MOBILE SATELLITE COMMUNICATIONS HANDBOOK

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FOREWORD

When Quantum Publishing first approached me about writing a comprehensive book on the subject of mobile satellite communications, my reaction was that the task was very nearly impossible. The industry, although not well known to the public at large, is quite diverse and extremely dynamic. My main fear was that almost any text would be outdated between the time it was written and the time it could appear. Only time will tell for how long this text, prepared for the most part during mid-1993, will endure.

From the outset, my goal has been to prepare a book that would be useful to nonengineers and nonexperts who have an interest in mobile satellite communications. This, I believe, is important because mobile satellite communications will touch the lives of millions of people over the next decade. Understanding how we got to where we are today, as well as what is happening in the United States and in other countries in the military, commercial, and scientific sectors will help telecommunication professionals and others understand and manage this growth.

As with any such book, this would not have been possible without the generous help of many people, nearly all of whom are more knowledgeable than I. I owe special thanks to the librarians and the historians of the National Aeronautics and Space Administration (NASA), who look after a great national treasure of information. Also, I am indebted to several retired officers of the United States Army Space Command as well as to Joseph Charyk and others from COMSAT, whose efforts did much to develop mobile satellite technology from a military to a commercial arena. A list of all of the other experts who assisted me in the research for this book would fill a book in itself. It is sufficient to say that many industry pioneers and nearly every mobile satellite system operator, or planned system operator, along with many equipment manufacturers, contributed material, information, and ideas for this book.

Finally, I would like to thank Susan Bruno for her research and Annita Kallam for her administrative skills, both of which made this publication possible, as well as my wife, Mary, and publisher Paul Mandelstein, whose support and counsel I value highly.

Roger Cochetti

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1

INTRODUCTION TO SATELLITE COMMUNICATIONS

1.1 A BRIEF HISTORY OF SATELLITE COMMUNICATIONS

1.1.1 Origins of Technology

The advent of satellite communications has revolutionized the world's ability to communicate. The modern age of space-based communication probably began in 1945, when Arthur C. Clarke, then secretary to the British Interplanetary Society and later the author of such popular works of science fiction as *2001: A Space Odyssey*, wrote an article entitled "Extraterrestrial Relays" for *Wireless World*. In it, Clarke described his idea for a worldwide satellite communications system that would be based on three satellites positioned equidistant from each other in orbit over the equator at an altitude of 22,300 miles. Each satellite would be linked by radio to the two others and to the ground, thereby allowing anyone on Earth to reach anyone else in the world—wherever that person would be located—by tapping into this radio network. Clarke described the orbital path as a geosynchronic orbit, referring to the fact that a satellite at that specific altitude above the equator could orbit Earth at precisely the same speed as Earth itself rotates, thereby making it appear to be stationary from the perspective of someone on the ground. Because such a satellite would stay above the same spot on Earth at all times, radio signals could be relayed through it without interruption. This orbit today is normally called geostationary, or GEO.

Geostationary satellites are by no means the only type that can be used for communications (as we will see in later chapters), but their development served as a foundation for most modern satellite technology. Two supporting technologies during the 1950s led to the development of communication satellites. The invention of the transistor made unattended, long-endurance satellites possible because, unlike tubes, transistors do not require frequent replacement—a difficult task when a satellite is 22,000 miles away. Second, advances—mainly military—in rocketry and rocket guidance systems made the deployment of a satellite at high altitudes feasible.

Although many theorists imagined satellite communications applications during the decade after World War II, a link from the United States to Europe was probably the first application in which the possibility of using satellites was seriously considered. An undersea telephone cable to Europe was also being considered at this time. Ten years after the end of World War II, the first transatlantic voice cable linking the United States and Scotland was completed. This transatlantic telephone cable, TAT-1, went into use in 1956. It replaced radio telephone technology and it provided reliable voice connections between the United States and Europe for the first time. The one major drawback was its limited capacity. It was designed to handle only 36 telephone calls at one time, and no television at all. More important, cables then were designed to connect a small number of points, often only two, with each other. Consequently, they did not reach beyond the largest cities in Europe.

Following World War II, the U.S. and Soviet military had thought about building and launching reconnaissance and communications satellites, but both military establishments were more interested in guided missiles. Their work on ballistic missiles would eventually make satellite launches possible.

Most U.S. plans for communications satellites (Satcoms) remained on the drawing boards, or the seminar table, however, until news of Sputnik splashed across the headlines in October 1957. As part of its contribution to the International Geophysical Year (July 1957 through December 1958), the Soviet Union launched a 184-pound sphere into a 560-mile orbit above the Earth. The satellite carried two small radio transmitters, which lasted for 22 days. As a form of propaganda, Sputnik represented an attempt by the Soviets to demonstrate to the world the superiority of Soviet over U.S. technology, power, and perhaps even ideology.

The impact of this point was not lost on the U.S. government; each of the three U.S. armed services had developed their own low-to-mid-level–priority satellite program prior to 1957 on the grounds that satellites were of debatable military value. In rapid order, the U.S. satellite program was given a very high priority by each of the services. Two months after Sputnik I, the U.S. Navy attempted and failed to launch a satellite on a Vanguard rocket in a spectacular launch explosion. About four months after the launch of Sputnik I, the U.S. Army launched the first U.S. artificial satellite, Explorer I, on a Jupiter rocket. In July 1958, the National Aeronautics and Space Administration (NASA) was established to pursue a civil space program. The so-called "space race" was on.

From this point forward, most satellite programs, industries, and technologies in the United States began to diverge into two distinct groups: military and civil/scientific. Later, a third group, commercial, emerged, and military satellites further divided between communications and reconnaissance (sometimes called remote sensing).

The first true communications satellite, the U.S. Army's experimental SCORE (Signal Communications by Orbiting Relay Equipment), was developed by the Defense Department and launched on December 18, 1958 into an elliptical orbit ranging from about 100 to 900 miles. It contained a very high frequency (VHF) radio receiver/transmitter and tape recorder to receive and store messages from the ground as the 99-pound satellite passed overhead on its orbit. The transmitter/receiver also permitted the satellite to serve as a real time relay between two ground stations below. The store-and-repeat mode was considered useful for military purposes because it would permit a satellite to transmit orders from the Pentagon to a commander in some distant region, and to carry intelligence in the opposite direction. SCORE proved that Atlas rockets could be used to launch satellites, but it lasted just 12 days. It was, however, an experimental success and was perhaps best known for proving that communication via satellite was possible as well as for the Christmas greetings it carried from President Eisenhower in 1958.

Following the success of SCORE, the U.S. Department of Defense (DOD) assumed responsibility for satellite programs. DOD's Advanced Research Projects Agency (DARPA) set up three study panels and through the U.S. Army it deployed Courier in 1960. This 500-pound satellite (there were two, but the first failed on launch) lasted only a few weeks, but demonstrated the use of solar cells for electric power in an active repeater satellite. Its success led the U.S. military to devote significant resources to develop satellite communications technology through the creation of Project Advent, which was assigned to the Army as the lead agency for the project.

On the civil side, virtually from NASA's birth, it assumed federal responsibility to develop civil communications satellites. During the early 1960s, NASA worked closely with ATT, Radio Corporation of America (RCA), Hughes Aircraft Company, and many other companies to define the technologies that would make communications satellites viable. This led to several NASA experimental and demonstration satellites that tested different techniques. In August 1960, the first of two Echo satellites, for example, tested a passive satellite communications technique by launching a 100-foot diameter balloon into a 1,000-mile orbit. Ground transmitters would literally bounce signals off the balloon's aluminum mylar skin so that receivers could catch the VHF and UHF (ultrahigh frequency) signals at some distant location. The next, and probably the most famous, satellite experiment involved two 1962/1963 satellites developed by ATT's Bell Laboratories and NASA called Telstar. Like SCORE and Courier, Telstar was a solar-powered, active satellite, but it carried live television or multiple channels for voice. It was placed in an inclined elliptical orbit about 600 miles from Earth's surface at its low point and 3,500 (almost 7,000 miles for Telstar No. 2) miles away at its high point. Telstar weighed about 170 pounds and was about the size of a large beach ball. It circled Earth about every three hours, making a live C-band (6 and 4 gigahertz (GHz)) communications link available at any one time for about ten minutes before the satellite passed overhead. More than any previous satellite, Telstar brought satellite technology to the public's attention through its live international television transmissions. The third early NASA experimental satellites were called Relay. Built by RCA, these two elliptically orbiting satellites were launched in 1962 and 1964. They tested redundant systems and demonstrated that satellites could operate at the C-band without interfering with terrestrial microwave systems.

None of these early experimental communications satellites led directly to an operational system, but they did provide important engineering data on various factors necessary for an operational communications satellite. Telstar and Relay shared a common technical limitation, however. Because of their orbit and because the speed of their rotation was faster than the rotation of Earth, they appeared to an observer on the ground to move eastward across the sky. So it did not take long for one of these satellites to move out of position to hold a continuous communications link. Such elliptically or medium earth orbiting (MEO) satellites were gone from sight within ten minutes of their appearance, and it would be hours before they reappeared. The only way to offset this limitation was to deploy a ring of such MEO satellites, so that as soon as one began to move out of sight, another would enter. But, in the early 1960s, this was a financially and technically daunting task for both government and industry.

Although most of the focus of NASA's early attention to communications satellites was on low- and medium-altitude technologies, DARPA and the Army focused on the idea of a large geostationary (GEO) communications satellite, called Advent. However, after several years of developmental effort, and much interservice wrangling, Advent was canceled. As a result of a growing list of demands from each of the military services, the planned GEO military satellite had grown to such a size that there was no rocket system powerful enough to launch it in the early 1960s.

While Advent stalled, Hughes Aircraft Company proposed to the U.S. military and to NASA a much smaller (86 pounds) geostationary communications satellite that would spin like a top to give it stability. After some resistance, and with Advent experiencing continued delays, NASA and DOD decided to provide the necessary support for three such satellites. They were called Syncom, and they were the first geostationary communications satellites. DOD supplied the ground stations and NASA developed the satellites. The Syncom series proved the viability of geostationary communications satellites beginning in 1963. Although Syncom I failed, Syncom II and III were successfully placed in orbit in 1963 and 1964, providing live TV transmission of the 1964 Tokyo Olympics. The joint NASA-DOD satellites used military frequencies of 7.36 GHz from the ground to the satellite and 1.815 GHz from the satellite to the ground, and they operated until 1966.

Syncom II and III demonstrated the value and reliability of GEO satellite technologies and set the stage for the domination of satellite communications by geostationary techniques for some time to come. Syncom's success was also instrumental in gaining worldwide agreement in 1963 to allocate 2.8 megahertz

(MHz) of radio frequency at the 6- and 4-GHz bands for satellite communications, which was an essential prerequisite for the later commercialization of satellite communications. They demonstrated that, as Arthur Clarke had predicted, as long as a dish antenna could get an unobstructed look at a GEO satellite as the satellite hovered above the equator, near worldwide communications coverage was possible.

1.1.2 Origins of the Legal Structure—International

Aside from the U.S. government military and civil satellite programs, as early as 1960 President Eisenhower had articulated a national policy to establish a *commercial* communications satellite system. With the advent of the Kennedy administration, federal satellite policy shifted, however. In his 1961 State of the Union message, President Kennedy invited all countries the join with the United States in developing a communications satellite program, thus giving greater emphasis to the foreign policy (versus the commercial) nature of the powerful new technology. Kennedy's initiative was clearly intended to support the U.S. in its growing rivalry with the Soviet Union.

Partly because of the Kennedy and Johnson administrations' emphasis on the foreign policy aspects of satellite policy, a lengthy debate took place in the Congress over how the government-developed satellite communications technology should be used for communications. Some felt that the U.S. government should take on the task of developing an international satellite communications system; others that it should be taken on by telephone companies and other common carriers; and still others that it should be taken on by altogether new organizations. Acting on a request from President Kennedy in 1962, the Congress decided to follow the later course and create a new organization, a shareholder-owned company, to commercialize international communications satellite technology through an international effort. This company, Communications Satellite Corporation, or COMSAT (today COMSAT Corporation), was intended to be nongovernmental but operat-