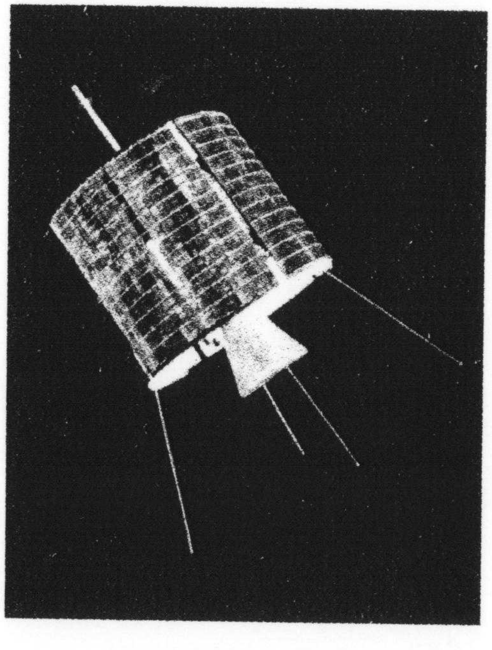
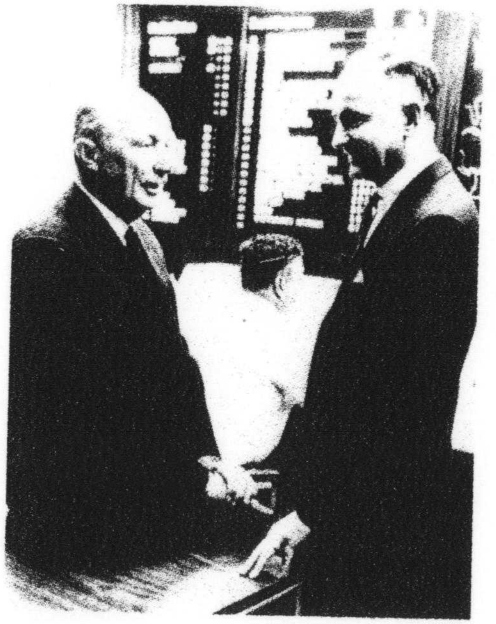
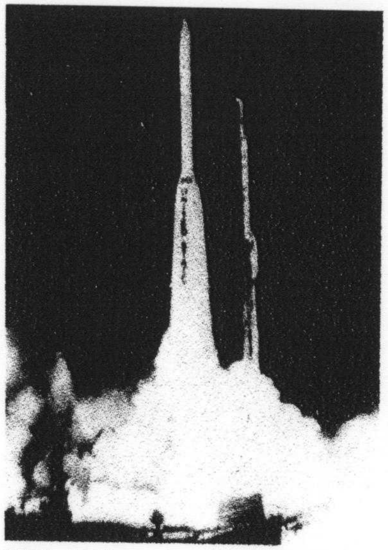
Early Bird was the first satellite in geosynchronous orbit designed exclusively for commercial use.



President John F. Kennedy had a vision for global satellite communications. His commitment to such a goal resulted in his signing the Communications Satellite Act on August 31, 1962 which created COMSAT.



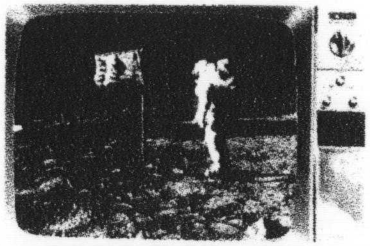
COMSAT was incorporated in the District of Columbia on February 1, 1963. Leo Welch, (left) former chairman of the Board of Standard Oil of New Jersey was elected as COMSAT's Chairman and Dr. Joseph Charyk, former Under Secretary of the Air Force in the Kennedy Administration, was brought in as COMSAT President.



With the launch of Early Bird on April 6, 1965, the modern international telecommunications era began. The launch was to put into geosynchronous orbit the first satellite designed exclusively for commercial use.

On June 28, 1965 President Lyndon Johnson inaugurated international commercial telephone service via the Early Bird satellite with a call to his political counterparts across the Atlantic.

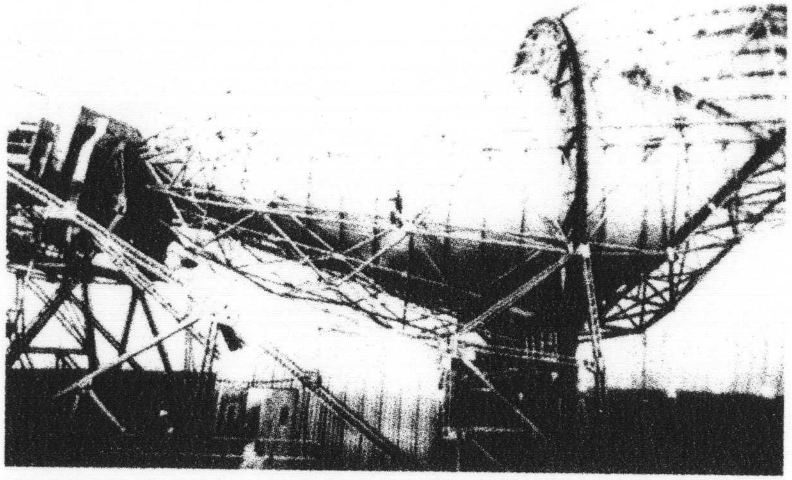
On May 3, 1965, The Today Show *became one of the first television programs to bring images from across the Atlantic via satellite. The show featured live originations from the Hague, Brussels, Paris and Rome with Hugh Downs anchoring from London.*



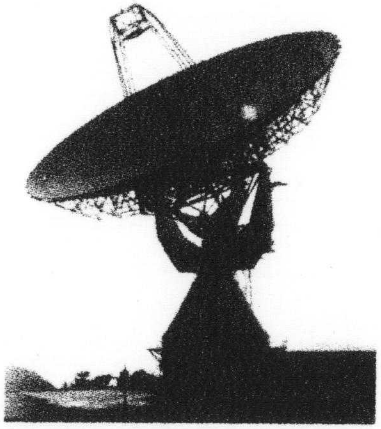
On July 20, 1969 Neil Armstrong placed man's first footstep on the moon. NASA contracted with COMSAT and INTELSAT to provide voice and broadcast services via satellite for the Apollo missions.

COMSAT Laboratories' first Vice President—Technical Sigried Reiger, accepted the Emmy Award on behalf of COMSAT. The award was given by the National Academy of Television Arts and Sciences for COMSAT's significant advancement in television research and development in the Early Bird program.

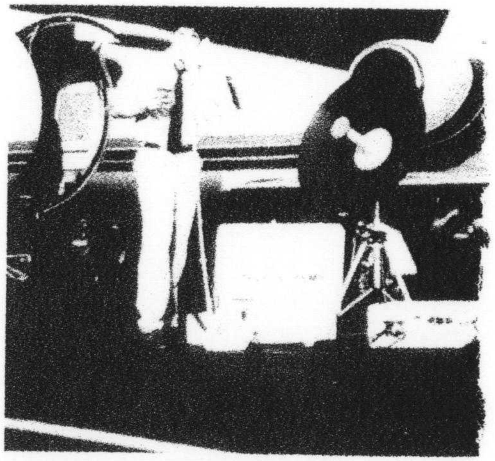
Secretary of State William Rogers and COMSAT President, Joseph Charyk, sign the Definitive Arrangements formalizing America's participation in INTELSAT. The August 20, 1971 signing brought to an end nearly three years of negotiation.



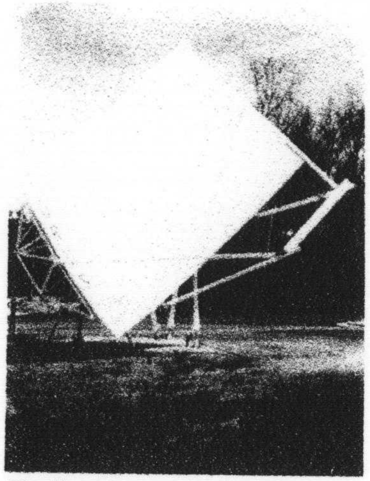
COMSAT Labs has devoted extensive efforts to making the ground segment of the global system smaller and more efficient. COMSAT's first antenna, the horn at Andover was leased from AT&T to conduct the first satellite experiments from Early Bird.



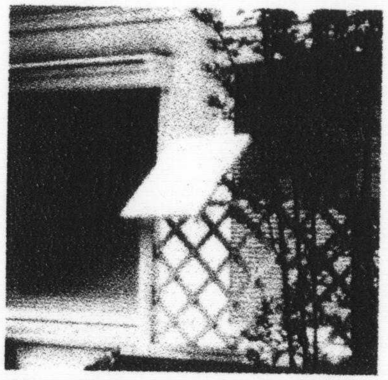
The Earth Station at Paumalu, Hawaii is representative of the large international earth stations which handle millions of phone calls and television broadcasts each year.



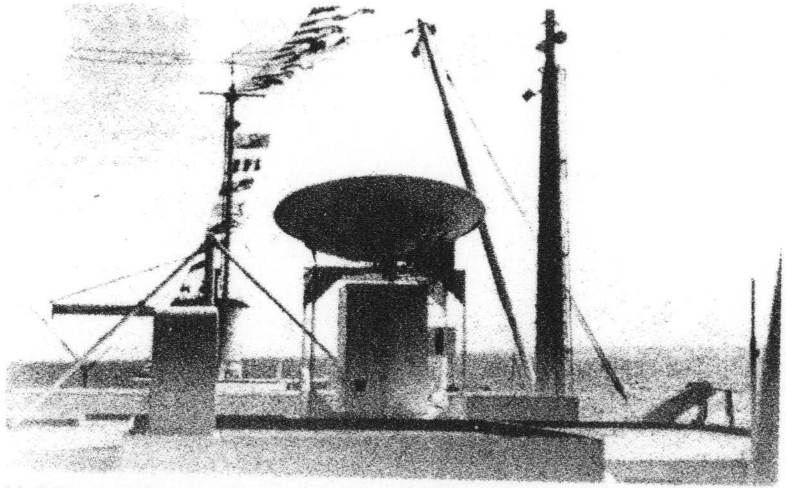
The TCS-9000, otherwise known as the satellite dish in a suitcase has allowed instant communications with remote areas and has been especially useful in aiding disaster relief efforts.



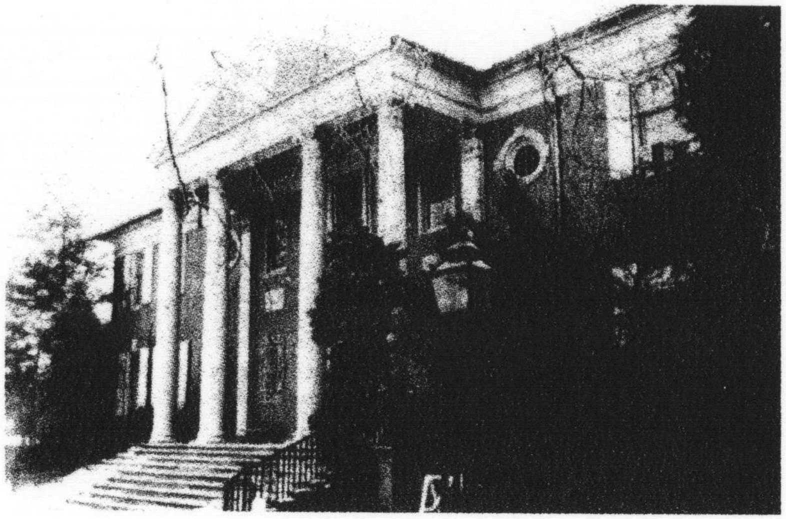
The Torus Antenna, another innovation of COMSAT Labs could access multiple satellite transmissions at the same time.



The newest generation of satellite receiving dishes is the flat plate antenna which will literally allow consumers to put a dish on their patios to receive satellite broadcasts.

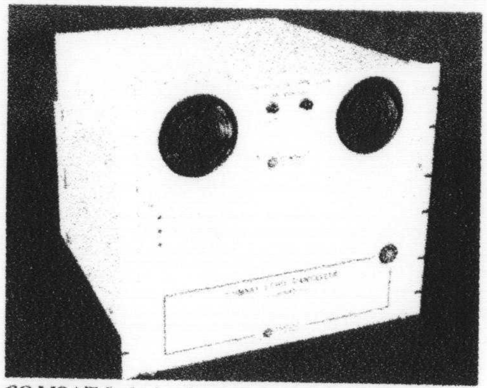


Mobile satellite service was one of COMSAT Labs' most successful innovations. Now, because of on-board terminals such as this one on the Queen Elizabeth 2, a variety of ship-to-shore services are provided via the INMARSAT satellite system to the ship's crew and passengers.



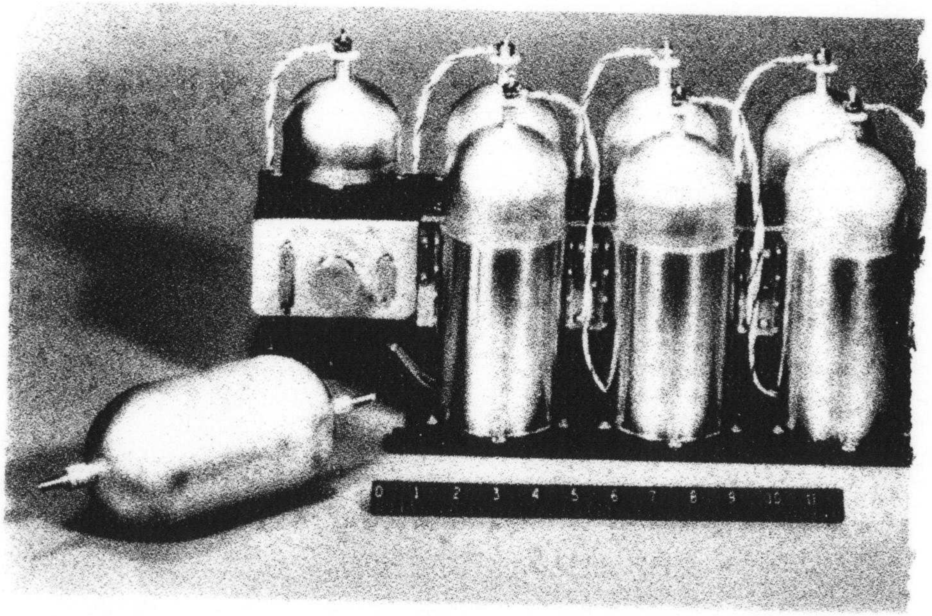
COMSAT Labs has had a number of unique homes. Above, COMSAT's first home in 1963 was Tregaron—the estate of former Ambassador to the Soviet Union, Admiral Davies. Twenty-one months later, COMSAT's research facilities moved to 2100 L Street in downtown Washington, pictured left, the site which housed the launch control center for Early Bird.

(Facing Page) By September 8, 1969, COMSAT Laboratories in Clarksburg, Maryland had been completed and occupied by a staff of 300. COMSAT headquarters are located at L'Enfant Plaza, in downtown Washington, D.C.



COMSAT Labs' echo canceller is one of the centerpieces of satellite-related technologies. By first developing the echo suppressor and later the echo canceller, shown here, COMSAT engineers made voice communications via satellite acceptable to the commercial public.

The hydrogen-nickel oxide battery was another critical innovation of COMSAT Laboratories. The battery has been crucial to extending operating lifetimes of satellites while alleviating the instability problems of earlier batteries.



CHAPTER NINE

Getting the Most Out of What You've Got

The ongoing challenge with satellites was how to cram the most capacity into a limited space. From the outset, COMSAT Laboratories tackled the problems of developing systems to get more and more traffic into a given amount of bandwidth. Inefficient use of capacity was endemic to the terrestrial-based systems common at the time. For example, circuits were assigned to carriers and were available only to the assignees whether or not they were used fully.

"When satellite communication started internationally, it used a lot of the communication technology of microwave radio, and long-distance telephony, which was natural," explained Bill Pritchard, first director of COMSAT Labs. "Since the 1920s telephone circuits have been bundled together in groups. They put each of them in a different carrier frequency and they bundle them together in groups of 12, 24, 60, 120. Then there was a hierarchy of groups, master groups, or super groups. The way the satellite business evolved to begin with was that each earth station was assigned its own carrier frequency, a bandwidth, and a channel assignment. It was given so many channels that it could transmit on. That worked fine between the United States and England and France and Italy and Germany, because they had plenty of traffic, which was growing quickly as people caught on to the desirability of long-distance telephone service and the high quality of the satellite circuits."

But there was a lot of inefficient use of this new capacity, which had to be remedied. One possible solution would be to make assigned frequencies work more efficiently, but that involved solving some inherent problems.

In the late 1960s, François T. Assal was working on his doctorate in electrical engineering, while serving as a professor at the City University of New York. He loved his job and he wanted to complete work on his doctorate, but he was getting itchy. He'd read about the formation of COMSAT Labs and that they were looking for people. He decided to go visit.

"I spoke to Lou Pollack [head of the Microwave Technology Lab]," Assal said, "and he made me an offer."

Assal went home to think about it. He was faced with a difficult choice; there were a number of key factors to consider. A native Tunisian, Assal had moved to Israel as a young man, met an American woman, and was married. He moved to the U.S. with his young family. Education, he knew, would be important to his future, and joining COMSAT Labs would mean putting his academic work on hold. On the other hand, he knew he was faced with the kind of opportunity that did not come along very often. At the same time, managers at COMSAT had developed this persistence for going after people they wanted.

"I don't know how Pollack managed to get my in-laws' phone number," Assal said, "but he called me there one night and he said that he was waiting for an answer."

Assal told Pollack he had decided to join.

By his own description a pencil-and-paper kind of theoretician, Assal was immediately put on the satellite capacity problem. "My first assignment was to try to come up with a solution for maximizing the capacity of the satellite, by bringing the carriers as close together as possible."

That involved designing filters the likes of which had never been designed before.

The transmission system in use at the time was of the analog type, modulated in one of two ways: by amplitude or frequency, the same system which creates the AM or FM of a common radio. But, as Bill Pritchard pointed out, the efficient way to deal with signals in a satellite of limited bandwidth is to bunch them in groups of twelve, twenty-four, sixty, or more, a method known as multiplexing. However, when you put signals in spatial proximity within a given bandwidth, they interfered with each other. Common practice was to minimize this interference by keeping the frequency of the signals far enough apart. That wasted bandwidth, however. To bring signals closer together, filters were needed that would keep the signals separate.

The problems were complex.

"If you don't do anything in the transmission, you will have adjacent-channel interference," Assal explained, "one channel will be coupling into the other. If you try to limit this on the receive end, it doesn't do you any good because the interference took place on the transmission side, it's already there. So you have a little bit of a tail that will affect your signal."

Filtering individual carriers benefits adjacent carriers while creating problems for the carrier being filtered. So the challenge was to design filters that were very sharp, while equalizing their effects on all carriers, demonstrating that they did in fact work—then convincing international partners to accept them. It was a whole new modus operandi for a man who had just come from the staid surroundings of academia.

As part of a team working on the filter problem, Assal worked long hours, went home for dinner and to share some time with his wife and children, then came back to the labs to work some more. When he had a design that he felt solved the problem, he presented it to his boss, whose response was, "That looks great, François, now build it."

Assal was stunned. In the past, he'd put it down on paper and that was the end of his involvement. When he needed something built, a technician was assigned to him. Now, he was faced with the prospect of proving—by himself—that the new filter could be built. It took some new-found manual dexterity, but he did it and demonstrated it. That, however, turned out to be just another battle in the war. Next, a contractor was chosen, Airborne Instrument Laboratories (AIL), and Assal had to work with the contractor to show him how to build it, in order to demonstrate to the technical committee of INTELSAT that the filters could be produced at the manufacturing level.

"I showed them that in fact you could achieve the performance as specified and satisfy all the requirements for communication, using these filters," he said.

The most tangible result was that by allowing the carriers to be placed closer together, they increased the capacity of the satellite by a whopping 20 percent. That translated into additional revenue, which in turn improved the bottom line performance of the satellite.

The work on microwave filters continued in earnest. Novel electrical and mechanical designs resulted in substantial weight and volume reductions, making it possible to increase communications capacity for a given total spacecraft mass. At COMSAT Labs, the work done in this field by Drs. Ali Atia and Albert Williams became well known nationally and internationally.

While the filters were being improved, scientists and engineers at COMSAT Labs were looking at the larger question of multiple access. They felt that a system that allocated capacity on the satellite as a function of time, as opposed to frequency, would be far more efficient, so they began experimenting with a concept called time division multiple access (TDMA).

Until the advent of TDMA, all satellites operated with continuously transmitted carriers, each assigned a different frequency. In order to maximize capacity on a frequency-division basis, each transponder in the satellite was assigned up to ten carriers. But this technique resulted in intermodulation distortion. To minimize this type of carrier-coupling distortion, the power output of the transponder needed to be reduced. However, this was an inefficient use of the satellite's limited power. If capacity on the satellite could be allocated as a function of time—i.e., one carrier per transponder during a given unit of time—then the power output could be held at its maximum without incurring this distortion, since during any specific time period there would be only one carrier assigned to the transponder. This, in effect would permit multiple access to the satellite, but as a function of time, not frequency. The signals to be transmitted were encoded into "bits," the digital language of a computer, then collected into a unit called a "burst" and the burst assigned a time segment during which it was "fired" at the satellite.

"Each earth station would transmit its messages as a burst," Joseph Campanella, chief scientist at COMSAT Labs explained. "Instead of tuning in frequency, the earth station would tune in time, and be given a specific time to transmit its burst. Every station transmitted at a different time so that when the bursts arrived at the satellite, they arrived one after the other and didn't overlap. TDMA was the discipline that permitted us to do that."

This transmission of bursts all happened during a very small fraction of a second, so the matter of synchronization was critical to the question of TDMA's viability. If you were to divide the satellite's capacity into segments allotted to earth stations on the basis of time—very tiny segments of time—the synchronization between the satellite and the earth station would have to be incredibly accurate. The first test to determine whether such critical synchronization was achievable outside of the laboratory was an experiment called MATE conducted over the Atlantic in 1966.

"We were using a Canadian station and making believe it was three stations in one," said William G. Schmidt, who was manager of TDMA project in the Communications Processing Lab. "We used Early Bird and it was very successful. Coming back we said, 'Well, what's the follow-on? How do we prove it further?' That was the birth of a system that became MAT I, a TDMA system."

The early systems were synchronized very carefully. Each earth station had to know exactly where the satellite was when it let loose its bursts of digitized conversation. The calculations were very complex. For each earth station the distance to the satellite was different, and many people in the technical world felt that the problems with synchronization would be a nightmare too horrible to confront.

"They felt you wouldn't know the distance to the satellite well enough to have any capacity," Schmidt explained. "They felt that maybe only 50 percent of the time would the satellite be overhead for synchronization, so the outstanding contribution of this system was the solution of the synchronization problem."

It also proved that they could compress the bursts between very, very small gaps.

"We proved that with the synchronization scheme you could effectively know the distance to the satellite to a much higher degree than that obtainable from any other measurement technology," Schmidt said. "The final result was a TDMA system that used something in the order of ten nanoseconds as the gap between the bursts, which means that you knew within ten feet the position of a satellite at 22,000 plus miles away, doing a 'lazy eight,' in orbit."

The validation of the burst synchronization approach created potential for a tremendous increase in the efficient use of the satellite's capacity. It meant that the members of the Communications Processing Laboratory could push full speed ahead in developing the new system.

They moved into the phase they called MAT I, which used higher speeds and, for the first time, demand assignment.

"Burst length determined capacity," Schmidt explained, "so a demand-assigned TDMA system has extendable bursts. You get your capacity when you need it, as opposed to being assigned it whether you use it or not."

An important advantage of TDMA was that it allowed flexibility of capacity at an earth station simply by changing the duration of the burst allotted to the station. If the station had little traffic, it was given a short burst; in the case of heavy traffic, a long burst was used. It was very easy to do as a function of time.

For example, the stations on the European side of the Atlantic begin their day earlier. So when they begin talking to each other, they are using "fat" bursts. As their day proceeds into evening, they get into a period of lighter usage, their bursts get thinner. They are moved in the TDMA frame to make room for the fatter bursts on the North American side of the ocean because people there are in the middle of their day and their demand is greater; they take up the greater amount of space allotted earlier to the other earth stations.

"So, the ability to move bursts automatically and still keep communications going is the key to a demand-assigned TDMA system," Schmidt said.

The typical frame in the INTELSAT-TDMA system was two milliseconds long.

"And in that two-millisecond frame we had as many as ten stations," Campanella said, "each of them having a burst duration of nominally 200 microseconds, average—some longer, some shorter, depending on the balance of traffic."

A TDMA transponder aboard an INTELSAT satellite, operating at 120 million bits per second could handle the equivalent of 3,000 telephone conversations at once.

"In frequency division multiple access (FDMA), you couldn't do that very easily," Campanella explained. "You had to change the bandwidth of the carriers to change the capacity. That meant you had to go in and change the filters. A lot of things had to be done which were very costly. This was avoided by TDMA because it gave us flexibility. It's the reason why TDMA has proven to be an interesting technique."

The earliest applications of TDMA were with satellites that used regional or global beams—i.e., send and receive beams that covered broad expanses of the earth.

"When we built the first TDMA system under INTELSAT funding," Campanella explained, "it was used to demonstrate experimentally the complete TDMA transmission on tests conducted in the Pacific Ocean. These tests actually demonstrated, very early on, many features which were very important: the ability of multiple stations to synchronize the traffic to the satellite and to carry end-to-end digital communications. But they also demonstrated the ability to adapt the capacity of the stations for demand-assigned traffic management."

Once the basic features of TDMA were shown to be viable, the teams at COMSAT Labs began to refine and improve the concept. For example, the TDMA team felt that one of the drawbacks of the concept derived from the need to allow the system to operate even in situations where stations were in different beams of the satellite. Beams on the satellite normally were interconnected in a fixed manner. What that meant was that a signal sent via a specific up-beam to the satellite would follow a predetermined down-beam to its destination. That would result in situations where time—i.e. capacity—went unused. Unused capacity was the enemy of Bill Schmidt and his team.

The decision was made to propose putting the switchboard in the sky, aboard the satellite. The concept, called "satellite-switched" TDMA, or SS-TDMA, was published by Schmidt as a paper for the first INTELSAT International Conference on Digital Satellite Communications held in London in 1969. The idea was to give the satellite a rapidly acting switchboard that cycled through a series of connections tailored to traffic distribution and demand, resulting in an extremely efficient use of its capacity.

Campanella likened the concept to giving earth stations "windows" to the rest of the world.

"Let's say one connection allows your earth station to 'see' France," he explained. "In the next instant, England appeared in the window. Next, there's Spain. Now, Africa. Every fraction of a second, a new area appears, and when it does, you send traffic for that area. The benefit of SS-TDMA is that it provides flexible connectivity among all the beams in the multiple-beam system. It also lets us shove more traffic through the same bandwidth because the satellite's transponders are used very efficiently."

The on-board switches would be very busy handling thousands of calls per second, fired in bursts from earth stations all over the world, so it would have to respond with all due speed. The switch developed at the labs operated at 50 nanoseconds—50 billionths of a second. (A nanosecond is to a second what a second is to thirty-two years.)

That required that the timing for connections be even more accurate than the seemingly incredible accuracy of the earlier systems.

"The timing unit could not slip by more than 125 millionths of a second in 72 days to remain properly synchronized," François Assal explained. Assal was project manager on the SS-TDMA switch. "If the clock ran too fast, the frame period would shrink and the system would lose bits. If the clock slowed down, the connections would wait for bits that weren't coming."

The success of the system hinged on the maintenance of a synchronization between the switch and earth stations 22,300 miles away. To provide the timing the team settled on what they called an acquisition and synchronization unit (ASU). It worked like this: Earth stations were given the switch connectivity plan—i.e., the order and timing of each connection. The ASU, located at a reference earth station, marked the beat of the satellite's clock, and informed the rest of the earth stations that the next series of connections was starting. And, it would also serve as the reference timekeeper, adjusting the satellite's clock faster or slower, accordingly. The ASU—actually a six-foot high rack of electronic gear—was so accurate, it took into account not only the 44,600 miles that signals would need to make the round trip up to and back down from the satellite, but even the six meters per second that the satellite moved within its orbital "box."

Allocating capacity as a function of time and digitally packaging those segments into bursts which were then directed via satellite switching was not a panacea. The brain trust at COMSAT Labs was troubled by an inherent inefficiency in telephone conversations, the dead time on the circuit during which one or both parties weren't saying anything. Since a telephone conversation requires both a send and a receive circuit, one line is not being used for half the time—i.e., when one party is listening to the other party. Then there are periods when neither is talking, natural pauses in the conversation. Statistically, a channel (i.e., either half of the circuit) is active less than 40 percent of the time.

COMSAT Labs developed a way to release the other 60 percent of time for use by active talkers. The technique called low rate encoded/digital speech interpolation (LRE/DSI) exploits the statistical properties of speech so that more than one conversation can be transmitted over one circuit, a kind of time-sharing of circuits by active talkers.

Campanella, along with fellow engineer Joe Sciulli, explored a concept that had been used on analog circuits to add capacity to undersea cables. When employed with digital circuits, however, it caused clipping at the beginnings of speech spurts.

"We wanted to do the job better by using the features associated with the implementation of the interpolation process on digital circuits," Campanella explained. "We came up with a concept called speech predictive coding (SPEC), which interpolated the individual pulse-code-modulated speech samples of the active talkers, based on the short-term predictability of the samples. This method totally avoided the clipping problem and replaced it with a mild increase in what is called quantizing error."

They built and demonstrated implementations of the device that clearly showed improved quality.

A 240-channel DSI terminal operates with independent transmit and receive sides, each independently synchronized to a TDMA terminal. The DSI encoder uses a voice switch to detect the presence of speech on a terrestrial channel, a telephone line. When the switch determines that a channel is carrying the voice of an active talker, an assignment processor in the unit begins searching a satellite channel pool for an available channel. When one is found, an assignment message is transmitted to the DSI decoder and the active terrestrial channel is connected to the selected satellite transmission channel, which in turn is connected to the specified terrestrial channel on the receive end.

When the spurt of speech ends, the selected satellite channel is returned to a pool of channels and made available for the next active talker. The system allows a 2:1 capacity enhancement—i.e., using only 120 channels to carry the voices of 240 telephone users.

Low rate encoding, developed in tandem with DSI, allows the speech to be encoded at 32 kilobits per second, instead of the standard 64 kbits/sec, providing an additional 2:1 advantage, or allowing two voice signals to be packaged into the same capacity that formerly carried only one.

"The LRE/DSI system was custom designed and a good example of the type of problem solving we do at the labs," said Dr. John Evans, director of COMSAT Labs. He pointed out that each new development was also a valuable research tool for developing the next level of improvements for a system, and foresaw the possibility of an 8:1 gain through further improvements in encoding.

The sheer physical capacity of each generation of INTELSAT satellites increased from 240 circuits on Early Bird to 15,000 circuits on INTELSAT V-A to 120,000 circuits on INTELSAT VI. Developments at COMSAT Labs stretched that existing capacity many times over with the likes of demand assignment, TDMA, LRE/DSI—to the point where capacity, once one of the critical limiting factors in satellite operations, had become an all but eliminated problem. The life-limiting factor for satellites had become almost exclusively a matter of getting and keeping the satellite in its proper orbit and extending the lifespans of its power and back-up power supplies. COMSAT had solutions to the many elements of those problems as well.

CHAPTER TEN

Keeping the Birds in the Air

In the staffing of a laboratory a kind of lemming effect often occurs. Scientists, engineers, and technicians from existing laboratories find themselves following a former leader to his new home. The motivation is often a renewed interest in their work, intensified by the new challenges of the new lab, the respect they'd held for the former leader and the desire to work with former colleagues who have jumped ship in favor of those new challenges. In the staffing of the Spacecraft Laboratory at the new COMSAT Labs, such a phenomenon took place. Many of the original staff members followed the division's new leader, Fred Esch, over from the Applied Physics Laboratory at Johns Hopkins University. These people had been in the satellite business, albeit mostly military satellites, at APL, and they joined a cadre that Esch was assembling, which would form the core of the Spacecraft Laboratory for years to come.

Esch had met Martin Votaw in 1964 when Votaw was working on a double-decker satellite for the Naval Research Laboratory (NRL). Esch was the payload engineer on the project. A mutual respect developed and when Votaw was selected to head engineering at COMSAT, Votaw asked Esch to join him as head of a key division.

Esch came to COMSAT in 1965, at a time when the technical activities were located in downtown Washington. "I joined with the understanding that there would be a laboratory formed," he said. "Sid Metzger was very much in favor of creating a laboratory as was his boss, Sig Reiger, and Dr. Charyk. The technical activities at the time were mostly just monitoring of ongoing programs."

Esch began to reshape the monitoring function and add more creative responsibilities. He formed a group he called the Spacecraft Techniques Department, which was later to become the Spacecraft Division and most recently, the Applied Technologies Division. At the time, a limited amount of laboratory work was going on, but the principals of COMSAT were anxious to get on with setting up a laboratory and creating the new technology that would define the satellites and earth stations of the future. But most of the emphasis and attention was concentrated in the communications and electronics areas. Esch saw that as a blessing in disguise.

"We enjoyed a situation where the rest of the company was not all that concerned with the spacecraft and left us alone," he said. "Most of the people involved with COMSAT at the time had electronics or communications backgrounds."

The Spacecraft people had to establish their own objectives and set their own courses.

"We did a lot in terms of laying out plans and identifying areas of interest to investigate," Esch said. "People were building kits for test instrumentation. Somebody had located a used lathe and a drill press, and that was the machine shop at the time."

It was the laboratory-in-the-garage scenario, played out in the middle of Washington.

"But we proceeded to influence the company to set up a budget for doing some laboratory work and started to form several groups pursuing various technology investigations," Esch said. "At that time, we were located in a downtown office building which wasn't the most convenient place to adapt to the kind of laboratory activity that we were pursuing, so we had to make a lot of adjustments as we went along. We were very cramped, with people sitting in the aisles, and we were faced with such problems as inadequate electrical service. We had to do a lot of jerryrigging and ran electrical lines where we'd have gotten written up for all sorts of unauthorized systems."

The completion of the new laboratory facilities in Clarksburg, Maryland, was "heaven," according to Esch. And he and his people turned to the challenges at hand. While it was the development, construction, installation, and operation of the communications packages that was the focus of attention, the size and life span of the spacecraft itself were critical limiting factors, determining what could and could not be done with these dramatic new satellites.

"In order to hold the satellites in geostationary orbit and to keep them pointed properly, you had to use on-board propulsion," Esch said. "Early on, the propulsion system was hydrogen peroxide that was decomposed in the catalytic thruster. It was a very sensitive system and temperamental, to say the least. We had a lot of problems with the early satellites in that regard (the failure of Lani Bird, a case in point). We were trying to set up experimental investigations into how to best operate those systems and also to find new systems that were more reliable and had a greater assurance of longer life."

Then there was the electrical power supply. Ongoing power was supplied by solar cells which provided very low efficiency in terms of the amount of sunlight they converted to usable power—about 8 percent. Further, during those times of the year when the spacecraft passed through the earth's shadow for more than an hour at a time—the spring and fall equinoxes—the communications systems needed a back-up source of power to maintain continuous service.

"We focused a lot of attention on the problem of energy conversion in the silicon solar cells," Esch explained, "the manner in which they were mounted and interconnected, the substances with which they were covered, sunlight filters, etc. We looked for alternatives such as cadmium sulfide cells, which were far more rugged for some applications, but far less efficient. They also had some characteristics that were not very attractive in terms of using them for long-life satellites."

Undaunted, they set about the task of improving the efficiency, durability, and lifespan of the solar cells.

Richard Arndt came to COMSAT Labs because, in his words, he was "a scientist who likes to get my hands dirty." Arndt, who rose to become senior scientist for the Microelectronics Division of the labs, remembered the early days as being fraught with unknowns about the lifespan of a satellite in high orbit. Along with the very real delay and echo problems, early concern about the economic viability of geosynchronous satellites centered around how much lifespan you could get out of them. One of the major concerns was whether radiation effects would do them in. Arndt had been a specialist in radiation effects at Brookhaven National Laboratory on Long Island.

"Satellites were still pretty unusual things," he said, "so there was a good deal of concern about the survivability of a spacecraft with respect to the radiation environment. Consequently, we had built up a rather small, rather good group of people who were specialists in both working with the damage resulting from the radiation itself, as well as trying to measure and predict what the radiation environment was going to be. The radiation effects were of particular concern for the solar cells, because they are on the outside of the satellite and they take the brunt of all the radiation that's out there. Being the primary supplier of the power, it was very critical."

There was also the question of what effects radiation might have on the electronic components of the communications package. Since the early satellites had to make maximum use of volume and weight for the communications packages, there was no room for equipment whose mission would be purely measurement and therefore would provide little, if any, data fed back for analysis purposes.

"You just had to guess by the seat of your pants," Arndt explained. "While the NASA people were doing a lot of monitoring of the environment, not much of it was at synchronous altitude. So you had to more or less guess what the whole long-term environment on a synchrosatellite was going to be, based upon just a few excursions through that part of the zone by NASA. You had to be very intuitive to take this minute amount of data, guess what the synchronous, or communications satellite environment, was going to be, and based upon that, predict what the lifetime of the solar cells was going to be."

So Arndt and his group simultated, on earth, what they thought the environment in space would be like, integrated that data with what little real data they got from NASA, put the two together, and came up with surprisingly good estimates of what the degradation in the solar power output would be as a function of time.

"What we found was that electrons that are trapped in the magnetic field [around the earth] bombard the solar cells and create a defect in the silicon host material. That defect acts as a capture site for the light-generated electrons so that they don't wind up generating the power that you need. As a result, over a period of time, the maximum power that you can get out of a solar cell drops off."

Methods were devised to protect the solar cell by adding an extra layer of quartz to its surface. But that decreased the conversion efficiency of sunlight to solar power, which meant you had to make up the difference by putting more solar cells on the spacecraft—and that ate up a percentage of the valuable weight limitation.

They decided to concentrate on ways of making a given solar cell more efficient—i.e., they had to do better than the 8 percent that the best solar cells in use at the time converted to usable power. First they set about improving the responsivity of the cells across the full spectrum of light.

"The earlier versions were not very sensitive to the short wavelength, or blue end of the light spectrum," Arndt explained. "The first advance COMSAT Labs made was to make cells sensitive to that wavelength. Consequently, you were able to convert about 30 percent more of the solar energy into electrical energy."

Next, they sought to reduce reflection from the surface of the solar cell.

"I mean, if you're shining light and most of it comes back off, it's not doing you any good," Arndt said. "So we made an improvement that permitted more of the light to get into the silicon material itself. That accounted for another big jump in the efficiency."

There were other, more subtle improvements until the early 1980s, when the labs succeeded in developing a very thin cell.

"You'd like to make a solar cell as thin as possible for two reasons," Arndt explained. "One is less mass you have to haul up. Second, the thinner the solar cell, the less susceptible it is to the radiation damage."

But a thin solar cell is very difficult to make, because a piece of silicon, only about 2/1000ths of an inch thick, can curl up like a potato chip. So if you make a very thin cell and then try to apply it to a flat surface, there's a good chance you will break it in the process.

"We came up with an idea that has an integral reinforcement on it," Arndt explained. "On the backside, it looks like a waffle; on the front side it's flat as a pancake."

Overall, the effort led to major improvements in the solar cells that have benefited many segments of society, including commercial and consumer interests. COMSAT Labs became the leader in improving the efficiency of certain solar cells. Within eight years, the scientists at COMSAT Labs had doubled the efficiency of the cells to more than 16 percent.

"We had gotten out onto the learning curve," Arndt said, "to a point where the returns were not paying back the investment in research anymore. The satellites would last longer and you could put more payload on for the same weight of solar array."

The back-up source of power for the solar panels was batteries, and with the early satellites the batteries were of the conventional nickel-cadmium variety. They were designed to last up to seven years, but in actual use generally lasted less. In the early 1970s, the INTELSAT IV satellites were the workhorses of the fleet. They contained the nickel-cadmium batteries and they were not getting the predicted seven years—i.e., the batteries were *the* life-limiting factor on the IVs and IV-As. After about five or six years in orbit, traveling wave tube (TWT) amplifiers had to be turned off to reduce the load on the battery during eclipse operation. Approximately half of the TWTs eventually were turned off on all the INTELSAT IVs, resulting in a substantial reduction from the original 4,000- or 6,000-circuit capacity.

Scientists at COMSAT Labs took on the challenge of extending the life-span potential of satellites by developing better, longer-lasting batteries. At the time, fuel cells, such as hydrogen/oxygen combinations, seemed most promising for sheer advanced energy-storing capabilities. The problem, and it was a big one, was their tendency to explode during periods of extended use. Experimentation with fuel cells and hybrid systems, however, led to the discovery of the beneficial properties of a hydrogen-nickel oxide marriage. For one thing, you could overcharge or discharge such a cell without damaging the battery.

Members of a team headed by Dr. Edmund Rittner and James Dunlop built and tested the first sealed nickel-hydrogen cells in early 1970. The results were promising, but the potential was not appealing enough to the original contractor selected to manufacture the batteries, so its management decided to drop the project. Convinced they were onto something, the COMSAT team took over the project completely, designing pressure vessels, electrode stacks, seals, weld rings, and other necessary components for a complete system. Then they took the design to Eagle Picher, another battery manufacturer. By 1975, they'd convinced the U.S. Navy to include the battery aboard a navigation satellite called NTS-2.

"A hydrogen-nickel oxide battery, fabricated by the Naval Research Laboratory, used seven COMSAT-supplied cells in a series," Dunlop explained. "Two of the batteries made up the energy storage system flown on NTS-2."

The satellite was launched in June 1977, with the prototype hydrogen-nickel oxide battery aboard. The final design was a hybrid system combining the best features of the fuel cell and the nickel-cadmium secondary battery. The fuel cell hydrogen electrode and the nickel-hydroxide positive electrode were two of the most reliable and stable secondary electrodes existing at the time. Combining the two electrodes into an electrochemical cell had many advantages, with the major one being the improvement in life expectancy, two to four times that of the nickel-cadmium cell. There was also the significant advantage of a reduction in mass, increasing the usable energy density twofold. The launch of the Navy satellite marked the culmination of more than ten years of battery research and development at COMSAT Labs, and it rewarded the confidence of the battery team by operating effectively well into the late 1980s.

By 1978, with actual field test data from the Navy satellite in hand, COMSAT Laboratories scientists proposed to the parent corporation and to INTELSAT that the hydrogen-nickel oxide battery be considered for INTELSAT V, then in the manufacturing stage. The battery, which was designed to be interchangeable with nickel-cadmium batteries, impressed scientists at Ford Aerospace, the prime contractor on INTELSAT V. Ford decided to use it in eight of the 15 satellites in the series. The battery was uniquely prepared to respond to the power demands of satellites well into the 1990s, when the stored-energy requirements on a new generation of satellites would increase by a factor of four to eight.

Along with the power sources, another important, life-limiting element was the on-board propulsion system, which was used to position the satellite properly and maintain that position. The propulsion system included thrusters and valves, which had to perform properly for the projected life of the satellite, and a supply of fuel, which itself limited the satellite's life span.

"You have to appreciate that once the thing is up there no one ever touches it again," Fred Esch emphasized. "We still don't have a screwdriver sufficiently long to reach up that high."

The problem was that the hydrogen peroxide system that powered the thrusters was unreliable and unpredictable. The hydrogen peroxide apogee motor had malfunctioned dramatically on the first launch of INTELSAT II, placing the satellite into an exaggerated elliptical orbit. The scientists in the Spacecraft Lab felt they needed something more reliable. The system they decided upon worked with hydrazine.

"It had some of the characteristics of hydrogen peroxide," Esch explained. "It was catalytically decomposed, but you could also electrically heat it and increase the thrust, thereby increasing the efficiency of the system."

While the hydrazine system was proving its effectiveness, Dunlop and his team were improving the hydrogen-nickel oxide battery to the point where it could be considered a complete electric power and propulsion system.

"Battery-powered electric propulsion is the next step," Dunlop explained. "Hydrazine fuel provides the propellant to maintain satellites in their proper orbits, but there's no reason why a battery-powered electric thruster can't perform this same function more efficiently. A satellite's lifetime could be extended from ten or fifteen years to twenty to twenty-five years with the same propellant mass."

Between periods of solar eclipse, the battery could provide power to an ion thruster for two hours each day in order to maintain a stable orbit. Over a twenty-year-plus life span, this would require the battery to undergo some 7,000 deep discharge cycles. The hydrogen-nickel oxide battery could meet that requirement.

The battery's long-life potential and rechargeability have made it a prime candidate as the power source for the United States' first manned space station, according to Dunlop.

When Howard Flieger, another APL import, joined the Esch team in the Spacecraft Lab, INTELSAT III was being designed and constructed. III was to be an innovative design by a new contractor—I and II had been built by Hughes.

"INTELSAT III was being made by TRW in California, so there was a cultural jump from Hughes," Flieger said. "COMSAT had opened its TRW offices and put technical people there to monitor the programs. That staff continued to call upon the growing staff at the laboratory in many fields as needed. INTELSAT III had a lot of technical difficulties, so labs people were called out to California very frequently."

Flieger was a thermal engineer, fortunately one with an extensive background in thermodynamics because INTELSAT III had thermal problems.

"The antenna was the most difficult one," Flieger said. "The first design for the satellite had what was known as an electrically de-spun antenna, a series of di-poles around the circumference of the satellite that could be switched on to receive or transmit in sequence so that portion of the antenna was always pointed toward the earth, as opposed to Early Bird and INTELSAT II, which radiated their signals in all directions. But, the electrically de-spun antenna could not be made to work."

In the middle of the satellite design phase, the electrically de-spun antenna was dropped in favor of one that was mechanically de-spun. (This is the familiar truncated conical antenna that can be seen in models of INTELSAT III.) In order to maintain the position of the antenna beam relative to the earth on a spinning satellite, the antenna is driven in the opposite direction from the spin of the satellite by a counter-rotating motor. Therefore, the satellite needs a series of bearings. These bearings, however, were being affected by the great swing in temperature they would experience in orbit. Whenever the bearings got too cold or too hot, they seized.

"We were aware that there was a cold condition on the satellites, so a heater was put on the bearing sytem to keep

it warm," Flieger explained. "But we found that the bearings still seized during tests."

The tests on the antenna were proving very frustrating.

"I spent a lot of time working with the engineers at TRW studying the problem," Flieger said. "I would pick up design information and test results in California and take the data back to the labs to conduct my analyses. I made so many trips back and forth that my wife threatened to leave me, but in those early days, many labs people traveled a lot."

It was the worst of all possible worlds for the thermal engineer, both too hot *and* too cold in space. The hot condition occurred when the sun was at its most northern extreme and the antenna exterior was in full sunlight. The cold condition occurred during the eclipse season around the equinoxes. But the worst condition, too hot and too cold, was when the sun was the farthest south and the antenna was only partially illuminated. To accommodate this, a lot of changes were made to the antenna thermal design. Heaters were used to correct the cold situation, and special thermal control coatings were applied to the outside of the antenna in an attempt to limit the heating effects of the sun.

"Everyone thought we finally had a handle on the problem and a fix in hand," Flieger said, "but we were in for a shock when the satellite finally went into orbit. The same old problem of the sticking antenna came up."

Finally an operational solution was found: simply flipping the satellite upside-down every six months, which kept the antenna uniformly sunlit.

Paul Schrantz was another of the engineers who follow Fred Esch to COMSAT from the Applied Physics Lab at Johns Hopkins, where he'd been working since earning his master's at Northwestern University in the early 1960s. At APL, he'd had a lot of hands-on experience launching thirty-three low-orbit satellites, including the United States' first double-decker satellite—a wedding of two satellites that are separated in space by an explosive clamp and sent to separate orbits. Schrantz was an expert in vibration dynamics; Esch had been impressed with him at APL and he needed a man of his particular skills for his new Spacecraft Laboratory.

Schrantz remembered those early days as a time when you did your own structural testing and vibration analysis, using strip charts, checking peak levels, and relying on a lot of gut engineering.

"During the early 1960s at APL, we'd go from concept to a launch in ninety days with a satellite, which was important for some research that the Navy wanted done," he said. "I worked under Fred Esch in the mechanical design, structural analysis, testing, and balancing of satellites, worrying about weights and how they go together and what the launch does to them—everything."

The decision to leave APL was a tough one for Schrantz, who liked what he was doing there.

"But I also knew Fred to be one of the finest engineers I'd ever met—in terms of total commitment and understanding and an ability to work with people," Schrantz recalled as being the deciding factor in tipping the scales for COMSAT. "He was just a total, people-type guy and totally competent. We launched thirty-three satellites together at APL and never had a flaw that was traced to poor engineering. He set a good example."

Schrantz came to COMSAT at the end of the INTELSAT III program, heading into INTELSAT IV. He had had only low-orbit experience, but he felt he knew his stuff when it came to launch dynamics and related areas. But, once again, his first experience was a matter of being thrown into the water to prove he could swim.

"I'd been at COMSAT about two weeks," he said, "and we had had a launch failure on INTELSAT III. Marty Votaw heard that I was on board and he said, 'We're going to have a meeting with TRW and the Air Force and NASA and I need a dynamics guy out there.' So I was invited to go out and join the meeting. The day before the meeting, Marty walked in with this stack of test reports on the satellite and said, 'Tell me if we should have had any problems with this launch.'"

Schrantz knew Votaw to be a demanding, can-do, gung ho kind of person. He decided he'd better burn the midnight oil to see what he could determine about the failure.

"I found that TRW had had a pump failure in the quality test," he explained, "and they'd had to discontinue the test. But, in tracking further through their documentation I couldn't find that they had ever rerun the test to the full level. So then I went through the stress report and looked at the margins."

He went to Votaw with his analysis.

"I'm confident that the thing was properly designed and tested," he told his superior, "but I don't think you have a test report here that you want to wave in front of the Air Force tomorrow. We need more time."

Schrantz recalled walking into the meeting and hearing Votaw tell the gathering, "Look, we've had a launch failure here. We all know something happened to our launch vehicle. I wish you'd tell us what you think. We're very confident about our satellite."

The Air Force did a thorough analysis and found the problem, but the handling of the situation made Schrantz feel good about the confidence that had been expressed in his ability and the credibility Votaw had placed in his recommendation. He felt COMSAT was going to be a place where if you had the skills they were going to put you in the hot seat and let you do something.

Schrantz went immediately to work on INTELSAT IV, coordinating with the contractor, Hughes Aircraft. He was working on structural design, the loads, the weight problems, balancing, and similar areas that he was responsible for as one of COMSAT's one-man gangs, coordinating the manufacture of the satellite in California.

"I was walking from office to office meeting people, and I'd say, 'Hey, this says COMSAT,'" he said. "COMSAT was in a position to make the contractor aware that we had competence in these areas and were going to hold them accountable. COMSAT was the manager, so we had direct responsibility. But I found the exciting part was that not only were we getting to create the new satellites, but also COMSAT at that time, in the late '60s early '70s, had a commitment to launch advanced satellite technology."

The evolution of the antennas on the satellites was a study in refinements. Advances in antenna design followed a smooth progression from one satellite to the other.

"The first satellites [Early Bird and INTELSAT II] had a doughnut-shaped beam," said Robert Gruner, who spent a career at COMSAT making better antennas, "The satellite was spun for stabilization and the energy from this doughnut-shaped beam would hit the earth. But this really wasn't very efficient because while you're sending some energy to the earth, you're also wasting energy by sending it into outer space. The INTELSAT III antenna directed the energy toward the earth only. This resulted in an improvement in the power that came down to the earth by a large factor."

The INTELSAT IV antenna took the next logical step. It had global beams which covered the earth, but it also had two spot beams that would concentrate energy on certain high-traffic areas.

"For example," Gruner continued, "you'd have a beam that would cover the eastern part of the U.S. and Europe, which are high density traffic areas. Thus even more power was being sent to discrete areas."

On the next satellite series, the INTELSAT IV-A, the beams were shaped to fit the continents.

"The beams were formed so that they actually covered the land masses, because there were no earth stations out in the middle of the ocean," Gruner said. "You now concentrated the power into beams that were shaped roughly like the continents. It was a major step."

This was done with multielement feeds and offset reflectors. If you took an antenna's reflector and its feed and you put the feed in a certain region of the reflector, it sent a beam to a point. Then you could add another feed and activate it to send a beam to another point. Now, if you fed these two feeds in phase, the two beams would form an ellipse instead of a circle. You then kept adding feeds until you defined the shape you were seeking.

"It was almost like following the dots," Gruner said. "For example, you might have fifteen beams which are placed at specific spots in the U.S. So when you add the individual beams, they form a rough contour of the map of the U.S. You're juggling a lot of factors around when you do this, including the size of the main reflector, which sizes the constituent beams, and the number of feeds used. The bigger the main reflector, the narrower the elemental beams, and the narrower the beams, the more closely you can approximate the shape of the continents. So there is a lot of interesting design work there."

On the next satellite series, INTELSAT V, dual polarization was used to increase capacity further. It was a method of sending and receiving signals at 90° (orthogonal) angles to each other.

"Think about dual-polarization in terms of your car radio," Gruner explained. "You have a vertical whip antenna out there receiving the ball game at some frequency. But you could also receive the opera in the other sense of polarization at the same frequency. So by using both a vertical and horizontal antenna, you could use the same frequency twice and receive both transmissions. You could look at the available frequency spectrum and the orbital arc as natural resources. There's only so much to go around and when you use orthogonal polarization, you actually double the use of the available frequency spectrum."

The development of spacecraft antennas has been an evolutionary process with a logical, step-by-step progression: INTELSAT I and II used broad toroidal beams; INTELSAT III used global beams; INTELSAT IV had global beams plus two transmit spot beams that could be steered around the earth; INTELSAT IV-A had regional beams that were shaped to the continents; INTELSAT V used the shaped beams with dual polarization. The major change in INTELSAT VI would be regional beams that would illuminate continents in the Northern and Southern hemispheres.

The life limits on the satellites had come a long way since Early Bird and the spacecraft had become more complex, but more dependable. Those working on the earth stations were laboring hard to keep up and were making dramatic progress in their own arena. The system had expanded far beyond the dreams of the early prognosticators.

CHAPTER ELEVEN

With Feet Firmly Planted on the Ground

> OCTOBER 20, 1964—The Communications Satellite Corporation today asked 15 companies to submit proposals to provide research data and consultant services for definition of design and performance requirements of ground terminal stations for the global communications satellite system. The solicitation has these purposes: to take advantage of research already done . . . to augment the Corporation's technical in-house effort . . . to insure an effective ground station design will be achieved . . . to establish performance and requirements for each subsystem . . .
>
> *—news release,*
> *Communications Satellite Corporation*

While the novelty of an orbiting communications satellite remained the focus of attention, and Early Bird gained a notoriety that elevated it to celebrity status, reality in the world of satellite communications was, for all terrestrial participants, the earth station. When Early Bird became a functioning satellite in 1965, there were only five countries that maintained legitimate earth stations: the United States, United Kingdom, France, Germany, and Italy. The new satellite's limited capabilities did not permit multiple access, so the four earth stations in Europe could communicate with the earth station in the U.S. only on a rotating basis. The prospect of satellites over the Pacific and Indian oceans joining the Atlantic satellite, and thereby completing a global network by 1969, meant that there was a lot of work to be done on the terrestrial side. Sometimes the work seemed a bit way out even to the engineers involved.

When Bob Gruner, a young engineer from the Boston area, first came to COMSAT, he was told he would be sent to the field to measure some antennas. Then his boss, Bill Kreutel, added, "You're going to measure earth station antennas using the signals from radio stars."

"C'mon," Gruner said, "don't kid with me. That's not very nice. I'm new here."

Kreutel explained that stars discovered by means of radio astronomy radiate energy in the communications spectrum, and one way to measure an earth station antenna was to receive that power. You pointed the antenna at the known position of the source and if you knew how much power per unit area (flux) it was sending toward you, and you measured what you received out of the antenna terminals, that allowed you to determine the effective collection area of the antenna. It was a technique developed by radio astronomers and picked up by people in the satellite industry. Kreutel had written a definitive paper on the subject, used for years by antenna test engineers.

The star sends you something called power density, at so many watts per square meter. The antenna receives it at say one watt per square meter. If you've got a square meter of antenna, out the other end should come one watt—if yours were a perfect antenna. In practice, only about 60 percent of the power is captured and fed to the receiver. Thus the effective collecting area might be 0.6 square meters. Except that the amount of a star's energy reaching the earth is generally quite small.

"The power density on the earth from the star is infinitesimally small," Gruner explained. "On the other hand, you've got a large earth station antenna which has a lot of capture area so you still could get some measurable amount of power—but you're talking millionths of millionths of a watt."

After learning the process, Gruner took the cases of measuring equipment and headed to Andover, Maine.

Gruner's next big surprise was the cassegrain horn antenna, itself. Although he had seen pictures of the big antenna at Andover, built by Bell Labs for the TELSTAR program and modified for Early Bird, Gruner was still not quite prepared for what he found. The antenna was housed in a bubble structure, which was kept up by air pressure similar to the bubbles used at swimming pools and tennis courts. There was a two-door entry system to maintain the pressure. Gruner opened the first door, walked into the interlock chamber, then closed the door behind him. After the pressure equalized, he opened the door into the room that held the antenna.

"I gasped," he recalled. "It was just unbelievable to me that man could build something like that. It was really the eighth wonder of the world, an enormous antenna built on a railroad track within the big bubble. The ceiling must have been 250 feet high, and the railroad track 200 feet in diameter, running around the room with this enormous horn mounted on the tracks, allowing the whole horn to pivot. The horn looked like a giant cornucopia with a sixty-five-foot opening. It blew my mind."

Measurements were done at night, because there was no sun interference then, and at that time, the earth station could be taken off the air during the night. Gruner prepared to take measurements from a star that would be at a prescribed position in the sky at four o'clock in the morning. He set up his equipment, clambered up into the feed room, pointed the giant antenna toward the proper azimuth and elevation angles, and waited. He was positioned in the bowels of the giant cassegrain antenna, listening to the groaning and creaking, waiting for something to happen.

"I was sitting there watching the meter when all of a sudden, at four o'clock in the morning, it began moving," he said. "I can remember saying, 'God, it works!' "

Gruner spent the rest of the night accumulating data, following the star to its zenith, then losing it over the horizon. The measurements allowed him to determine the gain and gain-to-thermal noise temperature.

The calibration and testing of earth station antennas has been critical throughout the years that the global satellite system has been in operation and, during this time, the antennas have remained cantankerous. For years, teams from COMSAT Labs have packed up and gone off to sites, tested for a week or two at a time, and have returned home with new discoveries, new challenges. A good deal of testing was done from the Paumalu antenna in Hawaii. Like Andover, Paumalu was a cassegrain horn antenna, a big snow shovel.

"One time," microwave expert Chris Mahle said, "I was taking data up there when the operator in the trailer put the antenna in auto-track on the spacecraft and just punched the button."

Instead of tracking on the spacecraft, the antenna began to swing up, with a surprising acceleration. It did this very fast. Mahle was standing there wide-eyed as half a ton of equipment began to slide toward him.

"The guy was not paying close attention," Mahle said. "When I called to him to put it in auto-track, he just looked over, punched the button, and went back to what he'd been doing. When I started screaming, he finally pushed the emergency stop."

To make matters worse, the testing platform was a makeshift Rube Goldberg affair of two-by-fours at a 45° angle, which created optical illusions like the old Ernie Kovacs TV trick in which the set and the TV camera were on the same angle, so it looked like he was pouring milk at a 45° angle. The COMSAT equipment sat on a platform which hung by two chains so pieces could be moved back and forth.

"We have a photograph that shows people standing up and there is this wrench hanging on a piece of string that comes across the picture, at an angle," Mahle said.

Paumalu was also very leaky and it rained a great deal in the mountains of Oahu.

"One day, we were up there and it was raining outside, and there was water dripping in," Mahle recalled. "We made measurements and wrote the data down on a piece of paper. Sy Bennett was sitting in the trailer keeping track of things and talking to the control center, because we needed things switched in the satellite, and so on."

"I need one more point, one more point," Bennett said.

"Simon it's raining," Mahle replied.

"Just take one more point," Bennett demanded.

Mahle took the measurement, climbed down the antenna, and went into the trailer, then handed Bennett the sheet of paper, crumpled and very wet.

"Well, where is the data?" Bennett asked.

"There!" Mahle pointed.

The rain had washed it off the page.

There was always some friction between the "space cadets," as the teams from the labs were called, and the station personnel.

"The station personnel did not like us to screw around with their antennas," Mahle explained. "I mean we came in sort of heavy-handed from Washington and the station personnel didn't like the fact that we had free run of things and could do pretty much what we wanted."

Sometimes they found ways to get even.

A recurring problem with the cassegrain horn antenna at Paumalu involved its tracking system. The antenna included a built-in tracking system that was designed to keep it pointed at the satellite at all times.

"For us to do measurements, it's vital that the system works," Mahle said. "One day we were working and the antenna had a particular problem at one frequency where we had to take data. There was something wrong and we didn't know quite what it was. So Sy Bennett left a note for the station personnel to fix the problem by the following day and our team left."

It was a problem with the power amplifier, which had lost a crucial vacuum. In the process of fixing it, however, the station personnel moved the antenna too far down and broke a hydraulic line.

"There was hydraulic fluid all over creation," Mahle remembered, "and there was that 45° angle to the platform we were working on, plus a big hole in the safety net. We thought, 'They're trying to tell us something.' "

This form of testing, which was for the most part noncomputerized, continued through INTELSAT satellites I to IV. With INTELSAT IV-A, computerization took over.

"IV-A had a more complicated antenna pattern," Chris Mahle explained. "We needed to do antenna pattern cuts in a short period of time and that called for computer assisting. We had six months to install the first permanent satellite test setup at Paumalu. We had to learn a lot about how the computer interfaced with the instruments, how you got your data out, and so on, but the process slowly but surely grew into a very sophisticated measurement machinery. Today, the measurement experience of the last twenty years is reflected in the software. A technician just needs to push a couple of buttons and the machine will get the right answer for him. If it can't, it will tell him why. It's very comfortable these days. You could actually do it by remote control from Washington."

One of the most significant developments in antenna design at COMSAT Labs was the multi-beam earth station antenna, called the Torus, described by COMSAT CEO Joseph Charyk as "the shape of things to come," when it debuted in 1981. "Shape" was the active word here. The Torus is named for the shape of its surface, which is toroidal. A toroidal-shaped surface is formed by swinging a second-degree figure—a circle, a parabola, an ellipse—around an axis. The relationship between the axis and the figure describes a conic section which gives the Torus its peculiar property. It does not scan in a flat plane but on the surface of a cone, and that approximates the geostationary arc of the satellite, an ideal configuration for earth stations of the global satellite communications system.

In the case of satellite communications, the birds in the sky were improving at a rate faster than the stations on the ground could keep up in several significant areas. For one thing, a one-satellite-per-earth station relationship was not an efficient system, considering the size and cost of an earth station vs. the satellite and the commitment in hardware and real estate necessary to build an earth station. An antenna that could interface with multiple satellites would result in significant cost efficiencies, not to mention productivity improvements. Solutions, however, come only with thinking and a good deal of hard work.

How does a Torus antenna come into being?

"You start with an objective," explained Dr. Geoffrey Hyde, who was one of the principal scientists on the Torus project in the late 1960s and early 1970s. "You consider the various configurations which have symmetries that you can take advantage of: a sphere, for example. No matter which way you look at a sphere, it looks the same—spherical symmetry. So I looked at a sphere for a while."

But a sphere has some very severe aberrations. Hyde had done his doctoral dissertation on a radio telescope in Puerto Rico, which uses a spherical surface. He wanted something better. He kept asking himself, "Is there anything of higher efficiency than the sphere, with less aberration?" He knew of one such shape, the Torus antenna used by the radar installations in his native Canada. But that antenna only scanned in a plane.

"When I scanned in a plane, I could only look at a little part of the geostationary arc," he explained. He experimented with cuts a little below and to one side of the toroidal shape, but they only approximated a small portion of the geostationary arc. He experimented with twisting the Torus into a smile and a frown and that started to look right. He discussed it with a colleague, Bill Kreutel.

"We thought about it," he said, "Bill and I both analyzed the problem and we came to the same conclusion: if you moved the axis of rotation, it approximated the geostationary arc."

Hyde designed and built scale models and did mathematical calculations and experiments with the shape of the scan cone. Then Kreutel showed that an optimum was reached for a 95° tilt of the axis, rather than the 90° tilt that was normal for the Torus. Hyde and Kreutel completed the initial design in 1973, and the design was a great improvement over existing antennas.

"You can put several feeds in the feed area, and their beams overlap on the reflector," Hyde explained. "As a consequence of that, if you were to look at three satellites at once, you would need an amount of surface area of metal significantly smaller than three separate antennas. Not only that, but we got some subsidiary benefits in very easy beam steering along the arc or even across the arc that were not obvious when we started, but were very obvious when we were done, so that even if the satellite moves a little you can follow it. It is a very well-behaved design; it does what you predict it will do."

But Hyde wasn't finished. The first Torus design was point-fed from the front. It had limitations due to aberration. That meant you could not change frequency arbitrarily because the amount of aberration was related to the number of wavelengths across the aperture illuminated with the feed horn. Hyde kept working on refinements.

"It turned out that restraint could be eliminated," he said. "I showed how that could be done, and indeed proved it with a scale model. If you were willing to accept some aberration, and chose your parameters correctly, you could raise the efficiency to very significantly higher levels. That meant you could cut down even further on the amount of metal you needed. This aberration-corrected Torus was the final step."

The Torus made a celebrated public debut in August 1981 at the annual Satellite Users Conference in Denver, Colorado.

"We stole the show," said Richard E. Thomas, chairman of Radiation Systems, Inc., the COMSAT-licensed manufacturer. The Torus received simultaneous television signals in the 4-gigahertz range from three different satellites and in the 12-gigahertz range from a fourth one. And that was less than one-quarter of its capability, which was up to seventeen independent beams, each of which could be directed at a satellite in geostationary orbit.

The Torus had important implications for cable TV operators, national TV networks, and independent TV broadcast stations. Because it could access multiple satellite transmissions at the same time, the dimensions of earth station locations could be reduced greatly, easing the burden of heavy real estate costs. Torus antenna installations could now make the transmission from the drawing boards to the tops of buildings. The Torus also had the potential to reduce the number of antennas in the expansive "antenna farms" of parabolic dishes that had sprung up across the United States.

The new developments in earth station design sent some of the early players back down to the farm. With the development of the INTELSAT V satellite in the early 1980s, all earth stations communicating with the new satellites had to be retrofitted for dual polarization. Bob Gruner was project manager of these modifications. The mission created a strange sense of déjà vu.

"When I worked on the COMSAT stations on the west coast, it was really quite a kick for me because I was one of the original designers of the antennas at Brewster, Washington, and Paumalu, Hawaii, back in 1966," he said. "I went out to antennas that I had helped design fifteen years before and took out the things that I had installed when I was in my mid-twenties. I actually pulled out the hardware that I'd built in 1966, then put in something that I had designed in 1980. It felt like lost youth. But it was a good feeling knowing that something you'd designed as a kid was still there, working, when you took it out with your own hands when you were forty."

The developments in earth stations continued the race to keep pace with the developments in satellites, with the objective of getting more benefits out of smaller and less expensive antennas. The improving technology allowed for such developments as earth stations in mobile vans that permitted broadcasters to do "live from the scene" telecasts. Maritime earth stations were shrunk to a size that could be accommodated by pleasure yachts as small as fifty feet. There was even the "earth station in a suitcase," a transportable earth station that fit into two cast-metal cases weighing a total of a hundred pounds.

However, the large, parabolic dishes were still the most prevalent and their proliferation, particularly during the 1980s, began to create problems of another sort. Town fathers viewed them as unsightly, and planning or zoning boards passed ordinances prohibiting or severely restricting the installation of the dishes. In 1983, the people at COMSAT Labs turned their energies toward finding a solution, an antenna everyone could live with. They concentrated their efforts on a flat-plate design, which could be mounted easily to the siding or on the roof of a house, even erected inside near a window. To make these function at the level of a dish antenna, the engineers would have to get the efficiency ratings of the antenna up and the cost of producing it down.

COMSAT began talking with the Matsushita Company of Japan, which had been designing a flat-plate antenna of its own, and a collaboration of efforts was struck. The Matsushita antenna had an aperture efficiency of only 20 percent, as opposed to a 55 to 65 percent efficiency for parabolic dish antennas.

COMSAT Labs managed steady increases in the bandwidth of the antenna and reduced the size to less than two feet square, designed around commercially available materials, in a manner that would lend itself to easy manufacture.

While the traditional parabolic dish antenna collected signals in its dish and focused them into a feeder horn, the flat-plate antenna collected them across its surface. It could receive channels over the full band of satellite transmissions.

The new antenna would be the shape of things to come, with applications in the developing direct broadcast market—i.e., from satellite to end user and in business conferencing networks.

So earth stations had gone from the gigantic cassegrain horns of the mid-1960s, through the giant parabolic dishes that followed. These have since been shrunk to about half their original size. For some applications still smaller earth stations can be used and, in one case, even fitted into a suitcase. Then the shapes were changed to improve efficiency, cost, even aesthetics, leading to the development of the Torus and the flat-plate antenna. While the earth station may have begun its life as the unglamorous stepbrother of the high-flying satellite, it certainly grew in stature over the years. It was, after all, the link to the invisible bird in the sky.

CHAPTER TWELVE

A Vital Link to the Ships at Sea

At the end of his retirement party in 1983, Kim Kaiser slipped into a room off the main corridor on the ground floor of COMSAT Laboratories, pulled on a pair of roller skates, and, as his final act, skated the length of the building and out the front door.

Why?

"I'd promised to do it on a skateboard," he said, "but my wife felt that was too dangerous."

Kaiser had spent his career at the labs living on the edge. A hands-on kind of person, he was one part scrounger, one part tinkerer, one part theoretician, and 100 percent can-do. Kaiser was the man who took the laboratories' solutions and demonstrated them in that often inhospitable environment known euphemistically as the field. His work took him to the tops of mountains, up the sides of buildings, to overgrown jungle landing strips, and, more often than not, to the pitching decks of ships, in sometimes unfriendly waters.

While not a part of everyday life for the vast majority of us, maritime communications have made a quantum leap since the potential of satellites has been harnessed for the benefit of ships at sea and offshore oil rigs. Unfortunately, while the technology had existed for more than a decade, it had not been applied on a broad scale until the 1980s. A witness before a U.S. House of Representatives committee put the need for applying the technology into perspective in 1981 when he described the state of radio communications on the high seas as remaining where Marconi had left it seventy years before. The necessity for improving maritime communications was brought into focus during investigations into the disappearance of an American merchant vessel, the SS *Poet,* in the North Atlantic in the late autumn of 1980. Bound for Port Said, Egypt, with a cargo of corn and a crew of thirty-four, the *Poet* disappeared without a trace and without anyone receiving a distress signal.

"It was the first time in eighteen years that a U.S. flagship had disappeared without anyone receiving a distress call or without someone subsequently finding some trace of the vessel," said Rep. Walter B. Jones, (D.-N.C.), chairman of the House Merchant Marine and Fisheries Committee. "The SS *Poet* tragedy poignantly brought to our attention the need for global satellite communications."

As a witness before Rep. Jones's committee put it, "Unreliable radio communications are a fact of life." And the consequences were sometimes fatal.

While the early development of satellite technology concentrated on providing communications between fixed points, those involved in the process knew that one of satellites' unique capabilities would be their ability to provide communications between mobile points—obviously impossible with cables.

In the early 1960s, Burton Edelson, who later became the second director of COMSAT Labs, was a lieutenant commander in the Navy involved in the Navy's Navigation Satellite Program. The idea of navigating ships via satellites had obvious appeal to the Navy.

"We put a large terminal on the USNS *Kingsport,* a converted World War II victory ship," Edelson explained. "It was a thirty-foot terminal under a big plastic radome. We sailed the ship off to sea. It went to Lagos, Nigeria, and when the SYNCOM satellite was launched, that ship was the first satellite communication connection between the U.S. and Africa."

The *Kingsport* had served as the distant communication terminal for SYNCOM, the progenitor of geostationary communications satellites, and, since it was aboard ship, was the first mobile terminal.

But it was not until 1976, eleven years after Early Bird's launch in 1965, that MARISAT became a reality—the first mobile satellite system to go operational on a grand scale. But before such a system could be put in place, COMSAT had to prove some of the critical systems could work in the field.

In the early 1970s, the career path of Kim Kaiser was about to intersect the need to help put a maritime system into place. Kaiser had received a liberal arts education at a small college in Parkville, Missouri. In his spare time he played with radios, taking them apart and trying to put them back together again, with varying degrees of success. In the process, he had caught the electronics disease. Drafted into the service, he learned radio and radar technology in U.S. Army Signal Corps schools at Fort Monmouth, New Jersey, then went overseas and was involved in message-sending activities.

"In a way I grew up with the practicalities of communications," he explained. "At Fort Monmouth, we had one of the first pulse-position-modulated, gigahertz transmission systems. This basically consisted of two small antennas—one for receiving, one for transmission—to provide communications for an Army corps area."

With his interest piqued, he went back to school, this time at the University of Michigan, where he took courses in mathematics. After completing his studies, he went to work for Bendix Corporation in the late '40s, then was asked to come to Washington to work for the Institute of Defense Analysis at the Pentagon. While he was there he met Siegfried Reiger, and they became good friends. From that point on he was involved in satellite communications.

"We ran—out of the Institute for Defense Analysis—a summer study on the hard-limiting repeater," he said, "which is basically used in every satellite. It was done in Maine in 1961 and a whole lot of communications experts were there. It ended up to be a very fruitful exercise. The report that came out of that formed the basis for an awful lot of the techniques that were developed later for satellite communications."

One of the satellites he worked on for the military was called ADVENT, a geostationary satellite, which kept him in a close working relationship with Sig Reiger. So when COMSAT was formed, Reiger asked Kaiser to join. It took five years for Kaiser and COMSAT to reach a meeting of the minds. He joined the team at the labs in 1968.

"I worked in systems analysis with George Welti and Sigmund Honnel, and we did a number of studies to see how you could get more communications out of satellites. Honnel issued a technical report on maritime satellite communications, without much coming of it. In those days people were interested in large antennas. The INTELSAT business was just starting and everybody was convinced that the eighty-foot- or one hundred-foot-diameter antenna was it."

Earth stations of that size would have little relevance for maritime communications, but as the work progressed, the equipment got smaller and satellite capabilities expanded. The work in mobile communications taking place at COMSAT Labs during the early 1970s was directed initially at solutions for aeronautical communications.

"We were trying to work in digital" explained Joseph Campanella, "but as it turned out, the digital technique at that time wasn't sufficiently good, so we chose FM as the method of transmission. In the same period of time there were a number of experiments in the interest of demonstrating mobility of communications via satellites, the most significant being an agreement with Cunard Lines to mount an antenna on the *QE2.* That particular event was one of the major turning points in alerting the world to the potential significance of satellites for maritime communications."

The impetus was a visit by a certain Colonel J. D. Parker.

"He was with CIRM," Kaiser said, "Committee Internationale Radio Maritime. He came to visit John Puente and they went to see a thing called DI-COM, which Dick McClure, Chet Wolejsza, and Eugene Katchamani were working on in Joe Campanella's laboratory. DI-COM was a rack of digital communications equipment designed to replace the analog system. Colonel Parker got to see this, then he and Puente went to lunch to discuss its implications. In the process, Parker asked if this equipment could be put on a ship. Eventually Puente said yes."

Two weeks later, they got a letter from Colonel Parker indicating that he had arranged to put DI-COM on the *Queen Elizabeth 2.*

"The letter came to John Puente," Kaiser said. "John didn't know what to do with me anyway, so he handed it to me and said, 'Kim, you take care of this.' "

Much easier said than done. While the DI-COM system did exist, not much else did—an appropriate antenna, for example. Activate Kaiser the scrounger.

"I called my friends at Bendix Communication Systems in nearby Towson, Maryland," he said, "and asked casually if by any chance they happened to have an antenna . . . about eight feet in diameter . . . C-Band . . . that could be moved around. The chap there said, 'Well, wait a minute, I'll call you back.' He called back ten minutes later and said, 'Yep, we have an eight-foot dish sitting on a pedestal. It's been there for a long time. It's got several drives on it and the feed you have to worry about, but it's C-band.' So, I said 'Well, can I have it?' He said, 'Well, I'll call you back.' He called me back ten minutes later and said, 'Bring a truck.' "

Kaiser located a "low-boy" truck, went to Maryland, dismantled the antenna, put it on the truck, and made his way back to the laboratories. It was a start.

"As luck would have it," Kaiser said, "I poked around in the upper reaches of the labs, where there weren't even any walls yet and found an old telemetry transmitter that COMSAT had inherited from the Andover earth station. It had a nice panel in front that said, 'Azimuth' and 'Elevation' and a big dial, and there were all kinds of instruments behind it."

The problem now became one of how to turn the hardware into a working version of what they needed. When you're stuck, read the book. Kaiser took a tour through the technical library at COMSAT, which, among other things, contained a full set of "Rad-Lab" series books, the electronics bibles of radar and communications personnel during World War II. He found a set of equations for stabilizing an antenna on-board ship, wrote them down, then stared at them for quite a while. They were complicated and had Kaiser scratching his head. "How," he wondered, "am I going to build such a device?"

"Then I remembered back at Bendix, when I was doing guided missile work, that we had worked with a horizontal gyro that was used to do the first over-the-pole airplane travel. So, I made another call to Bendix, this time to Teterboro, New Jersey, and asked my friends there if by any chance they had one of those gyros."

Déjà vu.

"One of the guys was about to retire and he had one," Kaiser said. "Not only did he have a gyro, but he had a motor-generator set, which was important because the gyro worked on 400-cycles AC, three-phase, rarely used except in airplanes."

Kaiser was off to Teterboro, whence he picked up the heavy equipment and trucked it back to COMSAT Labs. He had engineers from the Spacecraft Laboratory look over his equations, then put all the parts together, including an analog computer they built that actually transformed the ship coordinates to earth coordinates.

Then came the critical logistical questions. Where do they put it on the ship, and how do they get it all onboard?

The commodore who was in charge of the ship had some suggestions. He wanted them to put it on top of the children's playroom, which happened to have some skylights in it and was on the very top of the ship. But they decided the best thing to do was to literally glue it to one of the top decks. They'd had a platform built of unseasoned oak and it was affixed to the deck with epoxy glue. Then, in February 1971, Kaiser and a colleague, John McClanahan, made their way to Norfolk, Virginia, with the antenna and its attendant equipment in tow. They'd hired a helicopter to put the earth station in place onboard the ship and met with the pilot the night before. But there was a snag.

"Somebody asked the president of your company what would happen if the helicopter crashed on the *QE2,*" the pilot explained, "and they got worried about it and said we aren't going to take a chance on it." Then he added, ". . . But you didn't hear me say that, right?"

"Nope." Kaiser replied.

He'd been assured by the pilot that there'd be no problem; the pilot said he was used to tough assignments. He said he'd been a helicopter pilot in Vietnam, had crashed once, hurt his back, and was told never to fly a helicopter again, but he quickly added, "You know I'm not going to crack up this time. If anything goes wrong I'll be in the drink before you know it."

Kaiser was a bit confused about the job assignments. "There were only two of them," he said, "the helicopter pilot and his signal man. McClanahan and I looked at each other and asked, 'Who's going to unhook the cables?' 'You are,'" they said.

So, the COMSAT duo ended up beneath an enormous Sikorski helicopter, hovering twenty feet above them. But the pilot set the equipment right on the four bolts, they unhooked the cable, and off he went.

"We had those idiotic plastic helmets on that wouldn't have done anything," Kaiser said.

The ocean liner made four trips to the Caribbean with the team from COMSAT on board. Each time they got within the general vicinity of Cape Hatteras, North Carolina, it stormed.

"They had stabilizers on the ship," Kaiser said. "But when the waves and storm got too bad, they didn't risk them, they pulled them in so they wouldn't break up. So things were pretty grim. But we got our equipment going and it worked fine."

What they'd installed was one FM channel. They demonstrated its use with voice, a teletype machine, and a facsimile machine, transmitting all sorts of interesting things back to the small, four-and-a-half-meter antenna at COMSAT Laboratories, which was plugged into the telephone network, so they were able to make calls from the *QE2* to just about anywhere in the world. They even called the Cunard commodore back at his residence at two o'clock in the morning to tell him they were still working. Then they conducted demonstrations for the ship's crew and passengers. They asked for volunteers to make calls back home, then selected first a couple who wanted to wish their sixteen-year-old daughter a happy birthday.

"The call went through," Kaiser said. "There were a couple of thousand people listening in via a loudspeaker. Her boyfriend answers the telephone. It took several minutes before they found the grandmother, who'd been locked in a closet. It was a very embarrassing few minutes."

It got worse. A second couple called to talk to their children whom they'd left with a grandmother. The ten-year-old answered the phone and told her parents their apartment had burned down. Since no one was staying in the apartment, no one got hurt, but the news ruined the cruise for that couple as well. Fortunately, the rest of the calls were more mundane.

After the short runs to the Caribbean, the team was off to Europe on the *QE2*. Kaiser's luck with the weather did not improve, however.

"We got into the worst storm in the North Atlantic in forty years," he said. "The ship spent two days hovering in the middle of the Atlantic, exactly sixty years to the day after the sinking of the *Titanic* in the same place."

As part of their experiment they'd gotten charts of principal locations for ice, because they were going to send some weather information from the ship. Kaiser had the charts showing where the ice usually was, and he gave them to the captain. They compounded the navigational problems. To ride out the storm, the only way to go was north, into the wind, but that was where the ice was.

"So one evening, in the middle of dinner, he turned the ship around, for reasons best known only to him," Kaiser said. "This caused a real calamity because when he went broadside with the waves, the ship took an enormous roll, just when John and I went into the dining room. It rolled six times, back and forth, about forty-five degrees each time, and when you're on a ship that's 150 feet tall, it is an awful experience."

On the first roll, the one the captain anticipated when he turned the ship around, a computer which controlled the engine room, got conflicting information—simultaneous high- and low-water indications in the boilers from this enormous roll. Confused, the computer shut down everything.

"So here we were, dead in the water," Kaiser said. "The engineering officer, who had been eating his dinner, went down seven decks, by steps because the elevators had stopped, hit every button he could find and got the thing going again. John and I went into the dining room singing funeral hymns, and the maître d' kept saying, 'Don't do that!'"

The wind gauge had registered eighty knots. Kaiser remembered the radar officer praying for his equipment; while he was hoping against hope that the earth station had stayed put. It had.

Their experiments proved that you could send voice, teletype, and facsimile material via satellite, all of which had important ramifications for maritime communications, especially emergencies at sea, including problems requiring medical assistance and advice. Conducted over existing INTELSAT satellites, the *QE2* experiments used one of the 64-kilobit-per-second SCPC channels which were established as part of the INTELSAT transponder allocation to SPADE (Single-channel-per-carrier Pulse-code modulation multiple Access-Demand assignment Equipment).

"We had connected a fairly small antenna through an INTELSAT satellite, INTELSAT IV-F2, and it all worked," Kaiser said.

People in the Navy Department began to take notice.

"The aftereffect of the matter was that the SPADE channel wasn't the ideal bandwidth for going into a small antenna," Campanella explained. "Making that happen took a little bit of stress to power that channel down to the *QE2* with more power than we would normally put into a SPADE channel for a big thirty-meter, Standard A earth station."

They would make adjustments for future tests. With the *QE2* experiment completed successfully, interest shifted to the SS *Hope,* the hospital ship that seemed a natural for satellite communications. Roaming the seas on its ongoing mission of mercy, the *Hope* would benefit mightily from the type of link-up that COMSAT could provide. Joseph Charyk, COMSAT's president, knew the director of the *Hope* project and they agreed to do an experiment with the ship. So, off went Kaiser again, this time with a colleague, Dave Rieser, to a place called Maceio, a tiny town north of Rio de Janeiro in Brazil.

"It's right on the equator," Kaiser said, "a grim place. We stayed there five months."

They got there just in time for carnival. Now the carnival in Rio is famous throughout the world, but in Maceio, the carnival couldn't be that big a deal, right? Wrong.

"Carnival is taken so seriously that no one does anything for two weeks," Kaiser explained.

He and Rieser spent the downtime hooking up the equipment and demonstrating how it could be used for administrative communications. Then things got going in earnest. The ship was resupplied once a week by airplane from the States. COMSAT instituted a teletype schedule, and satellite communications replaced spotty ham radio service for supplies.

"After that, we did a number of very interesting experiments," Kaiser said. "We had an electrocardiogram and freeze-frame equipment from RCA. It was brand-new equipment that theoretically could be used to send a video picture using a telephone channel. You just froze the thing and scanned it at a very slow rate, then reproduced it."

To showcase the link with the *Hope,* a demonstration was arranged for the medical community which would link up the new auditorium in COMSAT headquarters at L'Enfant Plaza in Washington with the ship moored at Maceio. Dr. Charyk would chair the Washington end of the conference. It was nail-biting time. Kaiser was having trouble with the transmitter on the *Hope.* About half an hour before this event was to begin, he had arcing on the housing. He borrowed some cleaning tools from the dentist on-board the *Hope* and scrubbed down the high-voltage electrodes. They were arcing from the salt that had collected on them.

Minutes before the appointed time, the equipment began working beautifully. They sent signals using a slow facsimile transmission of X-rays and photos showing wounds and sores. The system demonstrated that you could take a picture of an X-ray and transmit it to a specialist back in the U.S., then he or she could give the medical people down on the *Hope* the recommended treatment. They could send up anything that could be photographed.

Doctors on the *Hope* gave presentations on different tropical diseases, including malnutrition problems and stomach diseases that occurred in that part of the world, which many of the doctors back in Washington had never seen before.

"The circuit held up very well over the entire span of the event," Campanella said, "then about fifteen minutes after it was over with, the circuit arced again and I don't think that Kim ever got it back up."

Kaiser and Rieser spent a good deal of time wrestling with the system, but the technology was young and they were making headway.

"We sent back pictures of patients," Kaiser said. "We sent back dental work that they had done. We transmitted these pictures to the laboratories, then to the headquarters of the *Hope* in Washington."

They had problems that were peculiar to the tropics.

"The 'look' angle to the satellite was eighty-one degrees," Kaiser explained, "which meant that the antenna was virtually pointing straight up. That was a problem because in the tropics it rains every afternoon. The first afternoon the dish filled with water, so we drilled a hole which kept the water draining."

A side benefit was that the Brazilian telecommunications people were becoming more impressed with what they saw. They wanted a demonstration in conjunction with their communications system.

"In our usual fashion, things didn't go easily," Kaiser said. "The access to the roof of the building in Brasília was too small for the dish, so the local fire department had to hoist it up ten stories with ropes."

They linked the demonstration circuit via Tangua, the Brazilian Standard A earth station, then demonstrated the quality of the satellite service versus the microwave service the Brazilians had been using between Brasília and Rio.

"They realized that their microwave system was terrible," Kaiser said. "As a matter of fact, I noticed in Brazil that everyone using the telephone had a handkerchief. When they were through, they wiped off the telephone because they had to speak so loud, they spit into it. When they talked over our satellite system, we had to keep them from shouting because they were overdeviating and wrecking our system."

The Brazilians wanted to see more to be convinced about the benefits of satellites, but they had one more condition.

"There was a general who had the say-so in these matters," Kaiser explained. "He said, 'I will believe this works if you can put in into the jungles of the Amazon.' So, we said, 'Well, if you can get us there, we can put it there.' "

The trip inland would have been a challenge for Indiana Jones.

"It was a fascinating journey over the jungles of the Amazon in an old C-119, 'Flying Box Car,' " Kaiser recalled. "We flew commercial to Belem, then on to Manaus, where they picked us up in the C-119."

It wasn't exactly American Airlines.

"Dave Rieser was a heavy smoker and I noticed he wasn't smoking in the back of the plane," Kaiser said. "I mentioned it to Dave and he pointed to six fifty-five-gallon drums of high-test aviation fuel for the return trip. But that wasn't stopping the crew from cooking over a hot plate."

When the COMSAT duo asked why they did not have parachutes in a military aircraft, they were told parachutes were irrelevant. If they had to bail out over that dense jungle, they would not survive anyway. They were assured that if the plane should go down, it would create an inferno that marked the spot, but two weeks later the jungle would move back in and you wouldn't know anything had happened. It was not the kind of reassurance they were looking for.

Kaiser found out later that the Brazilians referred to the C-119 as "the widow-maker." During the flight, however, he was too concerned about finding the airstrip they were supposed to use to worry about the larger issue of landing in one piece.

"I was in the cockpit watching," he said. "They were really searching, but there was nothing except green beneath us—water and trees . . . and nothing else, nothing. The crew members were getting a little concerned when finally I saw big grins spread over their faces. It was beneath us. Nobody knew how long the runway was so the sergeant who was cooking soup asked somebody to hold the lid on while we were landing. But his cooking was all for naught. We had been at 12,000 feet, in an unpressurized cabin, and it wouldn't cook."

The pilot had brought the aircraft to an abrupt halt. Smack in front of them was the River Amazon. They were at the very end of the runway.

The military guest of honor arrived later, in his own airplane, which had had a near-disaster of its own, running low on fuel and almost not finding the only refueling stop.

"He was a pompous individual," Kaiser recalled. "We had to eat in the mess hall and we had to eat when he wanted to, not when anybody else wanted. When we couldn't tolerate his arrogance any longer, Dave and I deliberately did not show up for dinner one night, which upset him very much. Then, Dave let it be known that at one time I had held the rank of brigadier general and this changed things considerably, even if it wasn't quite true. I'd had the rank bestowed on me for an exercise we did at the Institute for Defense Analysis. At that point he felt that I had equal rank, so we tamed him down a good bit."

There was a small army detachment on the base and they had never been able to talk to their families and friends back home. The communications link-up, if it worked, would be a godsend. After tackling problems of the rains, a sun outage—in which the sun shines directly into the satellite beam—and assorted other problems, the link was made and the Brazilian general convinced.

Two weeks later, they left the base in a short-take-off-and-landing aircraft, along with a load of bananas, a parrot, a group of Amazon Indians, and two Brazilian soldiers. Just another of what had become ordinary assignments for Kim Kaiser.

The Navy had become impressed with all that was going on at COMSAT Labs and in the field trials. As fortune would have it, in the early 1970s the Navy was looking for a way to fill a gap until the launch of its FLEETSATCOM satellites later in the decade. As a "gapfiller," the Navy decided to lease UHF capacity from COMSAT on a commercial basis during the interim period. COMSAT responded with a proposal of its own. It would design a hybrid satellite capable of providing the Navy with its UHF service requirements for a period of at least two years, while including aboard the satellite transponders operating at frequencies in the maritime services L-band. The Navy services would run at a peak as soon as the satellite was successfully in orbit, while the maritime services segment would begin with a low level of usage, which would increase as the Navy decreased its requirements. The Navy agreed. The awarding of the contract in 1973 represented the first time military and commercial capabilities would share the same satellite. It also marked the first time L-band capabilities would be offered via satellite communications. The transmitter could be operated at three different power levels, permitting the limited power of the satellite to be shared between the UHF and L-band users, and regulating the power as demand for one increased and the other decreased.

In 1976, maritime communications took a giant step forward with the orbiting of three MARISAT satellites over the Atlantic, Pacific, and Indian oceans. Shore stations were operational at Southbury, Connecticut; Santa Paula, California; and Yamaguchi, Japan while additional telemetry, tracking, and control was provided via the Fucino station in Italy.

The first commercial telephone call using the system occurred on July 9 of that year, when the seismic ship *Deep Sea Explorer,* at sea off the coast of Madagascar in the western Indian Ocean, called home, its head office in Bartlesville, Oklahoma. "The most fantastic communications I've ever seen," exclaimed ship's quality control officer Ronald Payne at the time.

The MARISAT system put into everyday use some of the most innovative concepts and designs developed at COMSAT Labs. Voice grade channels were frequency modulated on a single-channel-per-carrier basis. Telegraphy channels used time division multiplexing in the shore-to-ship direction, time division multiple access in the ship-to-shore direction. Twenty-two telegraph channels shared the same frequency.

There were standard sixty-six-words-per-minute telex services, fully interconnected with worldwide teleprinter networks. Automatic and semiautomatic telephone connections were possible. Medium- and high-speed data transmission at rates up to 2.4 kilobits per second and 56 kb/s were provided, plus both analog and digital facsimile transmissions, using telephone channels.

In 1978, the Communications Satellite Act of 1962 was amended to provide for COMSAT's mandate as the U.S. representative to the newly formed INMARSAT organization (which replaced MARISAT), and a Maritime Services Division was created at COMSAT to provide this ongoing representation.

By that time maritime communications services were being provided to freighters and container ships, tankers and liquid natural gas carriers, fishing ships, construction barges, government ships, passenger liners, seismic ships, ice breakers, tugs, cable ships, even pleasure yachts and stationary drilling platforms—a total of 5,000 ships and platforms.

Once the important requirements of maritime communications were satisfied, the engineers and scientists at COMSAT

Labs turned their attention to a little entertainment. They developed a revolutionary compressed video technique that permitted the viable transmission of TV signals to ships at sea. In January 1986, they conducted an experiment with a gracious old friend, the *QE2,* relaying the Super Bowl game to the ship a hundred miles off the coast of Peru. The experiment brought raves from the passengers and crew. Compressed video promised to turn the experiment into an ongoing process. Prior to its invention, live television transmissions to ships at sea had not been possible via maritime satellites. Compressed video allowed for the relay with adequate signal strength.

Once again, the transformation of an entire segment of the communications universe had occurred to the point where its use became a matter of course, taken for granted—almost. When a crewman on a container ship 900 miles off the coast of Bermuda was injured so seriously that the captain contacted a hospital in Staten Island, New York, for help, the transmission was so clear that the incredulous hospital operator kept having the captain repeat his "address." "Nine hundred miles off the coast of Bermuda," the exasperated captain kept repeating. Finally the operator yelled, "I've heard all that. Just tell me where to send the ambulance."

CHAPTER THIRTEEN

The Path to the 1990s

In a statement marking the twentieth anniversary of COMSAT in 1983, Massachusetts Senator Edward M. Kennedy said, in part:

> . . . Through COMSAT, we have learned anew the fundamental truth of the interdependence of the modern world. Information and technology transcend national borders and provide important building blocks for peace . . .
>
> The example of COMSAT . . . reminds us of the power of technology and the fundamental choice that humanity must make. Do we, as John Kennedy hoped, "advance the peaceful and productive use of space to accelerate the march of civilization?" Or, do we make space an arena for the arms race and accelerate the march of destruction?
>
> . . . Satellites . . . are circling the earth providing the kind of instant communications once mentioned only in science fiction. We know now that when we reach boldly into the future, we can accomplish important things. All those who have been a part of this magnificent endeavor can take pride in their participation. "Together," President Kennedy said, "let us explore the stars and invoke the wonders of sci-

> ence instead of its terrors." COMSAT has met
> the challenge of that last great frontier.

When John Evans came to COMSAT Labs in April 1983, he was about to take on one of the great challenges of his distinguished career. It was a difficult period for the labs. Twenty years after the founding of COMSAT, the great frontiers in satellite communications had long since been conquered. The new challenges involved perfecting the art, while at the same time trying to make sure the money was available to continue what was to be very sophisticated R&D for the next generation of satellite systems.

A native of the United Kingdom, Evans came to the U.S. in 1960 to work at MIT's Lincoln Laboratory. There he met Jack Harrington who was director of the Radio Physics Division.

"They had built a very high powered radar which was capable of getting echoes from Venus and had in the planning process a still more powerful one that could get echoes from Venus, Mars, and Mercury," Evans explained. "I was in radar astronomy, having worked in that field in Britain, studying reflection properties of the moon, so I went to work for Jack."

Jack Harrington left three years later to become head of MIT's Center for Space Research, set up in conjunction with NASA to serve as a bridge among different departments—physics, chemistry, etc. During this period Harrington served as a consultant to COMSAT, which had been trying to woo him away from MIT almost since the company's inception. Harrington, in fact, had been a strong supporter of the need for a research facility. "Engineers don't last long as paper pushers," he said, arguing that if COMSAT were to be an intelligent buyer of technology, it needed people who knew what they were buying. As chairman of a committee to evaluate the need for the labs—along with Sig Reiger, Jack Morton of Bell Labs, and fellow MIT department head Bill Davenport—he helped write the charter for the labs, which Reiger then presented successfully to the board of directors. While at MIT, Harrington had consulted on a number of technical projects for COMSAT, including the challenging problem of maintaining stability in the INTELSAT IV satellite with its new de-spun antenna. The symbiotic relationship turned into a formal one when Harrington became vice president of research and engineering in the mid-1970s. He took over as director of the labs when Burt Edelson left.

At about that time, Harrington and Evans bumped into each other at an airport one afternoon. The fortuitous meeting had long-range consequences.

"He told me that COMSAT was looking for people to fit various positions and asked me if I was interested," Evans recalled. "One thing led to another and I ended up coming here."

Evans joined as director of research, reporting directly to Harrington. He was also heir apparent to the lab director's job. However, he was not aware that he would make it to the top spot so rapidly. Harrington opted for early retirement and Evans became the fourth director of the labs in October 1983, just six months after coming to COMSAT.

It was a difficult time at the labs, which were laboring through a period of transition that was taking its toll on morale, resulting in an escalating turnover.

"The corporation had been engaged in a battle with the FCC since 1979 over the process of funding research at the labs and charging U.S. rate payers for it," Evans explained. "This battle came to a close in 1984 when the FCC basically enjoined us from doing that to the degree we had. It essentially said that for any basic research that was funded with any jurisdictional funding component, there had to be a matching component from the corporate shareholders. They set a formula for doing that which put it about four-to-one, four times as many dollars from the shareholders had to go into this pool as you could charge rate payers. We appealed and it ended up being two-to-one."

The shifting emphasis at the labs created a sense of uncertainty. The size of the staff fell from more than 600 to less than 400. The situation required a new sense of purpose. Evans felt the answer lay in taking on a difficult new challenge—the serious competition from fiber-optic cables—the biggest threat to satellites' domination of international communications since the launch of Early Bird.

"I think that this must have been a very exciting place in 1967, when the lab was first formed, and in 1969, when the people moved out here," Evans said. "It must have been akin in some respects to the early people in NASA who had the job of getting to the moon in ten years' time. In some ways we're victims of our own success. The INTELSAT system has worked, creating a global satellite system that carries two-thirds of the world's communications."

In view of what had been accomplished via INTELSAT, Evans said he felt that the only reason the undersea cables continued to be used after the dawn of the satellite age was because AT&T and the European PTTs kept traffic on the cables even while more and more customers moved to satellites. That move paid off for them with the development of the fiber-optic cable.

"With the advent of fiber-optic cables, the tables have been turned on satellites," Evans said. "You now have a technology which probably has greater capacity than satellites or at least as much potentially. So the problem we have is trying to remain competitive with this technical threat. The approach we've been taking, and the research we've largely been doing to address it, is to say that the cable only delivers the traffic to the shore and it then has to fan out through a network of either cables or microwave links to get to the ultimate customers. If satellites could be designed to deliver traffic much more closely to the ultimate customer, and bypass a lot of the internal toll charges, we could probably be as cheap or cheaper than the trans-Atlantic cable when its 'tail' costs are added."

So that was the direction in which Evans pointed the labs. Such a dramatic new satellite system would be built very differently from previous ones. Up until that time satellites illuminated large portions of the earth's surface, all of Africa, Europe, etc.—the so-called hemispheric beams. As such, the intensity of the signals falling in the areas illuminated was relatively weak because the signals spread out over a big surface. If you could focus the beam on the satellite to aim just the signals where you wanted them—in effect create a very thin, or "pencil" beam—you could receive those signals with very much smaller antennas than were currently used, while keeping the transmitter power on the satellite constant. The existing INTELSAT system was designed basically with very simple satellites and large, expensive earth stations—

the big INTELSAT Standard A earth stations. Therefore, a principal objective was to reduce the cost of the earth stations so users could afford many more of them, and they could be placed around the countryside where they were needed. COMSAT Labs' objective was to invert the cost structure—i.e., shift any increase in cost to the satellites—since they were much fewer in number—and make the earth stations correspondingly cheaper, because there were a lot more of them. The scientists and engineers began working on technologies to create the pencil-beam antennas for the satellites. Of course, the challenge involved solving complex problems, but that was the stock in trade of COMSAT Labs.

At the same time this was occurring, an old player was brought back into the commercial communications satellite game, NASA. NASA had all but bowed out of the arena with the establishment of COMSAT in 1963. But Presidential Directive PD-42, issued in 1978, changed all this. It directed NASA back into the communications satellite arena to help build the satellite system of the 1990s and beyond. To do that would take resources far beyond those available to the private sector, for which the risks were deemed too great and the potential rewards too far over the horizon. Not to mention the fact that foreign competitors, the Japanese in particular, were marking the trails to the new satellite technologies, so there was pressure for the U.S. to stay in the game.

NASA's reentry into communications satellite R&D was dubbed advanced communications technology satellite (ACTS). The objectives of ACTS were to develop areas of advanced technology with NASA assuming the high level of risk involved, test the performance of systems and subsystems, bring the technology to flight readiness, then verify the technology in experimental use.

In a sentence, ACTS would be an advanced switching communications satellite—a high-speed switchboard in the sky—which used high-powered, narrow-scanning beams to achieve geographically targeted, point-to-point communication. A lot of the ACTS program objectives overlapped the direction in which Evans was taking the labs.

RCA was awarded the principal contract. COMSAT Labs was selected to design and develop the ground elements of the system, including the earth stations and the master control station, one of the most complex pieces of hardware ever attempted for a communications satellite system.

So the teams at the labs went to work on the new technologies that would send and receive signals in far more well-defined routes, and to solve the myriad problems that would result from trying to create the new pencil-beam systems.

"Once you introduce these pencil beams you have a problem in that signals which go up one beam have to be switched on-board the satellite to go down the right beam and arrive at the proper destination," Evans explained. "So the satellite has to have on-board some processing capability. It has to be able to recognize the destinations of the signals and possibly store them. The down-beam may not be directed exactly where you want it at the moment you want to send those signals. Or, you have a packet of arriving signals, a burst with traffic in it for different destinations, and you have to pull it apart. The simple way to handle that is to demodulate the arriving signals, recover the actual digital bits, and store them in a memory of some kind and then switch out of the memory the pieces you need to the appropriate destinations."

Basically it was the same idea that would dominate the design of the ACTS experiment, with some important exceptions. The ACTS experiment involved frequencies in the Ka band, the highest frequencies assigned to the international satellite service. The most heavily used bands to that point were the C band, at 6 to 4 gigahertz or 5 and 7½ cm wavelengths; and the Ku band, at 12 and 14 gigahertz or roughly 2½ and 2 cm wavelengths. The Ka band that ACTS was working with was 20 and 30 gigahertz, or 1½ and 1 cm wavelength. At those high frequencies and correspondingly small wavelengths, the effects of rain-fading get to be very severe.

In Evans's view the Ku band frequencies were not yet so busy that they needed to go up to Ka band. His other key difference with the direction of the ACTS experiment involved antenna technology.

"What they were doing to move their beams around was simply turning horns on and off with ferite switches," Evans explained, "which is a way to go but is heavy and slow. We believed that the way to do it was the same way some radars are now made, to scan pencil beams around electronically with phased-array technology."

Then there was the matter of the on-board processor. Evans felt that the one being used in the ACTS experiment was of limited capability and forced everybody to address the satellite with a TDMA system at a certain bit rate.

"We think that a commercial satellite will be successful only if users have a much greater freedom to choose what kind of bit rate they want, what kind of modulation scheme they want, and so on," he explained. "You don't force them all into the same mode. So, we addressed these other facets to make a truly successful commercial international satellite."

That involved work in four of the technical divisions at the labs: Microwave Division, to design the antenna; Microelectronics Division, to design the electronic chips that would go in the antenna; Communication Techniques Division to design the on-board processing equipment; and Applied Technologies Division, to develop lightweight power supplies for the antenna array and remove the heat from it. It was the first time in a long time that the labs had a focused program integrating as many as four of the six divisions into a common objective and a common theme. But there were monumental issues that had to be addressed.

Meanwhile, the INTELSAT VI series of satellites, being built by Hughes, was nearing deployment. The VIs would be the final generation using essentially the existing technology, but carrying it to the nth degree—i.e., using the satellite as simply a microwave repeater.

"Think of a microwave repeater on the ground," Evans explained. "Basically a tower is built with an antenna that looks at a distant tower. The signals are received and picked up by this antenna, then go down through a cable. They're amplified, their frequencies changed and further amplified, and then with the small power of a few watts go up another cable into another antenna that beams them on. Our satellite is a microwave repeater in space. It receives the signals from the ground on one frequency, amplifies them, changes the frequency, and retransmits them in the new frequency back to the ground. If you didn't change the frequencies, you'd have the danger of the transmitted signals being picked up by the receiving antenna and the whole thing would go into self-oscillation."

The INTELSAT VIs were not designed to do any processing on-board. However, the major advance in the current technology that had been incorporated into the satellite was the reuse of the C-band frequencies several times over.

"In INTELSAT VI, the C-band frequencies are actually used six times," Evans said. "There's a hemispheric beam that illuminates South America and North America and uses the frequencies once; another hemispheric beam that illuminates the Atlantic Ocean, Africa, and Europe and uses the frequencies a second time. There are so-called regional beams which illuminate Europe and North America, with the opposite sense of circular polarization, so that you use the frequencies a third and fourth time. Then there is another regional beam on Africa and South America again with the same opposite sense of circular polarization, using it a fifth and sixth time. Finally, there are some transponders that have narrow spot beams at Ku band. But they're basically what we call 'bent-pipe' satellites—they take the signals, amplify them, and retransmit them."

The work at COMSAT Labs contributed to how the antennas were built, and how the frequency band was broken down into narrow channels which could use most effectively the available spectrum assigned through the FCC. That involved creating microwave filters which confine the operation of each of the repeater amplifiers into the appropriate range of frequencies without spilling over into adjacent ones. The INTELSAT VI was built with forty-eight transponders capable of carrying about 40,000 circuits without circuit multiplication. It was very large—forty feet tall—and in the view of many of the people at COMSAT Labs, the last of the big satellites.

Some of the differences in the development of the new technologies being worked on at the labs and the ACTS experiment involved mission. ACTS was being developed as a domestic system. The labs envisioned a new satellite that would be used internationally and had all the right ingredients to be a commercial success. On the other hand, outside of the ACTS program, COMSAT Labs had to take the economic risks of developing new technologies onto its own shoulders, in expectation that at some time the technology would be developed to the point where the labs could make a convincing case to INTELSAT, and to the manufacturers, that this was the way to go. Only then would it be able to compete effectively against fiber optics.

"Formerly, when we were the technical manager for INTELSAT, we could take positions that this was what should be done and more or less carry it," Evans said. "We were now a lot weaker in that we were no longer the technical manager, so we could only argue as one of the owners that this is what should happen."

Even before they got that far, the labs would have to convince its own corporate hierarchy at COMSAT itself, which was paying for the research, that it was not wasting the company's money, that it was building a case for a change in the technology that would give the labs a fighting chance to compete with the cables. If something were not done, the cables would increasingly eat into the two-thirds of the world's overseas traffic that satellites were carrying, bringing that share of traffic down to half or even less over the course of several years.

The new competition would be played out on a field that had lower cost as its principle objective, not increased capacity.

"In the early days capacity was the issue," Evans said. "Early Bird had 240 circuits and that was about equal to the capacity of the undersea cables at that time. I can remember phoning England in those days. You called AT&T and asked them to 'book you' to England. They called back a day or so later and said your call to England was then being put through. We've made enormous strides since then."

In the first several years of INTELSAT's operation, circuit capacity compounded at 20 percent per year. The real issue was to try and get more and more capacity out of the satellite. The people at INTELSAT made some technical mistakes, like trying to expand capacity by only broadening the bandwidth of the one or two transponders on the first satellites. They tried to make them cover a bigger and bigger band and that proved not to be the way to go because the amplifier on the transponder had, as its final stage a traveling wave tube, a microwave vacuum tube amplifier, with some unfortunate properties. It was a very nonlinear device and in electrical circuits, if you put two signals into a nonlinear device, they mix together and create unwanted new components which spill over and mix with other signals. Trying to put more and more signals into these broader and broader bandwidth transponders just created continual problems and the decision was made to go to narrow transponders, lots of them, which became operational with INTELSAT IV.

"That was a turning point in the ability to really create this capacity," Evans explained. "We killed the capacity problem and that was a factor in our research—we virtually have stopped working on trying to create additional capacity. That problem is dead and buried."

When asked to assess the communications satellite industry from the perspective of twenty-five years, Joseph Charyk said that there had been a clouding of the more clearly defined objectives that existed when he'd become COMSAT's first president. He emphasized that early on they had seen the importance of establishing a well-recognized level of technical excellence and that the result had been to define COMSAT Labs as the repository of communications satellite technical expertise.

"If you go anywhere in the world and ask where the most information on communication satellites exists," he said, "I think you'll find that COMSAT Labs is a household word. I think we can be proud of the kind of work that has been done. At the outset, there was never any question in anybody's mind, including the regulatory authorities and the Congress, that we had to spend a significant amount of money in doing research and development, otherwise we weren't going to be the leader very long. As long as the present legislation stays in effect, which says that COMSAT is the designated entity of the United States, then I think it is in the interest of the United States, if we are going to maintain the leadership role in communications satellite technology, to ensure that a proper level of R&D work is done, because once you have lost your leadership role, it is almost impossible to regain it."

He said there was a real challenge to the leadership role in the emergence of new pockets of technical excellence throughout the world.

"If the U.S. is going to maintain a leadership role," he said, "it is even more important than it was at the outset to make sure that we do the kind of work that is necessary, over a broad spectrum. Once you begin to cut way back, there is a serious danger that the sort of unique leadership role that the United States has enjoyed over all of these years will vanish. Whereas in 1962, although a lot of people didn't agree that this was the way to go, once the national policy was embodied in law, people said, 'If that's the law, okay, we'll follow it.' Unless there is someone clarifying that this is the policy of this country, more and more questions are going to be raised by more and more people, and the end result will be the loss of U.S. leadership in this technology. We're getting perilously close to that now."

CHAPTER FOURTEEN

Putting It all in Perspective

While an understanding of the complex solutions to complex problems solved by the people at COMSAT Laboratories over the years may elude all but the most technically minded among us, the applications of many of those technologies are readily apparent in many areas. The most obvious indication to the world that Early Bird was up there and functioning was not so much the news reports that heralded the accomplishment of the launch and the proper positioning of the satellite in geostationary orbit, but the television programs that began to appear from across the Atlantic and the new caption line, "live via satellite," or "live via Early Bird," that was appearing with greater frequency across the bottom of TV screens.

The escalation of the Vietnam War during the 1960s was watched as it unfolded on the television sets of Americans back home, as they sat down to their evening meals. The stark differences between the comfort of their surroundings and the rice paddies and gun emplacements of the men overseas were not lost on many. For the first time in American history, the folks back home got to observe the effects of the decisions being made in the meeting rooms of Congress, the offices of the White House, and the halls of the Pentagon on the foot soldiers in the Mekong Delta, the pilots at Bien Hoa, the marines dug in at Khe Sanh.

Much of the material for those broadcasts were recorded on the battlefields, then transmitted over the global satellite network. The effects of this kind of expansive, live or same-day news coverage, now possible from the most remote corners of the earth, were profound. The ultimate result was a smaller world with fewer secrets.

"NBC-TV's Huntley-Brinkley Report on Feb. 2 presented via satellite one of the most stark realities of the war in a film sequence in which South Vietnamese Police Chief General Loan executed a Vietcong terrorist," read a caption in the February 12, 1968, issue of *Broadcasting* magazine. That photo shocked Americans, many of whom had images of America's allies as men involved in the necessary evils of war, not as perpetrators of those evils.

But the dark side was not the only one shown in the broadcasts that were splashed across TV screens. On the brighter side, the launch of the early communications satellites ushered in a series of TV audience records that were eclipsed almost as soon as they were set, with the Olympics outdoing the previous World Cup soccer matches, which had outdone the previous Olympics, and so on.

Perhaps the most dramatic live coverage of all was the historic Apollo II landing on the moon in July 1969. Television coverage of the epic mission, from liftoff to splashdown, was transmitted overseas via satellite to a worldwide audience that was larger than for any previous event. Portions of the mission were seen by an estimated 500 million viewers in more than forty countries on five continents. There were more than 230 hours of satellite time, involving about 200 individual programs, during the nine-day mission. Along with satellites over the Atlantic, Pacific, and Indian oceans, twenty earth stations interconnected with terrestrial networks carried the programming to the broad-based audience.

The live video of the moon walk by Neil Armstrong, as he stepped down from the landing vehicle, *Eagle,* at 10:56 P.M. (EDT) on Sunday, July 20, 1969, was received by the big NASA parabolic dish antenna at Goldstone, California, and at the Parkes Observatory in Australia. Then the signals were relayed via land lines and ultimately INTELSAT III satellites. The telecasts from Tranquility Base on the surface of the moon, 240,000 miles away, were made possible by the global satellite system and the skills of people around the world, who had become part of an expanding network during the five years since its inception. Even coverage of the splashdown in the Pacific was broadcast without a hitch via signals transmitted through a small earth station aboard the recovery carrier USS *Hornet* and relayed via the INTELSAT III satellite over the Pacific.

In the process of developing the technologies for the INMARSAT systems, smaller, more efficient end products began to emerge. The development of the MCS-9100, a lightweight, extremely compact earth station, which expanded the market for satellite communications to pleasure yachts as small as fifty feet in length, had applications far beyond its maritime uses. The core technology developed for the MCS-9100 was modified for land-based applications and the result was the TCS-9000, literally an earth station in a suitcase—well, two suitcases actually, weighing less than a hundred pounds.

The TCS-9000 brought portability to earth stations. Folding up into two weather-tight suitcases, the unit required only 385 watts of power, but its reach was incredible. The user could connect with the worldwide public switched telephone network, in effect plugging into a system that covered the globe. It could be transported as luggage aboard a commercial aircraft or could fit in the trunk of a car. And, remarkably, the system could be unpacked and set up in less than fifteen minutes.

The user could pick up the telephone on the TCS-9000 and it was like picking up a telephone in the home or office. You could direct-dial to almost anywhere, while almost anyone who had a telephone could reach you. The connection was of long-distance telephone quality—i.e., without the static experienced with the old HF radio systems. Furthermore, the caller enjoyed the privacy of a long-distance call, as opposed to radio calls, which could be heard by anyone who happened to be tuned into your frequency. It was a powerful capability to have when the user was at an otherwise inaccessible location with a real need to receive and/or send information.

The Mexico City earthquake of September 1985 was a dramatic case in point. That quake, which resulted in almost 10,000 deaths and the loss of hundreds of buildings, wiped out Mexico City's terrestrial communications with the outside world. Immediately upon getting word of the disaster, engineers at COMSAT Labs began working to apply their particular talents, along with hardware they had created, to

reestablish a link to the devastated capital—a city that had grown to almost 16 million people. Concurrently, the broadcast media were in the midst of a frantic search to open communications lines for correspondents covering the tragedy. Within thirty-six hours of the quake, one COMSAT TCS-9000 was on the scene, with a second on the way, and a SkyBridge satellite broadcasting vehicle was being airfreighted in the cargo compartment of a C-130 aircraft.

The first TCS-9000 established a telephone link at Channel 13, Mexico City's only surviving television station, while the second was set up at the El Camino Real, a hotel popular with businesspeople and tourists. A sign-up sheet procedure was established for using the telephone, and a line of people soon materialized and continued twenty-four hours a day.

With the arrival of the SkyBridge, national news anchors Tom Brokaw and Peter Jennings were able to broadcast on-the-scene reports of the devastation and the search for survivors, including emotionally uplifting reports that people were in fact being found alive beneath the rubble.

The demonstration of this incredible shrinking technology began to raise expectations about just how portable such space age systems eventually could be made. Was a Dick Tracy wrist radio looming just over the horizon?

"A commercial wrist radio, usable for two-way communications with anyone anywhere in the world, is a lot closer than the average person suspects," a COMSAT executive remarked at the time.

Applications of technology designed and developed at COMSAT Labs was not limited to the broadcast image or sound, however. On September 23, 1974, COMSAT and Dow-Jones joined forces to transmit a production-quality page from the Dow-Jones regional composition plant in Chicopee, Massachusetts, to the publishing company's printing plant in South Brunswick, New Jersey. The result of the collaboration appeared as page 22 in the following day's edition of the *Wall Street Journal.*

To implement the procedure, COMSAT set up a small earth station at the Chicopee plant, which beamed its data off an INTELSAT IV satellite over the Atlantic, which in turn retransmitted the data down to a receive-only earth station at the South Brunswick plant. The photo film facsimile received in New Jersey was then used to create lithographic press plates for production pages. High-resolution scanners and recorders, data compression units, and digital communication channel units made the process possible. It was the first time an entire process from composition to printing was conducted via satellite transmission.

"Of course, from Chicopee to South Brunswick wasn't a very long distance," Burton Edelson explained, "however, what we showed was if you can transmit it from A to B, using the same facilities you can transmit it to points C, D, E, F, and G as well. It really made a lot of difference. Now, not only Dow-Jones is using it, but the *New York Times.* Of course *USA Today* lives off it, the *Christian Science Monitor* is using it, as do Reuters and others. We created a whole new industry. With regard to the *Wall Street Journal,* they had printing plants in several places. After this demonstration, they decided to build a printing plant in Orlando, Florida. They put an earth station right on the lawn there. That printing plant has no writers, no editors, no journalists, no proofreaders, etc. The only thing they've got is an electronic link that comes into the building and people there to develop the fax, put it on the plates, run the printing presses, load the newspapers, and send them out of the plant. Then they started building these printing plants all around the country."

Perhaps the ultimate vote of confidence in the technology came when the U.S. and USSR announced an agreement in 1971 to shift the hot line link between the two countries to satellites. The agreement was designed to take advantage of the new communications satellite technologies developed independently in both countries and to improve upon the terrestrial hot line system established in 1963. That hot line consisted of two teleprinters—one in Washington and one in Moscow—connected by a wire telegraph circuit routed under the Atlantic, then via London, Copenhagen, Stockholm, and Helsinki. There was also a back-up radio telegraph circuit via Tangier.

Under the satellite agreement, there would be multiple terminals in each country, providing greater flexibility and reducing the risk of outages associated with the vulnerability of each capital during periods of hostile environment.

The satellite hot lines were set up as duplex, telephone-bandwidth circuits, equipped for secondary telegraph multiplexing as well.

Both the INTELSAT and the Russian MOLNIYA systems were employed for the hot line to provide a level of redundancy. The system, which involves encoding, decoding, and translations of alphabets, is tested continually and has proven to be highly efficient.

These and scores of other widely used applications have translated the two decades of developments at COMSAT Labs into ingredients of everyday life throughout the world. Their greatest achievement is perhaps the fact that they are now taken totally for granted by those who use them as a matter of course.

As commercial communications entered the latter part of the 1980s, the major battle lines were drawn between advanced technology communications satellites and the fiber-optic cable. It could be looked upon as the good fight between two highly developed technologies. Unquestionably, there was room for both, each with its particular advantages. COMSAT Labs, however, was left with the task of demonstrating that this was indeed the case.

As for the communications satellites that had put the peoples of the world in easy touch with each other, Irving Goldstein, chairman and chief executive officer of COMSAT, offered this perspective on the first quarter century:

> When the final chapter is written a thousand years from now, I think I'd like it to say that what was accomplished here was accomplished through creative, innovative, healthy use of technology that benefitted the country, and benefitted the world. It was technology as well as good common business sense that made that happen and it really shows how clever, how far-sighted, the framers of the original Communications Satellite Act were. It's the only significant example of the commercialization of that kind of technology that's occurred yet in the world. It may prove to be the most significant ever. The people in that Kennedy era decided to take a major technology that had international and strategic implications for the United States and instead of holding it and hiding it, to give it to the rest of the world. By

> doing that, it would help us as well as everyone else. This had not been done from time immemorial, whether it was the crossbow or the long bow or whatever, anyone who had it kept it and tried not to let anyone else know about it. Instead, in the case of communications satellites, the idea was to broadcast it. I think that proved to be right.

What does the future have in store? Goldstein projected a positive impact in three areas. In an article for *Q*, the magazine of his alma mater Queens College in New York City, Goldstein predicted:

- The development of a global currency that would act as a common means of instantaneous and acceptable transfer of money anywhere in the world. He said Eurodollars and bank debit cards were steps toward that end.
- Rapid evolution of English as a global language for communicating ideas on an international basis.
- Transmission of solar, pulse and/or laser energy via satellite.

"Speed and distance are no longer limitations," Goldstein said. "Satellites are insensitive to the distance between points on the ground. Communication between points widely separated is near-instantaneous. Capacity is seldom a limiter. Between 1965 and 1987, the number of satellite communications channels grew from 150 to more than 100,000. Access to satellite communications is open to 173 countries via the global network of INTELSAT.... In the 23 years since the launch of the first commercial communications satellite, the cost of communicating on those satellites has dropped 19-fold."

Joseph N. Pelton, director of special projects for INTELSAT, likened the increase in capacity from Early Bird to INTELSAT VI, to comparing a tool shed to the World Trade Center in New York. He said the VIs could transmit the equivalent of a human lifetime of stored information in seven seconds.

The 1990s will see the development of the INTELSAT VII satellites, incorporating new technological advances, the most important of which include:

- C-band, spot-beam antennas that are independently steerable allowing INTELSAT the flexibility to reposition the satellite to accommodate increased traffic from specific locations.
- A third K-band antenna which will permit INTELSAT to switch transponders and amplify signals among different receiving dishes, accommodating increased traffic and extend K-band international services to new areas.
- Zone-switching capability, allowing INTELSAT to configure coverage within certain geographic areas, between areas and on a global scale.
- Increased power, permitting the use of smaller antennas.

The first launches of the VII series are projected for mid-1992 or early 1993 continuing a long record of service that began with Early Bird in the mid-1960s.

The on-going role of communications satellites was perhaps best described by Arthur C. Clarke, when in the British magazine, *Spaceflight*, he likened the satellites to a positive version of the Tower of Babel:

> "Higher than the wildest dreams of its builders, 22,300 miles above the earth, we may regain what was once lost, when the Lord said, 'Behold they are one people, and they have all one language, and this is only the beginning of what they will do; and nothing that they propose to do will now be impossible to them.'"

Epilogue

Infrequently, but on occasion and with great significance, technologies that initially appear widely separated come together to create new and different capabilities. When this happens, some novel applications emerge and, in a dramatic way, affect the way we live. Such was the case in the late 1950s, when developments in such widely diverse fields as rocket propulsion, solid-state devices, traveling wave tubes, attitude stabilization concepts, masers, and solar cell technology came together to suggest the feasibility of making Arthur Clarke's dream of 1945 a reality. But was all the technology sufficiently mature to actually be able to create an effective and economically viable global communications satellite network? If so, should it be done through government or private means? If the latter, through what type of private entity? The United States' answer was the Communications Satellite Act of 1962.

The story of the wisdom of that decision and the many debates and issues that have often clouded the development of communications satellites has been treated in much detail in many different articles and publications. History will provide a better assessment of the total issue than is possible today. One thing remains clear, however. Through the decision made in 1962, the United States brought to the world an enormous force with a potential for great good. It did so in a novel fashion, making available to the world technology it had developed over many years, gaining the respect and admiration of nations of all types and universal recognition as the technology leader in the dynamic new field of communications via satellite.

What is not so well known or appreciated is the story of the efforts of the fledgling new company, COMSAT, created through the Communications Satellite Act of 1962 to gather together the elements of that technological base and set a course not only to make the unique concept a viable commercial enterprise but to insure the U.S. maintained technology leadership in this critical new field. *Live via Satellite* has sought to bring together the recollections, ideas, motivations, and knowledge of many key scientists and engineers who came together from many different places and many different technical disciplines to seek to achieve and make available to the world the dramatic potential of global communications by satellite. Beyond the immediate goal, they strove to push the critical elements of the diverse technologies to open the door to the great potential that loomed in the future for this exciting new communications medium.

Not too many people have the good fortune that I did: to be present at the creation in a sense, and to play a role in the concept and formulation of a whole new industry. As I look back on those early days and reread the reflections of many of the members of that pioneering team of scientists and engineers, I am struck with the rare combinations of knowledge, motivation, self-sacrifice, dedication, and teamwork that in special situations can come together to make the difficult easy and the improbable a likelihood. To this very special group of people much is owed. I am confident that they all take special pride and satisfaction in the fact that they were the pioneers, they were the architects of an important element of a new world of communications.

When I became president of COMSAT in March 1963 and began to focus on the technical demands of this challenging new enterprise, several things dominated my thoughts. First, it would be necessary to recruit a cadre of individuals with a wide range of experience and knowledge in the many disciplines involved. Second, they would have to be motivated and molded into a dedicated team with a clear set of goals and objectives. Third, they would have to have the opportunity to build on their experience and skills in order to maintain their expertise in their technical disciplines. I concluded very early, therefore, that a research and development laboratory would be vital for success, not only to support the engineering efforts critical to the achievement of the immediate goals, but to sharpen the technical cutting edge vital to future success as well. I viewed such an investment to be critical and totally consistent with the objectives spelled out in the 1962 act. In the early years, this philosophy was accepted as basic by many of the government monitors involved. The result was that COMSAT Laboratories quickly became recognized worldwide as the leader in the technologies underlying communications satellites.

As I began my search for the nucleus of the critical technical team needed for the task ahead, the effort quickly focused on two individuals: Siegfried Reiger, who had been very active in studies of communications satellite potential at the Rand Corporation, and Sydney Metzger, a communications systems expert at RCA. Both agreed to join COMSAT, and the fortuitous outcome of those decisions provided the infant organization with the leadership skills on which its growth and development were to be based.

Temperamentally, emotionally, and in their methods of operation they were radically different; yet the combination of their capabilities provided the technical leadership that the new organization needed. Reiger was the driver for whom the word impossible did not exist. He demanded and expected high competence from all his people. He had no place for those he called fools, and he had little tolerance for bureaucracy. But he knew the goals and he drove himself and his people untiringly toward success. Metzger brought expert knowledge, insight, and excellent judgment to the technical challenges that lay ahead. He possessed the critical ability to judge how prudent it was to anticipate and plan for technical progress in the course of a development project and to discern the boundaries beyond which one should not reach if a reliable, efficient, and effective product were to be expected to emerge. Underreaching and overreaching are two of the most deadly sins in engineering. The new organization could not likely survive either one. Metzger brought that critical balance to the scene. Together, Reiger and Metzger assembled an unusual group of competent, imaginative, and dedicated technical people, some of whose stories and experiences have been recounted in this volume. They completely agreed that to gain and retain leadership in this new field of endeavor, the corporation must develop and maintain a research and development effort of the highest quality and that, too, became a joint goal. The result of course, was COMSAT Laboratories and its existence and its successes are a tribute to those space communications pioneers.

I remember a question that President Kennedy asked me in 1963 after a Father's Day session at the White House school attended by a small group of children, including his daughter, Caroline, and my son, Christopher. The question dealt with my estimate of when a satellite system would be in place to permit peoples from around the globe to see and be in touch with each other. My answer was that I had high confidence it would be done well within his administration. I was wrong. The President's administration came to a tragic end a short time later in Dallas. A global communications satellite system became a reality a few years later—a tribute to his foresight.

Joseph V. Charyk

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LIVE VIA SATELLITE

From the introduction by Arthur C. Clarke . . .

"Not for a moment did I consider, in the final spring of the war, that the first crude comsat (Score, December 1958) would be orbiting within 13 years, and that commercial operations would start within 20."

On Sunday, December 14, 1986, choirs of children in North and South America sang a song for peace in Central America. The broadcast was carried as a teleconference to more than 100 locations in the Western Hemisphere from Alaska to the tip of Argentina.

On April 29, 1981, the tanker Arco Juneau with a full load of Alaskan crude was struck by gale force winds off the Canadian west coast, near the Port Charlotte Islands. A crewman was swept down the length of the deck, sustaining fractures around his knee, in his arms and a broken jaw. A ship-to-shore link-up to San Francisco saved his leg, if not his life.

Every year from April to October, baseball-crazed fans gather each day at the Lucky Seven restaurant and bar in Santo Domingo in the Dominican Republic. There they sit transfixed by rows of television sets playing as many as six games simultaneously, broadcast from major league parks in the United States and Canada.

The common thread that links these stories and the global communications system we all take for granted is COMSAT. The amazing story of how COMSAT changed the world is inside this book.

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