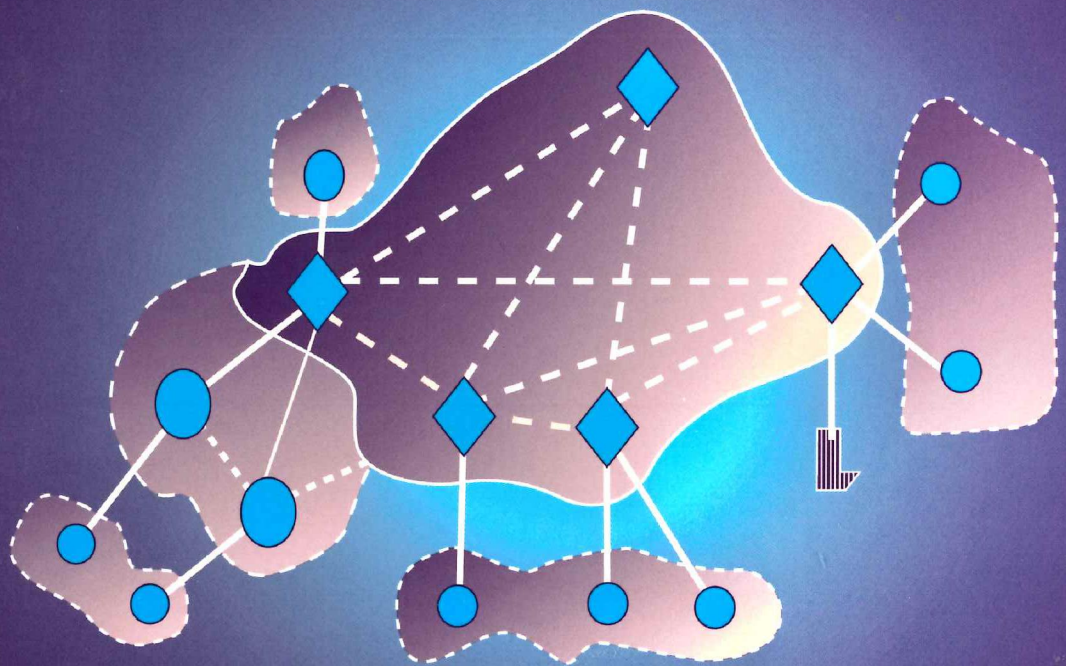


Telecommunication System Engineering

Third Edition



Roger L. Freeman

WILEY SERIES IN TELECOMMUNICATIONS AND SIGNAL PROCESSING
JOHN G. PROAKIS, SERIES EDITOR

AND

Telecommunication System Engineering

Third Edition

Roger L. Freeman



A Wiley-Interscience Publication
JOHN WILEY & SONS, INC.

New York • Chichester • Brisbane • Toronto • Singapore

The texts extracted from the ITU material have been reproduced with the prior authorization of the Union as the copyright holder. The sole responsibility for selecting extracts for reproduction lies with the author alone and can in no way be attributed to the ITU. The complete volumes of the ITU material from which the texts reproduced here are extracted, can be obtained from

International Telecommunication Union
General Secretariat—Sales and Marketing Service
Place de Nations
CH-1211 GENEVA 20 (Switzerland)
Telephone: +41 22 730 51 11 Telex: 421 000 itu ch
Telegram: ITU GENEVE Fax: +41 22 730 51 94
X.400: S=Sales; P=itu; A=Arcom; C=ch Internet: Sales@itu.ch

As referenced, some figures and tables throughout this text are copyrighted by The Institute of Electrical and Electronics Engineers, Inc. As referenced, some figures and tables from Chapters 12 and 14 are reprinted with permission from IEEE Std. 802.2 © 1989; 802.3 © 1992; 802.4 © 1990; 802.5 © 1989, 802.6 © 1990, and 802.7 © 1989. The IEEE disclaims any responsibility or liability resulting from the placement and use in this publication. All figures are reprinted with permission.

As referenced, figures and tables in Chapters 12, 14, and 15 are reproduced with permission from and copyrighted by the American National Standards Institute. Copies of the standards referenced can be purchased from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

As referenced, some figures and tables are copyrighted by Bellcore and are reprinted with permission.

This text is printed on acid-free paper.

Copyright © 1989, 1996 by Roger L. Freeman.

Published by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of this work beyond that permitted by Section 107 or 108 of the 1976 United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Permissions Department, John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012

Library of Congress Cataloging-in-Publication Data:

Freeman, Roger L.

Telecommunication system engineering / Roger L. Freeman. — 3rd ed.

p. cm. — (Wiley series in telecommunications and signal processing)

Includes index.

ISBN 0-471-13302-7 (cloth : alk. paper)

1. Telecommunication systems — Design and construction.
 2. Telephone systems — Design and construction. I. Title.
- II. Series.

TK5103.F68 1996

621.382—dc20

96-10943
CIP

Printed in the United States of America
10 9 8 7 6 5 4 3

CONTENTS

Chapter 1	Some Basics in Conventional Telephony	1
1	Background and Concept	1
1.1	Telecommunication Networks	1
2	The Simple Telephone Connection	2
3	Sources and Sinks	5
4	Telephone Networks: Introductory Terminology	6
5	Essentials of Traffic Engineering	7
5.1	Introduction and Terminology	7
5.2	Measurement of Telephone Traffic	9
5.3	Blockage, Lost Calls, and Grade of Service	11
5.4	Availability	12
5.5	“Handling” of Lost Calls	13
5.6	Infinite and Finite Traffic Sources	14
5.7	Probability-Distribution Curves	14
5.8	Smooth, Rough, and Random Traffic	16
6	Erlang and Poisson Traffic Formulas	17
6.1	Alternative Traffic Formula Conventions	20
6.2	Computer Programs for Traffic Calculations	31
7	Waiting Systems (Queueing)	37
7.1	Server-pool Traffic	37
8	Dimensioning and Efficiency	39
8.1	Alternative Routing	40
8.2	Efficiency Versus Circuit Group Size	42
9	Bases of Network Configurations	42
9.1	Introductory Concepts	42
9.2	Hierarchical Networks	45
9.3	Hierarchical Network Structures	46
9.4	Rules for Conventional Hierarchical Networks	47
9.5	Homing Arrangements and Interconnecting Network in North America	49
10	Routing Methods	51
		vii

viii CONTENTS

11	Variations in Traffic Flow	52
12	Both-Way Circuits	52
13	Quality of Service	53

Chapter 2 Local Networks **59**

1	Introduction	59
2	Subscriber Loop Design	61
2.1	General	61
2.2	Subscriber Loop Length Limits	62
2.3	Quality of a Telephone Speech Connection	63
2.4	Subscriber Loop Design Techniques	71
3	Other Limiting Conditions	77
4	Shape of a Serving Area	78
5	Exchange Location	80
6	Other Loop Design Techniques	84
6.1	Minigauge Techniques	84
6.2	New Loop Design Plans for US Regional Bell Operating Companies	86
7	Design of Local Area Trunks (Junctions)	88
8	Voice-Frequency Repeaters	89
9	Tandem Routing	90
10	Dimensioning of Trunks	93
11	Community of Interest	93

Chapter 3 Conventional Analog Switching in Telephony **99**

1	Introduction	99
1.1	Approach	99
1.2	Switching in the Telephone Network	99
1.3	Some Historical Background	100
1.4	Two-Wire and Four-Wire Switches	101
2	Numbering: One Basis of Switching	102
3	Concentration	103
4	Basic Switching Functions	104
5	Some Introductory Switching Concepts	106
6	Types of Electromechanical Switches	108
7	Multiples and Links	109
8	Definitions: Degeneration, Availability, and Grading	110
8.1	Degeneration	110
8.2	Availability	110
8.3	Grading	111

52
52
53

59
59
61
61
62
63
71
77
78
80
84
84

operating
86
88
89
90
93
93

ion
99
99
99
100
101
102
103
104
106
108
109
110
110
110
111

	CONTENTS	ix
9	Conventional Electromechanical Switches	111
9.1	Step-by-Step or Strowger Switch	111
9.2	Crossbar Switch	113
10	System Control	114
10.1	Introduction	114
10.2	Progressive Control	114
10.3	Common Control (Hard-Wired)	118
11	Stored-Program Control	124
11.1	Introduction	124
11.2	Basic Functions of Stored-Program Control	125
11.3	Additional Functions in a Stored-Program-Control Exchange	125
11.4	A Typical Stored-Program-Control Exchange: European Design	128
11.5	Evolutionary Stored-Program-Control and Distributed Processing	129
12	Concentrators and Satellites	133
13	Call Charging: European Versus North American Approaches	134
14	Transmission Factors in Analog Switching	135
14.1	Introduction	135
14.2	Basic Considerations	135
14.3	Zero Test-Level Point	136
14.4	Transmission Specifications	136
15	Numbering Concepts for Telephony	137
15.1	Introduction	137
15.2	Definitions	137
15.3	Factors Affecting Numbering	140
15.4	In-Dialing	143
16	Telephone Traffic Measurement	144
17	Dial Service Observation	146
	Chapter 4 Signaling for Analog Telephone Networks	151
1	Introduction	151
2	Supervisory Signaling	152
2.1	E and M Signaling	153
3	ac Signaling	155
3.1	General	155
3.2	Low-Frequency ac Signaling Systems	155
3.3	In-Band Signaling	156
3.4	Out-of-Band Signaling	157
4	Address Signaling: Introduction	159
4.1	Two-Frequency Pulse Signaling	159
4.2	Multifrequency Signaling	161

x CONTENTS

5	Compelled Signaling	165
6	Link-by-Link Versus End-to-End Signaling	168
7	The Effects of Numbering on Signaling	170
8	Associated and Disassociated Channel Signaling	170
9	Signaling in the Subscriber Loop	172
9.1	Background and Purpose	172
10	Metallic Trunk Signaling	173
10.1	Basic Loop Signaling	173
10.2	Reverse-Battery Signaling	174
Chapter 5 Introduction to Transmission for Telephony		181
1	General	181
2	The Three Basic Impairments to Voice Channel Transmission	182
2.1	Attenuation Distortion	182
2.2	Phase Distortion	183
2.3	Noise	184
2.4	Level	187
2.5	Signal-to-Noise Ratio	188
3	Two-Wire and Four-Wire Transmission	189
3.1	Two-Wire Transmission	189
3.2	Four-Wire Transmission	189
3.3	Operation of a Hybrid	190
4	Multiplexing	193
4.1	General	193
4.2	Frequency Division Multiplex	193
4.3	Mixing	194
4.4	CCITT Modulation Plan	195
4.5	Loading of Multichannel Frequency-Division-Multiplex Systems	202
4.6	Pilot Tones	206
4.7	Noise and Noise Calculations in FDM Carrier Systems	206
5	Shaping of a Voice Channel and Its Meaning in Noise Units	208
Chapter 6 Long-Distance Networks		215
1	General	215
2	The Design Problem	216
3	Link Limitation	217
4	International Network	219
5	Exchange Location	220
6	Network Design Procedures	222

Chapter 7 The Design of Long-Distance Links 265

5.6	Frequency Bands: Desirable and Available	296
5.7	Multiple Access of a Satellite	297
5.8	Earth Station Link Engineering	303
5.9	Digital Communications by Satellite	311
5.10	Very Small Aperture Terminal (VSAT) Networks	311
6	Fiber-Optics Communication Links	317
6.1	Application	317
6.2	Introduction to Optical Fiber as a Transmission Medium	318
6.3	Types of Optical Fiber	321
6.4	Splices and Connectors	322
6.5	Light Sources	323
6.6	Light Detectors	325
6.7	Optical-Fiber Amplifiers	327
6.8	Fiber-Optic Link Design	329
Chapter 8	Digital Transmission Systems	339
1	Digital Versus Analog Transmission	339
2	Basis of Pulse-Code Modulation	340
3	Development of a Pulse-Code Modulation Signal	341
3.1	Sampling	341
3.2	Quantization	342
3.3	Coding	347
4	Pulse-Code Modulation System Operation	354
5	Practical Applications	355
5.1	General	355
5.2	Practical System Block Diagram	357
5.3	The Line Code	360
5.4	Signal-to-Gaussian-Noise Ratio on Pulse-Code Modulation Repeater Lines	360
5.5	Regenerative Repeaters	361
5.6	PCM System Enhancements	363
6	Higher-Order PCM Multiplex Systems	367
6.1	Introduction	367
6.2	Stuffing and Justification	367
6.3	North American Higher-Level Multiplex	368
6.4	The European E1 Digital Hierarchy	369
7	Long-Distance PCM Transmission	371
7.1	Transmission Limitations	371
7.2	Jitter	373
7.3	Distortion	374
7.4	Thermal Noise	374
7.5	Crosstalk	374
7.6	Echo	375

asis, a radio carrier in each. The wire pair could be open at that follows it is assumed of multiplex configuration, pter 8.

s the medium of choice or use is driven by economics an well be another deciding group connectivity exceeds end of a forecast period, choice at the outset. We do nents. We size the link for near a link for that future

the discussion. It remains, radio-frequency transmission ontender in cable television port for telecommunication removed from contention. s per unit length than fiber n digital systems, builds up n. Another reason to favor hereas coaxial cable needs

- No requirement for right-of-way
- Less vulnerable to vandalism
- Not susceptible to "accidental" cutting of the link
- Often more suited to crossing rough terrain
- Often more practical in heavily urbanized areas
- As a backup to fiber-optic cable links.

Fiber-optic cable systems provide strong competition with line-of-sight (LOS) microwave, but LOS microwave does have a place and a good market.

Satellite communications is an extension of line-of-sight microwave. It is also feeling the "pinch" of competition from fiber-optic systems. It has two drawbacks. First, of course, is limited information bandwidth. The second is excessive delay when the popular geostationary satellite systems are utilized. It also shares frequency bands with LOS microwave.

One application showing explosive growth is very small aperture terminal (VSAT) systems. It is very specialized and has great promise for certain enterprise networks, and there are literally thousands of these networks now in operation.

Another application that will start to show explosive deployment in the next several years will be forms of mobile/cellular and personal communications such as Motorola's Iridium system. This system nearly eliminates the notorious delay problem by using low earth orbit (LEO) satellites.

4 DESIGN ESSENTIALS FOR LINE-OF-SIGHT MICROWAVE SYSTEMS

4.1 Introduction

Line-of-sight (LOS) microwave provides broadband bearer connectivity over a link or series of links in tandem. We can take advantage of this "line-of-sight" phenomenon at frequencies from 150 MHz and upwards into the millimeter spectrum. Each link can be up to 30 miles (46 km) long or more depending on terrain topology. Some links extend over 100 miles (160 km). A series of LOS links is shown in Figure 7.1. Perhaps the key term here is line-of-sight. It implies that the antenna of the radiolink on one end has to be able to "see" the antenna on the other end. This may not necessarily be true, but it does give some idea of the problem.

Let us suppose *smooth earth*. This means earth with no mountains or ridges, buildings, or sloping ground of any sort. Here our LOS distance is limited by the horizon. Given an LOS microwave antenna height h_{ft} or h_m above ground surface, the distance d_{mi} or d_{km} to the horizon just where the ray beam will graze the rounded earth surface horizon can be calculated using one of the formulas given below.