NASA SP-93

Significant Achievements in Communications and Navigation 1958-1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION U.S.A.

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Scientific and Technical Information Division 1966
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

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PRINTING OFFICE, WASHINGTON, D.C., 20402—PRICE 45 CENT

Foreword

THIS VOLUME IS ONE OF A SERIES which summarize the progress made during the period 1958 through 1964 in discipline areas covered by the Space Science and Applications Program of the United States. In this way, the contribution made by the National Aeronautics and Space Administration is highlighted against the background of overall progress in each discipline. Succeeding issues will document the results from later years.

The initial issue of this series appears in 10 volumes (NASA Special Publications 91 to 100) which describe the achievements in the following areas: Astronomy, Bioscience, Communications and Navigation, Geodesy, Ionospheres and Radio Physics, Meteorology, Particles and Fields, Planetary Atmospheres, Planetology, and Solar Physics.

Although we do not here attempt to name those who have contributed to our program during these first 6 years, both in the experimental and theoretical research and in the analysis, compilation, and reporting of results, nevertheless we wish to acknowledge all the contributions to a very fruitful program in which this country may take justifiable pride.

HOMER E. NEWELL
Associate Administrator for
Space Science and Applications, NASA

Preface

THE NEED FOR A COMMUNICATIONS SATELLITE developed as a result of increasing world requirements for long-distance, real-time communications. In 1945 Arthur C. Clarke proposed a relay station in orbit as an artificial Earth satellite; however, this solution aroused little interest and lay dormant for more than a decade. By 1957 many technical solutions to the need for long-distance communications had been exploited, but all represented compromise of some form and most were limited by their very terrestrial nature. Clearly, the communications satellite was the only answer, and in 1959 the National Aeronautics and Space Administration initiated a program to develop the necessary technology.

The Navy CMR (Communication by Moon Relay) system had operationally demonstrated that the Moon could be used as a relay for passively reflecting signals over the Earth's curvature. However, by 1960 this system had also demonstrated the Moon's limitations as a communications relay facility, and the need for an artificial Earth satellite became increasingly urgent.

Such satellites could be either passive or active. Passive satellites act as a mirror, like the Moon, retransmitting no more energy than they intercept. Active satellites, however, receive and amplify a signal before retransmitting it to the ground.

NASA's experimental satellite program was directed toward developing reliable active and passive satellites;

developing narrowband and wideband satellite equipment; and determining the feasibility of low, elliptical medium altitude, inclined synchronous, and geostationary types of orbits. Ground station experience confirmed critical design equations, evaluated various methods of satellite acquisition and tracking, and demonstrated the satellite potential in future communications systems.

Contents

chapter 1

Introduction

WHY COMMUNICATIONS BY SATELLITE?

THE HISTORY OF CIVILIZATION is a history of man's understanding of his environment and his attempts to master it. These attempts may take the form of trade, travel, exploration, education, or military operations, each of which requires rapid communication to be effective. For many millennia, communication was limited to the spoken or written word and physical delivery over long distances. There was no means of long-distance, real-time communications.

Telegraph and Telephone

When Samuel F. B. Morse demonstrated the telegraph in 1844, mankind had already witnessed the tragedies that can result from inadequate communications; men died in the Battle of New Orleans in 1815, 2 weeks after the Treaty of Ghent.

The problem of spanning the ocean was always a principal challenge in man's efforts to improve his means of communication. Transoceanic electrical communications began in 1866 with the completion of the first transatlantic telegraph cable. This gave virtually instantaneous telegraph communication between North America and Europe. In 1861 Reis demonstrated the magneto-telephone which could translate the human voice into electrical signals transmitted along wires. Long-distance, real-time conversation began in 1876 when Bell developed a practical telephone and patented it for commercial use.

Hertzian Waves

Communications were limited by man's ability to string wire or cable until James Clerk Maxwell postulated, and Hertz demonstrated (about 1885), the existence of electromagnetic wave radiation. If this radiation could be modulated in accordance with some intelligence, it could provide real-time communications without wires or cables.

Countless investigators searched for practical methods to achieve this, but one man stands out—Guglielmo Marconi. By 1896 he had successfully demonstrated short-range communications. His experiments prior to the turn of the century have since been calculated to have been at microwave, line-of-sight frequencies. It is a tribute to his intellectual courage that he planned and executed a notable communications experiment—transatlantic low-frequency radio from Poldhu, Cornwall, to St. John's, Newfoundland, in 1901.

Long after this experiment, reflecting on his early years, Marconi said:

> The idea of transmitting messages through space came to me suddenly as a result of having read in an Italian electrical journal about the work and experiments of Hertz. My chief trouble was that the idea was so elementary, so simple in logic, that it seemed difficult for me to believe no one else had thought of putting it into practice.

Marconi felt that the future of wireless telegraphy could only be assured by a convincing and dramatic demonstration of its potentialities for long-distance communication. He decided that nothing less than bridging the Atlantic would meet the situation.

Cornwall, in the southwest of England, quickly suggested itself as a transmitting location, and a satisfactory site was found at Poldhu Point. On December 12, 1901, on a Newfoundland hilltop, Marconi heard a radio signal that had spanned the Atlantic, traveling nearly 2100 miles from the Poldhu transmitting station.

The Frequency Problem

In 1957 the communications engineer was faced with a dilemma. Using low frequencies he could propagate signals that followed the Earth's curvature (as did Marconi) and even penetrated sea water to submarines. Still widely used, these very low frequencies require large and expensive antennas and transmitters and are limited in the amount of information they can carry. As a medium for voice, television, or data communications, very low frequencies fail.

The higher frequencies corresponding to the "short waves" provided a form of oversea voice communications, but were limited in reliability by the vagaries of the ionosphere. They were also limited in available bandwidth, particularly during periods of low sunspot numbers when the frequency range reflected by the ionosphere was reduced to its minimum of a dozen megacycles.

Only microwave frequencies were able to carry the tremendous communication loads of the near future, but microwave frequencies were limited to line of sight by their straight-line propagation characteristic. A high-altitude relay was the obvious solution, but all the compromises noted previously were limited in altitude.

Radio Relays

During the 60 years after Marconi's first transmission, there was a succession of attempts to improve wireless communication over long distances. Some of these attempts are listed as follows.

(1) Ionospheric relay uses reflection of high-frequency "short waves" by the ionosphere. By 1927, trans-atlantic radiotelephone communications began, first at longer wavelengths and then in the 1930's at high frequencies.

(2) In 1956 a newly developed high-quality undersea cable providing 36 high-quality transatlantic tele-

phone circuits was laid. By 1965 approximately 400 telephone channels had been established across the North Atlantic using such cables.

(3) Microwave ground relays became a common sight from the highways throughout the United States in the 1950's. Expanding telephone and television traffic requirements on overland routes were met by such microwave repeater systems. Terrestrial line-of-sight repeaters, however, must be spaced at intervals of about 20 to 30 miles. To extend this interval, the height of the antenna towers must be increased. However, to obtain a single mid-Atlantic tower-supported relay station, a structure more than 400 miles high would be required.

(4) In the early 1960's tropospheric scatter, called "White Alice," was first commonly used in far northern military Early Warning Networks. It later linked the United States and Cuba for television broadcasts and island-hopped the Atlantic and Pacific for defense traffic.

(5) Airplane broadcast was used successfully for a number of years for educational television broadcasting in the Midwest. Certain military over-the-horizon tactical links were established by this technique.

(6) Ionospheric scatter relay was proven feasible as early as 1951, and some operational transoceanic circuits were established.

(7) Meteor scatter, called "Juliet" in Canada, has been of interest to both military and civilian system designers.

(8) Knife-edge diffraction of microwave transmissions has carried telephone traffic over the Andes mountains from Chile.

The real solution, for which all those just listed were mere substitutes, is an orbiting satellite, for an orbiting satellite reduces the number of engineering or geographic compromises that must be made. The passive satellite was proposed by Pierce in 1955 and O'Sullivan in 1956, but had to wait until the problem of erecting a large structure in space was solved in 1960. The active satellite was proposed by Clarke in 1945, with technical detail being added by J. R. Pierce in 1954 and others soon after.

HIGHLIGHTS OF COMMUNICATIONS ACHIEVEMENTS

From 1954 to 1959 the Navy translated the Army's Project Diana (radar contact with the Moon in 1946, a form of passive reflection) into what has been called the world's first operational space communications system—Communication by Moon Relay (CMR). The result was an actual communications link between Washington and Hawaii, which was operational from 1959 to 1963.

On December 18, 1958, the Air Force launched the Army-built Score, which became the world's first active communications satellite experiment.

On August 12, 1960, Echo I was launched. This passive reflector balloon has been called one of the best U.S. ambassadors, inasmuch as it has been clearly visible to millions of people throughout the world.

In October 1960 the Army Signal Corps' Courier I–B demonstrated the use of active repeaters for both real-time and delayed transmission of high data rate messages.

Between July 1962 and August 1964, NASA's program resulted in the successful launches of two AT&T Telstars (July 10, 1962, and May 7, 1963); two Relays (December 13, 1962, and January 21, 1964); another Echo (January 25, 1964); and three Syncoms (February 14, 1963, July 26, 1963, and August 19, 1964).

In the early summer of 1963 the Air Force launched West Ford, a passive satellite system consisting of a belt of orbiting reflective needles. This type of passive system was shown to be workable, and the predictions of noninterference with radio astronomy were validated.

A malfunctioning communications satellite was first successfully diagnosed from the ground when Telstar I was commanded "on" again (January 3, 1963).

Relay I provided the first satellite communications link between North and South America. With a history of 81 television demonstrations, Relay I has operated through twice its designed lifetime.

Syncom II, also operating beyond its designed lifetime, has made outstanding contributions to our knowledge of gravitational anomalies. Syncom II has recorded more satellite communications "on" time, 4800 hours of experiments and tests, than all other communications satellites combined.

Relay II, though only a year old, has successfully handled 27 television demonstrations.

In August 1964, Syncom III became the first satellite to be successfully boosted, attitude controlled, and injected and maneuvered into a preselected station in geostationary orbit, requiring very precise control. Syncom III demonstrations have shown the feasibility and value of a communications satellite in geostationary orbit to provide multichannel voice communications, teletype, and television, with and without simultaneous voice. It successfully relayed the Olympics from Japan to the United States in October 1964.

The first phase of cooperative U.S.–U.S.S.R. experiments in communications satellites began with Echo II in 1964.

Of the 10 orbital communications satellite flights attempted by NASA since 1960, only one passive satellite

(Echo A–10) failed to achieve orbit, and only one active satellite (Syncom I) failed to provide the relay capability for which it was designed. There have been, at times, several active repeater spacecraft operating simultaneously (fig. 1), and Echo I has been continuously available, although slowly degrading in performance, since August 1960. Significant progress was made between July 1962 and August 1964 with seven successful and two partially successful launches (fig. 2) made by NASA and the Air Force. These satellites were of a variety of types with various altitudes and orbits.

The success of NASA's experimental communications satellite program is clearly established by its numerous and varied accomplishments. The plans for a consortium of 20 nations, together with the Communications Satellite Corporation (United States), to establish an international operational system in 1965 is clear evidence of the impact of this program.

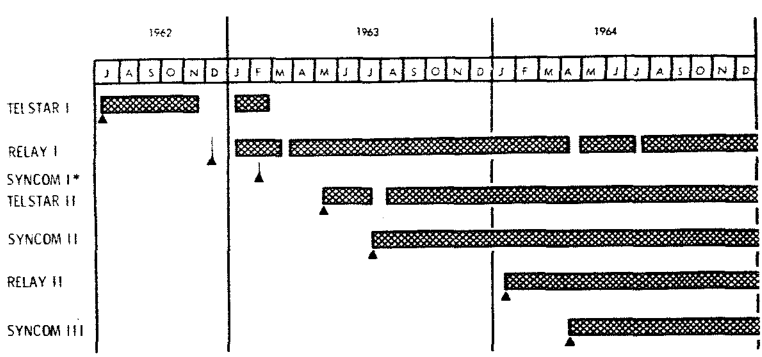

***Figure 1.*—Operating history of NASA-launched active communication satellites. Asterisk indicates successfully achieved synchronous orbit; spacecraft did not function electronically.**

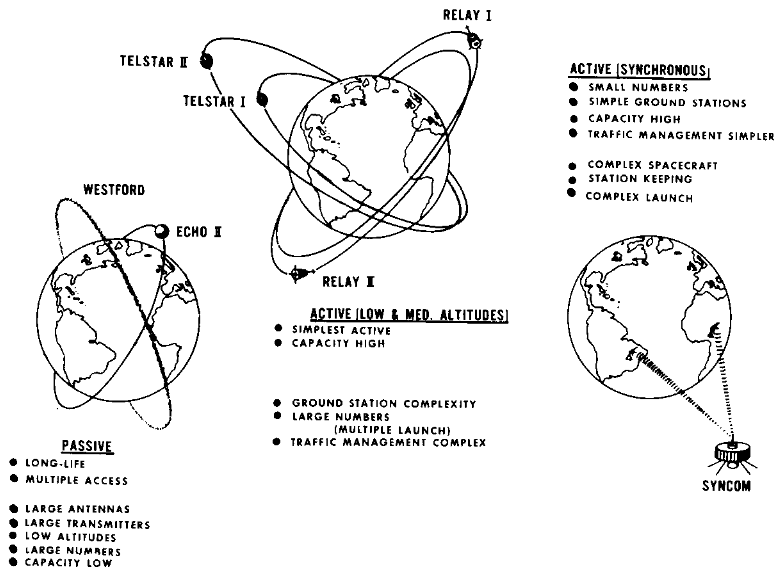

Figure 2.—Various types of communication satellites launched between 1962 and 1964.

chapter 2

Passive Communications Satellites

ECHO I

ECHO I, A 100-FOOT-DIAMETER BALLOON of aluminized Mylar, was launched into orbit by NASA on August 12, 1960 (fig. 3). Signals had previously been reflected experimentally from an orbiting Tiros weather satellite, but Echo I was used for a large number of well-planned transcontinental and intercontinental communications experiments. Most important, Echo I proved that it is practical to use a manmade passive satellite to reflect two-way telephone conversations across the United States. Echo I

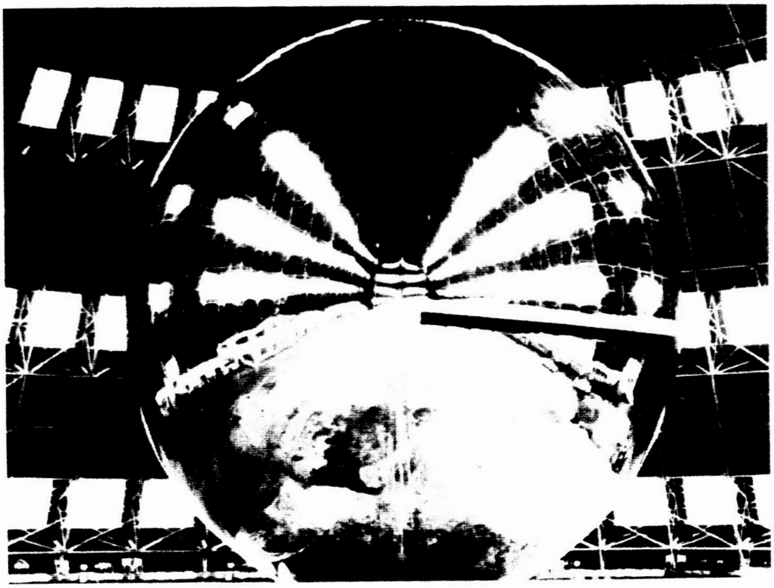

Figure 3.—Echo I.

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was large enough to be visible to the naked eye and people throughout the world have seen Echo I move across the sky in its 1000-mile-high circular orbit. Four years later, although wrinkled and deflated, the balloon was still in orbit, with a predicted further life until 1966.

Echo I provided valuable data for later work in satellite communications. It confirmed remarkably the validity of calculations used for designing ground stations, a substantial achievement. It also provided a mechanism for measuring solar pressure effects.

Two-way conversations of good quality were sent between the Bell Laboratories station at Holmdel, N.J., and the Jet Propulsion Laboratory station at Goldstone, Calif., and also between other points in the United States and Europe. The Holmdel scaled-up, horn-reflector antenna proved its value in these tests. Two features of the receiver circuitry were phase-lock loops and a technique known as frequency modulation with feedback (FMFB), originally described by J. G. Chaffee in 1939 but little used for two decades. New types of low-noise amplifiers using solid-state masers gave excellent results. Satellite tracking by radar and by telescope and computer prediction proved to be extremely reliable.

WEST FORD

West Ford, a different form of passive satellite system, was conceived in 1959 under military auspices. Originated and developed by the Massachusetts Institute of Technology's Lincoln Laboratory, the system consisted of a belt of millions of hair-thin reflective needles. This experimental West Ford belt was authorized but placed under severe constraints by the President upon advice of the National Academy of Sciences because of worldwide concern by radio and optical astronomers. A limited-life belt was successfully launched by the Air Force in the early summer in 1963. Although its formation was slower than anticipated, it demonstrated that predictions of noninterference with radio astronomy were correct; that the method of dispersing the belt was workable; and that a few such belts could provide a worldwide, reliable, low-data-rate communication system almost immune to physical destruction.

ECHO II

On January 25, 1964, Echo II was successfully orbited by a Thor-Agena vehicle from the Pacific Missile Range. The satellite configuration differed somewhat from that of Echo I, since a careful review of radar data taken on the second of two suborbital test flights in 1962 indicated that the balloons used had not been pressurized sufficiently to remove the wrinkles. As a result, an intensive program was started to develop a controlled pressurization system and to study in greater detail the effect of pressurization on surface smoothness and sphericity. This program involved static inflation tests in 1963 in a dirigible hangar at Lakehurst, N.J., and many precise measurements of surface conditions at various pressures. Stereomapping techniques were used as well as near-field monostatic and bistatic radar observations. These tests showed conclusively that an increase in pressurization provided a marked improvement in balloon sphericity and rf reflectivity. As a result, the controlled inflation system was used on Echo II.

A number of bags, each containing about 8 ounces of cast pyrazole, were sealed shut with temperature-sensitive wax and attached to the inside of the balloon before it was folded and packaged in its canister. Figure 4 shows the construction of one of these bags. After launch and canister opening, the residual air, at about 1 mm Hg, inflated the balloon to full extension, but did not completely pressurize it. As the sphere absorbed heat from the Sun, the wax melted, allowing the bags to open and the pyrazole to sublime and gradually pressurize the sphere. In all, it took about 42 minutes after canister opening for the Echo II sphere to reach its maximum pressurization of 218 μHg, close to the design goal. Figure 5 shows the inflation in orbit of Echo II as seen by television.

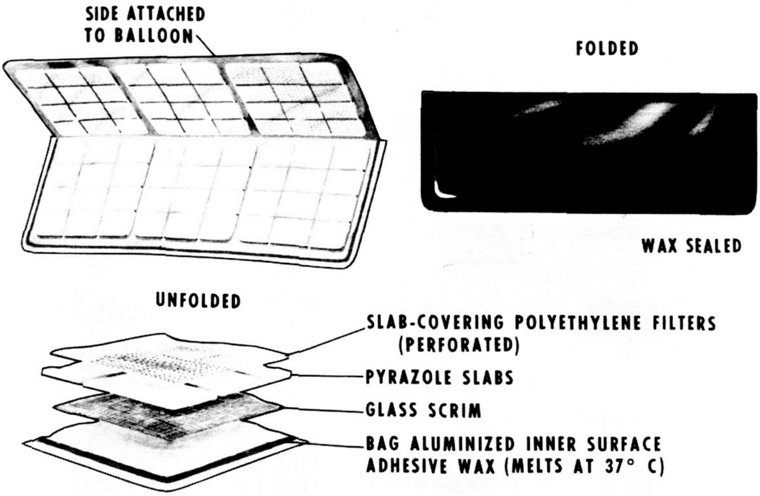
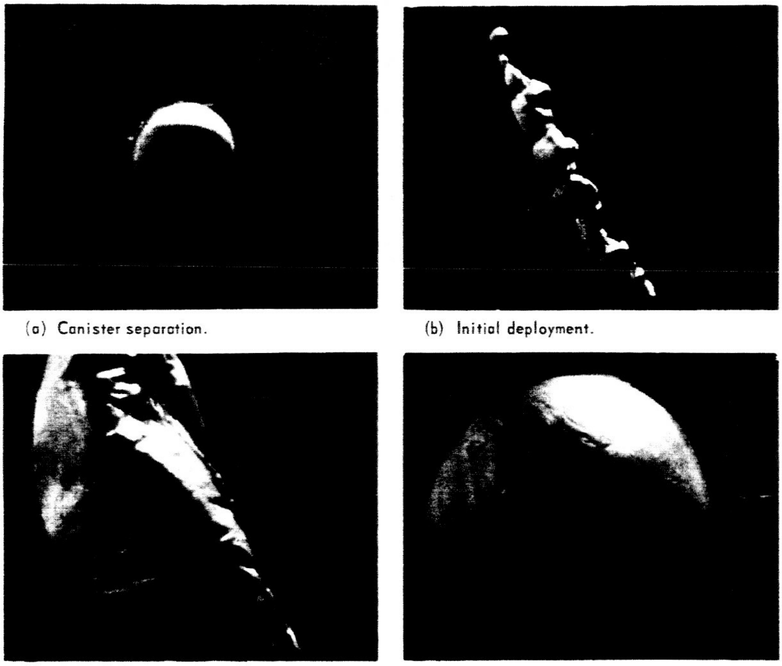


Figure 4.—**Construction of bags for the Echo II controlled inflation system.**

Echo II was studied intensively after launch by optical, radar, and telemetry measurements, and by analysis of communications experiments; in general, it behaved as expected.

In addition to U.S. experiments to determine the condition of the satellite, there was a cooperative experimental program with the U.S.S.R. During early orbits of Echo II, optical observations were made by stations in the U.S.S.R., and later a series of communications experiments was undertaken between the Jodrell Bank Radio Observatory of the University of Manchester, England, operating on NASA's behalf, and the Zimenki Observatory of the



(a) Canister separation. (b) Initial deployment. (c) Partial inflation. (d) Fully inflated.

***Figure 5.*—Echo II orbital inflation.**

Gorki State University, northeast of Moscow. This cooperative international effort was effected under a Memorandum of Understanding, which implemented the Bilateral Space Agreement reached at Geneva on June 8, 1962, between the U.S.S.R. Academy of Sciences and NASA.

During the prelaunch and early postlaunch phases of Echo II, the U.S.S.R. Academy of Sciences was notified of nominal orbital elements and kept informed of the launch schedule. They were also informed of the type of optical observations that would be helpful in evaluating satellite inflation and pressurization. Confirmation of satellite inflation and preliminary orbital parameters were transmitted to the Zimenki Observatory. The U.S.S.R.

supplied the United States with the results of optical and photographic observations from various sites during the early life of the satellite.

The U.S.–U.S.S.R. experiments with Echo II passive communications satellite included reception at Zimenki of 162–Mc/sec transmissions originating at the University of Manchester station, from which 33 communications experiments were conducted between February 21 and March 8, 1964.

chapter 3

Active Communications Satellites

EARLY ARMY COMMUNICATIONS SATELLITES

Score

IN 1958, the most immediately feasible design for an active relay satellite used battery power. Score, meaning "Signal Communications by Orbiting Relay Equipment," was built by the Army laboratory at Fort Monmouth, N.J., and launched by the Air Force on December 18, 1958, thus becoming the first active communications satellite. It was capable of real-time relay of voice, code, and teletype, and dramatically demonstrated its capabilities during its short life of 12 days. In one of these demonstrations Christmas greetings were transmitted from President Eisenhower. The repeated transmissions which were stored in the satellite on magnetic tape were triggered by ground command.

Courier

On October 4, 1960, the Army Signal Corps' Courier I–B was launched into a 500- to 600-mile-high orbit. This satellite weighed 500 pounds, measured 51 inches in diameter, was powered by 20 000 solar cells, and contained 4 receivers, 4 transmitters, and 5 tape recorders. It was designed to demonstrate the use of active repeaters for both real-time and delayed transmission at high data rates. Signals were received, stored on the tapes, and transmitted back to Earth. After 18 days in orbit, technical difficulties ended Courier I–B's transmission, but it received and retransmitted 118 million words during its active life.

THE PERIOD JULY 1962 TO AUGUST 1964

Telstar I

Telstar I was proposed by the Bell System as early as July 6, 1960, approved by the Federal Communications Commission on January 19, 1961, and launched on July 10, 1962. Telstar I (fig. 6) was launched into an elliptical orbit with an apogee of 3500 miles and a perigee of 580 miles and weighed 17 pounds.

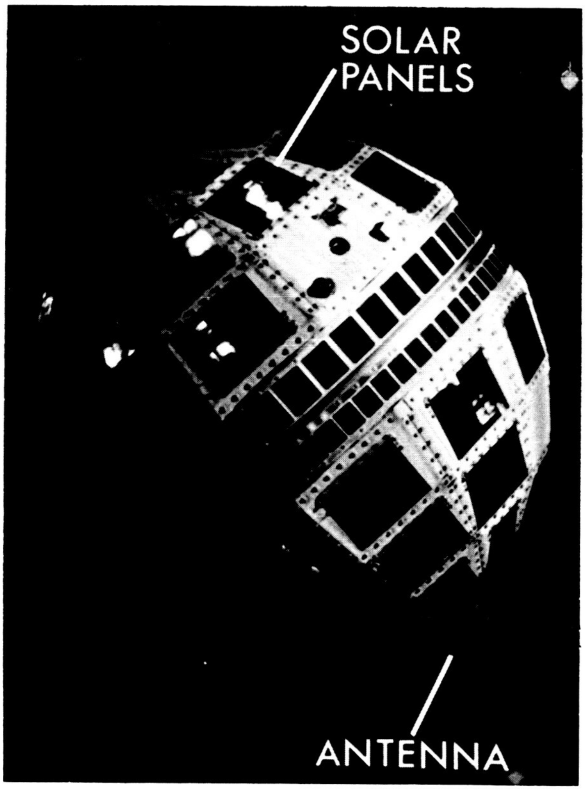


Figure 6.—Telstar active communications satellite: weight, 17 pounds; diameter, 34 inches; height, 34 inches.

Project Telstar had the following objectives:

(1) To prove that a broadband communications satellite could be used to relay telephone messages, data, and television

(2) To test some of the electronic equipment developed for satellite communications under launch and space stresses

(3) To measure the radiation encountered by a satellite in space

(4) To determine the best ways to track a moving satellite accurately

(5) To provide a real-life test for the satellite communications antennas and other ground station equipment

Much of the system technology incorporated in the Telstar project was developed or confirmed by work with Echo. Bell Laboratories had built a large horn-reflector antenna in Holmdel, N.J. For Project Telstar, a similar but larger antenna was designed. It was located at Andover, in western Maine, remote from microwave links with which it might interfere.

The Andover horn (fig. 7) is a steel-and-aluminum structure 177 feet long and 94 feet high, weighing 380 tons. The open end has an area of 3600 square feet and tapers down to a cab containing the receiver and transmitter.

A ground station very similar to the Andover installation was built soon after at Pleumeur-Bodou in Brittany by the French National Center of Telecommunications Studies (CNET). The British General Post Office established its station at Goonhilly near Marconi's Poldhu site in Cornwall. The British antenna is a deep parabolic dish rather than a horn reflector. Both the British and French stations participated in the first Telstar experiments. By

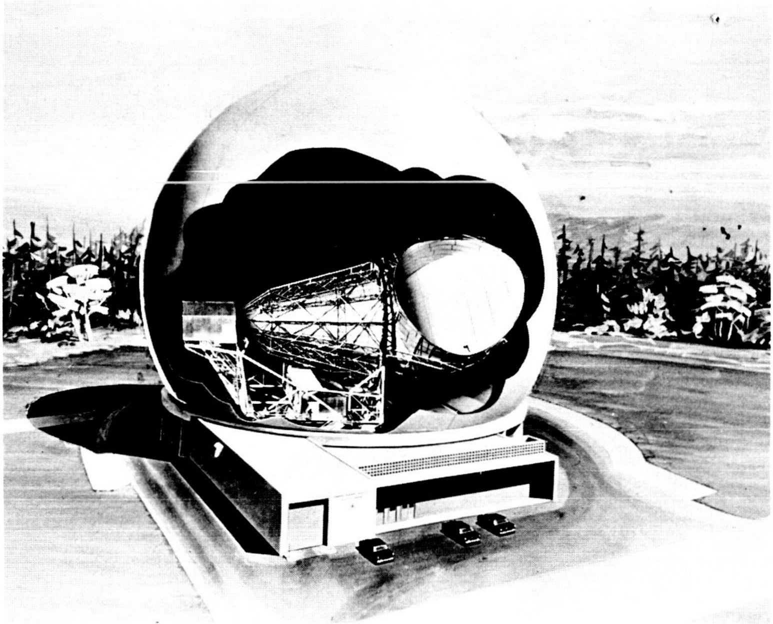


Figure 7.—The Andover facility.

late 1964, experimental Telstar ground stations had been set up in Fucino, Italy; in Raisting, Germany; and near Tokyo, Japan. Figure 8 shows the location of existing and planned communications satellite ground stations.

On Telstar's sixth orbit at 7:26 p.m., e.d.t., July 10, 1962, the first transmission via the satellite took place. During this pass, telephone calls, television programs, and photographs were transmitted between Andover and Holmdel. Some of these signals were also picked up in Europe. The next day a taped television program from France and a live program from England were transmitted to the United States. During the next 4 months more than 400 transmissions were handled by Telstar I, including 50 television demonstrations (black-and-white and color), telephone calls and data in both directions, and facsimile material.

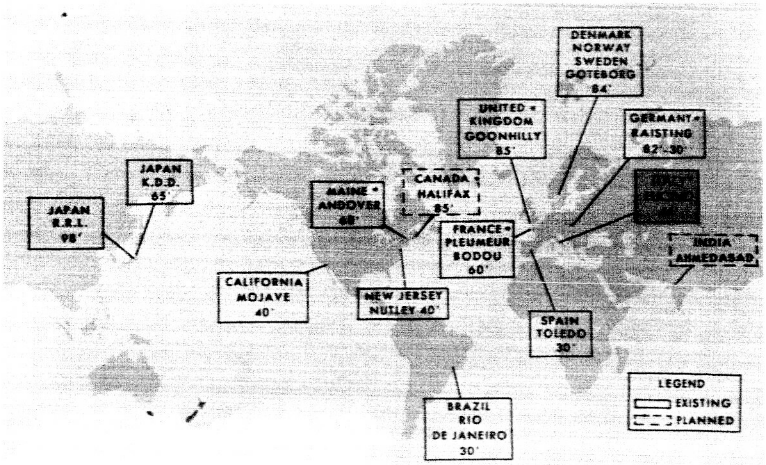


Figure 8.—**Existing and planned communications satellite ground stations. Asterisk indicates stations being modified for Early Bird.**

In addition, more than 300 valuable technical tests were made, almost all remarkably successful. Radio transmission was at least as good as expected. Telstar I's communications equipment worked exactly as planned, unharmed by the shock and vibration of the launch. Temperatures inside the satellite were within design range, and the solar cells worked almost exactly as expected. Tracking by the ground stations was accurate and almost routine. However, Telstar I unexpectedly encountered extreme manmade radiation in space, estimated to have been 100 times more intense than expected. As a result, difficulties arose during November 1962 in some of the transistors in its command circuit. Ground diagnosis of a malfunctioning communications satellite was successfully attempted for the first time, and Telstar I was commanded "on" again on January 3, 1963. The satellite later failed to respond to commands from the ground, and on February 21 went silent.

Relay I

Relay I was launched by NASA on December 13, 1962, and provided the first satellite communications link between the United States and South America, Japan, Germany, and Scandinavia. Relay satellites (fig. 9) are 33 inches long and weigh 172 pounds. A mastlike antenna at one end receives and transmits a single television broadcast or 12 simultaneous two-way telephone conversations. Four whip antennas at the other end handle control, tracking, and telemetry, turning experiments on and off and sending information on the behavior of its components and on the radiation it encounters. Relay satellites are powered by nickel-cadmium storage batteries charged by

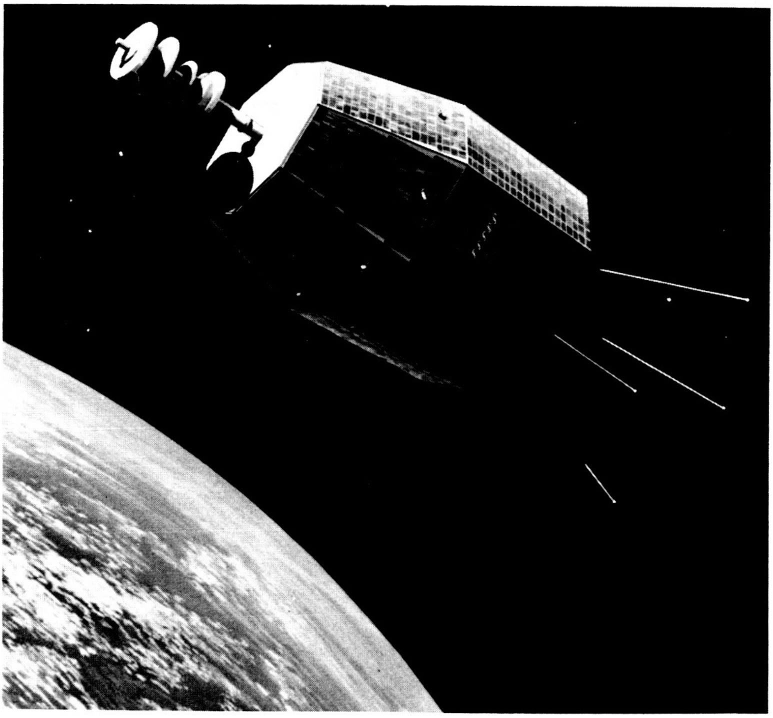


Figure 9.—Relay active satellite.

more than 8000 solar cells. They contain two identical receiving, amplifying, and transmitting systems, called transponders, each with an output of 10 watts.

In 1965, Relay I was still traveling in an orbit ranging from 820 to 4630 miles high and circling the Earth about every 185 minutes. Soon after launch, the Relay I telemetry reported trouble in the voltage-regulator switch for one of the transponders, which caused excessive power drain. On January 3, 1963, the alternate transponder was switched on, and a successful series of tests began, including live television broadcasts between the United States and Europe. Relay I contained a switch intended to terminate its usefulness automatically at the end of 1963, but the switch failed to function, and Relay I continued to operate, although with decreasing efficiency, for more than twice its design life of 1 year.

Syncom I

February 14, 1963, saw the first partial success of the Syncom project, NASA's most ambitious undertaking in the field of active communications satellites. The objective was to place active satellites in synchronous orbit. Syncom I was the first satellite to achieve a near-synchronous orbit (fig. 10).

A synchronous orbiting satellite is advantageous because a few can cover most of the Earth's surface. Such a satellite also requires simpler ground stations despite the greater distance from the Earth. Since low- and intermediate-altitude satellites move rapidly through the field of view of a ground station, at least two antennas are needed to maintain uninterrupted service. While one antenna tracks the satellite, a second antenna stands ready to acquire the next satellite as it comes into view. Message traffic must then be handed over from one antenna to the other. Very large antennas may have beamwidths

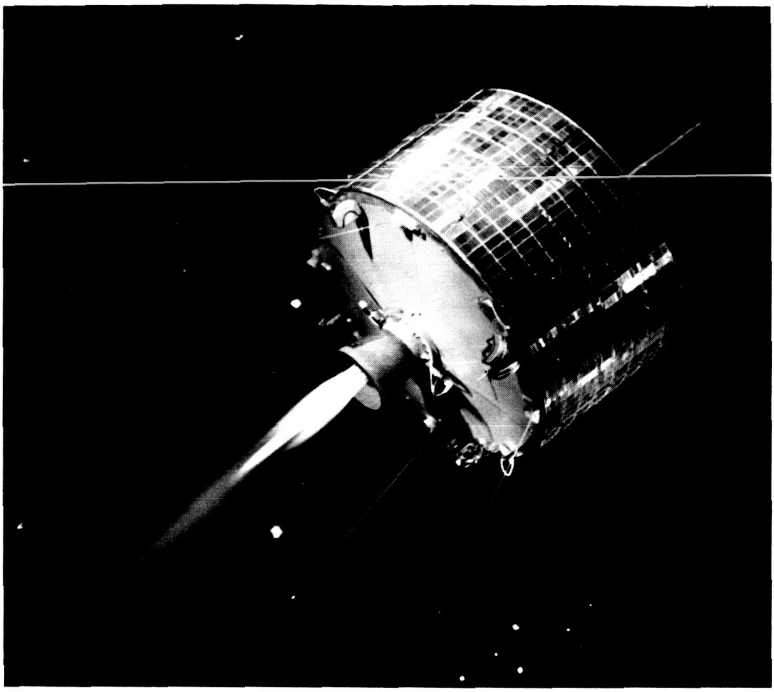


Figure 10.—**Syncom satellite.**

of about one-tenth of a degree. Pointing large antennas with such narrow beams at rapidly moving satellites is not easy, and expensive equipment is needed. Synchronous satellites, however, can be quite satisfactorily used with nearly fixed antennas. Of course, some steerability must be included to track small motions of the satellite and to permit transferring operations to a second satellite if the first should fail.

NASA's Project Syncom was a first step toward the use of synchronous satellites. A notable feature of Syncom satellites was that they carried an "apogee kick" rocket motor for supplementing the capabilities of the existing launch vehicle to place the 75-pound satellite in a near-synchronous orbit. Syncom satellites also carried gas-jet systems to orient them in the proper direction and to maintain their relatively stationary position with respect to the Earth's surface. The necessity for these systems to work properly is an extra complication of synchronous satellites as compared with those at intermediate altitudes.

The first experimental Syncom satellite, Syncom I, was launched from Cape Canaveral on February 14, 1963. The launch was almost perfect, and the satellite was placed in an elliptical orbit, with peak altitude of about 19 300 nautical miles. At that point the on-board rocket was to be fired, adding the velocity necessary to maintain the satellite at synchronous altitude. During the 5 hours it took for Syncom I to reach this 19 300-nautical-mile altitude, its communications equipment was checked out by the USNS *Kingsport* at Lagos, Nigeria, with satisfactory results. Approximately 20 seconds after the on-board rocket was fired, however, all signals ceased, and Syncom I has been silent since. Telescopic observations verified later that Syncom I achieved a 33° inclined orbit with a period of nearly 24 hours. NASA had placed the first satellite in a near-synchronous orbit.

Telstar II

On May 7, 1963, Telstar II was launched into an elliptical orbit with an apogee of 6700 miles and perigee of 600 took for Syncom I to reach this 19 300-nautical-mile altitude, almost twice that of Telstar I, provided Telstar II with longer periods of visibility at ground stations, and it kept Telstar II out of the high-radiation regions of space for a greater part of the time. The satellite itself was similar to Telstar I, except for a few minor changes that increased its weight to 175 pounds. Its radiation detectors had a greater range of sensitivity, and six new measurements could be made. Telemetry could use both the microwave beacon and, as before, the 136-Mc/sec beacon.

To help prevent the kind of damage that occurred to the transistors in the Telstar I command decoder, Telstar II had a different type of transistor with an enclosure which had been evacuated. A simplified method of operating the Andover horn antenna was begun, using autotrack alone for tracking and pointing. The first successful television transmission via Telstar II took place on May 7, 1963, and a new series of technical tests, radiation measurements, and experiments in transoceanic communications was started.

Syncom II

Syncom II was successfully launched on July 26, 1963, into an orbit inclined about 33° to the Earth's equatorial plane. A satellite in such an orbit appears from the ground to wander north and south at the longitude over which it is stationed. A truly geostationary satellite has a synchronous orbit and zero inclination. Figure 11 is a comparison of the inclined synchronous orbit of Syncom II with the geostationary orbit of Syncom III.

Syncom II provided the first television, voice, and facsimile experience with a satellite in 24-hour orbit and was the first satellite maneuvered to a specific longitude, 55°

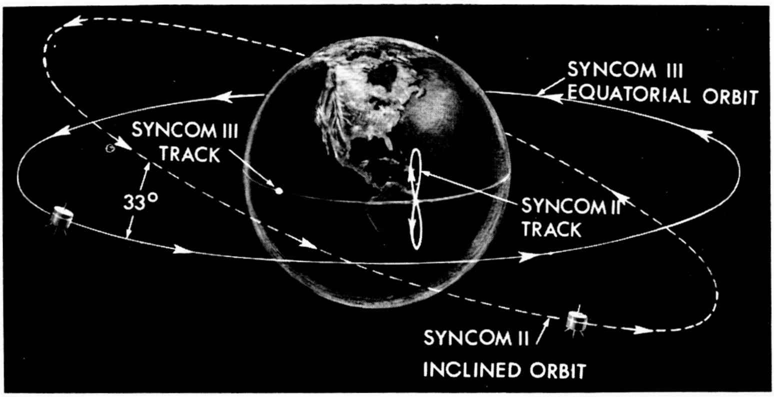


Figure 11.—**The synchronous orbit of Syncom II compared with the geostationary orbit of Syncom III.**

W. Period and attitude control of a spinning satellite was also achieved for the first time to station Syncom II. It has provided the world with many demonstrations between North America, Africa, and Europe. It carried the world's first telephone conference via satellite between heads of state (President Kennedy and Prime Minister Balewa of Nigeria).

Syncom II made several contributions to a determination of the Earth's shape and to the study of drift in synchronous satellites. The Syncom orbits lend themselves particularly well to the accurate observation of anomalies in the Earth's gravitational field. Because of their high altitude, effects of local unevenness of the Earth's topography are minimized. The accuracy of these observations was greatly enhanced by the Syncom range-and-range-rate system, which is capable of measuring range at synchronous altitude to an accuracy of less than 50 meters. Syncom II data have been used to obtain basic information on the size and location of the equatorial bulge as shown in figure 12. The Syncom determination for equatorial bulge, was 213 feet ± 6 feet; for the major axis longitude, 19° W$\pm 6°$; for the maximum drift correction, 5.36 ft/sec/yr. The previous data (1959–64) were, for the equatorial bulge, 671 feet to 69 feet; for the major axis longitude, 38.5° W to 0°; for the maximum drift correction, 17 to 1.75 ft/sec/yr. It was also concluded that station keeping takes considerably less energy than was formerly believed.

Relay II

Relay II was modified to increase its reliability and radiation resistance. It was launched into a slightly higher orbit than Relay I because of improved launch-vehicle performance. Relay II was successfully checked out on the first pass after launch on January 21, 1964, and was still working well a year later.

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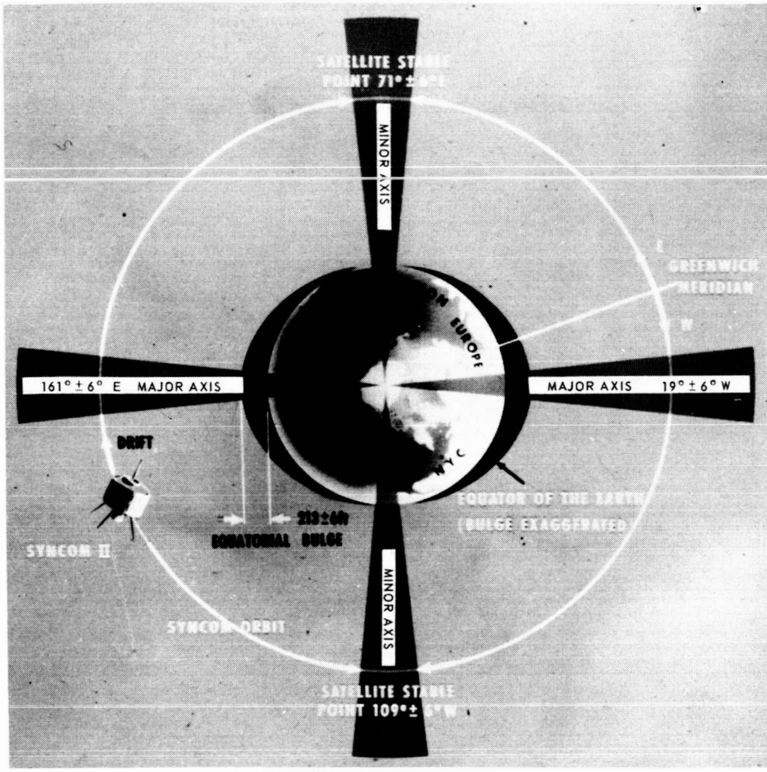

***Figure** 12.*—**Syncom II geodetic and orbital determinations.**

International Ground Station Cooperation

Not the least of the beneficial results of the Telstar, Relay, and Syncom satellite projects was the international cooperation on experiments between ground stations of the United States, Great Britain, France, Brazil, Germany, Italy, Japan, Spain, Scandinavia, and Canada. U.S.S.R. participation in test transmissions between the U.S.S.R. and the United Kingdom via Echo II satellite has already been described.

Syncom III

Syncom III was the first attempt to place a satellite in geostationary orbit. The ground track of a geostationary satellite is a point instead of a *figure* 8. Considerably more energy was required to achieve this orbit than the 33° inclined orbits of Syncom I and II. Zero inclination of the Syncom III orbit became possible with the availability, in 1964, of the thrust-augmented Delta (TAD) (fig. 13), a more powerful X–258 third stage, and the added thrust of the second hydrogen peroxide spacecraft control system. The latter was made possible by the omission of the nitrogen (N_2) vernier control system whose function was handled by the H_2O_2 system.

The launch maneuver to achieve geostationary orbit with the TAD vehicle required that the second and third Delta stages be yawed through an angle of about 38° so that firing of the third stage would reduce the inclination of the transfer orbit from 28° to 16°. The remaining inclination could then be removed by the firing of the apogee-kick rocket motor in the spacecraft.

The characteristics of the transfer orbit were determined during the first revolution of the satellite from range-and-range-rate measurements made at Clark Field in the Philippine Islands and the USNS *Kingsport* at Guam. The Syncom III spacecraft was precisely reoriented at the time of the second apogee so that the thrust of the apogee motor would place the satellite in a synchronous orbit of almost zero inclination. The apogee motor was fired by ground command at the time of the third apogee. Final orbital adjustments were made with the hydrogen peroxide control system, and the satellite drifted to its station near the international date line on September 11, 1964, 23 days after its successful launch on August 19, 1964.

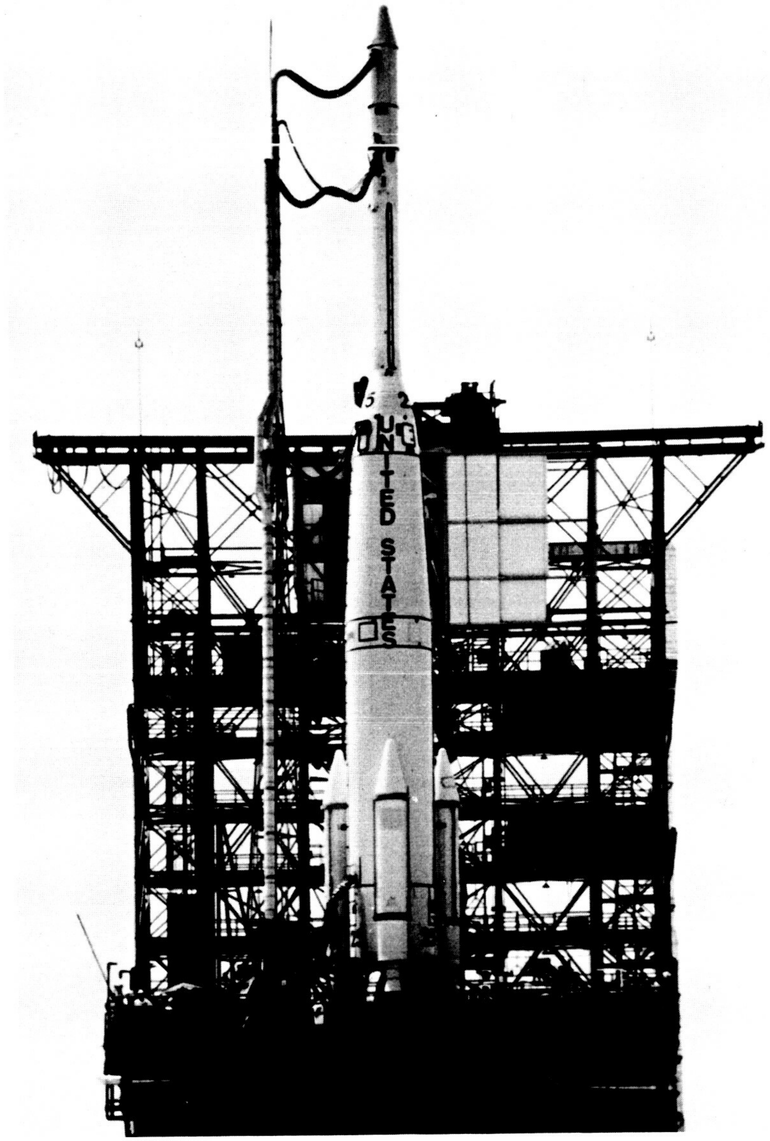

Figure 13.—Syncom III atop the thrust-augmented Delta third stage.

Public Demonstrations via Active Satellites

In addition to scientific and engineering tests of communication between spacecraft and ground stations, arrangements were made early in the planning phase of the NASA Communications Satellite Program to transmit real traffic of various types. A better subjective appraisal of system performance could be made, and the status of the work could be demonstrated to the public in the most understandable form. There was a substantial number of these public demonstrations covering virtually every type of telecommunications traffic. Through July 1964, Relay I and II, Telstar I and II, and Syncom II satellites carried a total of 133, 358, and 110 demonstrations, respectively. One notable reaction from persons communicating via the satellites was amazement at the high quality of the voice circuit. An important result of these demonstrations was that the availability of working satellites created a substantial demand for transoceanic television transmission, a demand that economic studies had predicted would be nonexistent or trivial. Some of the demonstrated practical uses of communications satellites follow.

On April 25, 1963, Relay I transmitted an electroencephalogram from the Burden Neurological Institute in Bristol, England, to the Mayo Clinic in Rochester, Minn. The electroencephalogram was processed by a computer which printed out data. A diagnosis was made from these data and immediately sent back via satellite to the patient's doctors in England.

Similarly, on May 28, 1963, a fetal electrocardiogram was transmitted from Mount Sinai Hospital in Milwaukee, Wis., to obstetricians in Paris, and two-way consultation took place.

A new medical procedure, hyperbaric pressurization, was demonstrated on November 6, 1963, at the Royal College of Surgeons in England and televised via satellite to the American Society of Anesthesiologists in convention at the Mayo Clinic in Rochester, Minn.

Medical consultation, diagnosis, and training on an international basis thus appear to be a practical benefit of operational communications satellite systems of the future.

Communications satellites have also been used successfully to synchronize master time standards located on different continents. This was first accomplished via Telstar I in August 1962 between the United States and the United Kingdom. An accuracy of 1 microsecond was achieved, compared with accuracies of 2000 microseconds previously attainable. Further tests between the United States and Japan over Relay I will extend this improved synchronization to another continent.

The wideband satellite, even though still in the experimental stage, provided solutions to many intercontinental timelag problems of the news media. Relay I carried 76 network TV demonstrations, useful simulations of what might occur in a real system.

The skills and techniques developed to that point were dramatically employed in November 1963 when Relay I handled 11 TV spot newscasts, 8 between the United States and Europe and 3 to Japan, in just 3 days at the time of President Kennedy's assassination. All the useful passes of the satellite were made available to permit immediate coverage of the tragic events.

The U.S. open attitude about its space program was clearly indicated to all those overseas who saw the nearly real-time broadcast of the Mercury flight of Astronaut Cooper relayed by satellite in May 1963. Acknowledgment of this attitude was shown in the European reactions to the flight relayed back to the United States.

The peoples of Europe were witness to the American hospitality extended to the Mona Lisa. The American people, in turn, saw the reception given to President Kennedy during his continental tour. Coverage of the last days of Pope John XXIII, his death and funeral, and the election and coronation of his successor were also of interest to people everywhere.

The feasibility of comparing newly taken oceanographic data with previous observations to check rapidly the accuracy of shipboard equipment was demonstrated on September 19, 1963. The U.S. Bureau of Commercial Fisheries vessel *Geronimo* was participating in Equilant II, an intensive survey of the tropical Atlantic in the Gulf of Guinea. *Geronimo* transmitted its data to the USNS *Kingsport* at Lagos, Nigeria, for relay via Syncom II to the National Oceanographic Data Center (NODC), Washington, D.C. At NODC the data were compared for consistency with available previous data from the 5° square within which the survey was made. Had the measurements been inconsistent with previous data, oceanographers would have been alerted to the discrepancy in time to confirm or correct it with minimum effort.

One of the most widely known communications satellite demonstrations was the international television coverage of the Olympics from Japan in October 1964. Television programs were transmitted not only to the United States but to Europe as well. The transmission to Europe marked the first time that two satellites had been employed in tandem for television broadcasting purposes. The programs were transmitted via Syncom III from Japan over the Pacific to Point Mugu, Calif., and retransmitted via Relay I over the Atlantic to Europe. Communications satellites are the only practical means of transmitting live television programs over such distances.

In addition to American viewers, more than 50 million Europeans, including many in Eastern Europe, viewed same-day transmission of the Tokyo Olympic games via

U.S. satellites. The Tokyo Olympic coverage was received throughout Europe as far east as Poland.

In addition to transmission to Europe via Relay I, Tokyo Olympic pictures, sent from Point Mugu, Calif., by landline, were videotaped in Montreal and flown to Europe for broadcast throughout the continent via the Eurovision network and behind the Iron Curtain by Intervision. Because of the time difference, European viewers saw events in Tokyo on the evening of the day they had taken place.

The total number of viewers in Spain, Italy, and Portugal was estimated at 16 million; the United Kingdom counted an audience of approximately 13 million. From Warsaw, the American Embassy reported that 85 percent of Poland's 1 500 000 television receivers were tuned to the Olympic programs.

The U.S. Embassy reported,

> Polish TV proudly credited the Syncom and Relay satellites. There was considerable press comment about the special transmissions and the fact that these facilities were the result of American technology is widely, if not universally, known here.

In a different kind of demonstration, NASA cooperated with the Federal Aviation Agency, Air Transport Association, and private industry in transmitting teletype test messages via Syncom III to a commercial aircraft operating between Hawaii and California, on November 22, 1964 (fig. 14). This was the first test demonstrating the feasibility of such transmissions and has implications for solving communications, navigation, air-sea rescue, traffic control, and small ground station problems.

Experimental Conclusions

By the end of 1964, Telstar I and II, Relay I and II, and Syncom II and III had shown that—

- Communications quality via satellite relay was good out to at least 19 300 nautical miles

- Existing ground stations operated routinely and effectively
- Ground station technology was not limited to the United States
- Accurate antenna pointing was practical
- Orbital information could be routinely derived and disseminated
- There was no reported interference to surface microwave services
- Central control of a number of ground stations was feasible

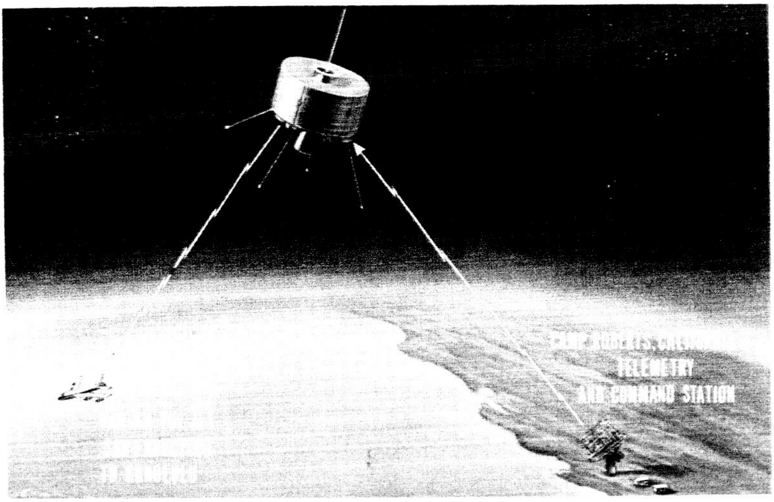

Figure 14.—Syncom III VHF data transmission.

chapter 4

Technology Developed by the United States for Use by Designers of Early Systems

THE COMMUNICATIONS SATELLITE CORPORATION

IN 1960 WORK HAD BEGUN on bringing about the legislation necessary to establish a private corporate entity for exploiting the commercial possibilities of the communications satellite. The Communications Satellite Corp. was authorized by an act of Congress on August 31, 1962, and incorporated on February 1, 1963. The act stipulated that NASA was to launch satellites for the privately owned corporation, furnish technical consultation, and cooperate with the corporation in research and development. Plans call for deployment of a global commercial system beginning late in 1966.

The decision of Congress to place commercial exploitation of communications satellites in the hands of a private corporation was preceded by more than 2 years of intensive study and discussion, both in and out of Government, on the use of satellites for international communications.

One of the earliest official actions directed specifically toward the operational use of communications satellites was a notice of inquiry issued by the Federal Communications Commission (FCC) in May 1960 concerning the allocation of frequencies for space communications. This inquiry prompted a joint industry-Government study which concluded, in March 1961, that it was feasible for communications satellite systems to share frequencies with surface microwave radio relay systems.

This and other studies formed the basis for U.S. proposals to the International Telecommunications Union that frequencies for communications satellite systems be allocated on a shared basis. These allocations were made in November 1963.

In April 1961 the FCC instituted another inquiry into the administrative and regulatory problems relating to the authorization of commercially operable space communications systems. This inquiry caused extensive discussion on the subject by Government agencies and communications carriers. Congress held hearings on various aspects of the establishment, ownership, operation, and regulation of a communications satellite system and, in July 1961, the President issued a policy statement favoring private ownership of the U.S. portion of a worldwide communications satellite system.

At the opening of the second session of the 87th Congress, several bills were introduced proposing both private and public ownership of communications satellite facilities. After considerable discussion and debate, an act authorizing private ownership was passed on August 31, 1962, and the Communications Satellite Corp. was incorporated on February 1, 1963.

The Communications Satellite Corp. had two principal tasks. One was to define and develop a technically feasible and economically viable system, and the other was to secure the participation of foreign carriers; these efforts proceeded concurrently.

By the summer of 1963, Communications Satellite Corp. and State Department personnel were engaged in discussions with representatives of European countries that had installed experimental communications satellite ground stations and, therefore, were obviously in a position to participate in an early operational system. These discussions were later broadened to include most of the countries in Western Europe and Japan, Australia, and Canada. The discussions and negotiations culminated in August 1964 in two multilateral agreements, one a General Agreement among the governments involved and the other a Special Agreement among the entities chosen to implement the global system. As of February 20, 1965, the following countries were participating in the system:

Algeria	Israel	Spain
Australia	Italy	Sudan
Austria	Japan	Sweden
Belgium	Jordan	Switzerland
Brazil	Kuwait	Syria
Canada	Lebanon	Tunisia
Denmark	Libya	United Kingdom
France	Netherlands	United States
Germany	Norway	Vatican City
Ireland	Portugal	

Technical studies by the Communications Satellite Corp. led to a two-part program. The initial effort would be a synchronous-altitude, low-inclination satellite, based on the NASA Syncom design, for service between North America and Europe. The second phase was to be a truly global system.

In December 1963 the Hughes Aircraft Co., designers of Syncom, submitted a proposal to the Communications Satellite Corp. for the initial satellite. This proposal was accepted, and the Early Bird (HS–303) satellite was conceived.

In addition to proving that a synchronous orbit was feasible, Project Syncom's technological growth made the following contributions to Early Bird:

(1) Same orientation and station-keeping system
(2) Same basic ground control techniques
(3) Same basic power supply system

(4) Same basic structure

(5) Same apogee motor

Early in 1964 NASA agreed to launch one or more of these satellites and provide related services on a reimbursable basis, as required under the act. In December 1964, NASA and the Communications Satellite Corp. signed a formal agreement detailing the services to be provided, the methods for determining costs, and related matters. Under this agreement, NASA has the following specific responsibilities.

(1) Procure and test thrust-augmented Thor-Delta launch vehicles

(2) Procure and test apogee motors

(3) Manage integration of launch vehicle and spacecraft

(4) Assure that launch vehicles are qualified for flight

(5) Manage and schedule launchings

(6) Provide tracking, orbital, and pointing data and telemetry recordings during transfer orbit

(7) Provide camera coverage of apogee firing if feasible

(8) Provide other data acquisition and communications services as requested by the Communications Satellite Corp. and agreed to by NASA.

The launching requirements of the Early Bird program were as follows:

(1) Initial launch on or about March 23, 1965

(2) Backup, if necessary, 60–120 days later

(3) Optional launch during second half of 1965

(4) Up to five optional launches between April 1, 1966, and March 31, 1967

(5) Replacement launches as necessary after March 31, 1967

NASA's charges to the Communications Satellite Corp. for Early Bird support and to AT&T for Telstar support were based on the principle of "identifiable additional cost,"[*] the principle advocated by NASA before Congress during testimony preceding adoption of the act.

For the later global system, the Communications Satellite Corp. had three separate design studies underway:

(1) Radio Corp. of America (RCA) and Bell Telephone Laboratories of AT&T studied a system of randomly spaced, medium-altitude, spin-stabilized satellites at an altitude of about 7000 miles.

(2) Space Technology Laboratories (STL) of Thompson Ramo Wooldridge, Inc., considered a medium-altitude system of "phased" satellites using gravity gradient attitude control.

(3) Hughes Aircraft Co. investigated an improved synchronous geostationary system.

The decision on which system to employ will be based on results of these design studies, experience with Early Bird, and other factors.

NASA PLANS: 1965–70

Applications Technology Satellite

The constant increase in launch-vehicle capability and the improvement in space-flight techniques led to the idea of an unmanned satellite performing several functions, not necessarily related. NASA initiated the Applications Technology Satellite (ATS) program in 1964 as a first step toward the idea of a multimission satellite. The following were the principal objectives of the ATS program at that time:

(1) Insuring continuing availability of the technology required for the useful application of satellites, with emphasis on stabilization and orientation techniques

(2) Providing the means for conducting space experiments with various technological applications of satellites, with emphasis on the geostationary orbit

(3) Conducting a definitive experiment in gravity gradient stabilization to obtain basic information needed in designing stabilization systems

The history of these objectives is important and is recounted as follows:

All experimental communications satellites discussed thus far radiated far more radio energy than was directed toward Earth. If a satellite could be developed which would always keep one face pointed toward Earth, directional antennas could be used, and the energy radiated toward the Earth could be increased.

Using simple stabilization techniques, NASA demonstrated through 1964 the application of satellites in meteorology and communications. For future growth, much technology needed to be developed, particularly in satellite stabilization and orientation. This is especially true for the higher altitude orbits. Many applications require Earth orientation of satellites in intermediate altitude orbits and, for precise stabilization, orientation and station keeping in the synchronous orbit. Evidently, a single spacecraft capable of accomplishing several different missions would be economical. A possible combination for a single satellite in synchronous orbit might be communications, meteorology, and navigation.

One form of stabilization not requiring on-board power is "gravity gradient stabilization," the phenomenon that keeps the same side of the Moon always pointed toward Earth. Several tests of a gravity gradient attitude control system had been conducted earlier at low altitudes, but none at the higher altitudes of interest for communications satellites. NASA, therefore, formulated plans for a thorough test of gravity gradient stabilization at higher altitudes under its ATS project.

A study conducted between 1962 and 1964, directed toward a large communications satellite, resulted in a systems concept and a subsystem and component engineering design for a spin-stabilized synchronous satellite requiring an Atlas-Agena class launch vehicle and a large "apogee kick" stage. This satellite design proved to be adaptable to other stabilization systems and to provide a capability for carrying several types of unrelated applications experiments. NASA proceeded to a full flight project based on this spacecraft concept in order to test different types of stabilization technology and to provide means for research in several engineering and technological disciplines on one spacecraft.

Plans for a five-flight project, beginning in 1966 and continuing through 1968, now include two satellites spin-stabilized in synchronous orbit, a satellite at an altitude of 7000 miles for a gravity gradient experiment in Earth orientation, and two Earth-oriented satellites in synchronous orbit using a gravity gradient technique. In addition to the gravity gradient experiments, others in the areas of communications, meteorology, navigation, radiation detection, and radio propagation will undoubtedly be carried out. The ATS–A, as conceived in 1964, is shown in figure 15.

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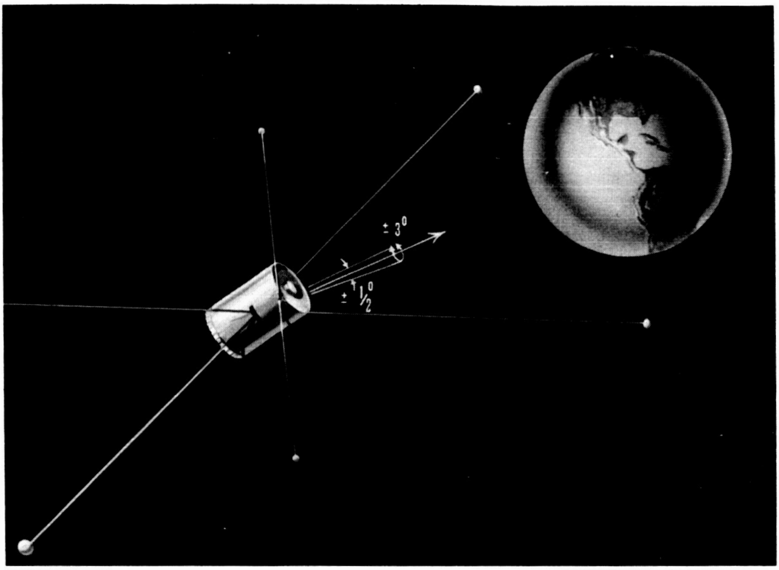

Figure 15.—ATS–A spacecraft showing orientation accuracy.

chapter 5

Summary and Outlook

PRESENT ACHIEVEMENTS

Satellite Design

THE ERECTION IN ORBIT of a large spherical passive reflector was accomplished through the Echo project, and later experimentation has resulted in improved materials and inflation systems. The large area-to-mass ratio of the Echo sphere made it possible to obtain data from which information on atmospheric density and solar pressure has been calculated. Echo I, being initially of known size, smoothness, and reflectivity, permitted total communications system calculations that agreed with theory to within 1 decibel.

Echo II was a long-lived, rigidized, spherical, passive satellite demonstrating the success of the technology for erecting large structures strong enough to maintain themselves against the environment.

The communications capacity of satellite transponders has been increased from narrowband (voice, teletype, and facsimile) to wideband, which is suitable for television or hundreds of telephone channels. Transponder design has stimulated the design of reliable traveling wave tubes, components, circuits, and systems.

The effect of solar radiation on many spacecraft components, particularly solar cells, has been observed and improvements made. In addition, the radiation environment and damage to the spacecraft components have been measured. Finally, a component failure was diagnosed and the orbiting satellite reactivated from the ground.

Ground Station Design

Echo I confirmed design parameters and system calculations, as well as the value of cryogenic techniques (masers and parametric amplifiers) for noise reduction. The lowering of the signal-to-noise ratio at which a frequency-modulated (FM) signal becomes readable by use of FM with feedback has been amply demonstrated.

Propagation anomalies have been studied and are beginning to be understood. As a result, ground stations small enough to be transportable or shipborne were used with Relay and Syncom satellites. Tracking data obtained are sufficiently precise to provide accurate pointing information for communications antennas.

Effects of Orbital Characteristics on System Design

The limitations of the low-altitude orbit for operational systems are known. The use of elliptic, medium-altitude orbits, not only as a method of minimizing radiation damage to the spacecraft but as a means of increasing mutual visibility periods between certain ground stations at certain times, has been demonstrated.

Early, subjective reactions to the fraction-of-a-second time delay in communicating via synchronous satellites indicate a less serious problem than often predicted. System design considerations have been thoroughly examined and design of communications satellite systems now stands on firmer ground, since all types of orbit have proved feasible.

Computers have been used to optimize system parameter tradeoffs for given boundary conditions.

Effects of Public Acceptance

Telstar set a precedent for the Government licensing and launching of privately built satellites and systems. American and European audiences are enthusiastic about intercontinental television. Transmission of facsimile copy of "speedmail" letters by communications satellite has been demonstrated. Cooperative experimental programs, both interagency and international, have been proven feasible and valuable. The reliable real-time transmission of conferences has been demonstrated.

Frequency Assignments

Frequency problems have been studied intensively, and present assignments seem to be adequate for a decade; future changes will be based on a consensus of experts on the International Radio Consultative Committee (CCIR) and on the Consultative Committee, International Telegraph and Telephone (CCITT).

Typical Technical Results—Relay I

Typical of the technical results obtained from each of the satellites described are those from Relay I, summarized here as an example.

The general conclusions drawn from Relay I were that the use of a communications satellite resulted in a link of commercial CCIR quality. A low-cost ground station with a small 30-foot antenna could successfully handle 12 telephony channels with a satellite of the Relay type.

Propagation and Noise

In practically all cases the measurements of received carrier power agreed with predicted values within measurement error. The spin modulation of received carrier signal strength caused by the spacecraft antenna pattern was noticeable, but became objectionable only when the received signal was near the FM threshold, and the 3-cps spin modulation carried it in and out of this threshold. Signal strength at low elevation angles showed the same fluctuations because of ground propagation effects as observed with Telstar; above 3°, these effects were negligible.

Overall receiving system noise temperatures held quite well at each station over a period of time. At the Pleumeur-Bodou and Andover stations, rain occasionally caused system noise temperatures to be higher at zenith than at low elevation angles. This was attributed to the fact that rain impinged more directly on the top than on the sides of the radome.

Measurements of continuous random noise, both wideband and narrowband, at all stations were higher than predicted. Departure from the predicted FM triangular noise spectrum had been observed at the lower baseband frequencies, but the increase was attributed to residual noise in the ground baseband equipment. The discrepancy between predicted and actual postdetection signal-to-noise ratio was largely attributed to this and other extraneous noise sources in the baseband equipment. Representative values were as follows: Pleumeur-Bodou predicted 54 dB, actual 46 dB; Goonhilly predicted 45 dB, actual 37 dB.

Linear Distortion

Both the CCIR (recommendation 267) standard video test signals and steady-state response measurements indicated that Relay I caused little linear distortion. The small amount noted was caused mainly by the ground baseband equipment. Measurements in the wideband mode of both video and audio steady-state responses at baseband indicated that the Relay I objectives, based on the CCIR recommendations, were met. Representative values were as follows: video, flat with ±0.3 dB from 50 kc/sec to 5 Mc/sec; audio, down 3 dB at 50 cycles and at 8 kc/sec. The conclusion was that linear distortion caused no problem for satellite links of the Relay I type beyond that inherent in ground microwave links.

Nonlinear Distortion

Data obtained on nonlinear distortion indicated that the Relay I objectives, based on CCIR criteria, for differential gain and phase shift across the radiofrequency and intermediate frequency passbands were not quite met at all times. Preemphasis at baseband was recommended to improve the differential gain characteristics from early measured values of 2.8-dB peak to peak to the objective of 2 dB. Phase differences as high as 45° were obtained, indicating that an objective of 5°, as required for color television, was not attained. Delay equalization and preemphasis were recommended to decrease the phase shift.

Nonlinear distortion in the Relay I system was tentatively concluded to be completely within limits for black-and-white television, but did not meet CCIR standards for color, although color transmission appeared adequate subjectively.

Multichannel Telephony, Intermodulation Noise

Measurements made of 300- and 600-channel intermodulation noise at the wideband stations indicated that the objective (15 000 picowatts for the sum of thermal and intermodulation noise) was not always met. Equalization of delay in all ground equipment was recommended. Representative values measured at Andover were 10 000 picowatts of thermal noise and 12 000 picowatts of intermodulation noise.

Narrowband measurements, mainly at the Nutley, N.J., IT&T station, were made of envelope delay distortion, harmonic distortion, and indirect measurements of intermodulation noise. Results indicated that the spacecraft met the Relay I objective of 7500 picowatts for intermodulation noise. Delay equalization in the ground equipment was again recommended to reduce intermodulation noise.

Envelope delay distortion and harmonic signal testing afforded a means of measuring multichannel telephony interchannel noise indirectly.

Two-Way (12-Channel) Telephony, Intelligible Crosstalk

Amplitude to frequency modulation conversion in the spacecraft traveling-wave tube appeared to cause crosstalk from the baseband of one carrier to the other. Complementary channel operation reduced this crosstalk to satisfactory levels.

Transmission Tests

Numerous television tests were conducted by the main wideband stations at Goonhilly, Pleumeur-Bodou, and Andover. Relay I was used for both the video and audio transmissions, obviating the use of the transatlantic cable for sound transmission. Subjective performance of the television transmission via Relay I was excellent in many tests and demonstrations. Color television without sound was transmitted via the spacecraft in loop configuration from Andover, with sufficient quality to be placed on U.S. commercial networks.

Technical Questions Still Under Investigation

The technology used in this early series of flight tests is clearly adequate for first-generation operational communications satellite systems. A number of important technical questions still need to be answered, however, and are under intensive study.

Frequency Allocations

It was apparent from the beginning that frequency sharing with surface systems was mandatory for communications satellites, since the 1000 to 10 000-Mc/sec band, which is best suited for space communications, was already fully allocated to surface use. Studies conducted in 1960–62 indicated that frequency sharing would be feasible. In November 1963, the International Telecommunications Union allocated 2800 Mc/sec of spectrum space for satellite communications systems on the basis of sharing with terrestrial systems (fig. 16). Sharing criteria are very conservative, and further experience may well provide a basis for relaxation, which is desirable since power flux at the Earth's surface required for operation of small and inexpensive ground terminals are higher than allowed by the present criteria.

Time Delay and Echo

A second important technical problem is the time delay inherent in synchronous-altitude satellite systems of about six-tenths of a second, round trip. This delay by itself is not usually detectable by a telephone user. When termi-

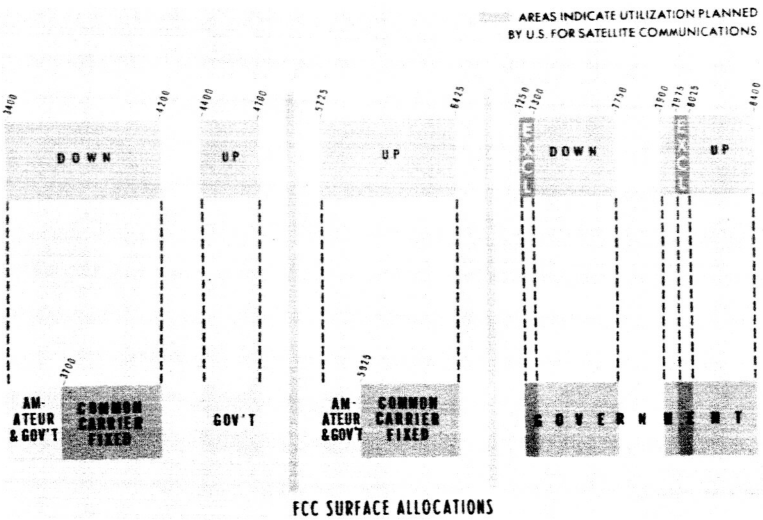

Figure 16.—ITU communications satellite allocations.

nations are imperfect, however, an echo occurs, and acceptability decreases rapidly with increasing echo amplitude. Although echo suppressors are used to eliminate the echo, they are essentially voice-operated switches and introduce undesirable side effects. The adverse effects of long-delayed echo led to a tentative international agreement that round-trip delays should not exceed 300 msec, as recorded in the annex to question 6/XII in the CCITT "Red Book," 1960.

Additional laboratory and subjective tests of user reaction to time delays and echo were conducted for 3 years, 1962–64, but with inconclusive results. The last in this group of tests was conducted by AT&T in collaboration with the FCC, NASA, and the Communications Satellite Corp. The most important results of these tests were submitted by the United States to the Plenary Assembly of the CCITT in Geneva in May 1964. Based on these results and on information submitted by other administrations, particularly those of the United Kingdom, the CCITT provisionally recommended the following limitations on mean one-way propagation times when echo sources exist and echo suppressors are used:

(1) Acceptable without reservation, 0 to 150 msec.

(2) Provisionally acceptable, 150 to 400 msec. Connections may be permitted in this range, particularly when compensating advantages are obtained.

(3) Provisionally unacceptable, 400 msec and higher. Connections with these delays should not be used except under the most exceptional circumstances.

The problem of time delay and echo is not limited to voice communications. In fact, the conclusions may well be different when considered in connection with high-speed data communications, particularly if automatic error detection, querying, and correction is included. Certain high-speed automatic signaling and routing systems may be sensitive to the amount of delay.

Multiple Access

The successful application of satellite-borne repeaters to global telecommunications provides the potential for extending high-quality telephone communications service to many points now served poorly or not at all. However, to realize this potential fully, a number of technical problems must be solved.

One of the most significant problems is called "multiple access": how to employ a single satellite-borne repeater simultaneously for communications among a number of ground stations, each communicating with one or more of the others.

Various methods of modulation and multiplexing can be employed to provide multiple access. However, each scheme is sensitive to the configuration of the satellite system (medium or synchronous altitude), the number of participating ground stations, the traffic demands of each, the required flexibility of routing, and other factors.

Many papers discuss four principal categories of multiple-access technology (multiple FM carriers, single sideband in the uplink, time division multiplex, and common spectrum), and assess their relative merits. It is very probable that continued efforts on this problem will yield an acceptable solution.

OUTLOOK FOR THE NEAR FUTURE

The Foundation

The first phase of the NASA communications satellite research and development program was completed with the launch of Syncom III on August 19, 1964. This was the last scheduled launch directed exclusively toward developing techniques for high-traffic-density, point-to-point communications satellite systems. The results obtained from Telstar I and II, Relay I and II, and Syncom II and III have made adequate technology available for the development of commercial systems such as that which the Communications Satellite Corp. will establish.

The ATS Program

The Applications Technology Satellites (ATS) program, initiated early in 1964, will provide a spacecraft to be used for research, development, and flight-testing efforts common to a number of applications. The five ATS flights will develop active and passive three-axis stabilization techniques for spacecraft in geostationary orbit and will perform critical experiments in communications, meteorology, and navigation.

The 1970's

The technology now available will permit establishment of early operational systems capable of high traffic densities, but only through the use of rather sophisticated and expensive ground terminals. Services which for any reason may have to use smaller terminals can use satellites only if the power flux at the surface of the Earth can be increased several orders of magnitude above that produced by the first generation of communications satellites. Examples of such services are air traffic control, navigation, broadcast, and mobile services. An increase in effective radiated power (ERP) from the spacecraft is required and attainable by increased spacecraft power output, by increased spacecraft antenna gain (fig. 17), by improved spacecraft stabilization, or by a combination of these. Any of these alternatives necessitate larger spacecraft than are required for systems using larger ground stations. Consideration should soon be given to flight projects directed toward higher power and improved stabilization and antenna gain in the period after the ATS–A through –E launches; i.e., during the early 1970's. System types which might be considered are interplanetary navigation satellites and radio and television broadcast satellites, shown in figure 18. Work on multiple-access techniques and on highly directional, electronically steerable antennas should continue.

NASA is currently studying the feasibility of satellites as a navigational aid for ships and transoceanic aircraft, for air traffic control, for coordination of air-sea rescue, and for tracking other satellites and spacecraft. Two of the satellites under study (fig. 19) utilize many of the technological advances of the synchronous-altitude ATS. One would weigh approximately 700 pounds, be placed in a 22 300-mile circular orbit by the Atlas-Agena, and be designed for a 3-year lifetime. Most of the technology required for the accomplishment of this mission will become available from the ATS program. To achieve the 3-year lifetime, how-

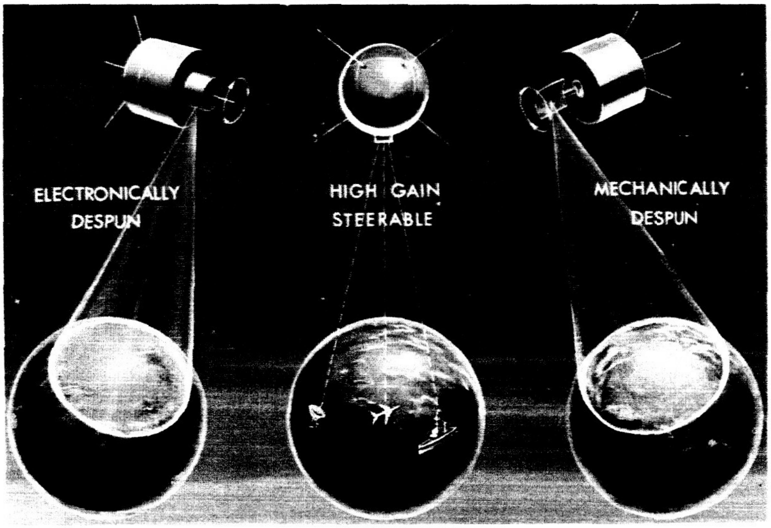

Figure 17.—Directive spacecraft antennas.

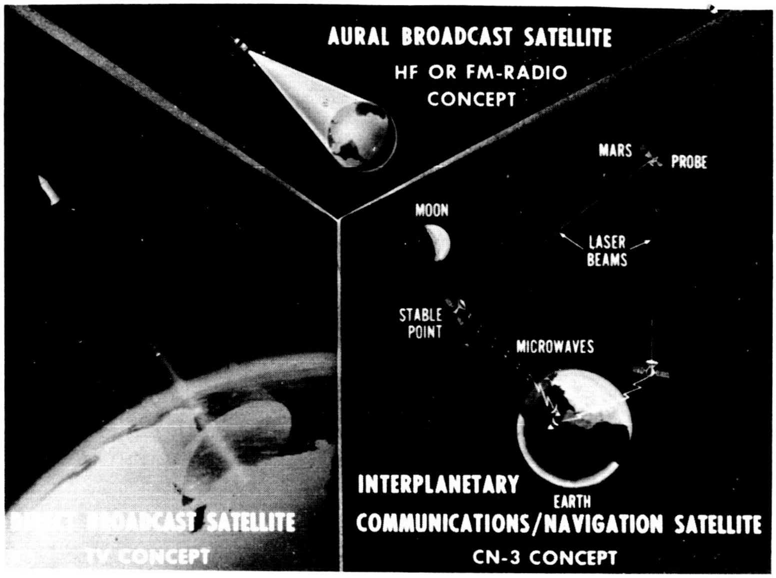

Figure 18.—Communication and navigation opportunities.

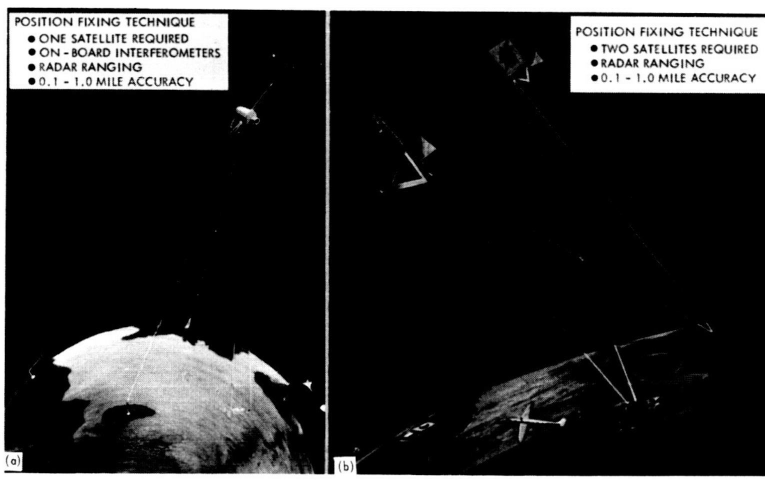

Figure 19.—Navigation satellite concepts. (a) Range-angle-angle; (b) range-range.

ever, improvements in components will be required, as will technology for a precision spaceborne interferometer.

Such a mission would typically depend on the ATS program for basic technology in the areas of satellite stabilization, component flight testing, and environmental data. No such missions will be attempted until these and other required technologies mature, notably those of launch vehicles and spacecraft power sources.

Further advances in higher power communications satellites are foreseen. Broadcast satellites could be capable of broadcasting either voice or television directly to the average home radio or television receiver. Broadcast satellites should be placed in geostationary orbit, so that the simplest receiving antennas could be used.

Broadcast satellites can further provide emergency and civil defense communications to an entire country. As an educational aid they can be used to bring the best of educational material to the remotest of communities. They can provide for global dissemination of information, and can ultimately serve to unite the people of large areas more rapidly than would conventional techniques.

A broadcast satellite for television, however, would require tens of kilowatts of radiated power to cover even limited areas. The development of nuclear reactors, however, could provide an initial capability, perhaps by 1975. The problems of reliably handling large power levels in space are great; therefore, as an intermediate step, a radio-broadcast satellite, using 1 to 3 kilowatts, in synchronous orbit appears desirable. Such satellites, perhaps by 1971, could provide voice broadcasts to home receivers over nearly an entire hemisphere, and provide the necessary experience with the problems of high power in space as well.

It is important to emphasize, however, that consideration of a broadcast satellite must include an assessment of the policy questions it raises.

Resolution of those questions—legal, economic, and political—must be sought at a pace appropriate to that at which the technical question is resolved.

A hopeful sign of a tolerant and optimistic attitude toward broadcasting from satellites is contained in Recommendation No. 5A of the Extraordinary Administrative Radio Conference (EARC) held in Geneva in 1963. The Conference recommended that the CCIR expedite its studies of technical feasibility and make early recommendations on technical characteristics of systems, and frequencies for operation.

It is significant that efforts to develop the technology of broadcast satellites can be matched by concurrent efforts to resolve policy questions. NASA, for its part, will work to provide information on the technical feasibility, need, and economic justification of these higher powered satellites.

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