Chapter Two

Fundamentals of Data and Signals

Data Communications and Computer Networks: A Business User's Approach

Eighth Edition

After reading this chapter, you should be able to:

- Distinguish between data and signals, and cite the advantages of digital data and signals over analog data and signals
- Identify the three basic components of a signal
- Discuss the bandwidth of a signal and how it relates to data transfer speed
- Identify signal strength and attenuation, and how they are related

After reading this chapter, you should be able to (continued):

- Outline the basic characteristics of transmitting analog data with analog signals, digital data with digital signals, digital data with analog signals, and analog data with digital signals
- List and draw diagrams of the basic digital encoding techniques, and explain the advantages and disadvantages of each
- Identify the different shift keying (modulation) techniques, and describe their advantages, disadvantages, and uses

After reading this chapter, you should be able to (continued):

- Identify the two most common digitization techniques, and describe their advantages and disadvantages
- Identify the different data codes and how they are used in communication systems

Introduction

- Data are entities that convey meaning (computer files, music on CD, results from a blood gas analysis machine)
- Signals are the electric or electromagnetic encoding of data (telephone conversation, web page download)
- Computer networks and data/voice communication systems transmit signals
- Data and signals can be analog or digital

Introduction (continued)

Table 2-1 Four combinations of data and signals

Table 2-1 Four combinations of data and signals

Data	Signal	Encoding or Conversion Technique	Common Devices	Common Systems
Analog	Analog	Amplitude modulation Frequency modulation	Radio tuner TV tuner	Telephone AM and FM radio Broadcast TV Cable TV
Digital	(Square-wave) Digital	NRZ-L NRZI Manchester Differential Manchester Bipolar-AMI 4B/5B	Digital encoder	Local area networks Telephone systems
Digital	(Discrete) Analog	Amplitude shift keying Frequency shift keying Phase shift keying	Modem	Dial-up Internet access DSL Cable modems Digital Broadcast TV
Analog	Digital	Pulse code modulation Delta modulation	Codec	Telephone systems Music systems

Data and Signals

- Data are entities that convey meaning within a computer or computer system
- Signals are the electric or electromagnetic impulses used to encode and transmit data

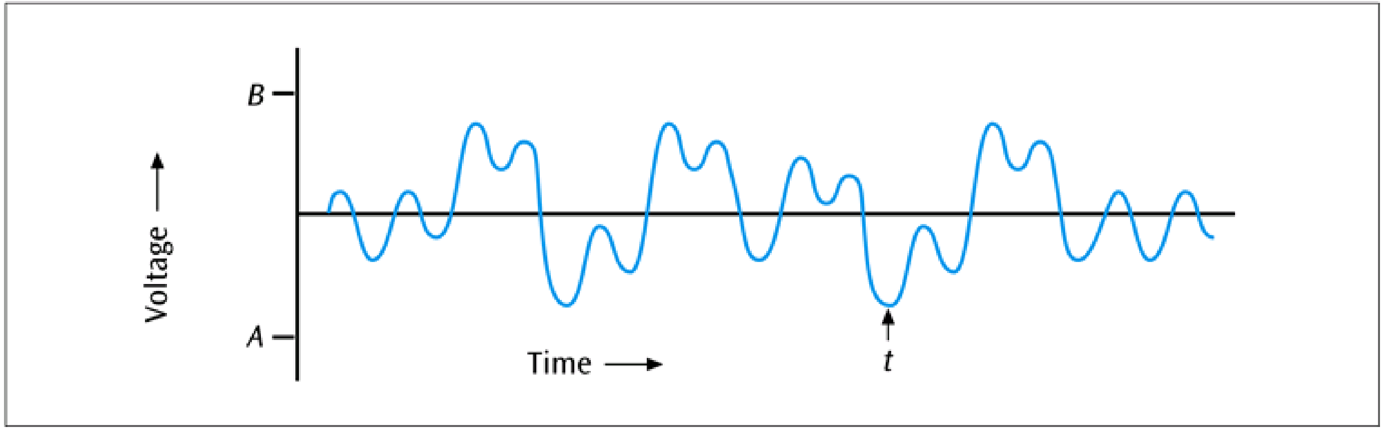
Analog vs. Digital

- Data and signals can be either analog or digital

- *Analog* is a continuous waveform, with examples such as (naturally occurring) music and voice
- It is harder to separate noise from an analog signal than it is to separate noise from a digital signal (see the following two slides)

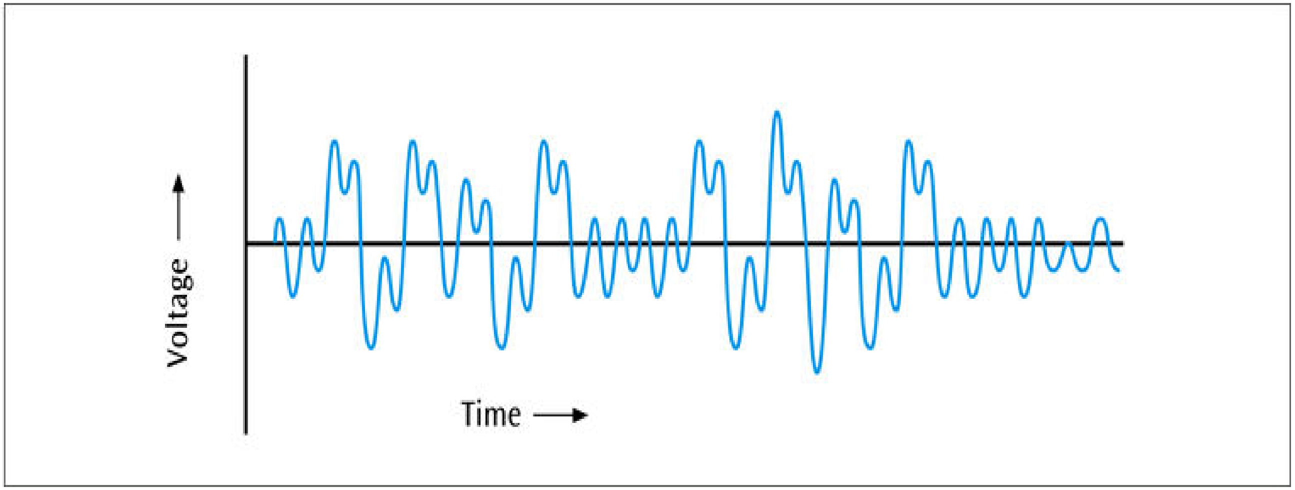
Analog vs. Digital (continued)

Figure 2-1
A simple example of an analog waveform



Analog vs. Digital (continued)

Figure 2-2
The waveform of a symphonic overture with noise



Analog vs. Digital (continued)

- *Digital* is a discrete or non-continuous waveform
- Something about the signal makes it obvious that the signal can only appear in a fixed number of forms (see next slide)
- Noise in digital signal
  – You can still discern a high voltage from a low voltage
  – Too much noise – you cannot discern a high voltage from a low voltage

Analog vs. Digital (continued)

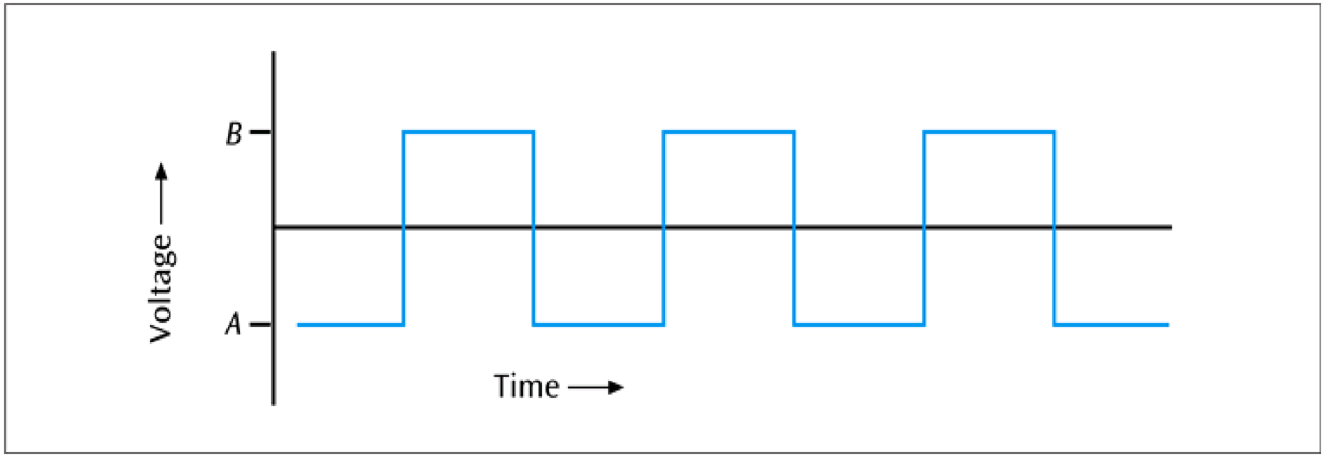
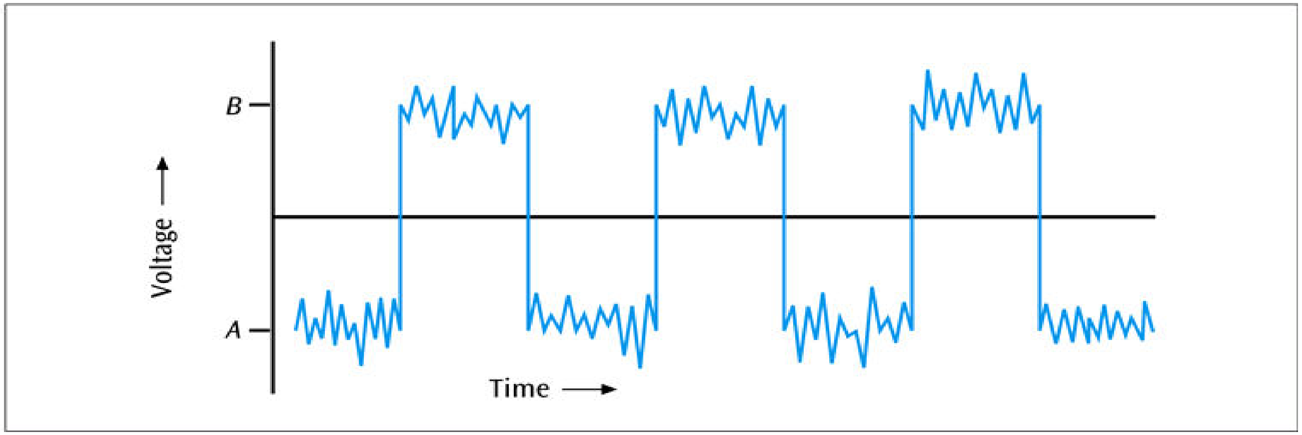


Figure 2-3
A simple example of a digital waveform

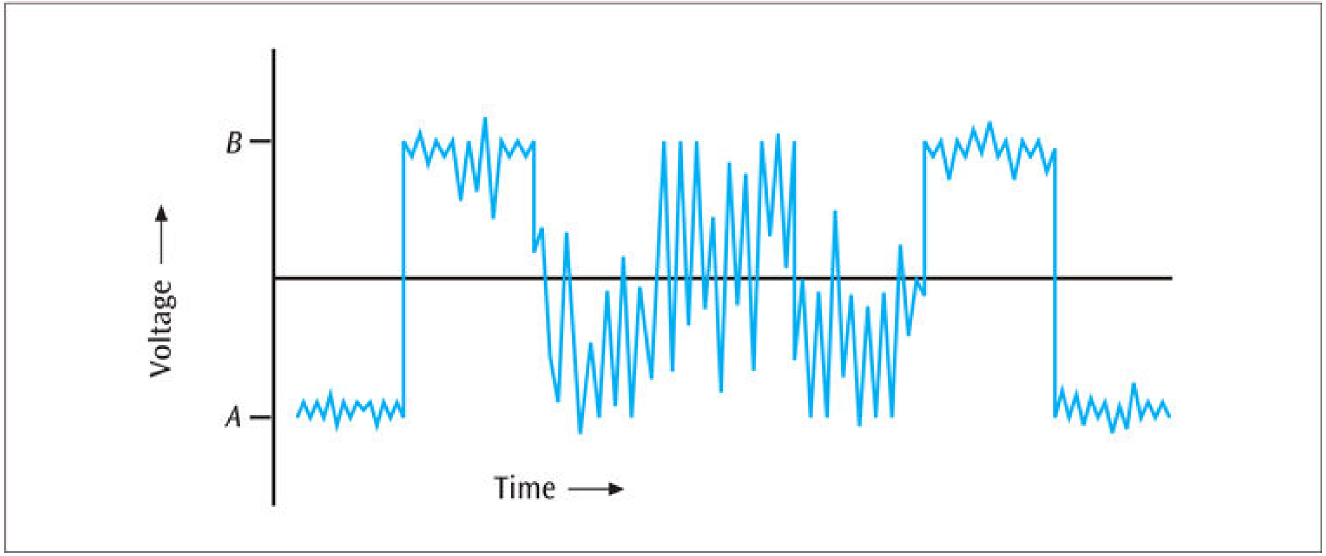
Analog vs. Digital (continued)

Figure 2-4
A digital signal with some noise introduced



Analog vs. Digital (continued)

Figure 2-5
A digital waveform with noise so great that you can no longer recognize the original waveform



Fundamentals of Signals

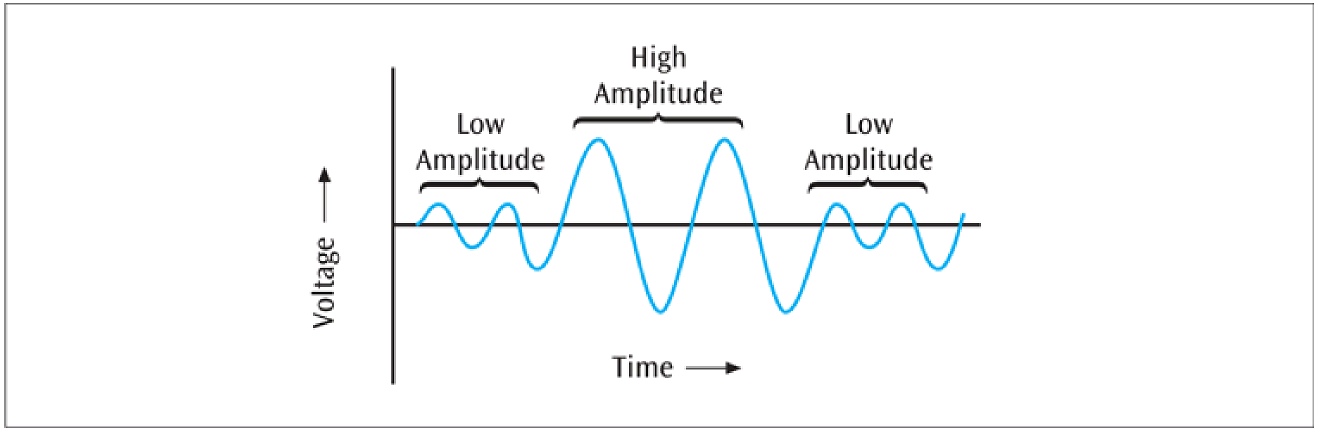
- All signals have three components:
  - Amplitude
  - Frequency
  - Phase

Fundamentals of Signals – Amplitude

- Amplitude
  - The height of the wave above or below a given reference point
  - Amplitude is usually measured in volts

Fundamentals of Signals – Amplitude

Figure 2-6
A signal with two different amplitudes

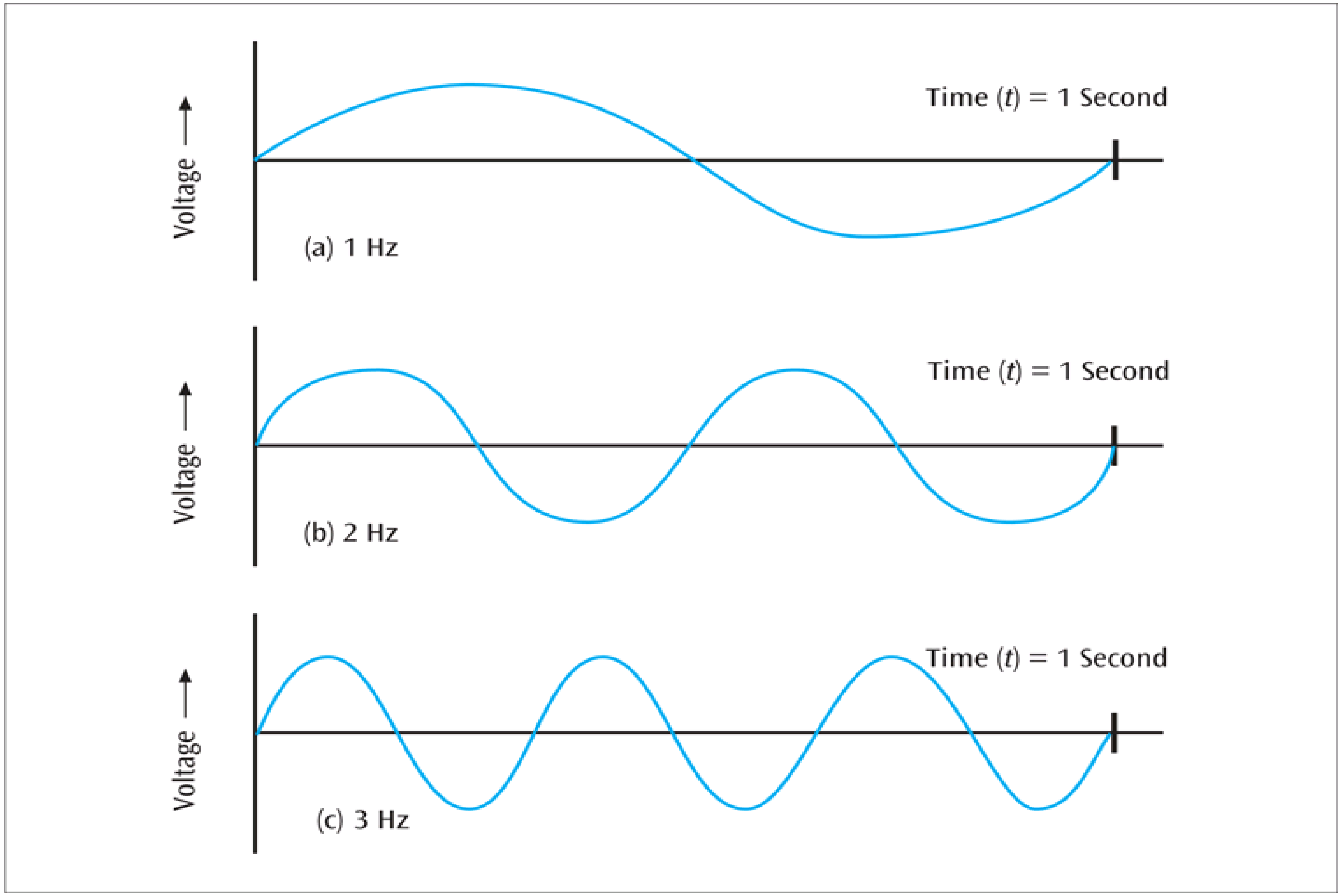


Fundamentals of Signals – Frequency

- Frequency
  - The number of times a signal makes a complete cycle within a given time frame; frequency is measured in Hertz (Hz), or cycles per second (period = 1 / frequency)
  - Spectrum – Range of frequencies that a signal spans from minimum to maximum
  - Bandwidth – Absolute value of the difference between the lowest and highest frequencies of a signal
  - For example, consider an average voice
    - The average voice has a frequency range of roughly 300 Hz to 3100 Hz
    - The spectrum would be 300 – 3100 Hz
    - The bandwidth would be 2800 Hz

Fundamentals of Signals – Frequency

Figure 2-7
Three signals of (a) 1 Hz, (b) 2 Hz, and (c) 3 Hz

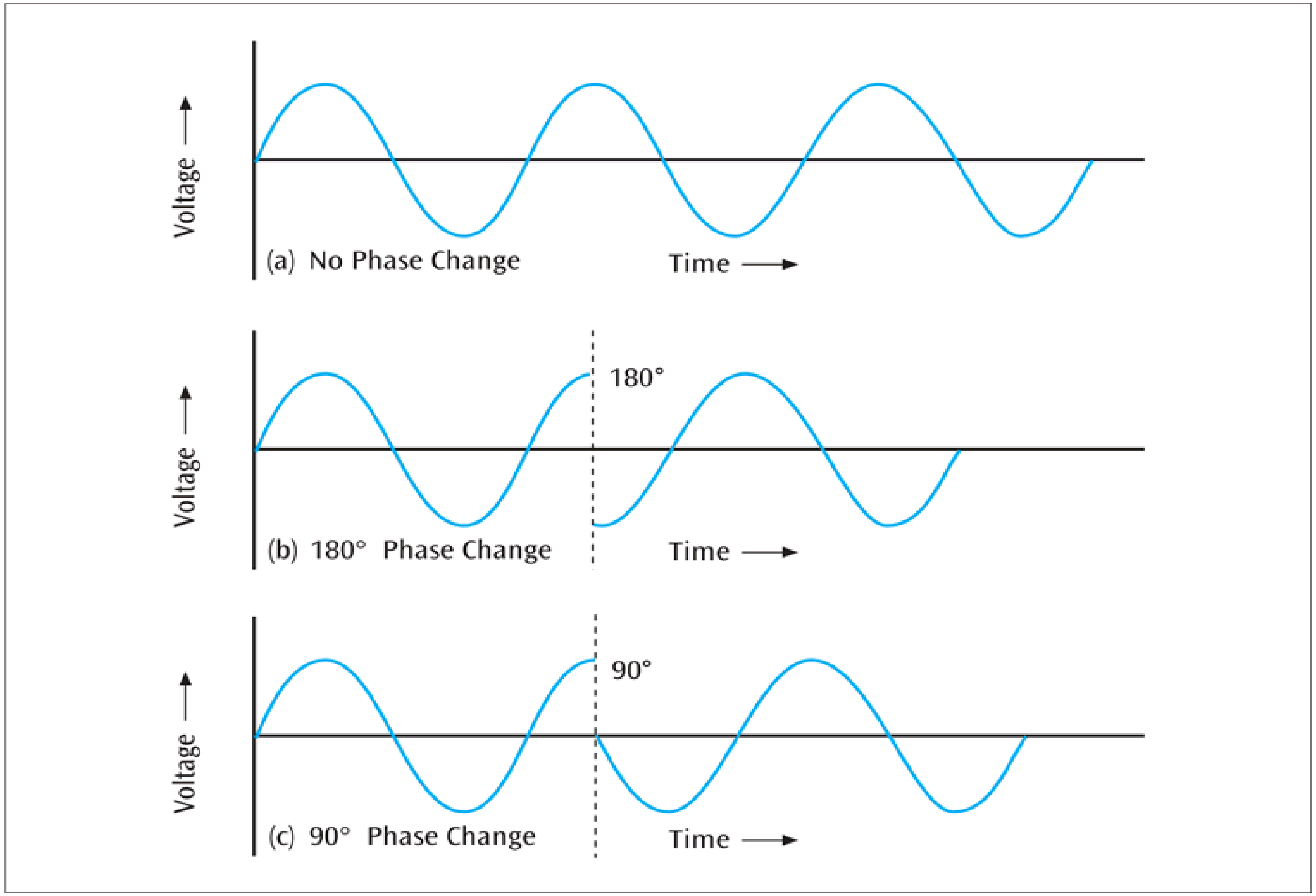


Fundamentals of Signals – Phase

- Phase
  - The position of the waveform relative to a given moment of time or relative to time zero
  - A change in phase can be any number of angles between 0 and 360 degrees
  - Phase changes often occur on common angles, such as 45, 90, 135, etc.

Fundamentals of Signals – Phase

Figure 2-8
A sine wave showing (a) no phase change, (b) a 180-degree phase change, and (c) a 90-degree phase change



Fundamentals of Signals

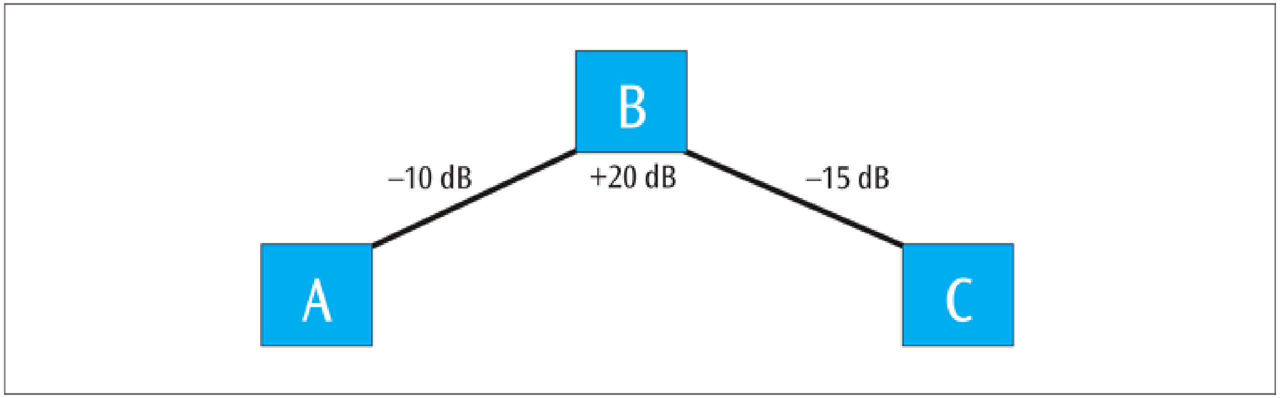
- Phase
  - If a signal can experience two different phase angles, then 1 bit can be transmitted with each signal change (each baud)
  - If a signal can experience four different phase angles, then 2 bits can be transmitted with each signal change (each baud)
  - Note: number of bits transmitted with each signal change = $\log_2$ (number of different phase angles)
  - (You can replace “phase angles” with “amplitude levels” or “frequency levels”)

Loss of Signal Strength

- All signals experience loss (attenuation)
- Attenuation is denoted as a decibel (dB) loss
- Decibel losses (and gains) are additive

Loss of Signal Strength (continued)

Figure 2-10
Example demonstrating decibel loss and gain



Loss of Signal Strength

- Formula for decibel (dB):

$$dB = 10 \times \log_{10} (P_2 / P_1)$$

where P_1 is the beginning power level and P_2 is the ending power level

Loss of Signal Strength (continued)

- So if a signal loses 3 dB, is that a lot?
- What if a signal starts at 100 watts and ends at 50 watts? What is dB loss?

$$dB = 10 \times \log_{10} (P_2 / P_1)$$

$$dB = 10 \times \log_{10} (50 / 100)$$

$$dB = 10 \times \log_{10} (0.5)$$

$$dB = 10 \times -0.3$$

$$dB = -3.0$$

- So a 3.0 decibel loss losses half of its power

Converting Data into Signals

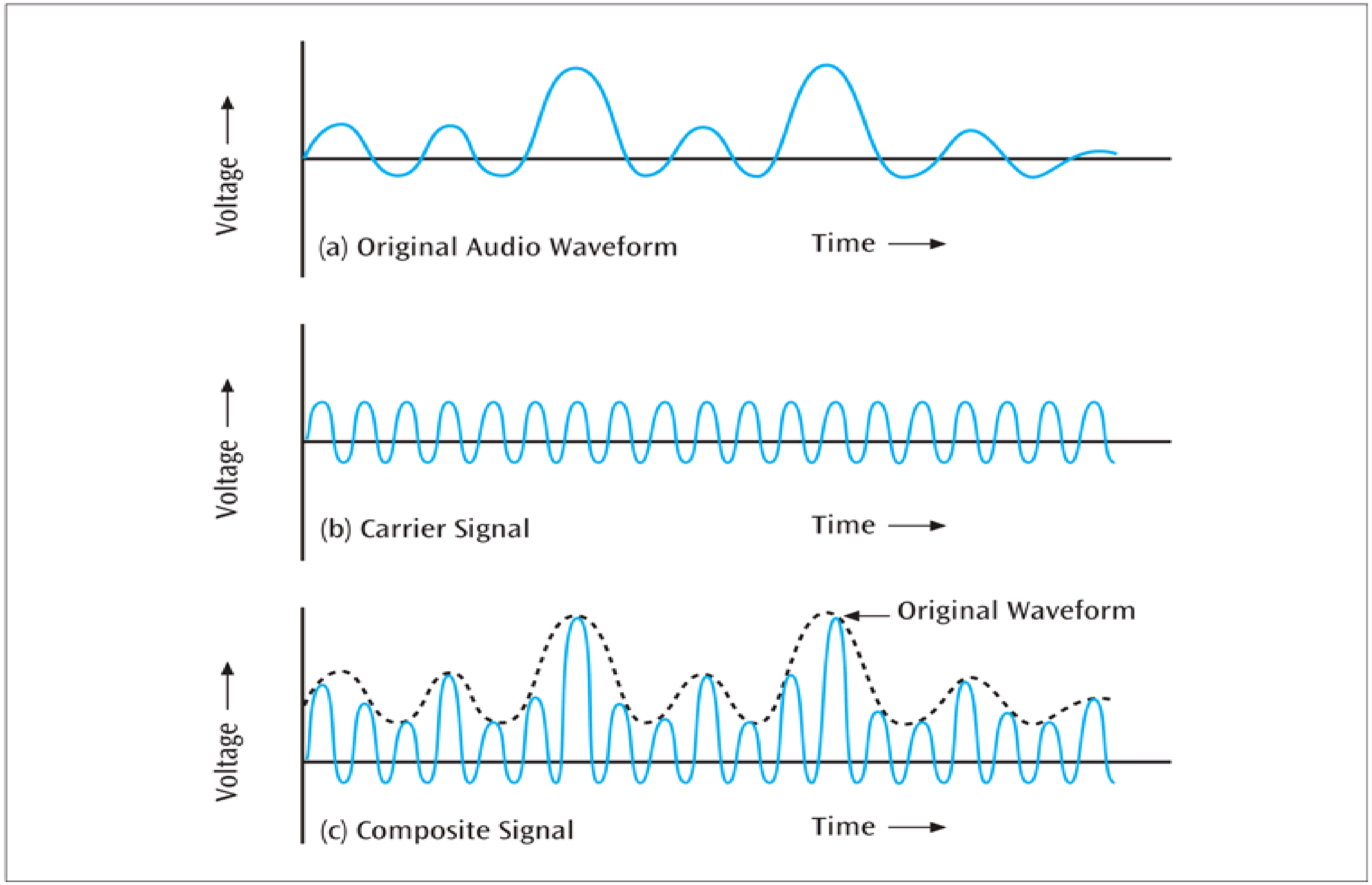
- There are four main combinations of data and signals:
  - Analog data transmitted using analog signals
  - Digital data transmitted using digital signals
  - Digital data transmitted using discrete analog signals
  - Analog data transmitted using digital signals
- Let's look at each these

1. Transmitting Analog Data with Analog Signals

- In order to transmit analog data, you can modulate the data onto a set of analog signals
- Broadcast radio and the older broadcast television are two very common examples of this
- We modulate the data onto another set of frequencies so that all the different channels can coexist at different frequencies

1. Transmitting Analog Data with Analog Signals (continued)

Figure 2-11
An audio waveform modulated onto a carrier frequency using amplitude modulation

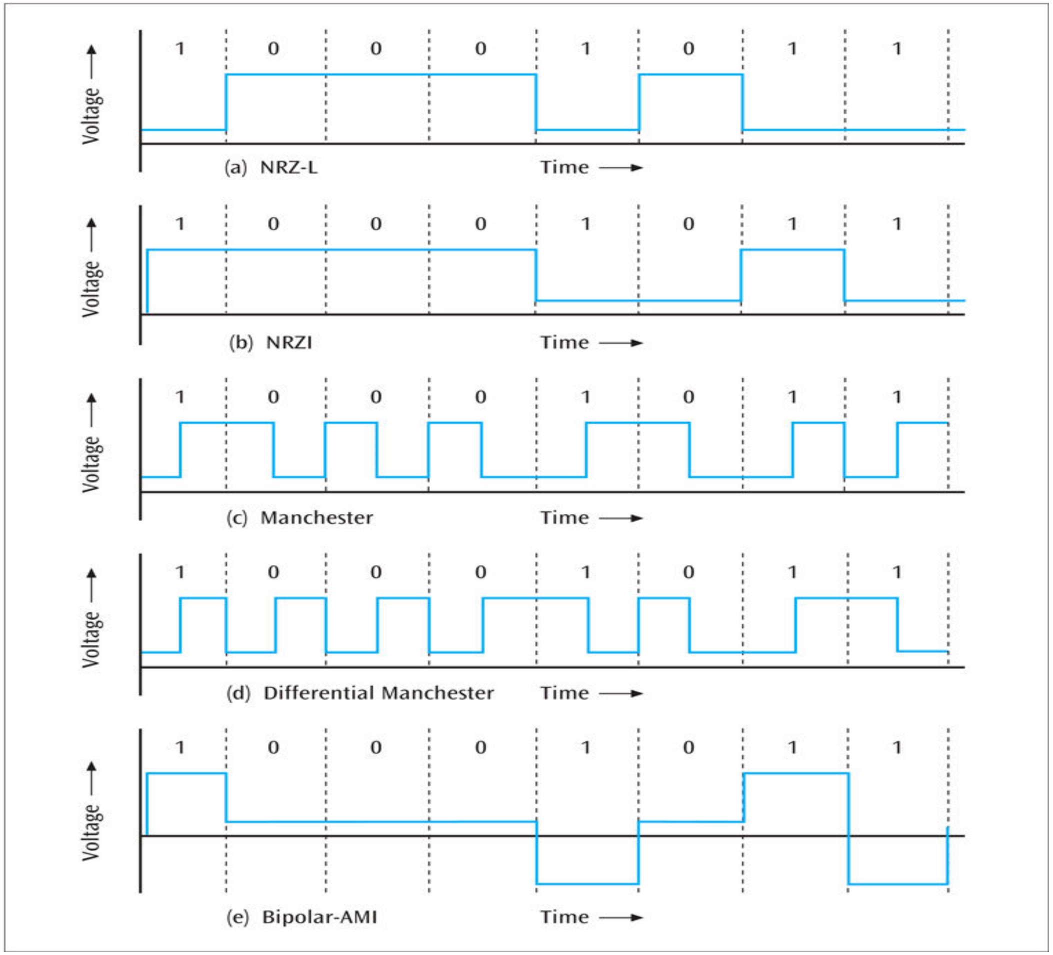


2. Transmitting Digital Data with Digital Signals: Digital Encoding Schemes

- There are numerous techniques available to convert digital data into digital signals. Let's examine five:
  - NRZ-L
  - NRZI
  - Manchester
  - Differential Manchester
  - Bipolar AMI
- These are used in LANs and some telephone systems

2. Transmitting Digital Data with Digital Signals: Digital Encoding Schemes (continued)

Figure 2-12
Examples of five digital encoding schemes



Nonreturn to Zero Digital Encoding Schemes

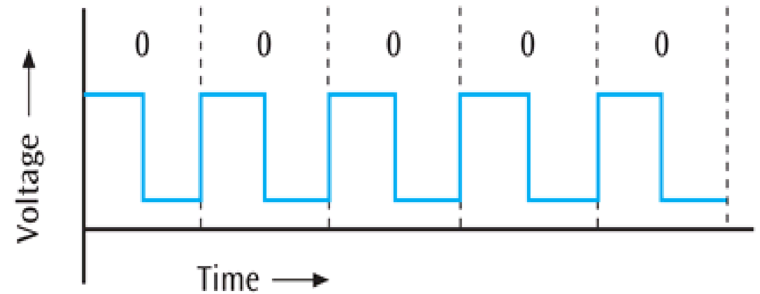
- Nonreturn to zero-level (NRZ-L) transmits 1s as zero voltages and 0s as positive voltages
- Nonreturn to zero inverted (NRZI) has a voltage change at the beginning of a 1 and no voltage change at the beginning of a 0
- Fundamental difference exists between NRZ-L and NRZI
  - With NRZ-L, the receiver has to check the voltage *level* for each bit to determine whether the bit is a 0 or a 1,
  - With NRZI, the receiver has to check whether there is a *change at the beginning* of the bit to determine if it is a 0 or a 1

Manchester Digital Encoding Schemes

- Note how with a Differential Manchester code, every bit has at least one significant change. Some bits have two signal changes per bit (baud rate = twice bps)

Manchester Digital Encoding Schemes (continued)

Figure 2-13
Transmitting five binary 0s using differential Manchester encoding



Bipolar-AMI Encoding Scheme

- The bipolar-AMI encoding scheme is unique among all the encoding schemes because it uses three voltage levels
  - When a device transmits a binary 0, a zero voltage is transmitted
  - When the device transmits a binary 1, either a positive voltage or a negative voltage is transmitted
  - Which of these is transmitted depends on the binary 1 value that was last transmitted

4B/5B Digital Encoding Scheme

- Yet another encoding technique; this one converts four bits of data into five-bit quantities
- The five-bit quantities are unique in that no five-bit code has more than 2 consecutive zeroes
- The five-bit code is then transmitted using an NRZI encoded signal

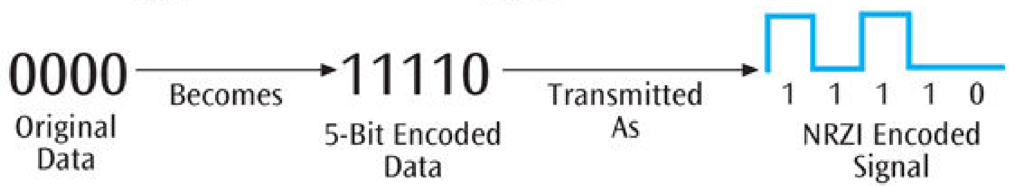
4B/5B Digital Encoding Scheme (continued)

Figure 2-14
The 4B/5B digital encoding scheme

Valid Data Symbols

Original 4-bit data	New 5-bit code
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

Invalid codes
00001
00010
00011
01000
10000



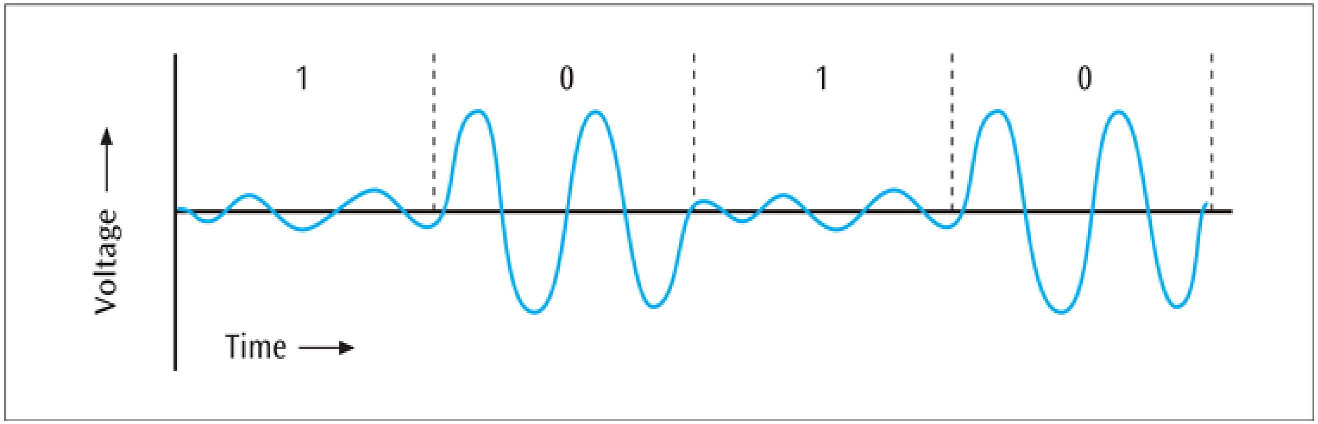
3. Transmitting Digital Data with Discrete Analog Signals

- Three basic techniques:
  - Amplitude shift keying
  - Frequency shift keying
  - Phase shift keying
- One can then combine two or more of these basic techniques to form more complex modulation techniques (such as quadrature amplitude modulation)

Amplitude Shift Keying

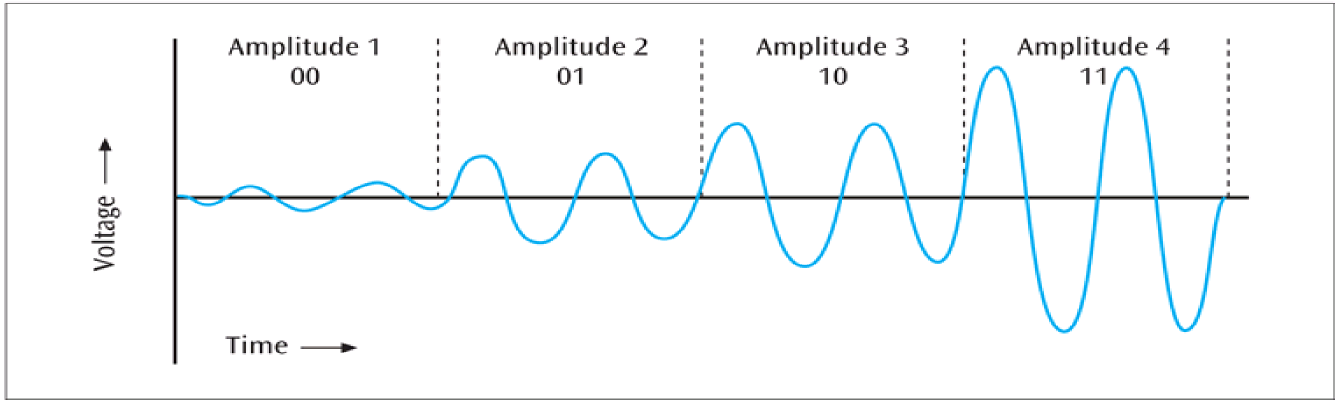
- One amplitude encodes a 0 while another amplitude encodes a 1 (a form of amplitude modulation)

Figure 2-15
Example of amplitude shift keying



Amplitude Shift Keying (continued)

Figure 2-16
Amplitude shift keying using four different amplitude levels

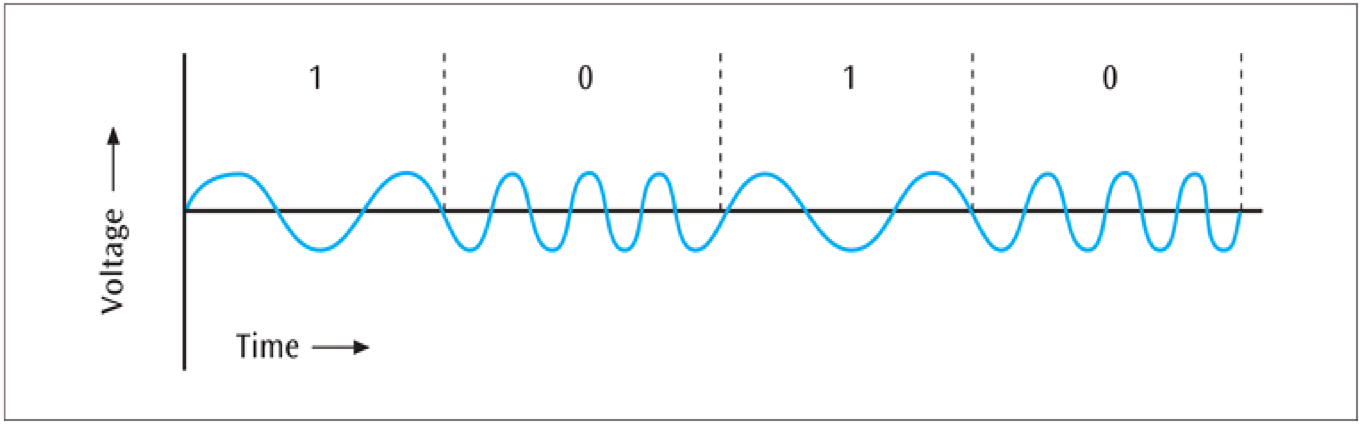


Note: here we have four different amplitudes, so we can encode 2 bits in each signal change (bits per signal change = $\log_2$ (amplitude levels)).

Frequency Shift Keying

- One frequency encodes a 0 while another frequency encodes a 1 (a form of frequency modulation)

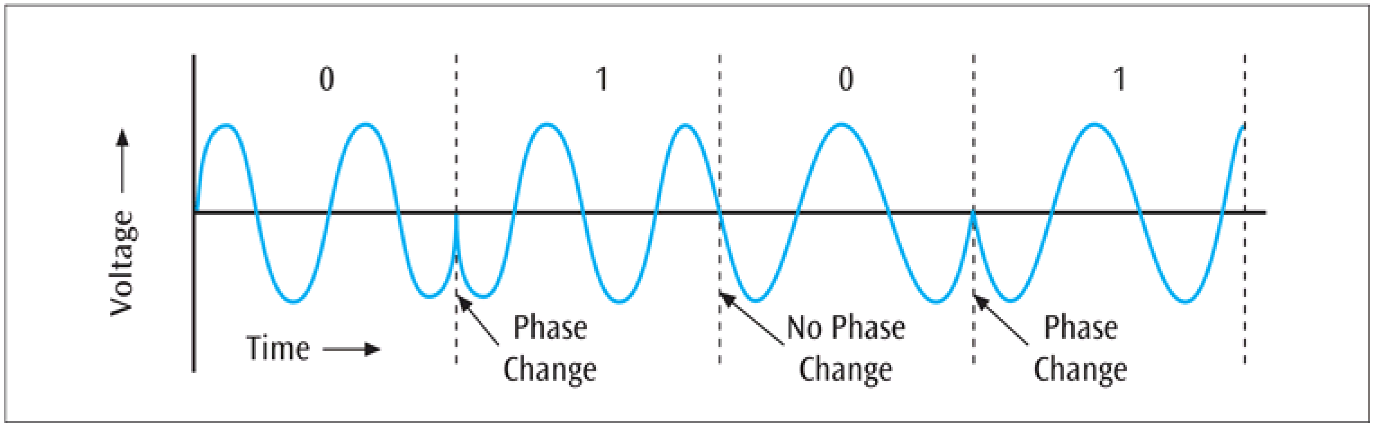
Figure 2-17
Simple example of frequency shift keying



Phase Shift Keying

- One phase change encodes a 0 while another phase change encodes a 1 (a form of phase modulation)

Figure 2-18
An example of simple phase shift keying of a sine wave

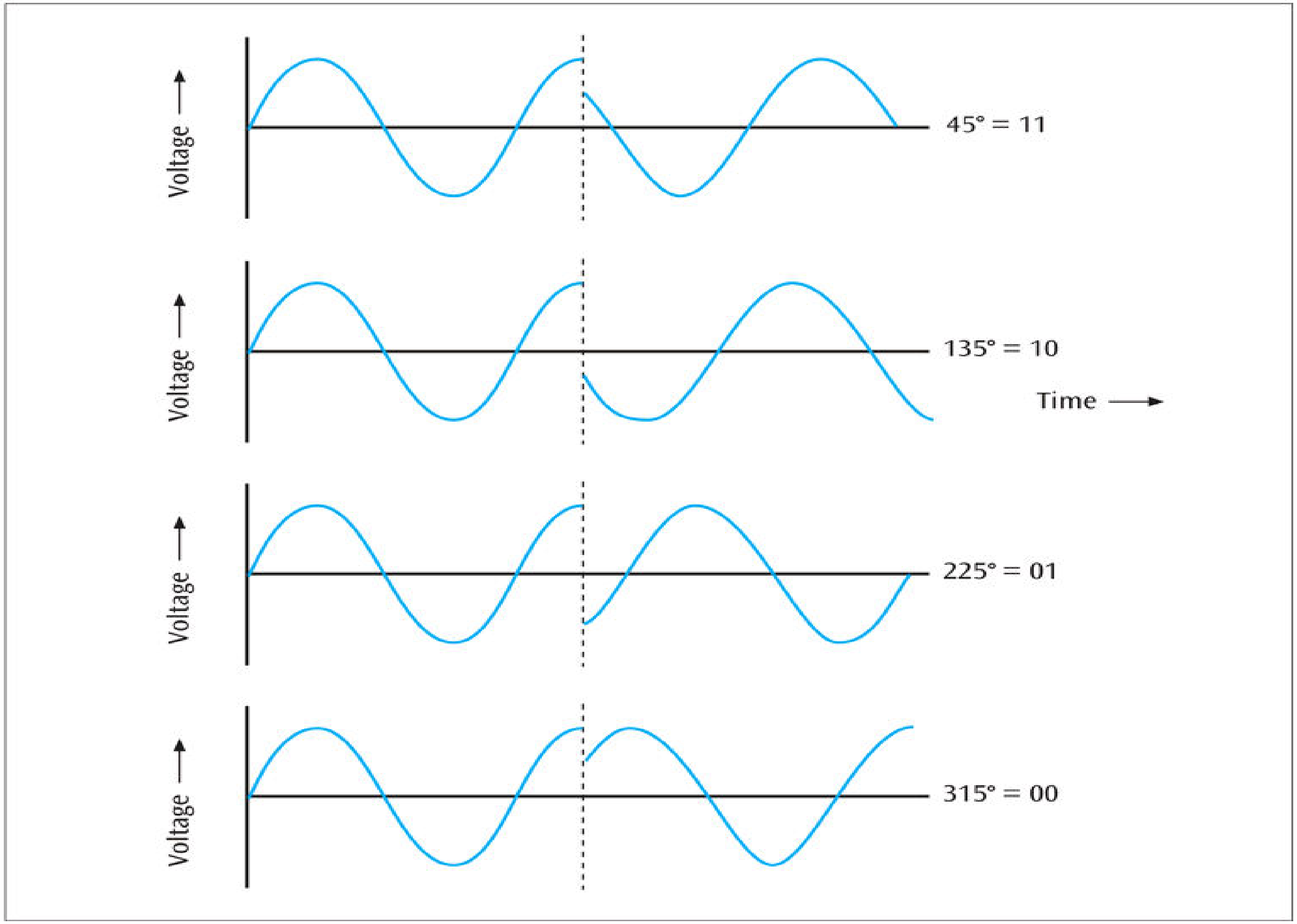


Phase Shift Keying (continued)

- Quadrature Phase Shift Keying
  - Four different phase angles used
    - 45 degrees
    - 135 degrees
    - 225 degrees
    - 315 degrees

Phase Shift Keying (continued)

Figure 2-19
Four phase angles of 45, 135, 225, and 315 degrees, as seen in quadrature phase shift keying

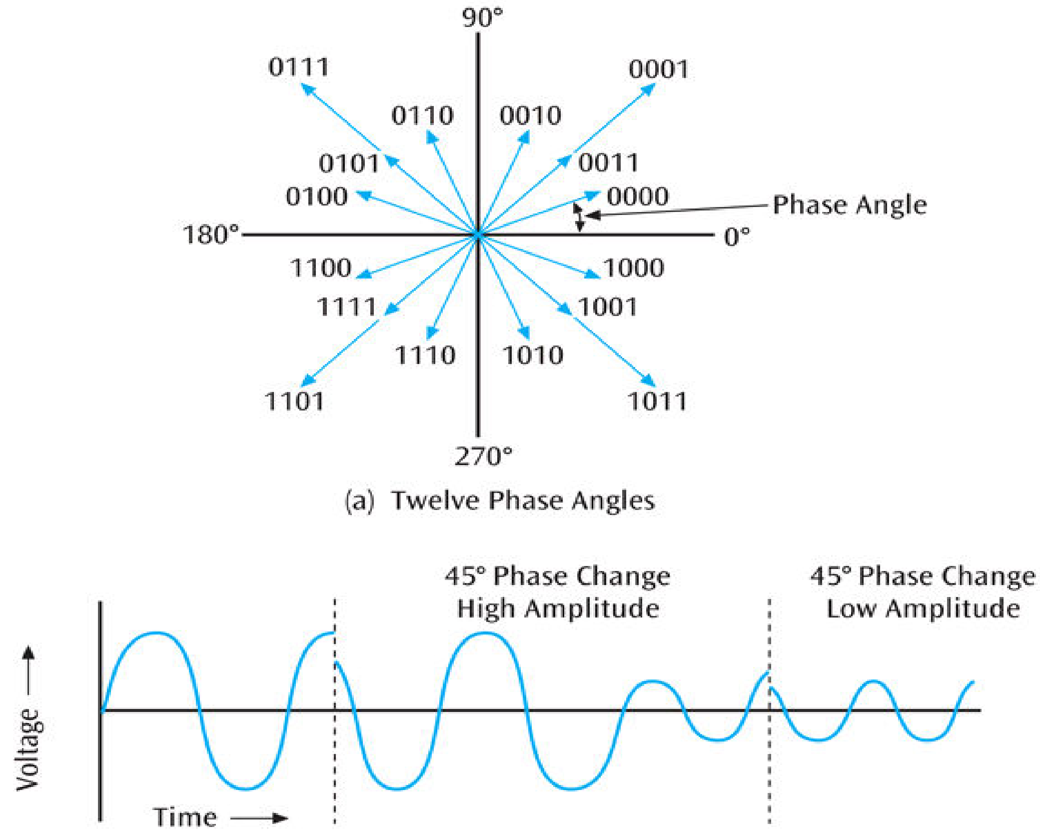


Phase Shift Keying (continued)

- Quadrature amplitude modulation
  - As an example of QAM, 12 different phases are combined with two different amplitudes
  - Since only 4 phase angles have 2 different amplitudes, there are a total of 16 combinations
  - With 16 signal combinations, each baud equals 4 bits of information ($\log_2(16) = 4$, or inversely, $2 \wedge 4 = 16$)

Phase Shift Keying (continued)

Figure 2-20
Figure (a) shows 12 different phases, while Figure (b) shows a phase change with two different amplitudes



(a) Twelve Phase Angles

(b) A Phase Change with Two Amplitudes

4. Transmitting Analog Data with Digital Signals

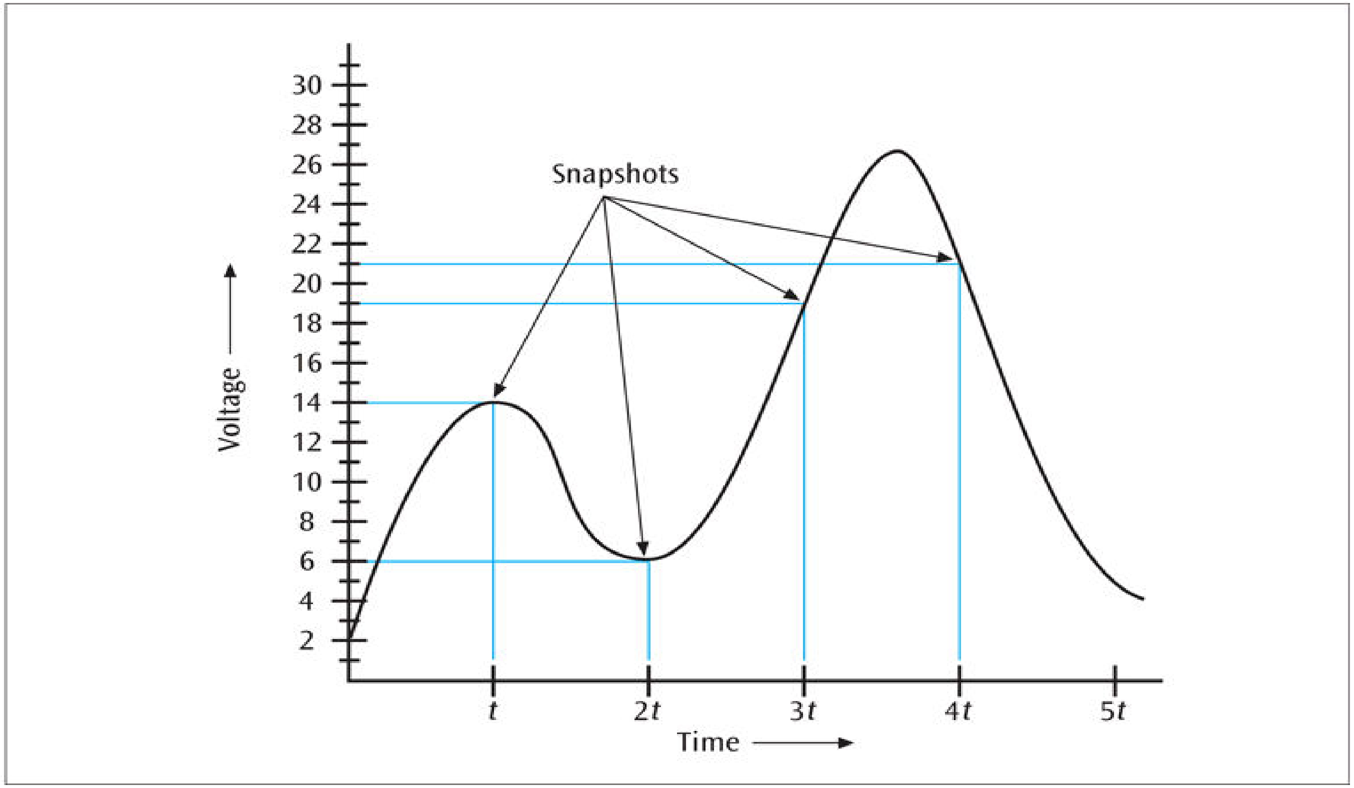
- To convert analog data into a digital signal, there are two techniques:
  - Pulse code modulation (the more common)
  - Delta modulation

Pulse Code Modulation

- The analog waveform is sampled at specific intervals and the “snapshots” are converted to binary values

Pulse Code Modulation (continued)

Figure 2-21
Example of taking "snapshots" of an analog waveform for conversion to a digital signal

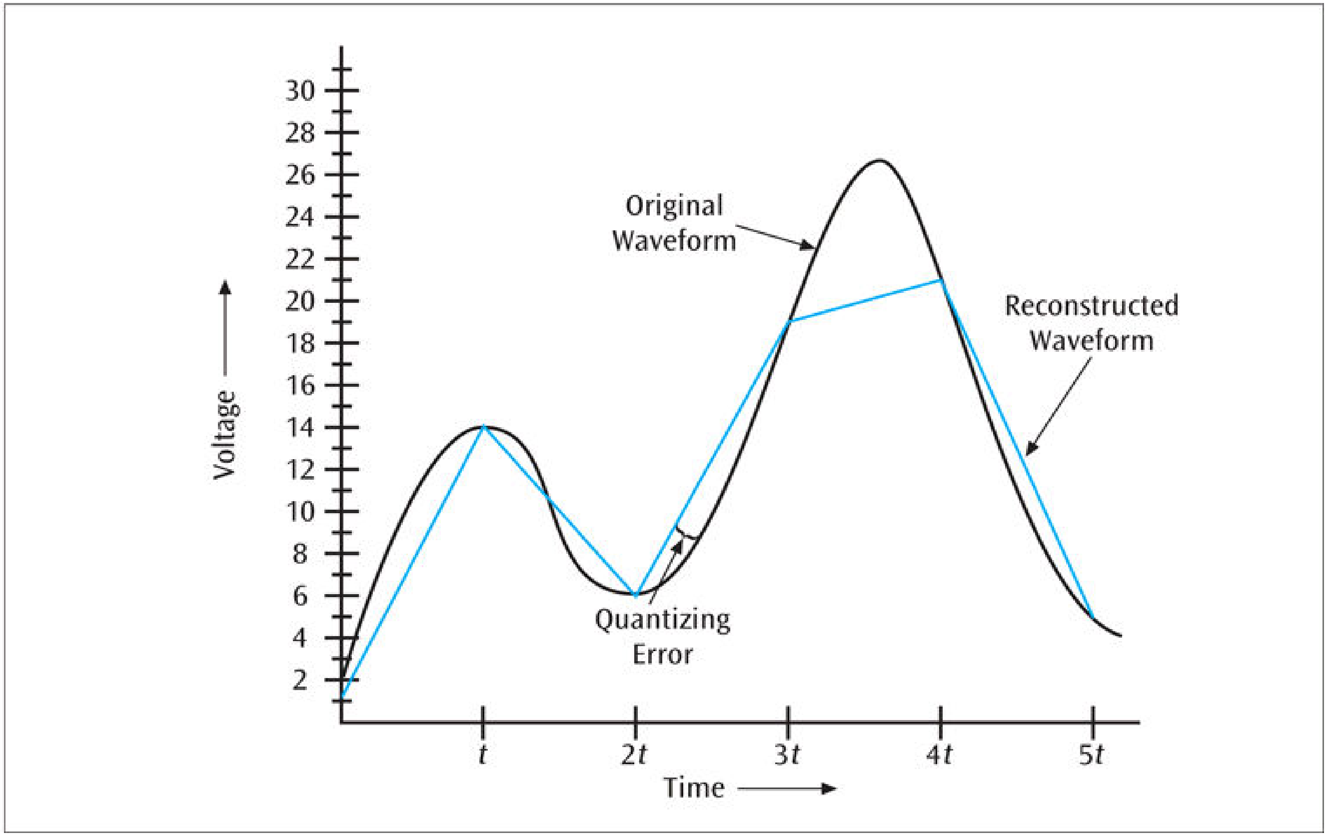


Pulse Code Modulation (continued)

- When the binary values are later converted to an analog signal, a waveform similar to the original results

Pulse Code Modulation (continued)

Figure 2-22
Reconstruction of the analog waveform from the digital "snapshots"

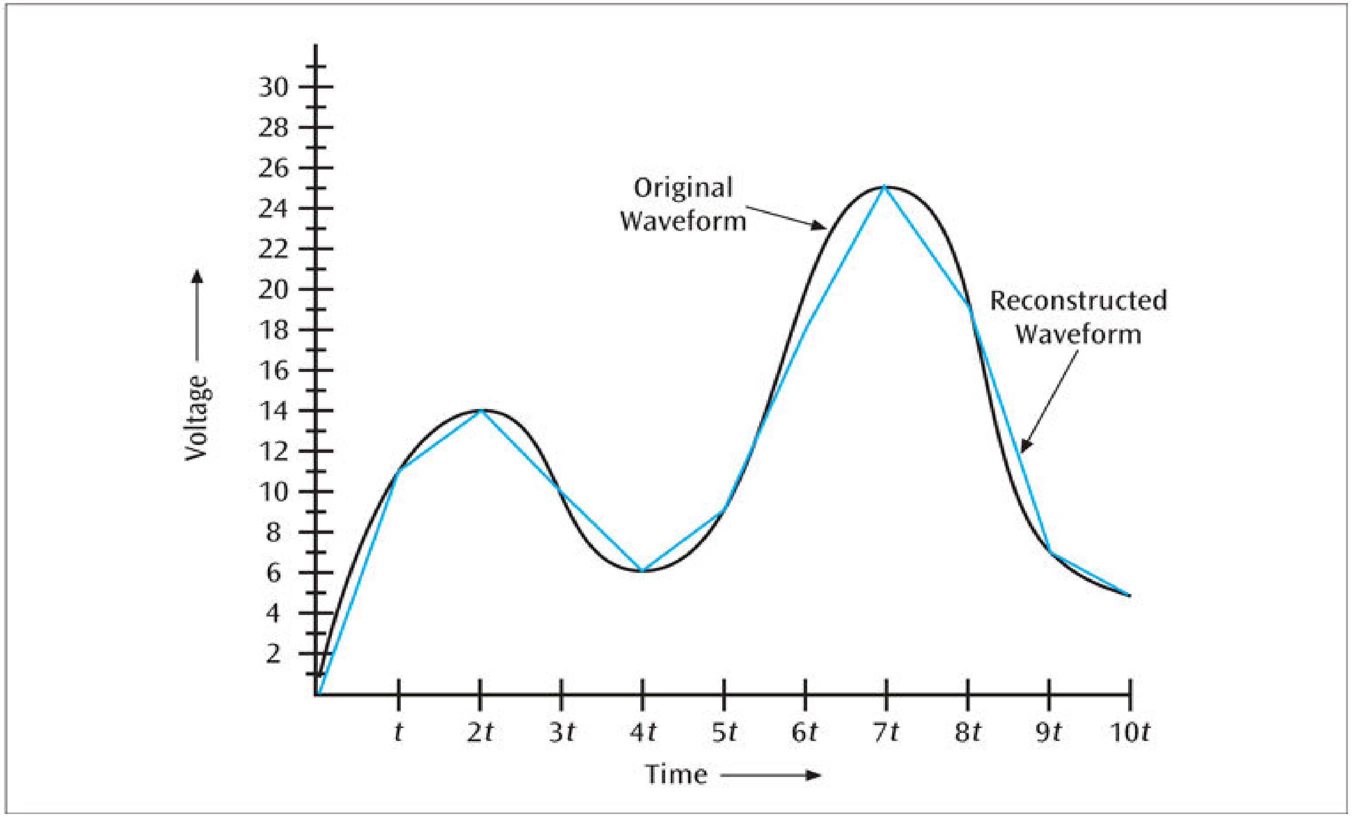


Pulse Code Modulation (continued)

- The more snapshots taken in the same amount of time, or the more quantization levels, the better the resolution

Pulse Code Modulation (continued)

Figure 2-23
A more accurate reconstruction of the original waveform, using a higher sampling rate



Pulse Code Modulation (continued)

- Since telephone systems digitize human voice, and since the human voice has a fairly narrow bandwidth, telephone systems can digitize voice into either 128 or 256 levels
- These are called quantization levels
- If 128 levels, then each sample is 7 bits (2 ^ 7 = 128)
- If 256 levels, then each sample is 8 bits (2 ^ 8 = 256)

Pulse Code Modulation (continued)

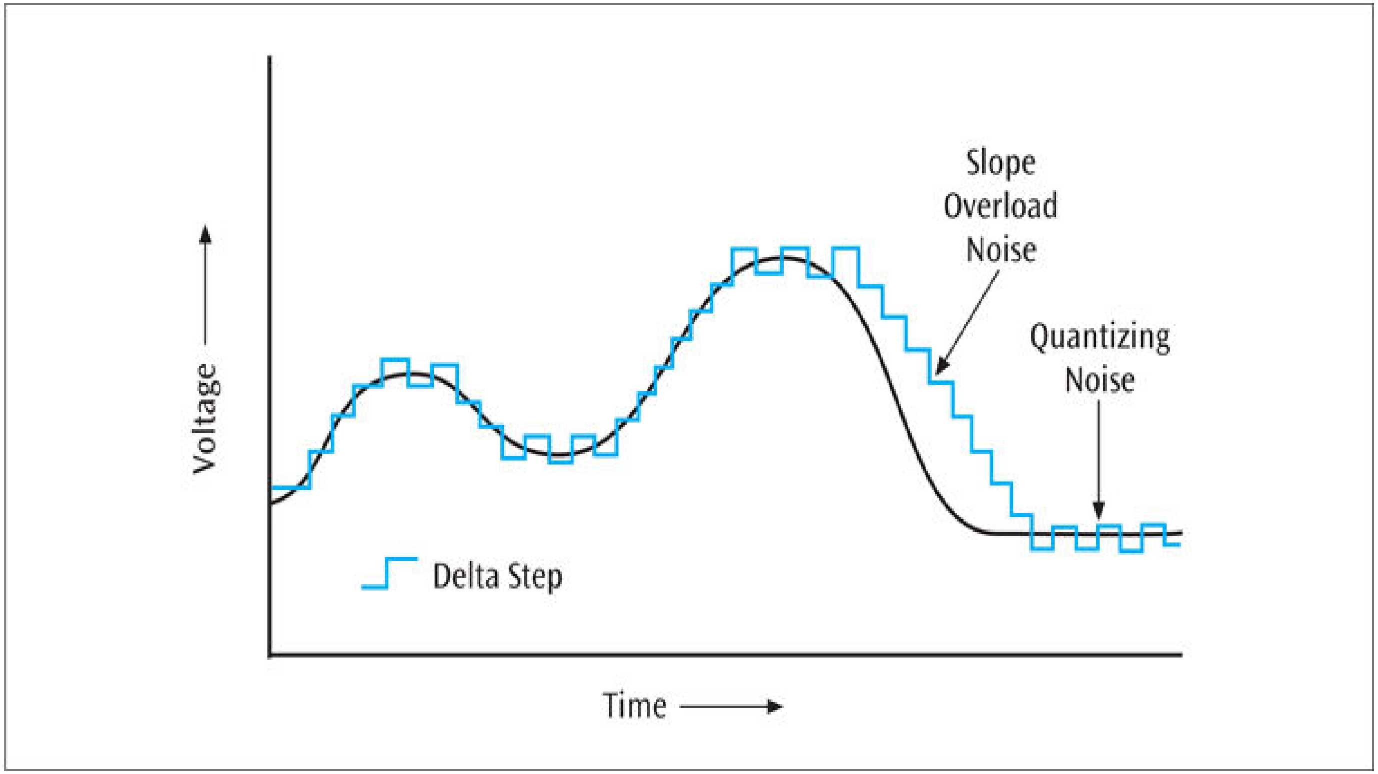
- How fast do you have to sample an input source to get a fairly accurate representation?
- Nyquist says 2 times the highest frequency
- Thus, if you want to digitize voice (4000 Hz), you need to sample at 8000 samples per second

Delta Modulation

- An analog waveform is tracked, using a binary 1 to represent a rise in voltage, and a 0 to represent a drop

Delta Modulation (continued)

Figure 2-24
Example of delta modulation that is experiencing slope overload noise and quantizing noise



The Relationship Between Frequency and Bits Per Second

- Higher Data Transfer Rates
  - How do you send data faster?
    - Use a higher frequency signal (make sure the medium can handle the higher frequency
    - Use a higher number of signal levels
  - In both cases, noise can be a problem

The Relationship Between Frequency and Bits Per Second (continued)

- Maximum Data Transfer Rates
  - How do you calculate a maximum data rate?
  - Use Shannon's equation
    - $S(f) = f \times \log_2 (1 + S/N)$
      - Where f = signal frequency (bandwidth), S is the signal power in watts, and N is the noise power in watts
  - For example, what is the data rate of a 3400 Hz signal with 0.2 watts of power and 0.0002 watts of noise?
    - $S(f) = 3400 \times \log_2 (1 + 0.2/0.0002)$
      $= 3400 \times \log_2 (1001)$
      $= 3400 \times 9.97$
      $= 33898$ bps

Data Codes

- The set of all textual characters or symbols and their corresponding binary patterns is called a data code
- There are three common data code sets:
  - EBCDIC
  - ASCII
  - Unicode

EBCDIC

Figure 2-27
The EBCDIC character code set

Bits			4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
			3	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
			2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
			1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
8	7	6	5																
0	0	0	0	NUL	SOH	STX	EXT	PF	HT	LC	DEL			SMM	VT	FF	CR	SO	SI
0	0	0	1	DLE	DC_1	DC_2	DC_3	RES	NL	BS	IL	CAN	EM	CC		IFS	IGS	IHS	IUS
0	0	1	0	DS	SOS	FS		BYP	LF	EOB	PRE			SM			ENQ	ACK	BEL
0	0	1	1			SYN		PN	RS	UC	EOT					DC_4	NAK		SUB
0	1	0	0	SP												<	(	+	|
0	1	0	1	&										!	$	.	)	:	¬
0	1	1	0	—												%	-	>	?
0	1	1	1													@		=	"
1	0	0	0		a	b	c	d	e	f	g	h	i						
1	0	0	1		j	k	l	m	n	o	p	q	r						
1	0	1	0			s	t	u	v	w	x	y	z						
1	0	1	1																
1	1	0	0		A	B	C	D	E	F	G	H	I						
1	1	0	1		J	K	L	M	N	O	P	Q	R						
1	1	1	0			S	T	U	V	W	X	Y	Z						
1	1	1	1	0	1	2	3	4	5	6	7	8	9						

ASCII

Figure 2-28
The ASCII character set

Low-Order Bits (4, 3, 2, 1)	High-Order Bits (7, 6, 5) 000	001	010	011	100	101	110	111
0000	NUL	DLE	SPACE	0	@	P	`	p
0001	SOH	DC1	!	1	A	Q	a	q
0010	STX	DC2	“	2	B	R	b	r
0011	ETX	DC3	#	3	C	S	c	s
0100	EOT	DC4	$	4	D	T	d	t
0101	ENQ	NAK	%	5	E	U	e	u
0110	ACK	SYN	&	6	F	V	f	v
0111	BEL	ETB	‘	7	G	W	g	w
1000	BS	CAN	(	8	H	X	h	x
1001	HT	EM	)	9	I	Y	i	y
1010	LF	SUB	*	:	J	Z	j	z
1011	VT	ESC	+	;	K	[	k	{
1100	FF	FS	’	<	L	\	l	|
1101	CR	GS	-	=	M	]	m	}
1110	SO	RS	.	>	N	^	n	~
1111	SI	US	/	?	O	—	o	DEL

Unicode

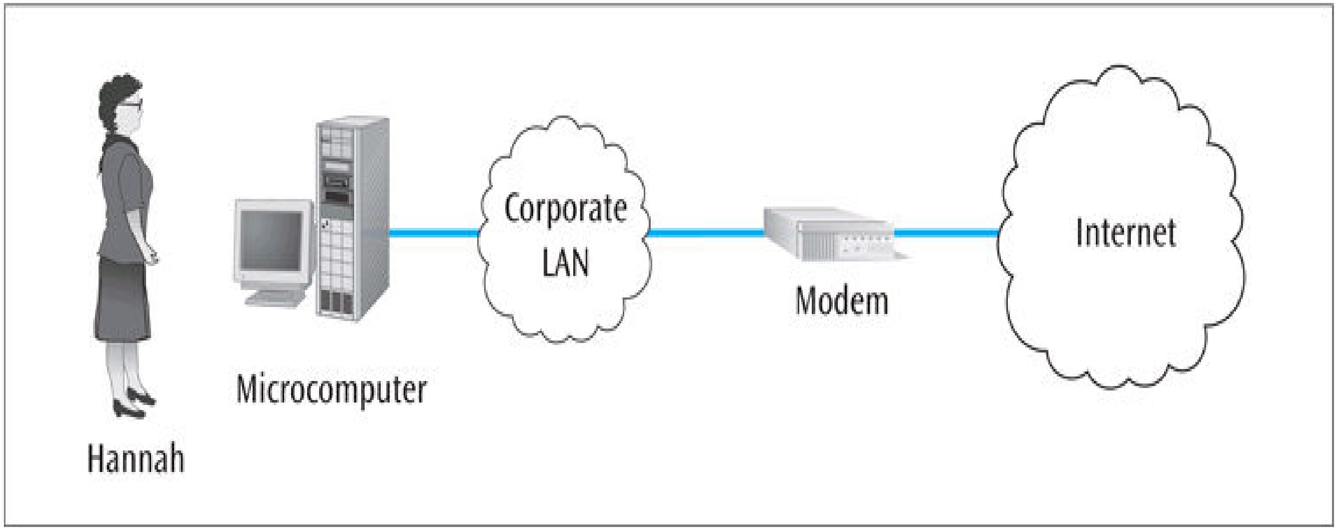
- Each character is 16 bits
- A large number of languages / character sets
- For example:
  - T equals 0000 0000 0101 0100
  - r equals 0000 0000 0111 0010
  - a equals 0000 0000 0110 0001

Data and Signal Conversions In Action: Two Examples

- Let us transmit the message “Sam, what time is the meeting with accounting? Hannah.”
- This message leaves Hannah’s workstation and travels across a local area network

Data and Signal Conversions In Action: Two Examples (continued)

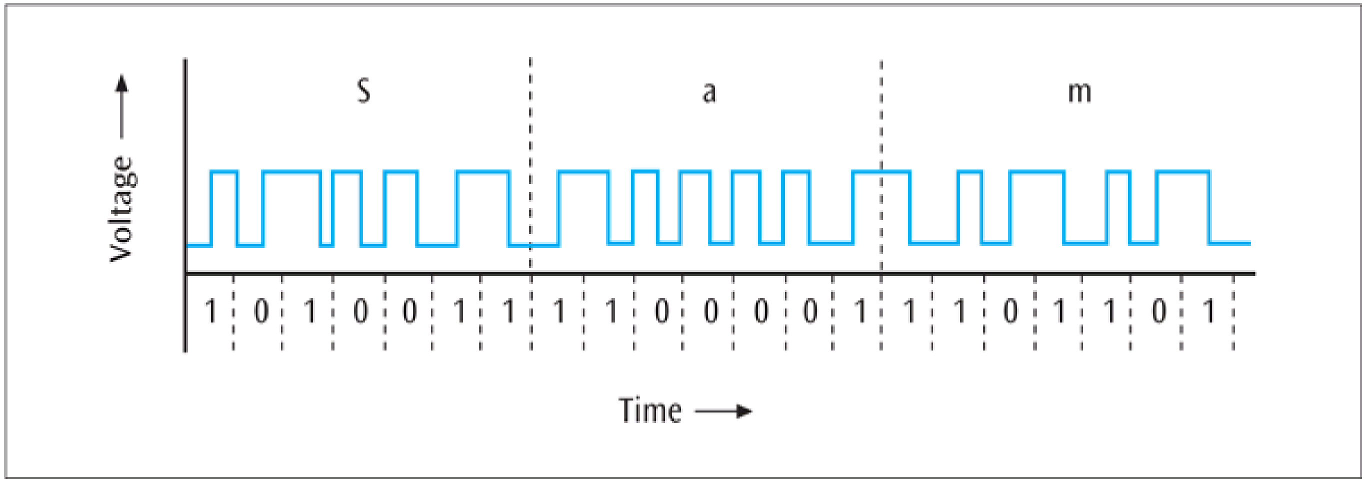
Figure 2-29
User sending e-mail from a personal computer over a local area network and the Internet, via a modem



Data and Signal Conversions In Action: Two Examples (continued)

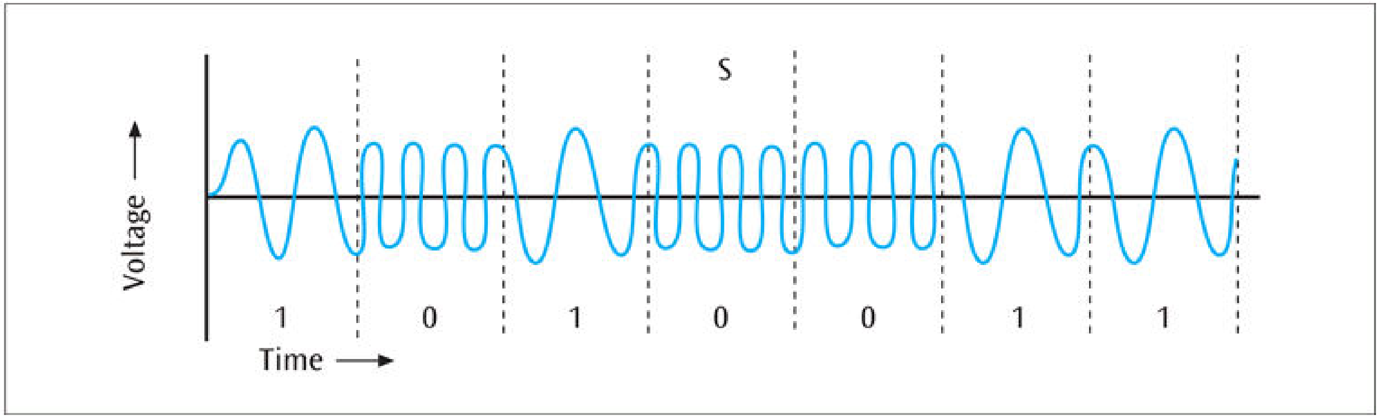
Figure 2-30

The first three letters of the message "Sam, what time is the meeting with accounting? Hannah" using differential Manchester encoding



Data and Signal Conversions In Action: Two Examples (continued)

Figure 2-31
The frequency modulated signal for the letter "S"



Summary

- Data and signals are two basic building blocks of computer networks
  - All data transmitted is either digital or analog
  - Data is transmitted with a signal that can be either digital or analog
- All signals consist of three basic components: amplitude, frequency, and phase
- Two important factors affecting the transfer of a signal over a medium are noise and attenuation
- Four basic combinations of data and signals are possible: analog data converted to an analog signal, digital data converted to a digital signal, digital data converted to a discrete analog signal, and analog data converted to a digital signal

Summary (continued)

- To transmit analog data over an analog signal, the analog waveform of the data is combined with another analog waveform in a process known as modulation
- Digital data carried by digital signals is represented by digital encoding formats
- For digital data to be transmitted using analog signals, digital data must first undergo a process called shift keying or modulation
  - Three basic techniques of shift keying are amplitude shift keying, frequency shift keying, and phase shift keying

Summary (continued)

- Two common techniques for converting analog data so that it may be carried over digital signals are pulse code modulation and delta modulation
- Data codes are necessary to transmit the letters, numbers, symbols, and control characters found in text data
  - Three important data codes are ASCII, EBCDIC, and Unicode