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国外电子与电气工程经典图书系列

Modern Electronic Communication

(Ninth Edition)

现代电子通信

（第九版）

〔美〕Jeffrey S. Beasley
Gary M. Miller 著

（英文影印版）

科学出版社

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内容简介

本书内容包括：幅度调制、单边带通信、频率调制、通信技术、编码技术、有线及无线数字通信、网络通信、波的传播、天线、波导与雷达、微波与激光、电视及光纤等，同时涉及通信领域很多新技术，如蓝牙、Wi-Max、DTV、DSP、HD-Radio等。

本书可作为电子信息工程、通信工程专业本科生的双语教材或参考书，也可作为相关领域工程技术人员的参考书。

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（如有印装质量问题，我社负责调换）

Dedicated to my family,
Kim, Damon, and Dana
Jeffrey S. Beasley

Dedicated to the youth of the world,
Especially my favorites,
Evan, Maia, Willo, Kevin, Richard, and Luca
Gary M. Miller

PREFACE

We are excited about the many improvements to this edition of *Modern Electronic Communication,* and we trust you will share in our enthusiasm as those improvements are briefly described. The 9th edition maintains the tradition of the 8th edition, including up-to-date coverage of the latest in electronic communication, readable text, and many features that will aid student comprehension.

This edition has greatly expanded the discussion on digital communications, focusing on the many changes and improvements in mobile communications, SS7 signaling, Bluetooth, Wi-Max, and DTV (digital television). Each chapter in the textbook includes Electronics Workbench™ Multisim simulations of the key components of the concepts presented. The 9th edition also includes new sections on wireless security, DSP (digital signal processing), radio frequency identification (RFID), and high-definition (HD) radio; an expanded discussion on satellite communications and parabolic reflectors; and an updated look at fiber optic communication.

We are also pleased to have incorporated a new section on high-frequency communication modules in the textbook. This section featurs the Mini-Circuits® modules with examples of the use of modular electronic systems to implement electronic communication circuitry. This section complements the updates made to the accompanying lab manual, with practical experiments that use the Mini-Circuits® modules.

We are also pleased to provide online “Operational Diagrams of Radio Transmitters and Receivers” prepared by Professors Lance Breger and Ken Markowitz, New York City College of Technology. This brochure provides an excellent look at radio frequency signals. The brochure can be downloaded at **www.prenhall.com/beasley.** Click on the *Modern Electronic Communication* text.

FEATURES

- The most up-to-date treatment of digital and data communications
- Updated treatment of digital television, from theory to application
- The use of Electronics Workbench™ Multisim in spread spectrum communications
- Extensive troubleshooting sections

- Numerous questions and problems for each chapter, including "Questions for Critical Thinking" designed to sharpen analytical skills
- Many circuits from the book are simulated using Electronics Workbench™ Multisim; additional circuits provide interactive, hands-on troubleshooting exercises
- Key terms and definitions highlighted in the margins as they are introduced in the text
- Complete directory of acronyms and abbreviations at the end of the book
- Extensive problem sets
- Color photos of typical industrial equipment
- Chapter outlines, objectives, and key terms identified at the beginning of each chapter
- Summary of key points following each chapter
- Comprehensive glossary at the end of the book

Partial Listing of New Material in the 9th Edition

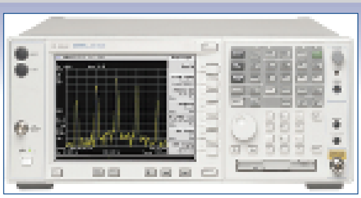
- Expanded coverage mobile (cell phone) communications
- SS7 and telephone signaling systems
- Wireless security
- Digital signal processing
- Monitoring the digital television signal
- High-frequency communication sections featuring the Mini-Circuits® modules
- Expanded fiber optics discussion
- High-definition (HD) Radio
- Radio Frequency Identification (RFID)
- Wi-Max
- Bluetooth (update)
- Fiber optics (update)
- Satellite communications (update)
- Figure of merit and satellite link budget analysis, plus a link to an online calculator for use in a satellite link budget analysis that has been developed specifically for this textbook
- Updated lab manual, incorporating traditional communication integrated circuits, Electronics Workbench™ Multisim exercises, and exercises featuring the Mini-Circuits® modules.

Illustration of Features

CHAPTER OPENER—Each chapter begins with a color photo related to content, a chapter outline, a list of objectives, and key terms being introduced. An example is shown on page vii.

Chapter Opener photo

WIRELESS DIGITAL COMMUNICATIONS



The Agilent E4440A PSA Series Spectrum Analyzer. (© Agilent Technologies, Inc. 2007 Reproduced with Permission, Courtesy of Agilent Technologies, Inc.)

CHAPTER OUTLINE

10-1 Introduction
10-2 Digital Modulation Techniques
10-3 Spread-Spectrum Techniques
10-4 Orthogonal Frequency Division Multiplexing (OFDM)
10-5 Telemetry
10-6 Troubleshooting
10-7 Troubleshooting with Electronics Workbench™ Multisim

OBJECTIVES

- Describe the basics of a wireless digital communications link
- Provide detail on the various schemes used to transmit digital signals, including FSK, PSK, BPSK, QPSK, DPSK, and QAM
- Describe the generation of eye patterns and explain their use
- Describe the OFDM technique and explain why it is used
- Detail the operation of a complete radio-telemetry system
- Understand the basic steps for troubleshooting cell phone problems

KEY TERMS

wireless digital communications
wireless
frequency shift keying
phase shift keying
data bandwidth compression
quadrature amplitude modulation
constellation pattern
loopback
eye patterns
pseudonoise (PN) codes
spread
PN sequence length
maximal length
frequency hopping spread spectrum
dwell time
DSSS
chips
code division multiple access (CDMA)
multiple access
hit
signature sequence
despread
orthogonal frequency division multiplexing (OFDM)
multitone modulation
orthogonal
cyclic prefix
HD radio
in-band on-channel (IBOC)
hybrid AM, FM
COFDM
flash OFDM
telemetry
radio telemetry
water mark sticker
preferred roaming list (PRL)
OTA
RF shield box

Chapter Outline

Chapter Objectives

Key Terms for this chapter

WORKED EXAMPLES—Numerous worked-out examples are included in every chapter, as shown below. These examples reinforce key concepts and aid in subject mastery.

Every chapter contains a Troubleshooting section

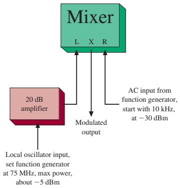


FIGURE 7-31 The suggested connection diagram for the ZP-3.

the input frequency (terminal L) needs to be less than or equal to –20 dBm. The theoretical mixer conversion loss is 6 dB. This means that if the input power is –20 dBm, the output power will be –26 dBm.

7-8 TROUBLESHOOTING

Transceivers, or two-way radios, are found in many commercial applications. In this section we will look at troubleshooting the transmitter portion of a mobile transceiver. General troubleshooting techniques are presented in this section. You should always consult the service manual before disassembling a transceiver and making any adjustments or repairs on it.

Today's communication equipment usually includes digital logic circuits to control various functions. We will learn to troubleshoot some basic logic circuits. We'll also consider troubleshooting a frequency synthesizer.

After completing this section you should be able to

- Describe the signal flow in a mobile FM transmitter circuit
- Describe common mobile transmitter failures
- Troubleshoot basic logic circuits
- Troubleshoot a frequency synthesizer

TRANSCEIVER TRANSMITTER

The block diagram in Figure 7-32 depicts the transmitter portion of a mobile transceiver. Mobile transmitters may differ somewhat in design. For example, this particular transmitter uses several frequency multiplier circuits in the exciter stage to step up the frequency to the necessary operating frequency. A press-to-talk microphone feeds the voice signal into an audio amplifier. The voice signal is amplified

Section 7-8 • Troubleshooting 335

Numerous worked-out examples aid in subject mastery

EXAMPLE 7-8

The receiver from Example 7-7 has a preamplifier at its input. The preamp has a 24-dB gain and a 5-dB NF. Calculate the new sensitivity and dynamic range.

SOLUTION

The first step is to determine the overall system noise ratio (NR). Recall from Chapter 1 that

$$\mathrm{NR} = \log^{-1}\frac{\mathrm{NF}}{10}$$

Letting NR_1 represent the preamp and NR_2 the receiver, we have

$$\mathrm{NR}_1 = \log^{-1}\frac{5\text{ dB}}{10} = 3.16$$
$$\mathrm{NR}_2 = \log^{-1}\frac{20\text{ dB}}{10} = 100$$

The overall NR is

$$\mathrm{NR} = \mathrm{NR}_1 + \frac{\mathrm{NR}_2 - 1}{P_{G_1}} \qquad (1\text{-}16)$$

and

$$\begin{aligned} P_{G1} &= \log^{-1}\frac{24\text{ dB}}{10} = 251 \\ \mathrm{NR} &= 3.16 + \frac{100-1}{251} = 3.55 \\ \mathrm{NF} &= 10\log_{10} 3.55 = 5.5\text{ dB} \\ &= \text{total system NF} \\ S &= -174\text{ dBm} + 5.5\text{ dB} + 60\text{ dB} = -108.5\text{ dBm} \end{aligned}$$

The third-order intercept point of the receiver alone had been +5 dBm but is now preceded by the preamp with 24-dB gain. Assuming that the preamp can deliver 5 dBm to the receiver without any appreciable intermodulation distortion, the system's third-order intercept point is +5 dBm −24 dB = −19 dBm. Thus,

$$\begin{aligned} \text{dynamic range} &\simeq \frac{2}{3}[-19\text{ dBm} - (-108.5\text{ dBm})] \\ &= 59.7\text{ dB} \end{aligned}$$

EXAMPLE 7-9

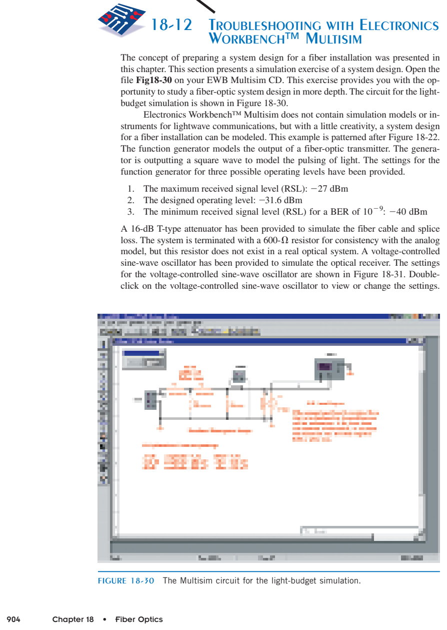
The 24-dB gain preamp in Example 7-8 is replaced with a 10-dB gain preamp with the same 5-dB NF. What are the system's sensitivity and dynamic range?

Section 7-4 • Receiver Noise, Sensitivity, and Dynamic Range Relationships 315

TROUBLESHOOTING—Every chapter contains an extensive troubleshooting section. An illustration is provided on page vii. Notice that areas of expected student mastery are highlighted. Students are very interested in applying knowledge gained by "fixing" real-world systems. Their comprehension is improved in this process. Equally important, employers and accrediting agencies strongly encourage emphasis on troubleshooting skills.

TROUBLESHOOTING—WITH ELECTRONICS WORKBENCH™ MULTISIM
Every chapter ends with a Multisim circuit simulation and troubleshooting exercise as well as end-of-chapter exercises incorporating Electronics Workbench Multisim. An illustration is provided below.

Troubleshooting with Electronics Workbench™ Multisim is featured in this edition



18-12 TROUBLESHOOTING WITH ELECTRONICS WORKBENCH™ MULTISIM

The concept of preparing a system design for a fiber installation was presented in this chapter. This section presents a simulation exercise of a system design. Open the file **Fig18-30** on your EWB Multisim CD. This exercise provides you with the opportunity to study a fiber-optic system design in more depth. The circuit for the light-budget simulation is shown in Figure 18-30.

Electronics Workbench™ Multisim does not contain simulation models or instruments for lightwave communications, but with a little creativity, a system design for a fiber installation can be modeled. This example is patterned after Figure 18-22. The function generator models the output of a fiber-optic transmitter. The generator is outputting a square wave to model the pulsing of light. The settings for the function generator for three possible operating levels have been provided.

1. The maximum received signal level (RSL): −27 dBm
2. The designed operating level: −31.6 dBm
3. The minimum received signal level (RSL) for a BER of 10^{-9}: −40 dBm

A 16-dB T-type attenuator has been provided to simulate the fiber cable and splice loss. The system is terminated with a 600-Ω resistor for consistency with the analog model, but this resistor does not exist in a real optical system. A voltage-controlled sine-wave oscillator has been provided to simulate the optical receiver. The settings for the voltage-controlled sine-wave oscillator are shown in Figure 18-31. Double-click on the voltage-controlled sine-wave oscillator to view or change the settings.

FIGURE 18-30 The Multisim circuit for the light-budget simulation.

904 Chapter 18 • Fiber Optics

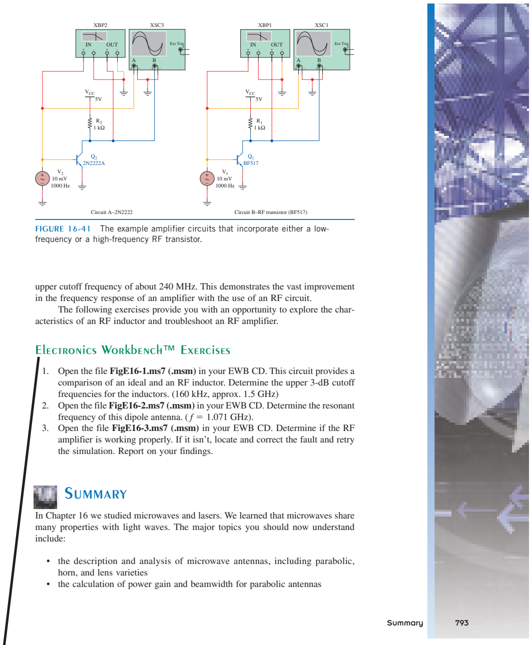


FIGURE 16-41 The example amplifier circuits that incorporate either a low-frequency or a high-frequency RF transistor.

upper cutoff frequency of about 240 MHz. This demonstrates the vast improvement in the frequency response of an amplifier with the use of an RF circuit.

The following exercises provide you with an opportunity to explore the characteristics of an RF inductor and troubleshoot an RF amplifier.

ELECTRONICS WORKBENCH™ EXERCISES

1. Open the file **FigE16-1.ms7 (.msm)** in your EWB CD. This circuit provides a comparison of an ideal and an RF inductor. Determine the upper 3-dB cutoff frequencies for the inductors. (160 kHz, approx. 1.5 GHz)
2. Open the file **FigE16-2.ms7 (.msm)** in your EWB CD. Determine the resonant frequency of this dipole antenna. (f = 1.071 GHz).
3. Open the file **FigE16-3.ms7 (.msm)** in your EWB CD. Determine if the RF amplifier is working properly. If it isn't, locate and correct the fault and retry the simulation. Report on your findings.

SUMMARY

In Chapter 16 we studied microwaves and lasers. We learned that microwaves share many properties with light waves. The major topics you should now understand include:

- the description and analysis of microwave antennas, including parabolic, horn, and lens varieties
- the calculation of power gain and beamwidth for parabolic antennas

Summary 793

Each chapter contains Electronics Workbench™ exercises

FULL-COLOR FORMAT—Color is used throughout as an aid to comprehension and to make the material more visually stimulating. A representative use of color is shown below.

KEY TERMS DEFINED—The important new terms and concepts are defined in the margins near where they are introduced in the text. An illustration is shown below. Having the key terms presented in this way allows the student to quickly access, review, and understand new concepts and terminology.

Full-color photos
enhance the text

(a) The 86100C digital communications analyzer with jitter analysis offers breakthrough speed, accuracy, and affordability. (Courtesy of Agilent Technologies. Reprinted with permission.) (b) The MT8820B radio communications analyzer was designed to support the test needs of the manufacturing, R&D, and maintenance markets. (Courtesy of Anritsu Company.)

242 Chapter 5 • Frequency Modulation: Transmission

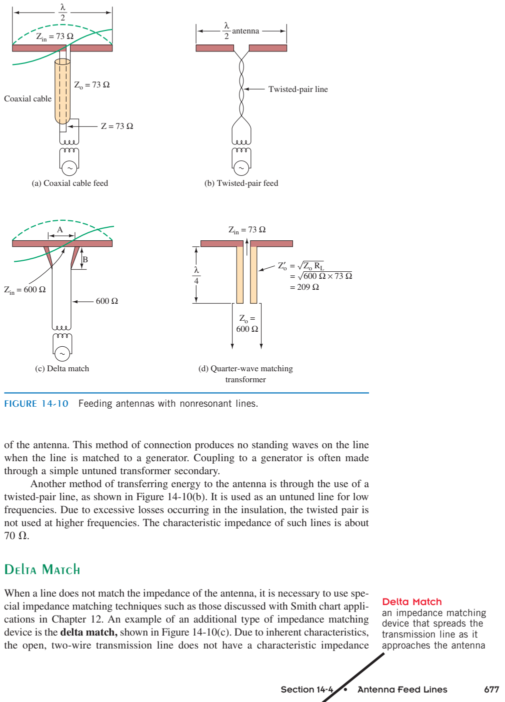


FIGURE 14-10 Feeding antennas with nonresonant lines.

of the antenna. This method of connection produces no standing waves on the line when the line is matched to a generator. Coupling to a generator is often made through a simple untuned transformer secondary.

Another method of transferring energy to the antenna is through the use of a twisted-pair line, as shown in Figure 14-10(b). It is used as an untuned line for low frequencies. Due to excessive losses occurring in the insulation, the twisted pair is not used at higher frequencies. The characteristic impedance of such lines is about 70 Ω.

DELTA MATCH

When a line does not match the impedance of the antenna, it is necessary to use special impedance matching techniques such as those discussed with Smith chart applications in Chapter 12. An example of an additional type of impedance matching device is the **delta match,** shown in Figure 14-10(c). Due to inherent characteristics, the open, two-wire transmission line does not have a characteristic impedance

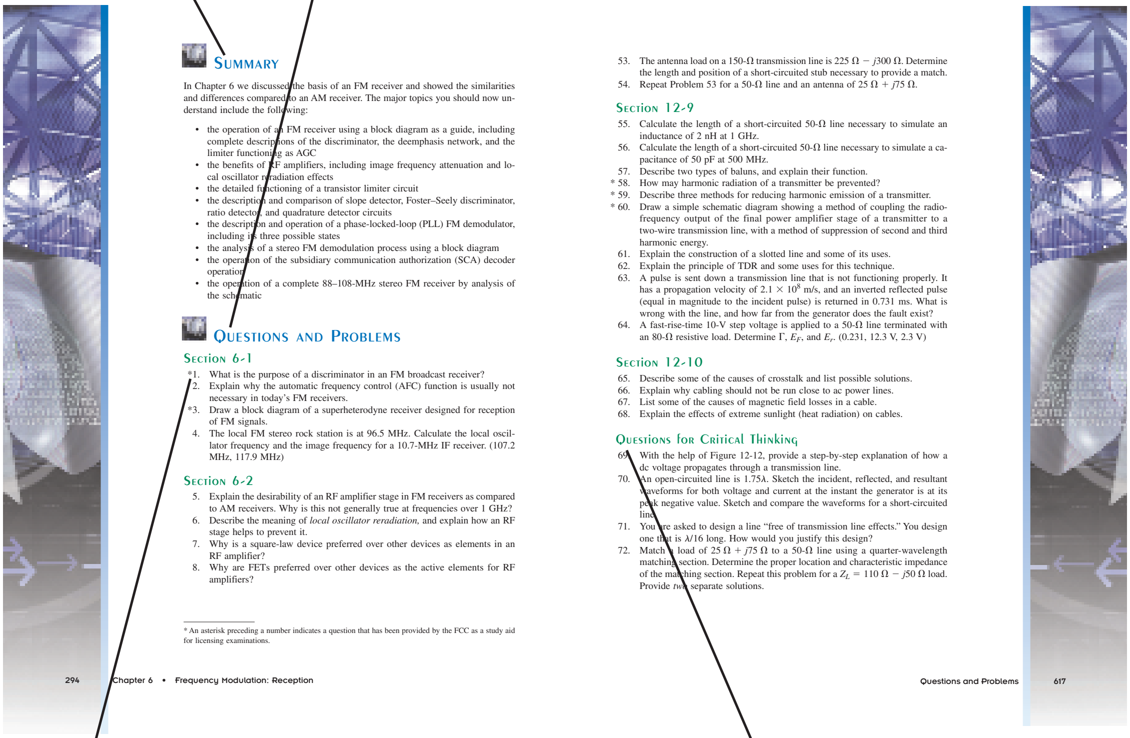
Delta Match
an impedance matching device that spreads the transmission line as it approaches the antenna

Section 14-4 • Antenna Feed Lines 677

Full-color format is used throughout, enhancing illustrations and highlighting key terms

Questions and problems
are organized by section,
including troubleshooting

Summary of key concepts



Summary

In Chapter 6 we discussed the basis of an FM receiver and showed the similarities and differences compared to an AM receiver. The major topics you should now understand include the following:

- the operation of an FM receiver using a block diagram as a guide, including complete descriptions of the discriminator, the deemphasis network, and the limiter functioning as AGC
- the benefits of RF amplifiers, including image frequency attenuation and local oscillator reradiation effects
- the detailed functioning of a transistor limiter circuit
- the description and comparison of slope detector, Foster–Seely discriminator, ratio detector, and quadrature detector circuits
- the description and operation of a phase-locked-loop (PLL) FM demodulator, including its three possible states
- the analysis of a stereo FM demodulation process using a block diagram
- the operation of the subsidiary communication authorization (SCA) decoder operation
- the operation of a complete 88–108-MHz stereo FM receiver by analysis of the schematic

Questions and Problems

Section 6-1

*1. What is the purpose of a discriminator in an FM broadcast receiver?
2. Explain why the automatic frequency control (AFC) function is usually not necessary in today's FM receivers.
*3. Draw a block diagram of a superheterodyne receiver designed for reception of FM signals.
4. The local FM stereo rock station is at 96.5 MHz. Calculate the local oscillator frequency and the image frequency for a 10.7-MHz IF receiver. (107.2 MHz, 117.9 MHz)

Section 6-2

5. Explain the desirability of an RF amplifier stage in FM receivers as compared to AM receivers. Why is this not generally true at frequencies over 1 GHz?
6. Describe the meaning of *local oscillator reradiation,* and explain how an RF stage helps to prevent it.
7. Why is a square-law device preferred over other devices as elements in an RF amplifier?
8. Why are FETs preferred over other devices as the active elements for RF amplifiers?

---

* An asterisk preceding a number indicates a question that has been provided by the FCC as a study aid for licensing examinations.

294 Chapter 6 • Frequency Modulation: Reception

53. The antenna load on a 150-Ω transmission line is 225 Ω − *j*300 Ω. Determine the length and position of a short-circuited stub necessary to provide a match.
54. Repeat Problem 53 for a 50-Ω line and an antenna of 25 Ω + *j*75 Ω.

Section 12-9

55. Calculate the length of a short-circuited 50-Ω line necessary to simulate an inductance of 2 nH at 1 GHz.
56. Calculate the length of a short-circuited 50-Ω line necessary to simulate a capacitance of 50 pF at 500 MHz.
57. Describe two types of baluns, and explain their function.
* 58. How may harmonic radiation of a transmitter be prevented?
* 59. Describe three methods for reducing harmonic emission of a transmitter.
* 60. Draw a simple schematic diagram showing a method of coupling the radio-frequency output of the final power amplifier stage of a transmitter to a two-wire transmission line, with a method of suppression of second and third harmonic energy.
61. Explain the construction of a slotted line and some of its uses.
62. Explain the principle of TDR and some uses for this technique.
63. A pulse is sent down a transmission line that is not functioning properly. It has a propagation velocity of 2.1×10^8 m/s, and an inverted reflected pulse (equal in magnitude to the incident pulse) is returned in 0.731 ms. What is wrong with the line, and how far from the generator does the fault exist?
64. A fast-rise-time 10-V step voltage is applied to a 50-Ω line terminated with an 80-Ω resistive load. Determine Γ, E_F, and E_r. (0.231, 12.3 V, 2.3 V)

Section 12-10

65. Describe some of the causes of crosstalk and list possible solutions.
66. Explain why cabling should not be run close to ac power lines.
67. List some of the causes of magnetic field losses in a cable.
68. Explain the effects of extreme sunlight (heat radiation) on cables.

Questions for Critical Thinking

69. With the help of Figure 12-12, provide a step-by-step explanation of how a dc voltage propagates through a transmission line.
70. An open-circuited line is 1.75λ. Sketch the incident, reflected, and resultant waveforms for both voltage and current at the instant the generator is at its peak negative value. Sketch and compare the waveforms for a short-circuited line.
71. You are asked to design a line "free of transmission line effects." You design one that is λ/16 long. How would you justify this design?
72. Match a load of 25 Ω + *j*75 Ω to a 50-Ω line using a quarter-wavelength matching section. Determine the proper location and characteristic impedance of the matching section. Repeat this problem for a Z_L = 110 Ω − *j*50 Ω load. Provide *two* separate solutions.

Questions and Problems 617

Asterisked questions are provided by the FCC as study
aids for licensing exams

"Questions for Critical Thinking" further develop
the student's analytical skills

END-OF-CHAPTER MATERIAL—Each chapter concludes with a summary of key concepts, an extensive problem set, a section entitled "Questions for Critical Thinking," and chapter exercises incorporating Electronics Workbench™ Multisim. See above for an illustration of how this material is presented. The questions and problems are very comprehensive and are keyed to the appropriate chapter section. An asterisk next to the question number indicates that a particular question has been provided by the FCC as a study aid for licensing examinations. In addition, the answer to quantitative problems is provided in parentheses following the question. Worked-out solutions to selected problems are available in the Instructor's Manual.

GLOSSARY AND ACRONYMS—The end-of-book material includes an extensive glossary and list of acronyms. These important tools are illustrated on page xi. Acronyms are widely used in electronic communications and are often a source of confusion for students. This listing solves the problem by offering a quickly accessible description.

Comprehensive listing of
commonly used acronyms

ACRONYMS AND ABBREVIATIONS

A

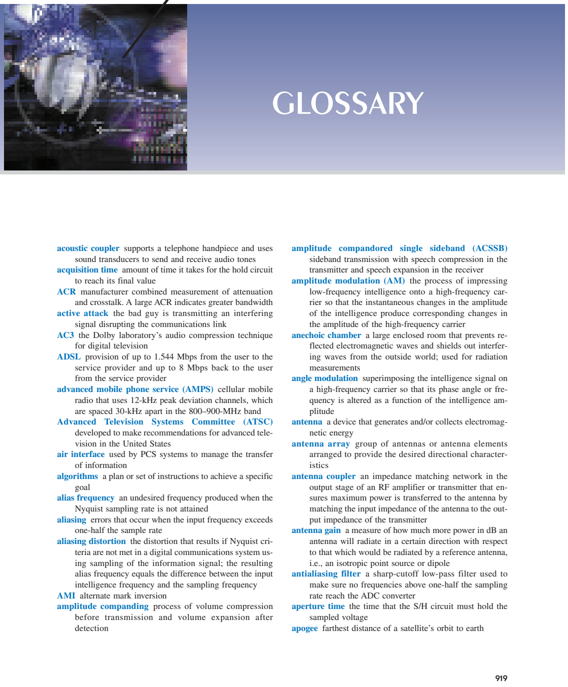
AAL	ATM adaptation layer
AC	alternating current
ACA	adaptive channel allocation
ACIL	trade association (formerly the American Council of Independent Laboratories)
ACK	acknowledgment
ACL	advanced CMOS logic
ACM	address complete message
ACR	attenuation and crosstalk measurement
A/D	analog-to-digital
ADC	analog-to-digital converter
ADCCP	advanced digital communications control protocol
ADSL	asymmetric digital subscriber line
AF	audio frequency
AFC	automatic frequency control
AFSK	audio-frequency shift keying
AGC	automatic gain control
AGCH	Access Grant Channel
AIAA	American Institute of Aeronautics and Astronautics
AlGaAs	aluminum gallium arsenide
ALC	automatic level control
ALU	arithmetic logic unit
AM	amplitude modulation
AMI	alternate mark inversion
AML	automatic-modulation-limiting
AMPS	Advanced Mobile Phone Service
ANM	answer message
ANSI	American National Standards Institute
APC	angle-polished connectors
APD	avalanche photodiode
AP-S	Antennas and Propagation Society
ARPA	Advanced Research Projects Agency (now DARPA)
ARQ	automatic repeat request
ARRL	American Radio Relay League
ASCII	American Standard Code for Information Interchange
ASIC	application-specific integrated circuit
ASK	amplitude-shift keying
ASSP	application-specific standard products
ATC	adaptive transform coding
ATE	automatic test equipment
ATG	automatic test generation
ATM	asynchronous transfer mode
ATSC	Advanced Television Systems Committee
ATV	advanced television
AWGN	additive white Gaussian noise

B

B	byte
BAW	bulk acoustic wave
BBNS	broadband network services
BCC	block check character
BCCH	broadcast control channel
BCD	binary-coded decimal
B-CDMA	broadband CDMA
BCI	broadcast interference
BeCu	beryllium copper
B8ZS	bipolar 8 zero substitution
BER	bit-error rate
BERT	bit-error-rate tester
BFO	beat-frequency oscillator
BiCMOS	bipolar-CMOS
BIOS	basic input/output system
BIS	buffer information specification
B-ISDN	broadband integrated-services digital network (an ATM protocol model)
BJT	bipolar junction transistor

911

Complete glossary of terms
provides quick reference



GLOSSARY

acoustic coupler supports a telephone handpiece and uses sound transducers to send and receive audio tones

acquisition time amount of time it takes for the hold circuit to reach its final value

ACR manufacturer combined measurement of attenuation and crosstalk. A large ACR indicates greater bandwidth

active attack the bad guy is transmitting an interfering signal disrupting the communications link

AC3 the Dolby laboratory's audio compression technique for digital television

ADSL provision of up to 1.544 Mbps from the user to the service provider and up to 8 Mbps back to the user from the service provider

advanced mobile phone service (AMPS) cellular mobile radio that uses 12-kHz peak deviation channels, which are spaced 30-kHz apart in the 800–900-MHz band

Advanced Television Systems Committee (ATSC) developed to make recommendations for advanced television in the United States

air interface used by PCS systems to manage the transfer of information

algorithms a plan or set of instructions to achieve a specific goal

alias frequency an undesired frequency produced when the Nyquist sampling rate is not attained

aliasing errors that occur when the input frequency exceeds one-half the sample rate

aliasing distortion the distortion that results if Nyquist criteria are not met in a digital communications system using sampling of the information signal; the resulting alias frequency equals the difference between the input intelligence frequency and the sampling frequency

AMI alternate mark inversion

amplitude companding process of volume compression before transmission and volume expansion after detection

amplitude compandored single sideband (ACSSB) sideband transmission with speech compression in the transmitter and speech expansion in the receiver

amplitude modulation (AM) the process of impressing low-frequency intelligence onto a high-frequency carrier so that the instantaneous changes in the amplitude of the intelligence produce corresponding changes in the amplitude of the high-frequency carrier

anechoic chamber a large enclosed room that prevents reflected electromagnetic waves and shields out interfering waves from the outside world; used for radiation measurements

angle modulation superimposing the intelligence signal on a high-frequency carrier so that its phase angle or frequency is altered as a function of the intelligence amplitude

antenna a device that generates and/or collects electromagnetic energy

antenna array group of antennas or antenna elements arranged to provide the desired directional characteristics

antenna coupler an impedance matching network in the output stage of an RF amplifier or transmitter that ensures maximum power is transferred to the antenna by matching the input impedance of the antenna to the output impedance of the transmitter

antenna gain a measure of how much more power in dB an antenna will radiate in a certain direction with respect to that which would be radiated by a reference antenna, i.e., an isotropic point source or dipole

antialiasing filter a sharp-cutoff low-pass filter used to make sure no frequencies above one-half the sampling rate reach the ADC converter

aperture time the time that the S/H circuit must hold the sampled voltage

apogee farthest distance of a satellite's orbit to earth

919

SUPPLEMENT PACKAGE

- *Laboratory Manual,* by Mark E. Oliver, Jeffrey S. Beasley, and David Shores
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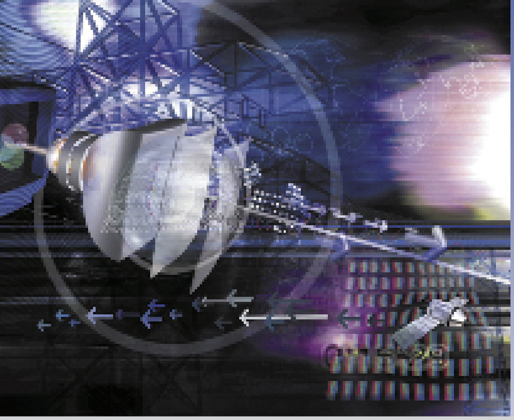

BRIEF CONTENTS

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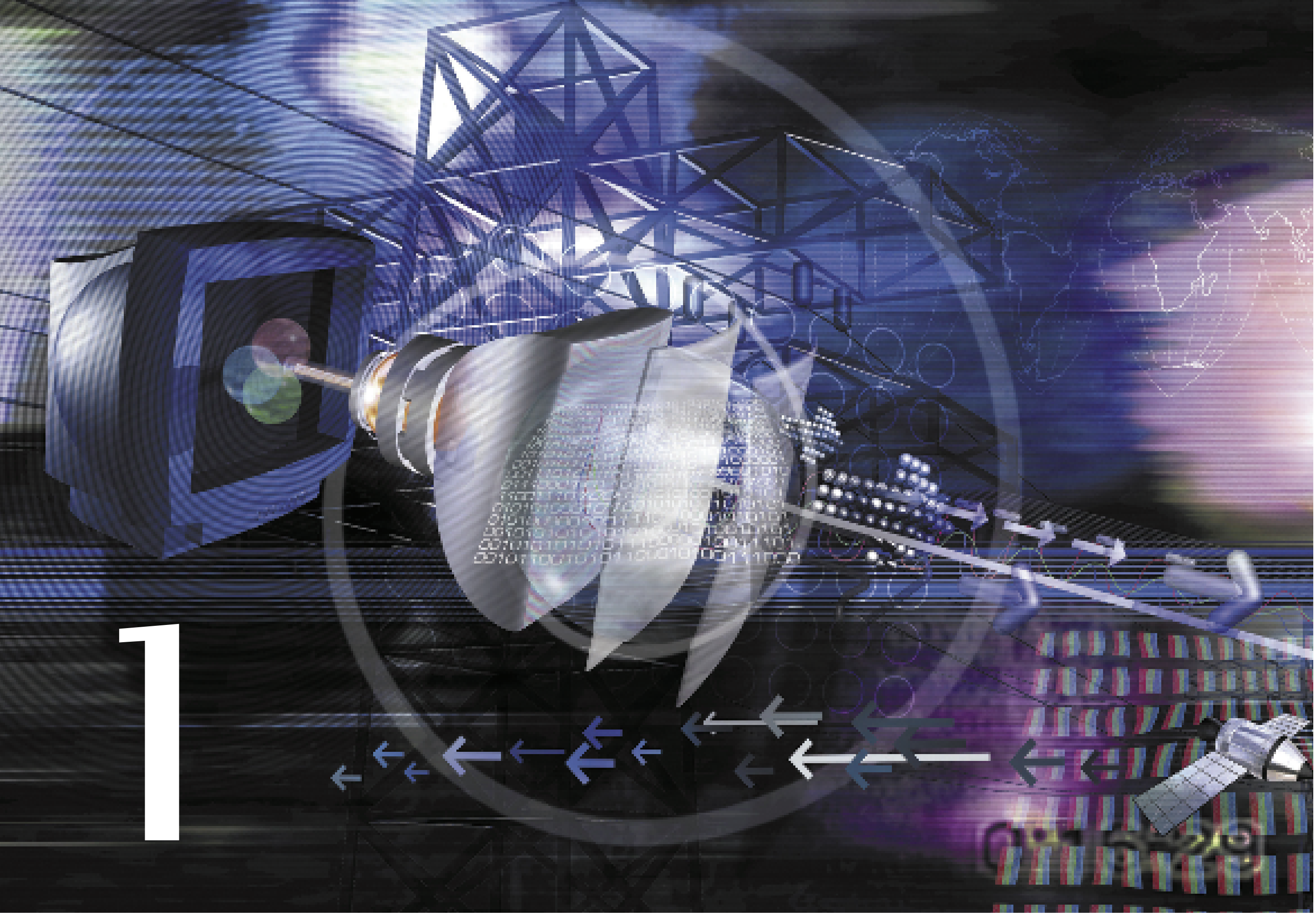

Chapter Outline

Objectives

- Describe a basic communication system and explain the concept of modulation
- Develop an understanding of the use of the decibel (dB) in communications systems
- Define *electrical noise* and explain its effect at the first stages of a receiver
- Calculate the thermal noise generated by a resistor
- Calculate the signal-to-noise ratio and noise figure for an amplifier
- Describe several techniques for making noise measurements
- Explain the relationship among information, bandwidth, and time of transmission
- Analyze nonsinusoidal repetitive waveforms via Fourier analysis
- Analyze the operation of various *RLC* circuits
- Describe the operation of common *LC* and crystal oscillators

INTRODUCTORY TOPICS

Key Terms

- modulation
- intelligence signal
- intelligence
- demodulation
- transducer
- dB
- dBm
- 0 dBm
- dBm(600)
- dBm(75)
- dBm(50)
- dBW
- dBμV
- electrical noise
- static
- external noise
- internal noise
- wave propagation
- atmospheric noise
- space noise
- solar noise
- cosmic noise
- Johnson noise
- thermal noise
- white noise
- low-noise resistor
- shot noise
- excess noise
- transit-time noise
- signal-to-noise ratio
- noise figure
- noise ratio
- octave
- Friiss's formula
- device under test
- tangential method
- information theory
- channel
- Hartley's law
- Fourier analysis
- FFT
- frequency domain record
- aliasing
- quality
- leakage
- dissipation
- resonance
- tank circuit
- poles
- constant-*k* filter
- *m*-derived filter
- roll-off
- stray capacitance
- oscillator
- flywheel effect
- damped
- continuous wave
- Barkhausen criteria
- frequency synthesizer

1-1 Introduction

This book provides an introduction to all relevant aspects of communications systems. These systems had their beginning with the discovery of various electrical, magnetic, and electrostatic phenomena prior to the twentieth century. Starting with Samuel Morse's invention of the telegraph in 1837, a truly remarkable rate of progress has occurred. The telephone, thanks to Alexander Graham Bell, came along in 1876. The first complete system of wireless communication was provided by Guglielmo Marconi in 1894. Lee DeForest's invention of the triode vacuum tube in 1908 allowed the first form of practical electronic amplification and really opened the door to wireless communication. In 1948 another major discovery in the history of electronics occurred with the development of the transistor by Shockley, Brattain, and Bardeen. The more recent developments, such as integrated circuits, very large-scale integration, and computers on a single silicon chip, are probably familiar to you.

The rapid transfer of these developments into practical communications systems linking the entire globe (and now into outer space) has stimulated a bursting growth of complex social and economic activities. This growth has subsequently had a snowballing effect on the growth of the communication industry with no end in sight for the foreseeable future. Some people refer to this as the age of communications.

The function of a communication system is to transfer information from one point to another via some communication link. The very first form of "information" electrically transferred was the human voice in the form of a code (i.e., the Morse code), which was then converted back to words at the receiving site. People had a natural desire and need to communicate rapidly between distant points on the earth, and that was the major concern of these developments. As that goal became a reality, and with the evolution of new technology following the invention of the triode vacuum tube, new and less basic applications were also realized, such as entertainment (radio and television), radar, and telemetry. The field of communications is still a highly dynamic one, with advancing technology constantly making new equipment possible or allowing improvement of the old systems. Communications was the basic origin of the electronics field, and no other major branch of electronics developed until the transistor made modern digital computers a reality.

Modulation

Basic to the field of communications is the concept of modulation. **Modulation** is the process of putting information onto a high-frequency carrier for transmission. In essence, then, the transmission takes place at the high frequency (the carrier) which has been modified to "carry" the lower-frequency information. The low-frequency information is often called the **intelligence signal** or, simply, the **intelligence.** It follows that once this information is received, the intelligence must be removed from the high-frequency carrier—a process known as **demodulation.** At this point you may be thinking, why bother to go through this modulation/demodulation process? Why not just transmit the information directly? The problem is that the frequency of the human voice ranges from about 20 to 3000 Hz. If everyone transmitted those frequencies directly as radio waves, interference would cause them all to be ineffective. Another limitation of equal importance is the virtual impossibility of transmitting

Modulation
process of putting information onto a high-frequency carrier for transmission

Intelligence Signal
the low frequency information that modulates the carrier

Intelligence
low-frequency information modulated onto a high-frequency carrier in a transmitter

Demodulation
process of removing intelligence from the high-frequency carrier in a receiver

such low frequencies since the required antennas for efficient propagation would be miles in length.

The solution is modulation, which allows propagation of the low-frequency intelligence with a high-frequency carrier. The high-frequency carriers are chosen such that only one transmitter in an area operates at the same frequency to minimize interference, and that frequency is high enough so that efficient antenna sizes are manageable. There are three basic methods of putting low-frequency information onto a higher frequency. Equation (1-1) is the mathematical representation of a sine wave, which we shall assume to be the high-frequency carrier.

$$v = V_P \sin(\omega t + \Phi) \tag{1-1}$$

where v = instantaneous value
V_P = peak value
ω = angular velocity = $2\pi f$
Φ = phase angle

Any one of the last three terms could be varied in accordance with the low-frequency information signal to produce a modulated signal that contains the intelligence. If the amplitude term, V_P, is the parameter varied, it is called amplitude modulation (AM). If the frequency is varied, it is frequency modulation (FM). Varying the phase angle, Φ, results in phase modulation (PM). In subsequent chapters we shall study these systems in detail.

COMMUNICATIONS SYSTEMS

Communications systems are often categorized by the frequency of the carrier. Table 1-1 provides the names for various frequency ranges in the radio spectrum. The extra-high-frequency range begins at the starting point of infrared frequencies, but the infrareds extend considerably beyond 300 GHz (300×10^9 Hz). After the infrareds in the electromagnetic spectrum (of which the radio waves are a very small portion) come light waves, ultraviolet rays, X rays, gamma rays, and cosmic rays.

Table 1-1 RADIO-FREQUENCY SPECTRUM

Frequency	Designation	Abbreviation
30–300 Hz	Extremely low frequency	ELF
300–3000 Hz	Voice frequency	VF
3–30 kHz	Very low frequency	VLF
30–300 kHz	Low frequency	LF
300 kHz–3 MHz	Medium frequency	MF
3–30 MHz	High frequency	HF
30–300 MHz	Very high frequency	VHF
300 MHz–3 GHz	Ultra high frequency	UHF
3–30 GHz	Super high frequency	SHF
30–300 GHz	Extra high frequency	EHF

Figure 1-1 represents a simple communication system in block diagram form. Notice that the modulated stage accepts two inputs, the carrier and the information (intelligence) signal. It produces the modulated signal, which is subsequently amplified before transmission. Transmission of the modulated signal can take place by any one of four means: antennas, waveguides, optical fibers, or transmission lines. These four modes of propagation will be studied in subsequent chapters. The receiving unit of the system picks up the transmitted signal but must reamplify it to compensate for attenuation that occurred during transmission. Once suitably amplified, it is fed to the demodulator (often referred to as the detector), where the information signal is extracted from the high-frequency carrier. The demodulated signal (intelligence) is then fed to the amplifier and raised to a level enabling it to drive a speaker or any other output transducer. A **transducer** is a device that converts energy from one form to another.

Transducer
device that converts energy from one form to another

Many of the performance measurements in communication systems are specified in dB (decibels). Section 1-2 introduces the use of this very important concept in communication systems. This is followed by two basic limitations on the performance of a communications systems: (1) electrical noise and (2) the bandwidth of frequencies allocated for the transmitted signal. Sections 1-3 to 1-6 are devoted to these topics because of their extreme importance.

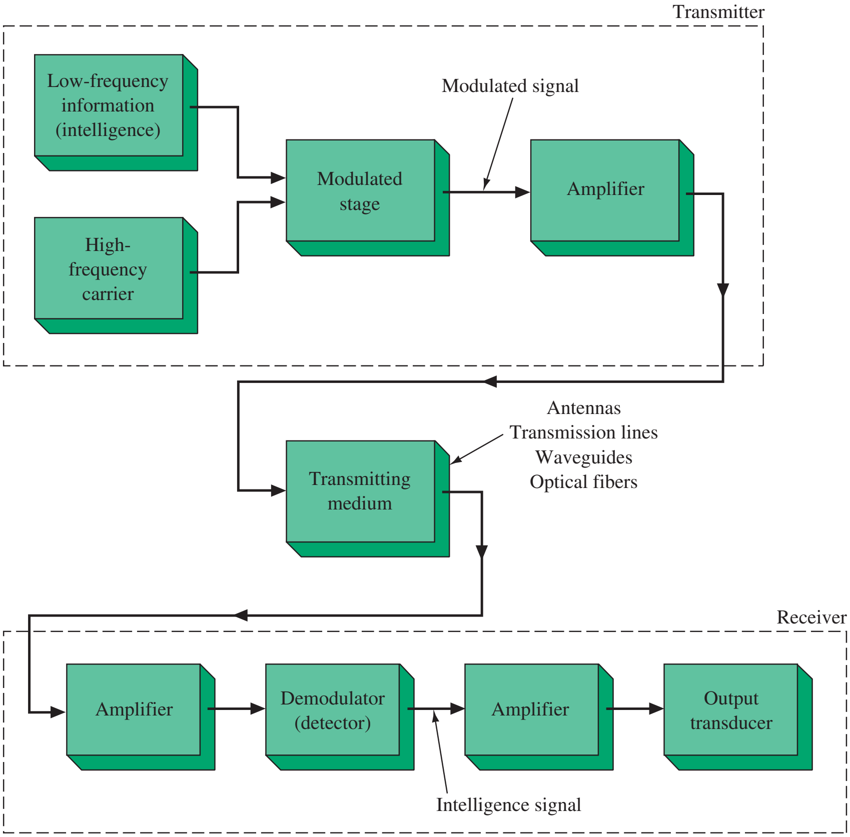

FIGURE 1-1 A communication system block diagram.

1-2 The dB in Communications

dB (decibel)
relative unit of measurement used frequently in electronic communications to describe power gain or loss

Decibels (dBs) are used to specify measured and calculated values in noise analysis, audio systems, microwave system gain calculations, satellite system link-budget analysis, antenna power gain, light-budget calculations, and many other communications system measurements. In each case, the dB value is calculated with respect to a standard or specified reference.

The dB value is calculated by taking the log of the ratio of the measured or calculated power (P_2) with respect to a reference power (P_1) level. This result is then multiplied by 10 to obtain the value in dB. The formula for calculating the dB value of two ratios is shown in Equation (1-2). Equation (1-2) is commonly referred to as the *power ratio form* for dB.

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} \tag{1-2}$$

By using the power relationship $P = V^2/R$, the relationship shown in Equation (1-3) is obtained:

$$\text{dB} = 10 \log_{10} \left(\frac{V_2^2/R_2}{V_1^2/R_1} \right)$$

Let $R_1 = R_2$:

$$\text{dB} = 10 \log_{10} \frac{V_2^2}{V_1^2} \tag{1-3}$$

Note that we have assumed that the resistances (R_1 and R_2) are equivalent; therefore, these terms can be ignored in the dB power equation. This is a reasonable assumption in most communication systems since maximum power transfer (a desirable characteristic) is obtained when the input and output impedances are matched. Equation (1-3) can be modified (using a property of logarithms) to provide a relationship for decibels in terms of the voltage ratios instead of power ratios. This is called the *voltage gain equation* and is shown in Equation (1-4).

$$\text{dB} = 20 \log_{10} \left(\frac{V_2}{V_1} \right) \tag{1-4}$$

Applying the dB Value

dBm
dB level using a 1-mW reference

0 dBm
1 mW measured relative to a 1-mW reference

The dB unit is often used in specifying input- and output-signal-level requirements for many communication systems. When making dB measurements, a reference level is specified or implied for that particular application. An example is found in audio consoles in broadcast systems, where a **0-dBm** input level is usually specified as the required input- and output-audio level for 100% modulation. Notice that a lowercase *m* has been attached to the dB unit. This indicates that the specified dB level is relative to a 1-mW reference.

In standard audio systems **0 dBm** is defined as 0.001 W measured with respect to a load termination of 600 Ω. A 600-Ω balanced audio line is the standard for professional audio, broadcast, and telecommunications systems. However, 0 dBm is not exclusive to a 600-Ω impedance.

Example 1-1

Show that when making a dBm measurement, a measured value of 1 mW will result in a 0 dBm power level.

Solution

$$\text{dB} = 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{1\text{ mW}}{1\text{ mW}} = 0\text{ dB} \qquad \text{or} \qquad 0\text{ dBm} \tag{1-2}$$

This result, 0 dB, is expressed as 0 dBm to indicate that the result was obtained relative to a 1-mW reference.

It can be shown that the voltage measured across a 600-Ω load for a 0-dBm level is 0.775 V. This value can be obtained by first modifying Equation (1-2) by inserting the 1 mW value for P_1, as shown.

$$\text{dB} = 10\log_{10}\left(\frac{P_2}{P_1}\right)$$

where $P_2 = \dfrac{V_2^2}{600}$

$P_1 = 0.001$ W

Since 1 mW is the specified reference for dBm, the voltage reference for 0 dBm can be developed as follows:

$$\begin{aligned}
0\text{ dBm} &= 10\log\frac{V_2^2/600}{0.001}\\
0\text{ dBm} &= \log\frac{V_2^2/600}{0.001}\\
\log^{-1}(0\text{ dBm}) &= \frac{V_2^2/600}{0.001}\\
1 &= \frac{V_2^2/600}{0.001}\\
0.6 &= V_2^2\\
V_2 &= 0.77459
\end{aligned}$$

The voltage value 0.77459 (0.775 V) is the reference for 0 dB with respect to a 600-Ω load when a voltage measurement is used to calculate the **dBm(600)** value. The dBm(600) term indicates that this measurement or calculation is made using a 1-mW reference with respect to a 600-Ω load.

dBm(600)
decibel measurement using a 1-mW reference with respect to a 600-Ω load

$$\text{dBm}(600) = 20\log_{10}\left(\frac{V_2}{0.775}\right) \tag{1-5}$$

Example 1-2 demonstrates how to solve for the voltage value (V_2) if a +8-dBm level is specified.

Example 1-2

A microwave system requires a +8-dBm audio level to provide 100% modulation. Determine the voltage level required to produce a +8-dBm level. Assume a 600-Ω audio system.

Solution

Since this is a 600-Ω system, use the 0.775-V reference shown in Equation (1-5).

$$\text{dBm}(600) = 20\log_{10}\left(\frac{V_2}{0.775}\right) \qquad \textbf{(1-5)}$$

$$+8\text{ dBm} = 20\log\frac{V_2}{0.775}$$

$$0.4 = \log\frac{V_2}{0.775}$$

$$\log^{-1}(0.4) = \frac{V_2}{0.775}$$

$$V_2 = 1.947\text{ V}$$

Thus, to verify that a +8-dBm level is being provided to the input of the microwave transmitter, approximately 1.95 V must be measured across the 600-Ω input.

The term *dBm* also applies to communication systems that have a standard termination impedance other than 600 Ω. For example, many communication systems are terminated with 75 Ω. The 0-dBm value is still defined as 1 mW, but it is measured with respect to a 75-Ω termination instead of 600 Ω. Therefore, the voltage reference for a 0-dBm system with respect to 75 Ω is obtained by solving for V in the expression $P = V^2/R$ as shown:

$$V = \sqrt{PR} = \sqrt{(0.001)(75)} = 0.274\text{ V}$$

To calculate the voltage gain or loss with respect to a 75-Ω load, use Equation (1-6). This value is specified as **dBm(75)** to indicate that this measure was made or calculated using a 1-mW reference relative to a 75-Ω load.

dBm(75)
a measurement made using a 1-mW reference with respect to a 75-Ω load

$$\text{dBm}(75) = 20\log_{10}\frac{V}{0.274} \qquad \textbf{(1-6)}$$

Fifty-ohm systems are usually used in radio communications. The dBm voltage reference for a 50-Ω system is

$$V = \sqrt{PR} = \sqrt{(0.001)(50)} = 0.2236\text{ V}$$

To calculate the voltage gain or loss expressed in dB for a 50-Ω system [**dBm(50)**], use Equation (1-4) with $V_1 = 0.2236$. This relationship is shown in Equation (1-7).

dBm(50)
a measurement made using a 1-mW reference with respect to a 50-Ω load

$$\text{dBm}(50) = 20 \log_{10}\frac{V}{0.2236} \tag{1-7}$$

It is common for power to be expressed in watts instead of milliwatts. In this case the dB unit is obtained with respect to 1 W and the dB values are expressed as **dBW.**

dBW
a measurement made using a 1-W reference

0 dBW is defined as 1 W measured with respect to a 1-W reference.

Remember, dB is a relative measurement. As shown by Equations (1-1) and (1-3), both power and voltage gains can be expressed in dB relative to a reference value. In the case of dBW, the reference is 1 W; therefore, Equation (1-1) is written with 1 W replacing the reference P_1. This gives Equation (1-8).

$$\text{dBW} = 10 \log_{10}\frac{P_2}{1\ \text{W}} \tag{1-8}$$

In some applications, it may be necessary to convert from one reference dB to another. Example 1-3 demonstrates how to convert from dBm to dBW.

Example 1-3

A laser diode outputs +10 dBm. Convert this value to
(a) watts.
(b) dBW.

Solution

(a) Convert +10 dBm to watts. Substitute and solve for P_2:

$$+10\ \text{dBm} = 10 \log \frac{P_2}{0.001}$$

$$\log^{-1}(1) = \frac{P_2}{0.001} \Rightarrow 10 = \frac{P_2}{0.001} \tag{1-2}$$

$$P_2 = 0.01\ \text{W}$$

(b) Convert +10 dBm to dBW.

$$\text{dBW} = 10 \log \frac{0.01\ \text{W}}{1\ \text{W}} = -20\ \text{dBW} \tag{1-8}$$

It is common with communication receivers to express voltage measurements in terms of **dBμV,** dB-microvolts. For voltage gain calculations involving dBμV, use Equation (1-4) and specify 1 μV as the reference (V_1) in the calculations, as shown in Equation (1-9).

dBμV
a measurement made using a 1-μV reference

$$\text{dB}\mu\text{V} = 20 \log_{10}\frac{V_2}{1\ \mu\text{V}} \tag{1-9}$$