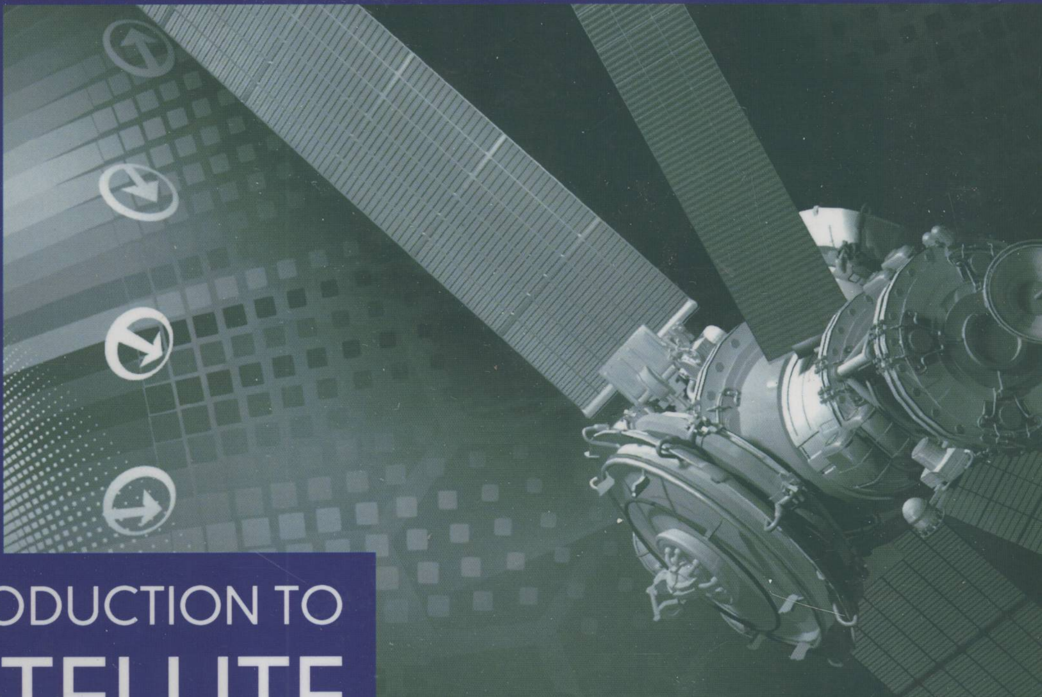
Bruce R. Elbert



# INTRODUCTION TO SATELLITE COMMUNICATION

THIRD EDITION

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**Third Edition**

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# Preface

*Introduction to Satellite Communication* is designed to meet the needs of working professionals and students. The first edition was a response to a request by many friends and associates for a basic and clear book that provides newcomers with an accessible way to gain knowledge and become productive. The second edition followed the same approach, updating the older and dated material and adding background in newer systems, particularly the global mobile personal communications systems introduced worldwide. This third edition brings the text in line with industry and technology trends. Whether the reader is technically trained or not, the need exists for an authoritative guidebook to the construction and usage of satellite networks.

This book is designed to give you, the reader, an understanding that should permit you to begin work as a satellite professional or as a user of satellite communication. Sufficient technical information has been included to instill a feeling for how systems are designed and operate. Many categories of professionals and students should profit from a significant portion of the material. The book's explanatory nature and broad coverage make it suitable as a textbook for university programs and internal training in communication systems design and planning. Nontechnical professionals in associated business management, contracts, legal, and financial fields will find the book particularly helpful when they must deal with telecommunication projects and issues.

The book is organized into 12 chapters to correspond to the major areas of commercial satellite communication systems. Chapter 1, "Fundamentals of Satellite Systems," identifies the structure and key features of satellite communication and reviews some of the more basic concepts in a nontechnical style. It is understandable to all readers, including high school students. Likewise, Chapter 2, "Evolution of Satellite Communication," provides an easy-to-understand history of the technology and its applications. It begins with geostationary Earth orbit (GEO) systems, which are the foundation of the industry, and moves into non-GEO systems used in mobile applications. Another purpose of Chapter 2 is to capture in one place the background with which many newcomers otherwise would not be acquainted (e.g., how we got from Arthur C. Clarke's concept in 1945 to the present day). Chapter 3, "Satellite Network Architectures," covers the ways in which satellite links can be applied to practical communication problems. It gives the reader an appreciation for the variety of uses in which satellites have gained a stronghold. Technologists involved with spacecraft or communication systems will find that Chapter 3 explains many of the mysteries surrounding the business of using satellites.

The next two chapters begin the core technical material, focusing on the engineering and design of radio transmissions to and from satellites. Chapter 4, "Microwave Link Engineering," gives the reader a basic understanding of the physics of the radio link between the Earth station and the satellite and covers the factors that are under the designer's control as well as those that are not. It is assumed that the reader has little or no technical training, so the only form of mathematics used is arithmetic. Chapter 5, "Modulation, Multiple Access and Impairments," rounds out the basic theory of communication as it relates to efficient satellite transmission. The chapter is fairly compact and may be helpful for interested readers to supplement their study with a basic textbook on communication engineering. Nontechnical readers can examine Chapters 4 and 5 but not delve deeply into the engineering details (which are more important to technical professionals, who need to understand features and trade-offs).

Chapters 6, 7, and 8 provide a comprehensive review of the functional elements of all communication satellites. The objective here is to aid readers in understanding the key issues in satellites and is not appropriate for the detailed engineering design of satellite components and subsystems. As is customary, the physical piece of hardware is referred to as the spacecraft, which becomes an artificial Earth satellite (or just satellite) when in orbit. The major elements of the spacecraft are the repeater (bent-pipe and digital processor), the antennas, and the spacecraft bus (the supporting vehicle), which are covered in Chapters 6, 7, and 8, respectively. While those chapters are not essential to understanding how to use satellite communications, they will be of general benefit because the actual operation of a spacecraft affects the performance of the services rendered.

The complementary topics for the ground facilities used in conjunction with the satellite are reviewed in Chapter 9, "Earth Stations and Terrestrial Technology." Care has been taken to include only current classes of Earth stations, particularly those used for satellite control, television broadcasting, fixed and mobile very small aperture terminal (VSAT) applications, and mobile satellite services (GEO and non-GEO). Chapter 9 will be useful for those readers who plan to use satellite transmission, since ground facilities fundamentally are under the control of the user rather than the satellite operator.

Chapter 10, "Launch Vehicles and Services," covers topics that are of great concern to operators and major users of satellites alike. The chapter is a complete review of the alternatives for placing satellites into Earth orbit and emphasizes that particular launch vehicle choices change over time. However, because reliability is based on a consistent experience record, much of the change is evolutionary rather than revolutionary. Chapter 10 also discusses the planning and operation of the mission, which is the sequence of events of launch and placement into operating orbit. Risk management is addressed as well.

Chapter 11, "Satellite Operations and Organization," addresses the special needs of this type of business. In some detail, it reviews the complete satellite control system, the communication network needed to support such a system, and the human resources that are appropriate to those functions. Chapter 12, "Economics of Satellite Systems," provides the underlying characteristics of satellites and Earth stations that are related to the cost of implementing and operating satellite networks. Our perspective is that of a commercial operator who is in business to make money (or reduce costs). The framework is useful for analyzing the economics of either a complete system or a portion of a system (e.g., one or a few Earth stations). Chapter 12 is expanded to address the overall systems engineering process in satellite communication. This is based on the structured approach found in the aerospace industry adapted to the needs of commercial applications. From this, we move into the topic of engineering economics and overall development of the entire satellite program.

The book can be read sequentially from cover to cover because the material follows a consistent thread. All the elements and uses of spacecraft and Earth stations are covered. Chapters also can be read out of sequence, if necessary, because each chapter explains the concepts relevant to it. References to other chapters are provided throughout. The material is completely current as of the time of publication (circa 2008), but care has been taken to emphasize concepts that are not likely to change quickly. That is the same approach taken in the first edition, a book that remained in print (and in demand) for 12 years. Once read, this book can be used as a reference because most of the terminology in current usage is defined and illustrated. This book is a mate to the author's previous work, *The Satellite Communication Applications Handbook, Second Edition,* and *The Satellite Communication Ground Segment and Earth Station Handbook.*

## Acknowledgments

I wish to acknowledge my friends and associates in the industry and around the world whom I have helped put satellite communication into practical use. My first introduction to satellites came at COMSAT Laboratories, where we examined many concepts and systems well before they were applied commercially. My subsequent 25 years with Hughes provided the experience to examine the entire satellite system at the depth needed to write these books and teach this technology to students and working professionals. Since 1990, I have been affiliated with UCLA Extension, and I wish to express my special appreciation to Dr. Bill Goodin, manager of the Engineering Short Course Program, for his continued support. My technical editor, Ray Sperber, made countless contributions to the quality and accuracy of this material (something he also did so ably in every prior edition). Finally, I wish to acknowledge my wife, Cathy, who provided the support and motivation necessary to start and complete the revision of this book, and my daughters, who every day make a dad proud.

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# Contents

CHAPTER 1

# Fundamentals of Satellite Systems

Satellite communications[1], no longer a marvel of human space activity, have evolved into an everyday, commonplace thing. By 2010, satellite systems will represent well over $100 billion of investment and provide an essential ingredient to many businesses and governments worldwide. Nearly all television coverage travels by satellite, today reaching directly to the home from space. Even in the age of wideband fiber optic cables and the Internet, satellites still serve the basic telecommunication needs of a majority of countries around the world. For example, domestic satellites have greatly improved the quality of service of the public telephone system and brought nations more tightly together. Satellites are adapting to developments in multimedia information and personal communication, with the cost of one-way and two-way Earth stations now within the reach of many potential users. A unique benefit has developed in the area of emergency preparedness and response. When a devastating earthquake hit Mexico City in September 1985, the newly launched Morelos 1 satellite maintained reliable television transmission around the nation even though all terrestrial long-distance lines out of the city fell silent. Similarly, communications were restored to facilitate disaster relief on the island of Sumatra after the December 2004 earthquake and subsequent tsunami.

To provide an overview of the field, the remainder of this chapter describes the features of satellite communication networks as well as the principal elements of an overall system. The brief history in Chapter 2 is intended to explain how the satellite industry developed and why things are the way they are. Chapter 2 can be read in sequence or deferred until other chapters have been read, to get a better feel for the technology and terms.

## 1.1 Basic Characteristics of Satellites

A communications satellite is a microwave repeater station that permits two or more users with appropriate earth stations to deliver or exchange information in various forms. As discussed later in this chapter and again in Chapter 6, a satellite in a geostationary Earth orbit (GEO) revolves around the Earth in the plane of the equator once in 24 hours, maintaining precise synchronization with the Earth's rotation. There are two other classes of 24-hour orbits: the geosynchronous orbit and the highly elliptical synchronous orbit. Both involve satellites that appear to

1. *Satellite communication* and *satellite communications* are used interchangeably throughout.

move relative to a fixed point on the Earth. It is well known that a system of three satellites in GEO each separated by 120 degrees of longitude, as shown in Figure 1.1, can receive and send radio signals over almost all the inhabited portions of the globe. (The small regions around the North and South Poles—above 81° NL and below 81° SL—are not covered.) A given GEO satellite has a coverage region, illustrated by the shaded oval, within which Earth stations can communicate with and be linked by the satellite. The range from user to satellite is a minimum of 36,000 km, which makes the design of the microwave link quite stringent in terms of providing adequate received signal power. Also, that distance introduces a propagation delay of about one-quarter of a second for a single hop between a pair of users.

The GEO is the ideal case of the entire class of geosynchronous (or synchronous) orbits, which all have a 24-hour period of revolution but are typically inclined with respect to the equator and/or elliptical in shape. As viewed from the Earth, a synchronous satellite in an inclined orbit appears to drift during a day above and below its normal position in the sky. While ideal, the circular GEO is not a stable arrangement, and inclination naturally increases in time. As discussed in Chapter 8, inclination is controlled by the use of an onboard propulsion system with enough fuel for corrections during the entire lifetime of the satellite. A synchronous satellite not intended for GEO operation can be launched with considerably less auxiliary fuel for that purpose. Orbit inclination of greater than 0.1 degree usually is not acceptable for commercial service unless the Earth station antennas can automatically repoint toward (track) the satellite as it appears to move. Mechanical tracking is the most practical (and cumbersome) approach, but electrical beam steering systems are available for specialized applications such as aeronautical mobile.

Orbits that are below a mean altitude of about 36,000 km have periods of revolution shorter than 24 hours and hence are termed non-GEO. As illustrated

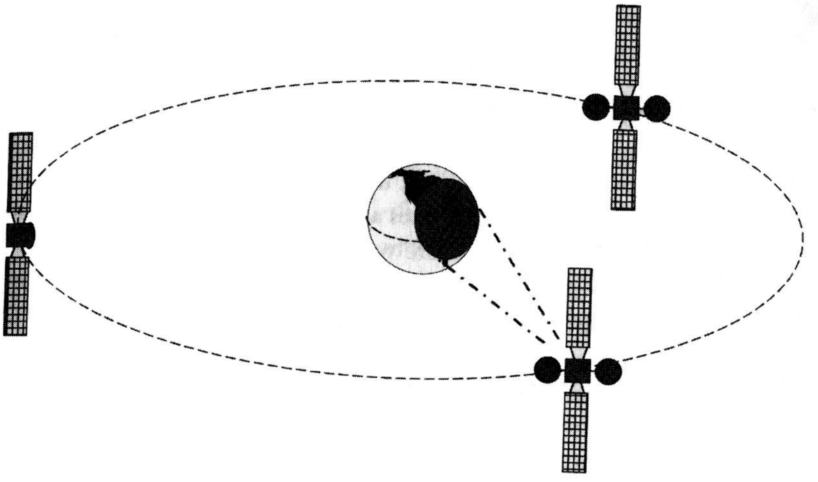

**Figure 1.1** A system of three geostationary communication satellites provides nearly worldwide coverage.