics; simulated restorals of damaged terrestrial networks; distance education; and propagation measurements.

Since ACTS reached its operational location, the majority of the fuel consumption was for north-south stationkeeping; continuance of this stationkeeping would have led to an end of the satellite life in summer 1998. Instead, that year this stationkeeping was discontinued. The satellite remained at 100°W longitude with the orbital inclination increasing.

NASA planned to terminate the ACTS mission by September 2000. However, NASA and various experimenters desired to continue use of the satellite. In May 2000, formal NASA operation of the satellite concluded, but it was not turned off. In the following months it was moved to 105.2°W, where it will remain due to the "gravity well" at that longitude. At that time the satellite and the 20 and 30 GHz communications equipment was in good health and had redundant units available. The only limit on satellite operations was the shortage of fuel.

Ohio University organized a consortium [67, 69] to continue use of ACTS; this consortium took formal control of ACTS in May 2001 and operated and experimented with the satellite until it was turned off in April 2004 because of a lack of funding to continue operations.

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Stentor

Stentor was a French program to develop, launch, and operate a high-technology satellite [1-8]. The name is derived from the words, Satellite de Télécommunications pour Expériences de Nouvelles Technologies en ORbite. The Stentor program was sponsored by Centre National d'Etudes Spatiales (CNES, the French Space Agency), France Telecom, and DGA (the French Ministry of Defense) with some contribution by French contractors Astrium and Alcatel. The goals of the program were to

- develop and operate new payload and bus technologies in space
- conduct in-orbit experiments and evaluate operational performance
- demonstrate new services using an in-orbit satellite
- improve manufacturing to reduce satellite production costs

CNES, France Telecom, and the contractors were to achieve their goals through development and operation of the spacecraft bus and a complex Ku-band payload. The DGA objectives were to be accomplished with a simpler EHF payload on the same satellite.

Preliminary studies were conducted in the early 1990s. Following approval of the program by the French government, a development contract was signed in December 1995. The satellite was to have a 9-year life. The first 2 years were to be for technology and system experiments and for demonstrations of new telecommunications services. The remaining years were to be for additional telecommunications demonstrations and for measurements of stability and aging of the new components on the satellite. Unfortunately the satellite was destroyed by a launch vehicle failure. In spite of this, some of the technology developments in the Stentor program have been applied to subsequent operational communication satellites,

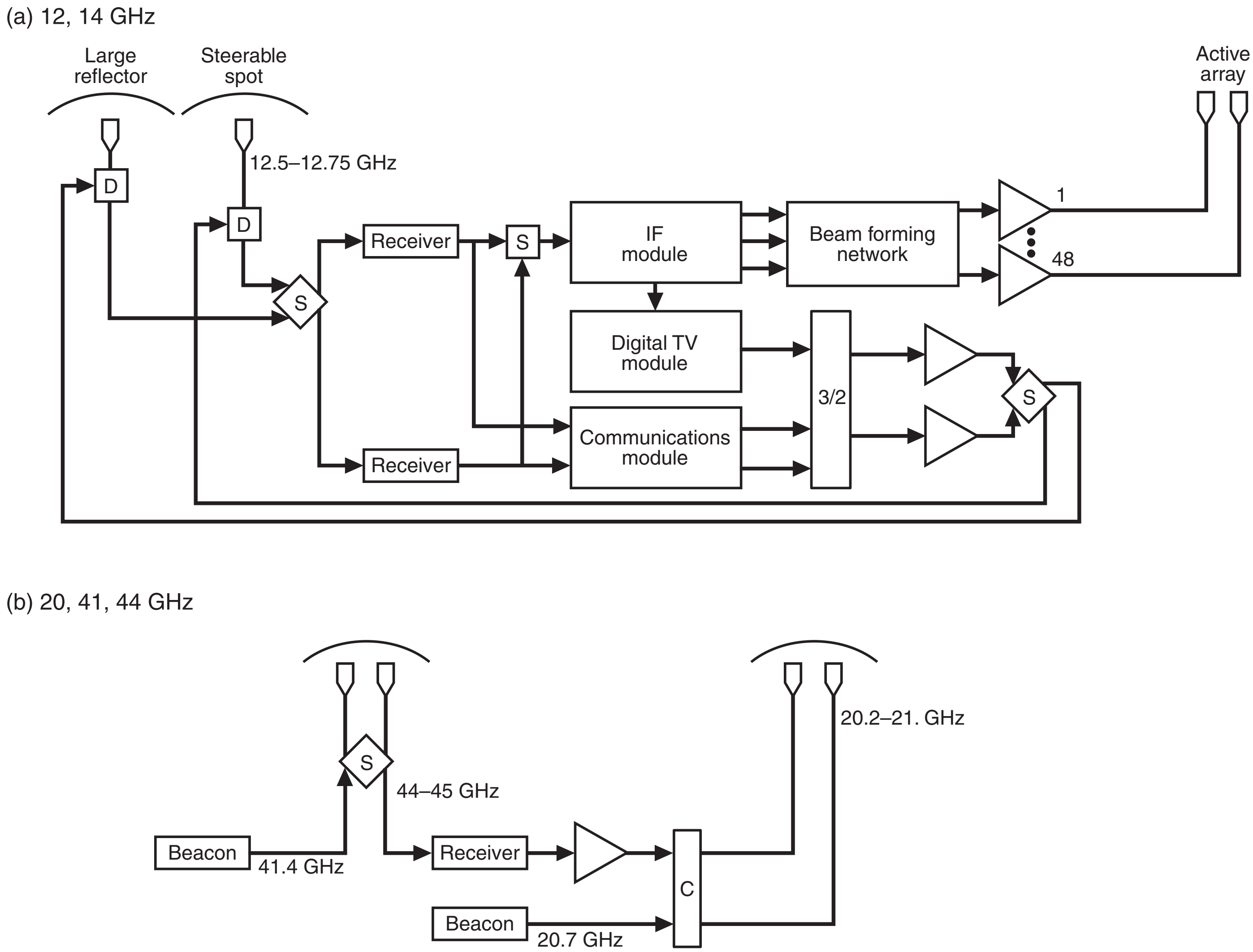

Fig. 1.55. Stentor communication subsystem.

albeit without the desired on-orbit proofs that Stentor was to have provided.

Technologies in the Stentor program were both for the bus (ion propulsion, lithium ion battery, deployable thermal radiator, fluid loops for heat transport, GPS receiver for autonomous stationkeeping) and for the communications payload (active array antenna, digital processors). The satellite was jointly developed by Alcatel Space and Matra Marconi Space (now EADS Astrium), which, after industry consolidation, are the two remaining satellite contractors in France.

The Ku-band (12, 14 GHz) payload had a WB transponder with very linear response, three transponders with surface acoustic wave filters, and onboard processing and multiplexing to combine up to 12 FDMA digital television uplinks in MPEG2/DVB-S format into a single TDM downlink. The maximum downlink rate for the television signals was 38 Mbps, with individual channels rates 1.095 to 7.664 Mbps The Ku-band payload had a phased-array antenna, a very lightweight 8 ft diam deployed reflector, and a steerable spot beam antenna. The array was composed of 48 subarrays, each powered by a solid-state amplifier; it could generate three independently steerable beams.

The EHF (20, 41, 44 GHz) payload had a two-channel transponder and beacons for propagation research at 20.7 and 41.4 GHz. The EHF antennas had one beam centered on France and one on French Guyana to support propagation measurements in two different climates.

Additional information follows.

Satellite

Astrium Eurostar 3000 bus

Dry weight approximately 1100 kg, launch weight approximately 2080 kg

Sun-tracking solar array with GaAs cells, lithium ion batteries, 2500 W at end of 2 years

Three-axis stabilization, pitch by onboard momentum control, roll and yaw by solar sail

Liquid bipropellant propulsion for apogee maneuver and east-west stationkeeping, xenon ion for north-south stationkeeping

Configuration

Ku: one 220 MHz bandwidth transponder, three transponders with bandwidths switchable between 36 and 72 MHz, one digital channel with onboard processing to multiplex up to 12 uplinks into a single downlink

EHF: one transponder divided into two 40 MHz bandwidth channels

Transmitter

Ku: in 12.5–12.75 GHz

48 SSPAs in active antenna, 3.2/1.6 W each (single/multiple carrier modes), 54/51 dBW maximum EIRP over France

Linearized amplifiers switched to either deployed reflector or steerable spot, 56 dBW maximum EIRP at edge of France

EHF: 20.2–20.24 and 21.16–21.2 GHz, 20.7 and 41.4 GHz beacons, 350/450 mW SSPA (20.7/41.4 GHz)

Receiver

Ku: 14.0–14.25 GHz

G/T +4/+8 dB/K at edge of coverage for steerable spot/deployed reflector

EHF: 44.0–44.04 and 44.96–45.0 GHz

G/T –3 dB/K at edge of coverage (3 dB below peak gain)

Antenna

Ku active array (transmit only): 48 planar subarrays arranged within 1.05 m diam octagon, 3 independent beams steerable ±4 deg east-west, ±2 deg north-south, beam size variable from France to much of Europe, gain 26 to 40 dB depending on beam size, linear polarization, 33 dB cross-polarization isolation

Ku transmit-receive antenna with fixed coverage over France, 2.4 m diam ultralight deployable reflector, same linear polarization as active array

Ku transmit-receive steerable spot beam, 1.8 deg beamwidth, linear polarization opposite to other Ku antennas

EHF transmit-receive antenna for 41.4 and 44-45 GHz, transmit-only antenna for 20.2-21.2 GHz, each antenna had an offset parabolic reflector with one feed horn for Europe and one for Guyana, 34–37 GHz peak gain, nominal coverage area is 1 deg off axis, right-hand circular polarization, 33 dB cross-polarization isolation

Telemetry and command

Command: in or near 12.5–12.75 GHz

Telemetry: in or near 14.0–14.25 GHz

Life

9 years

Orbit

Geostationary, planned for 11°W, N-S stationkeeping to ±0.05 deg

Orbital history

Destroyed by launch vehicle failure, 11 December 2002

Ariane 5 launch vehicle

Management

Developed by EADS Astrium (was Matra-Marconi Space when program started, then Astrium) and Alcatel

Would have been operated by CNES

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