

# SATELLITE COMMUNICATIONS

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# PREFACE

Communications satellites play a major role in telephone transmission, television and radio program distribution, computer communications, maritime navigation, and military command and control. The current strong demand for electrical engineers originates from all segments of the industry, ranging from satellite and earth station manufacturers to lessors of satellite channels. This book was written as a text for a one-semester senior or beginning graduate level course to provide these engineers with an appropriate background in satellite technology, link design, and operations. We hope that graduate engineers will also find it useful as a reference.

Satellite communications engineering combines such diverse topics as radio wave propagation, antennas, orbital mechanics, modulation, detection, coding, and radio electronics. Each of these is a major field of study, and each has its own extensive literature. In preparing this text we emphasized the material from these areas that is important to satellite communications and derived those equations that a beginning engineer might reasonably be expected to know and to understand. We have tried to make our coverage as practical as possible, stressing those techniques that are or soon will be in use.

We assume that our readers will have completed the usual undergraduate courses in physics (to provide a background for orbital mechanics), electromagnetic fields (to understand wavelength, power density, and electromagnetic radiation), and communications theory (for a background in modulation, detection, noise, and spectra). Although some familiarity with microwaves and radio electronics would be useful, these are not required.

Although later chapters build upon material covered in earlier ones, we have made each chapter reasonably self-contained for practicing engineers who are seeking information about a particular topic. To help with this process we have provided an end-of-book glossary and a list of symbols.

Chapter 1 introduces satellite communications and provides a brief history of the subject. Chapter 2 is a detailed discussion of orbital mechanics and orbital considerations in satellite launches and satellite link design. So far as we are aware, it is the first treatment of the subject for electrical engineers that covers everything from Newton's laws of motion to look angles. Chapter 3 presents a review of those aspects of spacecraft design and organization that are important in communications satellites. Chapter 4 derives the equations needed for calculating the carrier-to-noise ratio ( $C/N$ ) of a link and discusses techniques for achieving a specified ( $C/N$ ). Chapter 5 reviews digital and analog modulation and multiplexing techniques and provides the necessary information for determining the ( $C/N$ ) requirement that links designed by the procedure of Chapter 4 must meet. Chapter 6 discusses multiple access, and Chapter 7 presents error detection and correction, applications of coding theory that are particularly important to satellite systems. Chapter 8 presents propagation effects and their impact on system design; these are severe at frequencies above 10 GHz. Chapter 9 discusses earth station technology, emphasizing antennas. Chapter 10 describes Intelsat (The International Telecommunications Satellite Organization) and Inmarsat (The International Maritime Satellite Organization). Chapter 11 is about television distribution and satellite broadcasting, topics that the general public most strongly associates with satellite communications. The appendix provides background information on how decibels are used in communications engineering and on the effect of bandlimiting on digital radio signals.

**Timothy Pratt**  
**Charles W. Bostian**

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T. P.  
C. W. B.

# CONTENTS

<b>Chapter 1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 The Origin of Satellite Communications	2
	1.2 A Brief History of Satellite Communications	2
	1.3 The Current State of Satellite Communications	4
	1.4 An Overview of Satellite System Engineering	4
	1.5 Organizations Cited in This Book	9
	1.6 Summary	10
	References	10
<b>Chapter 2</b>	<b>ORBITAL ASPECTS OF SATELLITE COMMUNICATIONS</b>	<b>11</b>
	2.1 Orbital Mechanics	11
	The Equations of the Orbit	11
	Describing the Orbit	15
	Locating the Satellite in the Orbit	17
	Locating the Satellite with Respect to the Earth	19
	Orbital Elements	22
	2.2 Look Angle Determination	22
	The Subsatellite Point	23
	Elevation Calculation	24
	Azimuth Calculation	25
	Specialization to Geostationary Satellites	28
	Visibility	30
	2.3 Numerical Example	30



2.4	Orbital Perturbations	32
	Effects of the Earth's Oblateness	33
	Effects of the Sun and Moon	34
2.5	Orbit Determination	34
2.6	Launches and Launch Vehicles	34
	The Mechanics of Launching a Synchronous Satellite	35
	U.S. Expendable Launch Vehicles	37
	Ariane	38
	STS	40
	Selecting a Launch Vehicle	40
2.7	Orbital Effects in Communications System Performance	43
	Doppler Shift	43
	Range Variation	44
	Eclipse	44
	Sun-Transit Outage	46
2.8	Summary	46
	References	47
	Problems	48
<b>Chapter 3</b>	<b>SPACECRAFT</b>	<b>52</b>
3.1	Introduction	52
3.2	Spacecraft Subsystems	52
3.3	Attitude and Orbit Control System (AOCS)	55
	Attitude Control System	55
	Orbit Control System	60
3.4	Telemetry, Tracking, and Command (TT&C)	63
	Telemetry	63
	Tracking	64
	Command	65
3.5	Power Systems	66
3.6	Communications Subsystems	69
	Description of the Communication System	69
	Transponders	73
3.7	Spacecraft Antennas	78
	Basic Antenna Types and Relationships	78
	Spacecraft Antennas in Practice	82
	Frequency Reuse Antennas	85
3.8	Equipment Reliability and Space Qualification	91
	Space Qualification	91
	Reliability	92
	Redundancy	95

3.9	Summary	98
	References	99
	Problems	100
<b>Chapter 4</b>	<b>SATELLITE LINK DESIGN</b>	<b>104</b>
4.1	Basic Transmission Theory	108
4.2	System Noise Temperature and $G/T$ Ratio	113
	Noise Temperature	113
	Calculation of System Noise Temperature	114
	Noise Figure and Noise Temperature	117
	$G/T$ Ratio for Earth Stations	118
4.3	Design of Downlinks	119
	Intelsat IV-A Downlink	120
4.4	Domestic Satellite Systems Using Small Earth Stations	125
	Direct Broadcast Television	128
	Design of Low-Capacity Satellite Links	130
4.5	Uplink Design	133
4.6	Design of Satellite Links for Specified $(C/N)$	137
	Specification of $(C/N)$	137
	Hypothetical Reference Circuit	140
	Calculation of Noise Power Budget	141
	Design of Satellite Links to Achieve a Specified Performance	144
4.7	Summary	147
	References	148
	Problems	149
<b>Chapter 5</b>	<b>MODULATION AND MULTIPLEXING TECHNIQUES FOR SATELLITE LINKS</b>	<b>155</b>
5.1	Analog Telephone Transmission	155
	Baseband Voice Signals	157
	Voice Signal Multiplexing	158
	Frequency Modulation (FM) Theory	161
	FM Detection Theory: $(S/N)$ Improvement	162
	Frequency Modulation with Multiplexed Telephone Signals	164
	Bandwidth Calculation for FDM/FM Telephone Signals	167
	Telephone Performance Specifications	169
	Practical Examples	169
	Analog FM SCPC Systems	174
	Companded Single Sideband (CSSB)	175

5.2	Analog Television Transmission	176
	Television Signals	176
	Signal-to-Noise Ratio Calculation for Satellite TV Links	179
5.3	Energy Dispersal	179
5.4	Digital Transmission	182
	Baseband Digital Signals	182
	Baseband Transmission of Digital Data	182
	Bandpass Transmission of Digital Data	186
	Transmission of QPSK Signals Through a Bandlimited Channel	188
5.5	Digital Modulation and Demodulation	192
	Terminology	192
	Modulation and Coding	193
	Bit and Symbol Error Rates	193
	Binary Phase Shift Keying (BPSK)	195
	Quadrature Phase Shift Keying (QPSK)	199
	QPSK Variants	203
5.6	Digital Transmission of Voice	204
	Sampling and Quantizing	204
	Nonuniform Quantization: Compression and Expansion	208
	Signal-to-Noise Ratio in PCM Systems	209
	Delta Modulation	211
5.7	Digital TV and Bandwidth Compression	214
5.8	Time Division Multiplexing	214
	TDM Terminology: The U.S. T1 24-Channel System	215
	Other TDM Systems	216
	Channel Synchronization in TDM	217
5.9	Summary	217
	References	219
	Problems	220
<b>Chapter 6</b>	<b>MULTIPLE ACCESS</b>	<b>224</b>
6.1	Frequency Division Multiple Access (FDMA)	225
	FDM/FM/FDMA	225
	Calculating the Overall Carrier-to-Noise Ratio on an FDM/FM/FDMA Link	227
	Measuring and Calculating the Effects of Intermodulation Noise	230
	Overdeviation and Companded FDM/FM/FDMA	232
	Practical Limitations of FDM/FM/FDMA	233
	Companded Single Sideband	233
6.2	Time Division Multiple Access	235
	Bits, Symbols, and Channels	237

	TDMA Frame Structure and Design	237
	TDMA Synchronization and Timing	249
6.3	Code Division Multiple Access	251
	Spread-Spectrum Transmission and Reception	251
	Applicability of CDMA to Commercial Systems	257
6.4	Estimating Channel Requirements	257
	Measuring Traffic	257
	The Basic Traffic Equation	258
	Channel Requirements for Fixed Assignment and Demand Assignment Schemes	260
	Speech Interpolation and Prediction	261
6.5	Practical Demand Access Systems	263
	Demand Access in the Intelsat TDMA System	263
	SPADE	266
	The Inmarsat System	269
6.6	Random Access	272
6.7	Multiple Access with On-board Processing	273
6.8	Summary	274
	References	275
	Problems	278
<b>Chapter 7</b>	<b>ENCODING AND FORWARD ERROR CORRECTION FOR DIGITAL SATELLITE LINKS</b>	<b>281</b>
7.1	Error Detection and Correction	281
7.2	Channel Capacity	284
7.3	Error-Detection Coding	286
	Linear Block Codes	288
	Error Correction with Linear Block Codes	293
7.4	Error Detection and Correction Capabilities of Linear Block Codes	293
7.5	Binary Cyclic Codes	294
	Algebraic Structure of Cyclic Codes	294
	Generation of Cyclic Codes	297
	Error Detection and Correction with Cyclic Codes	298
	BCH and Burst Error Correction Codes	299
	Golay Codes	301
7.6	Performance of Block Error Correction Codes	301
7.7	Convolution Codes	302
	An Illustrative Example	303
7.8	Implementation of Error Detection on Satellite Links	309

7.9	Summary	313
	References	315
	Problems	316
<b>Chapter 8</b>	<b>PROPAGATION ON SATELLITE-EARTH PATHS AND ITS INFLUENCE ON LINK DESIGN</b>	<b>319</b>
8.1	Quantifying Attenuation and Depolarization	320
8.2	Propagation Effects That Are Not Associated with Hydrometeors	323
	Atmospheric Absorption	323
	Tropospheric Multipath and Scintillation Effects	323
	Land and Sea Multipath	324
	Multipath Effects in System Design	325
	Faraday Rotation in the Ionosphere	326
	Ionospheric Scintillations	327
8.3	Rain and Ice Effects	327
	Characterizing Rain	327
	Raindrop Distributions	331
	Calculating Attenuation	334
	Scaling Attenuation with Elevation Angle and Frequency	340
	Calculating <i>XPD</i>	341
	Rain Effects on Antenna Noise Temperature	342
	Ice Crystal Effects	343
	Examples of Rain and Ice Effects	343
8.4	Eliminating or Alleviating Propagation Effects	343
	Attenuation	343
	Site Diversity	345
	Depolarization	347
8.5	Summary	348
	References	348
	Problems	351
<b>Chapter 9</b>	<b>EARTH STATION TECHNOLOGY</b>	<b>353</b>
9.1	Earth Station Design	353
	Earth Station Design for Low System Noise Temperature	353
	Large Earth Station Antennas	357
9.2	Basic Antenna Theory	357
	Linear Apertures	359
	Rectangular Apertures	363
	Circular Apertures	366

9.3	Design of Large Antennas	368
	Large Cassegrain Antennas	370
	Optimizing the Gain of Large Antennas	376
	Antenna Noise Temperature	379
	Feed Systems for Large Cassegrain Antennas	385
9.4	Tracking	389
	Tracking Feeds	390
	Mode Extraction Schemes	392
	Tracking Geostationary Satellites	393
9.5	Small Earth Station Antennas	394
	Design of Small Earth Station Antennas	396
9.6	Equipment for Earth Stations	404
	Low Noise Amplifiers	406
	High-Power Amplifiers	406
	FDM Systems	408
	TDM Systems	412
9.7	Video Receive-Only Systems	415
9.8	Frequency Coordination	418
9.9	Summary	420
	References	421
	Problems	423
<b>Chapter 10</b>	<b>INTELSAT AND INMARSAT</b>	<b>426</b>
	10.1 History and Structures of Intelsat	426
	10.2 The Intelsat Network	427
	10.3 Inmarsat	427
	References	430
<b>Chapter 11</b>	<b>SATELLITE TELEVISION: NETWORK DISTRIBUTION AND DIRECT BROADCASTING</b>	<b>431</b>
	11.1 Transponder Frequencies and Designations	432
	11.2 Satellite Television Receivers	433
	11.3 Legal Matters	434
	11.4 Direct Broadcast Satellites	435
	11.5 Summary	436
	References	436
	Problems	437

**xviii CONTENTS**

<b>APPENDIX</b>	<b>439</b>
A.1 Decibels in Communications Engineering	439
A.2 RF Filtering of PSK Carriers	442
References	445
<b>GLOSSARY</b>	<b>446</b>
<b>LIST OF SYMBOLS</b>	<b>456</b>
<b>INDEX</b>	<b>463</b>

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# INTRODUCTION

In less than 20 years, communications satellites have become the dominant carriers of long distance communications. From the first commercial launch of INTELSAT I<sup>1</sup> (also called EARLY BIRD) on April 6, 1965, the satellite industry has grown until it handles most international telephone traffic, all international and almost all domestic long-distance television program distribution, and a rapidly growing proportion of new domestic voice and data channels. Direct satellite broadcasting will soon begin, and proposals for electronic mail and personal two-way satellite radios are under discussion. Satellites have significantly improved the reliability and the accuracy of aviation and maritime communications and navigation, removing these functions from the high-frequency (HF) portion of the spectrum. The International Telecommunication Satellite Organization (*Intelsat*) has grown at a rate of 20 percent per year since 1965 and, as of 1984, it operated over 35,000 two-way traffic links. United States domestic satellite use is expected to grow at an annual rate of 15 percent until the end of this century [2].

These changes have occurred because the technology is now available to put large *spacecraft* into synchronous orbit where, to an observer on the ground, they remain permanently at the same place in the sky. At an altitude of about 35,870 km (22,291 miles), the satellites can receive, amplify, and retransmit radio signals for most of a hemisphere. Thus, with one relay via a satellite, a single transmitter on the ground can reach nearly half the world. With three relays it can reach all of it.

<sup>1</sup> In this text we have followed the conventional practice of printing the names of individual spacecraft and families of spacecraft in capital letters. Individual members of multiple families are generally identified by Roman numerals, for example, INTELSAT III, except for those cases like the COSMOS series, where there have been over 1300 launches [1].



## 2 INTRODUCTION

As satellites have grown larger and more powerful, the cost of required terrestrial equipment has fallen. Where once an earth terminal was a multimillion dollar proposition, receive-only stations are now available for under \$1500. The result is that satellites are the cheapest way to send information reliably over a long distance, particularly if that information is intended for a large number of receivers, who may not always be in the same places.

### 1.1 THE ORIGIN OF SATELLITE COMMUNICATIONS

Most authorities credit Arthur C. Clarke, famous British science fiction writer and author of *2001: A Space Odyssey* [3], with originating the idea of a synchronous communications satellite. In 1945 Clarke noted [4] that a satellite in a circular equatorial orbit with a radius of about 42,242 km would have an angular velocity that matched the earth's. Thus it would always remain above the same spot on the ground, and it could receive and relay signals from most of a hemisphere. Three satellites spaced 120 degrees apart could cover the whole world (with some overlap); provided that messages could be relayed between satellites, reliable communication between any two points in the world would be possible.

As is appropriate for a science fiction writer, Clarke had ideas ahead of their time. It was not until the USSR launched SPUTNIK I on October 4, 1957, that rocket technology was available to put a satellite into even a low orbit; synchronous orbit was not achieved until 1963.

### 1.2 A BRIEF HISTORY OF SATELLITE COMMUNICATIONS [5]

The 1957 launch of SPUTNIK I was followed by the "space race" and a sustained effort by the United States to catch up with the USSR. This was reflected in SCORE (Signal Communicating by Orbiting Relay Equipment) launched by the U.S. Air Force on December 18, 1958. Essentially an Atlas 10B missile with a modified upper stage, SCORE was placed in a low elliptical orbit with a period of 101 min. It broadcast a taped message from President Eisenhower, but it was also the first successful "bent pipe in the sky" satellite repeater. Its normal operating mode was to record an uplink transmission while passing over one earth station and to play it back when requested by another earth station. The maximum message length was 4 min, and the spacecraft's capacity was either one voice channel or seventy 60-words-per-minute teletype channels. SCORE's transponder was a marvel of "quick and dirty" engineering; the receiver was a modified FM pocket pager and the transmitter was a "handy-talkie" with an outboard amplifier to boost transmitter power to 8 W. The uplink frequency was 150 MHz and the downlink frequency was 132 MHz, and the spacecraft carried a tracking beacon at 108 MHz. SCORE's batteries failed after 35 days in orbit.

The first communications satellites to draw widespread popular interest (because on clear nights they were visible to the naked eye) were ECHO I and II, launched by AT&T on August 12, 1960, and January 25, 1964. These were orbiting balloons 100 ft in diameter which served as passive reflectors. As such, they