Physical Layer

Leon-Garcia & Widjaja: *Communication Networks*
Figure 3.5

Physical Layer definitions

- the time required to transmit a character depends on both the encoding method and the signaling speed (i.e., the modulation rate - the number of times/sec the signal changes its voltage)
- baud (D) - the number of changes per second
- bandwidth (W) - the range of frequencies that is passed by a channel. The transmitted signal is constrained by the transmitter and the nature of the transmission medium in cycles/sec (hertz)
- channel capacity (C) – the rate at which data can be transmitted over a given channel under given conditions.

Modulation Rate

DCC 6th Ed. W.Stallings

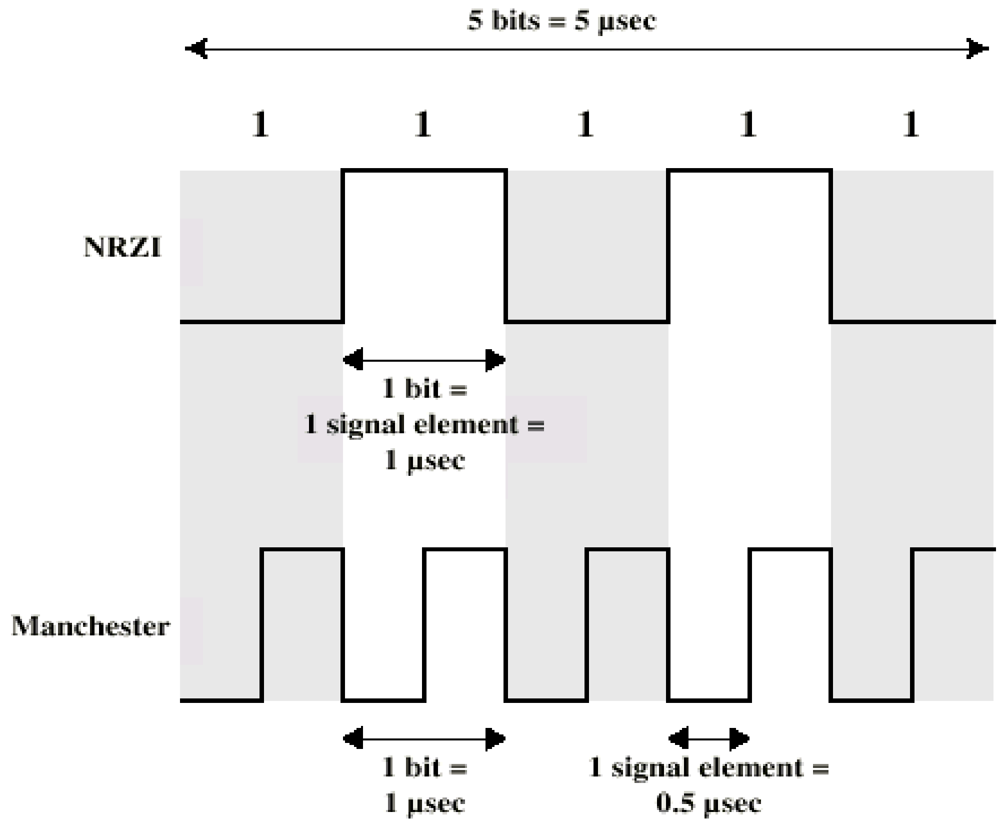


Figure 5.5 A Stream of Binary Ones at 1 Mbps

Nyquist Theorem

{assume a noiseless channel}

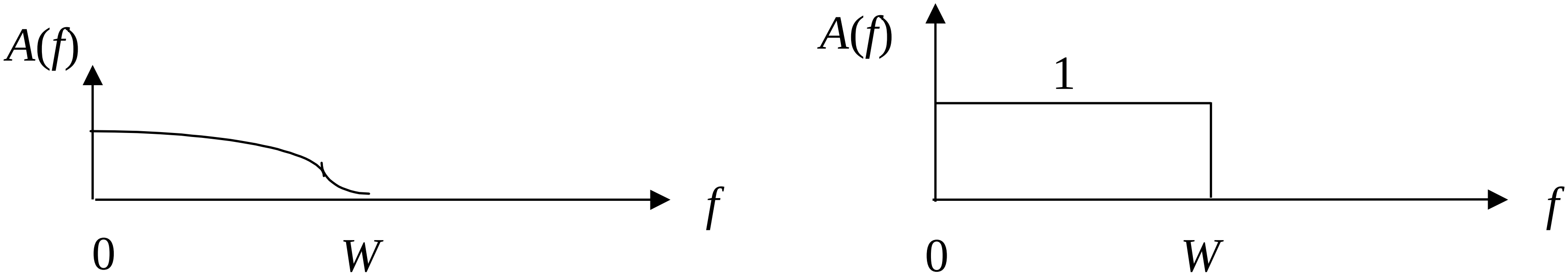
If an arbitrary signal is run through a low-pass filter of bandwidth **W, **the filtered signal can be *completely* reconstructed by making **2W** samples/sec.

This implies for a signal of **V** discrete levels,

Max. data rate :: $\mathbf{C} = 2\mathbf{W} \log_2 (\mathbf{V})$ bits/sec.

Note – a higher sampling rate is pointless because higher frequency signals have been filtered out.

(a) Lowpass and idealized lowpass channel



(b) Maximum pulse transmission rate is 2*W* pulses/second

 Leon-Garcia & Widjaja: *Communication Networks* Figure 3.11

Voice-grade phone line

1. $W = 4000$ Hz

   $2W = 8000$ samples/sec.

   ➔ sample every 125 microseconds!!

2. $D = 2400$ baud

   $V =$ each pulse encodes 16 levels

   $C = 2W \log_2 (V) = D \times \log_2 (V)$

   $= 2400 \times 4 = 9600$ bps.

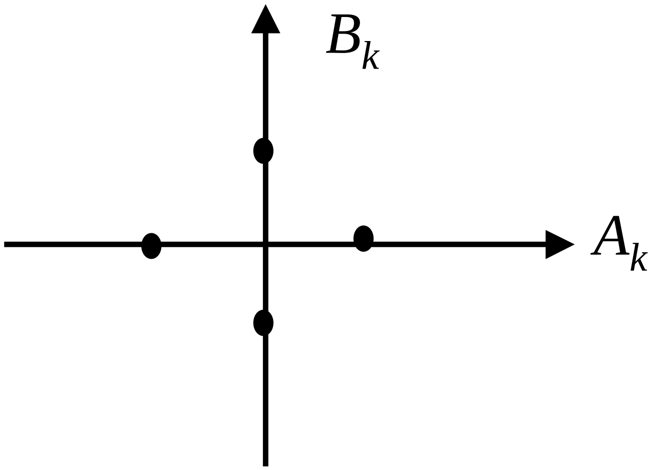
Nyquist Theorem

[LG&W Notation]

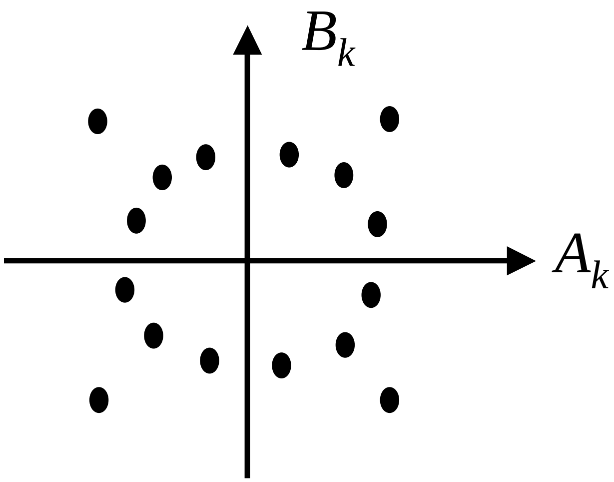
If we use **multilevel transmission pulses** that can take on $M = 2^m$ levels, then

$$R = 2Wm \text{ bits/second}$$

Signal Constellations



4 “levels”/ pulse
2 bits / pulse
2D bits per second

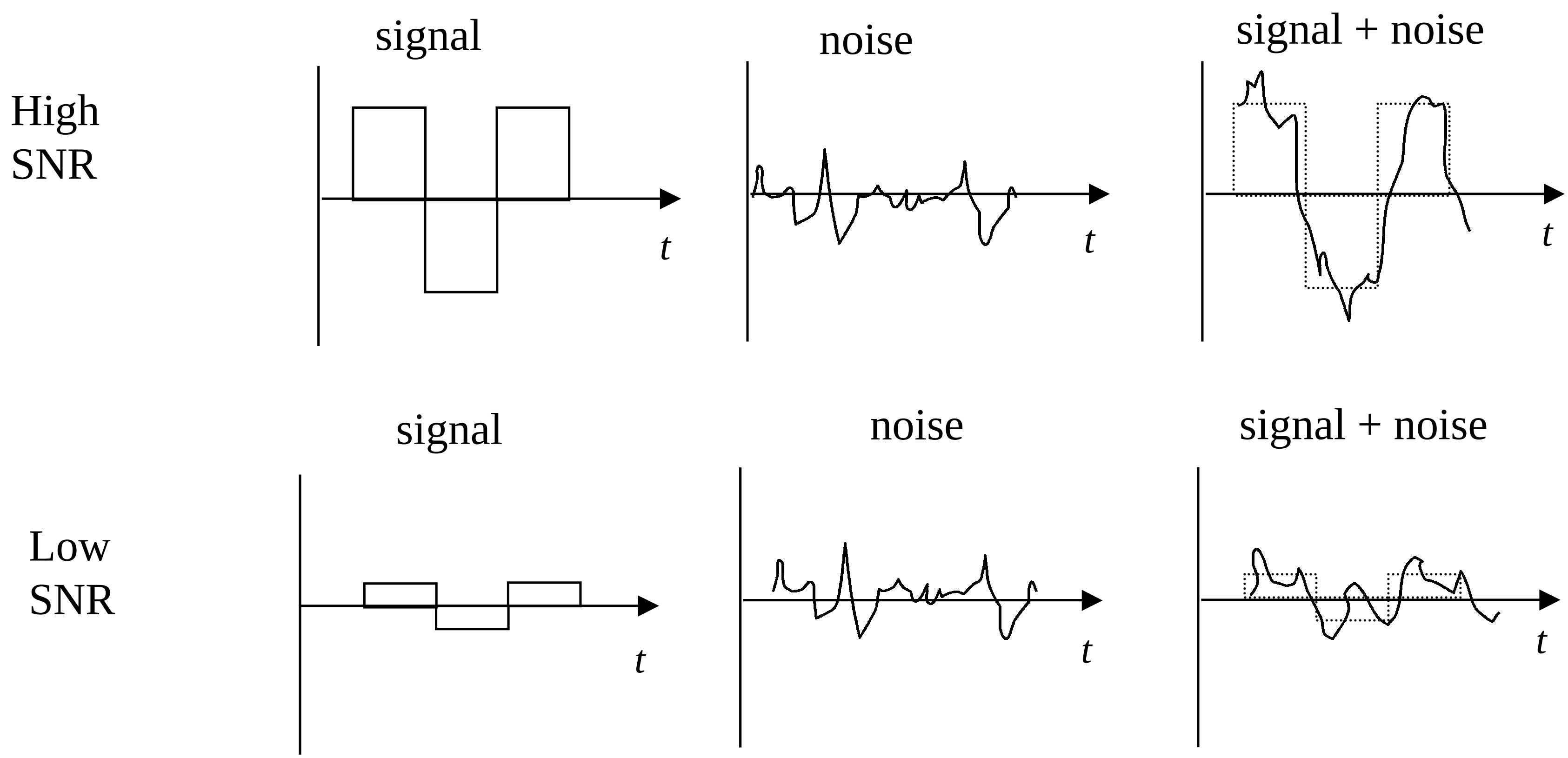


16 “levels”/ pulse
4 bits / pulse
4D bits per second

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

Leon-Garcia & Widjaja: *Communication Networks*

Figure 3.34



$$\text{SNR} = \frac{\text{Average Signal Power}}{\text{Average Noise Power}}$$

$$\text{SNR (dB)} = 10 \log_{10} \text{SNR}$$

 Leon-Garcia & Widjaja: *Communication Networks* Figure 3.12

Shannon Channel Capacity
{assuming only thermal noise}

For a noisy channel of bandwidth **W** Hz. and a signal-to-noise ratio **SNR**, the max. data rate::

$$\mathbf{C} = \mathbf{W} \log_2 (1 + \mathbf{SNR})$$

Regardless of the number of signal levels used and the frequency of the sampling.

Shannon Example [LG&W p. 110]

Telephone channel (3400 Hz) at 40 dB SNR

$C = W \log_2 (1+SNR)$ b/s

SNR =40 dB ; $40 = 10 \log_{10}(SNR)$;

$4 = \log_{10}(SNR)$; SNR =10,000

$C = 3400 \log_2 (10001) = 44.8$ kbps

Data Communications Concepts

Analog and Digital Data [Stalling's Discussion]

Analog and digital correspond roughly to *continuous* and *discrete*. These two terms can be used in three contexts:

1. data:: entities that convey meaning.

   analog – voice and video are continuously varying patterns of intensity

   digital - take on discrete values (e.g., integers, ASCII text)

Data are propagated from one point to another by means of <u>electrical signals</u>.

Analog and Digital Signaling

signals:: electric or electromagnetic encoding of data.

2. signaling :: is the act of propagating the signal along a suitable medium.

   Analog signal – a continuously varying electromagnetic wave that may be propagated over a variety of medium depending on the spectrum (e.g., wire, twisted pair, coaxial cable, fiber optic cable and atmosphere or space propagation).

Analog and Digital Signaling

digital signal – a sequence of voltage pulses that may be transmitted over a wire medium.

Note – analog signals to represent analog data and digital signals to represent digital data are **not** the only possibilities.

Signals DCC 6th Ed. W.Stallings

- Means by which data are propagated
- Analog
  - Continuously variable
  - Various media
    - wire, fiber optic, space
  - Speech bandwidth 100Hz to 7kHz
  - Telephone bandwidth 300Hz to 3400Hz
  - Video bandwidth 4MHz
- Digital
  - Use two DC components

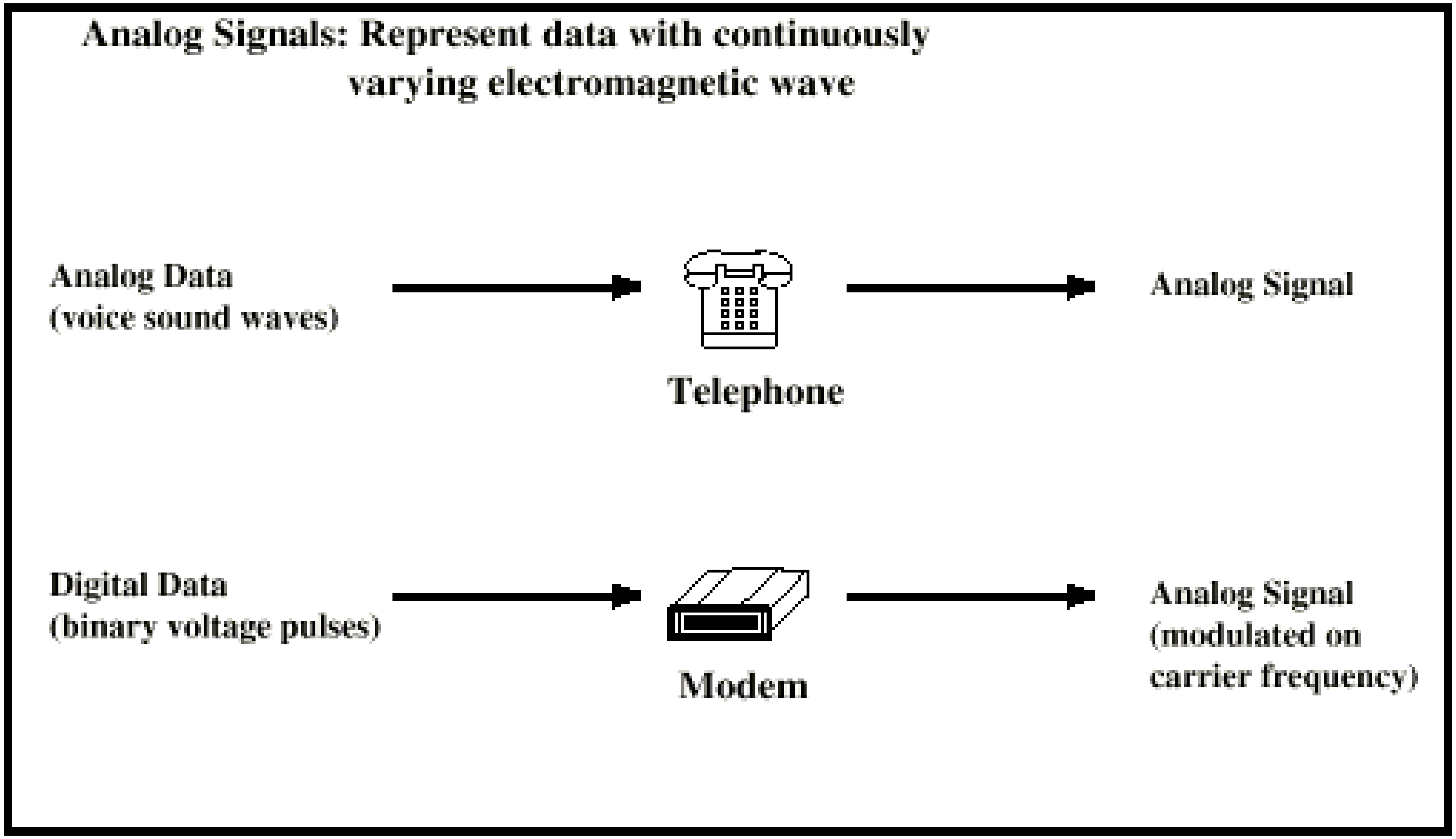
Analog and Digital Signaling

- Digital data can be represented by analog signals using a modem (modulator/demodulator).

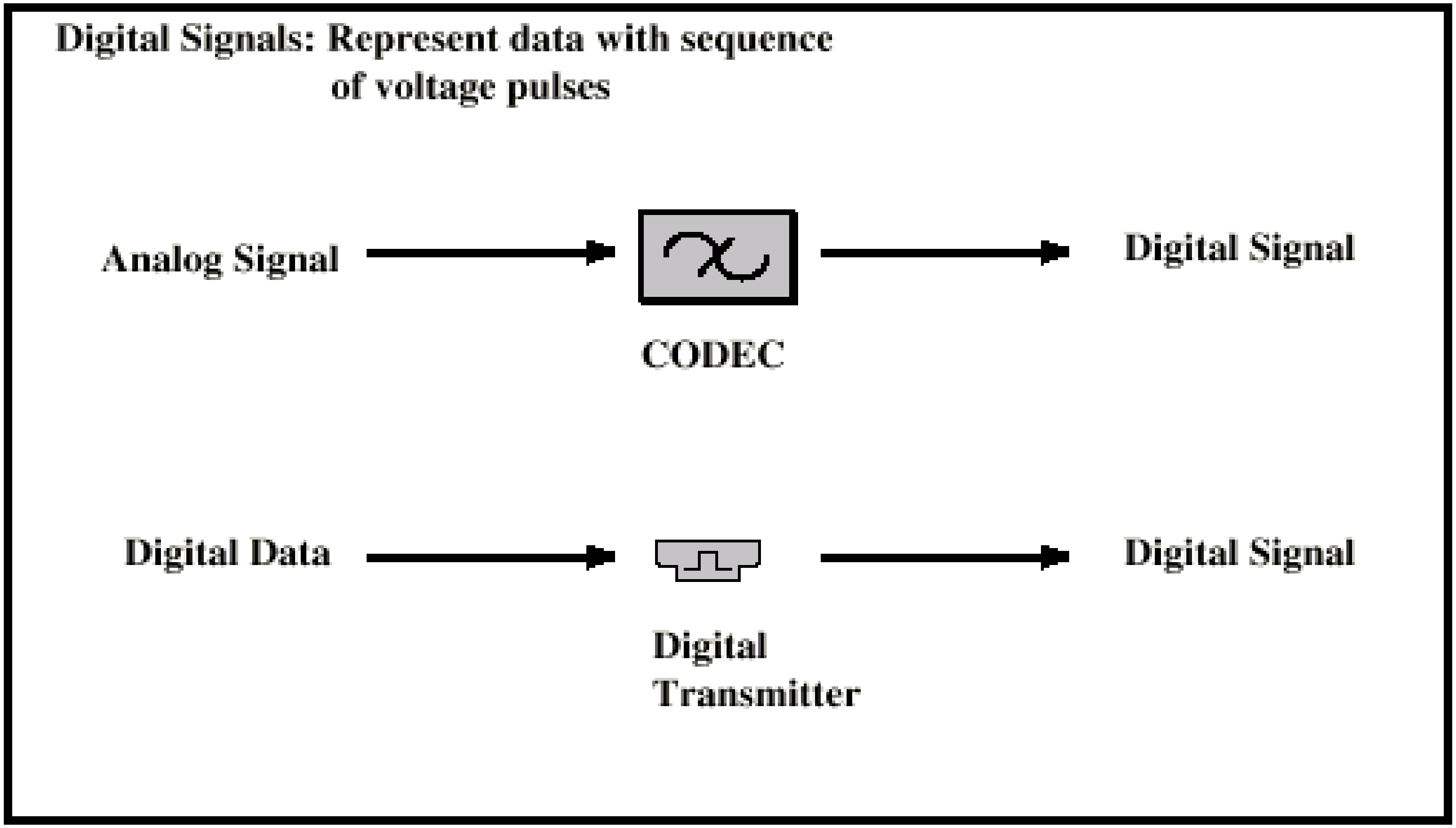
  The digital data is encoded on a carrier frequency.

- Analog data can be represented by digital signals using a codec (coder-decoder).

Analog Signals Carrying Analog and Digital Data DCC 6th Ed. W.Stallings



Digital Signals Carrying Analog and Digital Data DCC 6th Ed. W.Stallings



Analog and Digital Signaling Comparison

- Digital signaling is:
  - Cheaper
  - Less susceptible to noise interference
  - Suffers more attenuation.

Attenuation

attenuation of a signal:: the reduction or loss of signal strength (power) as it transferred across a system.

Attenuation is an increasing function of frequency.

The strength of the received signal must be strong enough for detection and must be higher than the noise to be received without error.

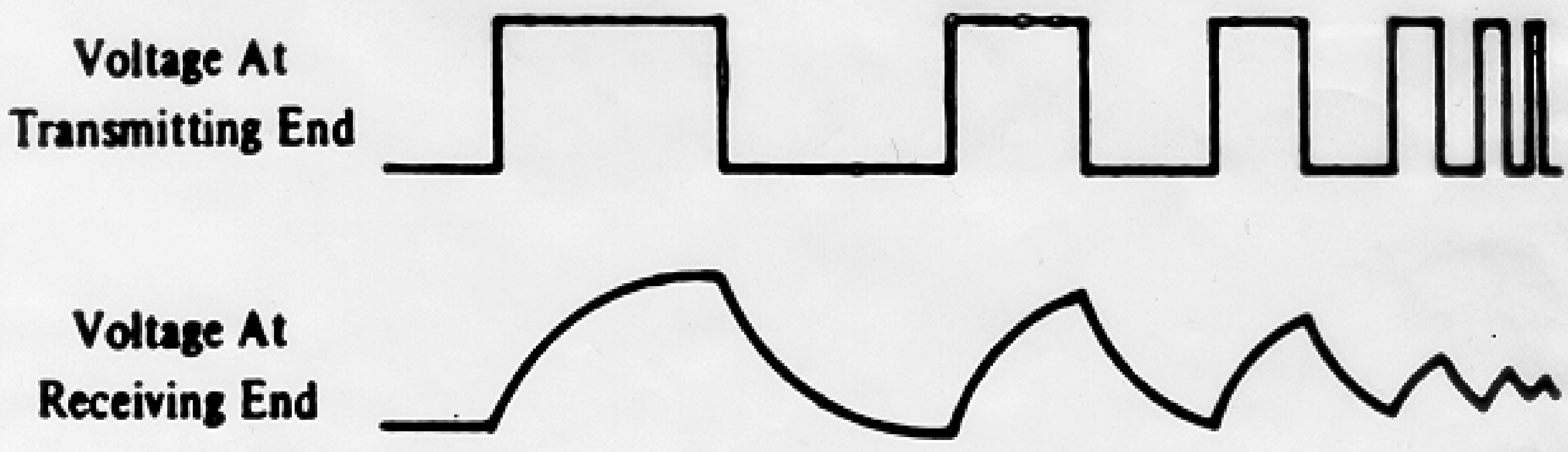


FIGURE 2.1 Attenuation of Digital Signals

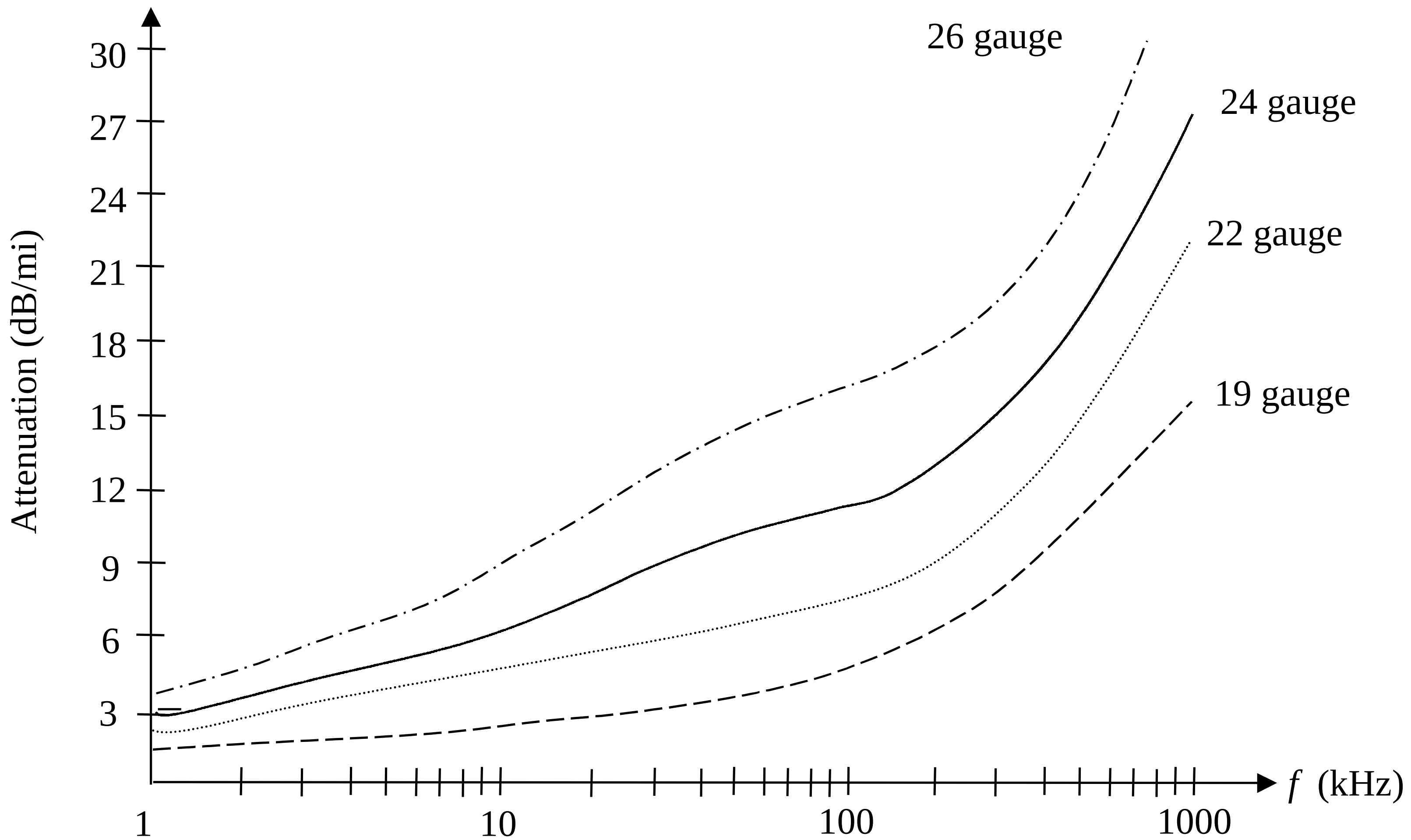

26 gauge
24 gauge
22 gauge
19 gauge
30
27
24
21
18
15
12
9
6
3
Attenuation (dB/mi)
1
10
100
1000
f (kHz)

Figure 3.37

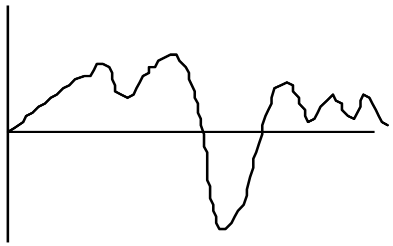
Analog and Digital Transmissions

{Stalling's third context}

3. Transmissions :: communication of data by the propagation and processing of signals.
   - Both analog and digital signals may be *transmitted* on suitable transmission media.
   - [Stalling's argument] the way the signals are "treated" is a a function of the transmission system and here lies the crux of the distinction between transmission types.

(a) Analog transmission: all details must be reproduced accurately

Sent

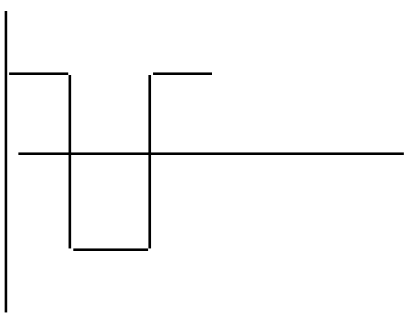


Received

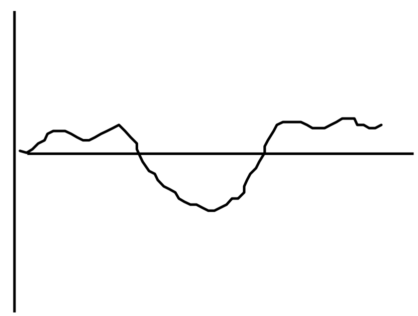
- e.g. AM, FM, TV transmission

(b) Digital transmission: only discrete levels need to be reproduced

Sent



Received



- e.g digital telephone, CD Audio

 Leon-Garcia & Widjaja: *Communication Networks* Figure 3.6

Analog Transmissions

Analog transmission :: a means of transmitting analog signals *without regard to their content* (i.e., the signals may represent analog data or digital data).

transmissions are attenuated over distance.

Analog signal – the analog transmission system uses amplifiers to boost the energy in the signal.

Analog Transmissions

Amps boost the energy ➔
amplifies the signal and amplifies the noise

The <u>cascading</u> of amplifiers distorts the signal.

Note – voice (analog data) can tolerate much distortion but with digital data distortion introduces errors.

Digital Transmissions

Digital transmissions are concerned with the content of the signal. Attenuation is overcome without amplifying the noise.

Analog signals {*assumes digital data*}:

With retransmission devices [analog repeater] at appropriate points the device recovers the digital data from the analog signal and generates a <u>new</u> clean analog signal.

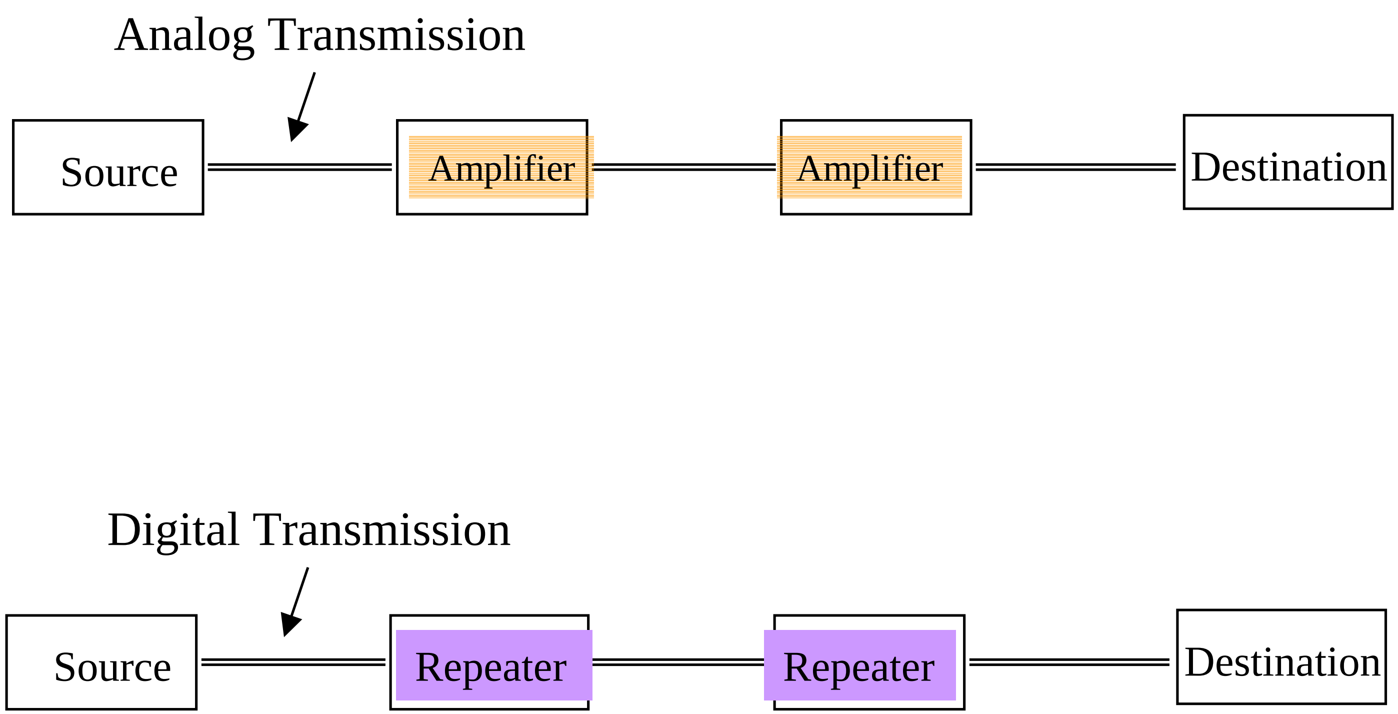
the noise is not cumulative!!

Digital Transmissions

digital signals – digital repeaters are used to attain greater distances.

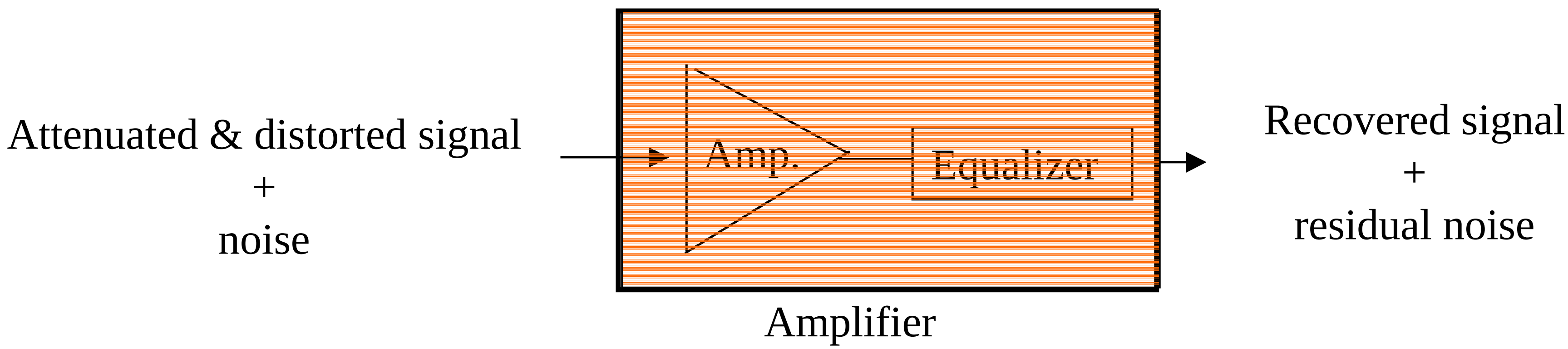
The digital repeater receives the digital signal, recovers the patterns of 0’s and 1’s and retransmits a <u>new</u> digital signal.

The treatment is the same for analog and digital data.



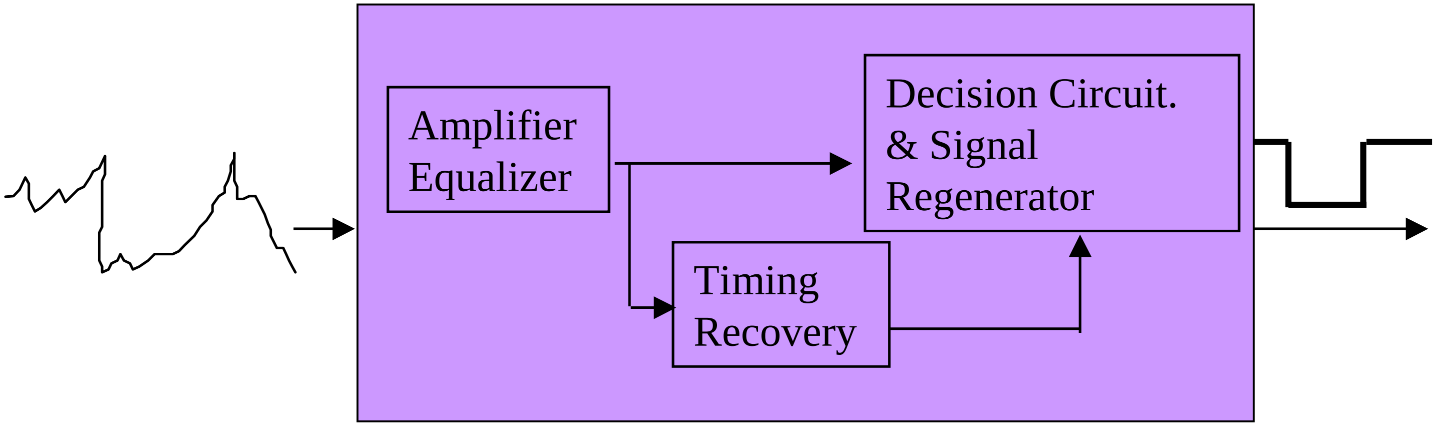
Leon-Garcia & Widjaja: *Communication Networks*

Figure 3.7



Analog Transmission

 Leon-Garcia & Widjaja: *Communication Networks* Figure 3.8



Repeater (digital signal)

Digital Transmission

Figure 3.9

Digital versus Analog Transmissions

DCC 6th Ed. W.Stallings

Digital transmission advantages

- Superior cost of digital technology
  - Low cost LSI/VLSI technology
  - Repeaters versus amplifiers costs
- Superior quality {Data integrity}
  - Longer distances over lines with lower error rates
- Capacity utilization
  - Economical to build high bandwidth links
  - High degree of multiplexing easier with digital techniques
    - TDM (Time Division Multiplexing) is easier and cheaper than FDM (Frequency Division Multiplexing)

Digital versus Analog Transmissions

DCC 6th Ed. W.Stallings

Digital transmission advantages

- Security & Privacy
  - Encryption techniques readily applied to *digitized* data
- Integration
  - Can treat analog and digital data similarly
  - Economies of scale from integrating voice, video and data

Analog transmission advantages

- Digital signaling not as versatile or practical (digital impossible for satellite and microwave systems)
- LAN star topology limits the severity of the noise and attenuation problems.