LIVE
VIA SATELLITE

The Story of COMSAT and the Technology that Changed World Communication

By Anthony Michael Tedeschi
Introduction by Arthur C. Clarke

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Library of Congress Cataloging-in-Publication Data
Tedeschi, Anthony Michael, 1941–
Live via satellite.

Includes index.
1. Artificial satellites in telecommunications—United States. 2. Artificial satellites in telecommunication. I. Title.
HE9721.U5T43 1989 384.5'1 88-8003
ISBN 0-87491-922-3

Art Direction and book design by Kathleen K. Cunningham

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This book is dedicated to
Bob Hunter
and
Joe Scott,
professional colleagues,
good friends.

Foreword

(The following is adapted from an essay entitled "A Short Pre-History of Comsats Or: How I Lost a Billion Dollars in My Spare Time," which appeared in "Voices From The Sky," an anthology of essays and stories by Arthur C. Clarke, published by Harper & Row, New York, 1961.)

It is with somewhat mixed feelings that I can claim to have originated one of the most commercially valuable ideas of the twentieth century, and to have sold it for just $40. This cautionary tale begins in May 1945, when I was a flight lieutenant in the Royal Air Force, stationed a few miles from Stratford on Avon. Here I was peacefully engaged—the whole of my war was a very peaceful one—in training airmen to maintain the Ground Controlled Approach radar gear used to talk down aircraft in conditions of bad visibility. Though this work was fascinating (and has since formed the background of my novel "Glide Path") it left me plenty of time to think about space flight, my chief interest since I joined the British Interplanetary Society in 1935.

As a serving officer, working with highly classified equipment and bound by the Official Secrets Act, I could not submit technical papers for publication until they had been passed by a reviewing board at the Air Ministry. I would give a good deal to know what it thought when, in July 1945, it received my epic, which I had boldly entitled "The Future of World Communications." Perhaps they thought it was harmless nonsense; anyway, they gave their approval in a suspiciously short period of time. I then sent the paper to the journal *Wireless World*, which published it in its October 1945 issue under the title "Extraterrestrial Relays."

The paper ran to four pages and four diagrams, and though most of it is quite understandable by those not versed in electronics, I will summarize its main points here in nontechnical terms.

It opened with a short discussion of the problem of long-range radio and TV, pointing out that, for the latter, expensive coaxial microwave cables or relay links would be necessary, and that these could never provide transoceanic services. (In 1945, of course, no such links existed even on land, but it was obvious that they would soon be built.) Then, rather gingerly ("Many may consider the solution too farfetched to be taken very seriously . . .") I introduced the reader to the idea of artificial satellites, explaining that if a rocket could reach a speed of five miles a second it would never fall down, but could continue to circle the earth indefinitely like a second moon. This was a pretty startling idea for 1945; who could have guessed that, within 15 years, the average person would be unable to remember how many moons the earth possessed at any given moment?

The article then pointed out that, although a satellite could be established at any altitude, so long as it was clear of the atmosphere, the most interesting and valuable orbit was at a height of 22,000 miles. At this elevation, a satellite would take exactly one day to revolve around the earth; therefore, if it was placed above the equator, it would appear to stay fixed in the sky. Unlike all other heavenly bodies, it would neither rise nor set.

Perhaps I should explain that, so far, there was nothing original in all this. It might be unfamiliar to most of my readers, but it was elementary to anyone interested in space flight. Artificial satellites had been discussed in the literature of astronautics for almost half a century, as observatories and refueling bases for outward-bound spacecraft.

"Using material ferried up by rockets," I continued, "it would be possible to construct a 'space station' in such an orbit. The station would be provided with living quarters, laboratories and everything needed for the comfort of its crew, who would be relieved and provisioned by a regular rocket service. . . . It could be provided with receiving and transmitting equipment, and could act as a repeater to relay transmissions between any two points on the hemisphere beneath. . . ."

Since a single station would only provide coverage to half the globe, I suggested that three "should be arranged equi-distantly around the earth, and the following longitudes appear to be suitable: 30 E—Africa and Europe; 150 E—China and Oceania; 90 W—the Americas." Then followed a calculation of the energy required for such a service, in which I arrived at the somewhat optimistic answer that a worldwide FM system would need no more power than the BBC's London TV transmitter.

All the electrical energy needed to run the relay stations could come from the sun. Except for very short periods round the equinoxes, when they would dip briefly into the shadow of earth, they would be in continuous daylight, and would intercept a flood of radiation which could be used to operate a heat engine coupled to an electric generator. I also remarked that "thermoelectric and photoelectric developments may make it possible to utilize the solar energy more directly." This is exactly what has happened; the solar cell, invented at the Bell Telephone Laboratories a few years later, now powers almost all satellites and space probes.

This, in brief outline, is the ground covered by my 1945 paper, and subsequent events have confirmed all its main details. Because of rocket payload limitations, the first communications satellites (Score, Courier, Telstar, Relay) were all launched into orbits quite close to the earth; the first truly stationary or synchronous TV satellite, Syncom III, was launched on August 19, 1964, just in time for the Tokyo Olympics.

This event, incidentally, is a good example of the perils that beset a prophet. In October 1961, while moderating a panel discussion at the American Rocket Society's "Space Flight Report to the Nation," I had mentioned that the 1964 Olympics would be a good target to shoot for with a synchronous satellite. (I cannot claim credit for the idea, which I'd picked up in general discussions a few days earlier.) Dr. William Pickering, director of the Jet Propulsion Laboratory, was in front row of my audience, and he was so tickled with the suggestion that he passed it on to (then) Vice President Johnson, speaker at the society's banquet the next evening. The vice president in turn thought it was such a good idea that he departed from his prepared speech to include it; so when "Profiles of the Future" was published in 1962, I felt confident enough to predict that most large cities would carry live transmissions from Tokyo in 1964.

Another fact which I did not foresee in 1945, though I make no apology for it, was that developments in electronics would make unmanned communications satellites possible long before there were any permanent manned space stations. I envisaged my "extraterrestrial relays" as fairly large structures with their own maintenance and operating crews, but miniaturization and, above all, the invention of the transistor, made it possible for tiny robots to do the work of inhabited space stations. Nevertheless, space communications may not be wholly reliable until we can have men on the spot; a troubleshooter who knows how to replace a component costing a few cents can put a multi-million dollar satellite back on the air. There are quite a few dead space vehicles in orbit that could be fixed by a screwdriver and a good mechanic, but are now so much junk costing many times their weight in gold.

During the late '40s and early '50s I publicized the idea of communications satellites fairly extensively in books and articles; the synchronous satellite network formed one of the end plates of "The Exploration of Space" (1951), and the Book-of-the-Month-Club edition in 1952 must have introduced the concept to a wide public. I also plugged comsats in my first novel, "Prelude to Space" (1950), and by the mid-'50s everyone seriously interested in space travel must have been aware of their potential, though probably few knew where the idea originated.

Can I, indeed, claim that it originated with me, or did I pick up the suggestion from somewhere else? My good friend Dr. John Pierce, director of communications research at the Bell Telephone Laboratories, has reminded me of a series of stories that appeared in "Astounding Science Fiction" during 1942 and 1943. These tales, written by George O. Smith as a relaxation while developing the radar proximity fuse, concerned the adventures of a group of scientists on an artificial planet known as Venus Equilateral, who purpose was to serve as a relay station between earth and Venus when direct radio communication was blocked by the sun.

Thanks to the generosity of Willy Ley, who kept me supplied with Astoundings throughout the war, I had read and enjoyed these stories, and it is quite possible that they had an unconscious influence on my thinking.

In any event (until *Pravda* trumps me) I think I can claim priority for the first detailed, specific technical exposition of the global comsat system, with particular reference to snychronous orbits, and the question which frequently nags me is this: Should I have published such a multi-billion dollar idea in the open literature? Should I have taken any steps to obtain more than the $40 (a fair price at the time) which *Wireless World* paid for the article?

I've no delusions on one point; if I'd not published in 1945, someone else would have done so by 1950 at the very latest. The time was ripe and the concept was inevitable; it was certainly bobbing around in the back of many ingenious minds.

The idea of patenting the concept never occurred to me, and my excuse for this is sheer lack of imagination. 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.

I now know that, in all probability, I could not have patented the idea in 1945 even if I had made the effort. A lawyer friend, who also tries to earn an honest living writing science fiction, looked into the matter and wrote up his conclusions in a story-article "The Lagging Profession" (originally published in *Analog*, January 1951, later reprinted in the *Sixth Annual of the Year's Best SF*)!

As far as I can understand the legal mind, and the labyrinthine intricacies of patent law, I gather from my friend Leonard Lockhard's thesis that (a) I couldn't have patented comsats in 1945; (b) if I had succeeded, the patent would later have been declared invalid, and (c) if it had been valid, it would have been worthless. It is fatal to be too far ahead of your time, and nowadays, "too far" can be about five years.

Even if I had slipped a patent past the examiners in 1945, there is another poignant aspect of the situation. The life of a patent is 17 years; so it would have expired just as the Communications Satellite Corporation was set up.

Yet I am quite sure that there were all sorts of loopholes that I might have exploited if I had been a better businessman and if I had realized just how quickly astronautics was going to get off the ground. Perhaps I could have registered a few trademarks and otherwise made an expensive nuisance of myself, to intercept a few of the billions of dollars that would soon be invested in the sky.

Sometimes, especially toward the end of the financial year, I like to imagine what I could do with even a minute royalty on the communications satellites' telephone, TV and radio traffic. It would have been pleasant, in my old age, to have gone cruising among the asteroids in my private spaceyacht. But there are other and more realistic moments when I think of all the soap operas and laxative commercials that bathe the earth from pole to pole, and a far different future begins to take shape in my mind.

Perhaps I shall spend the rest of my life trying to prove that communications satellites were invented, not by Arthur C. Clarke, but by another man of the same name.

Preface

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.

Ten days later, Dirk Van Der Loo, a lab technician in the Washington, D.C., area dialed his mother in The Netherlands, to wish her a Merry Christmas. Within seconds the phone was ringing at the family's home on the opposite side of the Atlantic.

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 of Canada, near the Port Charlotte Islands. A crewman was swept down the length of the deck by heavy seas and sustained compound fractures above and below the left knee, two broken arms and a broken jaw. A ship-to-shore link-up allowed medical crewmen aboard the tanker to gain life-saving advice from the Public Health Services Hospital in San Francisco. Doctors later credited the long-distance collaboration among medical personnel with saving the crewman's 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, where they sit, transfixed by rows of television sets playing as many as six games simultaneously, broadcast from major league baseball parks in the United States and Canada.

The common thread in each of these vignettes lies at the end of Shawnee Lane in Clarksburg, Maryland. It is COMSAT Laboratories, the research and development arm of the Communications Satellite Corporation, where during the last two decades, scientists, engineers, and technicians have changed the way the world communicates.

It is an odd trip, the thirty-five miles from nearby Washington, D.C., to the labs. All but the final mile is by superhighway, past the Washington area's version of Silicon Valley. Modern buildings housing corporations with names like Quantex, Spectrum, and MA/COM line both sides of Route 270, punctuated by the requisite golf course, business-traveler hotels, and fast-food restaurants. But a change takes place a few miles from COMSAT Labs. Here the road dissolves into a rural amalgam of hay bales, run-down service stations, weathered clapboard houses, and eerie Victorian mansions. When they decided to build COMSAT Labs in the late 1960s, they opted for a campus atmosphere. That would be more conducive to the kind of thinking required to solve the complex problems which lay ahead for the hundreds of people who eventually would devote the better part of their waking hours to this facility.

As you pull into the parking lot of the 400,000-square-foot complex, you are immediately confronted with a visual synopsis of what goes on here. Large antennas of various sizes and shapes point skyward. A display area near the main entrance contains models of each generation of communications satellite. There is an overall sense of space and light at the 200-acre site.

"I remember talking to the architects," said Wilbur L. Pritchard, the first director of the Labs. "I said let's get a laboratory in which everyone has a window. And let's make all the offices the same size. You don't often get a chance to have influence over the little irritants."

COMSAT Labs is a facility of long, open corridors and individual test labs crammed with equipment, vacuum chambers with sinister-looking foam spikes and offices sporting an array of personal computers. It is meeting rooms, screening rooms, and dust-free "clean" rooms. And it is people—bright, dedicated people, with an incredible command of their particular subject matter, the courage of their convictions, and the stubbornness to persevere when the faint of heart would have thrown in the towel. But more than anything COMSAT Labs is people with the love of a challenge, brought together by the excitement of a chance to break new ground and the understanding that if you did solve the unsolvable, your ideas would be translated into reality, become part of the hardware, the software, the systems—the solution . . . and you would have a direct effect on people's lives.

In many ways, the story of COMSAT Labs involves the conquest of the little irritants and in the process the reshaping of the big picture—a macro view of the world. While the man in the street may not be familiar with developments such as time division multiple access, single channel per carrier, the echo canceller, the hydrogen-nickel oxide battery, or the multi-beam antenna, during the period since the launch of the first commercial communications satellite in 1965, the world has become familiar with television live via satellite, direct-dial telephone service to the most obscure corners of the earth, lightning-fast data transmissions to and from anywhere, link-ups to ships at sea or between conferences in corporate board rooms.

On August 31, 1962, President John F. Kennedy signed the Communications Satellite Act, which said in part that it would be the policy of the United States "to establish, in conjunction and in cooperation with other countries . . . a commercial communications satellite system . . . which will contribute to world peace and understanding."

This is the story of the place where the gauntlet of that challenge was taken up and the world was altered in the process.

Acknowledgements

In the process of gathering research, conducting interviews and assembling other assorted materials for this manuscript, I have had to call upon the assistance of a great number of people, most of whom are acknowledged in the pages that follow. I would like to thank in particular, John V. Evans, who as director of COMSAT Labs during the period I was writing the manuscript, provided general guidance and invaluably lucid explanations when the going got a bit obscure. Geoffrey Hyde, also of COMSAT Labs, provided a great deal of assistance, especially in helping to track down former or retired members of the Labs staff. Nina Seavey was a great help in all elements of the research effort, particularly the historical aspects. Richard McGraw, vice president of public affairs at COMSAT headquarters, was invaluable in arranging interviews with members of the executive staff of the corporation.

Anthony Michael Tedeschi
Roslyn, NY
Spring 1989

CHAPTER ONE

Taking on the Challenge

In late November of 1962, Dr. Joseph Charyk was awakened in the middle of the night by a phone call. Charyk, who was undersecretary of the Air Force in the Kennedy administration, had indicated to his superiors that he intended to implement his oft-delayed plan to return to private life early in the coming year. The caller was Philip L. Graham, of the influential *Washington Post* publishing family, who was on special assignment for the administration. He'd just been advised of Dr. Charyk's plans, and being an impulsive man, Graham decided he had to talk to the undersecretary immediately about a top position with a company being formed to put in place an international communications satellite system. Graham was chairman of the board of incorporators of the Communications Satellite Corporation (COMSAT). Undersecretaries of military departments don't take phone calls in the middle of the night lightly, so it took Dr. Charyk a few moments to ascertain that this was not an emergency.

Graham got right to the point. Charyk had discussed his upcoming departure with Secretary of Defense Robert McNamara and Deputy Secretary Roswell Gilpatric, and Gilpatric had suggested, among other things, that Graham was looking for people to staff key positions at COMSAT. Gilpatric had spoken to Graham about Charyk's potential availability and Graham was interested in pursuing the matter. Graham asked Dr. Charyk if they could meet as soon as possible. Charyk said he would try to meet Graham in Los Angeles, where Graham was on a business trip. He made arrangements to fly there late the next day and the following day the two men had breakfast together at the Beverly Hills Hotel. After the meal the two took a walk around the grounds.

"He [Graham] said [the board of incorporators] had the responsibility to set in motion this new corporation," Charyk explained, "and that he thought it was going to be one of the greatest things that has ever happened. Its impact on the world was going to be profound, because it was going to provide a linkage between all of the countries of the world and would dramatically change the nature of the world."

Graham said he'd been impressed with Charyk's work at the Pentagon—where he had been in charge of key Department of Defense satellite programs. Graham told the undersecretary that he would be an excellent choice for chief operating officer. They would have to find a chief executive officer as well, Graham said, but he indicated that would be an easier task.

Charyk said he'd think about it and went back to Washington, but Graham, a persistent man, didn't allow him much peace. After a succession of phone calls, meetings, even trips abroad, Charyk accepted the board's offer. Then he played a hand in helping to bring in Leo Welch, a former chief executive officer of Standard Oil of New Jersey (later known as Exxon), as the first chairman of the board and chief executive officer.

On February 1, 1963, COMSAT was born, officially, with the issuance of its certificate of incorporation by the District of Columbia. A little over a month later, on March 10, the board of directors made the elections of Welch and Charyk official, and the enormous task of putting together the new company and fulfilling its charter of a global communications satellite system was begun.

One of the early concerns involved AT&T. Although the giant communications company, which had dominated the industry for so many years, was represented on the COMSAT board of directors, there were questions about whether AT&T, with its vested interest in transoceanic cables, would merely pay lip service to the concept of a global satellite communications network, or whether Ma Bell would put its substantial clout behind the new venture. On December 10, 1963, Leo Welch made public a letter he had received from James Dingman, executive vice president of AT&T, which Welch felt spoke to this concern, and the answer was an endorsement by AT&T. Dingman said, among other things, "The point can be stressed that we see a place, and a need, for both cable and satellite communications." He emphasized that if a satellite was launched successfully and made operational by early 1967, AT&T would prefer to use circuits on the satellite rather than place additional cables beneath the ocean, although he added that the appropriate communications agencies in other countries would have to be willing to use the satellite as well. Dingman said, "Diversity of routes and facility types is the best method of assuring service integrity and that is one of the major reasons for our interest in utilizing satellite circuits for overseas service as soon as possible. The high capacity cable will have many important applications but we see no basic reason why it should prevent satellite usage from reaching economical and profitable levels."

It was an important vote of confidence. The support of AT&T in general, and Dingman specifically, would serve COMSAT well at other critical points in COMSAT's early history.

One of the early priorities for the new company was the creation of an international communications consortium and that became the full-time job of John A. Johnson, who joined COMSAT in April 1964 as vice president, international. Johnson had been general counsel of NASA since its founding in 1958.

"He had the assignment from me to bring the message of satellite communications to the rest of the world," Charyk said, "to open a dialogue with countries of all stripes for the purpose of telling them about the promise of satellites, and encouraging their participation."

Johnson understood that even the earliest negotiations would set the tone for how the entire international environment would be structured. "My job was to help create the international organizational mechanism which would enable COMSAT to carry out its statutory mission to be the U.S. participant in the establishment and operation of a global commercial communications satellite system," he said. "We agreed from the outset that what was necessary was to look at this thing from a global point of view, with a satellite system in which ownership would be shared in some yet-to-be-defined manner. The definition of that kind of ownership, in its final form, took the better part of a decade, but the concept was developed quite quickly and we then had a series of negotiations with the Europeans, Japan, Canada, and Australia."

The first critical meeting took place in Karlsruhe, West Germany, in December 1963. It was a meeting of the European Conference of Post and Telecommunications Administrations (CEPT). Many of the Europeans had expressed a desire for caution in what they saw as eagerness by the U.S. to move too rapidly into space. While they were intensely interested in the new COMSAT entity, they were also skeptical of it and anxious to know the views of AT&T relative to satellite communications and the new company.

"We made it clear to the Europeans that COMSAT was going ahead with the construction of the first commercial communications satellite and that we were doing this without awaiting any further progress in the actual conclusion of international agreements," Johnson said.

Once again, it was a forthright and unequivocal statement by AT&T's Dingman that held sway.

"At&T's support of our venture and their intention to make use of satellite communications was very significant in conveying a sense of seriousness and urgency to all the [communications] administrations of Europe," Johnson said.

While the Europeans were getting their ducks in a row, and agreeing to speak with one voice despite any differences among them, COMSAT began lining up allies in the Canadians, Australians, and Japanese—the only countries outside of Europe with serious interests in satellite communications at the time.

"We could not tolerate the situation where we would have a stand-off," Charyk said, "with the United States on the one hand and Europe acting as a bloc."

Ultimately it was this alliance with Canada, Australia and Japan that broke any deadlock, because it didn't permit the Europeans, acting as a unit, to frustrate action. But the real questions centered around the terms and conditions of the international agreement. How would decisions be made? How could decisions be frustrated? What were the voting rights? What were the financial terms of the agreement?

"We were very much concerned about the economics of the thing," Charyk said. "We were not going to enter into any agreement where the terms and conditions would prevent the enterprise from operating in a sensible, business-like fashion."

There was also an effort to bring the Soviet Union into the fold. In the spring of 1964, representatives of COMSAT and the U.S. government met with a Soviet delegation in Geneva. The talks, however, were not successful.

John Johnson recalled the session ending with the Soviet delegate reading "a harsh statement which had obviously been produced in Moscow and which had little relevance to our presentations. He said that the whole effort was premature, the implication being that the technology was not yet ready for application to a global system. In addition, he blasted our plans as being a means of extending a capitalistic imperialism and monopoly around the world."

Then an odd thing happened. The Russian put down the document he'd been reading and changed his tone entirely.

"He expressed, in very gracious words his appreciation for all they had heard," Johnson said, "and said he hoped that at some future time, we could renew the experience."

At a meeting in London during late July 1964, final arrangements for the participation quotas in the new international body were hammered out, the meeting ending at two o'clock in the morning in the suite of COMSAT CEO Welch. The negotiating had brought results. In announcing a meeting of the minds, Welch described the agreement as a "very important chapter" in the development of a global space communications system.

The *New York Times* reported, "The evolution, in the opinion of [COMSAT] corporation and Administration officials, has taken place with remarkable rapidity and smoothness over the last six months."

On August 20, 1964, the International Telecommunications Satellite Consortium (INTELSAT) was created under international agreements for interim arrangements. COMSAT, which had a 61 percent investment in the new consortium, was named the manager. The European investment quota was 30.5 percent (exactly half of COMSAT's) and the remaining 8.5 percent was divided up among Canada, Japan and Australia.

"... The INTELSAT Agreement and the INTELSAT Special Agreement, which were signed into effect on an interim basis ... reflected a compromise between divergent national viewpoints," wrote former INTELSAT Director General Santiago Astrain in "The INTELSAT Global Satellite System." "... The Agreements were structured to allow participation either by governments or private enterprises designated by their governments. INTELSAT was created on the basis of commercial operating procedures, but, just as significantly, it was premised on the principle that all charges would be nondiscriminatory and the same charges would apply to all users for the same service, regardless of their traffic requirements."

The agreements were then opened up to other countries that might want to join. It was only a matter of weeks before Israel sent word that it wanted in.

"The State Department put out a press release announcing that Israel had signed the agreements," Johnson said, "and within twenty-four hours I had a call from the Washington office of the League of Arab States. They wanted to know what this new organization was all about. And so we had some very interesting meetings with representatives of that office and a number of Arab nations with the result that the entire group of Arab states very quickly came into INTELSAT, bringing its members to over thirty."

Within a decade the number grew to more than a hundred.

While all this negotiating was going on at the international level, COMSAT was preparing frantically to float its first issue of common stock.

"The company hasn't taken in a nickel yet, probably won't turn a profit for years, and doesn't even have a product to show potential customers," began the lead-in to the *Newsweek* cover story, March 16, 1964. "But with all those drawbacks, investors will be standing in line when $200 million worth of Communications Satellite Corp. stock is offered to the public."

While the company was leaning toward a satellite design that would involve high-orbiting satellites synchronized to the rotation of earth, a need for $200 million dollars was decided upon to provide enough funds in the event that this geosynchronous concept did not prove viable. The alternative approach involved a medium-altitude system, requiring two dozen or more satellites orbiting at once, plus sophisticated earth stations that could track and communicate with the satellites as they crossed the sky—a far more expensive proposition than the geosynchronous approach.

"We had to raise enough money so that if we were wrong, we could still get to the point where we could demonstrate something," Charyk said. "If we were going to go the medium-altitude route, $200 million was not nearly enough. But, we thought that $200 million would at least be enough to enable us to demonstrate something. We felt that it was essential that you raise enough money so that you could actually demonstrate the viability of a system before you had to go back for additional dollars."

Two months before the public offering, the *New York Times* reported brokers predicting so great a demand for the stock that many would entertain requests to buy only from favored customers. The stock offering was to be the largest since the Ford Motor Company had gone public eight years before. It was inspiring a tremendous amount of grassroots interest.

In a random sampling, the *Wall Street Journal* found, "a Chicago housewife buying it because it's 'the patriotic duty of every American.' ... a Dallas bank employee ordered some because it's 'something you can leave for your kids and really give them something.' ... a San Francisco radiator repairman placed an order because 'it might pay off and I like to help and support pioneers anyway ...' "

Of the 10 million shares of stock in the original issue, half were offered to authorized communications carriers, the other half to the general public. The results of the carrier offering were made public on May 28, five days prior to the public half of the offering. The carrier issue was a huge success. More than 160 communications companies, from the giants of the industry to much smaller firms, had oversubscribed the issue. At $20 per share, $100 million was raised, with AT&T emerging as the largest shareholder at $58 million. ITT bought $21 million, GTE $7 million, RCA $5 million.

The public offering was no less a success. Sold via hundreds of brokers across the country, the stock came on the market at $20 per share and rose to $27 within minutes. While AT&T had emerged as the largest stockholder, Wall Street analysts estimated that the COMSAT family included several hundred thousand shareholders.

"Quick profits were a motive for some people," the *New York Times* reported. "A man who could garner forty shares at the offering price, might have sold his stock within the first half-hour of trading and realized a short-term profit of around $250 on an $800 investment."

While the stock issue held the headlines on the business pages and the creation of the international consortium was the subject of a score of major articles in domestic and international publications, the real story of satellite communications was beginning in the laboratories and manufacturing facilities that would put the hardware in place, which in turn would make commercial satellite communications a reality. And that story begins with a tiny metal barrel about the size of an oil drum and an experiment that would chart the course for the future of communications satellites in space.

CHAPTER TWO

The Early Bird Captures the Imagination

> The greatest innovations are often simple in principle. All Early Bird does in essence is pick up a microwave signal sent from one ground station and relay it to another a long distance away. But the potential effect could be as far-reaching as the invention of the telegraph.
>
> *Fortune*, October 1965.

In the late afternoon of April 5, 1965, a young engineer named Simon Bennett stood atop the gantry alongside a Thor Delta rocket, more than ten stories above the launching pad at Cape Kennedy, Florida. Bennett and his team were performing the final tests before the launching of an experimental satellite that would play a pivotal role in world communications. The satellite, built by Hughes Aircraft Company, was known officially as HS-303, but it had been nicknamed "Early Bird" by an information officer in a shoot-from-the-hip answer to a reporter's question. The name would stick and become part of satellite lexicon.

Among other things, Early Bird was designed to provide answers to some critical questions about satellite communications. It weighed only eighty-five pounds, which was about all that could be lifted into high orbit by the rocket power of the day. And this satellite was bound for a high orbit indeed—22,300 miles above the earth, the altitude at which a satellite assumes a geosynchronous orbit—i.e., a stationary position relative to the revolving earth. The altitude was such that the Delta rocket had to be augmented with three solid-fuel boosters to provide the additional thrust needed to put the satellite into transfer orbit, from which it would be boosted into geosynchronous orbit.

The crew members testing the satellite on this particular afternoon in early spring were employees of Communications Satellite Corporation, or COMSAT, a brand-new corporation spawned by the Communications Satellite Act of 1962. They were performing tests on the microwave radio systems aboard Early Bird to make sure they would work as advertised and adjusting the on-board antenna.

"This whole launch thing was very new to me," Bennett said, "and a tremendous challenge. I had never been to a launch site before."

The crew wore special clothes, overshoes, and antistatic straps, because with the solid-fuel booster rockets already in place for the launch scheduled for the following morning, they didn't want to risk a spark.

April is part of the so-called shoulder season for the resort areas of Florida and the Caribbean. It is that time of year between winter and summer when visitors are fewest because of the prevalent thunderstorms that spring up. And at this particular moment, one of them sprung.

As he saw the dense, black clouds rolling in, Bennett ordered his crew down from the gantry. "You didn't really know if lightning could do something," he said.

There was a small problem. The elevator was overloaded with test equipment, so it wouldn't move.

"These elevators were external to the gantry," Bennett explained, "and they didn't always run, so *we* had to run all the way down."

For the scientists and engineers of COMSAT, it seemed they were always doing things at a dead run. In this case the lightning did nothing, the tests continued, and the systems performed perfectly. The satellite was pronounced ready.

A few months earlier, President Lyndon Johnson had called the concept of commercial communications satellites "sky trails to progress in commerce, business, trade and in relationships and understanding among peoples. . . . The objectives of the United States are to provide orbital messengers, not only of words, speech and pictures, but of thought and hope."

At the time, the only means of transoceanic communications were undersea telephone cables, completed across the Atlantic in 1956 and the Pacific in 1964. But transoceanic telephone calls followed odd routings, often dictated by present or prior political allegiances. For example, a call between Senegal and Nigeria, two African neighbors, was routed through France and the United Kingdom, two colonial powers in Africa. A call between American Samoa and Tahiti was made via Oakland, California, hundreds of miles away from either.

The alternative to cables was microwave radio, but such microwave transmissions would not work over great distances, because radio waves travel in a straight line. They do not bend to follow the curvature of the earth. While Guglielmo Marconi had managed a transoceanic telegraphy signal in 1901, the success of the experiment was dependent upon the ability of the ionized regions of the earth's atmosphere to reflect long-wave radio signals. While this did usher in an era of medium-frequency radio communications, the performance was not reliable and consistent, good quality telephone services not achievable. To send an effective microwave signal across an ocean, you would need relay towers at thirty-mile intervals, or a single tower almost 500 miles high, positioned at the halfway point. Obviously, neither solution is feasible, much less practical.

With the advent of the space age, the idea of the communications satellite was born. Although there were a growing number of people who could see the value of a communications satellite system, there were some very basic disagreements as to how to implement such a system. The most hotly contested issue involved the choice between a geosynchronous orbit versus a system of lower-orbiting—or medium-altitude—satellites. AT&T had already put the much-heralded TELSTAR into medium orbit. But in order to achieve continuous communications using satellites like TELSTAR, you would need a series of twenty-five or thirty satellites, because in anything but a geosynchronous orbit, the satellite and the earth are not rotating in unison. Therefore, satellites in subsynchronous orbit are only "visible" to a pair of communications stations for a short period of time—the time after the satellite "rises" over the horizon and before it "sets."

Using medium-altitude satellites creates further complications. When a medium-orbiting satellite begins to set, as seen by a pair of earth stations that are communicating with each other, it is necessary to reroute traffic quickly to the next satellite as it rises above the horizon to avoid disrupting communications. To do that requires a suitable period of overlap between the outgoing and incoming satellites. This, in turn, requires synchronized tracking by pairs of antennas at each earth station to set up the "hand-over" without a period of outage—one antenna tracks the final moments of the first satellite, while the second picks up the first moments of the incoming satellite. Forecasted costs for redundancies such as these were enormous.

On the other hand, to establish a global communications system via geosynchronous orbit would require only three satellites: one each above the Atlantic, Pacific, and Indian oceans. There were difficult problems to be solved, but the simplicity of the concept and the potential cost savings were attractive. Geosynchronous orbit began to win proponents.

The idea of the geosynchronous orbit first gained attention in a memorandum written by a British technical officer at the close of World War II. That officer, Arthur C. Clarke, who later achieved worldwide celebrity status as a science fiction writer, explored the idea in a memorandum titled, "The Space Station: Its Radio Applications." He expanded upon the idea in October 1945, in an article for *Wireless World* magazine. Clarke maintained a lifelong interest in things scientific, particularly those developments which opened the heavens and expanded mankind's reach into space. He was chairman of the British Interplanetary Society in the late 1940s and early 1950s and won numerous awards for his scientific writing—in addition to his highly successful novels, including the *2001, 2010,* and *2061* series.

As for his idea about the geosynchronous-orbiting satellite, while he knew the idea was sound, he felt it would not be put to any practical use in his lifetime because he didn't think the necessary rocket power or technology would be developed that quickly.

However, it would be less than twenty years before the concept was demonstrated, in 1964, a year before Early Bird. Live television transmission via satellite had been the subject of a successful experiment during the Olympic Games in Tokyo that year, when COMSAT coordinated the arrangements to broadcast the games, using an orbiting geosynchronous satellite called SYNCOM III, built for NASA by the Hughes Aircraft Company. That satellite and its predecessor, SYNCOM II, were the first to be placed in geosynchronous orbit, after a failure of the first satellite in the series. They were spin-stabilized satellites, a concept developed by two young Hughes engineers, Harold A. Rosen and Donal Williams. Rosen went on to become a valued technical adviser to INTELSAT and one of the most respected designers in the history of communications satellites.

In announcing plans to broadcast the games, COMSAT said the special experimental endeavor would be conducted on a nonprofit basis after a request from the U.S. State Department, which felt that it would be "in the national interest that this project be undertaken."

The live TV feed to the United States was via a U.S. Navy earth station at Point Mugu, California, modified by COMSAT specifically for the telecast. On their end, the Japanese built a special earth station at Kashima, fifty miles northeast of Tokyo. The TV feed would go via microwave link from Tokyo to Kashima, then up to the satellite over the Pacific, back down to Point Mugu, then via microwave to the Los Angeles test board in the Bell System for distribution to U.S. television and other participants in the project. The audio portion of the transmission was sent via undersea cable, since the image transmission required the full capacity of SYNCOM III.

Scientists and engineers at COMSAT had a number of concerns about the experiment, the principal one being that SYNCOM III had not been designed for television, so the company made it clear in its announcements that "the quality will not be as good as that of the satellites in the global commercial communications satellite system. The global commercial communications satellites will be far more powerful with much greater bandwidth to accommodate telephone, telegraph, facsimile, data transmission or TV signals of internationally accepted standards."

They need not have worried so much. Jack Gould, writing in the *New York Times,* called the telecast of the opening ceremonies, "a triumph of electronic technology that was almost breathtaking in its implications for global communications . . . in every way markedly superior to the previous international TV experiments by TELSTAR satellites over the Atlantic Ocean." The *Times* reviewer also lauded the quality of the images and the fact that the telecasts lasted longer than those done previously via TELSTAR.

Despite the success of the Olympics experiment, however, important questions remained unanswered, the two most critical of which were: What do you do about the delay and the echo in telephone conversations which were expected to provide the bulk of the traffic in satellite communications? And, could you get the necessary lifetime out of a high-altitude satellite?

As for the question of life span, scientists would try to simulate conditions of heat and cold in a deep vacuum and experiment with the type and amount of propellants needed to make ongoing adjustments of the satellite's position, but those questions could be answered only over time. The problems of delay and echo were more immediate.

With a satellite at 22,300 miles above the earth, the human voice, carried on a microwave radio broadcast at the speed of light (186,000 miles per second), would take a quarter of a second to travel from the speaker to the distant listener. During the process, the transformers that combine the send and receive circuits at all local telephone exchanges generated an echo of the speaker's voice. For the relatively short distances of most earthbound conversations, the echo was received so quickly that it was not noticeable. But via satellite communication, the echo would make the return trip to the party who was speaking about a half-second after he or she had spoken. It would make a conversation all but impossible. The problem, far less noticeable in long-distance terrestrial telephone conversations, was dealt with by using echo suppressors which open the leg of the circuit that is not active, thereby cutting off the echo. But these devices often operated imperfectly or made for choppy conversations over satellite circuits because of the long response time.

The debate raged. "If a medium-altitude system were built, with its twenty-five to thirty relatively simple satellites, it would be prudent to first launch a prototype model prior to manufacturing the total quantity," said Sydney Metzger, first manager of COMSAT's engineering division. "That satellite, even if successful, would prove out the design, but would be of no operational value until most of the others were launched. If we launched a single synchronous satellite as an experiment to test the effects of time delay and echo . . . and the satellite design as a whole was successful, it could be used operationally without launching additional satellites."

On March 4, 1964, COMSAT announced that it had made a decision to go geosynchronous and test the echo via the existing system of echo suppressors. It applied to the Federal Communications Commission for authority to "construct and place in orbit an experimental-operational synchronous satellite in the spring of 1965 . . . with the capability for up to 240 high-quality telephone voice circuits, or alternatively for message traffic, facsimile, or black-and-white television . . . a lightweight spacecraft with a minimum operational expectancy of one year, but with on-board spacecraft control aimed to keep it on station for three years."

The company, however, recognized that the subject of orbit would be a matter of experimentation, so as late as ten months before the launch, COMSAT was keeping an open mind on the matter. Despite the fact that Hughes Aircraft had been awarded a contract to build a geosynchronous satellite, COMSAT announced on June 8, 1964, that it had awarded engineering design studies to AT&T and RCA for a random-orbit, medium-altitude design; and Thompson Ramo Wooldridge and ITT for a phased-orbit, medium-altitude design.

Two weeks later, on June 22, COMSAT announced that it had reached agreement with AT&T to modify the huge cornucopia-shaped, cassegrain horn antenna at Andover, Maine, to enable the antenna to work with synchronous satellites. Services necessary for the operation of the Andover station would continue to be provided by AT&T. The earth segments of the experiment would include Andover and European stations at Goonhilly Downs in the United Kingdom; Pleumeur-Bodou, France; Raisting, West Germany; and Fucino, Italy.

Two days before Christmas 1964, COMSAT announced a contract with NASA to launch the new satellite, now dubbed "Early Bird." NASA was to provide thrust-augmented, Delta-type vehicles and to be responsible for preparations and the conduct of the launch and the injection of the satellite into transfer orbit. COMSAT agreed to pay on the order of $3.5 million for NASA's services, whether or not the launch were successful. The launch was targeted for the latter part of March.

Emotions ran high as the launch date approached.

"If this thing didn't work, the repercussions could be terribly profound," said COMSAT President Joseph Charyk, "not only nationally, but internationally—since now you'd had other countries who had been talked into participating in this thing on the basis that we could do it. Getting the satellite into synchronous orbit, then putting voice traffic through it, was a terribly important step in the development of the whole concept. A failure would be a pretty solid negative blow. So there was great tension."

There were other causes for tension. For example, even if the launch went without a hitch, there was concern that they would not be able to find the satellite, once it separated from the launch vehicle.

"The launch vehicles were not as accurate [as they are today]," said Robert Briskman, who was manager of telemetry tracking and control for COMSAT at the time. "That created uncertainty over exactly where and when the satellite would be first visible at Andover. Would we have enough orbital data and be able to compute it well enough that we could point this very narrow beam at Andover and find the satellite? If we didn't find it the first time, the likelihood of us ever finding it again became fairly small."

Among those who would be watching closely were members of the business community. The *Washington Post* reported, "Stock brokers expect a wide fluctuation in the price of COMSAT stock, depending upon whether the Early Bird launch succeeds or fails."

In early March, there was real cause for apprehension when transistors being used in the communications package failed repeatedly. All the transistors of the type that failed had to be replaced and the launch delayed from late March to early April. By mid-March the transistor retest was deemed satisfactory, and the satellite was shipped from Hughes's plant in California to Cape Kennedy. The launch was scheduled for April 6.

To most of the outside world, the idea of the historic experiment in space began to gain a kind of dramatic momentum. In the days immediately preceding the launch, the hottest ticket in town read:

Leo D. Welch, Chairman
and
Joseph V. Charyk, President
of
Communications Satellite Corporation
request the pleasure of your company at a
special closed circuit television viewing
of the launch of the first
Commercial Communications Satellite
"Early Bird"
Tuesday, April 6th at 5:30 p.m.
Corporation Offices
1900 L Street, N.W.
RSVP . . .

Among those accepting the invitation were Arthur C. Clarke, Vice President Hubert Humphrey, who also served as chairman of the National Space Council, and Minnesota Senator Walter Mondale.

On April 3, the COMSAT press office issued an announcement of a news briefing to take place at 4 P.M. on the launch day and invited journalists from major publications and news services, domestic and foreign. A closed-circuit, two-way TV hookup was installed that connected COMSAT headquarters with the Cape Kennedy launch site.

By 6 P.M. on April 6, VIPs and media were in place and the countdown was being monitored.

Shortly after COMSAT Chairman Welch told the fidgeting gathering, "We hope you are not going to be disappointed," the countdown was held at T minus eleven minutes when it was discovered that the automatic fueling system for the second-stage rocket engines was not functioning properly.

Switching to manual took about fifteen minutes and the countdown was resumed.

At 6:48 P.M., the thrust-assisted Thor Delta rocket carrying Early Bird sat for a moment atop a plume of flame, then lifted flawlessly off the launch pad at Cape Kennedy. The correspondent for the *London Times*, an eyewitness, described the launch: "The light was just fading and it presented an awe-inspiring sight as, illuminated by searchlights, the base of the 71-ton launcher erupted suddenly into a brilliant orange colour which soon changed to a red as the vehicle appeared to saunter lazily skywards. As it quickened its pace, it emitted a thick, whitish trail which was tinged pink as it caught the last rays of the sun."

Seventy seconds later, the three solid-fuel boosters burned out and fell away, while the first-stage engine continued to burn, pushing the tiny satellite further away from earth. Less than two minutes later, the second-stage rocket fired and within twenty seconds the nose fairings protecting Early Bird from the elements in the early phases of the launch were jettisoned. At 138 miles above the earth, the satellite began spinning, then coasted for about fifteen minutes until it separated from the third- and final-stage engine. Early Bird had assumed its elliptical transfer orbit, swooping down to within 195 miles of the earth's surface, then swinging out to its first apogee of 23,000 miles at forty-nine minutes after midnight.

After liftoff, Welch had told the group, "We will all sleep better tonight."

Humphrey broke the tension by joking, "Now we'll be able to call everybody. I don't know if this is a good thing or not. We have enough telephone calls in the office already." Then he added, "It is indeed an early bird and thank goodness it looks like an eagle."

The gathering broke up and an agonizing three-day period ensued while scientists prepared for the critical maneuver of boosting Early Bird into its synchronized orbit.

CHAPTER THREE

Achieving High Orbit

James B. Potts, COMSAT's manager of terrestrial interface, was stationed with his crew at Andover, Maine monitoring the progress of Early Bird. COMSAT had leased the big cassegrain horn antenna there from AT&T and had contracted with Bell Labs for extensive modifications so that the necessary telemetry, tracking, and control functions could be performed. The critical segments of Potts's assignment would be the three-day period from the launch until the satellite achieved geosynchronous orbit. NASA's role ended with the achievement of transfer orbit, at which point COMSAT assumed responsibility for the success or failure of a number of key operations that "could have had disastrous long-term effects," Potts explained, then added, "Maybe we weren't smart enough to be scared."

By launch time, they had pointed the big horn south toward Cape Kennedy, just above the horizon, to see if they could monitor the liftoff via VHF radio signals which would be transmitted during the launch. "We picked up the VHF signals as the launch cleared the horizon, and we knew the satellite had survived the launch," Potts said.

Early Bird's first apogee would be over the Indian Ocean, so the COMSAT team would have to wait for the second apogee to perform the first critical test, which would involve locking onto the satellite, then sending a command to turn on the microwave beacons. Instructions were to activate the command switch at Andover for two seconds. When the moment arrived, the switch was activated. There was no verification from the satellite; step one hadn't worked!

"Expectant silence turned to stunned silence," Potts said. "Did we miss something in the procedure? Had the transmitter failed?"

One of the Hughes engineers suggested that they had not executed the command for a long enough period. They tried it again. The beacons responded. There was a microwave signal—and many sighs of relief.

The firing of the apogee motor would not occur for three days and it was too much to expect the team to wait that long for something exciting to happen. They began muttering about checking out the communications package by sending up a television signal.

"Sid Metzger was the instigator," Potts said. "We had a small TV camera, something like you see in stores to monitor potential shoplifters. We also had some pictures out of the press folder—one of a bird caricature and one of an artist's rendition of Early Bird itself."

They set up a loop transmission—up to the satellite, then back down to Andover—then waited for the satellite to come within range. The loop worked. Instant exhilaration. They snapped some Polaroids of the return pictures on the TV monitor.

The *Washington Post* picked up on the story of the unscheduled, unauthorized act on the part of "overeager" engineers, but also reported on the excellent quality of the picture.

For the next three days, COMSAT engineers prepared for what would be the critical spacecraft maneuver: the boost into geosynchronous orbit. The sixth apogee was chosen for the kick into high orbit for several reasons. A firing at an earlier apogee would require additional use of precious fuel needed to make in-orbit adjustments during Early Bird's functional lifespan. A later firing would subject the solar panels to an extended exposure to potentially damaging rays as the spacecraft passed through the Van Allen belt in lower orbit. Again, this might shorten its lifespan.

On the morning of the appointed day, April 9, the control building at Andover was jammed with team members from COMSAT, Bell Labs, Western Electric, and Hughes. Anticipation and tension ran in equal measure as the satellite approached its sixth apogee. At 08:40:25, a signal was sent from the earth station at Andover and a small engine aboard the satellite fired its peroxide propellant as it reached the high point of the transfer orbit. A perfect burn kicked Early Bird into a circular path 22,300 miles above the equator. Its orbit was then synchronized with that of the earth and it was positioned at 27.5 degrees west longitude off the east coast of Brazil. It was a moment that created "a very special memory" for Jim Potts and the select few who watched it happen firsthand.

Back in Washington, COMSAT engineers monitored the goings-on from their new Control Center at 2100 L Street. Arnold W. Meyers described it as a "jack-of-all-trades facility" built for the limited capabilities projected for the early satellites. "Constructed in less than one year, the center was designed with the idea that the acquisition, handling and processing of information would have to be a largely manual rather than electronic affair," he said. "Grease pencils and sliding plexiglass panels were the methods and materials of the day . . . not video displays . . . The expertise we lacked in operating satellite systems was made up for by our enthusiasm over the opportunity to play a part in making history."

Nonetheless, the center functioned effectively, coordinating time on the satellite between earth stations in the U.S. and Canada on one side of the Atlantic, with those in the U.K., France, Germany, and Italy on the other side.

"Simplicity of operations stands out . . . as the important aspect of the Control Center," Meyers said. "The teamwork of the staff was excellent and amid the hectic pace there was no time for second-guessing and worrying."

During the week of April 15, engineers at Andover tested the satellite with TV transmissions from Andover-to-Early Bird-to-Andover and telephone tests between Andover and COMSAT headquarters in downtown Washington. Then, in preparation for live TV broadcasts in early May, engineers ran tests to align the earth station antennas in Maine and those in Europe to work with the satellite. Live transmissions were sent from Andover to Goonhilly Downs in England, Pleumeur-Bodou in France, and Raisting in Germany, while the Europeans returned test patterns and film segments.

On Sunday, May 2, broadcasters in North America and Europe pooled their resources for an inaugural, one-hour TV program, "This Is Early Bird," which was viewed by an estimated 300 million people. The following day, Monday, May 3, COMSAT made more than fourteen hours of Early Bird time available to TV stations in an effort to demonstrate the capability of satellites for use in international TV journalism. All three network morning shows took advantage of the opportunity.

NBC kicked things off during the "Today Show," from 7 to 9 A.M. with host Hugh Downs broadcasting live from London, and included segments from Paris, Rome, and Amsterdam.

CBS used the time during its "Morning News" program from 10 to 10:30 A.M. with anchor Mike Wallace and reports from correspondents in European capitals. Then from 12:30 to 2 P.M. CBS hosted a "Town Meeting of the World," a two-way roundtable discussion concerning the war in Vietnam, telecast between New York and London. Those discussing the situation were Senator Barry Goldwater and Secretary of State Dean Rusk on one side of the Atlantic and former British Prime Minister Sir Alec Douglas-Home and Foreign Secretary Michael Stewart on the other. It was the first of many telecasts that brought the Vietnam War into the living rooms of the world over the next several years.

ABC used its time on Early Bird for news segments, featuring correspondent Peter Jennings broadcasting from London. All three networks broadcast news segments from across the Atlantic on their evening news programs, as did the Canadian Broadcasting Corporation, with its newscaster Earl Cameron reporting from London. European television also took advantage of the opportunity via France's ORTF, Italy's RAI, and Britain's ITV, as did United Press International and the European Broadcasting Union.

Among other things, the day's flurry of activity gave birth to the now-familiar phrase, "Live Via Satellite."

On Monday, May 17, COMSAT made Early Bird available to the networks once again, during regular programming, for the first transmission of color. The inaugural color broadcast was for an NBC segment, "A New Look at Olde England," originating in London. The event was scheduled to coincide with the hundredth anniversary of the founding of the International Telecommunications Union.

The outside world was impressed with the new satellite. *TV Guide* reported that Early Bird "appears to be capable of doing just about anything except eating a worm."

With things going so well, on May 28, COMSAT filed a tariff to use Early Bird for transmission of voice, record, data, telephoto, facsimile, and television on a commercial basis. It was, of course, the first tariff of its kind filed with the Federal Communications Commission and was designated FCC No. 1. The tariff would take effect on June 27, unless the FCC took action to halt or alter it.

Use of the satellite required some tricky scheduling. Since Early Bird was not capable of providing simultaneous voice and television channels, voice-grade channels were made available on a lease basis for periods of one month, on a sixteen-hour, seven-day-a-week schedule. COMSAT made provisions for customers to surrender voice channels to accommodate TV when decisions were made to make TV channels available. The company said that the carriers would have to make their own arrangements with their European counterparts to complete the communications path. COMSAT promised that with additional satellites in orbit, it would be in a better position to provide for the use of TV on a less intricate and more regular basis.

Initial rates for satellite transmission were $4,200 per month for a two-way leased voice-grade channel; one-way transmission of black-and-white TV signals was $2,400 for the first thirty minutes, $475 for each succeeding fifteen minutes.

On June 8, COMSAT filed with the FCC for the appropriate licenses to operate Early Bird commercially. To support the application COMSAT included, among other things, the satellite's performance test results and the Andover earth station test results, both of which exceeded expectations. During the next three days, Early Bird continued to demonstrate its versatility by collaborating with ITT, RCA, and Western Union to transmit telegraphy, facsimile, telex, photographs, and data. Then, on June 15, the satellite was used to provide a space link for high-speed transmission of weather data and maps for the U.S. Weather Service between its headquarters in Washington and the French National Weather Center in Paris.

On June 28, Early Bird faced its next critical test. How would the telephone voice circuits work? In other words, would the delay and echo problems make conversation difficult, if not impossible? COMSAT engineers were confident that the echo suppressors would prove adequate. Consequently, arrangements were made for President Lyndon Johnson to exchange telephone greetings via the satellite with fellow heads of state on the opposite side of the Atlantic. In addition to President Johnson, speaking from the White House, other participants included former president Eisenhower, the prime ministers of Great Britain and Canada, and the chancellor of West Germany.

In addition to the two-way communication between heads of state, twelve phone booths, which had been set up at Washington's Mayflower Hotel, accommodated calls between other high-level members of government and industry on both sides of the ocean. The ceremony officially inaugurated commercial use, which provided service between the U.S. and Canada, on the one hand, and ten European countries on the opposite side of the Atlantic.

Although this initial test of Early Bird's voice capabilities was ballyhooed with much fanfare, the ongoing question of the quality of these communications in day-to-day use still remained. As Sid Metzger put it, "if the problems of time delay and echo proved unacceptable to the telephone user, any cost advantage over the other system would be of only academic interest."

AT&T leased 60 of the 240 circuits aboard the satellite and began sampling user reaction, with callbacks to the United Kingdom, France, Italy, Germany, and Scandinavia. This six-month user-test period caused a bit of apprehension for the people at COMSAT who had made the decision to go geosynchronous.

"If the conclusion had been that this was not satisfactory, the consequences would have been pretty serious," Charyk said, "because at this stage of the game, we would have had to look at other kinds of systems. The financial and other consequences of that would have been very significant."

Those who were in favor of the synchronous orbit found the sampling questions to be a bit leading—e.g., Was there anything wrong with your call? as opposed to: How would you rate this call? Nevertheless, the testing showed a high level of user acceptance and proved the viability of the concept. As Early Bird proceeded to provide positive answers to the questions about the geosynchronous orbit, it was made an operational satellite and work on the next generation of satellites proceeded with a higher level of confidence.

Recognition of the accomplishments of the satellite continued. At the Emmy Award ceremonies in June 1966, COMSAT technical VP Siegfried Reiger accepted a special Emmy from Rod Serling, president of the National Academy of Television Arts and Sciences. Serling called the Early Bird experiment "a significant advancement in television research and development."

It had been just five years since President Kennedy had addressed a joint session of Congress and asked for an extensive, three-pronged space program that would land a man on the moon before the end of the decade, develop the rocket engines to launch satellites far into space, and put in place a world communications system via satellites. "The 1961 statement was based largely on prediction and promise—very little on the results of development or on demonstrated technology," Burton I. Edelson wrote in *The INTELSAT Global Satellite System* for the American Institute of Aeronautics and Astronautics. Edelson, who was the second director of COMSAT Labs, went on to say, "At the time, no active satellite had flown to test voice or video transmission; no spacecraft had ever been put in geostationary orbit; no data on reliable operation of electronic devices or rotating mechanisms in space were available; and some considerable doubt existed as to the acceptability of long-delay transmission paths for commercial service. Still, engineers and managers pushed onward; and as each problem unfolded, they seemed somehow to find a solution."

In 1983, Emeric Podraczky, director of engineering for INTELSAT, co-authored a chapter also for the American Institute of Aeronautics and Astronautics, with Joseph Pelton, director of strategic policy formulation for INTELSAT, that traced the development of the INTELSAT satellites. By then, Early Bird had been renamed INTELSAT I. With the benefit of almost twenty years of hindsight, the two men said of the Early Bird experiment, the "project proved many things but, most fundamentally, it proved that a working network of a geosynchronous spacecraft plus earth stations could provide a high-capacity, reliable communications link between North America and Europe."

COMSAT scientists and engineers had hoped for a life span of a year and a half, based on what they might expect from mechanical valves operating in a vacuum. They got more than three-and-a-half years before the hydrogen peroxide propellant in the attitude-control motors began to turn to water and Early Bird drifted into what was to become a kind of burial ground for old satellites above the Indian Ocean. But by then, the second generation of satellites was already in orbit and world communications were changed unalterably.

CHAPTER FOUR

Some Odd Places for a High-Tech Lab

> 20 March 1967. Effective immediately, the correct designation for the research and development center will be COMSAT Laboratories. This title appears to give the proper connotation for the purpose and function to be performed and will provide a meaningful identification outside the corporation. The change in title, now, will provide a gradual transition and acceptance prior to complete implementation of our present plans.
>
> *Memo for Siegfried Reiger,*
> *Vice President, Technical*

Tregaron was an odd place for the origins of a laboratory that would have as its mission state-of-the-art technology for communications satellites. A mansion of near-baronial proportions, it was set on a hillside in northwest Washington, in a bucolic location, where squirrels and birds came to the windows in summer, and you could watch children sledding on the hill in winter. Once the home of a former U.S. ambassador to Moscow, the antiquated building seemed a more suitable location for the lab of a Dr. Watson or even Dr. Jekyll, than the site of a space-age corporation. The sundial out front, shaped in a medieval representation of the earth, appeared a failed attempt to hint at the nature of what was to go on inside.

"It was really a very unusual building," explained Dr. Charyk, COMSAT's newly appointed president when the corporation moved into Tregaron on February 15, 1963. "The only thing that was fairly clear was that the dining room would be the boardroom."

Charyk put his office upstairs, in the master bedroom, where flowering vines entwined around the windows. CEO Leo Welch moved into the library on the first floor, which opened onto a terrace overlooking the garden. The kitchen was designated as the copy room, supplies were kept in a steam bath (inoperable), and some test equipment was set up in one of the bathrooms.

The *Washington Star* said of the whole thing, "Such untidiness may shock those in Washington society who remember the late Ambassador Joseph E. Davies estate in its heyday, but those connected with Tregaron's present occupant could not be less concerned . . . the setting is at least in keeping with the unusual nature of the new corporation it houses."

Charyk remembered Tregaron as a place where the concept for an unusual team was born. "It was pretty clear from the outset that we had to have within COMSAT a group of individuals and resources that would permit us to get the best technical judgment on the key questions," he said. "There were the questions of time-delay, the question of lifetime—particularly of the different kinds of components, the batteries, the tubes, etc. The amount of data was very limited, therefore we were going to have to have resident experts who were on top of what was going on in the field—what was known, what was not known, what additional experimentation might be necessary, in what areas, what kinds of questions would be addressed, and so on. There would have to be a collection of people from different disciplines because satellites brought together combinations that normally would not have worked together. This cadre of people would be essential to our making the right kind of technical decisions. So there was, very early in the game, an emphasis on trying to get a collection of people who had exposure to the kinds of problems that were involved, who were very knowledgeable about what was going on in those areas and could pool their knowledge in order to make the best possible technical assessments. Now, it was clear that this was also going to be a continuing requirement regardless of what happened in round one, unless the whole thing went belly up."

The unusual tandem of new company and old building had no shortage of applicants, however. Hundreds of resumés began pouring in, to the point where a secretary had to be hired just to sort through and process the inquiries and employment applications.

The first such hire was a new vice president-technical, Siegfried Reiger, a man absolutely convinced of the system's potential for success.

"He was one of the most confident people that this could be done and I think he was oriented in the direction of the geosynchronous orbit, almost from the outset," Charyk said. "At Rand [Corporation], he had done studies on the feasibility of the different kinds of communication satellite systems, and he had talked to most of the people in the field who were knowledgeable about the status of the technology. Therefore I put a lot of faith in him and the kind of information he had been able to bring together from many different sources."

By most accounts, Reiger was a brilliant man, who understood the underlying technology and had good judgment regarding the way the technology would be heading—a real driver.

"He did not suffer fools lightly," Charyk said. "He admired people who had a strong technical position, provided it was founded on a strong technical foundation, but he would not tolerate discussions when he felt you were arguing for the sake of arguing and didn't have the technological back-up to justify your position. He would interrogate people roughly, so some people might have viewed him as being a pretty rough, brutal type of a person. There were others in whom he had a great deal of faith, those with a high level of technical ability and whose opinions therefore he would respect. He hoped to envelop those people in pursuing the work that needed to be done."

Reiger had another characteristic symptomatic of "doers"; he hated bureaucracy.

"He was totally intolerant of rules, regulations, and procedures," Charyk explained. "Whatever was necessary to get the job done, he felt should be done and it shouldn't be inhibited by paper reports and forms and things of that sort. So, anyone who had anything to do with the business management or the bureaucracy did not get along very well with him because he treated them as fools."

Emeric Podraczky was not a paper pusher. He was one of the first of a long line of foreign born scientists and engineers who would add a distinctly international flavor to COMSAT's research and development efforts over the years. Podraczky was born in Switzerland of a Swiss mother and a Hungarian father.

"The early years of my life were spent in France," he said. "My mother tongue is French. But in 1939, we got stuck in Hungary on a visit at the breakout of the second World War, so we stayed there and I learned Hungarian. That's where most of my education took place; that's where I went to the university. In 1956, I was involved in the Hungarian uprising, and eventually became a refugee."

Podraczky and his wife and two-month-old daughter crossed the border into Austria and were refugees in Vienna. They settled next in Canada where he joined RCA Victor, and they eventually became Canadian citizens.

Satellites had fascinated Podraczky at a very early age. "In Hungary I was leader of a research group in telecommunication equipment at the Telecommunication Research Institute," he said. "So when I joined RCA in Canada, I got involved in microwave radio relay systems, and I proposed that the future was orbit-state microwave radio relay systems. I was put in charge of a group which was designing solid-state microwave radio systems, which were very new at that time."

Podraczky was plowing new ground. The transistor had been invented only a few years earlier, but NASA, itself only a few years old, had already issued a request for proposal (RFP) for a communications satellite that would require the use of the new solid-state devices. One of the bidders, RCA, searched its staff for expertise in microwave using solid-state components.

"They found me in Canada," Podraczky said. "RCA got the contract, and I ended up doing the microwave hardware for the satellite, the repeater as it was called. I designed it in Canada. It was the first significant Canadian contribution to the space communication age and eventually that satellite, RELAY, was launched. It worked beautifully. It was launched a few months after TELSTAR and therefore did not have quite the same smash, but it was a highly successful satellite. It lasted much longer than the TELSTAR satellite. It was fundamentally a better design."

Meanwhile, back in the U.S., the Communications Satellite Act had been passed, COMSAT was formed, and the new company started to look for people who had some knowledge of communications satellites.

"One day I got a call at RCA, from Sid Metzger whom I knew from his RCA days," Podraczky explained. "He asked me if I would come to Washington for an interview. So I came down to Tregaron in 1963."

An offer was made to Podraczky and he accepted it. "Once you get the bug of the satellite business, you like it," he said. "It's very hard work but it's very exciting to pioneer. That was the biggest attraction. It was a new field. There were a lot of unknowns. We needed to find solutions to problems that sometimes we didn't even understand."

Podraczky was in his early thirties, RCA in Canada did not appear to have any more satellite projects on the immediate horizon, and COMSAT had said, in effect, make this your life's work.

At Tregaron, he and Jim Potts set up shop in what had once been a ballet room at the old mansion. "The wall was full of mirrors," Podraczky recalled, "which was a strange sort of atmosphere." But the big house, which had gone unoccupied for years, plus the need to deal with the winter chill and the bizarre mirrored room, became the ingredients for a near disaster. "When the heating system was turned on," Podraczky continued, "those good, old-fashioned radiators—the heat did something to the glue and the mirrors came crashing down one morning. So we lost our mirrored view."

After getting himself established, Podraczky knew he would need some highly qualified assistance. He remembered a young engineer he'd met at the Andover earth station during his work at RCA with the RELAY satellite, Simon Bennett.

"While I was working on RELAY, they had sent up a command to turn on the repeaters, but they appeared not to come on," Bennett recalled. "I was running strip-chart recordings of the received signal, and at the instant that they sent the command, I saw just a very momentary blip on the strip chart."

Bennett heard on his headset that the repeaters had failed to come on, but he thought otherwise. "I tore off the strip-chart, ran into the other room, and showed it to Emeric. "Look," I said, "it *did* come on, but it turned itself off."

It was important to Podraczky that the repeater had come on, if only for an instant, because it indicated that there was a problem in the command circuitry, not in his repeater. Podraczky never forgot the bearer of that good news, and a year later he offered Bennett a job at COMSAT.

Bennett joined the company in December 1963. "They were anxious to have me come because they were about to issue the contract to Hughes for Early Bird," he recalled, "and they were anxious to get some staff on-board to do some of the analysis and follow the progress of that work."

His hiring brought the total number of staff to thirteen people. He moved into an office up in the attic and started working on transmission plans for Early Bird. "Those were very interesting days because we were so small that all the decisions and considerations were made with immediate contact to top management." Bennett explained. "There was no difficulty getting ideas across because things were moving very, very fast."

The 1964 Olympics experiment using SYNCOM III was the first great challenge, and they set about getting ready for that.

"We were pretty confident that everything would work," Bennett recalled," but neither Emeric nor I had been used to working with a satellite transponder that used what's known as a hard limiter, which kind of clips the tops and bottoms of the signals. I had to do some analysis to see what kind of distortion this would cause to the signals and it turned out it would be fine the way we were using it."

While there was a close-knit feeling that went with the coziness of Tregaron, COMSAT quickly outgrew the quarters and moved into all five floors (plus basement) of a new office building at 2100 L Street, N.W. It was somewhat more accommodating to the mission of the corporation.

"We were a bit closer to reality," explained Sid Metzger. "We even had a launch control center, located in a corner ground floor area, originally planned by the builder for use as a retail shop."

While this new control center included telephone and telegraph lines to Cape Kennedy as well as the earth station at Andover, the telemetry tracking and control data still had to be copied manually from a teletype printout. Soon a small microwave lab was set up in the basement, and a computer was added to assist with mathematical problems and design models.

There were still space constraints. One of the technicians had established himself in a bathroom with a telephone, and was even negotiating with vendors in these cramped quarters. Others made do with shared space crammed with various kinds of test setups. The equipment pool was very small.

Basically it was what Emeric Podraczky called "the seed of a laboratory." Podraczky had drawn up a budget of what it would take to set up a small lab so they could do multiple-access and transmission measurements. He convinced Technical VP Sig Reiger to let him start it up with a few benches and some basic necessities.

"I borrowed equipment from friends at RCA and from NASA, and bought some," he said. "Then I set up a little measurement facility, in which we tested the chosen multiple-access system, frequency division multiple access." There were two or three other engineers helping him out.

As the role of COMSAT grew and more satellites began taking their places in geosynchronous orbit, spotted strategically above the earth, the need for a suitably equipped and staffed permanent lab of appropriate proportions was becoming a paramount concern. The company had outgrown 2100 L Street and now occupied space in two buildings with some offices at 1900 L and others, including the technical departments, at 1835 K Street. Again, the quarters would be temporary. Meanwhile, the company was looking for sites for a permanent lab in the Maryland or Virginia countryside, ideally not more than thirty minutes from downtown Washington, where the corporate headquarters would be built at L'Enfant Plaza. Serious consideration was given sites in Rosslyn, Virginia, and a plot in Maryland, just beyond the District of

Columbia, where the Beltway intersected Route 270. Both were rejected as too small, the thinking being that it was important to maintain a campus atmosphere and a sense of openness. Representatives on the board of directors who had been part of similar real estate exercises with other companies warned against selecting land in areas that were destined to become congested. The corporation began looking at a site consisting of 200 acres of land in Clarksburg, Maryland.

COMSAT also began searching around for the best person to lead such an effort. The man they settled on was Wilbur L. Pritchard, an engineer with long-time experience in communications, who had headed up two labs for Raytheon. The higher ups at COMSAT were familiar with Pritchard; he had been a bit of a thorn in their sides.

"For a while, there was a considerable debate between COMSAT and all the members of the communications community as to whether or not COMSAT should try to do both military and commercial satellite communication, using the same satellites," Pritchard said. "There were some people at COMSAT who were very much in favor of this. There were some people on the outside—especially me—who were very much opposed to it, thought it was not a good idea, either for COMSAT or for the military."

Pritchard, who was with Aerospace Corporation in California at the time, felt the satellites had sufficiently different requirements, so there just couldn't be a satisfactory compromise. Both would suffer. The satellites either would be unprofitable and no good commercially, or wouldn't do the job required by the military. The decision was made to develop separate satellites.

"Many people participated in that decision," Pritchard said, "and I like to think that I was one of the major parties who influenced getting it to go correctly, as it did. I think everyone in retrospect knows that decision was correct."

During the course of this debate within the communications community, he got to know the people at COMSAT very well. Despite the fact that many of them had had an adversarial relationship with Pritchard, there was no denying that Pritchard knew his craft and the attitude became one of if we can't beat him, let's have him join us.

The approach to Pritchard was somewhat fortuitous. Siegfried Reiger had known Pritchard since they had both done work for the Air Force, a decade earlier, Pritchard as an engineer for Aerospace Corporation, Reiger with Cambridge Research Center. Reiger respected Pritchard's work, both as an engineer and as a manager. So when the two of them ended up at the same press conference during a communications industry function in 1967, Reiger passed Pritchard a note. It said, "Would you like to be director of COMSAT Labs?"

"I just wrote on it, 'Yes. Let's talk about it,' and passed it back to him," Pritchard recalled.

The two men met later in the bar.

"We'd like to start a laboratory," Reiger said, "but we have no facilities, no programs, no people—nothing. Just the idea." Then he repeated his offer: "Do you want to be director?"

Pritchard answered, "Are you going to do it—seriously?"

Reiger said, "Yes."

Pritchard questioned, "Does Charyk know about it?"

"Yes."

"I'll take it," Pritchard said.

It was only after saying yes that Pritchard discussed salary. "It turned out I was getting paid only $2,000 a year less than Reiger was at the time," he said, "so I went for no change in salary and I didn't care, because it was a job I wanted. I thought it was a real challenge to create a laboratory from scratch, in a field I worked in, satellite communication. What better job could I ask for? I didn't give a damn what he was going to pay me."

Pritchard got going in earnest in the spring of 1967, putting together the teams of scientists, engineers, and technicians who would become the backbone of COMSAT Laboratories, while he also paid close attention to the design of the physical plant.

"This was my third lab, but it was the first time I ever had a chance to have anything to do with the architecture of the place, and with hiring all of the people," he said. "I hired almost everybody. Some people got transferred and had been with COMSAT before, but the great number of people at COMSAT in that period were hired by me."

Things had turned a bit tense for COMSAT shortly after the first launch of the new INTELSAT II series of satellites. Buoyed by the success of Early Bird, now renamed INTELSAT I, COMSAT watched as the second chapter began as flawlessly as the first had. As the satellite approached its transfer apogee, emotions ran high, but with the firing of the apogee motor, they came crashing down. The motor blew apart. Subsequent investigations and analysis have attributed the problem to ice formations in the hydrogen peroxide fuel system. As a result, Pritchard was entering an environment where the last program had been a failure. However, he had been hired by Reiger to build and staff a laboratory and that is what he set out to do.

There had been opposition to COMSAT's making such a heavy commitment to a lab. One line of thought was that COMSAT should serve only an operational role, doing nothing fundamentally new or original in the way of technical work, but simply buying satellites and earth stations, and staffed with a few technical people to put it all together.

"This is a view that's only held by nonengineering people," Pritchard explained, "never by engineering people. When I say engineering and nonengineering, I don't care what people's degrees are in. I care about what kind of work they've really done, because sometimes people have degrees in engineering and never work as engineers, and don't know what engineering is. They just studied engineering in college and then went on to do other things. They are not engineers. On the other hand, the reverse happens, too. Sometimes people don't study engineering, but they get into engineering and they learn it and teach it, and work at it. They are engineers."

Pritchard felt no engineer, at least no good engineer, could ever stand by and just buy things, even if the things being bought were satellites and earth stations. Furthermore, he felt that engineers—even good ones—who spent years doing nothing but writing specs and talking to contractors lost their touch.

He put his feelings on the record. "A top R&D man is a kind of amphibian," he wrote in the March 1969 issue of *R/D* magazine, "he doesn't have to be in the lab all the time, but he begins to get uncomfortable if he's kept in an office too long."

A true scientist breathes science, Pritchard contended, and science was like a language. "You've got to work at engineering, and you've got to have creative technical work to do. That's the biggest reason for a laboratory. The laboratory lets you keep good technical people around, doing creative, technical work."

Pritchard had a lot to offer the people who would listen to his pitch. They would get into a program that would offer a challenge most people never get in their lifetimes—the opportunity to pioneer. It was not merely a matter of operating within a certain narrow discipline. He was looking for people who could hear opportunity knocking—no, pounding. He looked for people who were technically oriented. He didn't look at college degrees; he listened to the way people answered questions during interviews. He wanted people who could design, who could build, who could solve the complex mathematical and engineering problems that lay ahead. He did not want people who would rather be in project management or operations or marketing.

Most of the people he selected joined the labs from outside the company. But there were those, already on staff, who wanted to be part of the new team that was preparing to move out to Maryland farm country. Emeric Podraczky was one of them.

"I didn't choose him," Pritchard recalled, "he chose himself. The first day I was there, he came to see me. He said, 'Hey Bill, I think I'd like to be in a laboratory.' I said, 'you're on!' "

Christoph Mahle was a microwave radio specialist living in Zurich at the time. Like many of those Pritchard was looking at, Mahle was a self-described multinational. The holder of an Austrian passport, Mahle was born in West Germany and grew up in Brazil, but had returned to Europe to study engineering.

"I wanted to work in hardware that had to do with space, satellites, radio astronomy, anything like that," Mahle said. "There was nothing going on in this field in Europe, in the practical sense, so I wrote lots of letters and sent lots of resumés, and with COMSAT, it eventually clicked. I was interviewed by Bill Pritchard, who came to London for this purpose."

Mahle was hired. Step by step, Pritchard continued to build his team.

"The technologies that we would be involved in were really dictated by communications satellite systems, which consisted of several different elements," said Burton Edelson, who was Pritchard's deputy and the second director of the labs, "satellites, earth stations, and transmission systems and the different scientific and engineering disciplines. A satellite system is a radio link that goes from earth to the satellite and then back to earth. So we had to have a radio research laboratory. There was also base-band equipment, which involves modulation and coding and transmission, etc., so we called that communication processing—which came into being just at the time of the digital revolution, so it became preeminent in digital communications. There was obviously a requirement for spacecraft technologies in mechanical engineering, power system engineering, and propulsion. There was an underlying requirement for applied science, solid-state physics, etc."

Edelson pointed out that there was a valuable infusion of Japanese know-how at the time, especially with the arrival of Dr. Tadahiro Sekimoto, an assignee of a new program that INTELSAT had instituted in conjunction with the labs that would allow foreign experts to come and work at COMSAT.

The initial organizational structure divided the R&D mission of COMSAT Labs into five laboratories: microwave technology, headed by Louis Pollack; communications processing, headed by Tadahiro Sekimoto; systems, under Emeric Podraczky; spacecraft technology, with Fred Esch in charge; applied science, headed by Edmund Rittner.

Meanwhile, efforts were continuing to find a permanent home for the laboratories.

CHAPTER FIVE

The Campus at Clarksburg

> The concept of the laboratory was Sig Reiger's. He really had a gut feeling that we needed a research and development capability and pushed for it. The support for the labs came largely from the three AT&T directors who were on COMSAT's board and who were knowledgeable about the communications industry. COMSAT Labs was patterned very much after Bell Labs.
>
> *Burton Edelson,*
> *Second Director, COMSAT Labs*

Early Bird had proven out the viability of geosynchronous orbit, but it was only a start. NASA had approached COMSAT concerning the need to put in place a communications satellite program that would help fill gaps in the manned space flight program. Negotiations among NASA, COMSAT, and INTELSAT had resulted in a go ahead on the INTELSAT II, a satellite similar in design to Early Bird, but larger—about three times its size and twice its in-orbit weight. The INTELSAT II generation not only would replace Early Bird over the Atlantic, but also would include sister satellites over the Pacific and Indian oceans to create three regions within which all countries of the world could be linked via satellite.

Launch dates were set for October 26, 1966, for the

Pacific Ocean satellite and November 23 for an Atlantic satellite to join Early Bird. As the launches approached, expectations ran high. The Pacific satellite's designated location was to be about a thousand miles east of the Gilbert Islands, but positioning it would be tricky. So COMSAT was reserving a decision on whether to go for the Pacific orbit on the first launch or wait for the second one. If an Atlantic positioning was decided upon, the new satellite would be placed above the west coast of Africa.

The October 26 launch went flawlessly and the satellite achieved transfer orbit. Within twenty-four hours a decision was made to go for a Pacific positioning and the satellite was nicknamed Lani Bird—Lani being the Hawaiian word for heavenly.

Lani Bird would usher in several firsts. UPI reported that the satellite would provide the first live TV coverage of the Vietnam War, and might even be ready for election coverage from Hawaii on November 8. The *New York Times* also anticipated improved telephone service across the Pacific. However, this optimism ended abruptly on October 29, when the satellite failed to achieve geosynchronous orbit. The apogee kick motor failed to function properly.

Simon Bennett and his crew were already in place near Paumalu in Hawaii to put Lani Bird through its first series of in-orbit tests. The crew had gone out days earlier to set up and calibrate the equipment, then wait for a go ahead. Word that the satellite had assumed a kind of cigar-shaped orbit, swinging from an apogee of 22,300 miles to a perigee of 1,800 miles was a terrible disappointment.

"Everybody was trying to look at all the telemetry data from both the satellite and the rocket, in Washington and at the Cape," Bennett said. "Meanwhile, I'm sitting in Hawaii dying to find out more about the satellite. I was thinking, if I can test the transponder and find out if that's working or not: one, it's a new design; two, if it's working, it means nothing serious—no explosion occurred on the satellite, no damage—and that would all be very important information."

Bennett kept calling but he couldn't get people's attention in Washington. They had other concerns. Meanwhile, the patience of his boss, Marty Votaw, the project manager, was beginning to wear thin. Finally Votaw got on the phone and said, "Listen, Bennett, the uniform of the day is a bathing suit. You and your team go to the beach and when we need you, we'll call you."

They eventually did test the transponder and it was fine, which proved out the new design.

The experience pointed out how little was really understood about the environment in which the satellites would operate, and how dependent the whole was on each of its parts. That, in turn, reinforced the need for an expanded, integrated R&D program, and the facilities to make such a program work.

"We tried to focus on what would be needed on a long-term basis if we were going to be able to carry out our mission properly to be the most knowledgeable group of technical people in the world on the subject of communications satellites," Charyk explained. "So the focus was clearly to make sure that this would be known as the group of people worldwide who knew more about communications satellites than anybody else. We talked to a lot of outside people from RCA, from Bell Labs, a lot of research institutions, about their estimate of the technology in different areas. We had a small group of people study what kind of a laboratory we should have, what size it should be. It was clear that there was going to be some sort of a minimal size. If you were smaller than that, you just wouldn't be effective and you probably couldn't afford something much bigger than that. So, we attempted to make a judgment as to what this critical mass should be, what it would cost, and basically to take the position that that was an essential element if COMSAT were to carry out its statutory mission. When we ultimately got into regulatory discussions, it was always our position that having this kind of a capability was fundamental to our statutory role and therefore was clearly an allowable expense in determining our rates."

On November 1, 1966, COMSAT announced that the company had signed agreements to purchase 210 acres of land on Interstate 70-S (now Route 270) in Montgomery County, Maryland, as the site for a research and development center. A COMSAT news release stated that the purpose of the new facility would be to "conduct advanced research on satellite communications with an initial staffing of about 200 persons, half of them scientists and engineers."

On February 24, 1967, the company selected Daniel, Mann, Johnson and Mendenhall, a Los Angeles-based architecture and engineering firm, to design the facility, which was expected to include about 250,000 square feet of working space. The design contract was for $450,000.

On December 27, 1967, a contract was signed with the J.W. Bateson Construction Company of Dallas, Texas, for $7.9 million to build the new facility. Bateson was authorized to begin at once.

Bill Pritchard, who had been named director of COMSAT Labs in May 1967, was overseer during the entire construction process and saw to it that the design and construction of the new facility reflected what his experience running other labs had taught him was needed.

"I watched every nut and bolt go up," Pritchard said. "In fact, the steel framework of COMSAT Labs was bolted together, not riveted."

After a little more than twenty months from groundbreaking, the new COMSAT Labs opened its doors on September 10, 1969. The staff, most of whom had been hired directly by Pritchard, went to work at the spanking new labs and offices, with the overall mission of fine tuning the hardware of the global satellite system now in place and operating in the skies far above the earth. One was a newly retired military officer, who, at the age of forty-one, was just beginning to hit his stride in the satellite business.

In the mid-'60s, Burton Edelson was in London finishing up a tour of duty as a lieutenant commander with the U.S. Navy. He was helping to establish the NATO and British military communications satellite system known as SKYNET. The United States had provided the impetus to develop and build these systems and Ford Aerospace, then known as Philco, built the satellites and the earth stations.

"The technical expert behind all that was Bill Pritchard, who was director of communications at Aerospace Corporation for the U.S. Air Force," Edelson explained. "Bill made many trips to England, where he helped me to promote U.S. industrial capability to build satellite systems. On one of his trips over, I mentioned that I was going to complete my twenty years in the Navy and I thought that I would leave the service and go into civilian life."

Pritchard, who at the time was still being considered for the director's position at COMSAT Laboratories, said if he got the job he wanted Edelson to be deputy director. Edelson said he would definitely be interested.

"I actually had my job offer to come to COMSAT written on Aerospace stationery," he said.

On December 31, 1967, Lieutenant Commander Edelson retired from the Navy and on January 1, 1968, he became the number two man at COMSAT Labs, joining the company while the technical functions were still playing musical buildings in downtown Washington and the labs were an empty plot of land in Maryland. Edelson got right into the middle of everything with Pritchard, working on the design of the building; the layout of the laboratories; and the selection of hardware, software, and—most important—the humans who would create the professional personality of the new facility.

"I was kind of the general manager of the labs," he explained. "We quickly divided up the responsibilities because we were good friends and we'd worked together before. Bill was responsible for all policy, personally hiring the top people, and providing the tie with the rest of the company. COMSAT Labs had the in-depth technical capability, and the labs' most urgent role at the time was to support the development of INTELSAT II and INTELSAT III. The latter, INTELSAT III, was in deep technical trouble. The contractors, TRW and ITT, didn't have the experience that Hughes had with SYNCOM, and INTELSATs I and II, and they were having a great deal of trouble developing the satellite. So during 1968 and 1969, the labs were very much devoted to providing engineering support for the development of INTELSAT III."

The trouble they were having with INTELSAT III caused COMSAT scientists and engineers to get more and more technically involved with what was being built for the satellites. And the director got directly involved as well.

"It meant that Bill was almost 90 percent involved in that," Edelson explained, "while I was very much devoted to developing and setting up the administrative organization of the labs and the R&D programs and dealing with our potentially great customer, INTELSAT. COMSAT as manager of INTELSAT was organizing programs, and in my particular case, the INTELSAT Research and Development Program."

COMSAT Labs worked very closely with the technical committee at INTELSAT to come up with a research and development program that would develop new spacecraft technology, develop new transmission techniques, and improve the INTELSAT system in one or more ways, by making communications more effective through lower costs or higher quality or new types of services. The program grew into a multimillion-dollar revenue producer for the new labs.

One of the great problems of any high-tech company, however, is to tie research and development into operations.

"COMSAT had that problem, too," Edelson said, "but in early days we made the bridge very often. We had a very strong engineering capability and we tied the engineering division very closely to the labs. Because the development of the satellites was in trouble, particularly INTELSAT III, this tie became very close and there were people going back and forth all the time. For more than a year Bill Pritchard had a regular Thursday meeting out at TRW and he flew from Los Angeles to Washington to Nutley, New Jersey, and back every week."

Meanwhile they expanded the size of the lab from some 200 employees who moved into the building at Clarksburg to twice that many within two years.

"One of our programs was corporate R&D," Edelson explained, "which was a jurisdictional research and development program and it helped to support COMSAT's three roles in INTELSAT—as one of the owners, as operator of earth stations, and as management contractor. Research that we did to support any one of those three roles was considered jurisdictional. Therefore, the research that we did was capitalized, put in the rate base, and amortized over a five-year period. All the equipment and facilities that were used for that would be considered in our rate base as well."

With all the new programs under way, there was some sorting out to do.

"There was some amount of confusion as to the details of who was to do what," said Christoph Mahle, one of the new labs' new engineers, "but there was overall a very profound sense of mission. The attitude was that this company and this laboratory are here to get an international satellite system going and up there and working as well as we can do it, and this seemed attractive to some of the best engineering minds in the world."

While there was already fierce competition for engineering excellence among the staff, among the managers, there was at the same time a very friendly and collegial atmosphere.

With the staff selection going well and the nuts and bolts in place, they began to outfit the lab. They brought in equipment of all kinds to help them design the satellite systems, then test their performance, both in the lab and in orbit.

"Testing a satellite to see if it's going to work or not in outer space is no joke," Pritchard explained. "That is one complicated and expensive business, because you have to simulate outer space. That means you've got to simulate the high vacuum—and it really is a high vacuum—and the solar energy. You do this in what are called thermal vacuum chambers. You have to simulate the temperatures and the vacuum at the same time. It is not a minor operation and of course you have all kinds of chambers."

They built large chambers to test whole satellites, smaller chambers to test systems, still smaller ones to test specific components. Overall, the testing of antennas, all the components and subsystems and finally the entire satellite itself, was an operation requiring many millions of dollars in test equipment.

"A satellite is a complicated business," Pritchard went on. "It doesn't only have the communications equipment. It's got propulsion. It's got temperature-control equipment, because it's got to operate at a congenial temperature for everything. It's got the attitude control system."

The attitude control system was both critical and fraught with problems. "You have to have some way of keeping a satellite's antennas pointed at that area of the earth that you want to communicate with," he said. "You have to keep your solar panels pointed at the sun, because all commercial communications satellites use solar energy. So you've got the double attitude control problem to stay pointed at the sun and pointed at the earth."

In many of the five new divisions at the labs, groups were developing whole new technologies.

"The laboratory pioneered the tremendous improvements in solar cells," Pritchard said, citing some specific examples. "Solar cell improvement is translated into tens of millions of dollars. Originally, they were converting less than 8 percent of solar energy into electricity. We doubled it to about 15 percent. We did a lot of work in attitude control and understanding the dynamics of attitude control. This is a very sophisticated, highly mathematical, theoretical subject, but the results are dramatic."

Aside from the challenge of positioning the satellites properly with respect to the earth and the sun, there is also the problem of the satellite's tendency to tumble. A major contributor to instability is the fuel that is on board, which is a double-edged sword. It is needed to make constant corrections of the satellite's position, but it has a tendency to slosh during these corrections.

"A satellite carries a lot of fuel," Pritchard explained. "As long as a tank is full of fuel, it is okay. But when you start to use up some of the fuel, and you get any motion of the satellite, the fuel sloshes, which destabilizes the satellite even more, which makes it slosh some more, and pretty soon you have a tumbling satellite."

This process can be analyzed to some extent mathematically. It also can be modeled on computers, and it can be simulated experimentally. The engineers in COMSAT's spacecraft division did all three of those things at the labs to understand what was going on with the fuel.

Then there was the matter of the eclipses. The satellite goes into eclipse when it gets into the shadow of the earth. Thus shielded from the sun, it has no solar power. With the satellite in geosynchronous orbit above the equator, it is in view of the sun during the summer when the sun is far north of the equator and during the winter, when it is far south. During a six-week period in the spring and a similar period in the fall, while the sun approaches and then passes the plane of the equator, the earth casts its shadow on the satellite during part of each twenty-four-hour period. To avoid an interruption in service, it must carry batteries.

"The batteries on a satellite are about as agreeable as they are in your automobile," Pritchard said. "They are heavy, expensive, and they are not the world's most reliable devices. You've got to charge them. You've got all the charging circuits and regulating circuits and you've got a structure to carry and the fuel to keep it in orbit. It's a chain-reaction of money. Each thing leads to something else, and everything costs money."

COMSAT Labs made big improvements in batteries, the crowning achievement of which was the hydrogen-nickel oxide battery. Its development was something Pritchard attributed to serendipity.

"We didn't start out to design nickel-hydrogen batteries," he explained. "We started out to design hydrogen-oxygen fuel cells. The shuttle and the moon trips used hydrogen-oxygen fuel cells. If you keep hydrogen and oxygen separate, then bring them together carefully, you generate water and electricity. So it is a great way of storing a lot of electrical energy."

The reaction can be very explosive, however. So the two gases must be brought together in a carefully controlled process. But, the hydrogen-oxygen fuel cells allow you to carry a lot more energy per weight than the more common batteries. Pritchard had thought in terms of using the fuel cells as storage devices on communications satellites.

"In the process of trying to develop the specific technology, we came across—by accident, but were alert enough to notice it—the realization that hydrogen and nickel made a fine battery and that combination was a lot safer than hydrogen and oxygen."

Pier Luigi Bargellini had been a top communications expert in Italy, during a career that began prior to World War II. After the war, he emigrated to the United States, taught for almost twenty years at the University of Pennsylvania, and worked during that period on R&D projects. He'd met Pritchard at the Aerospace Corporation in Los Angeles and stayed in touch. In 1968, Pritchard made Bargellini senior scientist and assistant to the director at the labs. Bargellini was impressed with the team that Pritchard had put together for the move to Clarksburg.

"He surely did a magnificent job in forging an instrument which was really unique in the world," Bargellini said. "I left the University of Pennsylvania, where I had a tenured position. I was well established and I enjoyed teaching and consulting. It was very risky to leave the position which I had had for more than eighteen years. But I told my wife, if I don't do it—take advantage of this opportunity—it will never come again. It was 1968, and I was already fifty-four."

The opportunity that Bargellini saw, like so many of his colleagues, was that for decades, space would be the dominant factor in communications.

"I had been in communications all my life," he said. "I'd been on cable ships repairing submarine cables. I had seen telecommunications move from VLF to LF to HF, VHF, and UHF. Satellites were going to redefine communications. I felt it was going to be fun. I was right. It was fun because the technical challenge was considerable. There was a great deal of enthusiasm. Good men had been chosen and there was a vibrant atmosphere. We almost felt that we had a mission. Major technical breakthroughs were accomplished in all areas. Communications satellites were such a novel art, notwithstanding the know-how of the manufacturers. The continuous interface between COMSAT and the manufacturers was absolutely essential. We moved the art forward in a number of areas. We had the opportunity of seeing the payoff in terms of continued improvements in the series of INTELSAT satellites."

In 1971, the staff established the *COMSAT Technical Review,* the first journal devoted exclusively to satellite communications technology and systems, which grew to be recognized internationally as the leading periodical in the field.

"The first four years of INTELSAT operations after the launch of Early Bird were years of dramatic progress," wrote Santiago Astrain, former director general, INTELSAT in *The INTELSAT Global Satellite System.* "The number of earth station-to-earth station pathways grew from one to 20. The number of half-circuits in operation grew from 150 to 1142, representing, in effect, an eight-fold increase. The number of hours of television transmissions increased . . . and, perhaps most significantly, the total communications capacity increased more than ten-fold. At the end of 1968, INTELSAT had a system capability of some 2,400 two-way voice circuits and four television channels. This dramatic shift in only four years' time enabled INTELSAT to reduce its utilization charges by some 35 percent. By the end of 1968, therefore, INTELSAT had already established itself as the predominant international overseas telecommunications facility, providing two-thirds of the world's overseas service."

CHAPTER SIX

The California Connection

One day during the summer of 1966, Irv Dostis sat at his desk contemplating his fate. He had been on the job with COMSAT at 2100 L Street in Washington for two months, getting acquainted with his new duties. At least he was trying to. Things were defined a bit loosely. Dostis got up from his desk and walked into his boss's office. "What am I supposed to be doing?" he asked.

"Well, we were thinking about that," he was told. "Actually, you're really supposed to be in California."

"Oh?"

"You're only going out there for a little while," the young engineer was reassured. "Don't worry, Irv. You'll be back before you know it."

It was a critical period during the development phase of the early satellites. Hughes Aircraft, the primary contractor, had just finished work on Early Bird (INTELSAT I) and had started work on INTELSAT II. COMSAT was putting a team in place out at the contractor's facility to monitor the development of the next generation of satellites and assist in their design.

So Dostis left Washington and returned to his home in New Jersey, now a man with a mission. He gathered some personal effects then headed out for his temporary assignment in California. The timing was not good. There was a major airline strike, so when he got to New York, there were no flights. Dostis camped out in the airport for three days and three nights. It wasn't the greatest of accommodations and it was having a psychological effect on him.

"While I was sleeping in the airport, I kept thinking, this is a bad omen," he said. "I just joined this company and I can't even get out to the place where I'm supposed to be working."

But Dostis, like so many of his contemporaries, was not the type to shrink from a challenge, and an airline strike could not be more than a temporary inconvenience. He persevered. After hanging out at the airport, becoming grimy, and battling aggravation, he finally got a seat. It was a smooth flight to California.

Filled with a sense of accomplishment at finally having made it to work, Dostis paraded in to meet his new boss, Martin Votaw, who was the COMSAT project engineer on-site at Hughes. Votaw stopped him dead in his tracks.

"Where have you been?" Votaw asked. "You're late."

To the people who worked for COMSAT Labs in those early days, it seemed as if they were always late for something. There was indeed a great deal to be accomplished. And much of the effort was directed at getting the hardware in place. For the satellites, that meant working closely with the manufacturers. Hughes had the working model of a geosynchronous satellite at the time—SYNCOM II—and that intrigued the technical people at COMSAT. Hughes offered to build a commercial version that would have a wider bandwidth, higher power, and higher antenna gain. So, in September 1963, COMSAT sent a team out to the Hughes plant in El Segundo, California, to open a dialog. Votaw wrote of the experience in the twentieth anniversary issue of *COMSAT* magazine in 1983:

> After these discussions were concluded, Sig Reiger [then COMSAT director of systems analysis] asked, "What specifications are you prepared to meet?"
>
> One of the Hughes people responded, "No specifications. This is a straight commercial arrangement, like a TV set. You don't expect specifications when you buy a TV set, do you?"
>
> Reiger responded, "I had specifications on my swimming pool." Then Reiger left the room and after a well-placed phone call came back and said, "No specifications. No contract. If you want to continue the discussions tomorrow, we'll come back with a list of parameters to be specified, and you fill in the performance numbers that you are willing to meet."

The COMSAT group retired to Reiger's residence in Los Angeles and hammered out a list of a dozen parameters, which were presented to, and accepted by, the Hughes negotiating team the next day. Hughes agreed to fill in the appropriate numbers and the discussions would continue.

Since one of the major concerns early on was whether a satellite would enjoy a long enough lifetime functioning in high orbit, COMSAT was concerned that a contractor not push a product out the door that merely met the specs. The company wanted to provide some incentive, secure some guarantee, that the product would live out a projected lifespan, high above the earth where repairs were not possible. Consequently a fixed-price concept was decided upon, with back-ended, or in-orbit, incentives. It put pressure on the contractor to build something that worked—and lasted.

At the time, the accepted method of letting contracts was on a cost-plus basis. In simple terms, that meant the profit on a contract was fixed, but cost overruns were added to the price. COMSAT fixed the price. On the other hand, to prevent the contractor from simply choosing the cheapest solution, the in-orbit incentives were added. These incentives could increase a fee by as much as 30 percent.

"Your fee was going to be a function of lifetime," Charyk said. "Not only would you not get a fee if the thing didn't work, but you might not even get your costs back. [On the other hand] the lifetime of the satellite was a determination of the magnitude of your fee—and you could get fees much larger. In theory, we could pay you any kind of fee. We were prepared to play this game to the hilt."

"This operating philosophy was at the root of the very big technical success that we had with the INTELSAT system," Chris Mahle said. "If you look at the record broadly, the INTELSAT satellites and other satellites COMSAT has been involved with have had some aches and pains, but by and large they have performed very, very well in orbit, and the overall price tag was not outrageous, when you compare it with some other systems. We said all right, the spacecraft contractor is building hardware for money, so we give him a specification. As soon as the piece meets the specification, he's going to ship it. If he doesn't understand why it behaves the way it behaves, that's not part of the contract. Maybe something in there will make this thing quit after a year in orbit and we won't be able to repair it."

That's where the scientists back at the labs on the east coast provided some invaluable back-up.

"The labs were always a resource that was available to support the programs," Simon Bennett explained. "We used the labs quite a bit, to do off-line investigations, to assess hardware that was delivered by the contractor, for performance measurements, to figure out how to write specifications for new satellites. We'd figure out what we needed, then ask the labs, 'Is that feasible?'"

For example, if the California contingent wanted to know whether it was feasible to achieve a certain filter characteristic that approached the ideal, the labs would do development work and show that such a thing was feasible, then the engineers in place at the contractor could specify it that way with confidence. They also used the labs for problem solution. Sometimes that meant long-distance coordination; other times it meant trips back and forth on the red-eye flights between coasts.

"We had the charter of really understanding why the circuits worked the way they worked," Mahle said. "We had the time and money to know circuit design and circuit functioning better than the guy who was building it for money. And so, we made it our job to look at every circuit they built. We typically built a similar test model at the laboratory just to understand what makes it tick. What are the pitfalls? What might you do wrong, that will stop working after a year or two in orbit? I think we did it very, very successfully."

And they had to do it against deadlines.

Richard Mott came to COMSAT Labs out of college in 1966 and rose from technician to engineer to staff scientist. He recalled the deadline pressures. "We had to be timely in our inputs to change or have an effect on Hughes's design and to make recommendations that weren't after the fact. And that was really COMSAT's role in general, and the labs' role in particular, during all those years. It was one of riding herd on satellite contracts for INTELSAT, first to make sure that the contract concept was correct and, finally, when the contract was let, that the house selected to build the satellites was honest, did its best work, used the best technology for the job, and maintained the contract specifications. To do that we would think up experiments, even think up designs and actually build them in-house and beat the contractor over the head with this alternate design if it was better than the contractor's design. If we could do that early enough we couldn't force the contractor to use our design but we could embarrass him or her into a better design. If we were late, the contractor of course then had the option of saying, 'Well, this is going to affect my schedule; this design works but it's not as efficient as ours and we're not obligated to use your design.'"

While Hughes was receptive to the idea of the fixed-price contract, the company was not overly enthusiastic about COMSAT moving a contingent of people into the plant.

"The idea of having a live-in crew monitoring every facet of the satellite development, that Hughes did not like," Charyk added. "They basically called it a way of increasing the cost of the program, that it was slowing the program down and was totally unnecessary."

It fell to Votaw and his crew to change the contractor's perception of this new west coast division, called Spacecraft Engineering.

"I managed a group of people who were engineers with a fair amount of experience in the various technical areas of the satellite," he said. "We monitored the production of the satellite and decided whether or not the satellite was satisfactory to ship."

It was a process that took some getting used to, not only on the part of the manufacturer, but by the new players in COMSAT's west coast office.

"The first thing that happened," Irv Dostis said, "was that the guys I was working with took me out to look at this new gadget that we were building, which was a satellite. It was half the size of a round kitchen table, and had one or two little boxes that I looked at and asked, 'that's what I'm going to be working on? Holy mackerel, what did I get myself into?' Well, the story gets to be real exciting real fast, because by the time we started getting into things and started looking at the development of all of the items, the thing that became clear is that there were probably no more than half a dozen of us out there at the time and we never had the luxury of arguing about who was in charge of one area or another area. There were so few of us that whenever somebody needed help, you had to help, because there was nobody else around. So all of us became a little bit more general than we probably would have ever been if we had stayed back on the east coast."

As time went by, and the weeks turned into months, the west coast assignment seemed to take on a permanence that the COMSAT contingent working there began to accept. And the relationship with the manufacturer became better defined as well. The COMSAT crew found that despite the fact that the spacecraft manufacturer was certainly expert at building things, the manufacturer had to achieve its profit objective, which, in its most basic terms, boiled down to: How do you build the satellite at the lowest cost, while still satisfying the requirements, and getting it out the door on time?

"Our objectives were a lot different," Dostis said. "We were going to have to operate it for a number of years and we wanted to make sure it really worked. We weren't worried about just getting it delivered to us; we wanted to make sure it worked right."

The difference between the COMSAT contingent and other monitoring organizations was that most quality assurance people would have a list of procedures and would check if the procedures were followed and the numbers were right.

"Very rarely would you get a quality assurance person who understood the type of design of a particular item," Dostis said. "Now for the first time the spacecraft manufacturer was looking into the face of a guy who was looking over his shoulder who knew, probably as well he did, how to design the unit. It was probably resented very much at the beginning, but I think as time went on, the manufacturer began to realize that it was a real asset."

The COMSAT people observed many aspects of the operation at the manufacturing plant. With their technical skill and ability to move through the organization, they were able to spot things that weren't exactly right, things that weren't getting coordinated right, measurements that really weren't matching up properly, correlations between different measurements and different organizations . . . and it all brought a new flavor to the system. In other words, here was a group of people, highly skilled technically, who—although they could generate a significant amount of trouble for the manufacturer—could produce a significantly greater amount of information and reliability, could approve products and help in a lot of ways that nobody anticipated at first, and do a lot of the analysis work that was required to make the satellite successful. But they had to draw the line somewhere, because, in the final analysis, it was the manufacturer who was going to take the heat if the satellite wasn't right.

"It was tricky ground, a tightrope operation," Dostis emphasized, "but the way it was set up and the way we operated was that, we had a contract and the contract required certain performance characteristics. We could stop the contract at any time the performance was not right. However, if there were things that didn't look like they were right, even though they did meet the objective, we could try to convince them to do something different. Nobody is going to do something, no matter how good, if it's going to cost them money, because that's their profit margin and it's not fair to ask them to do that. However, if there was a risk to the long-range capability of the spacecraft or there was a danger that something could get in trouble later on, where it would be more expensive to repair, then you had to convince the people to do that."

It was tricky business because they were dealing on an engineer-to-engineer basis, with no contractual leverage to force the manufacturer to see it their way. That's where the laboratories came in.

Dostis explained. "We would look at these devices and say, 'We think that's not exactly right.' We would call up our friends at the labs and say: 'We think we see something that doesn't look right. You guys see if you can simulate it or set it up. We'll tell you what we want you guys to check to see if it makes sense.'"

Sometimes the tests at COMSAT Labs would indicate that a change was required. Other times, they would reinforce the correctness of the manufacturer's design. It was a kind of gratis consulting service that worked to the benefit of both COMSAT and the manufacturer. There were many times during the construction of the early satellites when both the manufacturer and COMSAT crews went without a day off for months. And this kind of shared hardship helped cement the working relationship, which continued to develop into a growing mutual respect.

"People said, 'Well you were lucky; the company that you worked with was smart,'" Dostis said. "But we worked with Ford, we worked with TRW, we worked with ITT, we worked with Hughes Aircraft. Every one of them developed that kind of relationship with us."

When additional on-site support was needed, experts from the labs headed for California. "I visited Hughes a lot at that time," said Chris Mahle, an expert in microwave technology, "helping to look over Hughes's shoulder, to understand how the individual circuits would work. We had a good, friendly competition of engineering excellence with Hughes."

Mahle cited the design of multicavity filters as an example of how the friendly competition worked. "Nobody at the time could design multicavity filters that came out exactly as predicted theoretically," he said. "We needed these filters to perform like the theory and when they didn't we said, 'Hey, let's find out why, then make them better.' We pushed the state of the art very substantially in a very short time."

Filters select out part of the frequency spectrum, let that part pass, and reject everything else. The desired effect in a satellite is similar to the effect you seek when you tune a radio to a particular frequency. You want to hear only the radio station at that particular frequency, nothing else. The function of a filter is to shut out all the other frequencies on either side of the selected frequency. On the INTELSAT IV satellite, for example, the assigned microwave radio band was subdivided into twelve channels. The twelve channels would go through individual transmitters and then be combined to go to the antenna. To keep adjacent channels from interfering with each other, two antennas were installed on the satellite.

Channels 1, 3, 5, 7, 9, and 11 went to one antenna; channels 2, 4, 6, 8, 10, and 12 went to the other. The solution was viable as long as the antennas weighed only a few pounds. The design of later satellites called for antenna systems that were big and complex, more than a hundred pounds. Weight, of course, is a limiting parameter in a satellite. To eliminate one antenna required a whole new kind of filter.

"The specifications on those filters were pushing the state of the art," Mahle said. "Nobody could build these filters, and we and Hughes together learned how to do it. We had done a lot of research and work on filters and we said, 'Well we think we can make a multiplexor that will allow you to combine adjacent channels.' We did indeed put a crash effort together and in something like eight months we demonstrated the feasibility of this."

The new filter design paid back years later by making the launch of INTELSAT V possible on an Atlas Centaur rocket instead of a Titan III, a very substantial savings in the cost of the launch.

"I use this example when the accountants say to me, 'R&D is just money poured down the drain,'" Mahle explained. "You invest today, then ten or fifteen years later you reap the benefits."

The intensity of the work made for some lighter moments as well.

Dostis and a crew were testing INTELSAT II in a thermal vacuum chamber, a big metal can with a steel bottom, which closes tight with wedges that permit a high vacuum. They were engrossed in their work, but there was a very distracting element.

"All these building maintenance guys from Hughes were walking around," Dostis said, "looking around the floor, in the drain pipes—all over. We didn't know what they were looking for. We were measuring the satellite. They'd walk around; they'd disappear; they'd come back; they'd disappear."

All of a sudden, everything in the satellite went off.

"All the signals went off," Dostis explained, "and we were sitting there looking at each other and wondering, what was going on? We started checking our equipment, but we couldn't find anything wrong. We were saying, 'Holy mackerel, we had a major failure and we don't know what it was.' We were all sitting there thinking, 'God, this satellite is really in trouble.' "

When they cracked the locks of the vacuum chamber it was not an inrush of air that greeted them, but a deluge of water.

"Oh," the chief of the maintenance crew said, "that's where the water is."

A cooling pipe had broken in the vacuum chamber, which drained the water in the tank on the roof into the chamber. Since the search by the maintenance people did not turn up evidence of where the water had gone, they filled the tank again. It proceeded to drain, a second time, into the vacuum chamber.

"Well, what was more interesting," Dostis said, "was that we were sitting there scratching our heads, saying, 'Now we have a couple-of-million-dollar satellite in here all blown to hell.' And a Hughes spacecraft engineer we were working with said, 'Hey, maybe what we ought to do is just get all the water out of the chamber and put a vacuum on it. The vacuum will take all the water out and dry it.' So we said, 'That sounds like a good idea.'"

It took many hours to reestablish the vacuum, but that did get all the water out, and when they turned everything back on, it all worked.

"You know, you look at it and you say that's pretty ingenious," Dostis recalled. "Nine out of ten people wouldn't have thought of it. And if this one guy hadn't, we would have had a complete loss. That was the first experience I had that showed me you better turn your brain on when you're testing satellites, because if you don't, all kinds of bad things can happen."

There were a lot of complex problems ahead that had to be solved to increase the lifespan, efficiency, and effectiveness of the satellites and a lot of smart people were going to have to turn on a lot of brain power to put it all in place.

CHAPTER SEVEN

Going Digital

When John Puente was hired by COMSAT in 1963 as one of the company's first dozen employees, he—like his colleagues and many of the scientists and engineers yet to be hired—was very excited about the opportunity to ply his particular expertise along a new and as yet largely unexplored frontier. Puente was one of the country's first digital communications experts. He'd been exposed to electronics in general and radar in particular during a stint in the U.S. Air Force, extended from two to three years by the outbreak of the Korean War in 1950. Trained as a radar technician, Puente was hooked. After his discharge, he used the G.I. Bill to earn a degree in electrical engineering from Brooklyn Polytechnic Institute in New York, then went on for a master's at Stevens Institute of Technology in Hoboken, New Jersey. While in college, he worked nights as a technician, first at Bell Laboratories, then at ITT. After Puente earned his degrees, IBM offered him a job in the Washington, D.C., area, which he accepted.

"I designed one of the first modems for land lines for IBM," he explained. "Of course that kind of work was being done at other parts of IBM too, but I was in the communications department, which was a new department at that time."

Friends and colleagues started talking about the new communications satellite company and Puente began to listen. COMSAT was looking for a digital engineer and there weren't too many people with that kind of background in

1963. Puente felt his training at IBM and his expertise in radar would make him uniquely qualified to work for the new company. Radar was not that much different from satellite communications, in the sense that you were dealing with a very weak signal from very far away. Puente was interviewed by Sid Metzger and Emeric Podraczky but was having difficulty making up his mind because he liked working for IBM.

"Then Joe Charyk made me an offer I couldn't refuse," Puente recalled. "He made the whole satellite business sound so interesting. It was absolutely risky because no one had launched a commercial satellite. It was very challenging and it just intrigued me."

His first office was in the attic at the Tregaron mansion, where the young engineers around him were deeply involved in using their various skills. Puente began to get frustrated. A design engineer, he kept trying to create digital systems for satellite communications, but there was early resistance to going digital. Part of the problem derived from the nature of the backgrounds of his colleagues. Most of the people at COMSAT were analog-oriented, their backgrounds based in FM transmission. Analog transmissions were quite adequate for the early satellites and, at this point, less expensive than digital systems.

An analog system carried a voice signal on a continuous, nondiscrete basis. A digital system put the signal into a neat little discrete package. The packaging relied on the binary number system used in computer memories.

"You take the analog signal and convert it into numbers," Puente explained. "Take a sample and say all right, the signal at this moment in time is ten units. Now I'm going to write a binary number, which is a computer number, and say this binary number represents ten. Then I take another sample of the signal and I say this binary number represents eight. Now on the other side [the receive side], all I ever get are numbers. I take the numbers, convert them back to the samples, and put the signal back together again. All I do is send numbers and they're all digital numbers, ones and zeros. They have a beginning and an end. In other words it's discrete."

They could process numbers, store numbers, change numbers; the potential was very exciting. Like the geosynchronous orbit, this digital concept seemed the embodiment of simplicity itself.

"I could switch a number," Puente explained, "put this number here and this number there. I could use digital switching devices, that really work on ones and zeros—the switch is either open or closed. The signal that you've converted to digital makes it easier to do a whole lot of processing."

The economics didn't support him, however, because digital systems were a new concept and their costs hadn't come down yet. They didn't yet have the methods to mass produce large chips and integrated circuits. So it was hard to justify going to digital when analog was so much cheaper. It had to be a transition over time, especially in the heavy traffic, point-to-point systems they were working with, where even today analog is a very economic solution.

"Still, I always felt the world had to go digital," Puente says. "I felt fiber optics were coming, switches were going digital, computers were getting cheaper, digital was getting cheaper every year. The economics were going to change on a systems-wide basis. So getting all signals, whether they're video, voice, or data, into a digital number scheme was the right way to go."

With his firm convictions of a digital-based future, Puente began to take his frustrations out on paper. He wrote reams of internal memos that got the "that's nice, but . . ." treatment.

Enter Tadahiro Sekimoto, INTELSAT assignee from Nippon Electric Company (NEC) in Japan. Sekimoto had been reading, among other things, Puente's memos. When Sekimoto began to push for digital systems, literally on his way in the front door, it was as if the concept had gained an unbiased third-party endorsement. He was placed in charge of a newly created Communications Processing Laboratory and Puente went to work for him. They became close working partners and lifelong friends.

The first act of major significance by the new Communications Processing Lab did was designing a system called SPADE — *S*ingle-channel-per-carrier *P*ulse-code-modulation multiple-*A*ccess *D*emand-assignment *E*quipment. Puente felt he needed an acronym for that mouthful if he was going to continue to put his thoughts down on paper. SPADE was designed to bring smaller countries into the satellite universe.

"In the early days of INTELSAT, earth stations cost five, ten, fifteen million dollars," he said. "For these smaller countries with their low traffic, we had to come up with a system concept which was much lower cost—i.e., a million-dollar earth station. SPADE allowed you to use a smaller earth station and get sufficient traffic into your country to make you a partner, a real partner."

But there was opposition to the concept.

"I never really understood at the time," Puente said, "why people were giving us such a hard time. Why couldn't we get this kind of system in? The arguments against it were always technical. 'Single-channel FM is better than single-channel digital.' Okay, but why debate the concept?"

What he found out was that technical decisions sometimes were driven by political considerations. The traffic patterns around the world were controlled by the larger countries. Puente's system was for the benefit of smaller countries. Under existing systems, smaller countries had to route their traffic through the larger, more highly developed countries. Under SPADE, these circuitous traffic patterns could be bypassed, but the larger countries lost revenue. While such a hierarchy of communications may have been necessary when international communications were in their infancy, satellites and systems like SPADE had the potential to make them obsolete.

"Going through that hierarchy, every administration got a piece of the call," Puente explained, "that's why calls used to cost twelve dollars a minute. The most profitable business was the international. When TAT I, the first transatlantic cable, was put across the ocean, it cost roughly a hundred million dollars, and carried thirty-six circuits. It was designed to last twenty years. When satellites went up, that traffic pattern started to change rather rapidly because suddenly things were easy."

The beauty of SPADE was that you could take the satellite system as it was and convert to digital on the ground; you didn't have to do anything to the spacecraft. The satellite could remain a simple repeater in the sky. Even at this early stage, consideration was given to designing a system where the switching would be done aboard the satellite, but that would be far riskier.

"It's a big risk because it's up in space and you can't fix it in space," Puente emphasized. "But you could do a lot of it on the ground and you could make that whole satellite look like a digital switch, even though the satellite remained basically dumb, a simple repeater."

The new SPADE system received the enthusiastic support of Bill Pritchard, who was director of the labs at the time. "What we really needed was a different way of operating a satellite system, in which anybody could have one circuit, not twelve or twenty-four," Pritchard emphasized. "We needed a module of one, so that small countries could call anywhere. The SPADE system had a pool of a couple of thousand circuits. If you wanted to call someone else, you got on and there was a signaling channel. You sent a signal in effect saying, 'Hey, I got a call for you.' If you got a response saying 'Yes, the call is okay,' you took a pair of frequencies, one going and one coming, and you used them to talk. When you were finished you returned the frequencies to the pool. The other way, with preassigned channels, you had a lot of idle channels all the time. This way you could do something they do with airplanes; you could overbook them. You could handle an awful lot of traffic if you had 2,000 available channels. What's more, if you add up all the power of the 2,000, it's much more than you really do have, but you don't care about that, because you know they are not going to be used all at once."

SPADE was tested, approved by INTELSAT, and rolled out as a system for smaller countries. The digital revolution in satellite communications had begun. And that led to other applications.

An obvious satellite use of digital systems was the transmission of data from the growing number of computer users. With that in mind, COMSAT Labs' digital wizards created the wherewithal to transmit such data, which ultimately became COMSAT's DIGISAT service, demonstrated for the general public at COMSAT's new L'Enfant Plaza visitors' center in early 1975.

Utilizing the single channel per carrier (SCPC) equipment designed and developed at the labs, COMSAT had first introduced a high-speed 50-kilobits-per-second international service, but it only had viable applications for heavy users. With the new DIGISAT service, COMSAT brought mainstream users in the 2.4, 4.8, and 9.6 kilobits-per-second range into its potential markets. It represented a significant economic breakthrough, using the more efficient digital transmission capabilities unique to satellite systems. Via SCPC and the allocation of time segments through time division multiplexing, COMSAT could handle, digitally, volume that would require the equivalent of 12 voice-grade channels, using conventional FM techniques.

One of the early members of the team in the new Communications Processing Lab (CPL) working with Sekimoto and Puente was Dr. Joseph Campanella, a lifelong native of the Washington, D.C., area, who had earned engineering degrees from Catholic University and the University of Maryland. Sekimoto had hired him to head up a signal-processing research branch of CPL to deal with analog and digital signal processing. Campanella came from a background in digital signal processing and pattern recognition applied to speech and other types of signals, including units called Vocoders, created for the military.

CPL had become an exciting place to work in the late 1960s. There were numerous projects underway that ultimately would lead to significant new communications applications for the next generations of satellites. For example, the early work in time division multiple access (TDMA) had begun (see chapter 9) and there was some exciting work being done with television.

"Under the leadership of Dr. Len Golding, the digital TV branch of CPL performed pioneering efforts in the digital compression of broadcast-quality TV," Campanella said. "The system was referred to as DITEC, an acronym of digital TV compression. The concept was based on sampling of TV chrominance (color) and luminance (brightness) signals and use of a special scheme for coding sharp edges."

The result of the compression was full-motion TV pictures at a transmission rate of only 32 megabits/sec as opposed to the 120 megabits/sec that would be required to achieve equivalent quality without DITEC. That meant the equivalent in quality would use much less of the satellite system's capacity.

Digital was now solidly on the move as the method of choice for many of the new communications systems. John Puente's insistence that digital was the way to go had gotten a foot in the door with SPADE. It then wedged the door open as an integral element in many new developments at the labs, eventually becoming part of systems in voice, data, and video—in the satellites and earth stations. The future of satellite systems was getting more exciting and more challenging with each passing day.

CHAPTER EIGHT

Defeating the Echo

The dramatic decision to develop the global communications satellite network at the geostationary level brought the echo problem immediately to the fore. While the question of whether existing echo suppressors could provide at least an acceptable level of quality was answered almost immediately, the scientists at COMSAT Labs were not satisfied. Echo suppression, they felt, was simply a short-term solution. They would settle for no less than cancellation. Tests run at the labs in the late 1960s compared echo suppressors of different manufacturers in an effort to establish technical parameters for existing suppliers who were producing suppressors that ranged in quality from good to unacceptable.

Meanwhile, recognizing the inherent limitations of echo suppressors and the serious impact poor quality would have on customers using the satellite links for telephone calls, COMSAT initiated what was to become a very successful program to improve the quality of long propagation delay circuits, conducted in the Communications Processing Lab (CPL).

At that time Michael Onufry was working with Fairchild-Hiller Corporation in Rockville, Maryland, where he was unhappy about a personnel situation that had developed during the merger of staffs from the company's Maryland and New York offices. His career path led him to COMSAT in April 1966. Onufry had been an expert in voice communications in the analog area at a time when the movement was toward digital processing. He became part of the movement. He went to work almost immediately on the echo problem in the signal-processing research branch of CPL.

"Another engineer, Don Kutch, and I worked together with echo control, in testing echo suppressors and looking at the subjective effects of propagation delay," Onufry recalled. "We conducted some experiments trying to simulate the satellite delay by using the FDM carrier system and a tape recorder. The carrier system was specially modified, and we were able to take the modulated carrier (the signal) from the FDM system, put it into the analog tape recorder, and use the separation between the record and play-back heads by going through it a number of times to simulate the satellite propagation delay. Then we conducted some subjective experiments to see what the effect of this delay would be on people talking over a circuit that was patched through the thing."

They were not surprised to find that the delay was not the problem; the echo was. They began to look into better ways of controlling the echo.

The echo was created as follows. In basic terms, the telephone in a person's home or office is connected to the nearest switching office of the telephone company by a single twisted pair of wires that serve for both transmission and reception. At the telephone switching office is a transformer called a hybrid, which takes the transmit and receive speech and separates it into two different paths. This energy is now carried through the entire telephone system along separate paths, one pair of wires for transmit, another for receive. The hybrid tries to maintain a kind of balance in impedance—i.e., match the impedance of the receive channel to that of the user's telephone. The nature of the telephone system makes this all but impossible since different users have lines that are dissimilar, depending upon their distance and route from the local exchange. Thus the hybrid can become unbalanced and the energy from the receive side can leak across into the transmit side. Then the person who is talking may experience an echo of his or her own voice. When the distance between the two parties is short, the echo comes back so quickly that it's masked by the talker's speech and he or she doesn't hear the echo. But as the distance increases, there is first a hollow sound, then an intelligible echo, which, depending upon the length of the delay, can make conversation all but impossible. When the signals travel on a satellite circuit, the delay is such—about half a second—that if there is no echo control, it can begin to interfere with the thought process and even cause some people to start to stutter.

The commonly used echo suppressor was a voice-activated switch which detected the arrival of the receive speech and simply opened a switch in the return path. This prevented the echo from reaching the person who was talking. That was fine as long as only one person was talking. When the second party wanted to interrupt, you had problems. For one thing the person who shouted the loudest gained control of the voice-activated switch. If you didn't shout loud enough, segments of your speech would get cut out, a phenomenon known as chopping. If you did speak loud enough to gain control of the switch, your speech would get through, but so would the echo. You were damned if you shouted, damned if you didn't.

The international communications agencies had defined a specification for an echo suppressor and COMSAT Labs tested suppressors against that spec, then put them through subjective testing to gauge user acceptance of the different models. Manufacturers of inferior models were told to get them up to standards. Inadequate echo control would reflect badly upon the entire concept of geosynchronous satellites. They had to come up with a better mousetrap.

Among other things, echo control was important to provide technical reasons for modifying the appropriate specs of the International Telegraph Union's Consultative Committee on Telephone and Telegraph. One concept that had promise was to create a model of the terminating echo path, pass the speech on the receive end through this model and subtract out the echo. If the model did its job of creating a perfect replica of the echo, it could be subtracted from the transmit-side signal and precisely cancel the echo. This method would not interrupt the speech transmission path the way suppressors did and therefore was not prone to chopping.

"At the time, a Japanese engineer, working for Nippon Electric Company, had reported on an experimental, digitally implemented device called the blockless echo suppressor, which actually did this job," Joseph Campanella explained.

"However, it developed its impulse response by pulsing the echo path before the talker started to speak. But, with this method, once the conversation began, the echo path could not be corrected conveniently and changes in the echo path—which could take place during a conversation—would spoil the cancellation. The method was also subject to noise in the echo path, which created errors."

At the same time, Campanella had been studying experimental computer simulation work done at Bell Labs on feedback control with a device called the transversal filter, using a technique known as "the maximum rate of descent convergence." He felt this technique could be applied to the blockless echo suppressor. The seeds were planted that would result in the development of the echo canceller.

Campanella and Onufry presented their idea to INTELSAT in early 1968 and gained support to develop an experimental model. They were joined in their efforts by Dr. Henry Suyderhoud, whose experience at Bell Labs was perfect for the task of designing and building a real-time echo canceller. At Bell Labs, Suyderhoud had worked with transversal filters, manually applying coefficients, which he adjusted using a headset, then applying an analog multiplication process to show that some echo control could be obtained by simply tuning the device.

Results of the team's work bore fruit almost immediately when at the 1968 Mar del Plata Plenary, the CCITT modified its regs to say that satellite circuits were fully acceptable for international telephony for circuits with a mean, one-way propagation delay as great as 400 milliseconds. The revised recommendation noted that echo cancellers were under development and promised to improve quality even further. The change caused post, telephone and telegraph administrations (PTTs) around the world to take notice. World satellite circuits had become fully acceptable as a form of telephone communications in the eyes of the PTTs.

Under INTELSAT sponsorship, a specification was prepared to procure an echo canceller, using adaptive processing which involved the marriage of impulse response modeling, convolution with the received signal, and maximum rate of descent convergence to adjust automatically the impulse response coefficients continuously using the actual receive and transmit signals encountered in the telephone circuit. A contract was awarded to Nippon Electric, which implemented this adaptive process with its blockless echo suppressor to produce the first real-time echo canceller. The end product had one rack of power supplies and two other racks of equipment associated with it.

"And this was to control the echo on *one* end of the telephone circuit," Onufry said. "You would need one of these things at *both* ends. It was an extremely long way from practical reality at that point."

But it worked. Its principal shortcomings were that it required almost a second to develop the computer model of the echo, and it provided only 14 decibels (dB) of speech cancellation when they needed about 50 dB for complete cancellation of the echo. It was a good first step—but only a first step.

"The way the device worked was that if you were talking to me, the device that protects you against echo is at my end of the circuit," Onufry said. "So your speech arriving to me would come into the receive input of the echo control device and that speech signal, combined with the actual echo signal that results from it, was used to develop the model inside the canceller in an adaptive process."

They looked at the sign bit of samples of the echo signal and the sign bit of samples of the speech signal, examined the correlation, and through this cross-correlation process, described the echo path impulse response. The impulse response, called the "model," could be used to create a replica of the echo from the received signal by a mathematical process called convolution.

"Once you have the model," Onufry explained, "you process the speech through it, and generate the estimate of the echo. When we encode speech in a digital format, we sample it 8,000 times a second in order to be able to reproduce the amount of bandwidth that we have in a telephone channel. Then we encode each of those samples at 8 bits per sample, so it takes 64,000 bits per second for one telephone channel. The samples are stored inside the echo canceller, where they are used as input to the echo estimating process."

In order to generate the estimate of the echo—just one sample—you must take a sample of speech and multiply it by a mathematical coefficient and store that product. Then take the next sample of speech and multiply it by the next coefficient, total those two products, and continue that process typically through 256 coefficients. The sampling occurred every 125 microseconds or 8,000 times a second. That was more than two million multiplications plus two million additions each second.

So they had the first echo canceller . . . and all those racks of equipment . . . and a long way to go.

"We said, 'Well, the first thing we have to do is make it adapt faster,'" Onufry said. "One second to develop the model was too long. When people would start talking, they would hear an echo for too long at the beginning of the call and that was not acceptable."

The team was spending all of its time working with the new device, trying to come up with ways of improving it. They got the modeling delay down to one-third of a second.

"But we found we couldn't do anything about improving the amount of cancellation that it provided because the system was noise-limited," Onufry explained. "There was too much electrical noise picked up through the combination of the analog and digital circuitry, the length of wires, and the way it was put together. So at that point we decided the best thing to do would be to build another device and switch to all digital."

They started building their own unit, while INTELSAT issued another request for proposal. Campanella, Onufry, and Suyderhoud drafted the INTELSAT RFPs. Meanwhile, the COMSAT Labs team continued working to develop a canceller of its own. They decided to go digital all the way.

"We continued to be concerned with the problems of what to do when both people talked at the same time," Onufry explained. "How do we prevent the model from getting contaminated? Also, how fast did the device have to track in order to be satisfactory? How much cancellation did we need in order to have it work adequately? We didn't even know what the character of the impulse response was in the telephone system. So, we were probing to find out all of these things."

At this point, Campanella introduced another novel concept, which he called the "electronic black hole," to overcome the fact that a canceller cannot reduce the echo to zero and a whisper of echo may remain. The electronic black hole was implemented easily by not passing signal values that fall below a specified level. Any residue of echo of amplitudes less than this preset level was eliminated—i.e., got sucked into the black hole.

Meanwhile, satellite users were making do with echo suppressors. Subjective call-back testing resulted in the satellite circuits getting generally satisfactory ratings but invariably finishing lower than undersea cable circuits, in the opinion of the end users. The reason given most often was echo control.

"If both people try to talk at the same time, you might hear a burst of echo or you might have a loss of some information because the echo suppressor cut out the speech," Onufry said. "And if the echo suppressor wasn't adjusted properly, these problems could be aggravated. Twenty-five to 30 percent of those called would say, 'Yes, I had some difficulty.'"

However, people making international calls were predisposed to know that the call was not going to be as good as if they called someone in Brooklyn or Oak Park. It was also felt that a bit of education wouldn't hurt the cause while the work on the canceller proceeded.

"We were going out to electronic shows and exhibits and demonstrating what the effect of delay was," Onufry said. "One of the demonstrations that we used was the 'COMSAT Double-Hopper,' via the Etam, West Virginia, earth station. We actually simulated the effect of two satellite circuits in tandem and had people talk through it. We would ask their opinions of the quality of the circuit and we would interview them to see what their normal use of the telephone system was. Were they occasional users, for local calls only or business long-distance calls, international calls, etc. Surprisingly, we found that the rating of the circuit was independent of the user's background. In other words, whether or not people made a lot of international calls, the rating came out about the same for the mean opinion score."

Then, in the early 1970s, COMSAT Labs built the first version of an echo canceller they felt they could field test. A model dubbed "The Refrigerator," it was a single rack about four and a half feet tall. The parts for it cost in the neighborhood of $40,000.

"Since we were concerned about how fast we needed to develop the model of the echo," Onufry said, "we had a mode in it that was controlled by a single switch, whereby we could cause it to do this processing two times between each of the 125 microsecond sampling intervals. We were able to drop the time it took to develop the model to under 100 milliseconds, which turned out to be faster than what we actually needed. The ultimate specifications required it to happen in less than one-quarter of a second for a noise signal. And we were able to get up to about 25 to 30 dB of cancellation."

COMSAT Labs built two of the new echo cancellers and NEC developed two other units. They went to INTELSAT and asked if the consortium would like to participate in a field trial. That created a problem.

"Six other countries said yes," Onufry recalled, "and we didn't see a political way to weed out, so we went to all of them."

They chose New York-London for the first test, preceded by a two-week course for foreign technicians who would be participating, so that they understood how the canceller worked and could at least perform some minor trouble-shooting should there be malfunctions during the field test. The other tests were Brazil to France, Hawaii to Australia, Hawaii to Japan, and Brazil to Germany.

"The field-testing process took almost two years," Onufry said, "with shipping and moving the equipment around and the trips that were involved. But it showed that the concept of echo cancellation did in fact work. It provided better echo control than the echo suppressors."

With the success of the field trials, COMSAT Labs began to seek ways to reduce the size of the device and improve its efficiency.

"We went to time-sharing schemes and we had a central processor that worked on six different channels," Onufry explained. "You would switch from the processor to the operating unit and try to gain improvements in size that way. We looked at an approach using differential encoding rather than just straight pulse code modulation to try and save bits and reduce the size of the hardware in the processing. We looked at a logarithmic implementation of the multiplier, where instead of doing a full parallel multiply, you converted it to a logarithm and did a simple addition of two numbers. Throughout all of this, there was very close interaction between Dr. Campanella, Henry Suyderhoud, and myself. I was in the lab implementing things and making changes and bouncing ideas off of them, because I had worked for Henry, who was manager at that time, and Dr. Campanella had moved up to director of CPL."

Campanella still maintained close contact with the echo canceller development. In the spring of 1974, he became very concerned about implementing an echo canceller that could be effective and economical. He assigned to the project Dr. Otakar Horna, a digital circuit design expert, and gave him the assignment to redesign the canceller using log representations of the input and output signals and of the internal processing steps. Horna, along with a summer student, worked intensely on this project and by the end of the hot weather had a working—albeit hay-wired—echo canceller on the bench, a major breakthrough.

"We had gone from our large rack to something that was about three times the size of a tape recorder," Onufry said. "We built a limited number of these under the authorization of Dr. Edelson, who was the director of the labs at the time, and we sold them to companies like RCA and Western Union. We said, 'Here, take them into your lab, test them, do what you want to with them and see how they work.' The response that came back overwhelmed us. We started getting back orders for 300 units."

The demand for the echo cancellers led to the creation of a marketing arm. The unit was a hot seller, but all the customers seemed to want different versions.

"They wanted different bells and whistles and they wanted different monitoring schemes that fit with their own maintenance aspects," Onufry recalled. "So each unit required a different design."

The basic unit was called the COMSAT Labs Echo Canceller (CLEC) Model 2000 and it represented the conquest of the echo problem. The biggest question about the viability of satellite voice communications had been answered. Future acceptance was assured and the scientists who had worked to solve the complicated echo problem could now turn their energies to other areas.

The work of COMSAT Labs on the echo canceller was directly responsible for bringing the process from a computer-programmed mathematical curiosity to a practical, economical telephone system component that replaced the earlier echo suppressor in all telephone service in the U.S. and was replacing echo suppressors worldwide. COMSAT carried its message to the CCITT and spearheaded the acceptance of Recommendation G.165 for the echo canceller.

"It had been a cycle that started with the conception of the idea and proceeded all the way through to seeing it standardized and then rolled out into widespread applications," Onufry said. "It had been very interesting and represented the work of a dedicated team."