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Chapter 8

COMMUNICATION SATELLITES: THE EXPERIMENTAL YEARS[*]

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"It may seem premature, if not ludicrous, to talk about the commercial possibilities of satellites," wrote Arthur Clarke in 1957. "Yet the aeroplane became of commercial importance within 30 years of its birth, and there are good reasons for thinking that this time scale may be shortened in the case of the satellite, because of its immense value in the field of communications."[1]

Good reasons indeed! Only a few weeks later the Soviet Union launched *Sputnik 1*, and the United States soon followed with *Explorer 1* and a number of other scientific and applications spacecraft, many involving communications experiments. Technical and economic feasibility were soon demonstrated. As a result, not thirty, but only eight years elapsed before the first commercial satellite, "Early Bird", entered service; and in just twelve years commercial satellite service extended around the globe and became profitable.

How was it that the communications satellite gained commercial value in such a short time? Three ingredients were necessary for this to happen, and fortunately all three were, or shortly became, available: technology to create the system; communications requirements to form a market; and a management structure to implement the system. This paper treats the development of all the technologies through experimental and developmental satellites that made satellite communications not only possible, but eminently practical and profitable, in a very short span of time.

Many different technologies are needed to create a communications satellite system. These flowed from diverse sources. Launch vehicle and spacecraft technologies came from work supported over many years by the U.S. Department of Defense (DoD) and for a shorter time, but more intensely, by the National Aeronautics and Space Administration (NASA). The communications and electronics technologies, on the other hand, came mostly from civil and commercial sources, as did the system design and engineering. The first communication satellites were launched in the United States on NASA Delta vehicles which were

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derived from earlier military rockets. The spacecraft technologies for the first commercial satellites came from NASA experimental spacecraft; and the communications technologies were inherited largely from commercial microwave systems. The first Earth stations found their roots in radiotelescopes, radars, and microwave transmissions systems. The technologies of satellite communications are truly eclectic and their origins and development paths interesting indeed.

FORMING THE CONCEPT

It is Arthur C. Clarke, the internationally known science fiction writer, then a Royal Air Force officer, to whom we are principally indebted for the concept of using Earth orbiting satellites for telecommunications. In 1945, he recognized the unique nature and usefulness of the geostationary orbit[2] and suggested "space stations" in that orbit as a means "to link TV services to many parts of the globe." He foresaw (incorrectly) a rather limited future for terrestrial radio links and cables as means for distributing communications services. "A relay chain several thousand miles long would cost millions," he wrote, "and transoceanic services would still be impossible."

A few years later in the United States, John R. Pierce of Bell Laboratories, writing without knowledge of Clarke's words, independently suggested several promising system configurations employing passive as well as active satellites in low altitude as well as geostationary orbits.[3] He raised a point, which has since proved the very basis for the ascendance of the satellite over the cable for transoceanic telephony: Looking at the first 36-channel submarine cable just then (1955) being laid under the Atlantic by the British Post Office and American Telephone and Telegraph Company and costing some $35 million, Pierce asked, "would a channel 30 times as wide, which would accommodate 1080 phone conversations or one TV signal, be worth 30 x 35 million dollars?" He recognized this then as an absurd thought and predicted (correctly) that a technical solution could be found before the commercial demand reached that point. Satellites, of course, have proved to be the solution and we can now provide a thousand channels and more--not at a cost equivalent to many cables, but for only a fraction of the cost of one cable.

With the concepts of Clarke and Pierce in place, the launch capability demonstrated by several Sputniks and Explorers and electronics technologies becoming available, it was possible in the early 1960s to envision an operating satellite communications system. Still, the means and organization for developing and operating a system were not apparent.

Then, in 1961, President John F. Kennedy took two considered steps to accelerate the pace of the U.S. space program. One, quite famous now, was his announced goal to send an astronaut to the Moon in that decade; the second, not so well known, was his "Policy Statement on Communications Satellites."[4] His statement recognized the potential value of satellites to provide communications services; established government policy to coordinate activities and carry out research and development; called for implementation by the private sector and, most importantly, invoked an international effort with these words: "I invite all nations to participate in the communications satellite system, in the interest of world peace and closer brotherhood among peoples of the world."

President Kennedy's bold and prescient statement led to passage by the U.S. Congress of the Communications Satellite Act of 1962[5], which in turn, set in motion a series of events which resulted in the formation of the Communications Satellite Corporation (Comsat) in 1963, and INTELSAT in 1964, and the initiation of the global system in 1965.

It is interesting to realize now that the 1961 statement was based largely on prediction and promise, very little on the results of development or on demonstrated technology. At the time, no active satellite had flown to test voice or video transmission, no spacecraft had ever been put in geostationary orbit, no data on reliable operation of electronic devices or rotating mechanisms in space were available, and some considerable doubt existed as to the acceptability of long-delay transmission paths for commercial service. Still, engineers and managers pushed onward, and as each technical, economic, operational, political, and organizational problem unfolded, they seem somehow to have found solutions.

As the stage was being set for the initiation of commercial satellite communications, a number of particularly knotty technical and operational questions posed themselves. Those engineers and planners in DoD and NASA who were involved in developing technology and launching experimental satellites and those members of Comsat's technical staff responsible for designing and specifying the initial system, faced and tried hard to solve these key problems:

o Should the satellites be active or passive?

Previous experimental work using both the Earth's natural satellite, the Moon, and the metallized plastic balloon, Echo, had shown that signals could be bounced successfully off a passive reflector in orbit and received on Earth. But a very high level of transmitted power would be required and the aperture of the receiving station would have to be quite large. An active electronic receiver, amplifier, and transmitter on the satellite would provide much more system gain. But could this electronic instrumentation withstand the trauma of a rocket launch and survive the orbit for the months or years necessary to make the system economically viable?

o What orbit should the satellites be in?

With relatively low-powered rockets, rudimentary guidance systems, and limited orbital control capabilities, the geostationary orbit suggested by Clarke, though desirable, looked very difficult to attain in the early 1960s. Test flights had been at altitudes of a few hundred kilometers. Then too, the question was raised (largely by experienced system engineers at AT&T) as to whether the long delay time involved in transmission through a satellite in geostationary orbit (over 1/2 second for the two-way trip) would be tolerated in commercial telephone service. There was concern both for the inherent delay and for the ability to suppress "echo" on the circuit. However, since a geostationary satellite system could provide global coverage with three satellites, whereas a medium altitude (say 3000 to 5000 kilometers) would require 20 or more satellites; and since the former would require just one Earth antenna at each location, while the latter would need two steerable antennas--there were powerful technical and economic reasons for going to a geostationary satellite system if it proved technically possible.

o What frequency band should be used?

Various experimental military and civil satellites had used frequencies in the VHF and UHF bands for tracking, telemetry, and command functions; but for telecommunications it would be more efficient to use higher frequencies in the "microwave" region (above one gigahertz) where a great deal more bandwidth would be available, and therefore, a higher information transmission capability attained. Microwave transmitting and receiving equipment was then available from radar systems for ground use, but not for space. Could it be made available? Particularly, could light, efficient, and reliable power output tubes be developed for spacecraft use? If so, which frequencies in the one to ten gigahertz band should be used for transmission up? and down? Because of the power output tube challenge, it seemed desirable to use the lower frequency on the down link.

o What services should be provided?

The obvious advantages of satellite communications over other forms lie in their wide area coverage, broad bandwidth, and direct access to small terminals. These advantages would seem to make satellite communications particularly useful for television broadcast and mobile services. Indeed, television broadcast was originally suggested by Clarke. However, the commercial infrastructure already existed for transoceanic point-to-point telephone service, and a market existed in the early 1960s, at least in the Atlantic region.

SATELLITE EXPERIMENTS

The years from 1958 to 1964 were the true "experimental years" for satellite communications. During this crucial period, technology developed rapidly. At the beginning of the period, little technology existed, no service had been tested in orbit, and not one of the questions raised above could be answered. But by the end, enough technology was available to provide confidence to answer those questions and to create an operational satellite communications system which became INTELSAT.

Passive Satellites

Even before Sputnik, design and experimental work had been conducted on passive satellite communications. The U.S. Navy began testing Moon relay communications in 1954 and started an operational service between Washington, D.C., and Hawaii in 1959.

A metallized balloon satellite was first suggested for tracking purposes at the London Congress of the International Astronautical Federation in 1951. In 1956, William J. O'Sullivan at the Langley Research Laboratory of the National Advisory Committee for Aeronautics (NACA--later to become NASA) proposed to develop a 12-foot diameter version of such a balloon. His concept came to the attention of John Pierce of Bell Laboratories and William H. Pickering, Director of the Jet Propulsion Laboratory of CalTech, who suggested it as a passive communications satellite. First, the DoD turned down the opportunity to sponsor this project preferring to concentrate on active satellites which seemed more likely to meet their requirements. But then, NASA, in one of its earliest decisions, decided to support the concept, which resulted in the Echo program.

Leonard Jaffe, an engineer, who had just come from the Lewis Research Center in Cleveland to be Chief of Communication Satellite Programs at NASA Headquarters, saw the potential value in both passive and active communication satellites. He was responsible for directing the Echo program and all the active satellite development work that NASA was later to pursue and which developed the many technologies that eventually became the foundation for INTELSAT and many other systems. Jaffe's book, *Communications in Space,* published in 1966[6], is the best source of detailed information on the early development of communication satellites.

Passive satellites were touted as "simple, reliable, and long-lived." The Echo spacecraft were the simplest type of isotropic reflectors. There was no expectation that they would ever develop into operational systems, but their purpose was to test propagation through the atmosphere and ionosphere and to develop transmission techniques. Not so incidentally, they turned out to be valuable in the development of Earth station equipment and technology.

Echo I was a 30-meter diameter, metal, and plastic balloon launched in August 1960, into an inclined 1600-kilometer orbit from Cape Canaveral on a Thor-Delta vehicle. *Echo I* provided the first live, two-way voice communications via satellite. Many other optical and radio tests were made using stations around the world. Within a week of its launching, the first transoceanic satellite signal transmitted from Bell Laboratories in New Jersey was received in Paris by an Earth station of the Centre National d'Etudes de Telecommunication.

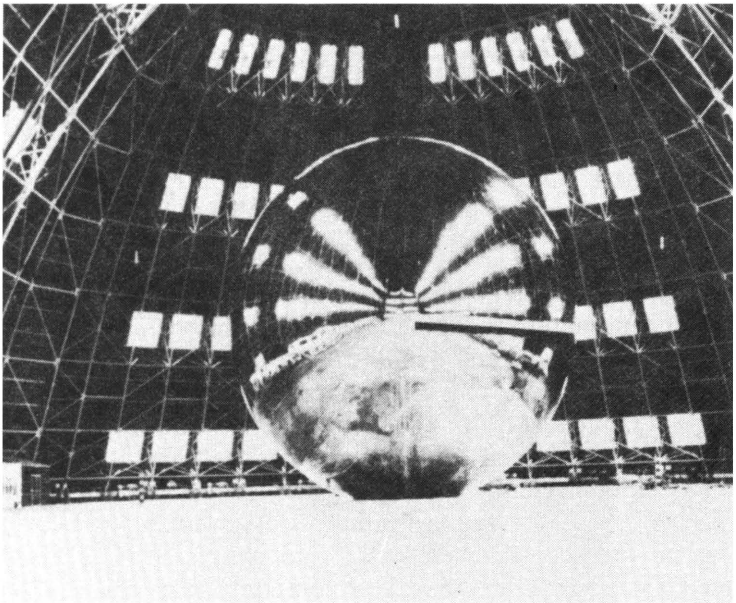

Figure 1 The Echo-II passive reflector satellite.

Echo II, somewhat larger and more rigid, was launched in January 1964, by a Thor-Agena. Tests with *Echo II* included transmission between a station at the University of Manchester, England, and the State University at Gorky, U.S.S.R. The Echo satellites proved the feasibility of radio transmission via satellite, measured propagation characteristics, and demonstrated the effectiveness of various items of transmitting, receiving, coding, and modulation equipment. Perhaps because they were so easily visible to observers on Earth, the Echo satellites excited the general public and stimulated enormous interest not only in satellite communications, but in all the practical applications that space systems had to offer.

Whereas the Echo balloons were discrete reflectors, Project *West Ford*, sponsored by the U.S. Air Force, used an orbital "belt" of small wire filaments as dispersed reflectors. This project was carried out by the Lincoln Laboratories under the direction of Thomas F. Rogers and Walter E. Morrow, Jr. The advantages of a dispersed reflector system over a discrete system were continuous availability and large reflection area, whereas the disadvantages included frequency limitations and interference with other systems. Successful tests of *West Ford* were conducted in 1963. Although no attempt was made to implement an operational system, the project contributed in important ways to developing ground terminal equipment and transmission techniques. Also, it brought the efforts and talents of people like Rogers and Morrow and others at Lincoln Labs working on military research to bear on the field of satellite communications with many future beneficial results to civil systems.

ACTIVE SYSTEMS

The first active communication satellite was *Score*, a 60 kilogram payload built in just a few months by DoD and carried into orbit on the side of an Atlas rocket in December 1958. As a "delayed repeater," it received a message from Earth, stored it on tape, and later in another part of its orbit transmitted the message to ground. *Score* transmitted President Eisenhower's Christmas message to the world and became known as the first "voice from space." Its 8-watt VHF transmitter lasted less than two weeks on battery power and died on New Year's Eve.

The second DoD effort was *Courier*, like *Score* a delayed repeater, but this time a separate spacecraft intended to develop an operational capability. *Courier* was spherical, 130 centimeters in diameter, with a mass of 230 kilograms. It was a highly complex, solar cell powered satellite with four receivers, four transmitters, and five tape recorders, processing and repeating several kilobits per second of digital data. It was launched on a Thor-Able-Star vehicle into a 1000 kilometer orbit in October 1960. *Score* and *Courier*, together, proved that delicate and complex electronic equipment could be made to survive the trauma of rocket launch and function in orbit. *Courier* demonstrated all essential subsystems of an active satellite--communications, power, telemetry, and command. It also demonstrated the unfortunate and inevitable tradeoff between complexity and reliability. *Courier* operated perfectly for 18 days, then failed, due to a command system fault.

Encouraged with the success of *Courier* and *Score*, the DoD in late 1960 embarked on a most ambitious project, *Advent*--aimed at placing a 1000 kilogram body-stabilized, high-powered microwave satellite in geostationary orbit. Two years were scheduled for this task. The Air Force assumed responsibility for building the spacecraft; the Army and Navy, for the ground and shipboard terminals. *Advent* was terminated in 1962 after the expenditure of $170 million. The reason was simple: Requirements were set well beyond technological capability to meet them--a lesson to be learned over and over again in aerospace systems development.

Telstar was the most famous experimental communication satellite of all--technical contributions were so significant and its impact on the public so great-that its name for a while became generic for "communication satellite." Telstar was developed by Bell Laboratories at AT&T under the guidance of John Pierce, and with AT&T corporate funding, became the first significant undertaking in space by private enterprise.

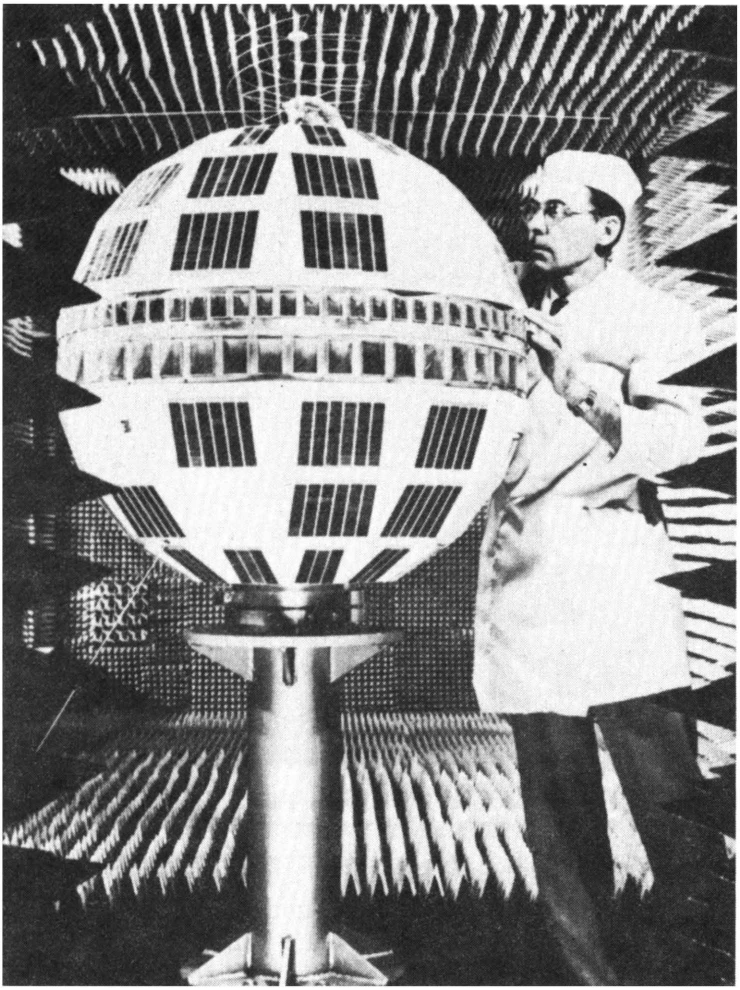

Figure 2 The Telstar satellite, developed and built by the American Telephone and Telegraphy Company.

Telstar was an 88-centimeter diameter, with a faceted sphere, mass of 80 kilograms, covered with solar cells with an antenna belt around its waist. Significantly, Telstar received at six GHz and transmitted at four GHz bands that later were assigned to commercial service and used by INTELSAT and other "fixed service" systems exclusively during the 1960s and 1970s. Telstar was the first satellite to use a traveling wave tube (TWT) power output amplifier. Its output was three watts. A complete description of Telstar can be found in the *Bell System Technical Journal.*[7]

Telstar I was launched on July 10, 1962, on a Thor-Delta vehicle into an elliptical inclined orbit of perigee 950 kilometers, apogee 5,600 kilometers. Its period was 158 minutes. For months, many types of communications tests were conducted between Earth stations especially built or modified for the project at Andover, U.S.A.; Goonhilly Downs, England; and Pleumeur-Bodou, France. These Earth stations were coordinated by the NASA ground station committee formed and chaired by Len Jaffe.

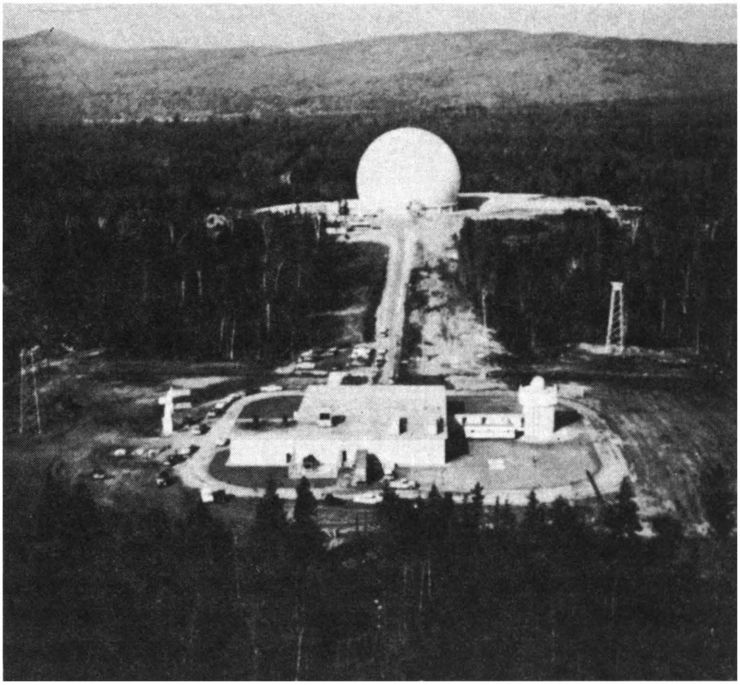

Figure 3 The original Earth station at Andover, Maine, used for experimental service with projects Telstar and Relay and later with the operational INTELSAT system.

The day *Telstar I* was launched, live television was transmitted from the U.S. and received in England and France and transmitted from France to the U.S. This spectacular demonstration was followed by many other communications tests over its four months of operation. *Telstar I* demonstrated the specific communications techniques and equipment that would be used in commercial systems. It also showed that a medium altitude satellite system could be used effectively with antenna tracking the many satellites, and communicating, simultaneously.

Telstar II was launched in May 1963 into a considerably higher orbit, 10,800 kilometers, giving its period of 225 minutes with relatively long periods of visibility across the Atlantic. *Telstar II* served long and well enough to prove to all that a medium-altitude commercial system was feasible, and to many that such a system was preferable.

NASA's medium-altitude communication satellite, termed Relay, followed Telstar by several months. Although similar in concept, Relay, had two transponders and used ten-watt TWT's. *Relay I* was launched in December 1962, and *Relay II* in January 1964, both into inclined orbits with apogees of about 7,400 kilometers. Both performed very well over several years demonstrating live television transmission around the world, including "firsts," to Germany, Italy, Brazil, Japan, and the U.S.S.R.[8] Several Earth stations, later to become part of the INTELSAT system, first operated with the Relay satellite including those at Fucino, Italy, and Raisting, Germany.

Far and away the most important experimental communication satellite was Syncom--the first to be placed in geostationary orbit. Its design became the model for INTELSAT's first four generations of satellites and for satellites in many domestic systems. The concept of a spin-stabilized spacecraft for use in geostationary orbit was created by Harold A. Rosen and Donald Williams of Hughes Aircraft Company in 1959-60. After DoD turned the mission down, NASA awarded Hughes a contract in August 1961 to design and build a satellite following their concept. Syncom was planned to fly on a Thor-Delta rocket which could put about 70 kilograms into an elliptical transfer orbit with an apogee of 36,000 kilometers. The spacecraft was to be designed with its own apogee kick engine capable of circularizing the orbit and placing about half the weight, or 35 kilograms, into final orbit. The Syncom satellite was packed full of stabilization and control equipment; its communications package had rather limited capacity in two transponders, each with two-watt TWT output stages. Because the Syncom system inherited ground and ship terminals from the defunct Advent program, it had to use their frequencies in the 7/2 GHz bands.[9]

Syncom I, launched in February 1963, failed to survive the apogee motor firing; but *Syncom II* in July 1963, and *Syncom III* in August 1964, succeeded admirably and demonstrated the great utility of the geostationary orbit for almost all satellite communications services.

Actually, due to limited propulsion capability, the orbit of *Syncom II* was not in the equatorial plane, but was inclined 33° so that it traced a figure eight pattern in the sky. Still, it clearly demonstrated the great advantage to ground stations of minimal tracking and continuous coverage. Communications links once established could be maintained for days or months without interruption. Its obvious use for full-time telephone and live television were quickly accepted. *Syncom III*, using a thrust-augmented version of Thor-Delta, a true geostationary satellite, clinched the argument for most system engineers.

Tests and demonstrations with the Syncom satellites went a long way toward gaining acceptance of the use of geostationary orbit satellites for telephone service. NASA, Stanford Research, AT&T, and the FCC all participated in evaluating the tolerance of users for the half-second round-trip delay along the 150,000 kilometer path from ground station to satellite to ground station, and back. Electronic echo suppressors were developed to limit the amount of original signal of the return path. The result of these tests was that, while critical engineers could not agree, the general public found the circuits quite acceptable.

Figure 4 Syncom, which became the world's first geostationary satellite.

The Syncom satellites operated for several years performing many experiments and demonstrations, including the first satellite communications to the African continent, to a ship at sea, and to a jet airliner in flight. Syncom started the trend to small antennas, with the Army using a transportable five-meter diameter terminal for two-way voice communications. Although not designed for TV transmission, Syncom brought the 1964 Olympic games from Tokyo to the U.S. After experimental tests, the Syncoms were used by NASA for operational support of the Gemini and Apollo manned spaceflight programs and by the DoD for operational support of the military services.

Syncom set the stage for INTELSAT, the first operational system. It proved out the rocket, spacecraft, and communications technologies needed for geostationary satellites, and it introduced a superb design and manufacturing team in Hughes Aircraft Company to the communications satellite business. Harold Rosen, a co-author of the concept, carried on to become the world's leading designer of communication satellites for over two decades and a principal technical contributor to many systems.

It should be noted that the network of ground stations developed for use with the NASA experimental satellites--Andover, Maine, in the U.S.; Goonhilly, England; Pleumeur - Bodou, France; and Raisting, West Germany - provided the early base for commercial service in the INTELSAT system.

Development Satellites

The INTELSAT system, as the first operational system, benefited greatly from the technologies developed during the experimental years from *Score* to *Syncom*, 1958-1964. However, it was still not clear in the years 1963 and 1964--when Comsat was forming and making initial technical decisions--and even into the late 1960s, what the ultimate INTELSAT system configuration should be.

Some questions were settled early. Active satellites were deemed more effective for commercial service than passive ones. The 6/4 GHz band, tested by Telstar and allocated by the ITU, would be employed. But the orbit question was still open. Although Syncom had proved that the technology would work in geostationary orbit, the question of whether the geostationary orbit would be acceptable for commercial telephone service was not settled. Also, concern was expressed as to whether the electronics, stabilization, orientation and electrical power systems would be suitable for long life in orbit.

INTELSAT considered both medium and geostationary orbit satellites for its initial system. The Comsat technical staff, working then as "Manager" for INTELSAT, observed carefully and critically as NASA and DoD continued their experimental work to test and demonstrate new technologies, to improve spacecraft performance and reliability, and to develop more efficient communications techniques.

In doing this, Comsat was fortunate to have on its early technical staff a number of engineers who had previous firsthand experience with satellite experiments. To mention only a very few: Siegfried H. Reiger, a brilliant systems analyst from the Rand Corporation, headed their technical team; Sidney Metzger from RCA who had participated in projects *Score* and *Relay*, became Comsat's chief engineer and made major contributions to Earth station technology, and Martin J. Votaw, who had built experimental satellites at NRL, became project manager for satellite development. Wilbur L. Pritchard from Aerospace Corporation, with extensive experience developing military systems, was appointed the first director of Comsat

Laboratories and led it to become a principal research center for satellite communications technology. This team created the INTELSAT system using at first inherited technologies from experimental projects, and, later, technologies developed at Comsat labs as part of INTELSAT's own R&D program.

During its first decade of operational service, INTELSAT continued to benefit greatly from the flow of spacecraft and communications technologies from experimental satellites. Many of these came from the NASA Applications Technology Satellite (ATS) program. Six satellites in this series, each designed to test different new technologies, were built and launched by NASA in the ATS program in the years 1967 to 1974.[10] The technologies included electronically and mechanically despun antennas (*ATS-1* and *-3*, respectively), hydrazine propulsion for stationkeeping (*ATS-3*), and the use of large antenna (*ATS-6*). All six demonstrated the use of wide-band multiple-access microwave communications; *ATS-5* introduced K-band, and *ATS-6*, L-band communications. It is interesting that *ATS-2* and *-4*, both intended to be body-stabilized spacecraft, failed to attain proper orbit, and thus, were prevented from demonstrating the advantage of this technique. *ATS-1* and *-3*, both spin-stabilized spacecraft, performed very successfully and are still operating. No doubt this comparison of stabilization systems influenced the future course of satellite design. However, *ATS-6*, a body-stabilized spacecraft, did achieve orbit in 1974 and with its multifrequency 9.1-meter diameter antenna, very successfully demonstrated the use of satellite broadcasting, networking, and data collection with small antennas. The NASA ATS series, all of which were built by Hughes Aircraft Company, were extremely useful in developing and stockpiling technologies that were later to be used not only by INTELSAT, but by domestic, maritime, broadcast, and military systems as well.

The Lincoln Laboratories of MIT was very active in developing technology specifically for the military services. Their work on the Lincoln Experimental Satellites (LES) series was done at X-band and at VHF, but involved advances important to commercial communications, such as transmission efficiency, spacecraft power, high-gain antennas, stabilization and stationkeeping, and the use of small ground terminals.

The LES developments led to the Tacsat program which was designed to provide both experimental tests and operational communication services for the U.S. military forces. An important technology advance in Tacsat was the "gyrostat" stabilization concept which allowed a cylindrical spacecraft to be spun about its long central axis. This concept found immediate application in the *INTELSAT IV* spacecraft which served successfully throughout the decade of the 1970s and into the 1980s.

The *Symphonie* satellite, sponsored by France and Germany, also contributed to communications technology development and demonstration during this period. Symphonie-1, a body-stabilized spacecraft launched in 1974, was very helpful in demonstrating the advantages of satellite communications for regional and domestic services and helped greatly to spread knowledge and capability in this burgeoning field to Europe and around the world.

One other development satellite program made important technological contributions during this period. This was the Canadian Communication Technology Satellite (CTS). Launched in 1976, it used an advanced body-stabilized spacecraft design with lighweight, foldout solar arrays. It carried a high-power, 200-watt, 12-GHz traveling wave tube power amplifier and demonstrated broadcast and "thin route" communication services to very small ground terminals.

CONCLUSION

INTELSAT went into operation in 1965 having benefited from a very exciting and productive period of development and test of experimental communications satellites from 1958-64. During those six years, all of the spacecraft subsystems--structure, stabilization, control, propulsion, and electrical power; and all the communication subsystems--antennas, wideband receivers, filters, and power amplifiers; were developed, tested, and demonstrated to the extent that INTELSAT could proceed directly into operational service. Then, during its first decade of operations, INTELSAT continued to receive the technological output of many development satellite projects. These technologies carried INTELSAT through four generations of satellites. Then, starting with *INTELSAT-V*, more dependence was placed upon technologies resulting from its own R&D efforts than from outside sources.

INTELSAT was the first and is still the largest communications satellite system. However, the same technologies that allowed international communications traffic to flow across oceans and continents were applicable to other services as well. The Soviet Union was the first to develop a domestic satellite communication system for its own needs. Canada, the United States, Indonesia, and other countries followed. In 1976, a maritime satellite communication system was initiated. Today more than a dozen separate international, regional, domestic, and mobile systems are operational, providing needed, and unusually profitable telephone, television, and data services via satellite.

The whole history of communication via satellite has been a short one. Technologies and systems have evolved in rapid, almost explosive, growth from experimentation, through development and operational service, to a routine business--all in a quarter century. The rapid past progress, the present prosperity, and the glorious future of satellite communication represent a triumphant demonstration of the benefits of technological development in general; and, in particular, the world's investment in space exploration.

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