Data Communications and Computer Networks

A Business User's Approach

Chapter 2

Fundamentals of Data and Signals

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  - William Stallings, “Business Data Communications, 4th Edition”, Prentice Hall publisher

Objectives

- Distinguish between data and signals, and cite the advantages of digital data and signal 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
- 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

Objectives (Cont.)

- 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

Objectives (Cont.)

- Identify the two most common digitization techniques and describe their advantages and disadvantages
- Discuss the characteristics and importance of spread spectrum encoding techniques
- Identify the different data codes and how they are used in communication systems

Introduction Data & Signals

- Data are entities that convey meaning (computer file, music on a 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

Data and Signals

- **Data**
  - Entities that convey meaning
- **Signals**
  - Electric or electromagnetic representations of data
- **Transmission**
  - Communication of data by propagation and processing of signals

Data and Signals

- Examples of data include:
  - Computer files
  - Movie on a DVD
  - Music on a compact disc
  - Collection of samples from a blood gas analysis device

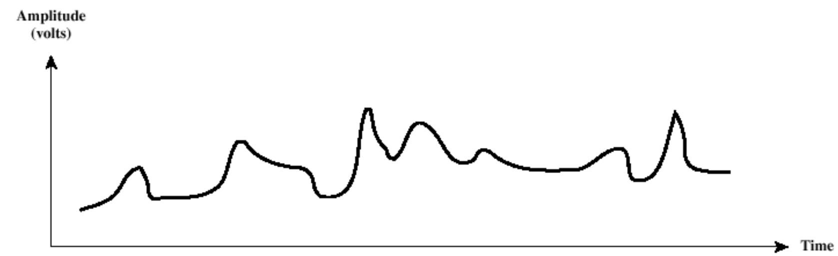
Data and Signals

- Examples of signals include:
  - Telephone conversation over a telephone line
  - Live television news interview from Europe
  - Web page download over your telephone line via the Internet

Continuous / Discontinuous Signals

- Continuous signal:
  - Varies in a smooth way over time

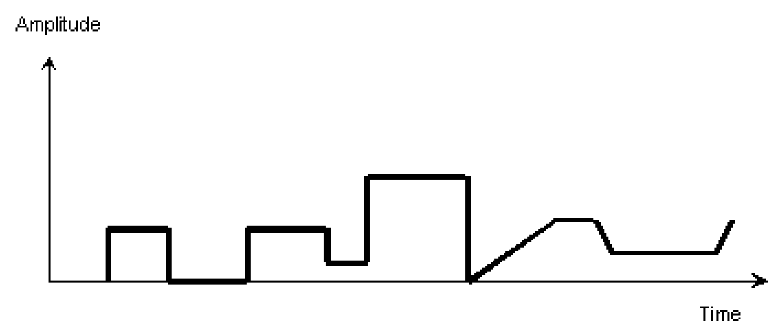
$$\lim_{t \to a^-}\{f(t)\} = \lim_{t \to a^+}\{f(t)\} = \lim_{t \to a}\{f(t)\}$$



(a) Continuous

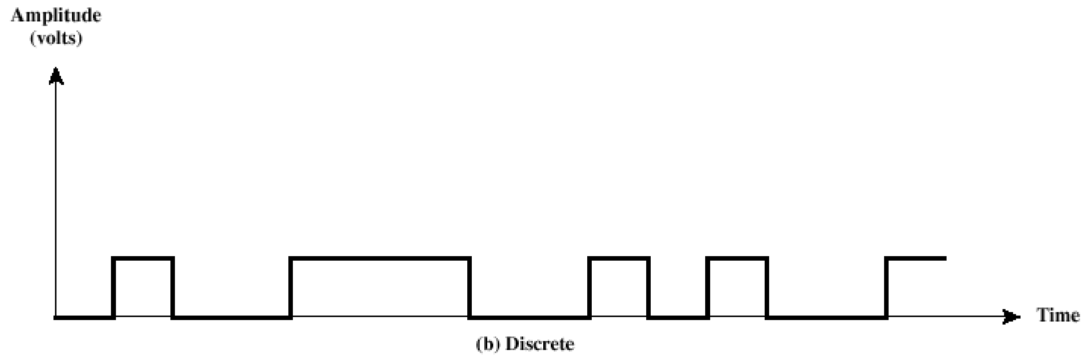
- Discontinuous signal
  - Values jump abruptly over time

$$\lim_{t \to a^-}\{f(t)\} \neq \lim_{t \to a^+}\{f(t)\}$$

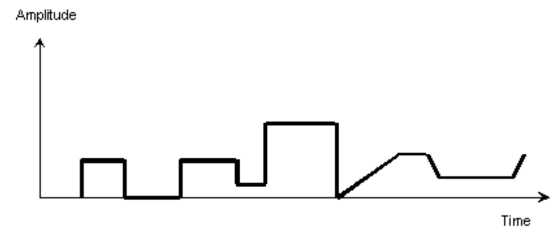


Discrete Signals

- Maintains a constant level then changes to another constant level
  - Takes finite number of values



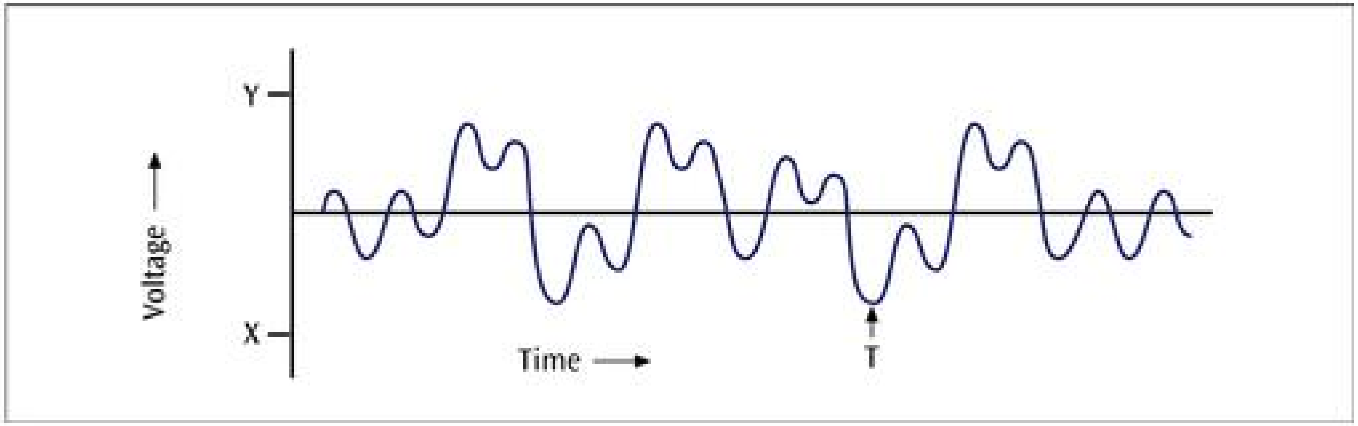
  - Example of a non-discrete signal



Analog Versus Digital

- Analog signal is a continuous waveform, with examples such as music and video.

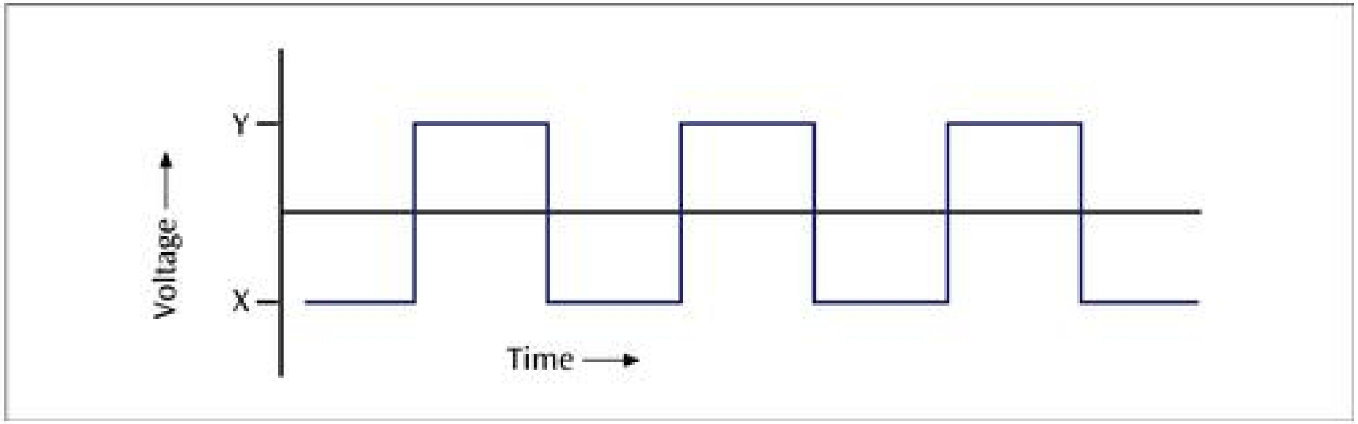
Figure 2-1
A simple example of an analog waveform



Analog Versus Digital

- Digital is a discrete or non-continuous waveform with finite number of values (levels)
  - Examples such as computer 1s and 0s.

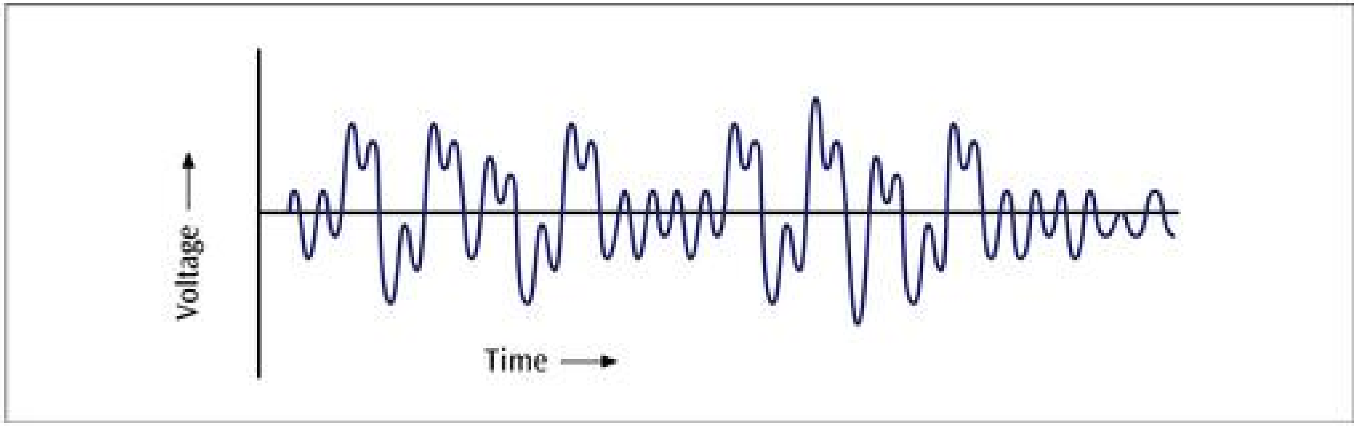
Figure 2-3
A simple example of a digital waveform



Analog Versus Digital

- It is harder to separate noise from an analog signal than it is to separate noise from a digital signal.

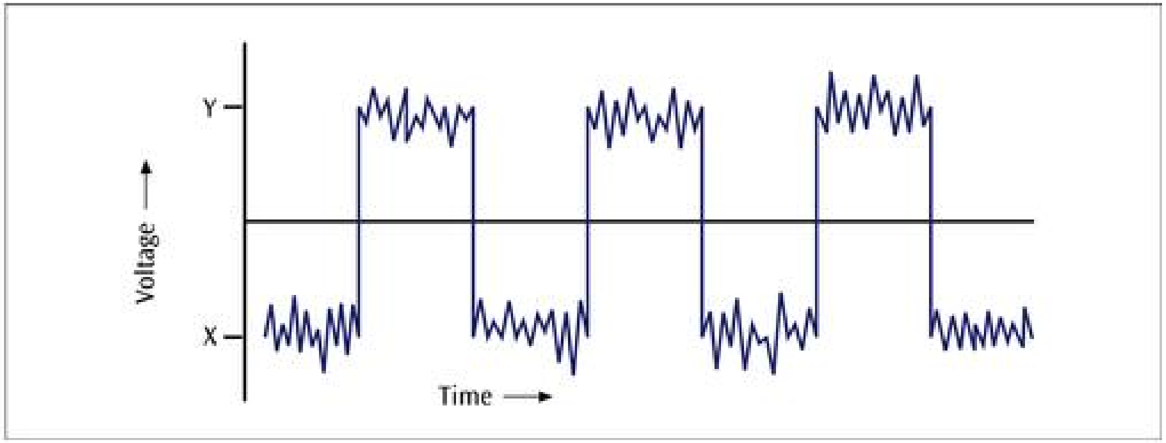
Figure 2-2
The waveform of a symphonic overture with noise



Analog Versus Digital

- Noise in a digital signal.
  - You can still discern a high voltage from a low voltage.

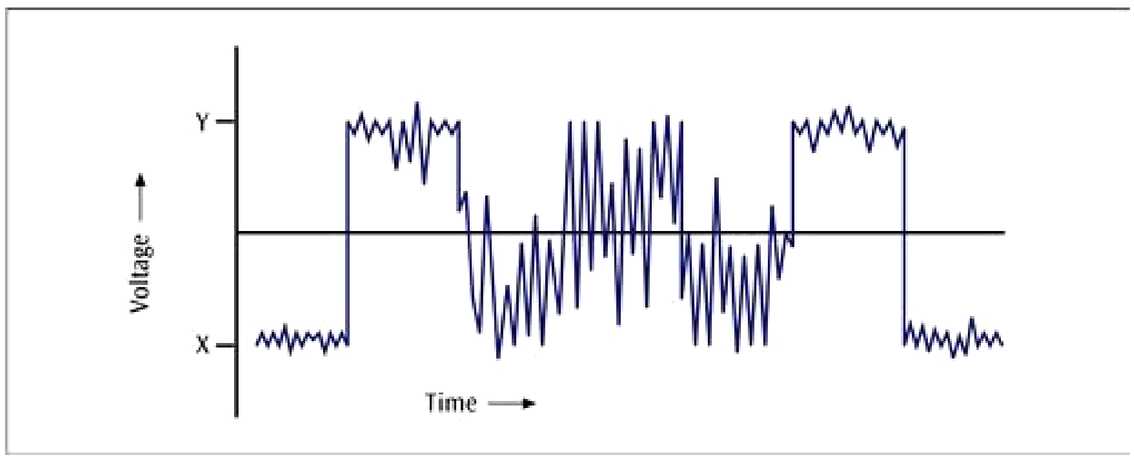
Figure 2-4
A digital signal with some noise introduced



Analog Versus Digital

- Noise in a digital signal: too much noise.
  - You cannot discern a high voltage from a low voltage.

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



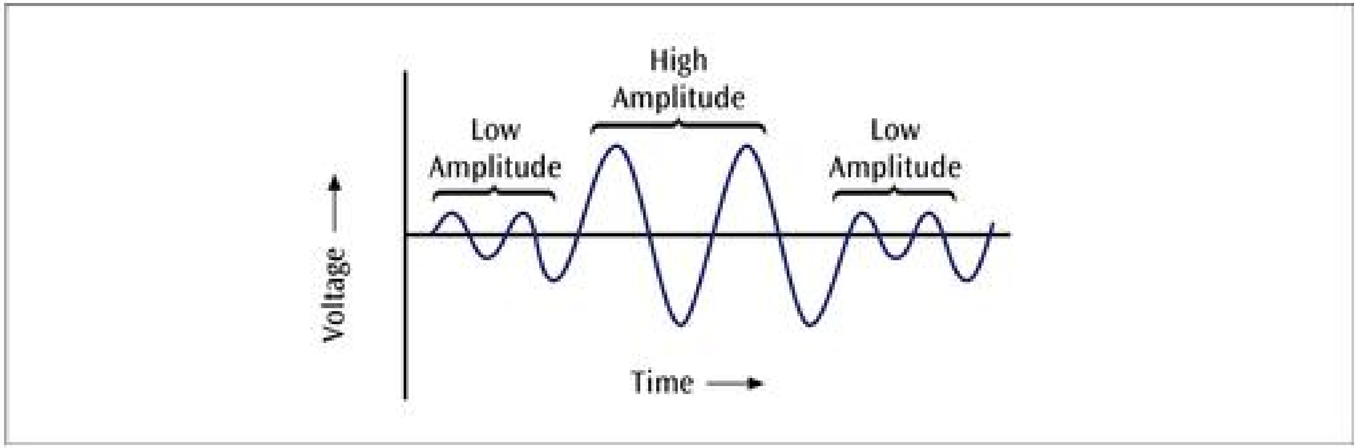
Components of Signals

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

Amplitude

- The amplitude of a signal is the height of the wave above or below a given reference point.

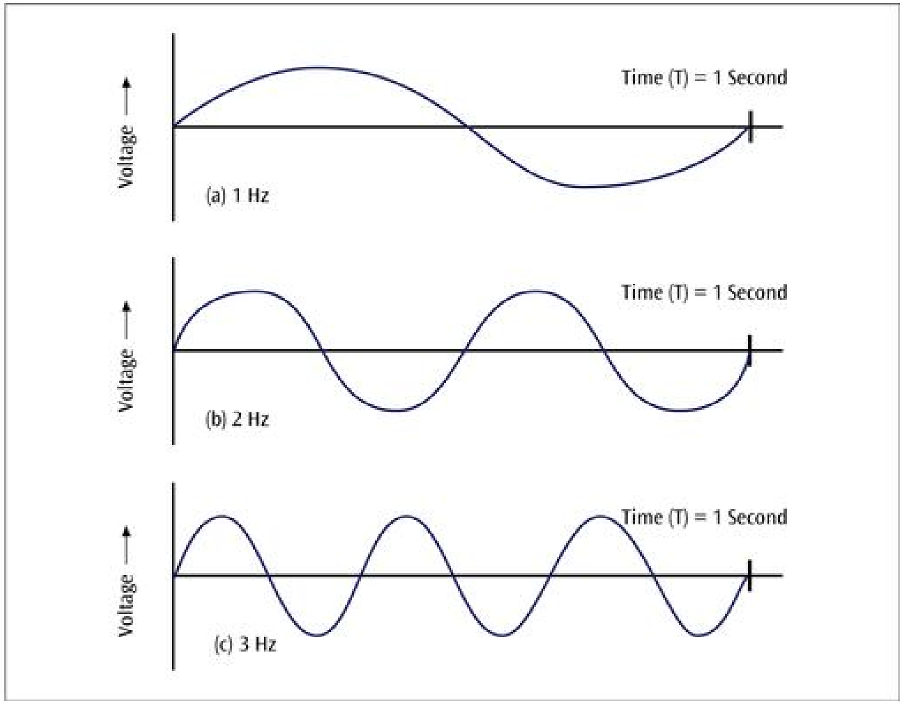
Figure 2-6
A signal with two different amplitudes



Frequency

- The frequency is the number of times a signal makes a complete cycle within a given time frame.

Figure 2-7
Three signals of 1 Hz, 2 Hz, and 3 Hz



Frequency Related Properties

- Period – time or interval of one cycle.
- Spectrum - the range of frequencies that a signal spans from minimum to maximum.
- Bandwidth - the absolute value of the difference between the lowest and highest frequencies of a signal.
- Attenuation - loss of signal strength.

Frequency

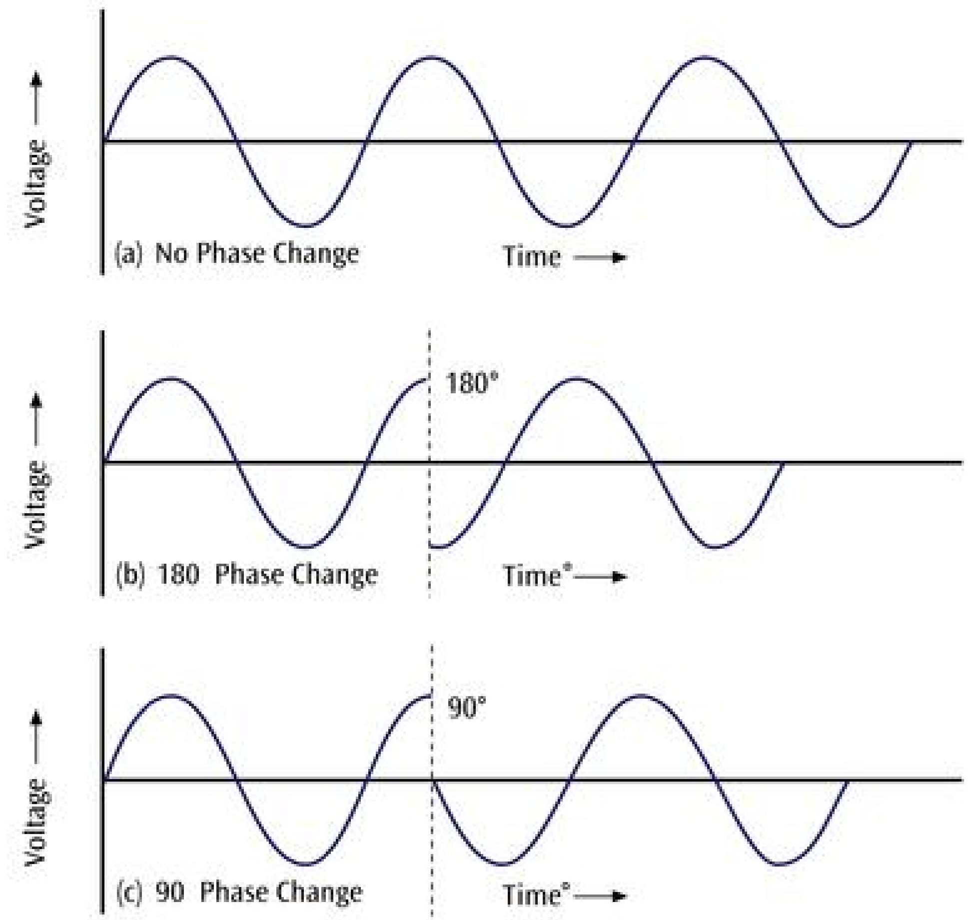
- For example, consider an average voice:
  - The average voice has a frequency range of roughly 300 Hz to 3100 Hz.
  - The spectrum would thus be 300 - 3100 Hz
  - The bandwidth would be 2800 Hz

Phase

- The phase of a signal is 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.

Phase

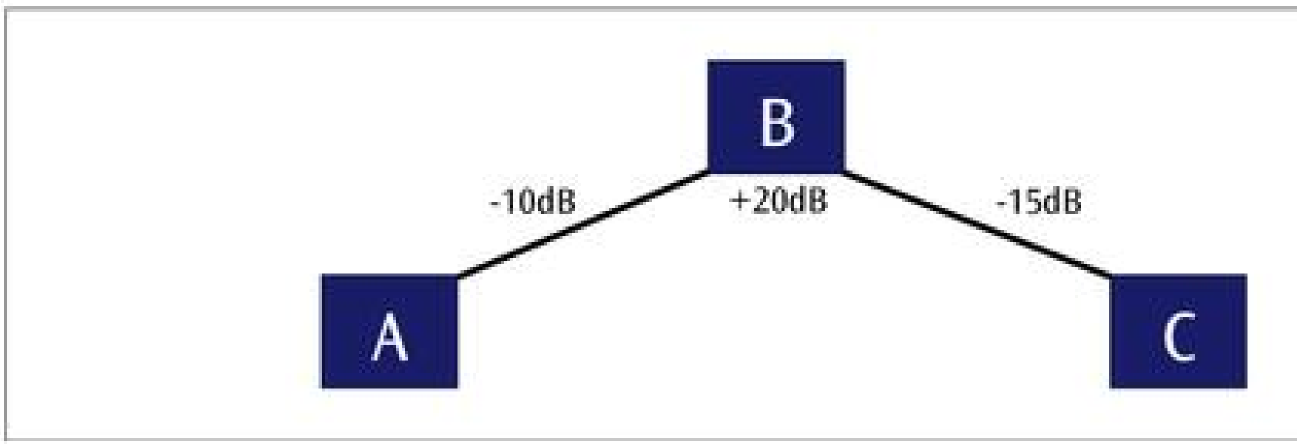
Figure 2-8
A sine wave showing no phase change (a), a 180 degree phase change (b), and a 90 degree phase change (c)



Signal Strength

- All signals experience loss (attenuation).
- Attenuation is denoted as a decibel (dB) loss.
- Decibel losses (and gains) are additive.
  - Decibel defined as dB= 10 $\log_{10}$(P2/P1)

Figure 2-10
Example demonstrating decibel loss and gain



Signal Strength

- So if a signal loses 3 dB, is that a lot?
- A 3 dB loss indicates the signal lost half of its power.
  - $dB = 10 \log_{10} (P2 / P1)$
  - $-3\ dB = 10 \log_{10} (P2 / P1)$
  - $-0.3 = \log_{10} (P2 / P1)$
  - $10^{-0.3} = P2 / P1$
  - $0.50 = P2 / P1$
  - $P2 = 0.5 * P1$

Data and Signals & Their Conversions

Table 2-1

Five combinations of data and signals

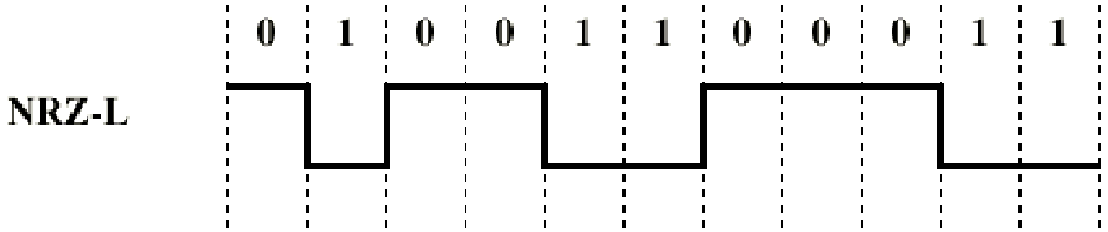
Data	Signal	Common Conversion Technique	Common Devices	Common Systems
Analog	Analog	Amplitude modulation Frequency modulation	Radio tuner TV tuner	Telephone Cable TV Broadcast TV AM and FM Radio
Digital	Digital	NRZ-L NRZI Manchester Differential Manchester Bipolar-AMI 4B/5B	Digital encoder	Local area networks Telephone systems HDTV
Digital	Analog	Amplitude shift keying Frequency shift keying Phase shift keying	Modem	Dial-up Internet access DSL Cable modems
Analog	Digital	Pulse code modulation Delta modulation	Codec	Telephone systems Music systems
Analog or Digital	Analog	Spread spectrum technology	Spread spectrum encoder	Cordless telephones Wireless LANs

Converting Digital Data into Digital Signals

- There are numerous techniques available to convert digital data into digital signals.
- Let’s examine five techniques:
  - NRZ-L: Nonreturn to Zero-Level
  - NRZ-I : Nonreturn to Zero Inverted
  - Manchester
  - Differential Manchester
  - 4B/5B Digital Encoding

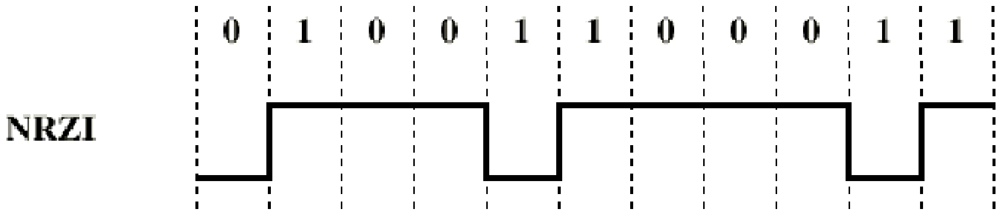
Nonreturn to Zero-level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - no transition i.e. no return to zero voltage
- Absence of voltage for one (1), constant positive voltage for zero (0)
- More often, negative voltage for one value and positive for the other
- This is NRZ-L



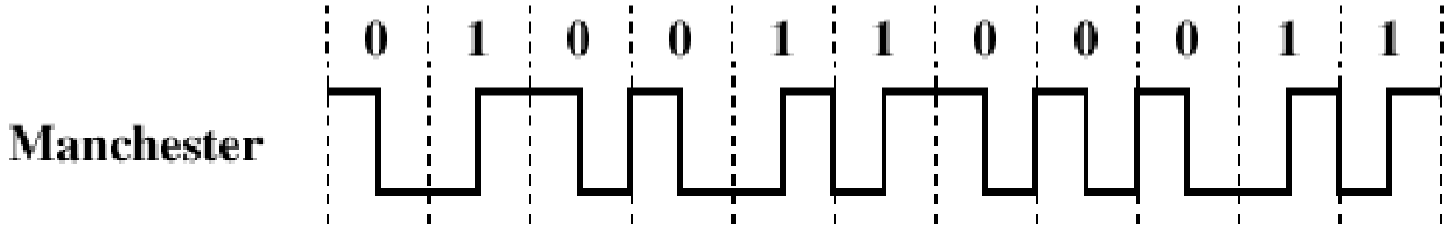
Nonreturn to Zero Inverted (NRZ-I)

- Nonreturn to zero inverted on ones
- Data encoded as presence or absence of signal transition at beginning of bit time
  - Transition (low to high or high to low) denotes a binary 1
  - No transition denotes binary 0
- Constant voltage pulse for duration of bit
- An example of differential encoding



Manchester (Biphase)

- Transition in middle of each bit period
- Transition serves as clock and data
- Low to high represents one
- High to low represents zero
- Used by IEEE 802.3

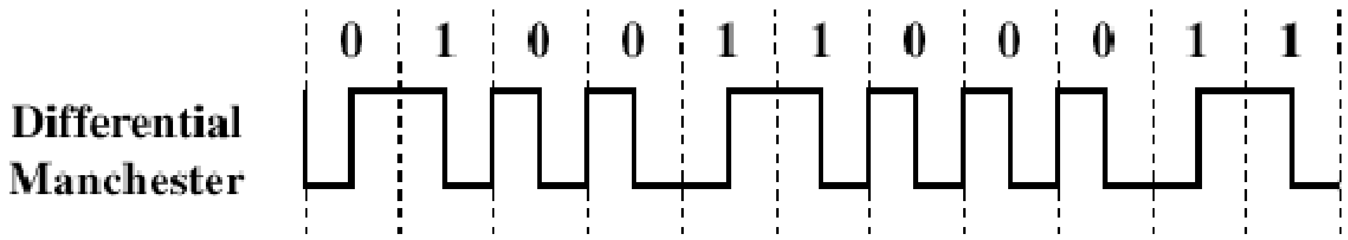


Differential Encoding

- Data is represented by changes in signal rather than signal levels
- More reliable detection of transition rather than level
- In complex transmission layouts it is easy to lose sense of polarity

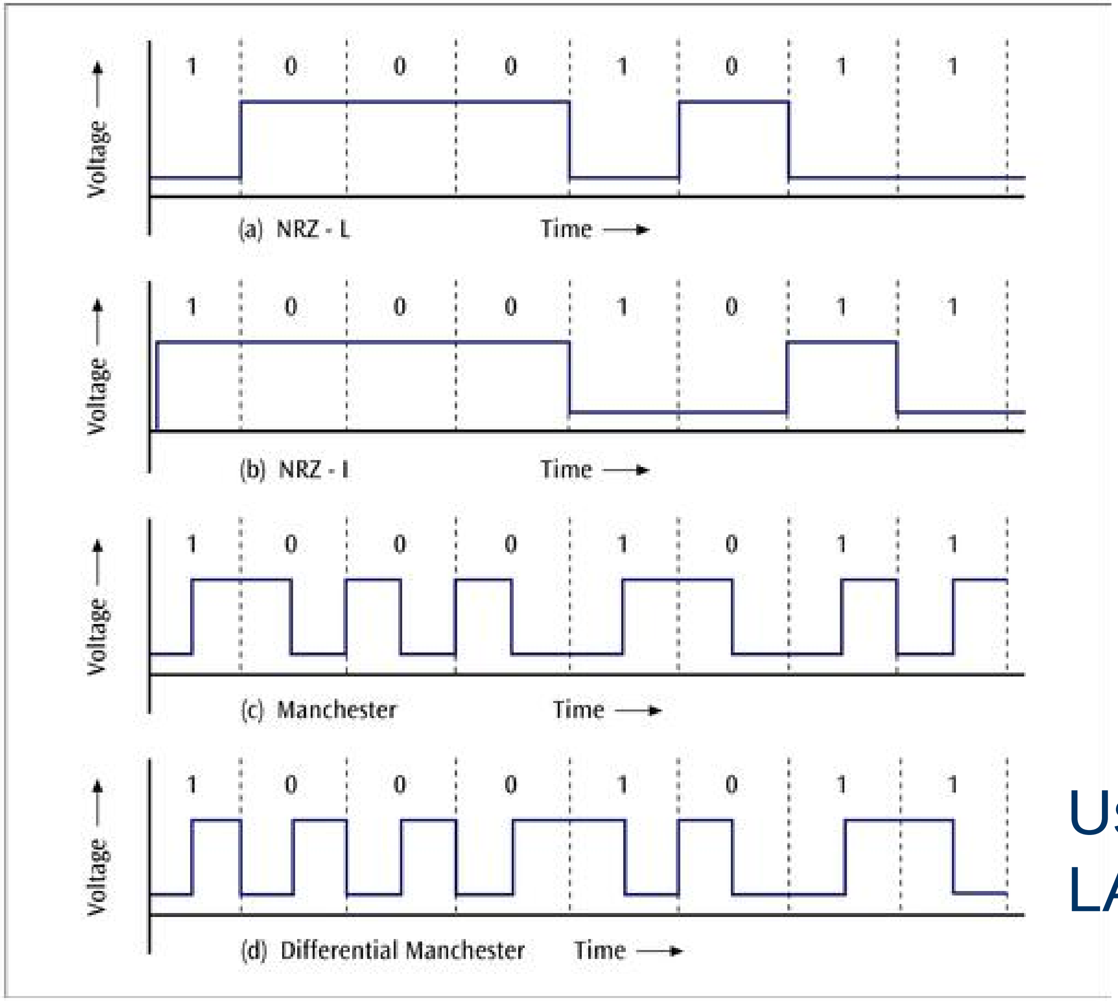
Differential Manchester

- Mid-bit transition is clocking only
- Transition at start of a bit period represents zero
- No transition at start of a bit period represents one
- Note: this is a differential encoding scheme
- Used by IEEE 802.5



Converting Digital Data into Digital Signals

Figure 2-11
Examples of four digital encoding schemes

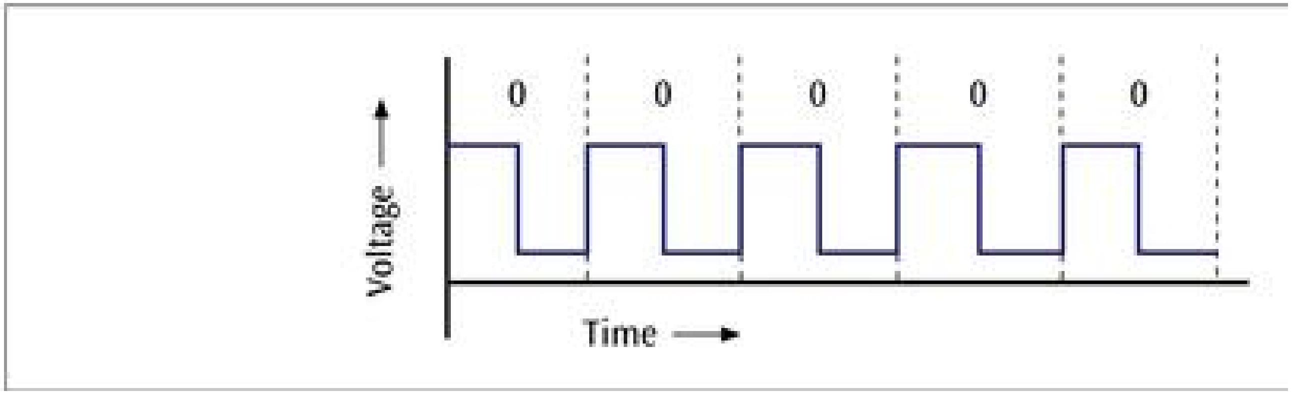


Used in LANs

Differential Manchester Encoding

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

Figure 2-12
Transmitting five binary 0s using Differential Manchester encoding



4B/5B Digital Encoding

- Yet another encoding technique that 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 NRZ-I encoded signal.

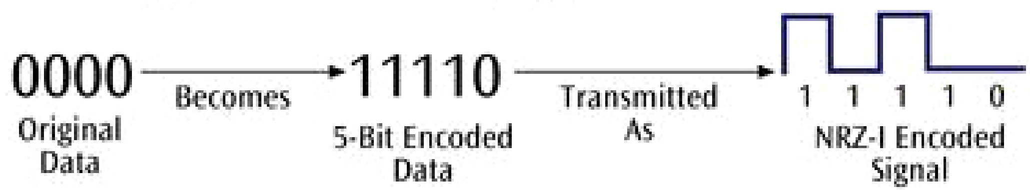
4B/5B Digital Encoding

Figure 2-13
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



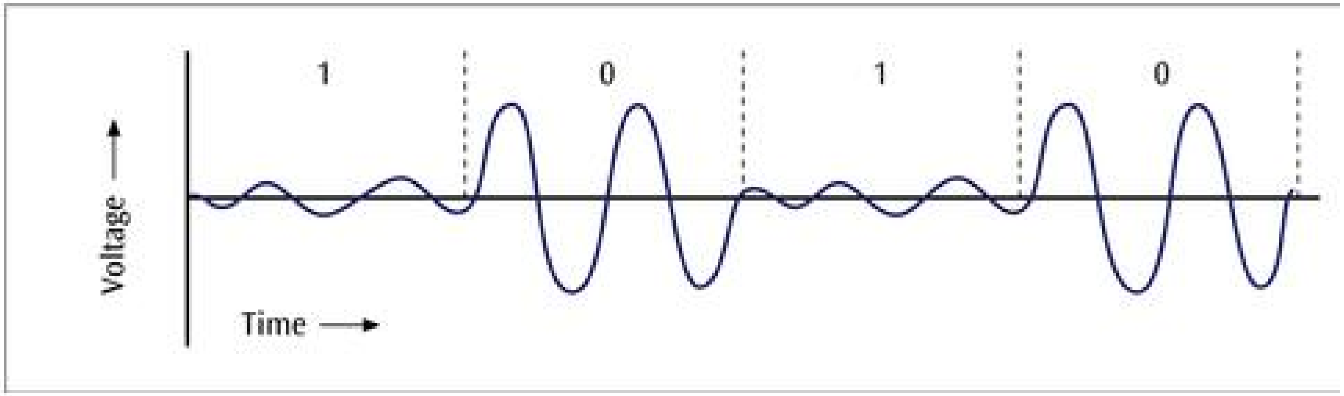
Converting Digital Data Into Analog Signals

- Example: (digital) data transmission over telephone lines
- Three basic techniques:
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation

Amplitude Modulation

- One amplitude encodes a 0 while another amplitude encodes a 1 (amplitude shift keying).
  - Each level carries 1 bit

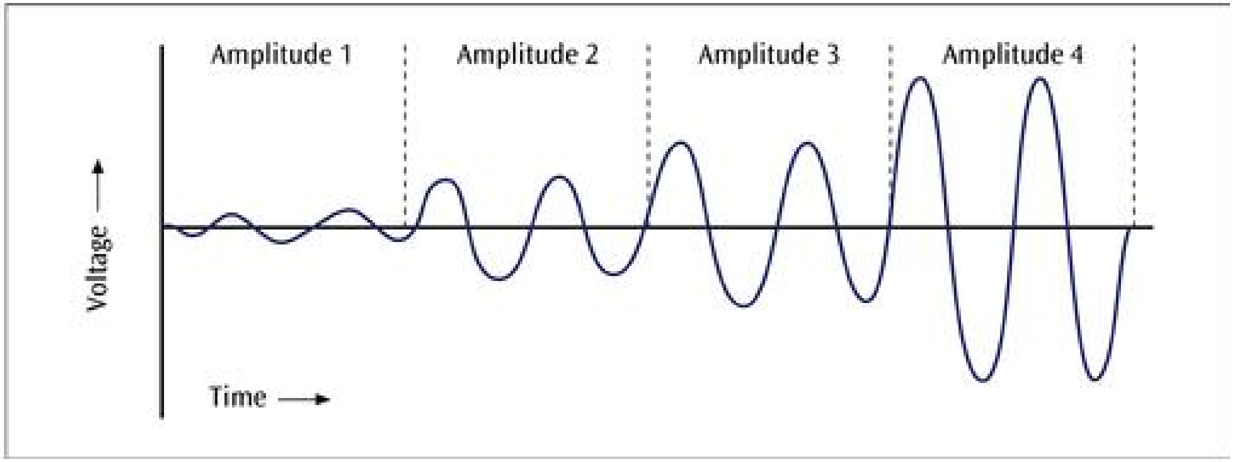
Figure 2-14
Example of amplitude modulation



Amplitude Modulation

- Some systems use multiple amplitudes.
  - Each level carries more than one bit

Figure 2-15
Amplitude modulation using four different amplitude levels



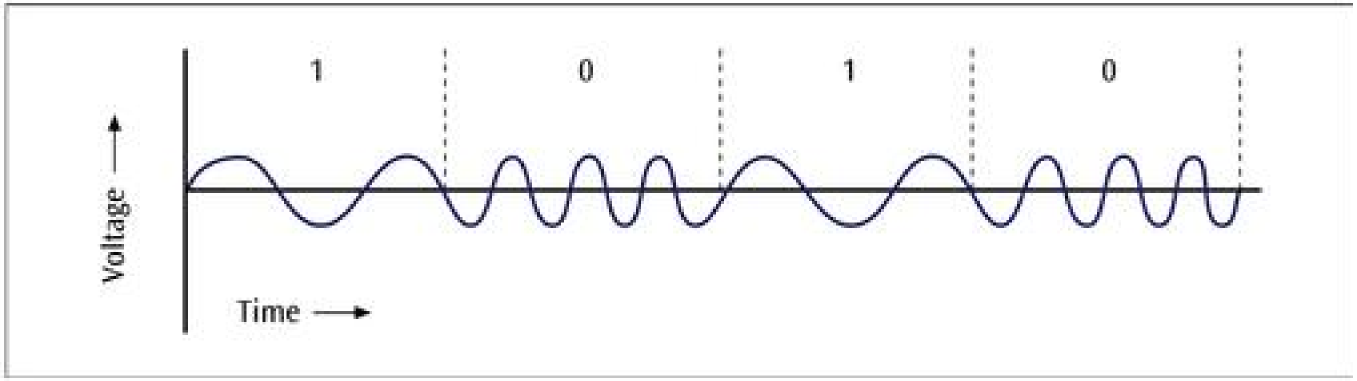
Multiple Signal Levels

- Why use multiple signal levels?
- With two-signal, each level represents one bit, 0 or 1.
  - We can represent two levels with a single bit, 0 or 1.
- With four-level signal, each level represents two bits, 00, 01, 10, or 11
  - We can represent four levels with two bits: 00, 01, 10, 11.
- With eight-level signal, each level represents three bits, 000,001, 010, 011, 100, 101, 110, or 111.
  - We can represent eight levels with three bits: 000, 001, 010, 011, 100, 101, 110, 111
- Note that the number of levels is always a power of 2.
- For *n* level signal, each level can carry $log_2 n$ bits
  - A 4 level signal can carry 2 bits per level

Frequency Modulation

- One frequency encodes a 0, while another frequency encodes a 1 1 (frequency shift keying).

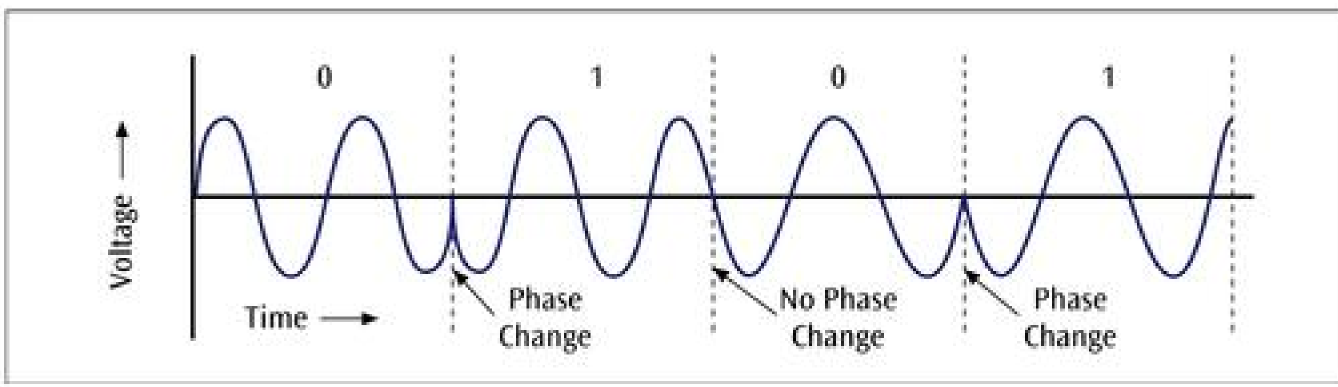
Figure 2-16
Simple example of frequency modulation



Phase Modulation

- One phase change encodes a 0, while another phase change encodes a 1 (differential phase shift keying).

Figure 2-17
An example of simple phase modulation of a sine wave

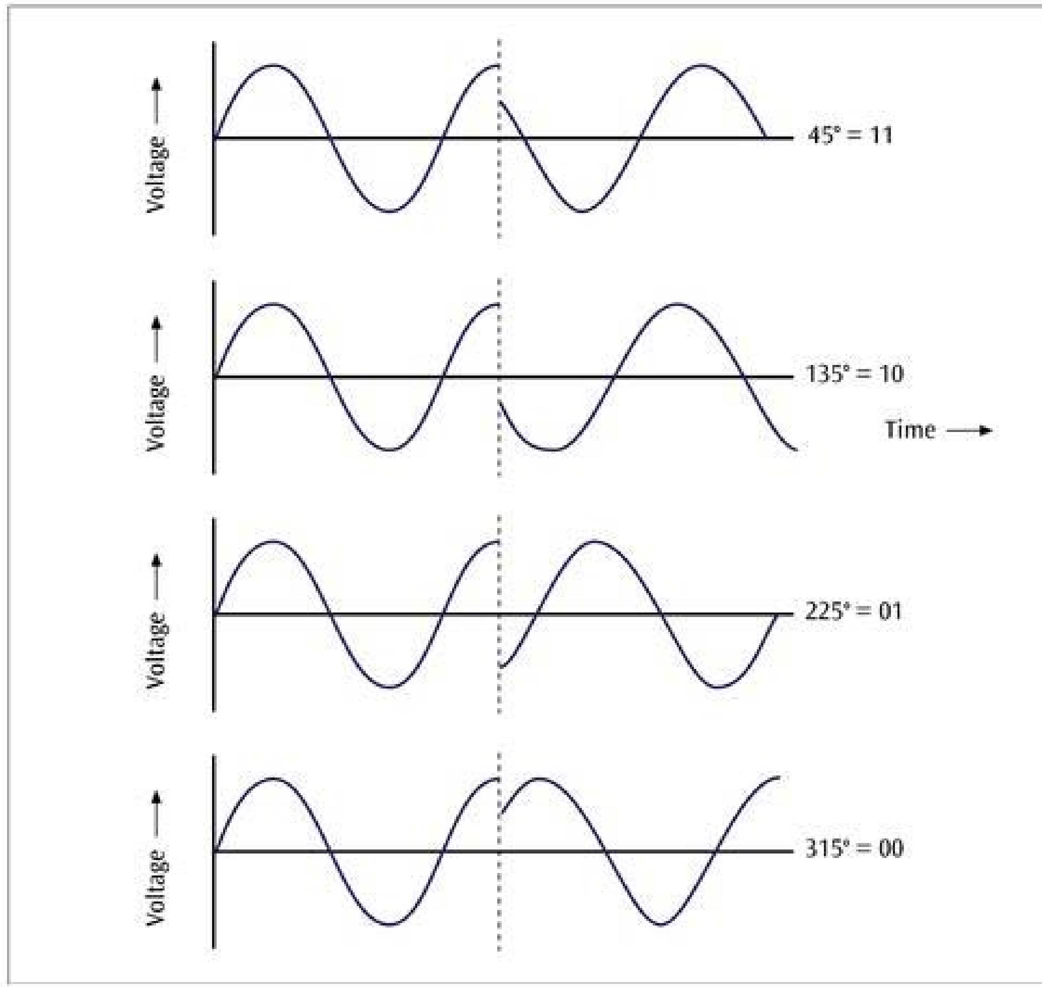


Quadrature Phase Modulation

- Four different phase angles are used:
  - 45 degrees
  - 135 degrees
  - 225 degrees
  - 315 degrees
- How many bits can be transmitted per phase (signal)?

Quadrature Phase Modulation

Figure 2-18
Four phase angles of 45, 135, 225, and 315 degrees

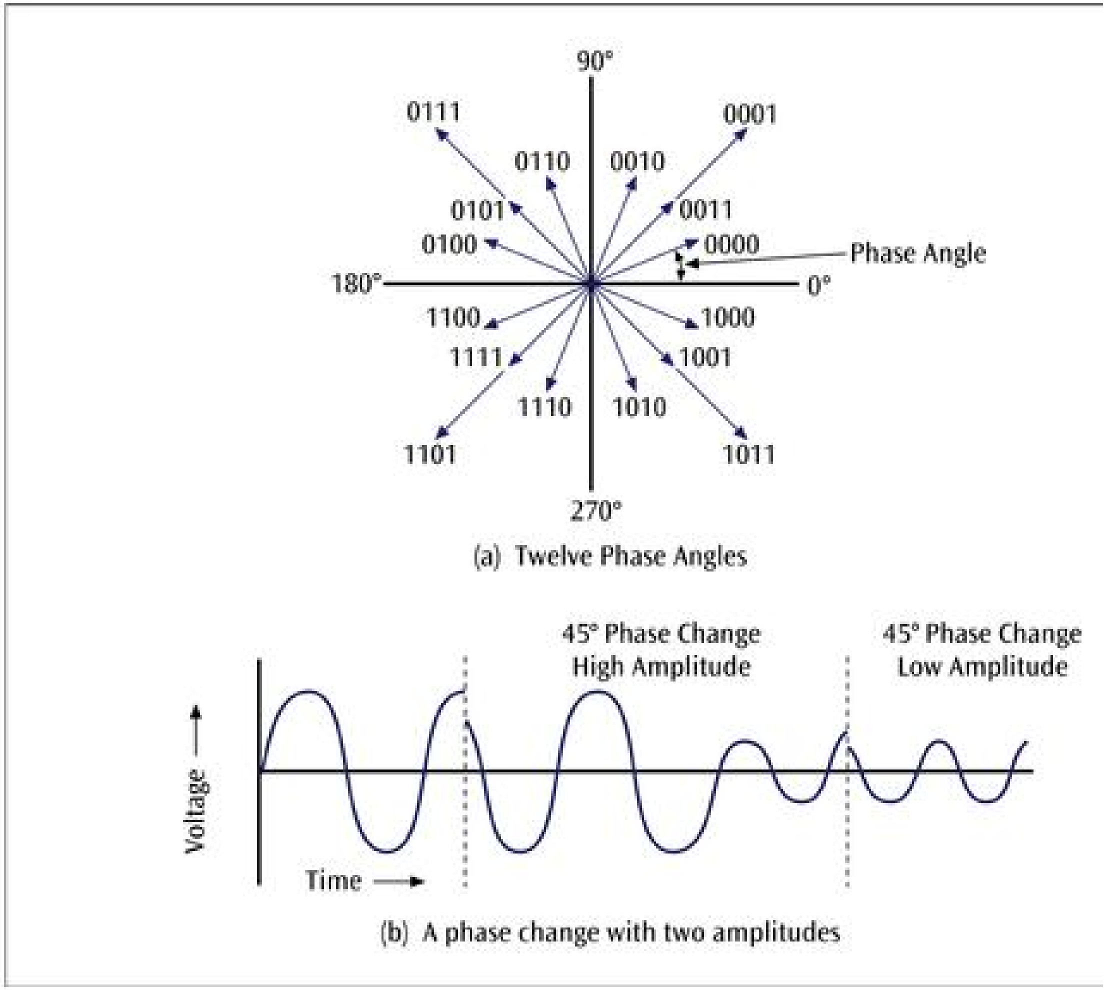


Quadrature Amplitude Modulation (QAM)

- In this technology, 12 different phases are combined, some (4) 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 $2^4 = 16$

Quadrature Amplitude Modulation

Figure 2-19
Figure (a) shows 12 different phases while Figure (b) shows a phase change with two different amplitudes



Higher Data Transfer Rates

- How do you send data faster?
  1. Use a higher frequency signal (make sure the medium can handle the higher frequency)
  2. Use a higher number of signal levels
- In both cases, noise can be a party pooper.

Maximum Data Transfer Rates

- How do you calculate a maximum data rate?
- Use Shannon's equation:

$$S(f) = f \log_2 (1 + W/N)$$

- Where f = signal frequency, W is signal power, and N is noise power

Maximum Data Transfer Rates

- 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

- Note: The S/N in dB is:

  $dB = 10 \log_{10} (P2 / P1)$

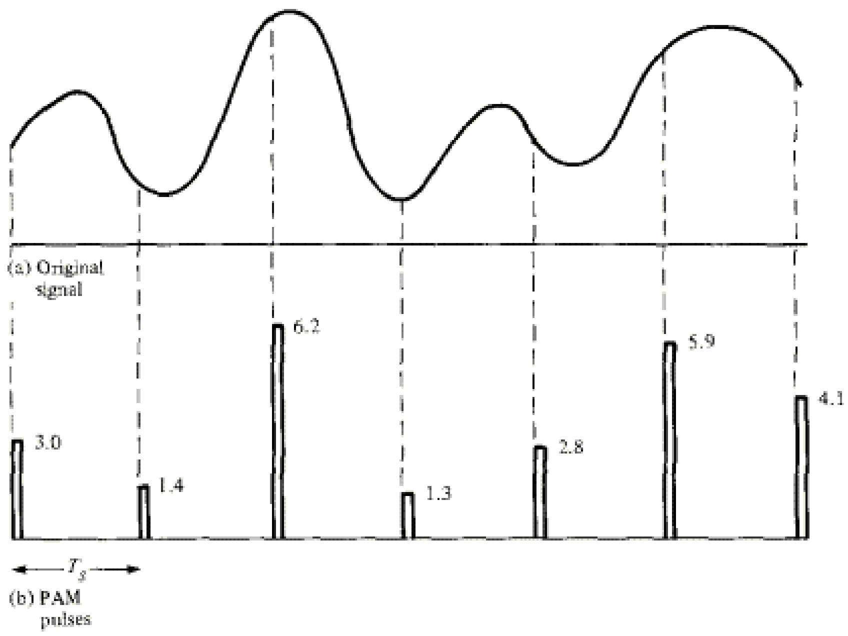
  $= 10 \log_{10} (.2/.0002) = 10*3 = 30$

Converting Analog Data into Digital Signals

- To convert analog data into a digital signal, there are two basic techniques:
  - Pulse modulation
    - Pulse amplitude modulation: PAM
    - Pulse code modulation: PCM
  - Delta modulation

PAM: Pulse Amplitude Modulation

- The analog waveform is sampled at specific intervals and the “snapshots” are transmitted
  - Note: analogue signals

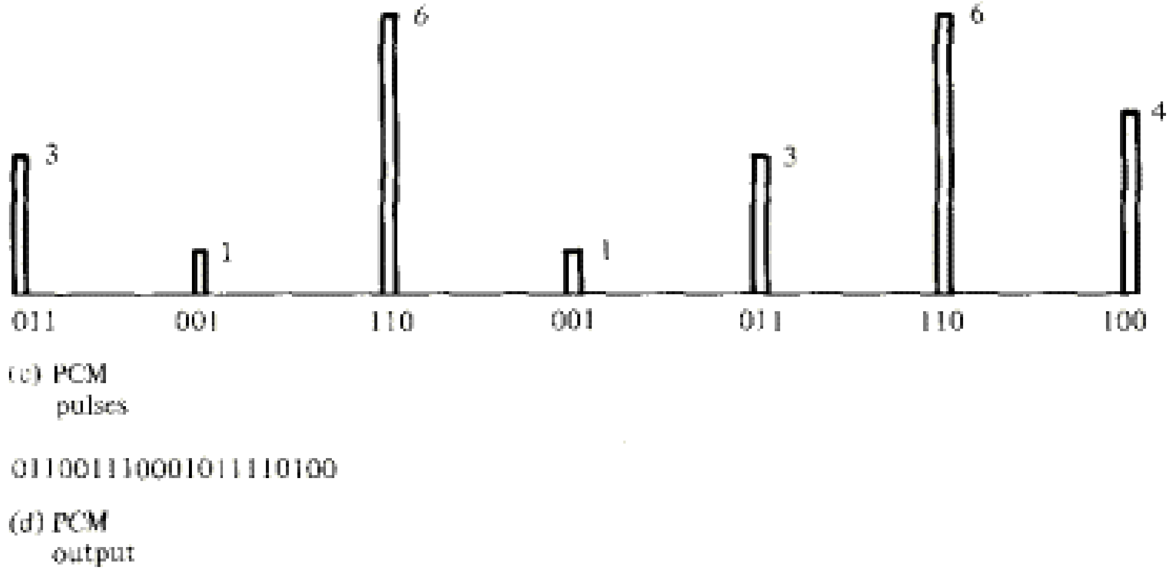


Nyquist Sampling Theorem

- Sampling Rate: frequency at which snapshots are taken
- Low sampling rate → inaccurate signal reproduction
- Too high sampling rate→energy waste
- Nyquist theorem: sampling rate must be at least twice the highest frequency of the original analog waveform

PCM: Pulse Code Modulation

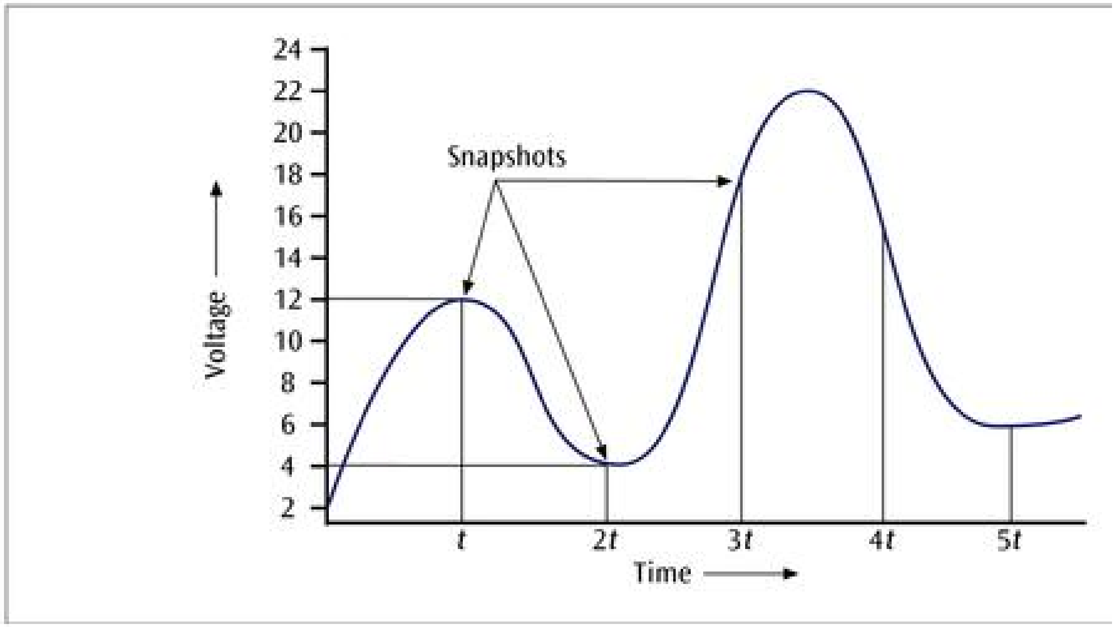
- Digitize PAM signals in *n* bits
  - Approximation involved



Pulse Code Modulation

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

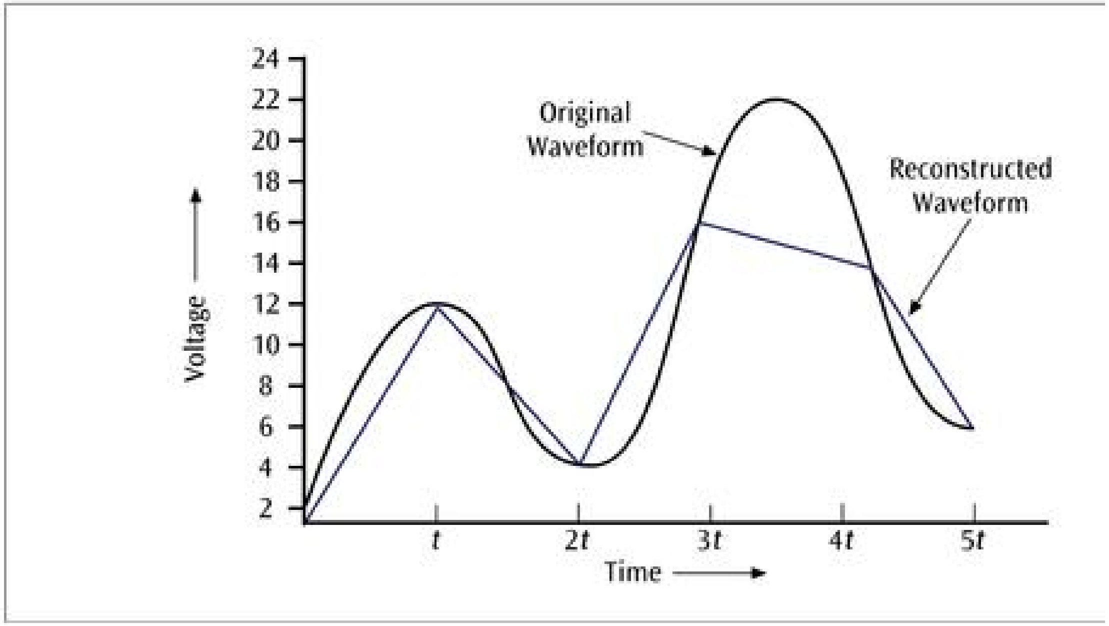
Figure 2-20
Example of taking “snapshots” of an analog waveform for conversion to a digital signal



Pulse Code Modulation

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

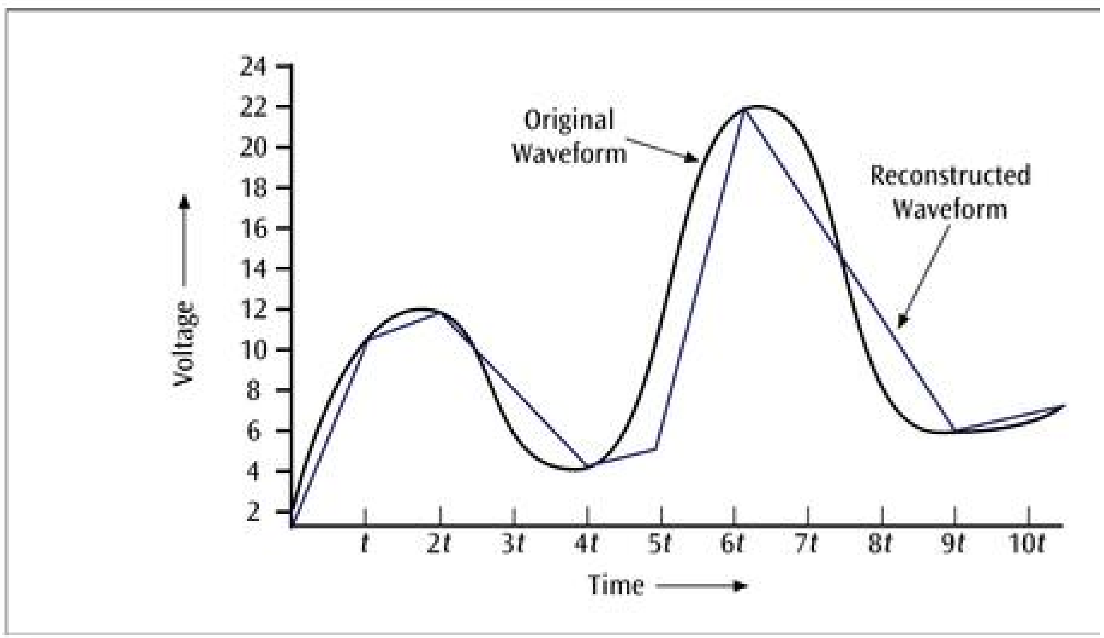
Figure 2-21
Reconstruction of the analog waveform from the digital "snapshots"



Pulse Code Modulation

- The more snapshots taken in the same amount of time, the better the resolution. Test test

Figure 2-22
A more accurate reconstruction of the original waveform using a higher sampling rate



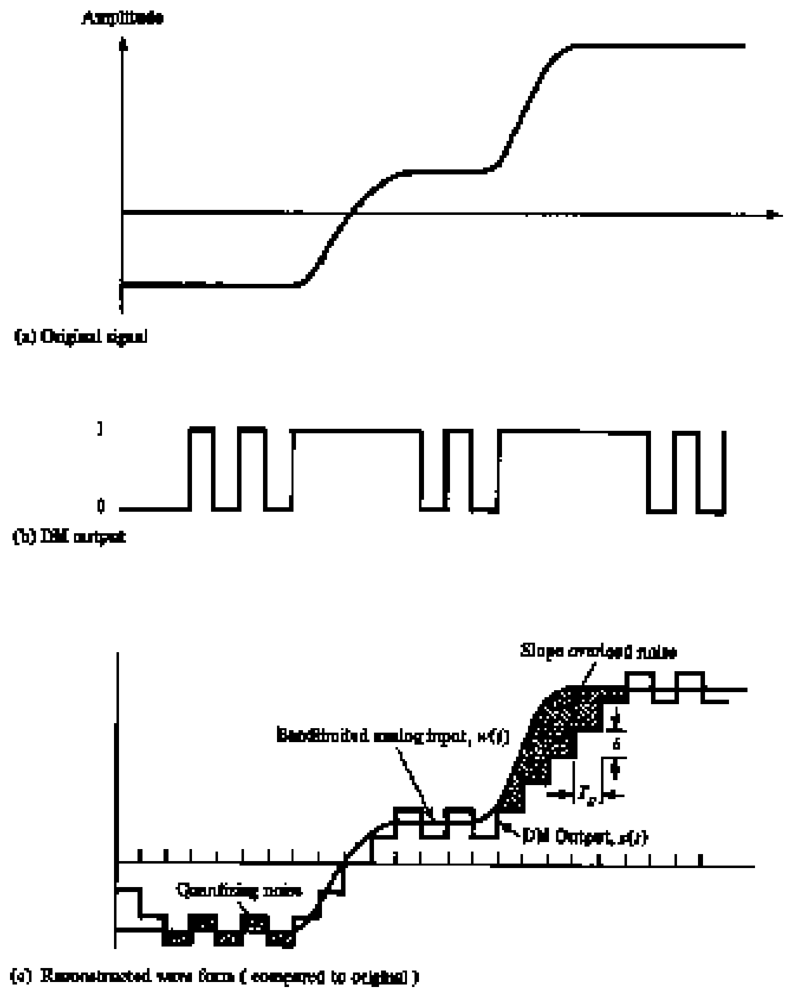
Pulse Code Modulation

- Since telephone systems digitize human voice, and since the human voice has a fairly narrow bandwidth, telephone systems can digitize voice into either 128 levels or 256 levels.
- These levels 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 ($2^8 = 256$).

Delta Modulation: DM

- Instead of transmitting the quantized samples, the difference between sample values at time epochs are sent
  - The difference is usually smaller than the absolute value, but is still analog data.
  - Less information (number of bits) needs to be transmitted.
- Quantize the difference, use 1 bit
  - 1: Increase the output signal by $+\delta$
  - 0: Decrease the output by $-\delta$.

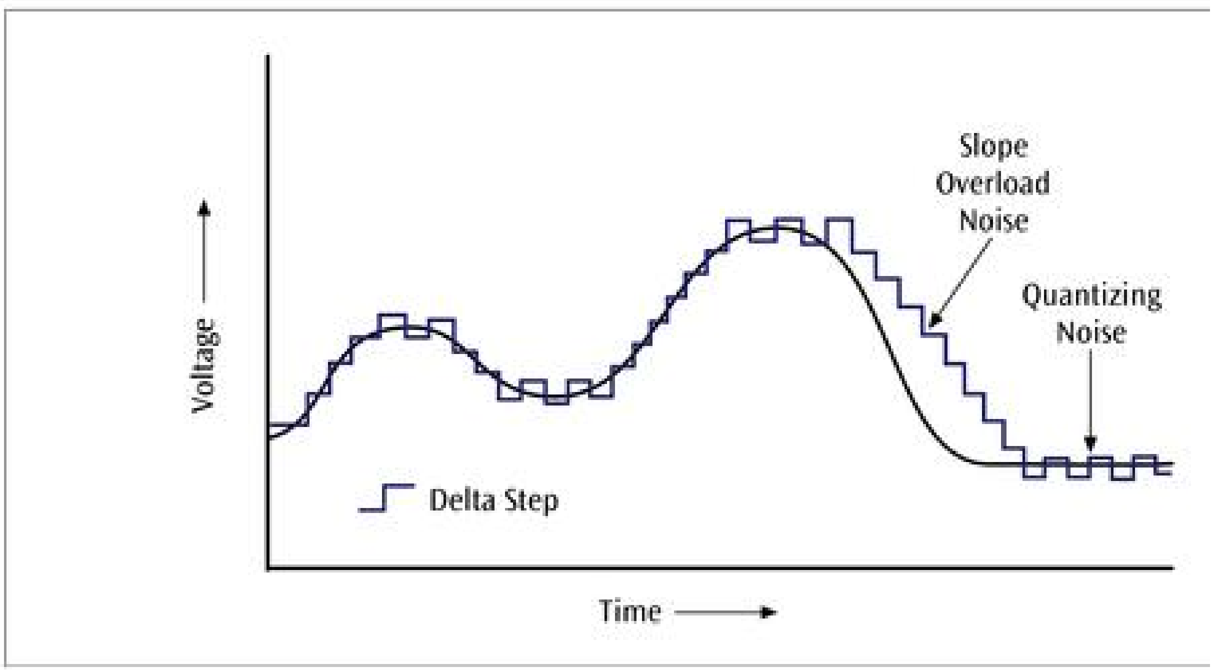
Delta Modulation



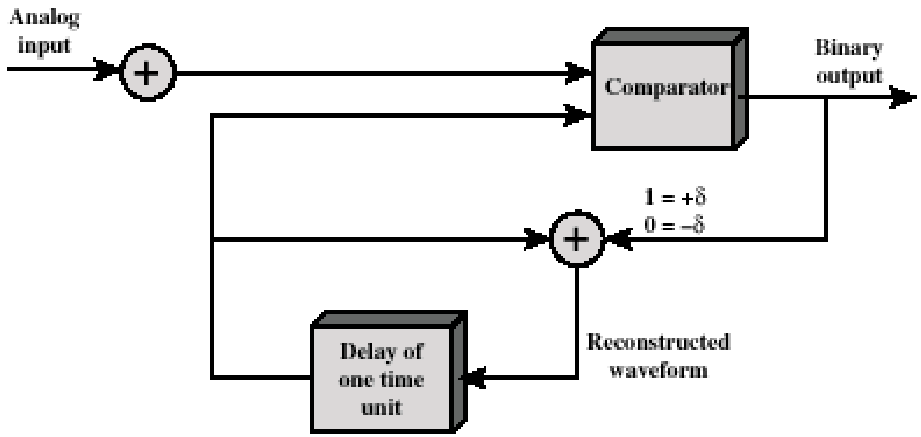
Delta Modulation

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

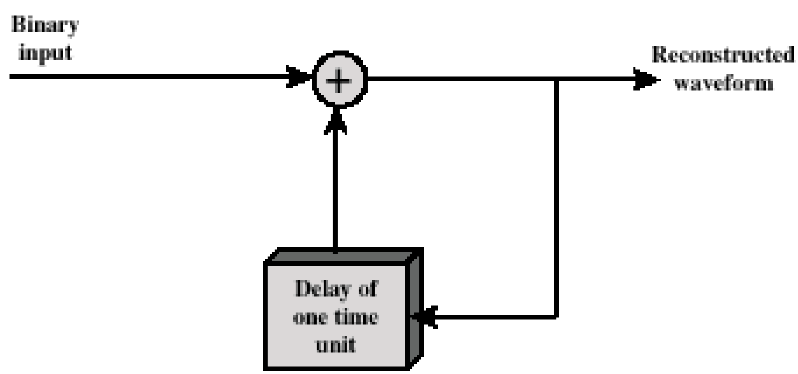
Figure 2-25
Example of delta modulation that is experiencing slope overload noise and quantizing noise



Delta Modulation: Process



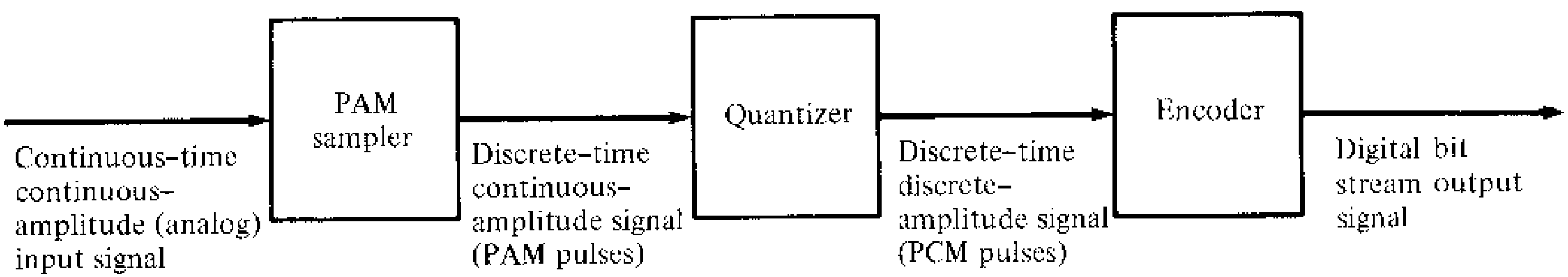
(a) Transmission



(b) Reception

Analogue to Digital Converter

- Conversion of analogue data to digital data
  - PAM: discrete-time continuous amplitude signal
  - Quantizer: Discrete-time, discrete-amplitude
  - Encoder: digital bit stream output

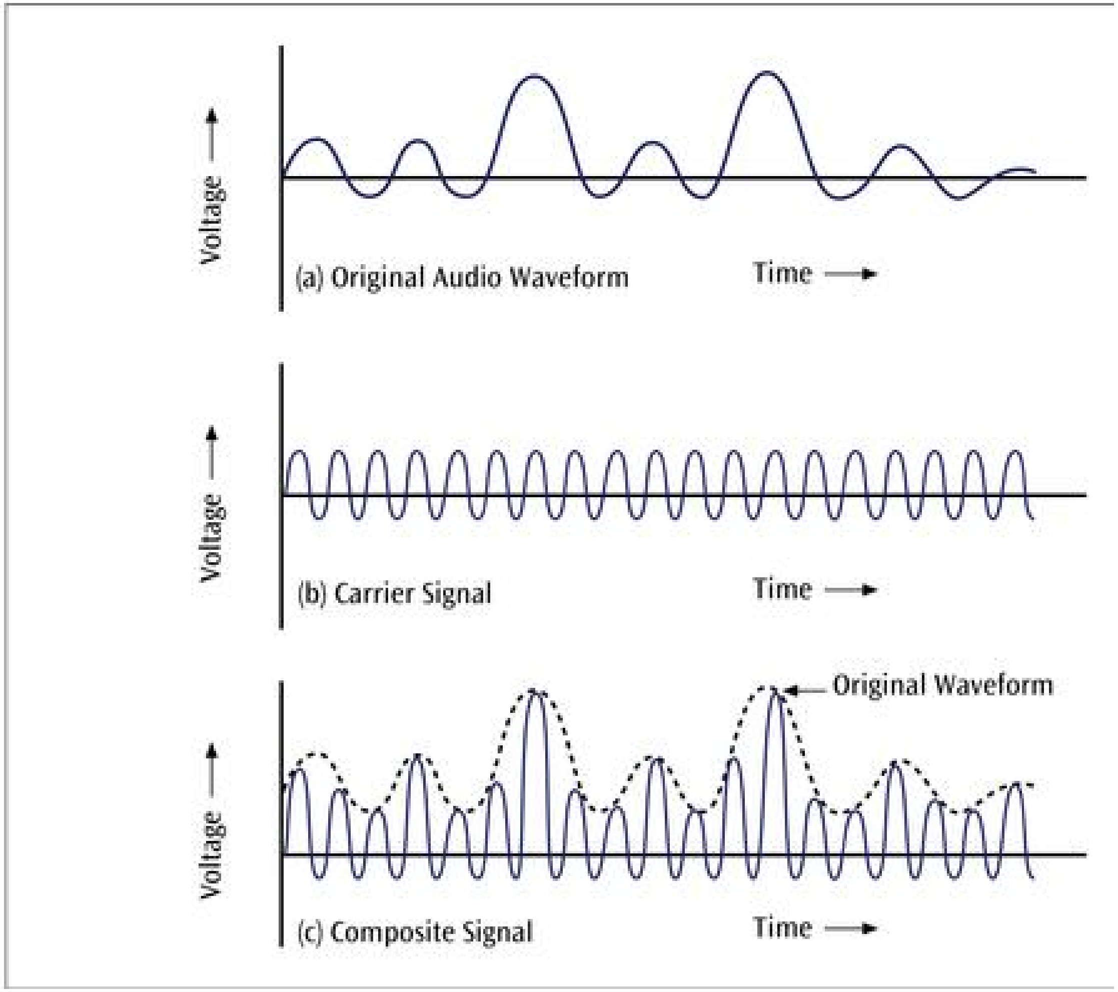


Converting Analog Data into Analog Signals

- Many times it is necessary to modulate analog data onto a different set of analog frequencies.
- Broadcast radio and television are two very common examples of this.
- Types of modulation
  - Amplitude (AM)
  - Phase
  - Frequency (FM)

Amplitude Modulation

Figure 2-26
An audio waveform modulated onto a carrier frequency using amplitude modulation

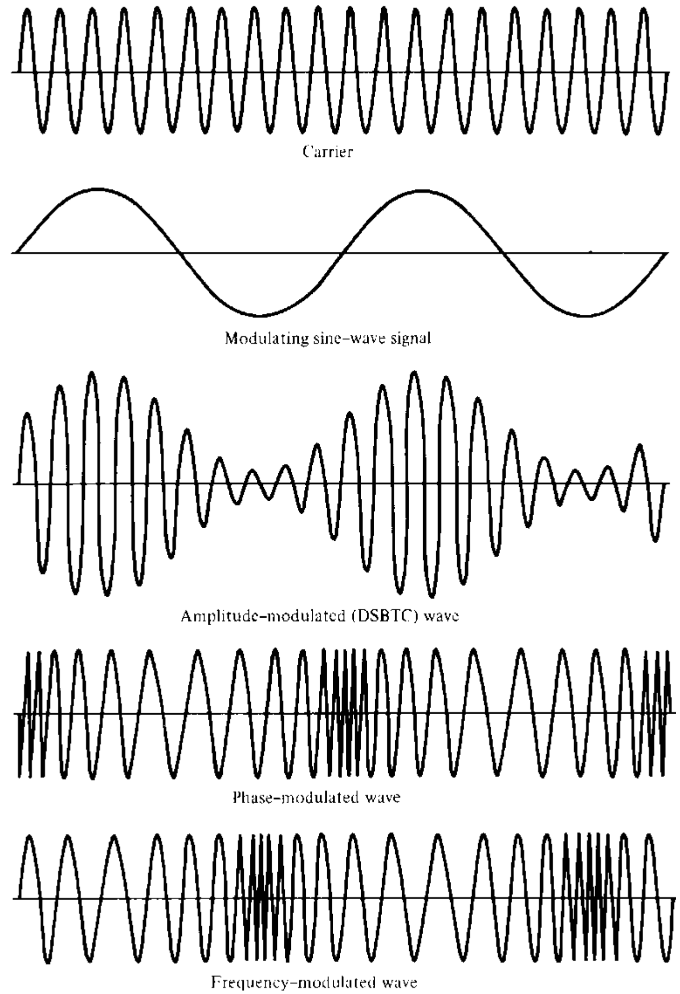


Analog Modulations

Amplitude

Phase

Frequency

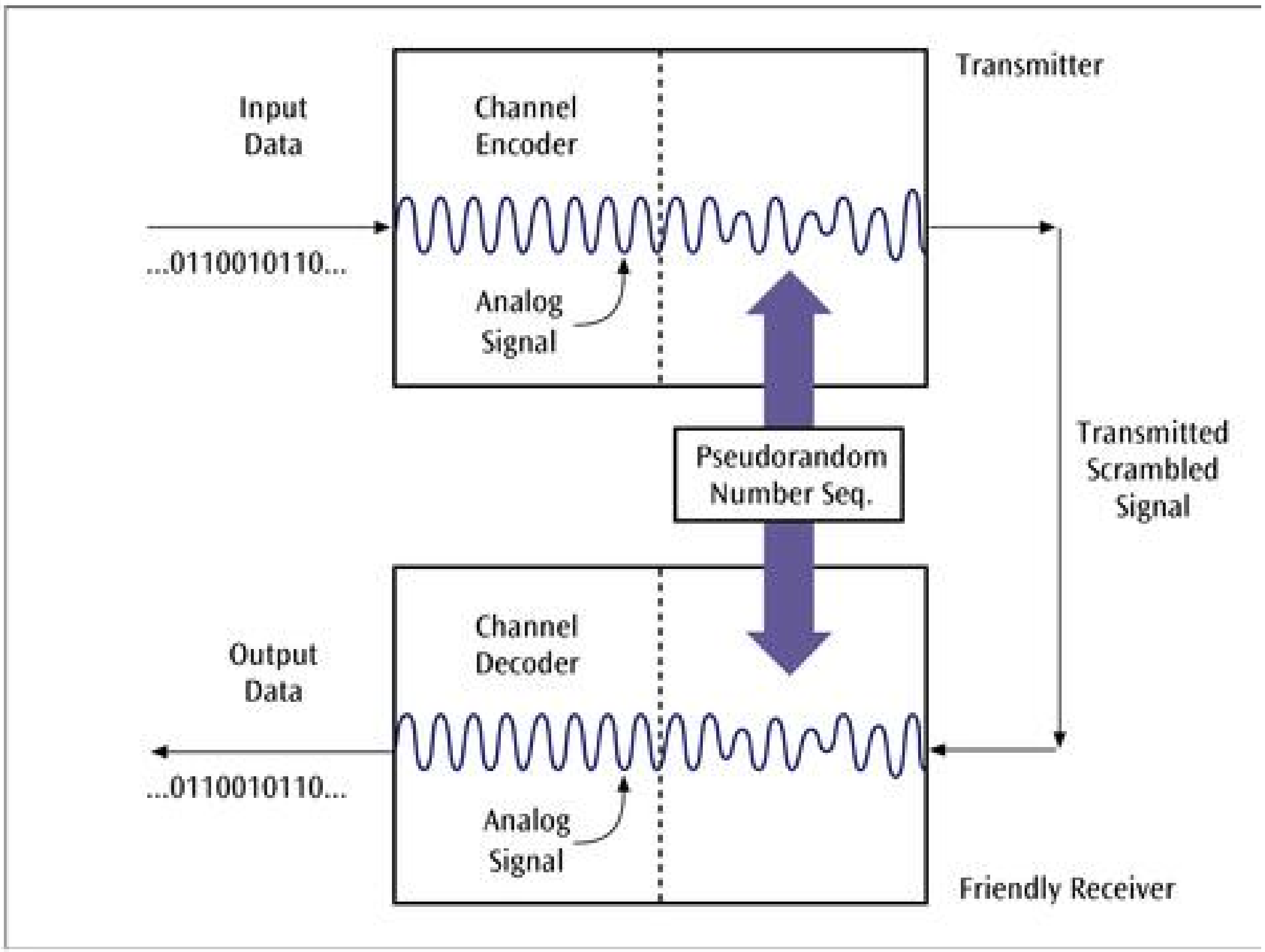


Spread Spectrum Technology

- A secure encoding technique that uses multiple frequencies or codes to transmit data.
- Two basic spread spectrum technologies:
  - Frequency hopping spread spectrum
  - Direct sequence spread spectrum

Frequency Hopping Spread Spectrum

Figure 2-27
Basic operation of a spread spectrum receiver and transmitter system



Direct Sequence Spread Spectrum

- This technology replaces each binary 0 and binary 1 with a unique pattern, or sequence, of 1s and 0s.
- For example, one transmitter may transmit the sequence 10010100 for each binary 1, and 11001010 for each binary 0.
- Another transmitter may transmit the sequence 11110000 for each binary 1, and 10101010 for each binary 0.

Channel Capacity

- Nyquist's Theorem: No noise
  - Data transfer rate of a signal given its frequency and the number of signal levels
  - $C=2\,f\log_2 L$
    - 6200 bps for a 3100Hz signal & 2 level signaling
- Shannon's Theorem: Noise present
  - Maximum capacity of a channel
  - $S(f)=f\log_2(1+W/N)$ bps

Data Code

- The set of all textual characters or symbols and their corresponding binary patterns is called a data code.
- There are two basic data code sets plus a third code set that has interesting characteristics:
  - EBCDIC
  - ASCII
  - Baudot Code

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 Character Set

High-Order Bits (7, 6, 5)

Low-Order Bits (4, 3, 2, 1)	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
0010	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

Baudot Code

- Developed by Emile Baudot
- Uses 5 bits for A-Z & 0-9
- Uses special chars
  - 11111 downshift
  - 11011 upship
- A special control character signals a change in the symbol that follows

	Letters	Figures		Letters	Figures
Binary	Shift	Shift	Binary	Shift	Shift
00000	blank	blank	10000	T	5
00001	E	3	10001	Z	+
00010	LF	LF	10010	L	)
00011	A	-	10011	W	2
00100	space	space	10100	H	reserved
00101	S	'	10101	Y	6
00110	I	8	10110	P	0
00111	U	7	10111	Q	1
01000	CR	CR	11000	O	9
01001	D	WRU	11001	B	?
01010	R	4	11010	G	reserved
01011	J	BELL	11011	FIGURES	FIGURES
01100	N	,	11100	M	.
01101	F	reserved	11101	X	/
01110	C	:	11110	V	=
01111	K	(	11111	LETTERS	LETTERS

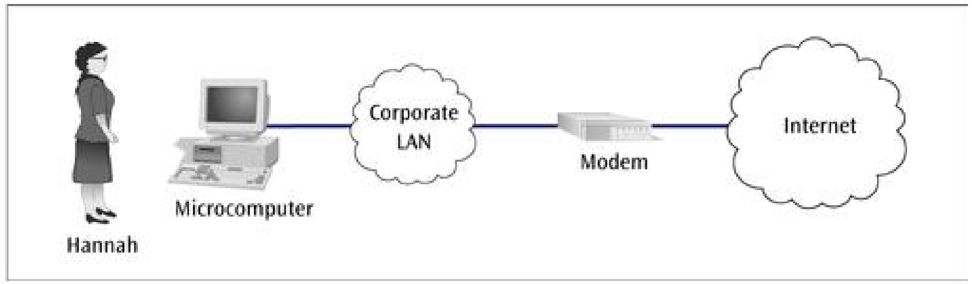
Data and Signal Conversions in Action

- Let us transmit the message “Sam, what time is the meeting with accounting? Hannah.”

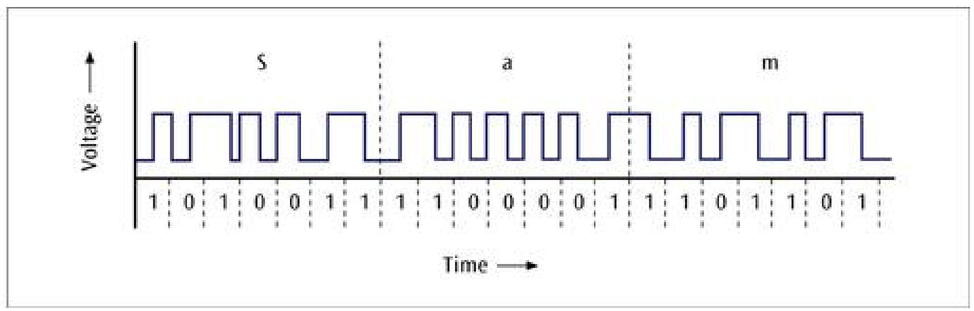
- This message first leaves Hannah’s workstation and travels across a local area network.

Data and Signal Conversions in Action

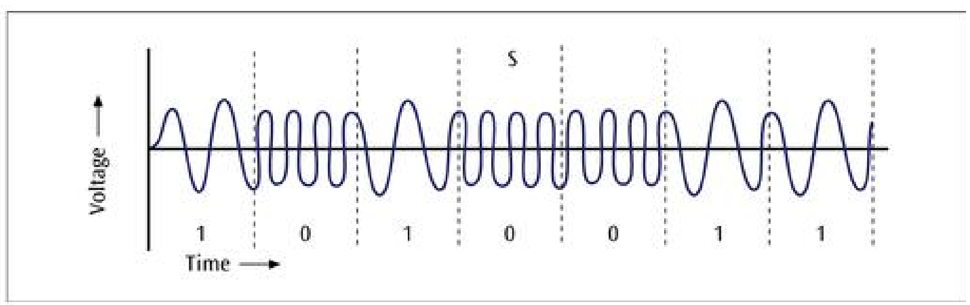
User sending email from a personal computer over a local area network and the Internet, via a modem

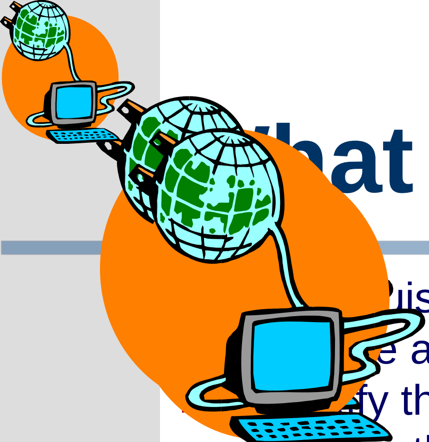


The first three letters of the message "Sam, what time is the meeting with accounting? Hannah," using Differential Manchester encoding



The frequency modulated signal for the letter 'S'





What we learned in this chapter

- uish between data and signals
- e advantages of digital data and signals over analog data and signals
- fy 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
- Outline the basic characteristics of transmitting digital data with digital signals, analog data with digital signals, digital data with analog signals, and analog data with analog signals
- List and draw diagrams of the basic digital encoding techniques, including the advantages and disadvantages of each Identify the different modulation techniques and describe their advantages, disadvantages, and uses
- Identify the different modulation techniques and describe their advantages, disadvantages, and uses
- Identify the two most common digitization techniques and describe their advantages and disadvantages
- Discuss the characteristics and importance of spread spectrum encoding techniques
- Identify the different data codes and how they are used in communication systems