Physical Layer (Part 2) Data Encoding Techniques

Advanced Computer Networks

Data Encoding Techniques

- Digital Data, Analog Signals [modem]
- Digital Data, Digital Signals [wired LAN]
- Analog Data, Digital Signals [codec]
  - Frequency Division Multiplexing (FDM)
  - Wave Division Multiplexing (WDM) [fiber]
  - Time Division Multiplexing (TDM)
  - Pulse Code Modulation (PCM) [T1]
  - Delta Modulation

Analog and Digital Transmissions

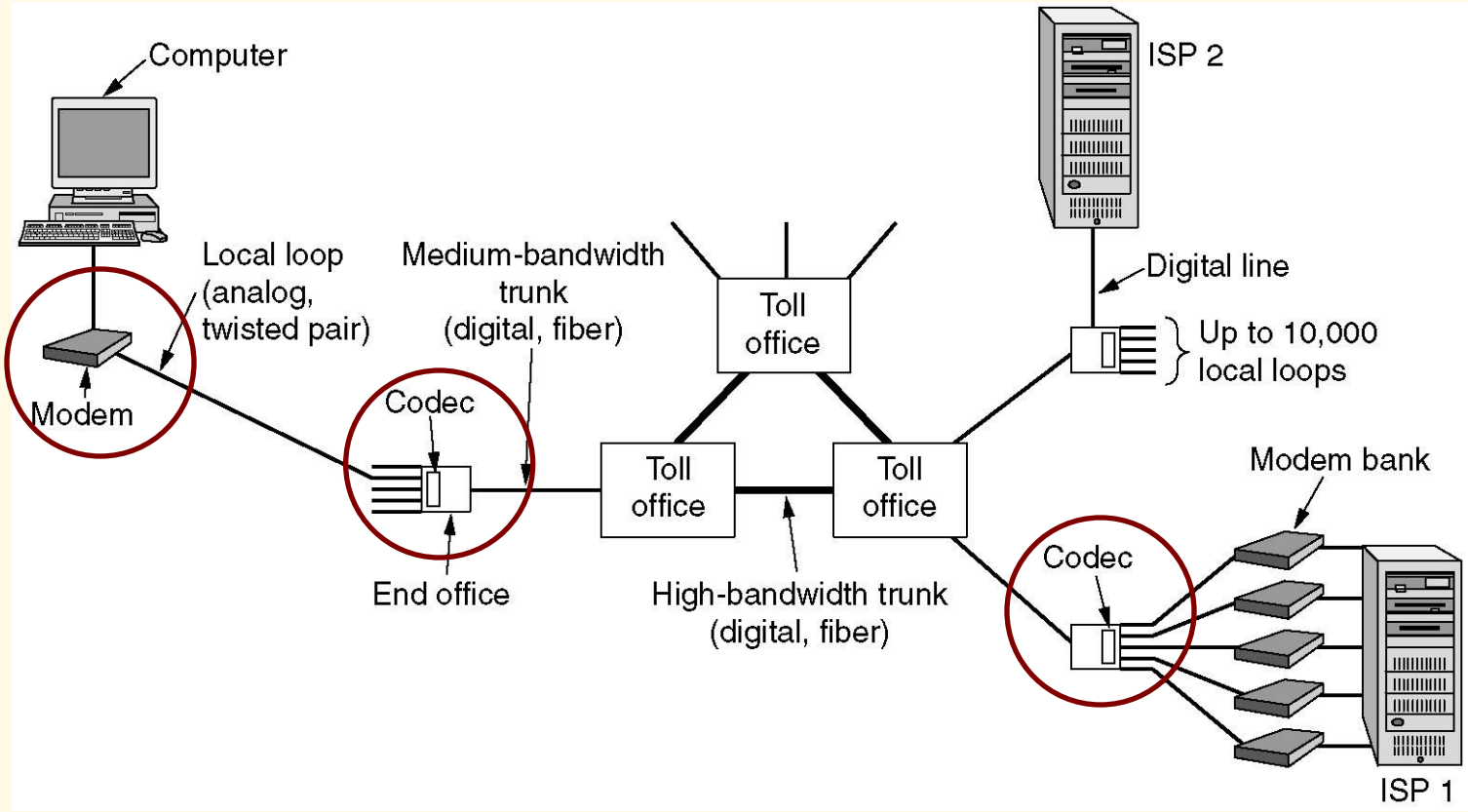


Figure 2-23. The use of both analog and digital transmissions for a computer-to-computer call. Conversion is done by the modems and codecs.

Tanenbaum

Digital Data, Analog Signals

[Example – modem]

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

Signal Modulation

A binary signal

Amplitude modulation

Frequency modulation

Phase modulation

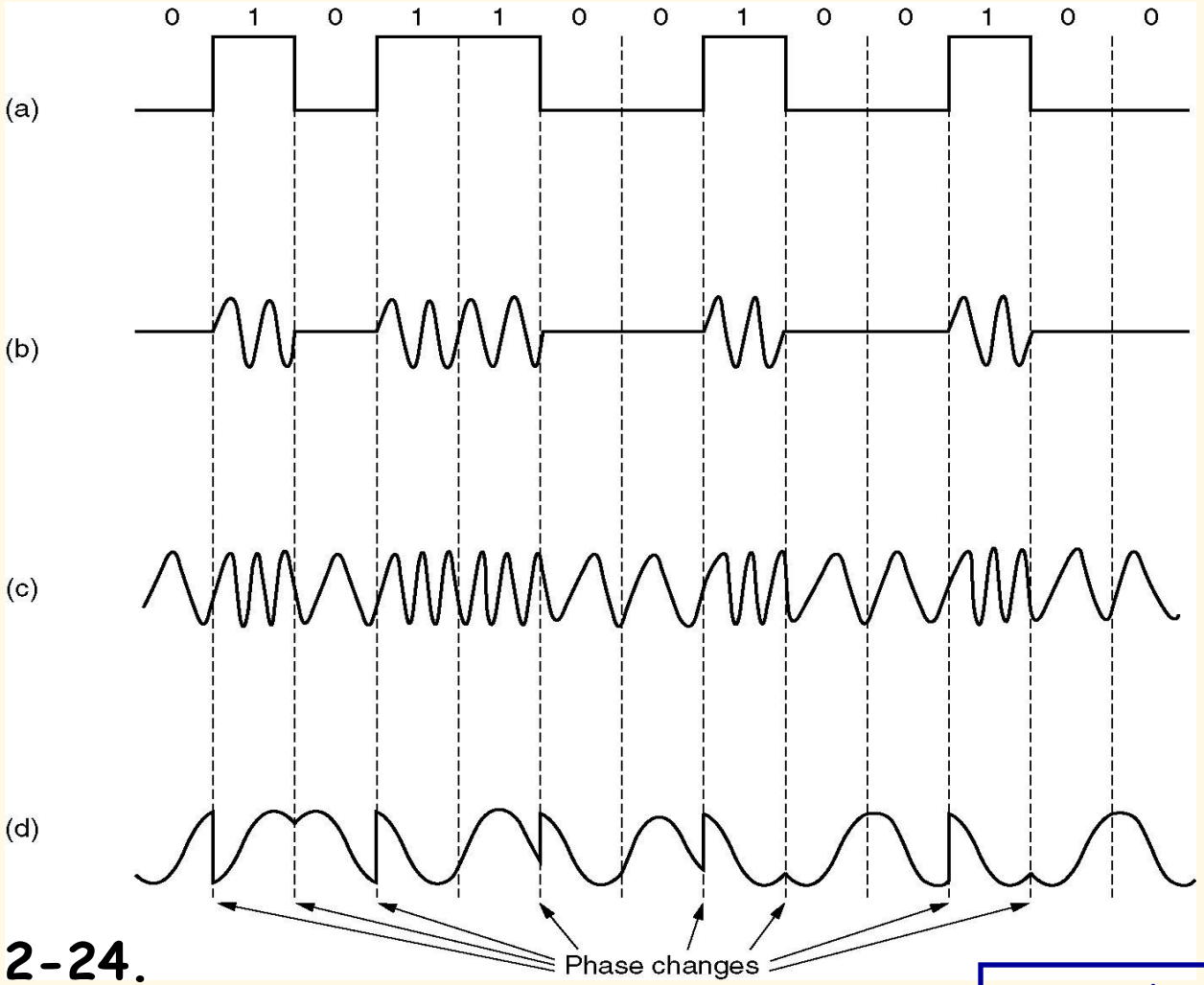


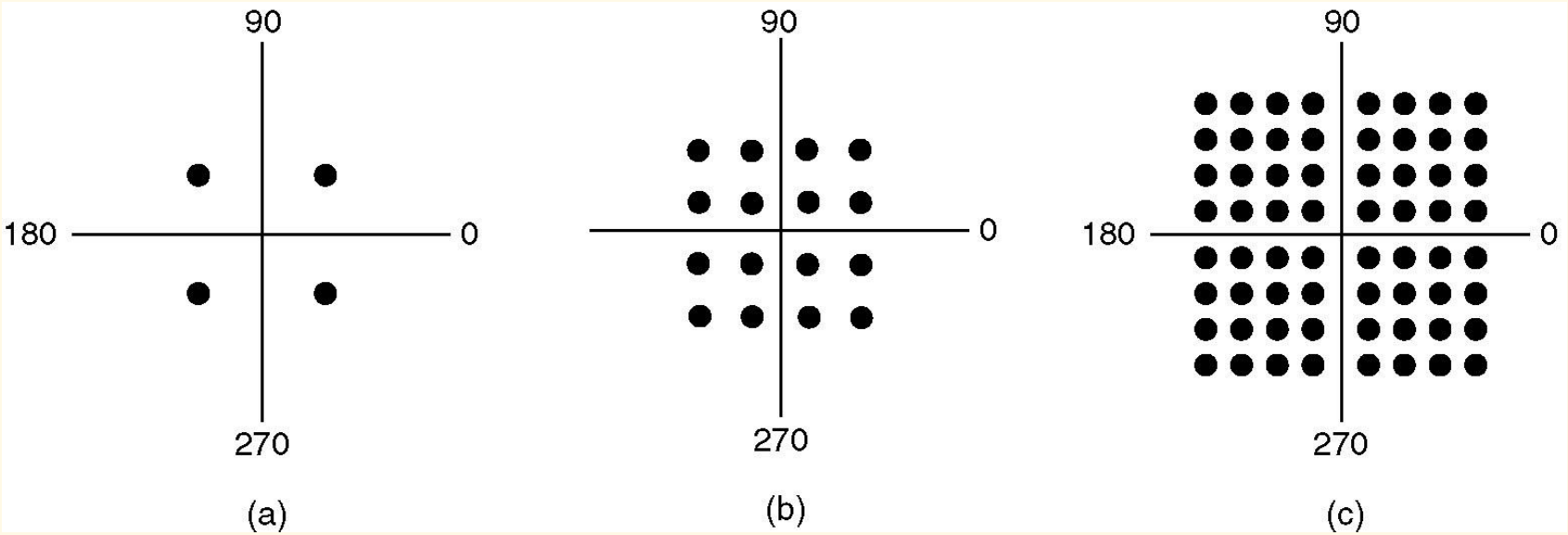
Figure 2-24.

Tanenbaum

Modems

- All advanced modems use a *combination of modulation techniques* to transmit multiple bits per baud.
- Multiple amplitude and multiple phase shifts are combined to transmit several bits per symbol.
- QPSK (Quadrature Phase Shift Keying) uses multiple phase shifts per symbol.
- Modems actually use Quadrature Amplitude Modulation (QAM).
- These concepts are explained using constellation points where a point determines a specific amplitude and phase.

Constellation Diagrams



(a) QPSK. (b) QAM-16. (c) QAM-64.

Figure 2-25.

$V = 64$

$v = \log_2 V = 6$

Tanenbaum

Digital Data, Digital Signals

[the technique is 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 (sender/receiver clock drift)
  - 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

NRZ-L *is used for short distances between a terminal and modem or terminal and computer.*

NRZ (Non-Return-to-Zero) Codes

NRZ-I (**N**on-**R**eturn-to-**Z**ero-**I**nvert 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 *scheme* (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 be 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

Some textbooks disagree on this definition!!

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 convention for Differential Manchester 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.

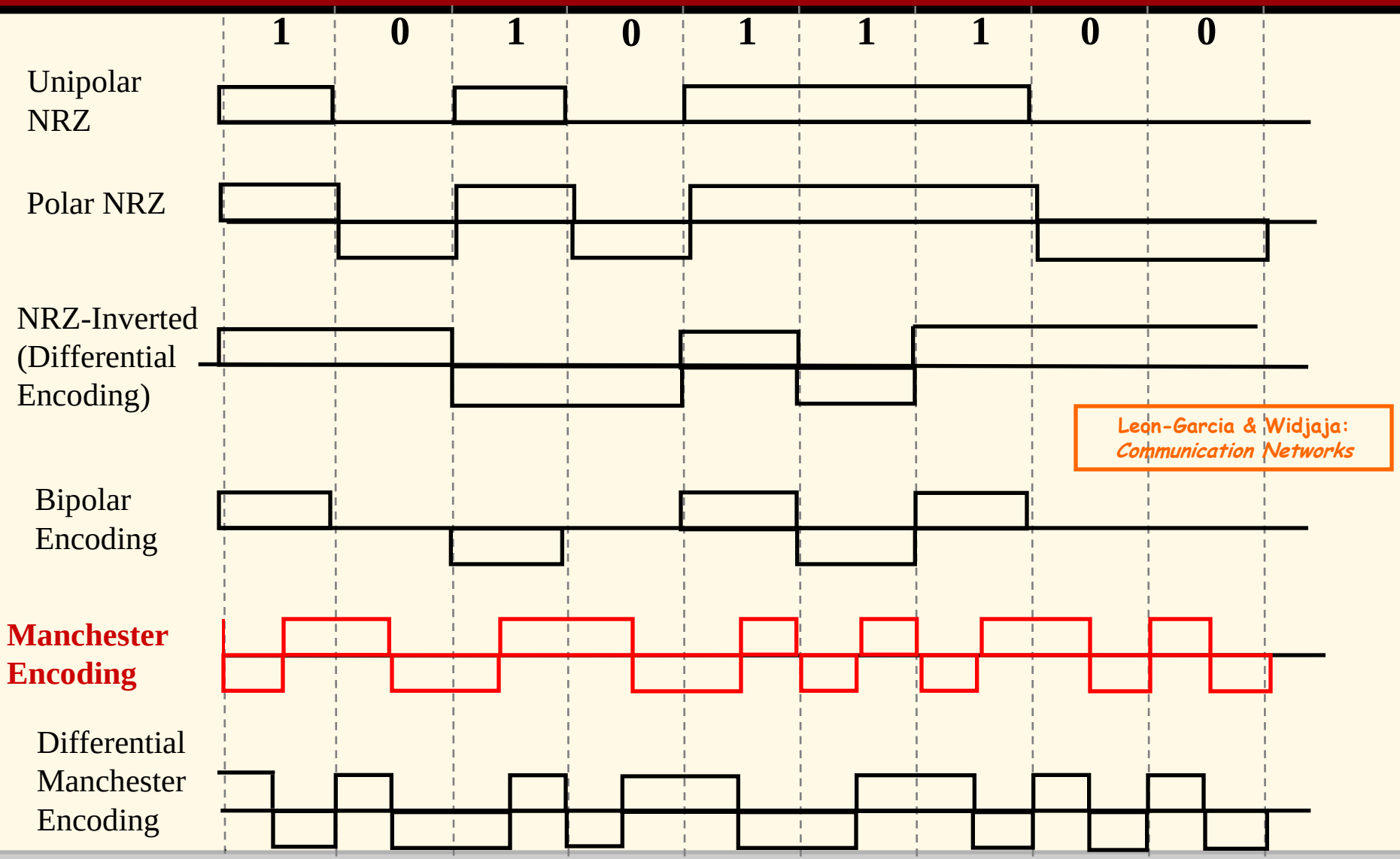
Bi-Polar Encoding

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.

Digital Encoding Techniques



Analog Data, Digital Signals

[Example – PCM (Pulse Code Modulation)]

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

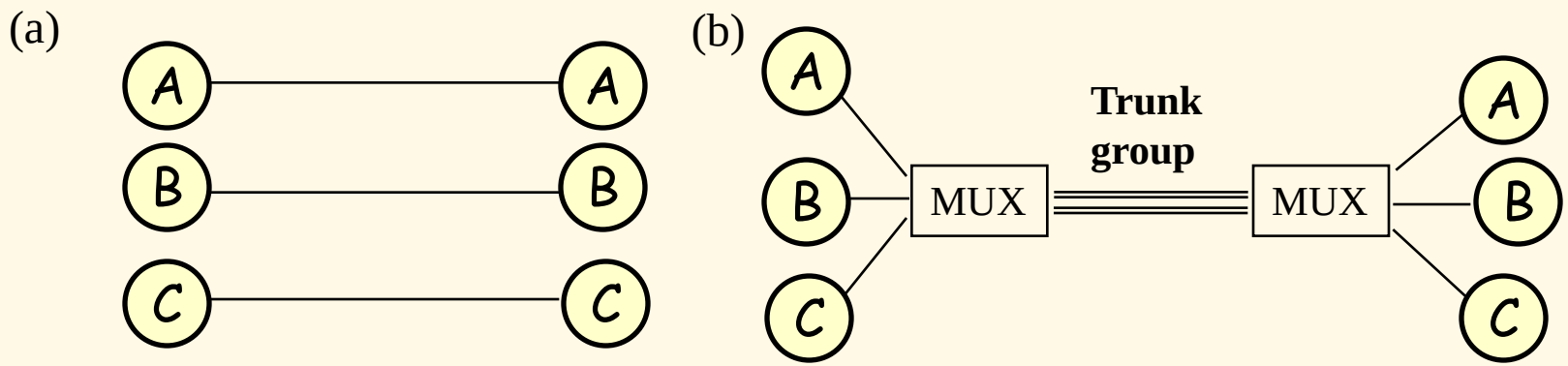
Example: *To transfer analog voice signals off a local loop to digital end office within the phone system, one uses a* codec.

Because voice data limited to frequencies below 4000 HZ, a codec makes 8000 samples/sec. (i.e., 125 microsec/sample).

Multiplexing

Multiplexing {general definition} ::

Sharing a resource over time.



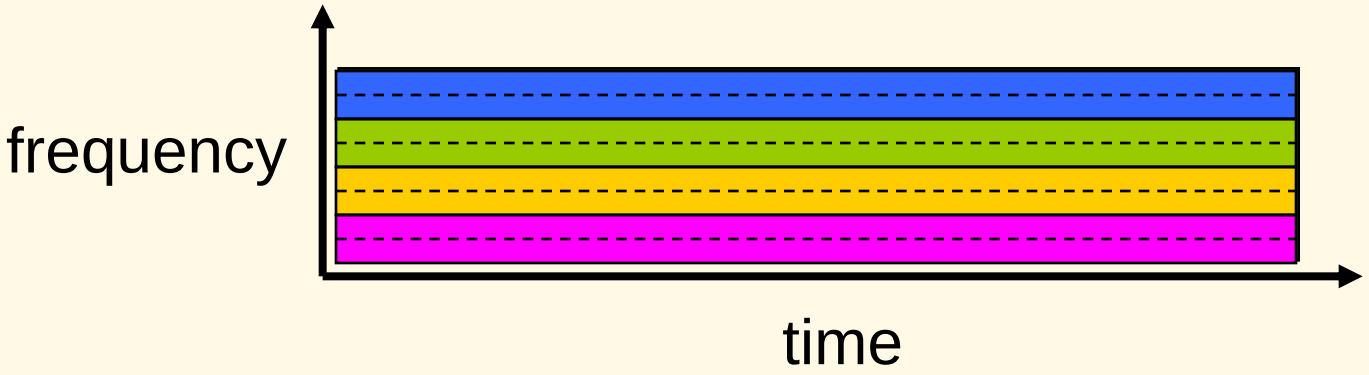
Leon-Garcia & Widjaja: *Communication Networks*

Frequency Division Multiplexing (FDM) vs Time Division Multiplexing (TDM)

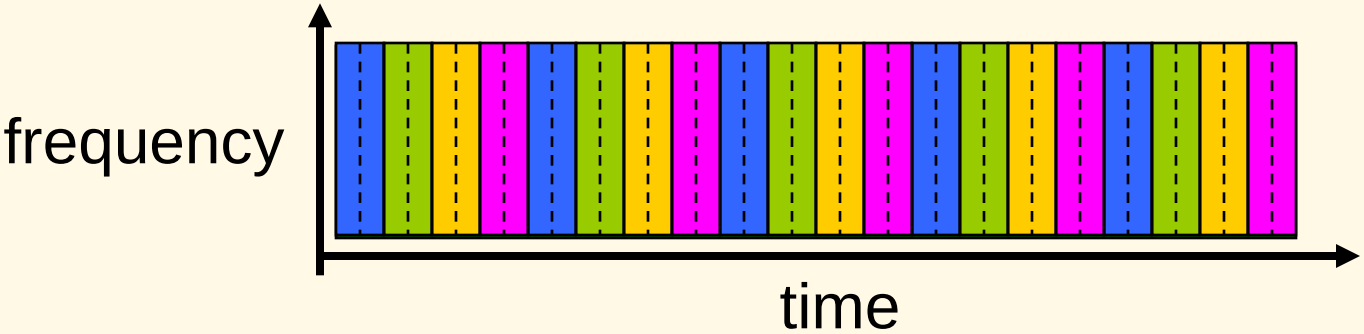
Example:

4 users

FDM



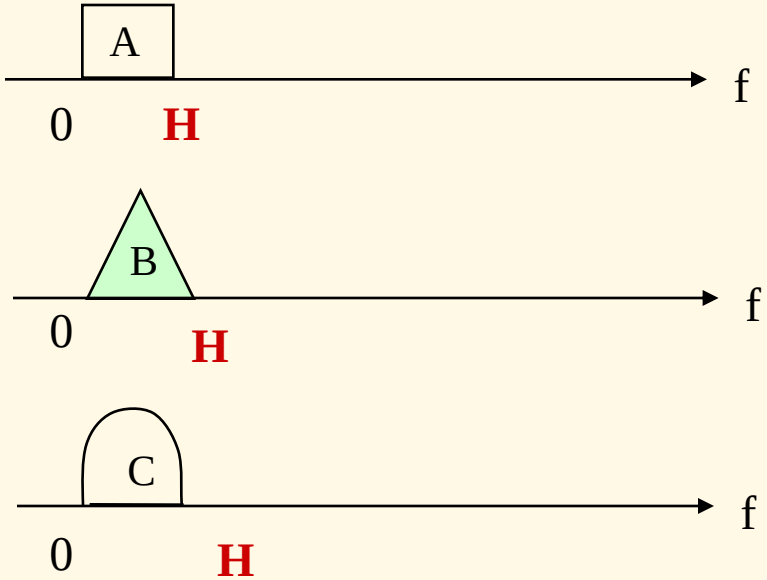
TDM



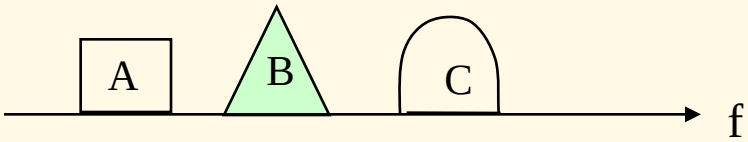
K & R

Frequency Division Multiplexing

(a) Individual signals occupy H Hz



(b) Combined signal fits into channel bandwidth



Leon-Garcia & Widjaja: *Communication Networks*

Frequency Division Multiplexing

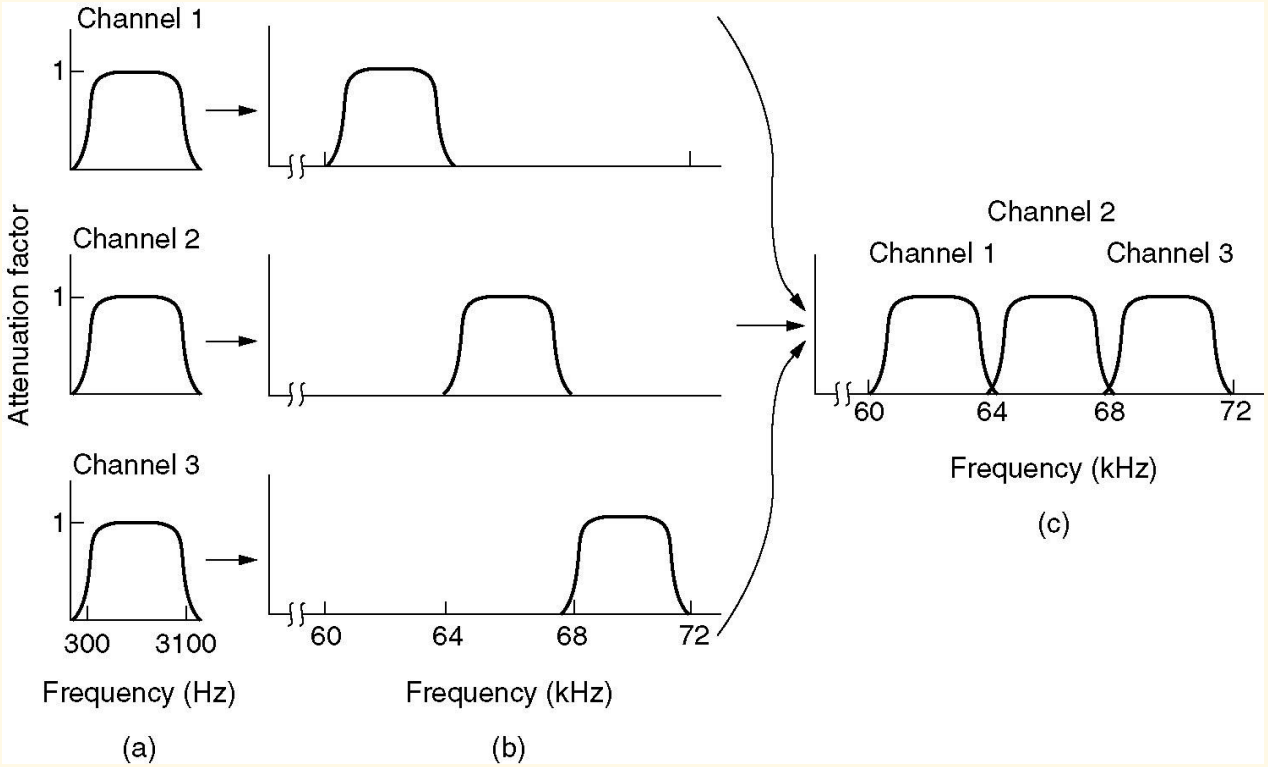


Figure 2-31. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

Tanenbaum

Wavelength Division Multiplexing

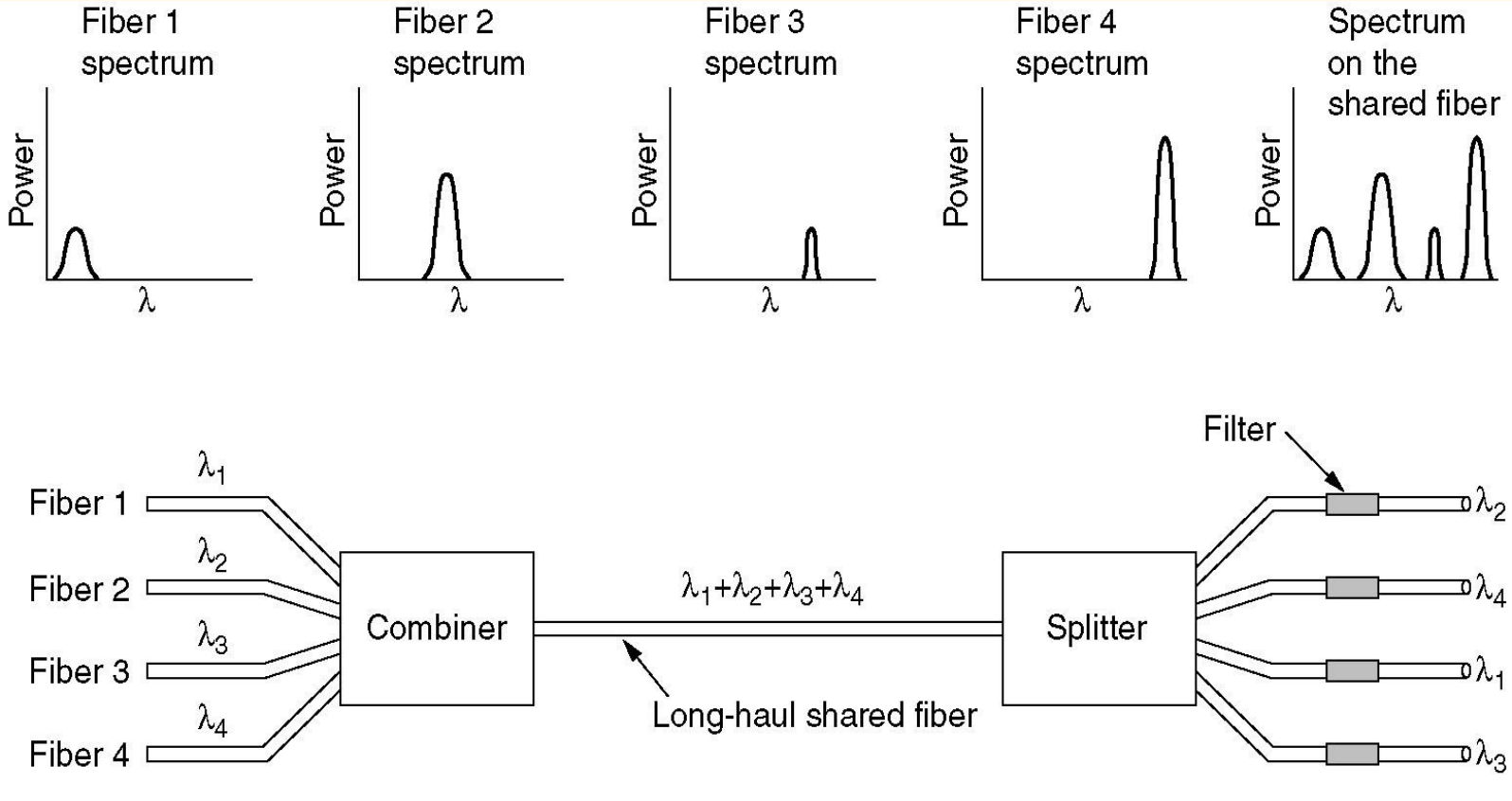
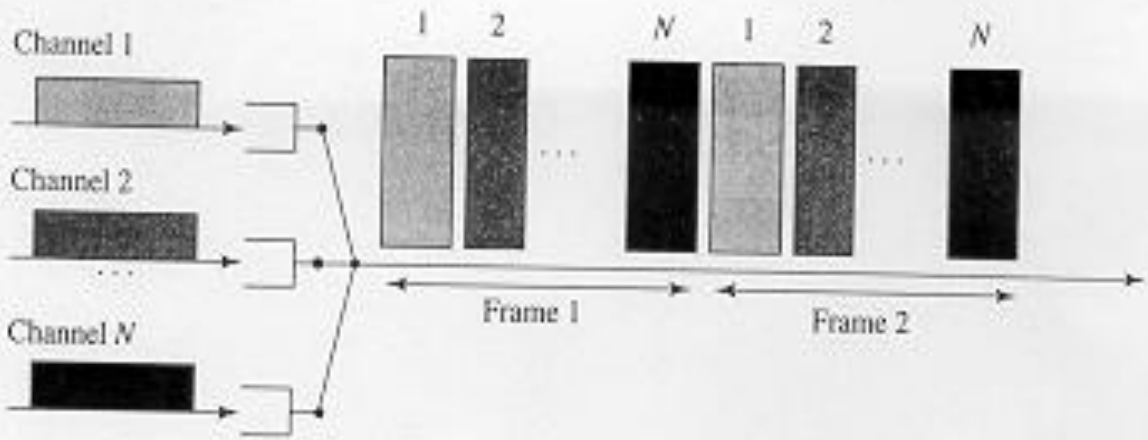


Figure 2-32.

Tanenbaum

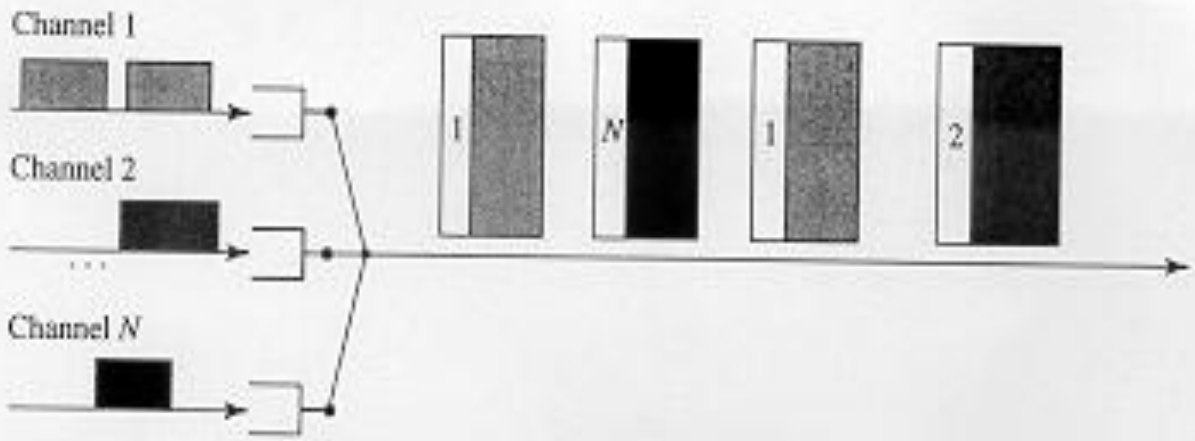
Time Division Multiplexing



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.

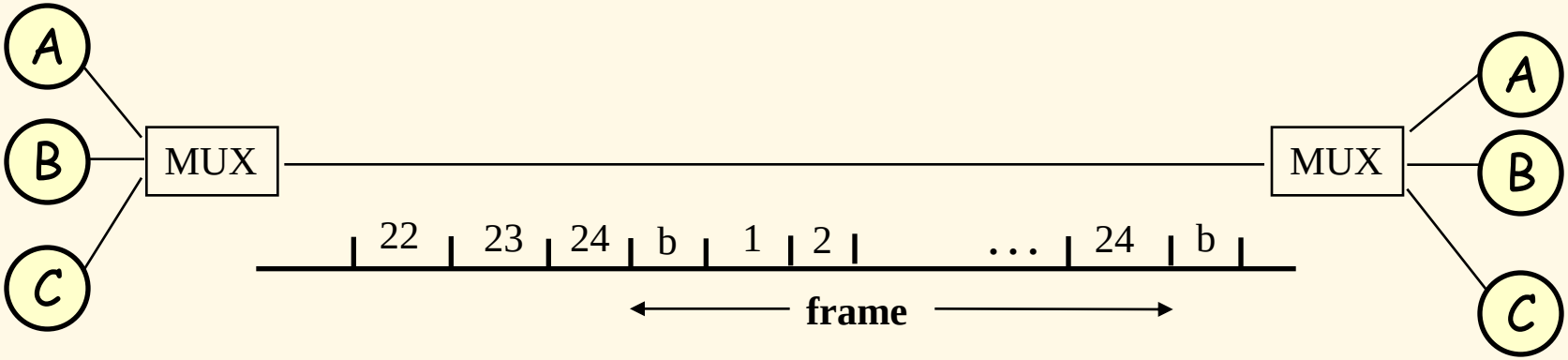
Concentrator [Statistical Multiplexing]



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.

T1 System



Leon-Garcia & Widjaja:
Communication Networks

T1 - TDM Link

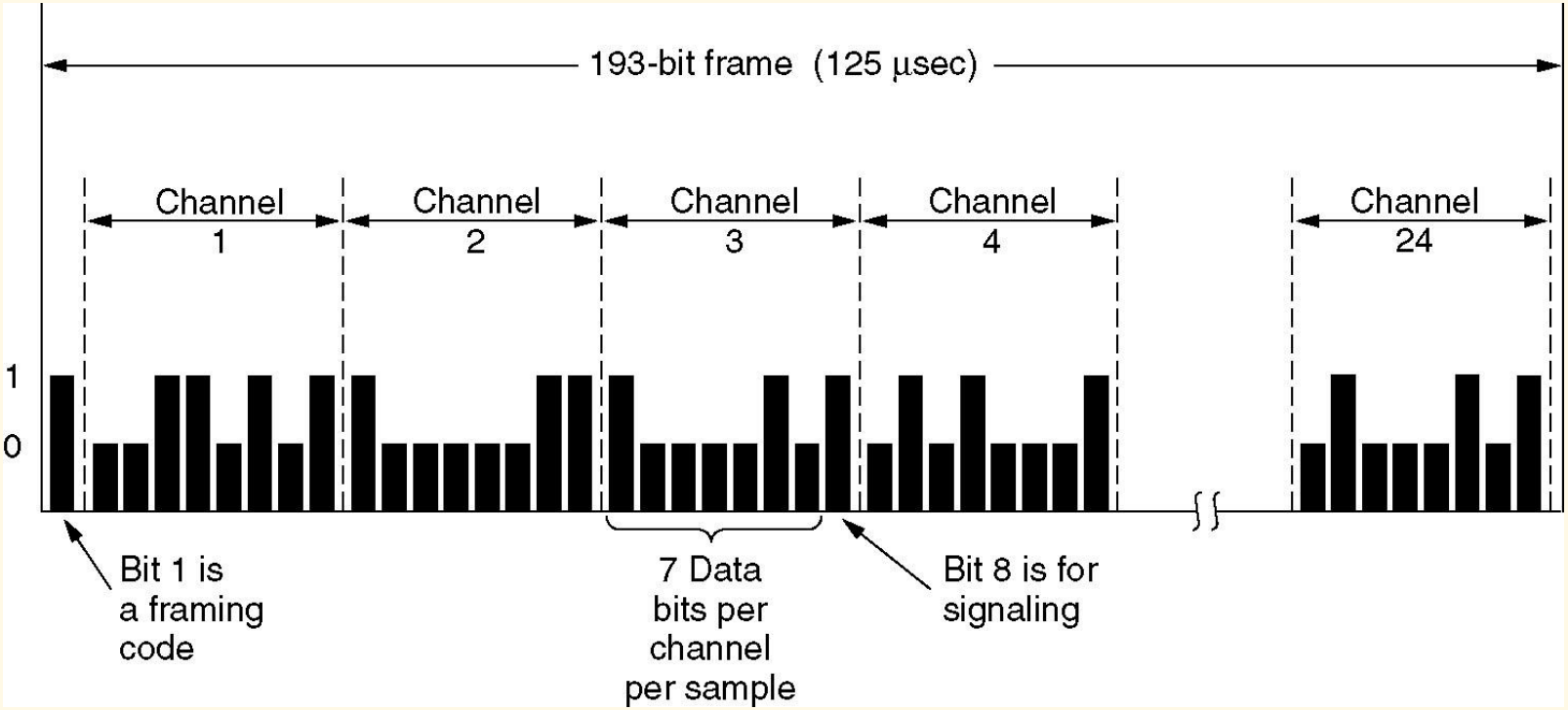


Figure 2-33. T1 Carrier (1.544Mbps)

Tanenbaum

Pulse Code Modulation (PCM)

T1 example for voice-grade input lines:

implies both codex conversion of analog to digital signals (PCM) and TDM.

Pulse Code Modulation Stages

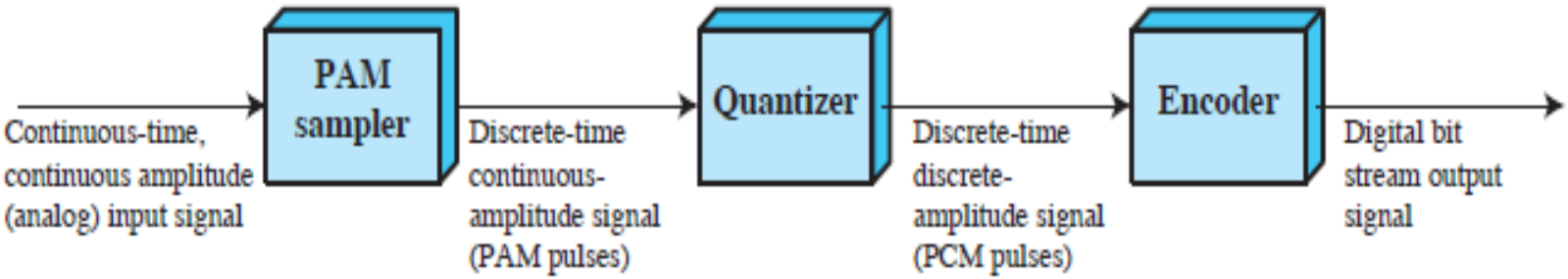


Figure 5.17 PCM Block Diagram

DCC 8th Ed. Stallings

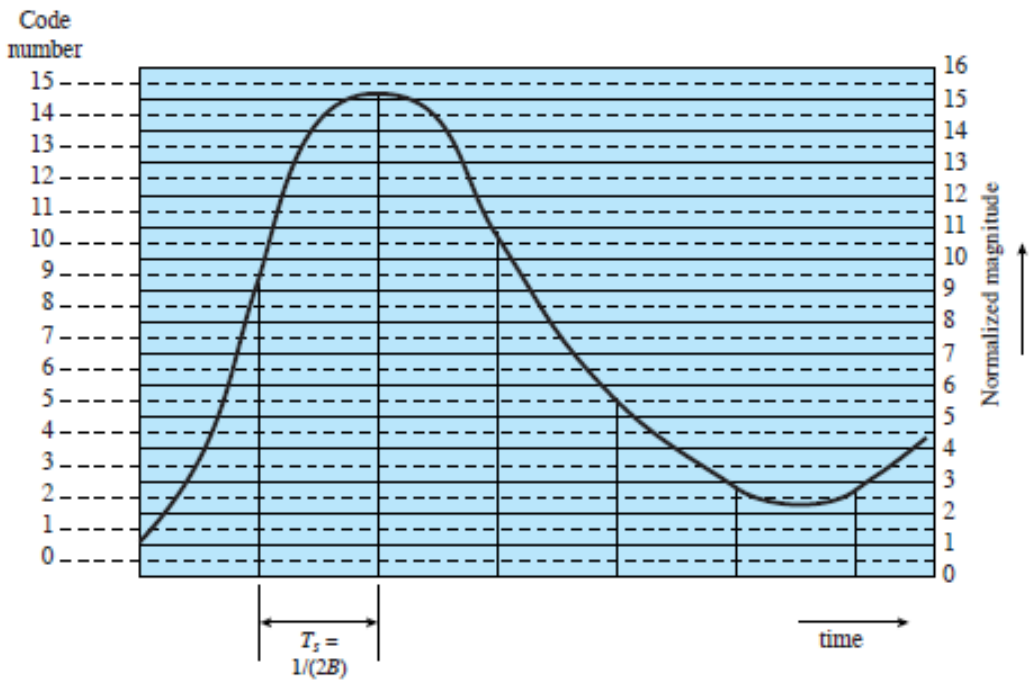
Pulse Code Modulation (PCM)

- 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 = 56 Kbps for a single voice channel.

PCM Stages



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Figure 5.16 Pulse-Code Modulation Example

DCC 8th Ed. Stallings

PCM Nonlinear Quantization

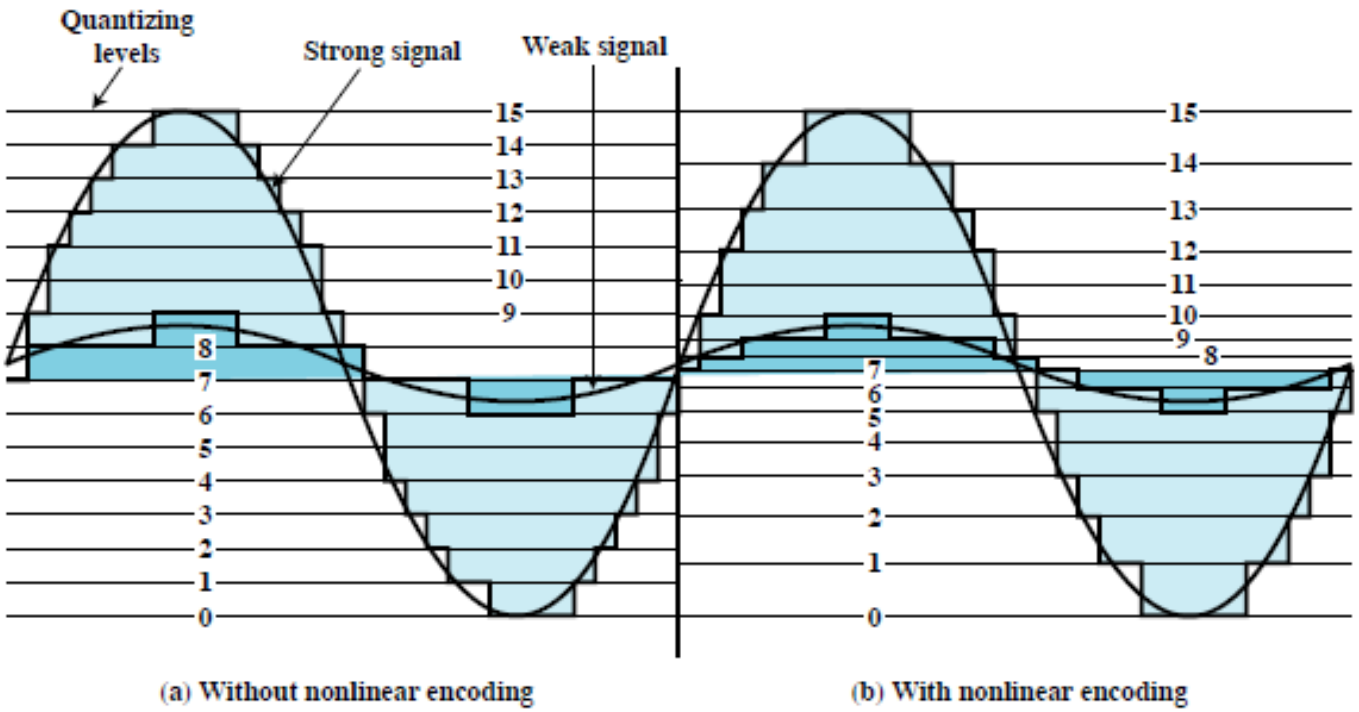


Figure 5.18 Effect of Nonlinear Coding

DCC 8th Ed. Stallings

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

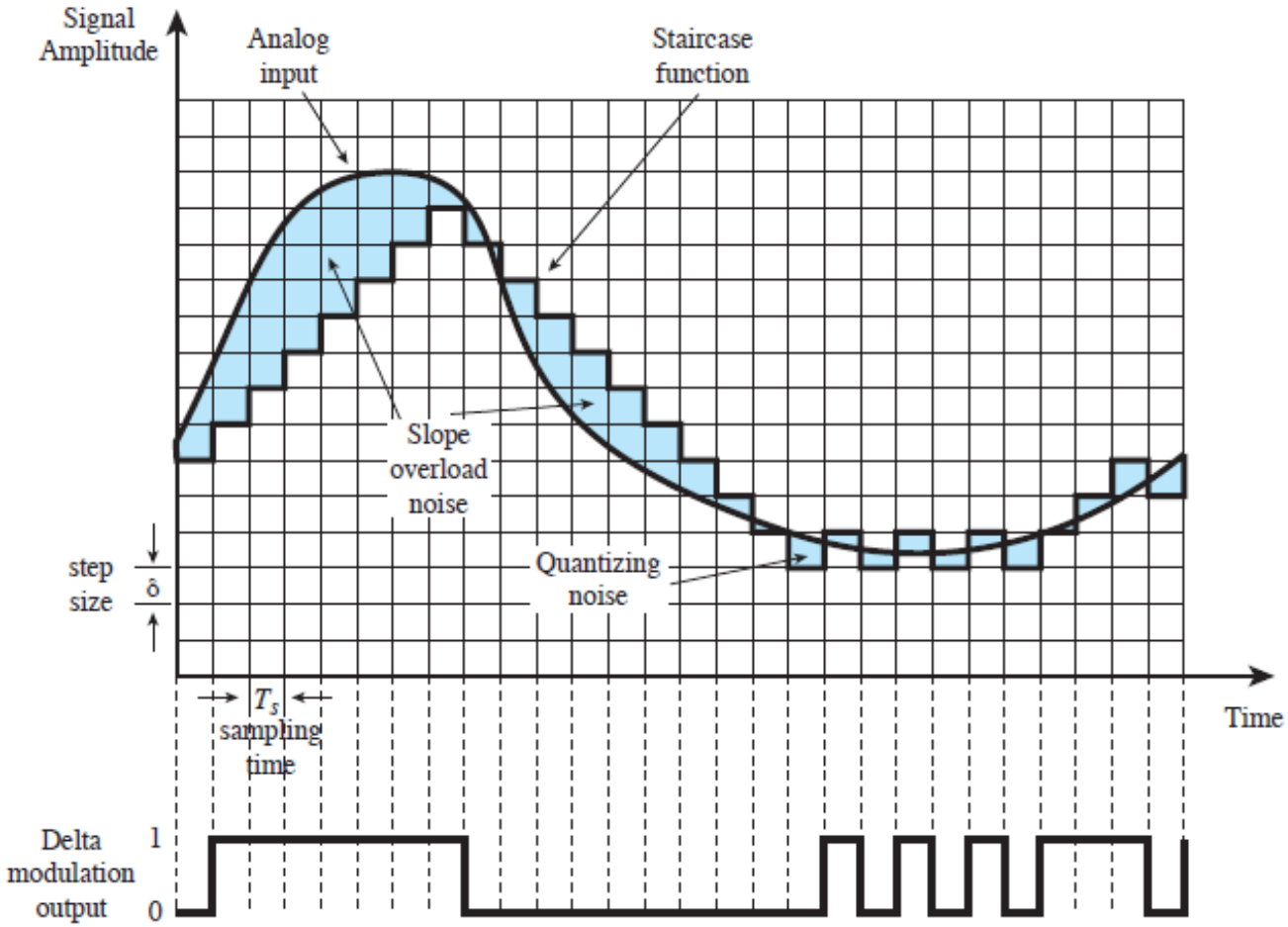


Figure 5.20 Example of Delta Modulation

DCC 8th Ed. Stallings

Data Encoding Summary

- Digital Data, Analog Signals [modem]
  - Three forms of modulation (amplitude, frequency and phase) used in combination to increase the data rate.
  - Constellation diagrams (QPSK and QAM)
- Digital Data, Digital Signals [wired LANs]
  - Tradeoffs between self clocking and required frequency.
  - Biphase, differential, NRZL, NRZI, Manchester, differential Manchester, bipolar.

Data Encoding Summary

- Analog Data, Digital Signals [codec]
  - Multiplexing Detour:
    - Frequency Division Multiplexing (FDM)
    - Wave Division Multiplexing (WDM) [fiber]
    - Time Division Multiplexing (TDM)
    - Statistical TDM (Concentrator)
- Codex functionality:
  - Pulse Code Modulation (PCM)
  - T1 line {classic voice-grade TDM}
  - PCM Stages (PAM, quantizier, encoder)
  - Delta Modulation