

Telecommunication Circuit Design

Second Edition

Patrick D. van der Puije

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PREFACE

The first edition of this book was published in 1992. Nine years later it had become clear that a second edition was required because of the rapidly changing nature of telecommunication. In 1992, the Internet was in existence but it was not the household word that it is in the year 2001. Cellular telephones were also in use but they had not yet achieved the popularity that they enjoy today. In the current edition, Chapter 1 has been revised to include a section on the Internet. Chapter 10 is new and it covers the facsimile machine; I had overlooked this important telecommunication device in the first edition. Chapter 11 is also new and it describes the pager, the cordless telephone and the cellular telephone system. These are examples of a growing trend in telecommunications to go “wireless”.

This book is about telecommunications: the basic concepts, the design of subsystems and the practical realization of the electronic circuits that make up telecommunication systems. The aim of this book is to fill a gap that exists in the teaching of telecommunications and electronic circuit design to electrical engineering students. Frequently, courses on electronic circuits are taught to students without a clear indication of where these circuits may be used. Later in their career, students may take a course in communication theory where the usual approach is to treat subjects such as modulation, frequency changing and detection as mathematical concepts and to represent them in terms of “black boxes”. Thus the connection between the function “black boxes” and the design of an electronic circuit that will perform the function is glossed over or is completely missing.

The approach followed in this book is to take a specific communication system, for example the amplitude modulated (AM) radio system, and describe in mathematical terms how and why the system is designed the way it is. The system is then broken down into functional blocks. The design of each functional block is examined in terms of the electronic devices to be used, the circuit components and requirements for power. The effectiveness of each functional block is determined. In most cases, more than one circuit is presented, starting from the very elementary which usually illustrates the principles of operation best, to more sophisticated and practical varieties. The order in which the signal encounters the

functional blocks determines the order of the presentation, so new information is presented at an opportune moment when the interest of the student is optimal. Examples are provided to emphasize the link from concept, to design and realization of the circuits. Systems examined in this text include commercial radio broadcasting, television and telephone, with sections devoted to personal wireless communication, satellite communications and data transmission circuits.

This book was written with the final-year engineering undergraduate student in mind, so a clear and explicit style of writing has been used throughout. Illustrative examples have been given whenever possible to promote the active participation of the student in the learning process. However, the practical approach to electronic circuit design will no doubt be useful to people involved in the telecommunications industry for updating, review and as a reference.

Prerequisites to the course in telecommunication circuit design are university mathematics, basic electronics and some familiarity with communication theory (although this is not strictly necessary). In every case where communication theory has a direct impact on the design, enough background has been given to gain an understanding of the topic.

A number of specialized topics have been excluded in the interest of brevity. These include antennas, filters and loudspeakers. Many books are available on these subjects. Rather than presenting a cursory treatment of these very important subjects, I opted for a qualitative description of the operation and design of antennas, filters and loudspeakers in the hope that the reader can develop an appreciation of the outstanding features of these devices which can be built upon if they are of special interest. A list of available reading material has been given in the appropriate chapters.

Although most of the circuits discussed in this book can be found in integrated circuit form, I have, in general, avoided detailed discussion of integrated circuit design. This is because the “rules” of integration aim to reduce the area of the chip to a minimum and thus tend to increase the number of transistors or active components, which take up little area, at the expense of passive components such as resistors and capacitors, which take up relatively large areas. Furthermore, because the integrated circuit process can produce very closely matched transistors, the integrated circuit designer often uses symmetry to achieve circuit functions not possible with discrete devices. An explanation of how an integrated circuit works is therefore more complicated than its discrete counterpart. In every case where the simple and the modern have clashed, I have chosen the simple. However, integrated circuit design techniques have been discussed whenever they are relevant and do not distract the reader from a good understanding of the basic principles of circuit design.

In Chapter 1, a brief history of telecommunication is given. The last 150 years has been a time of tremendous growth and change in telecommunications, more than enough change to qualify as a “revolution”, perhaps the greatest revolution in the history of mankind — the Information Revolution.

Chapters 2 and 3 describe the amplitude modulated (AM) radio system and the electronic circuits that make it possible, from the design of the crystal-controlled

oscillator in the transmitter to the loudspeaker in the receiver. Chapters 4 and 5 repeat the process with the frequency modulated (FM) radio and include sections on stereophonic commercial broadcast and reception.

Television—the transmission and reception of images—is discussed in Chapters 6 and 7. The design of the circuits involved in the acquisition of the video signals, the processing, transmission, coding, broadcasting, reception and decoding are described.

In Chapters 8 and 9, the growth of the telephone system is traced from its humble beginnings to the world-wide network that it is today. The need to open up the system to an increasing number of subscribers has led to the development of sophisticated signal processing techniques and circuits with which to implement them.

Chapter 10 describes the facsimile machine as a system, as well as the design of its component parts.

In Chapter 11 the pager, the cordless telephone and cellular telephone systems are described.

Chapter 12 covers the development of channels in new transmission media, such as satellites and fiber optics, as well as improvements to hard wire connections made possible because circuit designers have produced the hardware at the right time and at the right cost. The growing traffic of “conversations” between machines of various descriptions has accelerated the trend towards “digitization” of signals in the telephone network. The design of circuits capable of accepting data corrupted by noise, restoring and retransmitting them is discussed.

This book started off as lecture notes for a senior college course in electrical engineering called “Telecommunication Circuits”. At the time I proposed the course, it was becoming increasingly clear that the knowledge of our graduating students of communication systems left much to be desired. Students seemed to think that anything analog (including radio, television and the telephone) was *passé*. Digital circuits (computers and software development), on the other hand, were considered “cutting edge”. It was necessary to bring some balance into this situation and I hope that this book helps to restore some semblance of symmetry. The seemingly simple task of changing a set of lecture notes into a textbook turned out not to be quite as simple as I had imagined. However, I have learned a lot from it and I hope the reader does, too.

The material contained in this book is more than can be presented in the normal 13-week term. However, the organization of chapters is based on the three major telecommunication networks: radio, television, and the telephone. It is therefore convenient to organize such a course around a group of chapters with minimal rearrangement of the material and still maintain coherence.

PATRICK D. VAN DER PUIJE

*Ottawa, Ontario, Canada
September 2001*

CONTENTS

Preface

xiii

Chapter 1 The History of Telecommunications

1

- 1.1 Introduction 1
- 1.2 Telecommunication Before the Electric Telegraph 1
- 1.3 The Electric Telegraph 2
- 1.4 The Facsimile Machine 4
- 1.5 The Telephone 6
- 1.6 Radio 8
- 1.7 Television 9
- 1.8 The Growth of Bandwidth and the Digital Revolution 10
- 1.9 The Internet 11
- 1.10 The World Wide Web 13
- References 15
- Bibliography 16

Chapter 2 Amplitude Modulated Radio Transmitter

17

- 2.1 Introduction 17
- 2.2 Amplitude Modulation Theory 18
- 2.3 System Design 21
 - 2.3.1 Crystal-Controlled Oscillator 22
 - 2.3.2 Frequency Multiplier 22
 - 2.3.3 Amplitude Modulator 22
 - 2.3.4 Audio Amplifier 22
 - 2.3.5 Radio-Frequency Power Amplifier 23
 - 2.3.6 Antenna 23

2.4	Radio Transmitter Oscillator	23
2.4.1	Negative Conductance Oscillator	24
2.4.2	Classical Feedback Theory	26
2.4.3	Sinusoidal Oscillators	28
2.4.4	General Form of the Oscillator	28
2.4.5	Oscillator Design for Maximum Power Output	31
2.4.6	Crystal-Controlled Oscillator	35
2.5	Frequency Multiplier	37
2.5.1	Class-C Amplifier	40
2.5.2	Converting the Class-C Amplifier into a Frequency Multiplier	40
2.6	Modulator	47
2.6.1	Square-law Modulator	47
2.6.2	Direct Amplitude Modulation Amplifier	49
2.6.3	Four-Quadrant Analog Multiplier	51
2.7	Audio-Frequency Amplifier	54
2.7.1	Basic Device Characteristics	54
2.7.2	Class-A Amplifier	55
2.7.3	Class-B Amplifier	60
2.8	The Radio-Frequency Amplifier	67
2.9	The Antenna	71
2.9.1	Radiation Pattern of an Isolated Dipole	72
2.9.2	Monopole or Half-Dipole	72
2.9.3	Field Patterns for a Vertical Grounded Antenna	74
2.10	Classification of Amplitude Modulated Radio-Frequency Bands	75
	References	76
	Problems	76

Chapter 3 The Amplitude Modulated Radio Receiver

79

3.1	Introduction	79
3.2	The Basic Receiver: System Design	79
3.3	The Superheterodyne Receiver: System Design	82
3.4	Components of the Superheterodyne Receiver	85
3.4.1	Receiver Antenna	85
3.4.2	Low-Power Radio-Frequency Amplifier	86
3.4.3	Frequency Changer or Mixer	90
3.4.4	Intermediate-Frequency Stage	99
3.4.5	Automatic Gain Control	101

- 3.4.6 Demodulator 103
- 3.4.7 Audio-Frequency Amplifier 105
- 3.4.8 Loudspeaker 105
- 3.5 Short-Wave Radio 107
- References 108
- Bibliography 108
- Problems 108

Chapter 4 Frequency Modulated Radio Transmitter 111

- 4.1 Introduction 111
- 4.2 Frequency Modulation Theory 111
- 4.3 The Parameter Variation Method 115
 - 4.3.1 Basic System Design 115
 - 4.3.2 Automatic Frequency Control of the FM Generator 117
 - 4.3.3 Component Design with Automatic Frequency Control 118
- 4.4 The Armstrong System 122
 - 4.4.1 Practical Realization 125
 - 4.4.2 Component Circuit Design 127
- 4.5 Stereophonic FM Transmission 137
 - 4.5.1 System Design 137
- Bibliography 138
- Problems 139

Chapter 5 The Frequency Modulated Radio Receiver 143

- 5.1 Introduction 143
- 5.2 Component Design 146
 - 5.2.1 Antenna 146
 - 5.2.2 Radio-Frequency Amplifier 146
 - 5.2.3 Local Oscillator 147
 - 5.2.4 Frequency Changer 147
 - 5.2.5 Intermediate-Frequency Stage 147
 - 5.2.6 Amplitude Limiter 148
 - 5.2.7 Frequency Discriminator 148
- 5.3 Stereophonic Frequency Modulated Reception 156
 - 5.3.1 Synchronous Demodulation 158
 - 5.3.2 Stereophonic Receiver Circuit 158
- References 158
- Problems 159

Chapter 6	The Television Transmitter	161
6.1	Introduction	161
6.2	System Design	162
6.3	Component Design	163
6.3.1	Camera Tube	163
6.3.2	Scanning System	167
6.3.3	Audio Frequency and FM Circuits	169
6.3.4	Video Amplifier	170
6.3.5	Radio-Frequency Circuits	179
6.3.6	Vestigial Sideband Filter	179
6.3.7	Antenna	179
6.3.8	Color Television	180
	References	184
	Bibliography	184
	Problems	185
Chapter 7	The Television Receiver	187
7.1	Introduction	187
7.2	Component Design	189
7.2.1	Antenna	189
7.2.2	Superheterodyne Section	189
7.2.3	Intermediate-Frequency Amplifier	189
7.2.4	Video Detector	190
7.2.5	The Video Amplifier	191
7.2.6	The Audio Channel	191
7.2.7	Electron Beam Control Subsystem	191
7.2.8	Picture Tube	202
7.3	Color Television Receiver	203
7.3.1	Demodulation and Matrixing	203
7.3.2	Component Circuit Design	205
7.3.3	Color Picture Tube	207
7.4	High-Definition Television (HDTV)	209
	Bibliography	210
	Problems	210
Chapter 8	The Telephone Network	213
8.1	Introduction	213
8.2	Technical Organization	213
8.3	Basic Telephone Equipment	216

8.3.1	Carbon Microphone	216
8.3.2	Moving-Iron Telephone Receiver	218
8.3.3	Local Battery – Central Power Supply	220
8.3.4	Signalling System	220
8.3.5	The Telephone Line	221
8.3.6	Performance Improvements	222
8.3.7	Telephone Component Variation	224
8.4	Electronic Telephone	224
8.4.1	Microphones	225
8.4.2	Receiver	225
8.4.3	Hybrid	226
8.4.4	Tone Ringer	229
8.4.5	Tone Dial	230
8.5	Digital Telephone	243
8.5.1	The Codec	244
8.6	The Central Office	253
8.6.1	Manual Office	253
8.6.2	Basics of Step-by-Step Switching	253
8.6.3	The Strowger Switch	256
8.6.4	Basics of Crossbar Switching	257
8.6.5	Central Office Tone Receiver	259
8.6.6	Elements of Electronic Switching	261
	References	263
	Problems	263

Chapter 9 Signal Processing in the Telephone System 267

9.1	Introduction	267
9.2	Frequency Division Multiplex (FDM)	267
9.2.1	Generation of Single-Sideband Signals	268
9.2.2	Design of Circuit Components	269
9.2.3	Formation of a Basic Group	269
9.2.4	Formation of a Basic Supergroup	270
9.2.5	Formation of a Basic Mastergroup	270
9.3	Time-Division Multiplex (TDM)	272
9.3.1	Pseudodigital Modulation	273
9.3.2	Pulse-Amplitude Modulation Encoder	273
9.3.3	Pulse-Amplitude Modulation Decoder	279
9.3.4	Pulse Code Modulation Encoder/Multiplexer	286
9.3.5	Pulse-Code Modulation Decoder/Demultiplexer	286

9.3.6	Bell System T-1 PCM Carrier	286
9.3.7	Telecom Canada Digital Network	290
9.3.8	Synchronization Circuit	290
9.3.9	Regenerative Repeater	291
9.4	Data Transmission Circuits	295
9.4.1	Modem Circuits	298
	References	300
	Problems	301

Chapter 10 The Facsimile Machine **305**

10.1	Introduction	305
10.2	Systems Design	307
10.2.1	The Transmit Mode	308
10.2.2	The Receive Mode	308
10.3	Operation	310
10.3.1	“Handshake” Protocol	310
10.4	The Transmit Mode	311
10.4.1	The CCD Image Sensor	311
10.4.2	The Binary Quantizer	315
10.4.3	The Two-Row Memory	317
10.5	Data Compression	318
10.5.1	The Modified Huffman (MH) Code	318
10.5.2	The Modified READ Code	318
10.6	The Modem	319
10.7	The Line Adjuster	319
10.8	The Receive Mode	319
10.8.1	The Power Amplifier	319
10.8.2	The Thermal Printer	321
10.9	Gray Scale Transmission: Dither Technique	322
	References	323
	Bibliography	323
	Glossary	323
	Problems	324

Chapter 11 Personal Wireless Communication Systems **325**

11.1	Introduction	325
11.2	Modulation and Demodulation Revisited	326
11.3	Access Techniques	327
11.3.1	Multiplex and Demultiplex Revisited	327
11.3.2	Frequency-Division Multiple Access (FDMA)	328

11.3.3	Time-Division Multiple Access (TDMA)	328
11.3.4	Spread Spectrum Techniques	329
11.4	Digital Carrier Systems	331
11.4.1	Binary Phase Shift Keying (BPSK)	333
11.4.2	Quadrature Phase Shift Keying (QPSK)	334
11.5	The Paging System	338
11.5.1	The POCSAG Paging System	338
11.5.2	Other Paging Systems	341
11.6	The Analog Cordless Telephone	343
11.6.1	System Design	343
11.6.2	Component Design	343
11.6.3	Disadvantages of the Analog Cordless Telephone	347
11.7	The Cellular Telephone	347
11.7.1	System Overview	348
11.7.2	Advanced Mobile Phone System (AMPS)	348
11.8	Other Analog Cellular Telephone Systems	355
11.8.1	Disadvantages of Analog Cellular Telephone Systems	357
11.9	The CDMA Cellular Telephone Systems	358
11.9.1	System Design of the Transmit Path	358
11.9.2	Component Circuit Design for the Transmit Path	359
11.9.3	System Design of the Receive Path	361
11.9.4	Component Circuit Design for the Receive Path	362
11.10	Other Digital Cellular Systems	362
	References	363
	Bibliography	363
	Problems	364
	Abbreviations	364

Chapter 12 Telecommunication Transmission Media

367

12.1	Introduction	367
12.2	Twisted-Pair Cable	367
12.2.1	Negative-Impedance Converter	370
12.2.2	Four-Wire Repeater	374
12.3	Coaxial Cable	375
12.4	Waveguides	376

12.5	Optical Fiber	376
12.6	Free Space Propagation	377
12.6.1	Direct Wave	379
12.6.2	Earth-Reflected Wave	379
12.6.3	Troposphere-Reflected Wave	379
12.6.4	Sky-Reflected Wave	379
12.6.5	Surface Wave	380
12.7	Terrestrial Microwave Radio	380
12.7.1	Analog Radio	381
12.7.2	Digital Radio	384
12.8	Satellite Transmission System	384
	References	389
	Bibliography	389
	Problems	390

Appendix A	The Transformer	391
A.1	Introduction	391
A.2	The Ideal Transformer	392
A.3	The Practical Transformer	394
Appendix B	Designation of Frequencies	397
	VHF Television Frequencies	397
	UHF Television Frequencies	398
Appendix C	The Electromagnetic Spectrum	399
Appendix D	The Modified Huffman Data Compression Code	401
Appendix E	Electronic Memory	405
E.1	Introduction	405
E.2	Basics of <i>S-R</i> Flip-Flop Circuits	405
E.3	The Clocked <i>S-R</i> Flip-Flop	407
E.4	Initialization of the <i>S-R</i> Flip-Flop	409
E.5	The Shift Register	409
E.5	Electronic Memory	411
E.6	Random Access Memory (RAM)	411
Appendix F	Binary Coded Decimal to Seven-Segment Decoder	415
Index		417

THE HISTORY OF TELECOMMUNICATIONS

1.1 INTRODUCTION

According to UNESCO statistics, in 1997, there were 2.4 billion radio receivers in nearly 200 countries. The figure for television was 1.4 billion receivers. During the same year, it was reported that there were 822 million main telephone lines in use world-wide. The number of host computers on the Internet was estimated to be 16.3 million [1]. In addition to this, the military in every country has its own communication network which is usually much more technically sophisticated than the civilian network. These numbers look very impressive when one recalls that electrical telecommunication is barely 150 years old. One can well imagine the number of people employed in the design, manufacture, maintenance and operation of this vast telecommunication system.

1.2 TELECOMMUNICATION BEFORE THE ELECTRIC TELEGRAPH

The need to send information from one geographic location to another with the minimum of delay has been a quest as old as human history. Galloping horses, carrier pigeons and other animals have been recruited to speed up the rate of information delivery. The world's navies used semaphore for ship-to-ship as well as from ship-to-shore communication. This could be done only in clear daylight and over a distance of only a few kilometres. The preferred method for sending messages over land was the use of beacons: lighting a fire on a hill, for example. The content of the message was severely restricted since the sender and receiver had to have previously agreed on the meaning of the signal. For example, the lighting of a beacon on a particular hill may inform one's allies that the enemy was approaching from the north, say. In 1792, the French Legislative Assembly approved funding for the demonstration of a 35 km visual telegraphic system. This was essentially

semaphore on land. By 1794, Lille was connected to Paris by a visual telegraph [3]. In England, in 1795, messages were being transmitted over a visual telegraph between London and Plymouth – a return distance of 800 km in 3 minutes [4].

North American Indians are reputed to have communicated by creating puffs of smoke using a blanket held over a smoking fire. Such a system would require clear daylight as well as the absence of wind, not to mention a number of highly skilled operators.

A method of telecommunication used in the rain forests of Africa was the “talking drum”. By beating on the drum, a skilled operator could send messages from one village to the next. This system of communication had the advantage of being operational in daylight and at night. However, it would be subject to operator error, especially when the message had to be relayed from village to village.

1.3 THE ELECTRIC TELEGRAPH

The first practical use of electricity for communication was in 1833 by two professors from the University of Goettingen, Carl Friedrich Gauss (1777–1855) and Wilhelm Weber (1804–1891). Their system connected the Physics Institute to the Astronomical Observatory, a distance of 1 km, and used an induction coil and a mirror galvanometer [4].

In 1837, Charles Wheatstone (1802–1875) (of Wheatstone Bridge fame) and William Cooke (1806–1879) patented a communication system which used five electrical circuits consisting of coils and magnetic needles which deflected to indicate a letter of the alphabet painted on a board [5]. The first practical use of this system was along the railway track between Euston and Chalk Farm stations in London, a distance of 2.5 km. Several improvements were later made, the major one being the use of a coding scheme which reduced the system to a single coil and a single needle. The improvement of the performance, reliability and cost of communication has since kept many generations of engineers busy.

At about the time when Wheatstone and Cooke were working on their system, Samuel Morse (1791–1872) was busy doing experiments on similar ideas. His major contribution to the hardware was the relay, also called a repeater. By connecting a series of relays as shown in Figure 1.1, it was possible to increase the distance over

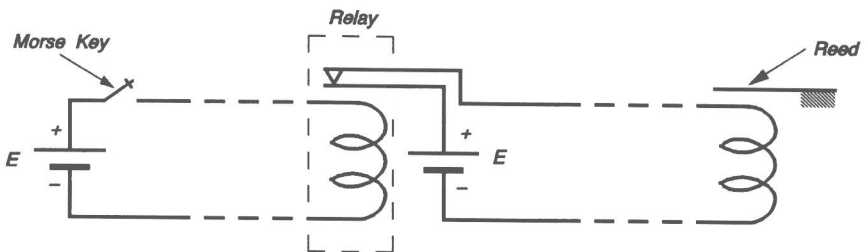


Figure 1.1. The use of Morse's relay to extend the range of the telegraph.

which the system could operate [5]. Morse also replaced the visual display of Wheatstone and Cooke with an audible signal which reduced the fatigue of the operators. However, he is better known for his efficient coding scheme which is based on the frequency of occurrence of the letters in the English language so that the most frequently used letter has the shortest code (E: dot) and the least frequently used character has the longest code ('-apostrophe: dot-dash-dash-dash-dot). This code was in general use until the 1950s and it is still used by amateur radio operators today.

In 1843, Morse persuaded the United States Congress to spend \$30,000 to build a telegraph line between Washington and Baltimore. The success of this enterprise made it attractive to private investors, and Morse and his partner Alfred Vail (1807–1859), were able to extend the line to Philadelphia and New York [6]. A number of companies were formed to provide telegraphic services in the east and mid-west of the United States. By 1851, most of these had joined together to form the Western Union Telegraph Company.

By 1847, several improvements had been made to the Wheatstone invention by the partnership of Werner Siemens (1816–1892) and Johann Halske (1814–1890) in Berlin. This was the foundation of the Siemens telecommunication company in Germany.

The next major advance came in 1855 when David Hughes (1831–1900) invented the printing telegraph, the ancestor of the modern teletype. This must have put a lot of telegraph operators out of work (a pattern which was to be repeated over and over again) since the machine could print messages much faster than a person could write. Another improvement which occurred at about this time was the simultaneous transmission of messages in two directions on the same circuit. Various schemes were used but the basic principle of all of them was the balanced bridge.

In 1851, the first marine telegraphic line between France and England was laid, followed in 1866 by the first transatlantic cable. The laying of this cable was a major feat of engineering and a monument to perseverance. A total of 3200 km of cable was made and stored on an old wooden British warship, the HMS Agamemnon. The laying of the cable started in Valentia Bay in western Ireland but in 2000 fathoms of water, the cable broke and the project had to be abandoned for that year. A second attempt the following year was also a failure. A third attempt in 1858 involved two ships and started in mid-ocean and it was a success. Telegraphic messages could then be sent across the Atlantic. The celebration of success lasted less than a month when the cable insulation broke down under excessively high voltage. Interest in transatlantic cables was temporarily suspended while the American Civil War was fought and it was not until 1865 that the next attempt was made. This time a new ship, the Great Eastern, started from Ireland but after 1900 km the cable broke. Several attempts were made to lift the cable from the ocean bed but the cable kept breaking off so the project was abandoned until the following year. At last in 1866, the Great Eastern succeeded in laying a sound cable and messages could once more traverse the Atlantic. By 1880, there were nine cables crossing the ocean [6].

The telegraph was and remained a communication system for business, and in most European countries it became a government monopoly. Even in its modernized