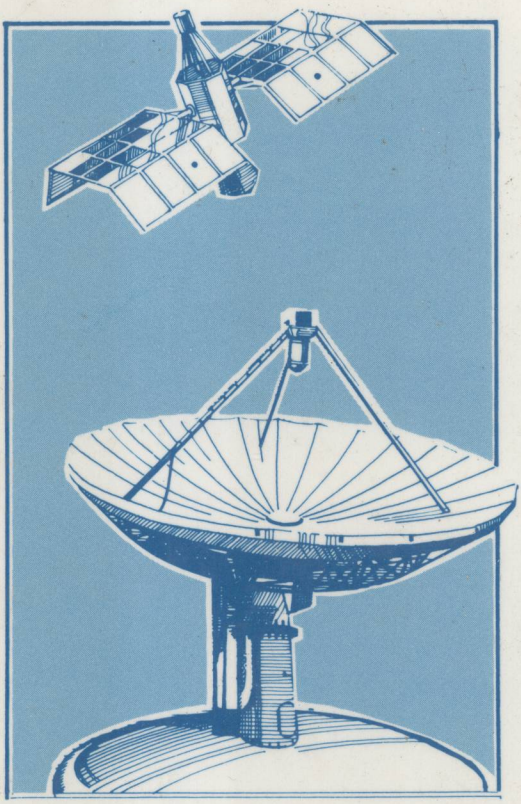
Satellite Communication Systems Design



Edited by
Sebastiano Tirró

Satellite Communication Systems Design

Edited by

Sebastiano Tirró

Plenum Press • New York and London

Library of Congress Cataloging-in-Publication Data

Satellite communication systems design / edited by Sebastiano Tirró.
p. cm.
Includes bibliographical references and index.
ISBN 0-306-44147-0
1. Artificial satellites in telecommunication--Systems engineering. I. Tirró, Sebastiano.
TK5104.S3628 1993
621.382'5--dc20 92-29910
CIP

ISBN 0-306-44147-0

Satellite Communication Systems Design

To my son Emanuele,
love of his mother and father
made person

Contributors

F. Ananasso
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

A. Bonetto
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

G. Chiassarini
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

R. Crescimbeni
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

E. D'Andria
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

G. Gallinaro
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

R. Lo Forti
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

A. Puccio
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

G. Quaglione
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

E. Saggese
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

V. Speziale
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

S. Tirró
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

A. Vernucci
Space Engineering S.r.l., Via dei Berio 91, 00155 Roma, Italy

V. Violi
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

G. Vulpetti
Telespazio S.p.A., Via Tiburtina 965, 00156 Roma, Italy

Preface

Writing a comprehensive book on satellite communications requires the command of many technical disciplines and the availability of up-to-date information on international recommendations, system architectures, and equipment standards. It is therefore necessary to involve many authors, each possessing a good level of knowledge in a particular discipline.

The problem of using a coherent and unambiguous set of definitions and basic terms has been solved by including in the book all the background information needed for understanding satellite communication systems, without any major reference to other textbooks specializing in particular disciplines. The obvious consequence of this approach has been the large size of the book, with the advantages, however, of practically complete independence from other books, more systematic discussion of the subject matter, and better readability.

After the required background information, emphasis has been placed on the discussion of techniques and system design criteria rather than on specific equipment implementation or description of particular systems.

The book may be divided in five parts as follows:

- The first five chapters provide most of the required background information.
- Chapter 6 is an introductory outline of satellite communication systems.
- Chapters 7 to 13 deal with the various aspects of technical system design.
- Chapter 14 discusses system economics.
- Chapter 15 provides a brief insight into some foreseeable future developments of satellite communications.

More specifically, Chapter 1 defines the basic characteristics of the various signal types; four different types of signals are considered in the book: speech, sound-program, television, and data.

Chapter 2 discusses all the causes of signal impairment, such as thermal noise, radio-frequency (RF) intermodulation noise generated in nonlinear multicarrier amplification, linear distortions, propagation delay, and echo. The importance of each cause of impairment is strictly related to the type of signal, so

that it is not possible to define performance specifications independently of the signal.

Chapter 3 concentrates on the source signal processing, including source coding, deterministic or statistical multiplexing of various signals (of equal or different nature), and cryptography. This chapter comprises the discussion of the various speech interpolation techniques, which have found wide application in satellite systems, but not yet in terrestrial ones.

The various telecommunication services are classified in Chapter 4 with reference to their major characteristics, such as unidirectionality and bidirectionality, point-to-point or point-to-multipoint connectivity, transmission capacity assigned in real time or on a reservation basis, etc.

Chapter 5 is a comprehensive and up-to-date review of the various CCIR and CCITT recommendations concerning the quality of service for the various types of signals defined in Chapter 1 and the limits to be imposed on the single sources of signal impairment as defined in Chapter 2. The relevant INTELSAT specifications are also summarized.

Chapter 6 gives an introductory outline of satellite communication systems and is therefore a very articulated chapter, comprising historical notes (more detailed than those provided in the introduction), a preliminary assessment of the link budget problem, the discussion of satellites and earth stations (ESs) major characteristics, etc.

Particular emphasis has been placed in this chapter on the concept of margin, i.e., of difference (in decibels) between the carrier-to-noise ratios (CNRs) experienced at the time percentages defined in CCITT–CCIR recommendations (see Chapter 5) or between the CNRs necessary to obtain from the considered transmission system the signal quality as specified by CCITT–CCIR in some recommendations previously mentioned. These two margins may be called atmospheric margin and transmission margin, respectively. A major peculiarity of the book is the importance given to a "balanced" design of the system, such that neither bandwidth nor power resources are wasted. Balanced conditions are obtained when the transmission margin equals the atmospheric margin. Attention must be paid to a precise definition of the margins, since various types of atmospheric and transmission margins exist. An additional consideration is that, whereas frequency modulation (FM) generally allows a balanced condition to be attained whenever the atmospheric margin is not too large, other modulation techniques generally produce unbalanced systems.

When the communication service is bidirectional, an additional problem of design optimization arises, since it is useless to have available for service just one of the two channels composing the transmission circuit. When atmospheric events produce attenuation of the carrier at one of the two communicating ESs, one channel will suffer fading in the uplink and the other one in the downlink, The two channels may therefore be called up-faded (UF) and down-faded (DF), respectively, and an optimally designed system will be UF–DF balanced, in addition to being power–bandwidth balanced.

Apportionment of the total specified service unavailability to equipment failures and to propagation events experienced in the two communicating ESs allows determination of the CNR deterioration due to atmospheric propagation.

The subject of optimal operational orbits for communication satellites and of

the best strategy to be followed for injecting the satellite in the operational orbit is dealt with in Chapter 7. Particular emphasis is placed on the characteristics of the geostationary earth orbit (GEO), by far the most interesting for present satellite communications. The problems of visibility from GEO, Doppler effect, and eclipse are addressed. The satellite orbit is subject to perturbations, so that maneuvers are periodically required to maintain it throughout satellite life. The discussion in Chapter 7 is limited to the causes of the perturbations. After a short discussion of some advanced propulsion and orbital concepts, the chapter concludes with a presentation of the available launch vehicles and of the developments foreseeable in the field of space transport.

Chapter 8 deals with some major RF design issues, such as antennas and atmospheric propagation.

Chapter 9 discusses analog transmission, emphasis being on FM and the related threshold phenomenon. Much attention is also paid to the use of syllabic compandors, which has been rather frequent with FM (companded FM) for domestic communications in developing countries, and with single sideband (amplitude companded single sideband, ACSB) for trunking communications in domestic U.S. systems.

Frequency modulation is also the preferred technique for television transmissions in general and for television broadcasting satellites (TVBS) systems in particular. The WARC'77 plan for TVBS and the perspectives for high-definition television are discussed.

Digital transmission, which is becoming more and more popular with the advent of the integrated services digital network (ISDN) is the subject of Chapter 10, which discusses both modulation and channel coding, plus the joint optimization of modulation and coding, which is also called *codulation.* A basic theorem of systems theory states that an optimal system is in general composed of nonoptimal subsystems. It must therefore be expected that an optimal modulation scheme combined with an optimal channel-coding scheme cannot reach the performance offered by an optimal codulation scheme. Phase-shift keying (PSK) is by far the most utilized modulation scheme for bidirectional fixed-point communications. This justifies the emphasis put on PSK, for which many results of computer simulations and field trials are reported. Many other digital modulation schemes are also discussed, such as frequency-shift keying (FSK), which finds application in data collection systems, and pulse position modulation (PPM), which is used in some intersatellite link (ISL) configurations to increase the diode laser life. Channel coding is extensively discussed, the emphasis being on convolutional coding with soft Viterbi decoding, a scheme often used, since superior performance may be coupled with VLSI implementation of coding–decoding circuits.

Chapter 11 deals in detail with the optimal design of a bidirectional circuit, where the UF–DF balance condition must be implemented. This is done for several types of analog and digital transmission systems. An interesting conclusion is that coded 8-PSK only looks attractive in C-band, whereas uncoded 4-PSK seems generally preferable in K_u-band, and 4-PSK plus convolutional coding/Viterbi decoding may be convenient in K_a-band, where excess bandwidth is generally available.

Channel access schemes are discussed in Chapter 12. The most complex

scheme is time-division multiple access (TDMA), which is given the most attention, but frequency-division multiple access (FDMA) and code-division multiple access (CDMA) are also discussed, and their performances are compared with that of TDMA. The satellite-switched versions of TDMA and FDMA, respectively called SS-TDMA and SS-FDMA, are also considered.

The subject of networking, which is often overlooked, receives extensive attention in Chapter 13.

Terrestrial networks and satellite systems are typically rather different from a topological viewpoint. In particular, the location of several ESs in the same satellite antenna beam makes possible the features of multiple access and multiple destination. The transmission capacity is therefore assigned in primitive (global coverage) satellite systems according to modalities which justify the name of "demand assignment," as opposed to "switching," which is used to designate modalities adopted in terrestrial networks. The unification of the two disciplines in a single wider context requires the definition of a new technical term: *commutation* is the term suggested in this book. Chapter 13 discusses the various commutation functions possible in a satellite system, and the achievable network efficiencies, computed as the ratio between the handled traffic and the transmission capacity.

The analysis of the system performance for telephony is performed by using the classical Erlang and Engset formulas. Also, packet services using random-access schemes (e.g., ALOHA) and point-to-multipoint videoconferences are examined. The possible signaling standards usable for telephony, packet services, and videoconferencing are also outlined. Finally, the subject of integrating a satellite system with a terrestrial network is discussed.

Chapter 14 deals with system economics, first by suggesting a methodology for the design of a viable satellite system, then by analyzing several important examples. The viability of the system must be assessed comparing its cost both with the price offered by competitors in the market and with the amount the customer is prepared to pay for the service. The analysis confirms that the satellite is generally attractive for unidirectional systems and for mobile systems, whereas the comparison is much more articulated for bidirectional fixed-point communications.

The implementation of systems heavily using the space-segment capacity (e.g., file transfer, videoconferencing, etc) at a cost which the user is willing to pay, will probably imply the use of sophisticated onboard processing techniques.

The possible future developments of satellite communications are briefly addressed in Chapter 15, which concentrates on ISLs, satellite antennas, and processing repeaters, for reasons already mentioned.

The book concludes with four appendixes, which deal respectively with radio regulations provisions, coordination between a satellite system and terrestrial systems, coordination between satellite systems, and optimal use of the GEO–frequency resource.

This book came into existence thanks to many contributions, which I am pleased to acknowledge. First of all, I would like to thank my parents, Francesco Tirró and Giuseppina Lombardo, to whom I will be eternally indebted for their sacrifices that enabled me to get a degree in electronics. I would also like to thank

Professor Bruno Peroni, my most important teacher at the University of Rome, who guided me to a doctoral thesis on threshold extension demodulators and gave helpful suggestions for the production of the book, and Mr. Livio Bruno, Director General of Telespazio from 1984 to 1989, who has been my professional teacher and to whom I am mostly indebted for my personal competence in satellite communications.

When I was contacted by Plenum to write a book on satellite communications, my first consideration was that, because of the wide and multidisciplinary nature of the domain to be covered, competence in many areas was required. Therefore, I decided to be the editor of the book and to ask other experts to contribute as authors. A lucky circumstance was the availability in my company of practically all the required expertise. Therefore, I asked and obtained from Telespazio the necessary support to produce the book. Grateful acknowledgment is therefore made to Telespazio S.p.A., the company where I spent about 22 years of my professional life, and to all the authors for their competent and enthusiastic cooperation.

My special gratitude to Mr. Cesare Benigni (Director General of Telespazio from 1971 to 1984) for authorizing the work and providing many helpful comments. A hearty nod of appreciation to Mr. Ken Derham, my Plenum Publishing interface, and to Prof. Barry Evans of the University of Surrey, for important suggestions concerning editorial aspects and book structure.

Finally, to my secretary, Mrs. Marina Minorenti, for her patient and precious work, to Mr. Bruno Cacciamani, who produced most of the drawings, and to my wife Rosangela, who made the final revision of the manuscript, my deepest thanks. To all of them, may this book be an evidence of the high professional level of their assistance.

S. Tirró

Contents