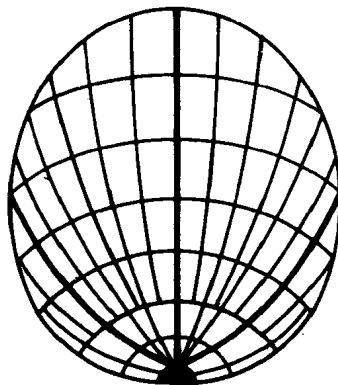


Emanuel Fthenakis

**MANUAL OF
SATELLITE
COMMUNICATIONS**

73-46113073
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Emanuel Fthenakis



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McGraw-Hill Book Company

*New York St. Louis San Francisco Auckland
Bogotá Hamburg Johannesburg London Madrid
Mexico Montreal New Delhi Panama Paris
São Paulo Singapore Sydney Tokyo Toronto*

8750010

EC94/113

Library of Congress Cataloging in Publication Data

Fthenakis, Emanuel.

Manual of satellite communications.

Bibliography: p.

Includes index.

1. Artificial satellites in telecommunication.

I. Title.

TK5104.F8 1984 621.38'0422 83-842

ISBN 0-07-022594-X

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1234567890 KGP KGP 898 185 48

ISBN 0-07-022594-X

The editors for this book were Harry Helms and George Watson,
the designer was Elliot Epstein, and the production supervisor
was Thomas G. Kowalczyk. It was set in Caledonia by University
Graphics, Inc.

Printed and bound by The Kingsport Press.

8720010

PREFACE

The design of a good, reliable satellite communications system presents a significant challenge to the designer. Low available signal power, limited bandwidth, nonlinear operation, proximity of adjacent channels, high cost, severe weight restrictions, and inaccessibility for maintenance are only some of the technical problems encountered. Restrictions stemming from governmental regulations and nationalistic interests have further complicated the system designer's task. Fortunately, however, innovative minds have coped with these complex factors and have succeeded in bringing the space communications era to the office, computer room, or television set of the user at competitive prices.

Engineers, especially new graduates, in their efforts to adapt their general academic training to this new field of satellite communications find it necessary to take additional specialized courses. The material in this book is based on lecture notes which I used in teaching such a course for a first-year graduate curriculum. The lectures were prepared for engineers who were just starting their careers in the satellite communications industry and who thus had little or no practical experience in the field. In addressing this audience I found it necessary to include material on certain fundamental principles of network and communications theory which are widely used in the design of satellite communications systems. Since there are several excellent references specializing in one or more of the topics on fundamentals covered in this material, I did not attempt to treat these subjects with strict mathematical rigor. In addition, because of the wide variety of topics that had to be covered in a single semester, the depth of presentation had to be limited in some cases.

As a result of my association with several technical organizations specializing in satellite communications, it became obvious that the lecture material could be adapted to the use of a much larger group of practicing professional engineers. I was encouraged by many of my colleagues to publish this material, and

as a result this book was written. The following paragraphs present a brief chapter-by-chapter description of the text.

The first chapter summarizes the development of satellite communications systems in the period from 1962 to 1982. The emphasis is on U.S. systems and the evolution of commercial communications via satellite, including some of the regulatory aspects. The second chapter is descriptive in nature and acquaints the reader with the terminology and the function of the key elements of a complete system, including cost elements. Some of the unique characteristics of satellite communications are also examined.

Chapter 3 covers satellite orbits and some typical launch sequences. The purpose of this chapter is to acquaint the reader with terminology and fundamental relationships of the various orbital parameters. The spacecraft, considered as a platform designed to carry a communications repeater station, is covered in Chapter 4. Again the main purpose of this chapter is to acquaint the reader with the terminology and the critical parameters that affect the platform's main function, i.e., to house a long-life communications repeater.

Chapter 5 discusses the communications repeater and defines the terminology used in two-port network theory, which is helpful in the characterization of the low-noise front section of the repeater. Since noise is a critical problem, an elementary treatment of noise sources is also included. Finally, the nonlinear characteristics of the power amplifier are discussed, including an elementary illustration of the intermodulation problem. A similar approach is used in Chapter 6, which discusses communications earth stations.

Chapter 7 develops the space-link equations.

Chapters 8 to 12 examine some of the fundamentals of communications system theory that are directly applicable to satellite communications. Appendixes B, C, and D summarize the mathematical tools utilized in these chapters.

The intention of Chapter 13 is to provide better understanding of the most significant transmission impairments.

Finally, Chapter 14 addresses the characteristics of voice, video, and data channels. It treats the baseband signals and the techniques used for designing satellite communications networks.

The field of communications via satellite is still developing. Both new applications and new technology are strong driving forces in this respect. In addition, alternative advanced communications concepts are emerging every day, creating pressures for continuous improvement of the economic aspects. Consequently, there is a great need for continuous innovation and improvement, and at the same time, excellent opportunities for contribution by the practicing engineer in the field of satellite communications.

Many of my colleagues and associates have assisted me in preparing this book. Their contributions range from assistance with certain theoretical elements to suggestions and recommendations on the basic material, provision of illustrations, and review of drafts.

It would be impractical to acknowledge all the contributors by name, but I wish nonetheless to express here my sincere appreciation for their help. In particular I wish to thank several of my colleagues at Fairchild Space and Electronics Company and American Satellite Corporation who made material contributions toward the creation of this book. I am also indebted to Mary Shaw for her valuable assistance in organizing, producing, and correcting the drafts.

Emanuel Fthenakis

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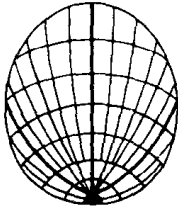
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1

THE FIRST 20 YEARS OF COMMUNICATIONS SATELLITE DEVELOPMENT (1962-1982)

During the 20 years from 1960 to 1980, the capability for worldwide satellite communications developed dramatically to become an integral part of the various operating communications networks. At the same time, the regulatory and legal concepts governing the communications industry were revolutionized in order to accommodate the new technological capabilities.

ORIGINAL SYSTEMS

The first serious efforts by the United States for the development of a satellite communications capability date back to the late 1950s. At that time the U.S. Department of Defense initiated a number of projects, such as Project Courier, which finally resulted in the Initial Defense Communications Satellite Program (IDCSP). The IDCSP satellites were launched by the U.S. Air Force and were placed in operation in 1966. The system was used for strategic communications by the Defense Communications Agency (DCA). By 1982 the third generation of a Defense Satellite Communications System (DSCS-III) had been developed and placed in operation.

Simultaneously, the National Aeronautics and Space Administration (NASA) also initiated a number of experimental satellite programs, such as Relay and Syncom, which culminated in the first operational commercial communications satellite, Early Bird, launched in 1965 for the Intelsat consortium. The Early Bird was immediately followed by the launch of the Intelsat II in 1966. Intelsat, a consortium of many countries of the western world, including the United States, the United Kingdom, France, and Germany, utilized this system to provide international communications across the oceans. By 1982 Intelsat had developed and placed in operation its fifth generation of communications satellites.

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At about the same time, the Soviet Union placed the first of many communications satellites in operation. The Molniya satellite was launched and placed in operation in 1965.

Intelsat, although providing satellite communications services for commercial use, did not represent a real competitive commercial venture since all the members of the consortium were government-controlled entities. The first U.S. commercial satellite communications system to operate under the forces of the free marketplace and to be financed with risk capital went into operation during 1974. The Federal Communications Commission (FCC) accepted applications for U.S. domestic satellite communications systems in 1971. After the FCC's adoption of a limited "open skies" policy, three domestic carriers initiated operations within months of each other during 1974: American Satellite Corporation, a subsidiary of Fairchild Industries, Inc.; Americom of RCA; and Western Union. Initially all three carriers utilized the 12-transponder, spin-stabilized Westar I and II satellites as their space segment. The previous year Canada had procured the U.S.-built and -launched satellite, Anik, and, through special agreements, transponders in the Anik spacecraft were leased to the U.S. domestic carriers. During 1976, RCA-Americom launched the 24-transponder, three-axis-stabilized satellite Satcom I, the first of a series of similar spacecraft. American Telephone and Telegraph (AT&T) and General Telephone and Electronics (GTE) shared a space segment, Comstar I and II, also launched in 1976. The sixth U.S. domestic carrier, Satellite Business Systems (SBS), a partnership formed by IBM, Comsat, and Aetna Insurance, launched its first spacecraft in 1981 and initiated service shortly thereafter. Eventually American Satellite Corp. acquired a 20 percent ownership in the Westar I, II, III, IV, and V space segment. Table 1-1 tabulates these six original U.S. domestic carriers.

Until the launch of the SBS space segment, every commercial system, with the exception of some experimental systems, operated at C band (4 GHz/6 GHz). SBS initiated operations utilizing the K_u frequency band (11 GHz/14 GHz). The Westar, Comstar, and SBS satellites are spin-stabilized whereas Satcom is a three-axis, body-stabilized spacecraft with deployable solar arrays. With the exception of Comstar, which utilized the Atlas-Centaur as a launch vehicle, all spacecraft were launched with a Thor-Delta booster.

TABLE 1-1 U.S. DOMESTIC SATELLITE CARRIERS

Operational date	Carrier	Space segment	Frequency
1974	American Satellite	Westar I, II, III	C band
1974	Western Union		
1974	RCA-Americom	Satcom (1976) I, II, III, IV	C band
1976	AT&T	Comstar D-1, D-2, D-3, D-4	C band
1976	GTE		
1981	SBS	SBS F-1, F-2	K _u band

0100578



FIGURE 1-1 Initial Defense Communications Satellite Program (IDCSP): single spacecraft. (Photograph courtesy of Ford Aerospace and Communications Corporation.)

Each of the six original satellite carriers has expended in 1978 dollars somewhere between \$200 and \$600 million in capital and start-up costs for its original system. This figure includes both the space and ground segment. It is estimated that the total amount spent by the six carriers is in the neighborhood of \$2 billion. Figures 1-1 to 1-3 depict some of the above-mentioned satellites.

SECOND-GENERATION U.S. DOMESTIC CAPABILITY

During the 1980-1982 time frame a number of new applications for new systems or for expansion of existing systems were filed with the Federal Communications Commission. Table 1-2 tabulates these proposed systems, indicating the owner and the approximate year of launch. The two new entrants in the list are Hughes Aircraft Company and Southern Pacific Communications Corporation (SPCC). (For several previous years Southern Pacific Communications had been operating as a terrestrial carrier.) With the exception of the SBS sat-

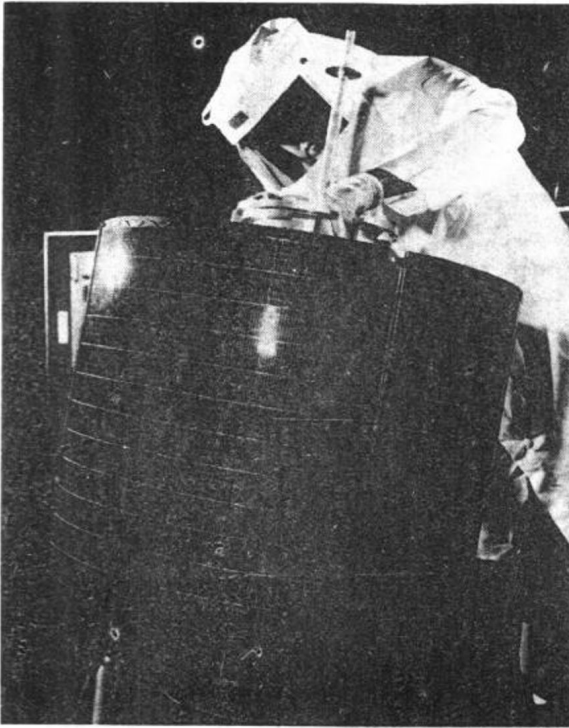


FIGURE 1-2 Early Bird. (Photograph courtesy of Hughes Aircraft Company.)

TABLE 1-2 SECOND-GENERATION PROPOSED U.S. DOMESTIC SPACE SEGMENTS

Satellite system	Owner	Starting year	Frequency
Galaxy H-1, H-2, H-3	Hughes (new)	1982	C band
Spacenet I, II, III	SPCC (new)	1983	C band, K _u band
Advanced Westar F-1, F-2, F-3, F-4 (TDRSS)	Spacecom (new), American Satellite, Western Union	1983	C band, K _u band
G-Star I, II	GTE (new)	1984	K _u band
Telstar 3-A, 3-B, 3-C	AT&T (new)	1983	C band
American Satellite I, II	American Satellite (new)	1985	C band, K _u band
Westar IV, V, VI	Western Union (new), American Satellite	1982	C band
SBS III, IV	SBS	1982	K _u band

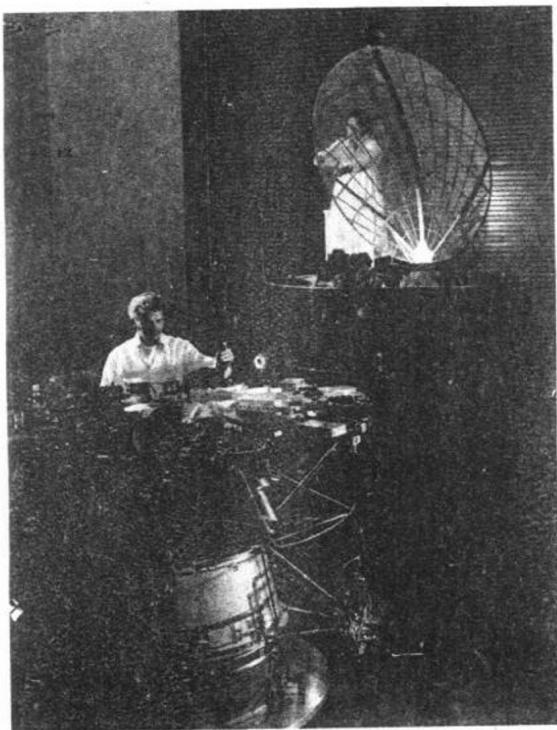


FIGURE 1-3 Westar II and electronics and propulsion sections of Westar III. (Photograph courtesy of Hughes Aircraft Company.)

ellites, the space segments represent a new design of spacecraft configuration employing at least 24 transponders, some utilizing both the C and K_u bands simultaneously.

If one excludes the Advance Westar of the Tracking and Data Relay Satellite System (TDRSS) space segment, the aggregate cost in 1981 dollars of all the proposed additional U.S. domestic space segments in Table 1-2 will be about \$1.5 billion, which does not include the establishment of additional ground segments to serve the new entrants. In its original configuration, the TDRSS/Advance Westar space segment consisted of four spacecraft in orbit and two on the ground and was to be dedicated to both the U.S. government and domestic commercial service on approximately a 3:1 ratio. The total cost of the space segment was estimated to be about \$1.5 billion.

Each of the initial five domestic carriers before 1976 developed a backbone ground segment of major earth stations. Each of these ground segments involved somewhere between four and ten major earth stations. Subsequently,

a substantial amount of additional ground segment was established for specific business users, government networks, receive-only stations for television operations, etc. Figure 1-4 depicts the 1981 network configuration utilized by American Satellite Corp. It consisted of over 100 earth stations of which only four belonged to the original backbone network. A typical business-dedicated network (for First Interstate Bancorp) is represented in Fig. 1-5. By 1982 literally thousands of stations had been deployed all over the United States with multi-channel receive-only capabilities for the service of the television entertainment industry.

Some of the terrestrial networks were modified to be fully digital by utilizing time-division, multiple-access (TDMA) techniques and digital voice transmission. For example, by 1980 the American Satellite backbone network used a 63-Mb/s-per-transponder TDMA system. The voice was compressed from the usual 64-kb/s pulse-code modulation (PCM) to 32 kb/s per channel by near-instantaneous companding (a modified PCM technique). SBS utilized a 48-Mb/s TDMA system.

Table 1-3 summarizes the major services provided by the U.S. domestic satellite carriers.

It is interesting to note that the problem of satellite delay for high-speed interactive data was solved as early as 1978 and that high throughput efficiencies of about 98 percent have been achieved. In addition several dedicated networks—such as banking networks—utilize special encryption techniques for

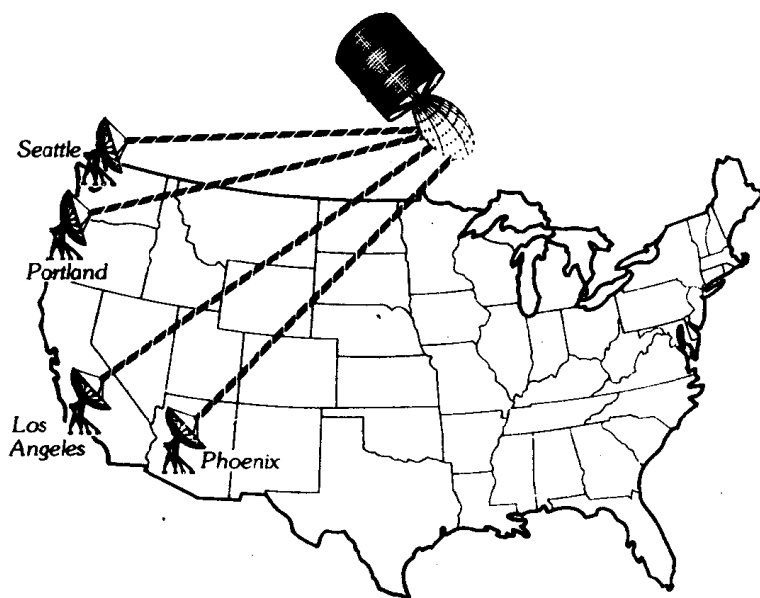


FIGURE 1-5 First Interstate Bancorp Data Processing Company network map.