PEARSON NEW INTERNATIONAL EDITION

Modern Electronic Communication

Jeffrey S. Beasley Gary M. Miller

Ninth Edition

ALWAYS LEARNING

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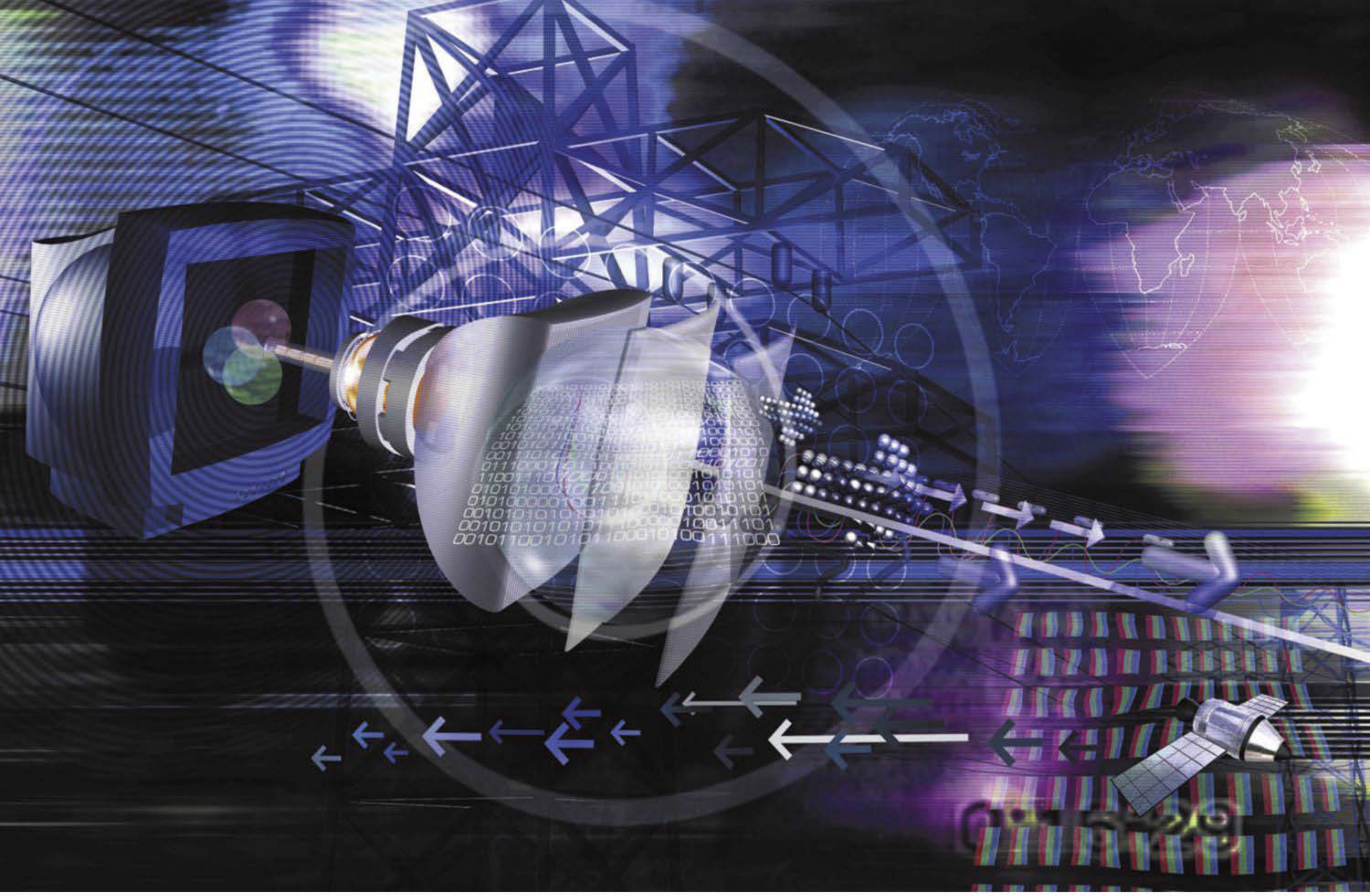
INTRODUCTORY TOPICS



Chapter Outline

1 Introduction
2 The dB in Communications
3 Noise
4 Noise Designation and Calculation
5 Noise Measurement
6 Information and Bandwidth
7 *LC* Circuits
8 Oscillators
9 Troubleshooting
10 Troubleshooting with Electronics Workbench™ Multisim

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

Tektronix's digital oscilloscopes include easy-to-use features, high bandwidth, MegaZoom rates, and integrated logic timing channels. (Courtesy of Tektronix, Inc.)

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 Introduction

We will provide 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
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

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 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) is the mathematical representation of a sine wave, which we shall assume to be the high-frequency carrier.

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

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 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 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 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 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 3 to 6 are devoted to these topics because of their extreme importance.

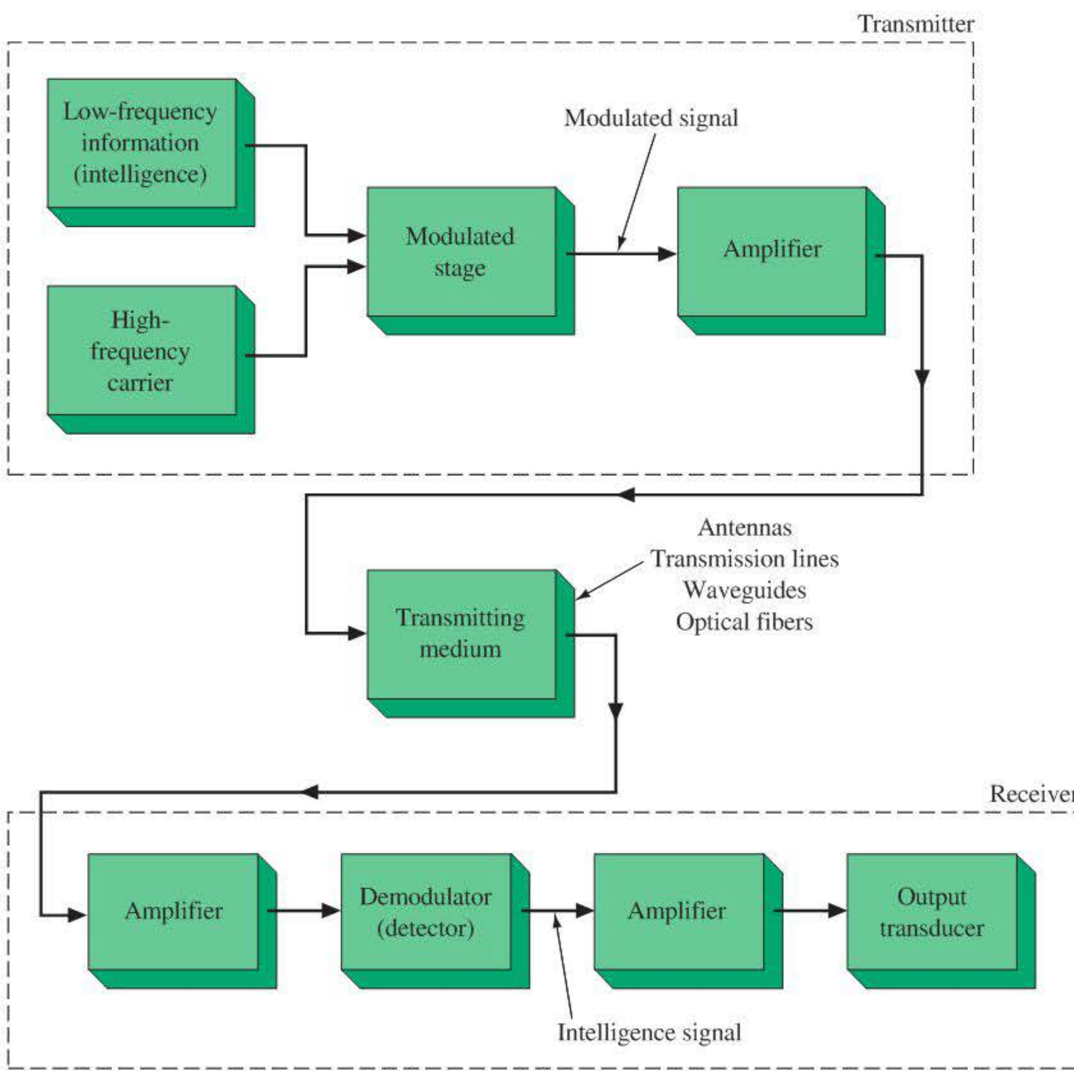


FIGURE 1 A communication system block diagram.

2 The dB in Communications

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.

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

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 (2). Equation (2) is commonly referred to as the *power ratio form* for dB.

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

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

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

Let $R_1 = R_2$:

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

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 (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 (4).

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

Applying the dB Value

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.

dBm
dB level using a 1-mW reference

0 dBm
1 mW measured 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

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

Solution

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

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

$P_1 = 0.001\text{ W}$

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

$$0\text{ dBm} = 10 \log \frac{V_2^2/600}{0.001}$$

$$0\text{ dBm} = \log \frac{V_2^2/600}{0.001}$$

$$\log^{-1}(0\text{ dBm}) = \frac{V_2^2/600}{0.001}$$

$$1 = \frac{V_2^2/600}{0.001}$$

$$0.6 = V_2^2$$

$$V_2 = 0.77459$$

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

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.

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