# Data Encoding Techniques

# Digital Data, Analog Signals

[Example – modem]

- Basis for analog signaling is a continuous, constant-frequency signal known as the *carrier signal*.
- Digital data is encoded by modulating one of the three characteristics of the carrier: amplitude, frequency, or phase or some combination of these.

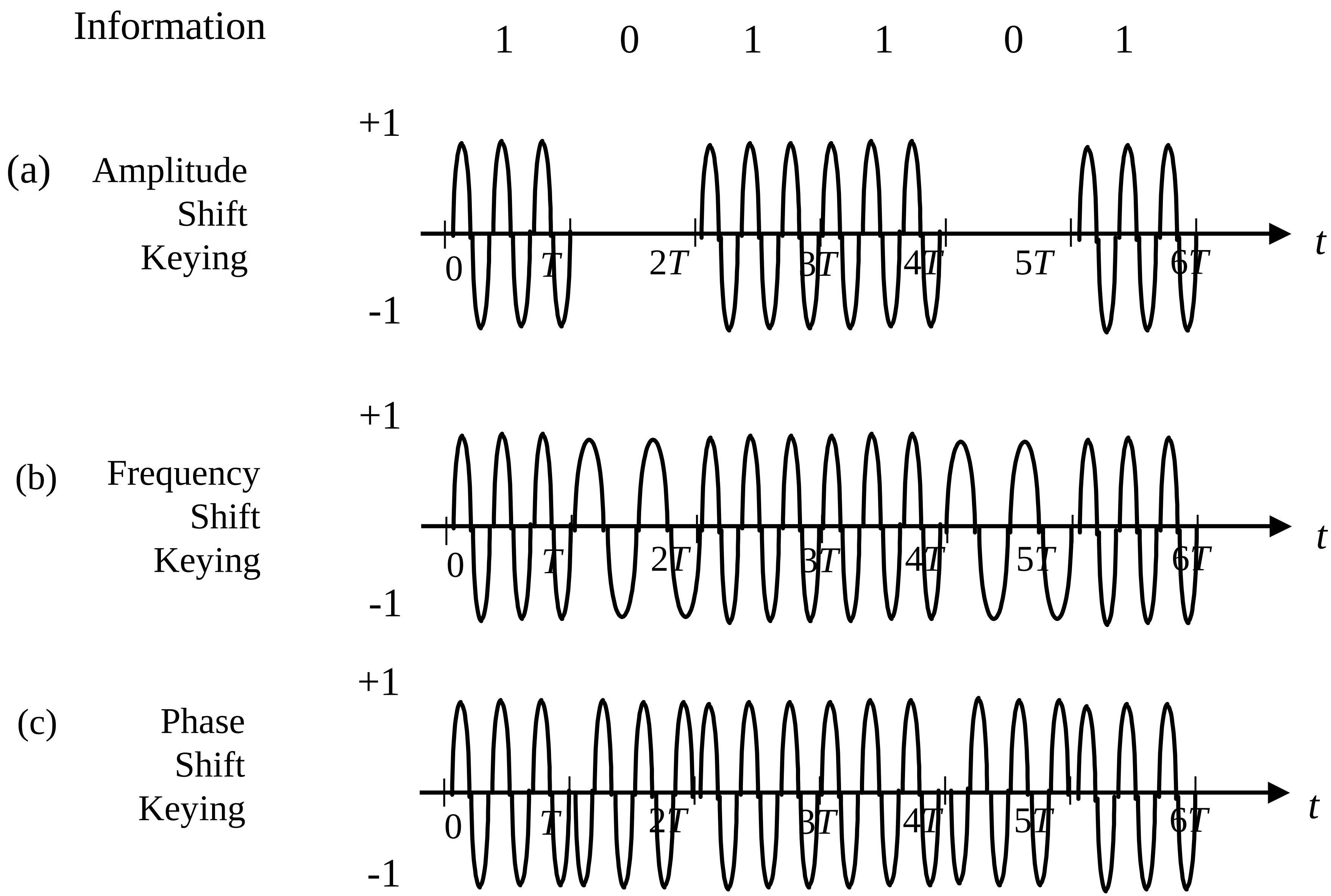




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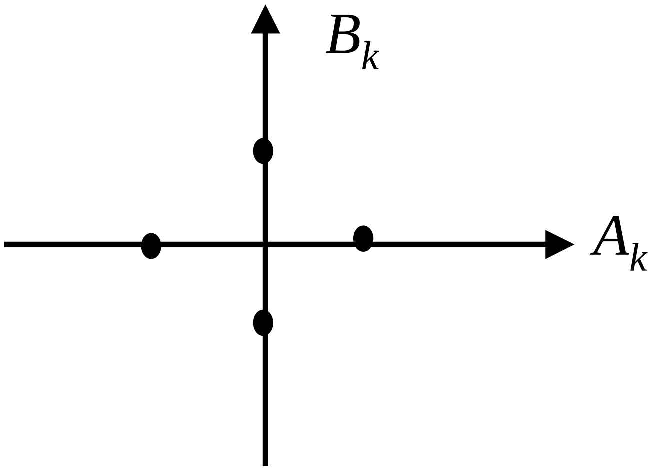
Figure 3.28

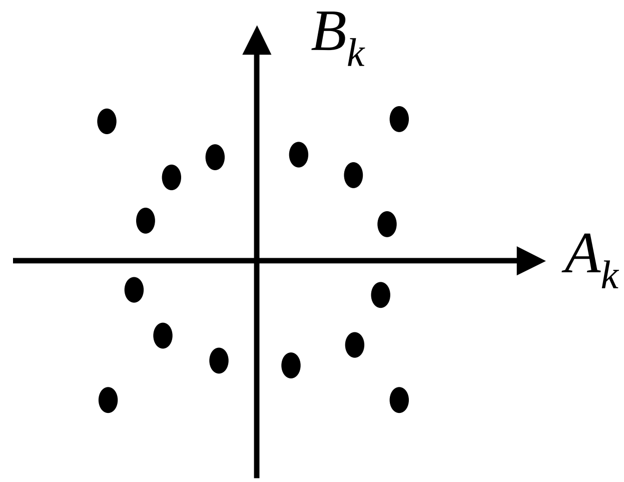
# Modems

- Actually use Quadrature Amplitude Modulation (QAM)
- Use <u>constellation points</u> where point determines a specific amplitude and phase.

# Signal Constellations




4 "levels"/ pulse
2 bits / pulse
2D bits per second




16 "levels"/ pulse
4 bits / pulse
4D bits per second

Note – textbook uses W instead of D in this figure!!



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Figure 3.34

# Digital Data, Digital Signals

[the technique used in a number of LANs]

- Digital signal – is a sequence of discrete, discontinuous voltage pulses.
- Bit duration :: the time it takes for the transmitter to emit the bit.
- Issues
  - Bit timing
  - Recovery from signal
  - Noise immunity

# NRZ ( Non-Return-to-Zero) Codes

- Uses two different voltage levels (one positive and one negative) as the signal elements for the two binary digits.

**NRZ-L ( Non-Return-to-Zero-Level)**

The voltage is constant during the bit interval.

| | | |
|---|---|---|
| 1 | ⇔ | negative voltage |
| 0 | ⇔ | positive voltage |

*Used for short distances between terminal and modem or terminal and computer.*

# NRZ ( Non-Return-to-Zero) Codes

## NRZ-I ( Non-Return-to-Zero-Invert on ones)

The voltage is constant during the bit interval.

1 ⇔ existence of a ***signal transition*** at the beginning of the bit time
(either a low-to-high or a high-to-low transition)

0 ⇔ **no *signal transition*** at the beginning of the bit time

**NRZI** is a *differential encoding* (i.e., the signal is decoded by comparing the polarity of adjacent signal elements.

# Bi –Phase Codes

- Bi- phase codes – require at least one transition per bit time and may have as many as two transitions.
- ➔ the maximum modulation rate is twice that of NRZ ➔ greater transmission bandwidth is required.

Advantages:

Synchronization – with a predictable transition per bit time the receiver can “synch on the transition [self-clocking]

No d.c. component

Error detection – the absence of an expected transition can used to detect errors.

# Manchester encoding

- There is **always** a mid-bit transition {which is used as a clocking mechanism}.
- The **direction** of the mid-bit transition represents the digital data.

1 ⇔ **low-to-high** transition

0 ⇔ **high-to-low** transition

**textbook is wrong here!!**

Consequently, there may be a second transition at the beginning of the bit interval.

Used in 802.3 baseband coaxial cable and CSMA/CD twisted pair.

# Differential Manchester encoding

- mid-bit transition is **ONLY** for clocking.

1 ⇔ **absence** of transition at the beginning of the bit interval

0 ⇔ **presence** of transition at the beginning of the bit interval

Differential Manchester is both differential and bi-phase.

Note – the coding is the opposite convention from NRZI.

Used in 802.5 (token ring) with twisted pair.

* Modulation rate for Manchester and Differential Manchester is twice the data rate ➔ inefficient encoding for long-distance applications.

# Bi-Polar Encoding

1 ⇔ **alternating** +1/2 , -1/2 voltage

0 ⇔ **0** voltage

- Has the same issues as NRZI for a long string of 0's.
- A systemic problem with polar is the polarity can be backwards.

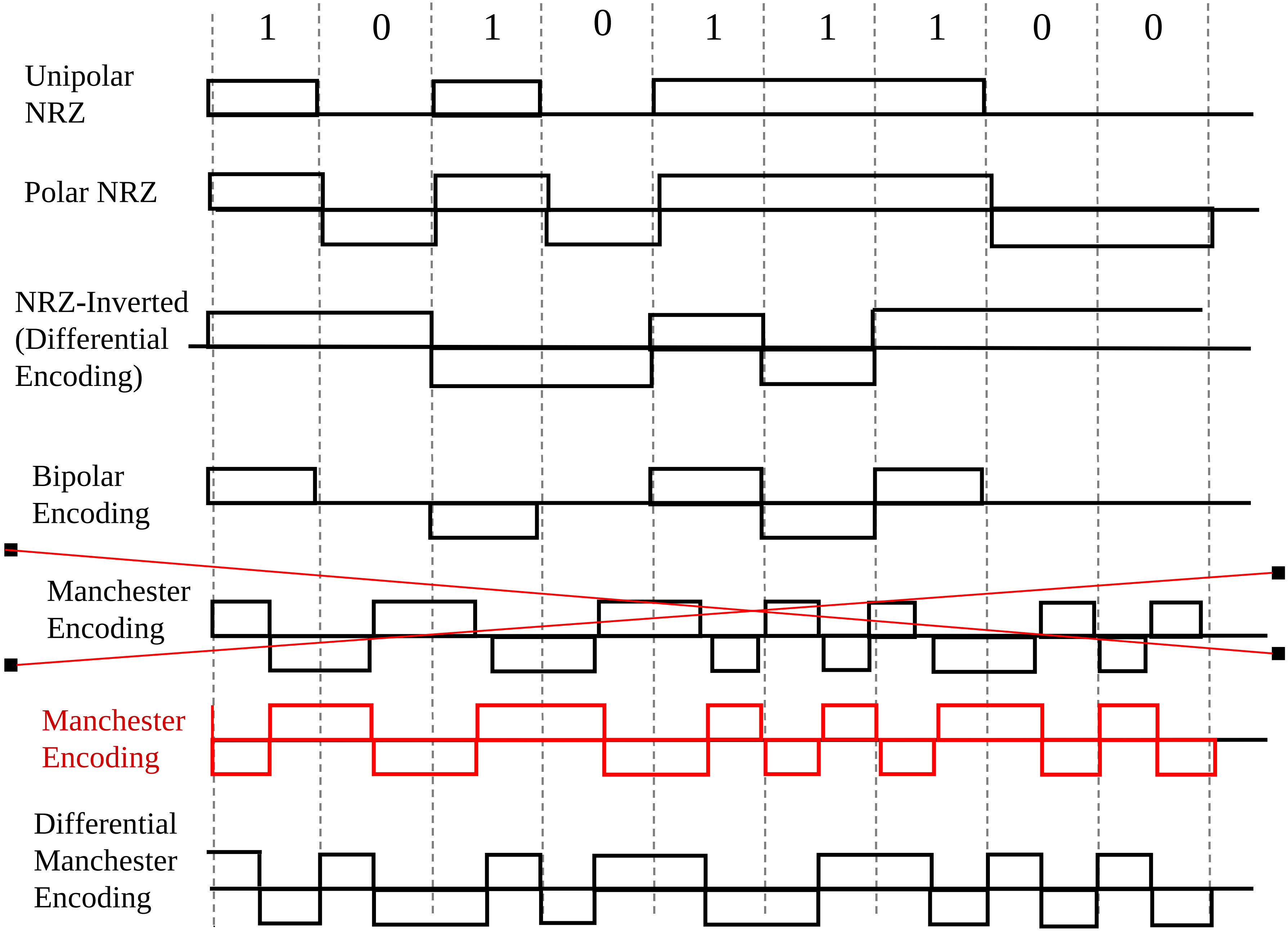

1 0 1 0 1 1 1 0 0
Unipolar NRZ
Polar NRZ
NRZ-Inverted (Differential Encoding)
Bipolar Encoding
Manchester Encoding
Manchester Encoding
Differential Manchester Encoding





Figure 3.25

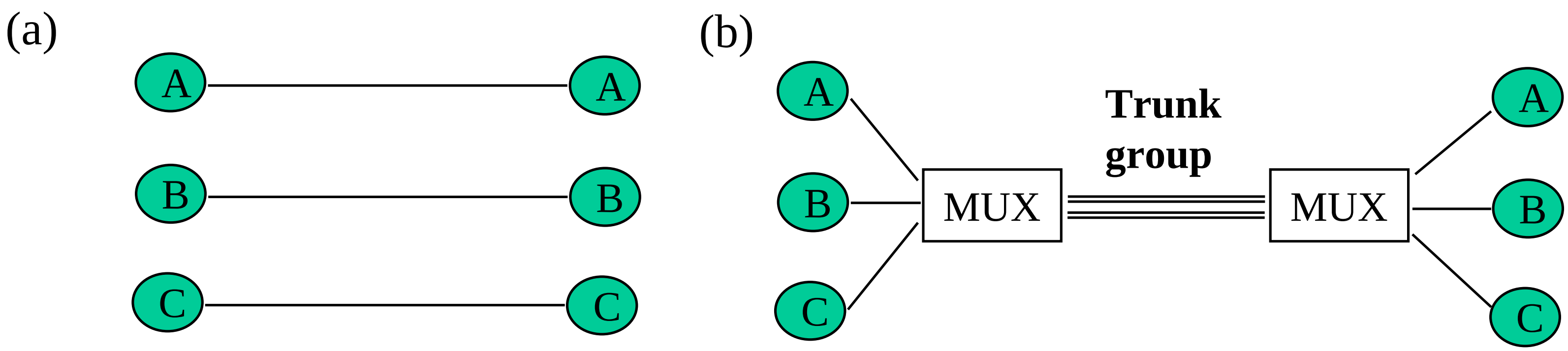
# Analog Data, Digital Signals

## [Example – PCM (Pulse Code Modulation)]

- The most common technique for using digital signals to encode analog data is PCM.

Example: To transfer analog voice signals off a local loop to digital end office within the phone system, one uses a codec.

Because voice data limited to frequencies below 4kHZ, a codec makes 8000 samples/sec. (i.e., 125 microsec/sample).




# Multiplexing


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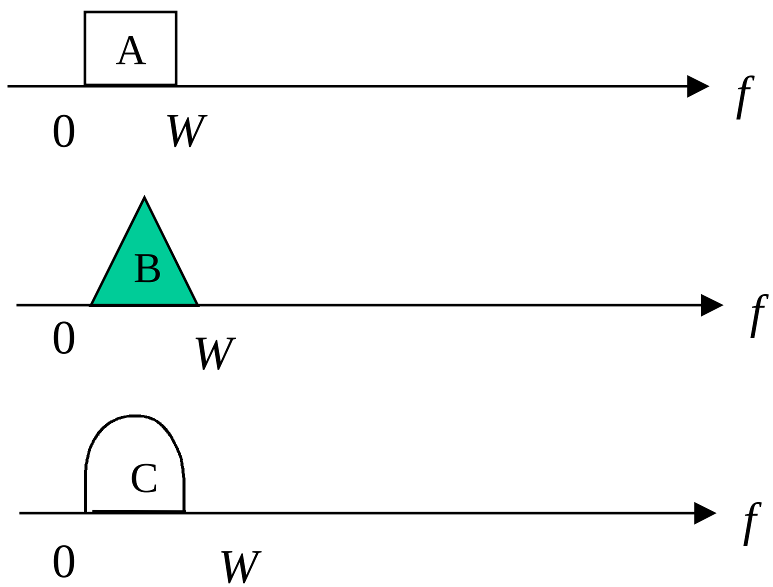
Figure 4.1

# Frequency-division Multiplexing

(a) Individual signals occupy *W* Hz




(b) Combined signal fits into channel bandwidth

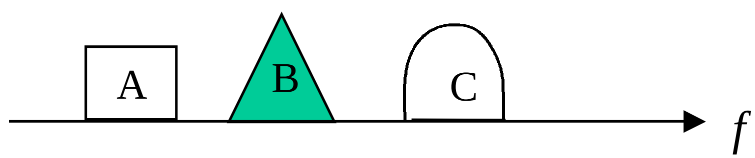





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Figure 4.2

# Frequency-division Multiplexing

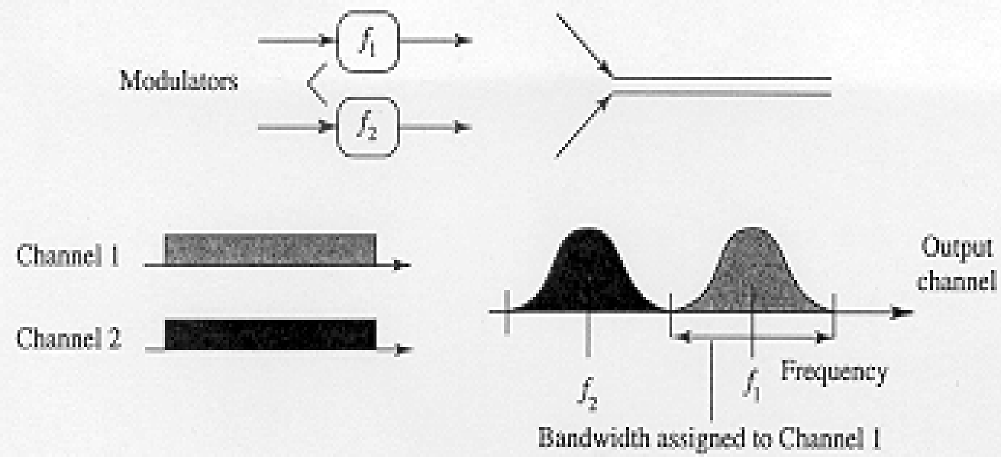
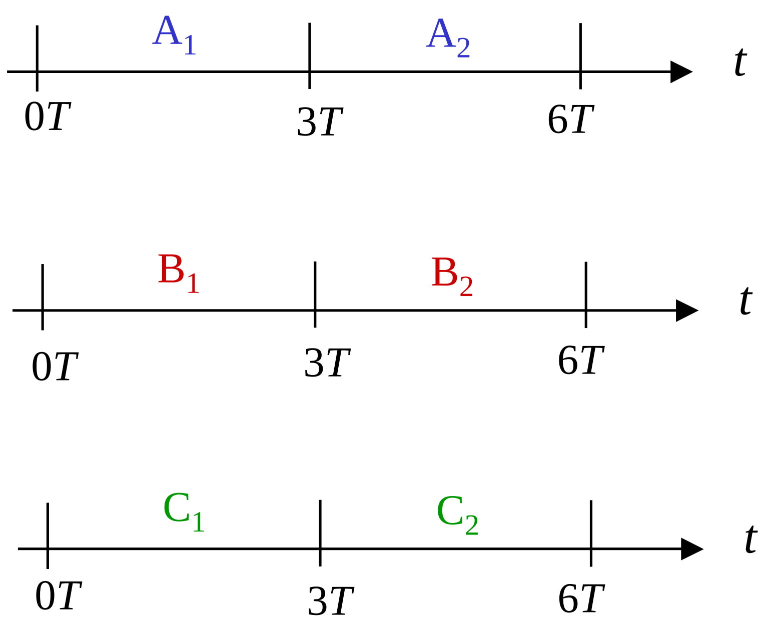



FIGURE 2.12

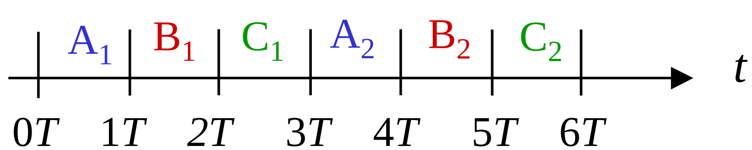
In frequency-division multiplexing, the frequency band is divided into distinct fixed bands, one for each incoming channel. The signal in each incoming channel is modulated to fit into its assigned band.

# Time-division Multiplexing

(a) Each signal transmits 1 unit every 3*T* seconds




(b) Combined signal transmits 1 unit every *T* seconds

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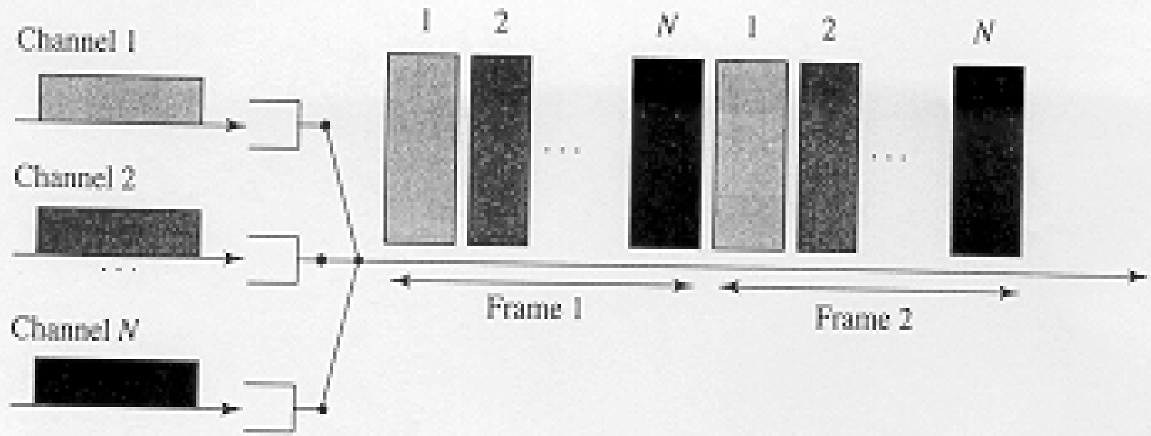
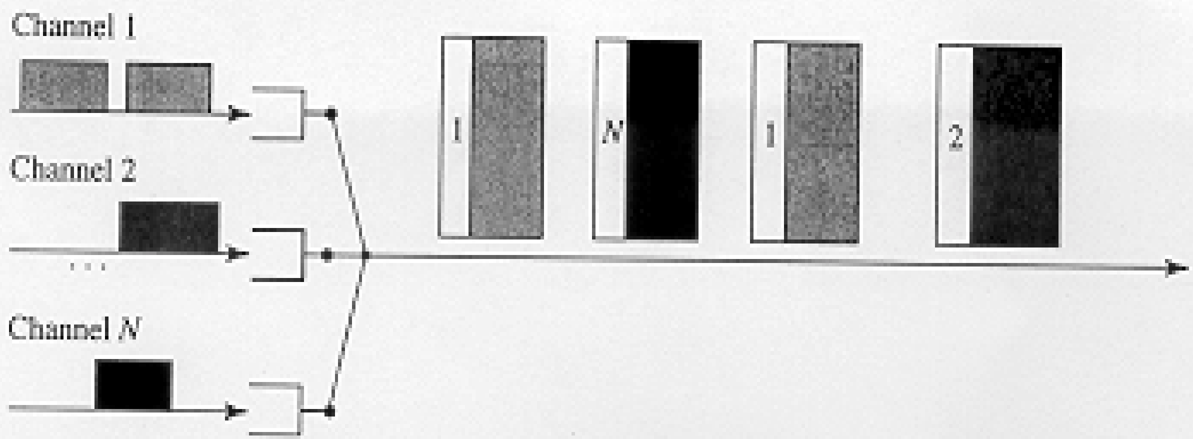
# Time-division Multiplexing




2.9
FIGURE

When a communication link is shared by time-division multiplexing, time is divided into frames. Each frame is divided into time slots that are allocated in a fixed order to the different incoming channels.

# Statistical Multiplexing [Concentrator]




2.10 FIGURE

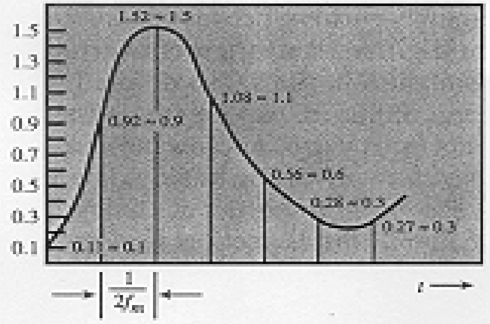
In statistical multiplexing, the multiplexer visits the incoming channel buffers in some order. The multiplexer empties a buffer before moving to the next one. The buffer contents are tagged to indicate their incoming channel. An idle channel does not waste transmission time.

# Pulse Code Modulation (PCM)

- Analog signal is sampled.
- Converted to discrete-time continuous-amplitude signal (Pulse Amplitude Modulation)
- Pulses are *quantized* and assigned a digital value.
  - A 7-bit sample allows 128 quantizing levels.

# Pulse Code Modulation (PCM)

- PCM uses non-linear encoding, i.e., amplitude spacing of levels is non-linear
  - There is a greater number of quantizing steps for low amplitude
  - This reduces overall signal distortion.
- This introduces *quantizing error (or noise)*.
- PCM pulses are then encoded into a digital bit stream.
- 8000 samples/sec x 7 bits/sample = 56Kbps for a single voice channel.




(a)

| Digit | Binary equivalent | PCM waveform |
|---|---|---|
| 0 | 0000 | |
| 1 | 0001 | |
| 2 | 0010 | |
| 3 | 0011 | |
| 4 | 0100 | |
| 5 | 0101 | |
| 6 | 0110 | |
| 7 | 0111 | |
| 8 | 1000 | |
| 9 | 1001 | |
| 10 | 1010 | |
| 11 | 1011 | |
| 12 | 1100 | |
| 13 | 1101 | |
| 14 | 1110 | |
| 15 | 1111 | |

(b)

**Figure 5.10** Pulse Code Modulation

# PCM
# Nonlinear Quantization Levels

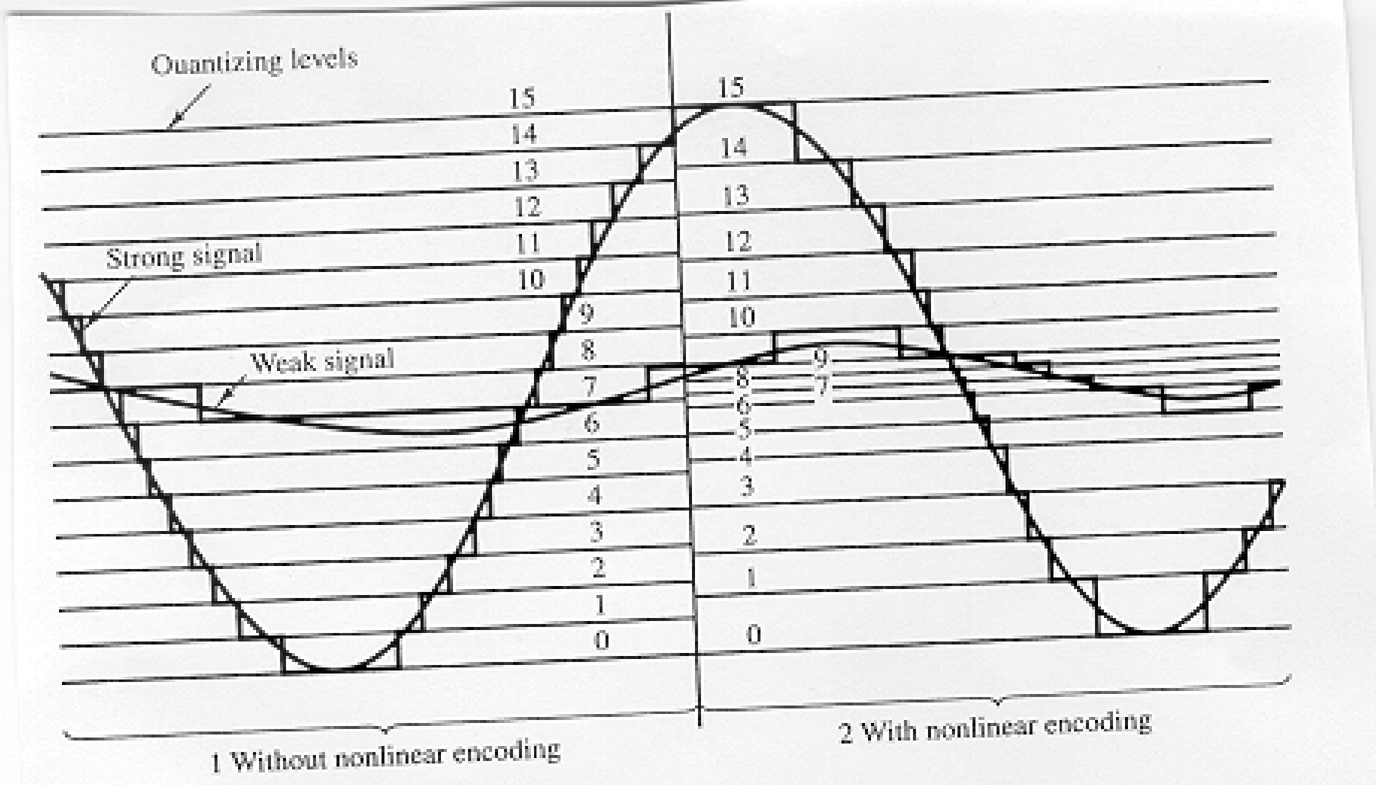
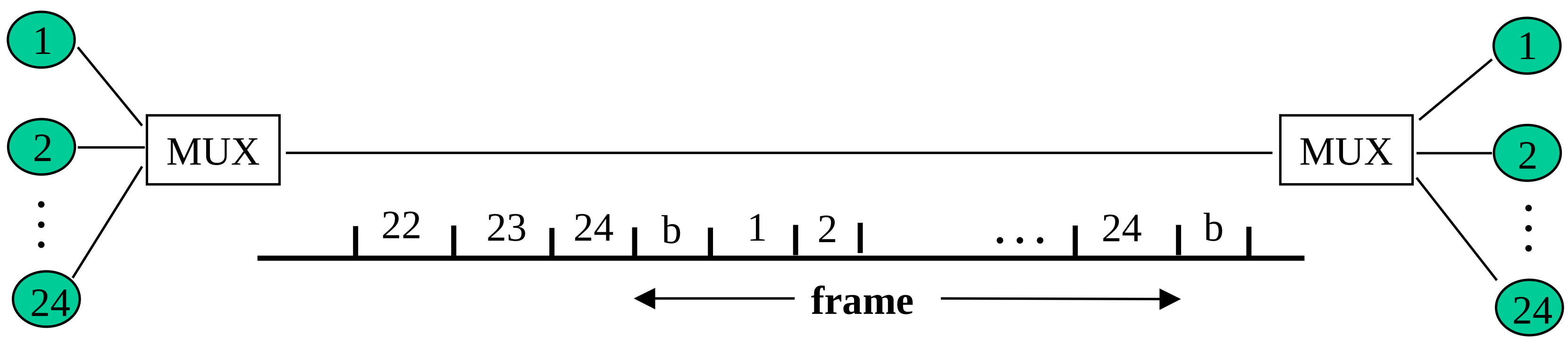


Figure 5.11 Effect of Nonlinear Coding




T1 system




Figure 4.4

# T1 Carrier

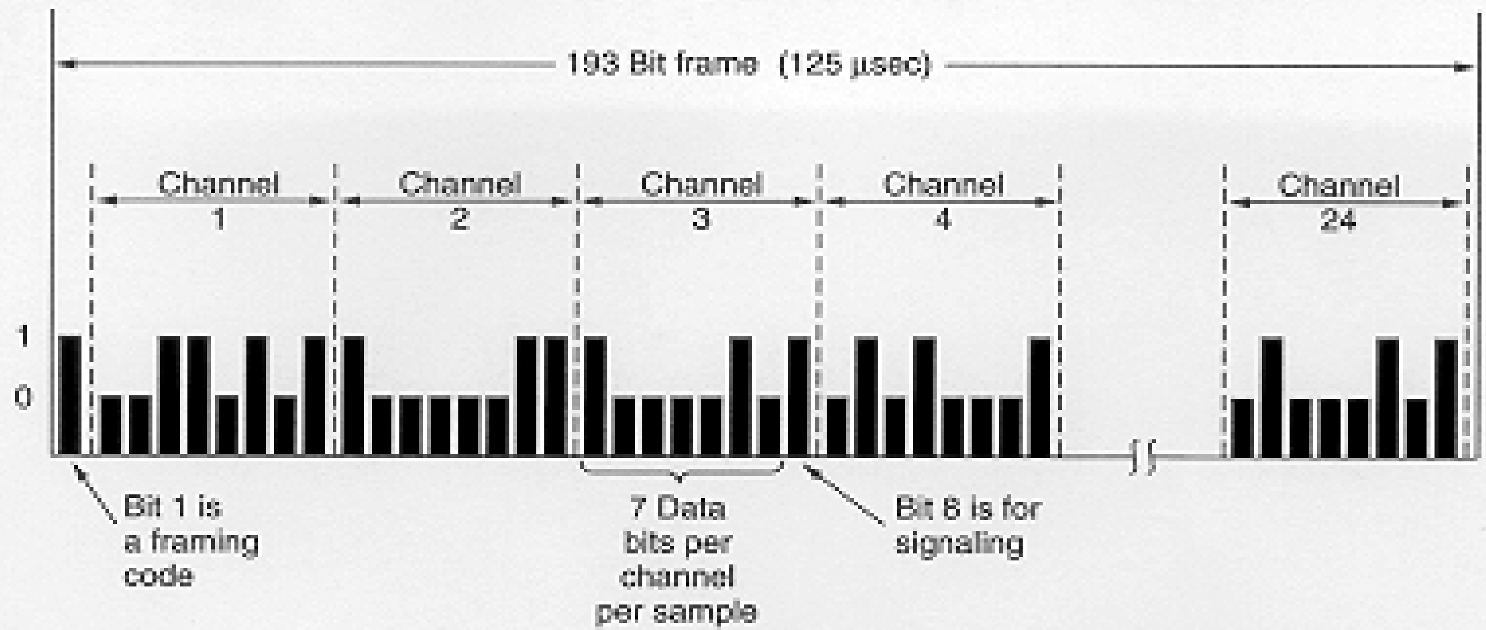



Fig. 2-26. The T1 carrier (1.544 Mbps).

# Delta Modulation (DM)

- The basic idea in *delta modulation* is to approximate the derivative of analog signal rather than its amplitude.
- The analog data is approximated by a staircase function that moves up or down by one quantization level at each sampling time. ➔ output of DM is a single bit.
- PCM preferred because of better SNR characteristics.

# Delta Modulation - example