DIGITAL COMMUNICATIONS

SATELLITE/EARTH STATION ENGINEERING

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FOREWORD

Communicating via satellite is no longer the novelty it once was. Yet, the impact of the extraordinary growth and development of satellite technology and services during the 1960s and 1970s has rendered satellite communications an indispensible part of our daily lives as we move into the 1980s.

Soon to become another indispensible part of our daily world of communicating is the rapidly expanding technology of digital satellite communications.

In the 1960s, digital communications was largely regarded as theoretical and experimental; in the 1970s the premise began to be realized; and now, the 1980s is clearly the decade of digital satellite communications. The analog satellite communications techniques that were the mainstay of services during the 1960s and 1970s are no longer adequate to meet the exploding communications demand for the future, and thus the implementation of digital communications systems, including a growing number of communications satellite systems, is well under way. Already millions of users are benefiting from advanced telecommunications systems that have brought digital technology from infancy to maturity in little more than a decade. The future of digital communications has already arrived.

This, then, is an opportune time for a well-reasoned, pragmatic book on digital satellite communications—and Dr. Kamilo Feher has given us just such a publication.

One of the most significant contributions of *Digital Communications: Satellite/*

Earth Station Engineering is its broad scope. It covers all aspects of digital radio communications, both space and ground.

The author's many years of industrial and research experience are reflected throughout this thorough work that undoubtedly will be of particular interest to the engineer who is seeking extensive knowledge of a complete modern satellite system, including the earth segment. Recognizing the importance of satellite earth station design, the book contains a wealth of information related to earth station operating principles, design, and operation.

The technical advantages of digital satellite communications, which are explored in depth in Professor Feher's book, give promise of efficiencies of greater than 2 bits per second per Hertz of radio-frequency spectrum. When coupled with satellite clusters, space platforms, and narrower spacing of satellites in geosynchronous orbit, these efficiencies hold promise of communications satellite systems that can provide global capabilities in excess of 100 gigabits per second—capabilities that were virtually inconceivable just a decade ago. These breakthroughs will not come easily, however. They will require the expertise of countless scientists and engineers to bring the new digital satellite communications technologies to fruition. Dr. Feher's clearly written book, which includes three chapters by other internationally acclaimed experts, should serve well as a "training tool" to enable engineers of the 1980s and 1990s to achieve these goals.

It is, of course, interesting and gratifying to see the recognition accorded the organization I represent—the International Telecommunications Satellite Organization. INTELSAT has been deeply involved in and committed to the development of digital satellite services, most notably TDMA—which we regard as essential for satisfying the vast digital communications requirements lurking on the horizon. Thanks to Professor Feher's comprehensive presentation, not only INTELSAT but a complete spectrum of domestic satellite systems, with numerous design examples, have been given excellent coverage.

My congratulations to Dr. Feher for this important contribution to the field of digital satellite communications and its future development.

S. Astrain
Director General
INTELSAT

PREFACE

By mastering this book, you acquire the tools and skills necessary to analyze and design elements of modern satellite communications systems. As you advance through the chapters and study the numerous "*real-life*" examples, you learn the principles and better understand operational and planned domestic, international, and intercontinental digital communication satellite systems. This book is for the professional engineer and manager, for the advanced student who wants a solid understanding of this field and for the researcher who needs a consolidated comprehensive up-to-date reference text of digital communications systems.

The growth of satellite communications capacity and capability has been revolutionary, a result of the flexibility provided by multiple-access, global-coverage digital satellite systems.

The *unique ability* of telecommunication satellites to cover the globe has opened a new era for regional and *global* communications. Systems using a *single* satellite offer the *flexibility* to interconnect any pair of users separated by great distances up to 17,000 km (approximately one-third of the circumference of the earth), and systems using three satellites can provide a *global coverage* with multiple-access flexibility.

14/12-GHz transmit–receive antenna of the University of Ottawa. The performance of new modems, codecs and SCPC and TDMA systems is evaluated under the research direction of Dr. K. Feher. The Canadian ANIK satellites are used in these experiments. Professor Feher is in foreground.

This *truly unique multiple-access* flexibility includes communication links between satellites and:

Fixed points on earth
Ships at sea
Airplanes
Trains
Automobiles
Other moving space vehicles
"Man-pack" terminals carried by a person and installed in 5 minutes or less

There are no other communication systems that can approach *this flexibility.* Satellite communications costs are essentially insensitive to the distances between terminals, whereas the costs of terrestrial (nonsatellite) services are dependent on distance.

The variety of data formats and services that can be provided by satellite links include:

Telephony signals
Television (vision and audio) signals
Computer-generated signals (computer communications)
Broadcast data for computer communications
Teleprinter
Large-screen teleconferencing
Interactive education
Medical data
Emergency services
Electronic mail
Newpaper broadcast
Control data for power systems and utilities
Traffic information
Weather and land surveillance
Navigational data for ships and airplanes
Military strategic data

This list is far from complete, and as each year passes, will become even less complete as new requirements are created and accommodated. The flexible multiple-access long- and short-distance satellite systems offer more and more reliable, cost-effective solutions.

A large number of U.S., Canadian, Japanese, European, and other domestic communications satellites, as well as the INTELSAT satellite systems, are now either operational or under construction. More than half of the commercial overseas long-distance telephone calls, as well as almost all of the overseas commercial live television programs, are relayed by "*synchronous*" satellites that, with the exception of slight drift due to imperfect "stationkeeping," appear to float at synchronous attitude (76,000 km) above a single point on the earth's surface. A significant number of countries are also relying on satellites for their data transmission and military communication needs.

During the late 1970s and early 1980s most major operational satellite and terrestrial line-of-sight microwave systems use *analog* FM modulation techniques. However, the trend in *new development* is such that the overwhelming majority of new satellite systems employs *digital* methods. This trend has been reinforced by recent domestic system decisions in the United States, Canada, and France (also in many other countries), where the digital approach for new transmission facilities will be predominant. The decision of the board of directors of INTELSAT, taken during 1980, to use time-division multiple-access digital modulation techniques on INTELSAT-V and future generations of satellites has a significant impact on the development of digital satellite communications—over 100 countries use the INTELSAT satellite network. Should this present trend continue, it is expected that by 1993 almost all new system additions will be digital. Consequently, engineering *students*, telecommunications professionals, and academics must become familiar with the *principles, design, applications,* and *planning* of digital satellite communications networks and systems.

In most system applications one satellite serves many earth stations. The number, type, and size of satellite earth stations is dramatically increasing. There is even more growth and *investment* in the *satellite earth station* segment than in the satellite transponder business. For this reason particular attention is focused on *earth station analysis and design criteria.*

Elaborating on the scope of this book, the *engineers* and *managers* employed by the operators of satellite communications networks, systems, and equipment designers employed by manufacturers of telecommunications equipment, manufacturing engineers and managers, marketing managers, product planners, consulting engineers, engineers engaged in research on telecommunications, and also those of the managerial, administrative, and technical staff of government agencies concerned with the regulation of telecommunications will find this book to be an invaluable source of information in problem-solving skill development. This book is also intended to be suitable for use as a *text* at the first-year *graduate* or *senior undergraduate* level, as well as for reference purposes, in *universities* and other technical institutions. It is expected that you have been exposed to the fundamentals of communications systems. A prior exposure to probability theory would be an asset.

You are introduced to the satellite communications challenge of the 1980s and 1990s, to illustrative earth station and satellite communications subsystems, and to link budget calculations in *Chapter 1.*

Signal processing and multiplexing techniques used in terrestrial interface subsystems are described in *Chapter 2.* Following a brief review of conventional PCM techniques you are introduced to more advanced analog-to-digital conversion techniques (adaptive differential PCM modulation, DPCM) for audio and television signals, to transmultiplexers, echo suppression/cancellation, digital speech interpolation, and energy dispersal systems.

In *Chapter 3* baseband transmission systems principles and design techniques are described. Baseband spectra, Nyquist theorems, and filtering/equalization techniques are presented which are essential for the design of spectrally efficient digital satellite systems.

The techniques presented in this and also in other chapters may be applied also to digital cable, fiber optics, line-of-sight microwave, and to telephony data transmission systems. You are exposed to numerous original data transmission, signal-processing, and modulation techniques which are presented for the first time in a book. A careful study of these innovative techniques will enhance your creativity and understanding of new, frequently competitive, system developments.

You study the principles, performance analysis, and design tools of *power-efficient digital modulation* techniques for linear and nonlinear satellite earth station and satellite system applications in *Chapter 4.* There is *no other book* which presents this important subject in an in-depth, pragmatic, comprehensive manner. Also included are the more important design aspects of conventional QPSK and also new innovative modulation techniques and the performance analysis of these systems in both adjacent and co-channel interference environment. Integrated-circuit implementation of frequently used building blocks are also presented. *Illustrative design examples taken from our experience in INTELSAT and domestic digital satellite system and hardware designs reinforce your understanding of the practical system capabilities and constraints.*

In *Chapter 5* you are exposed to *spectrally-efficient digital modulation* techniques which have a spectral efficiency of more than 2 b/s/Hz. The congestion prevailing in many regions of the radio spectrum has created the need for improved spectrum utilization techniques. With the recent discovery of nonlinearly amplified modulation techniques, it is reasonable to expect that some future generation satellite systems will have a sufficiently high signal-to-noise ratio to employ highly spectral efficient modulation techniques. This chapter includes a concise summary of the material contained in my previously published book, *Digital Communications: Microwave Applications* (Prentice-Hall, Inc., 1981).

You learn the principles and applications of error correction and detection codes in *Chapter 6.* This chapter, written by **Dr. W. H. Tranter,** *Professor, University of Missouri,* presents a down-to-earth, clear treatment of the most important principles of coding and information theory and their applications in digital satellite systems. You are guided gradually from the simplest concepts to a solid understanding of the advantages of coded systems.

Synchronization subsystems (particularly carrier recovery and symbol timing recovery systems) used in coherent digital transmission systems are described in *Chapter 7,* written by **Dr. L. E. Franks,** *Professor,* at the *University of Massachusetts.* The in-depth theoretical treatment of complex signal envelopes and of maximum likelihood receivers is presented in the appendices of this chapter, in order to enable understanding of synchronization systems, without the need to go through complex equations. The material presented in this chapter is of particular interest to engineers who have to acquire a solid theoretical foundation of synchronization systems.

Dr. S. J. Campanella, *Executive Director,* and **Dr. D. Schaeffer,** both of *COMSAT Laboratories,* describe time-division multiple-access (TDMA) satellite systems in *Chapter 8.* These systems are becoming the backbone of INTELSAT and of numerous domestic satellite systems. Both background and advanced material are presented in this chapter.

You learn about powerful signal-processing techniques used in regenerative satellite systems in *Chapter 9.* The advantages of these techniques and the additional flexibility introduced by the regenerative "*switchboard-in-the-sky*" systems are described.

In *Chapter 10* single-channel-per-carrier (SCPC) digital satellite systems are described. These systems are operational in numerous countries and are cost-effective, particularly for small data users. A novel, more powerful modulation technique invented by the author for SCPC applications is also presented. Finally, trade-offs and trends in satellite system design are presented.

Specifications and photographs of modern digital satellite systems are presented in many chapters. These are included to illustrate typical-state-of-the-art systems. In addition to the illustrative *design examples* and solutions given in the text, carefully selected problems are given at the ends of chapters, where additional emphasis on problem solving is considered desirable. Classroom instructors may obtain a *complete solutions manual* from Prentice-Hall, Inc. I believe that you will find the design examples and the problems educative and interesting. Some of these are tailored to enhance your *intuition,* which leads to **creative original designs.**

In a number of chapters *original research* material has been included. Even though this book is intended to be an *introductory text* to digital satellite communications fundamentals, design, and applications, I felt that it is worthwhile to introduce modern research concepts and ideas. To limit the size of this volume and to meet its original objective of being a *practical digital satellite communications book* that could be *understood* by readers who *do not* necessarily have the *mathematical* sophistication of research engineers, certain derivations have been omitted. Rather, particular emphasis is placed on the physical interpretation of final equations, the practical hardware, system constraints, and the digital *satellite earth station* systems applications. The numerous up-to-date references provided at the end of the text should be helpful to those who wish to study the theoretical derivations and obtain more in-depth knowledge of the material covered.

Considering the evolutionary style and philosophy of this book, I feel it is appropriate to state how this book was conceived. Throughout my background, which includes over 10 years of full-time industry research, design, and applications engineering and management, plus approximately nine years of university teaching, research, and **consulting,** I realized that the vast majority of practicing telecommunications engineers seldom use sophisticated mathematical tools. For their successful professional advancement they are required to have a solid knowledge of the principles of system and equipment operation and are expected to apply this knowledge to the design of modern cost-effective systems.

The material in my *previously published books*

(1) K. Feher: *Digital Modulation Techniques in an Interference Environment,* Don White Consultants, Inc., Germantown, Virginia, 1977.
(2) K. Feher: *Digital Communications: Microwave Applications,* Prentice-Hall, Englewood-Cliffs, N.J., 1981.

was based on material covered in short courses and seminars given in the United States, Canada, Mexico, South America, and many European countries. This material was supplemented by both graduate and undergraduate course material which I teach at the university. The positive feedback that I have been continuously receiving from telecommunications professionals, students, and professors who have been studying or teaching from my two books listed above encouraged me to have the same pragmatic and progressive approach in this book.

I would be delighted to hear from you. If you have questions, comments, or suggestions related to the content of this book, please feel free to write to me.

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Dr. L. E. FRANKS, Professor, University of Massachusetts, for his chapter on synchronization systems

Dr. W. TRANTER, Professor, University of Missouri, for his chapter on coding techniques

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Being a consultant of Spar Aerospace Limited (formerly RCA Limited) for many years, I have had the opportunity to work on many challenging digital satellite communications projects. The drive and enthusiasm of Mr. M. J. MORRIS (Engineering Manager, Spar) inspired me to complete this project in a relatively short time.

As Guest Editor of the *IEEE Transactions on Communications*, Special Issue on "Digital Satellite Communications," I wish to thank my Associate Guest Editors, Dr. L. GREENSTEIN (Bell Laboratories), Mr. L. POLLACK (COMSAT), and Mr. D. LOMBARD (CNET, France). The Guest Editors, authors, and reviewers of this issue (published January 1983) have had valuable suggestions.

Participants of our numerous short courses and seminars (in the United States, Canada, Europe, Mexico, and South America) from various companies, government organizations, and universities suggested improvements. My graduate students at the University of Ottawa, Carleton University, and Concordia University "classroom-tested" the manuscript and the problems. Mr. D. H. M. Reekie of Telesat Canada improved the overall style and presentation of the manuscript.

Mrs. Suzanne Racine conscientiously typed major parts of the manuscript and its revisions.

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Dr. Kamilo Feher
Ottawa, November 1982

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