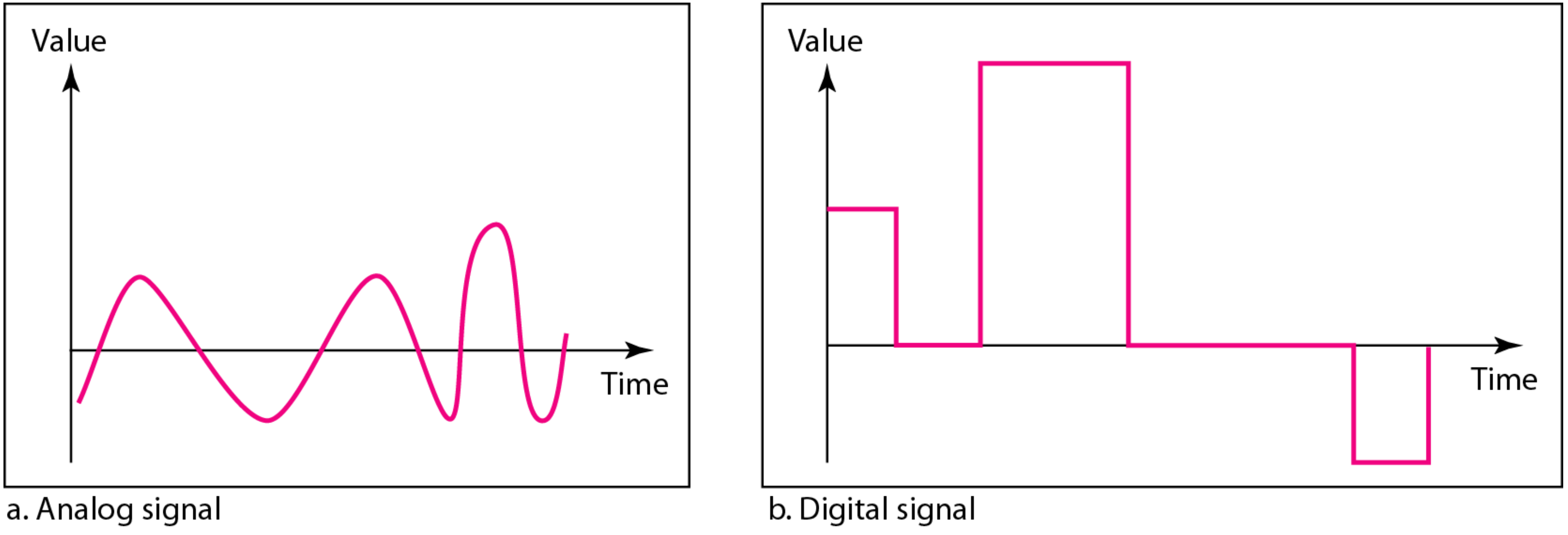
Data and Signals

Data and Signals

- To be transmitted, data must be transformed to electromagnetic signals.
- Data can be analog or digital.
- Analog data are continuous and take continuous values.
- Digital data have discrete states and take discrete values.
- Signals can be analog or digital.
- Analog signals can have an infinite number of values in a range.
- Digital signals can have only a limited number of values.
- In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

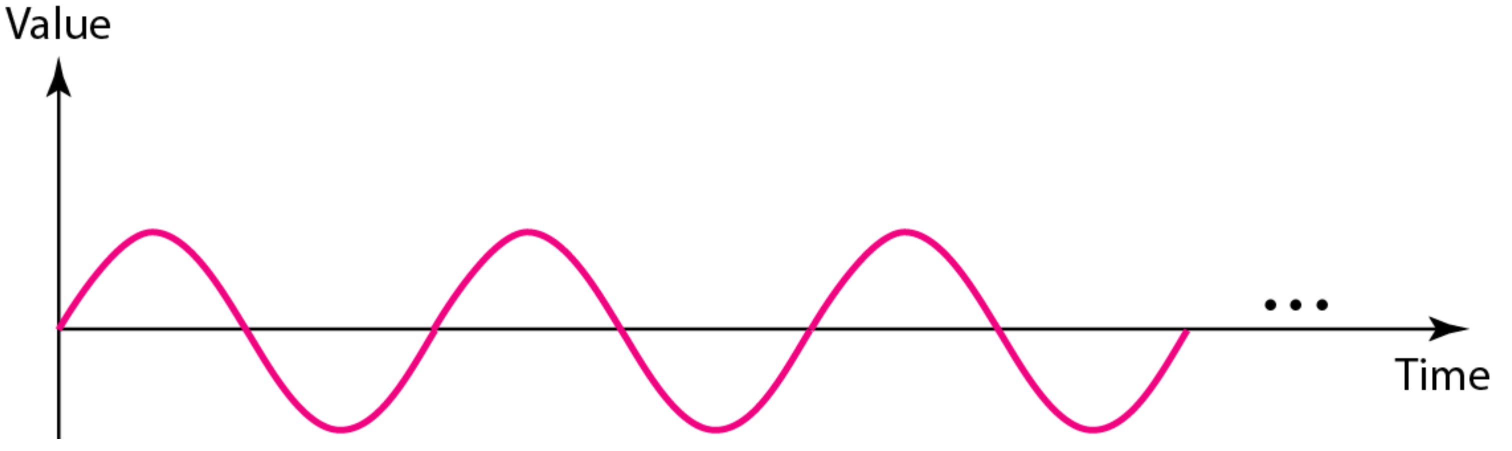
Comparison of analog and digital signals



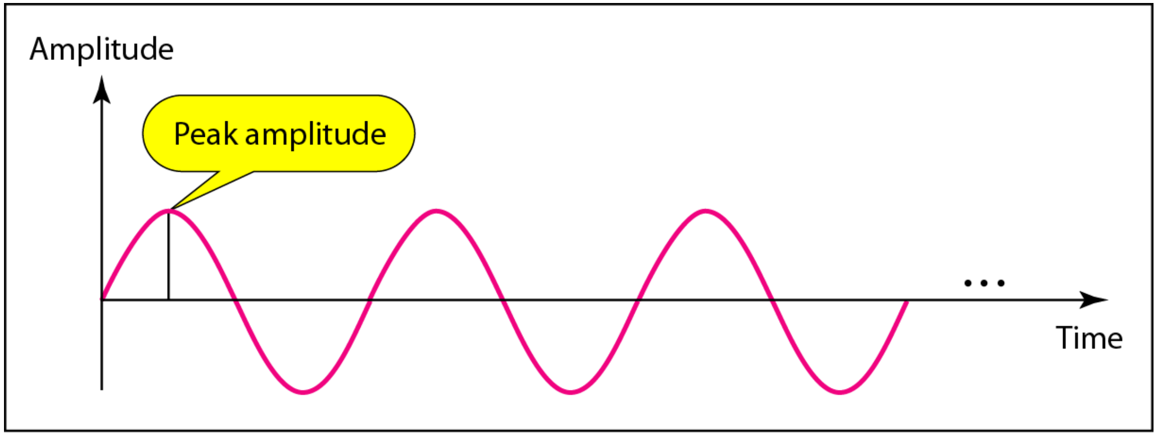
PERIODIC ANALOG SIGNALS

- Periodic analog signals can be classified as simple or composite.
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.
- The power in your house can be represented by a sine wave with a peak amplitude of 155 to 170 V.
- The voltage of a battery is a constant; this constant value can be considered a sine wave.

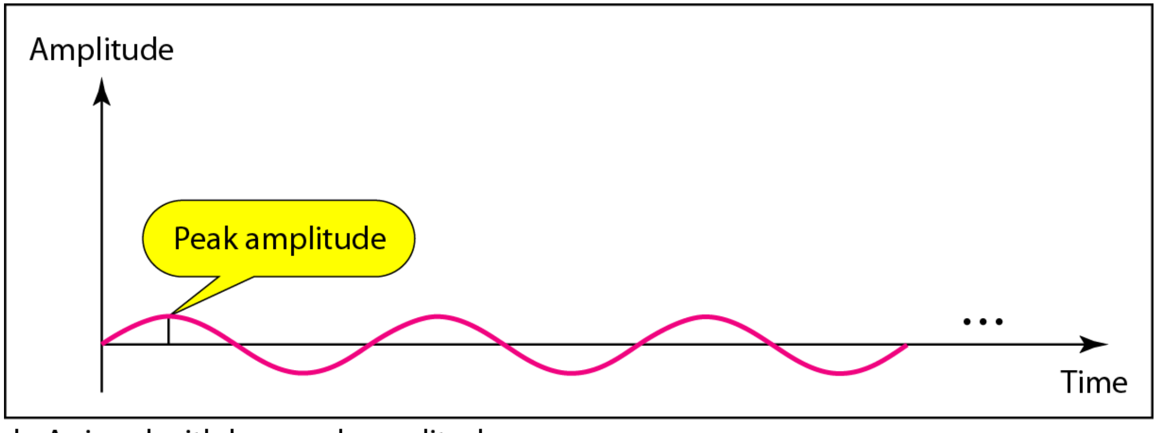
A sine wave



Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude



b. A signal with low peak amplitude

DIGITAL SIGNALS

- In addition to being represented by an analog signal, information can also be represented by a digital signal.
- For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

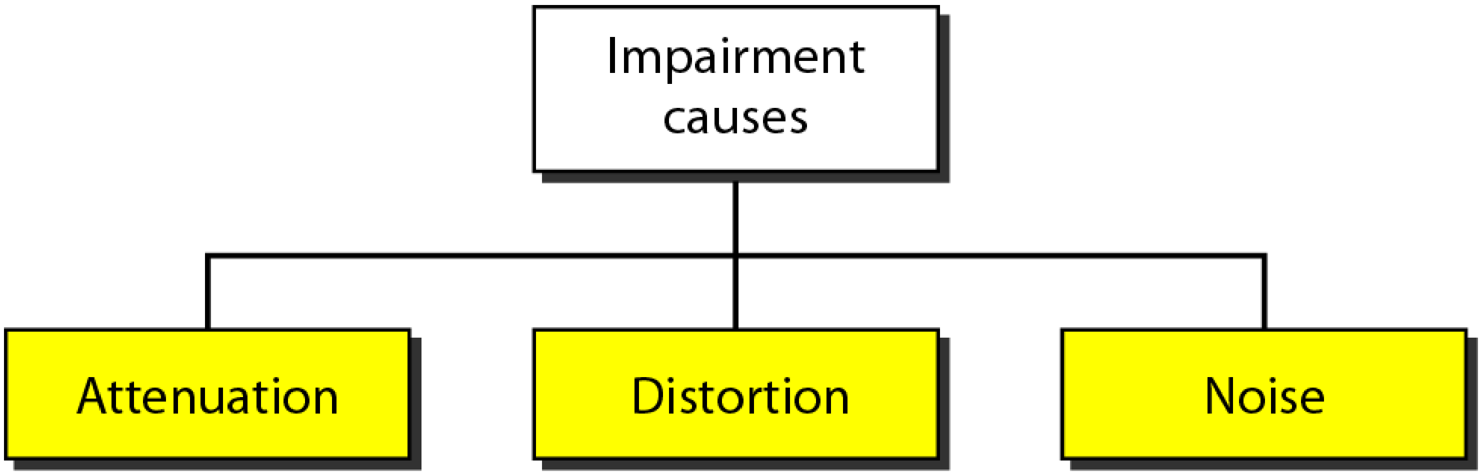
A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

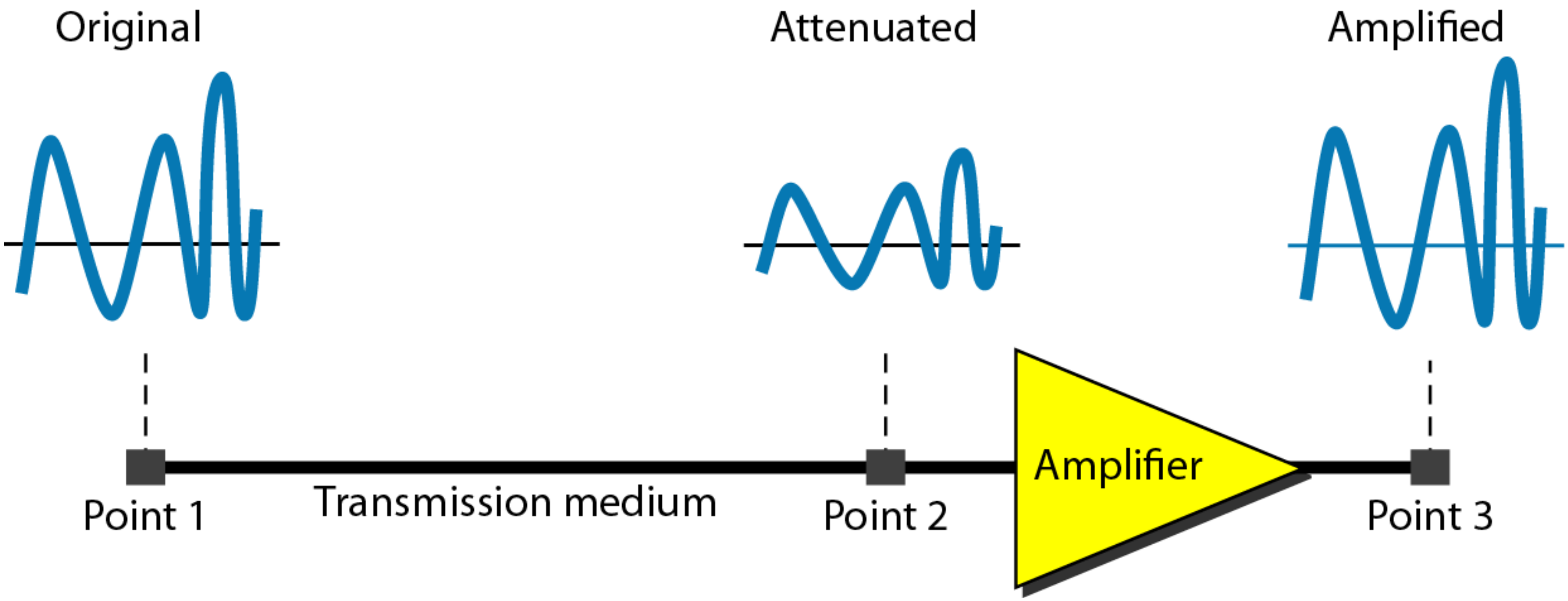
TRANSMISSION IMPAIRMENT

- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal impairment.
- This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.
- What is sent is not what is received.
- **Three causes of impairment are attenuation, distortion, and noise.**

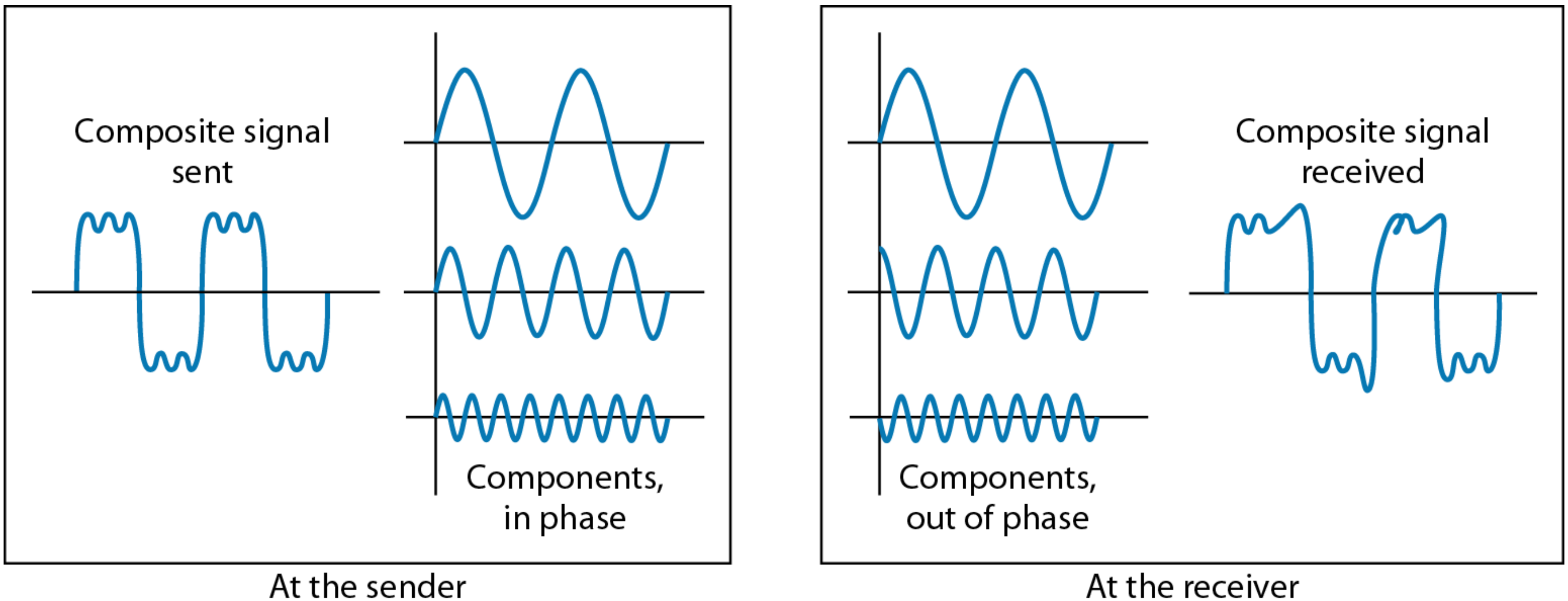
Causes of impairment



Attenuation

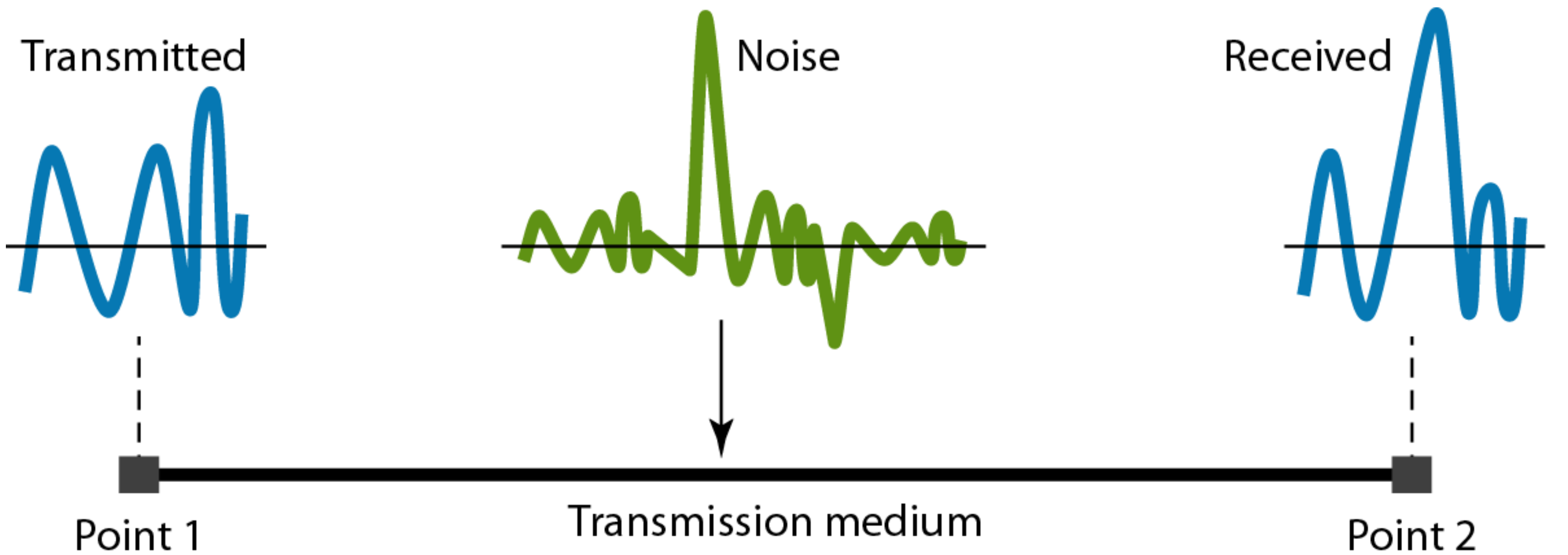


Distortion



Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

Noise


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

DATA RATE LIMITS

- A very important consideration in data communications is how fast we can send data, in bits per second, over a channel.
- Data rate depends on three factors:

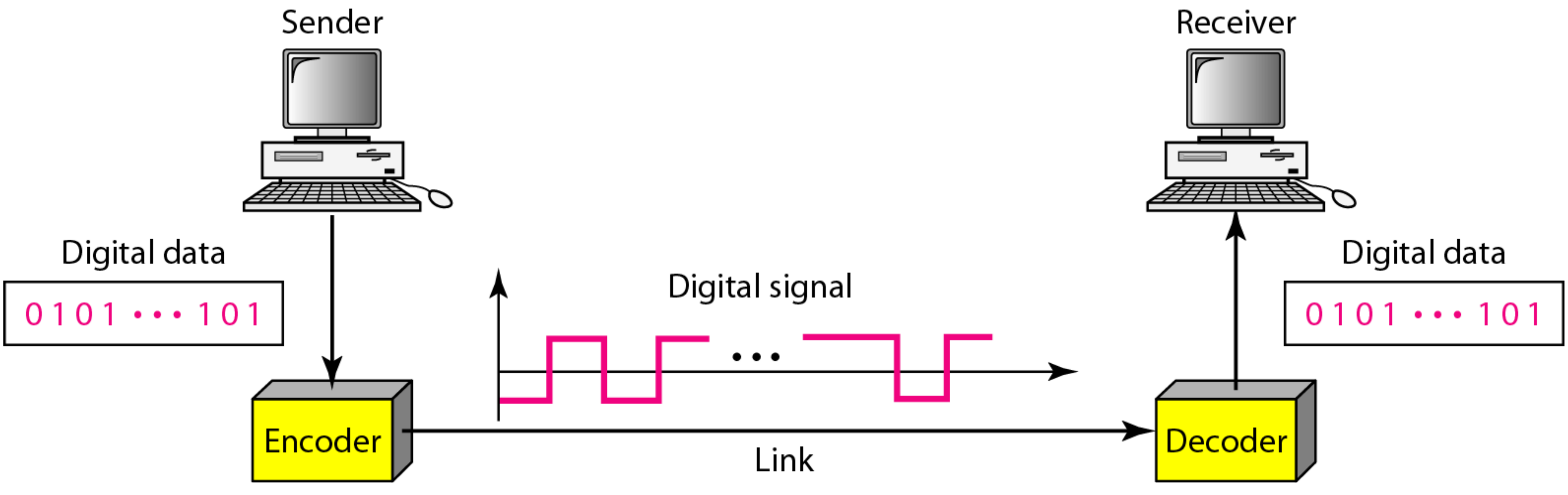
1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

Digital Transmission

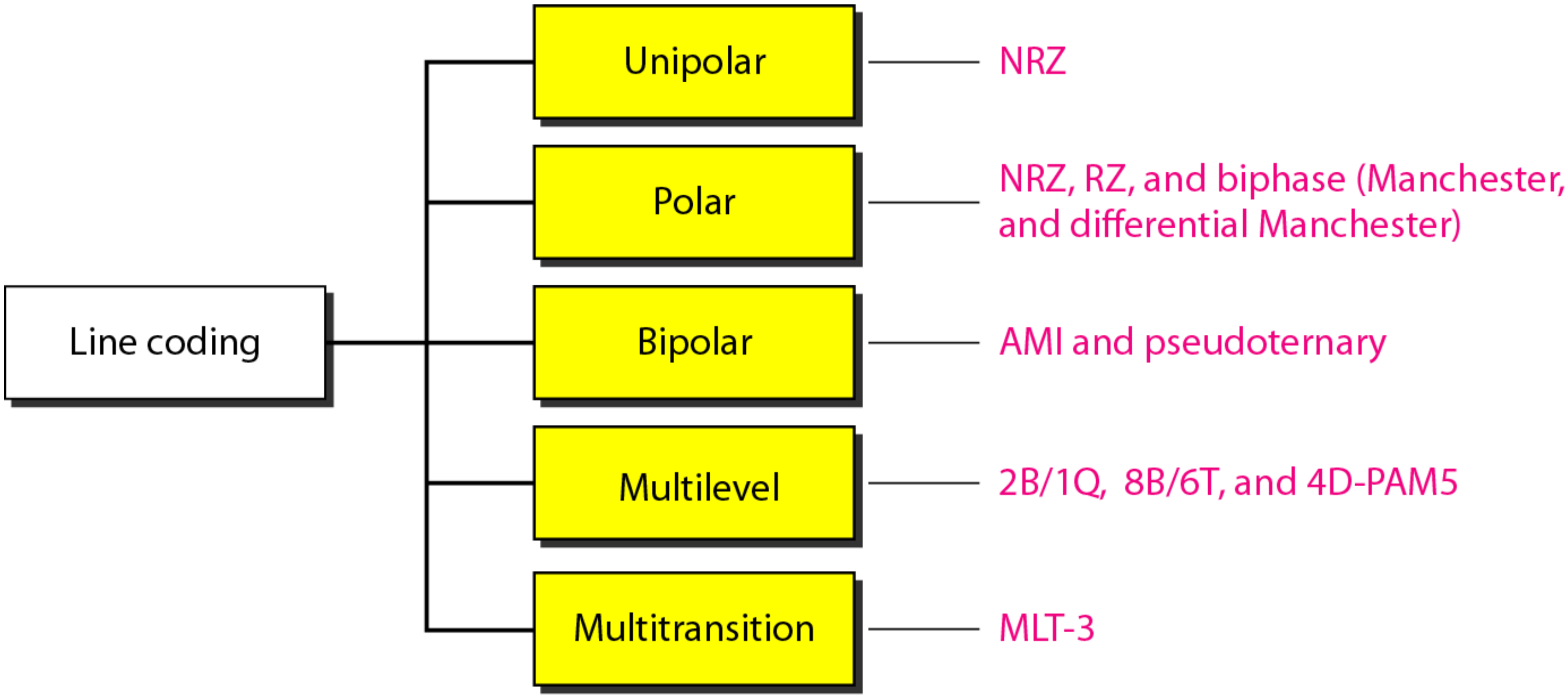
DIGITAL-TO-DIGITAL CONVERSION

- How we can represent digital data by using digital signals.
- The conversion involves three techniques: line coding, block coding, and scrambling.
- Line coding is always needed; block coding and scrambling may or may not be needed.

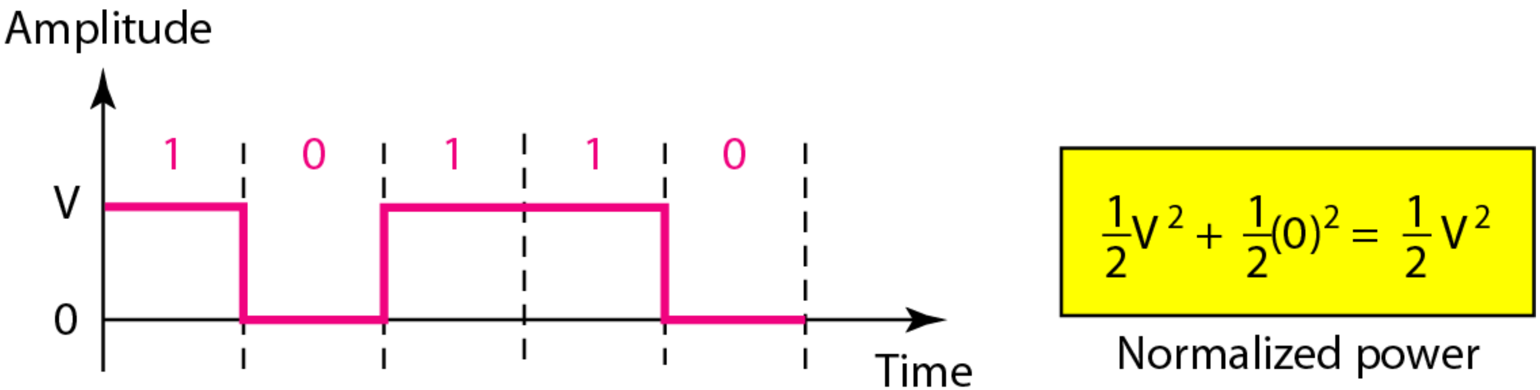
Line coding and decoding



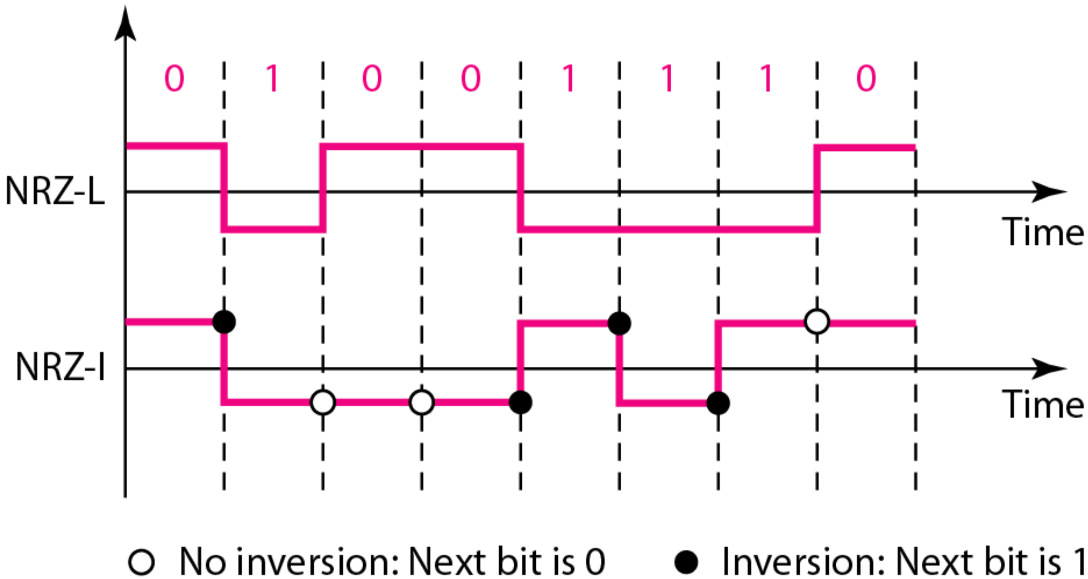
Line coding schemes

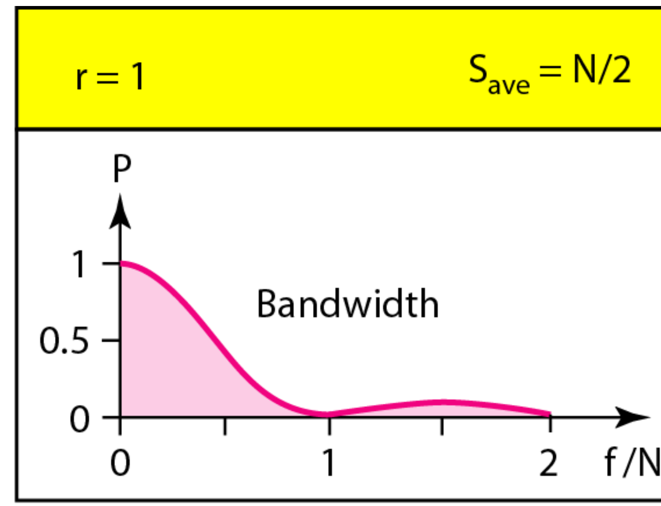


Unipolar NRZ scheme



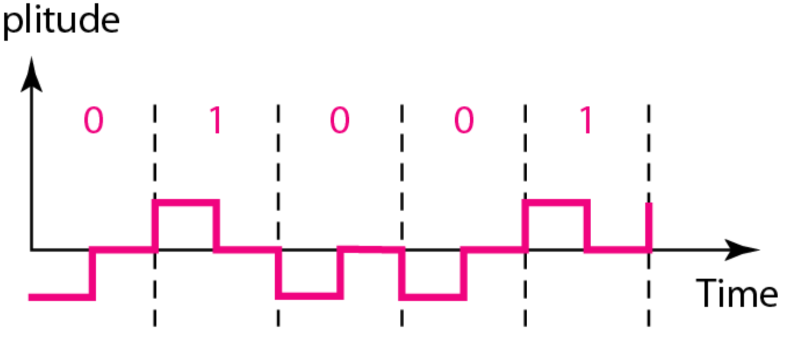
Polar NRZ-L and NRZ-I schemes

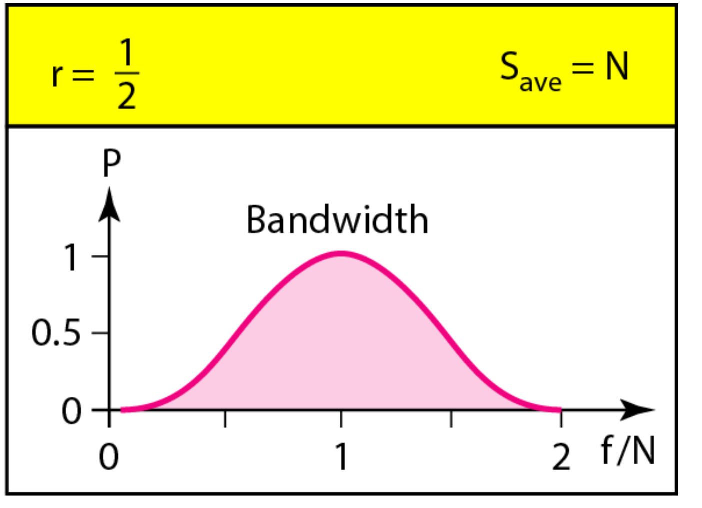




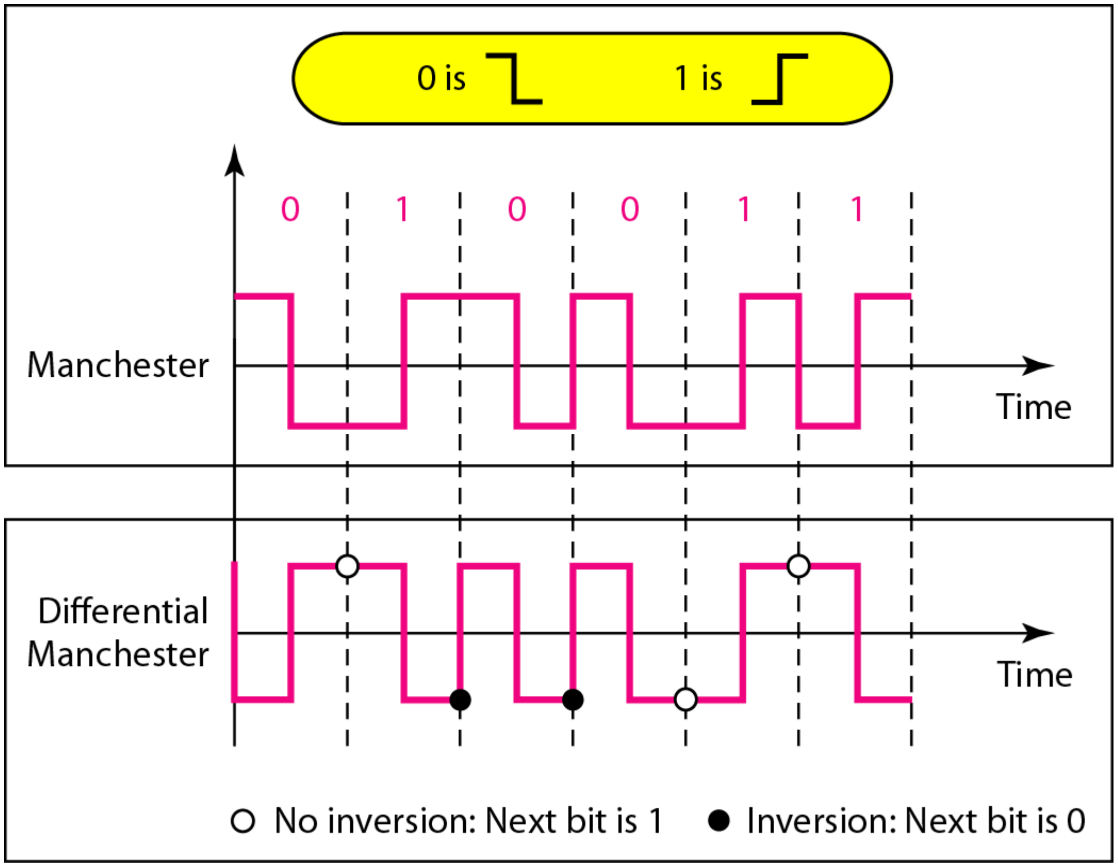
- In NRZ-L the level of the voltage determines the value of the bit.
- In NRZ-I the inversion or the lack of inversion determines the value of the bit.

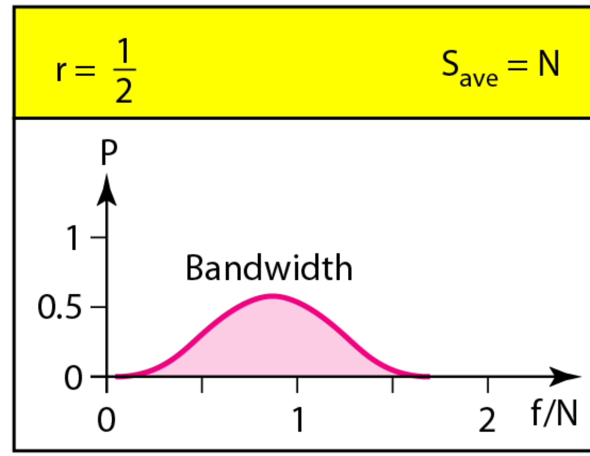
Polar RZ scheme





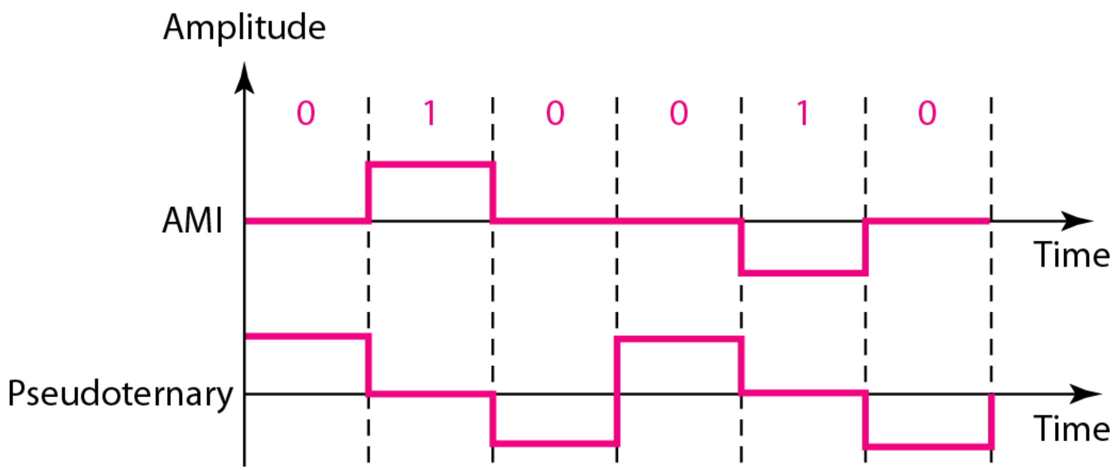
Polar biphase: Manchester and differential Manchester schemes

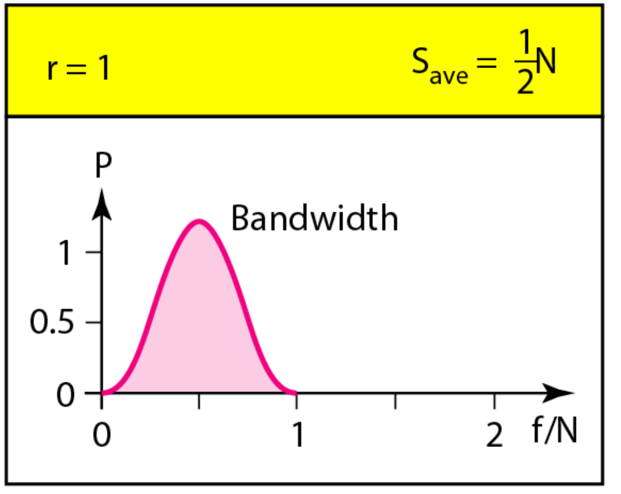




- In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.
- The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Bipolar schemes





In bipolar encoding, we use three levels: positive, zero, and negative.

Summary of line coding schemes

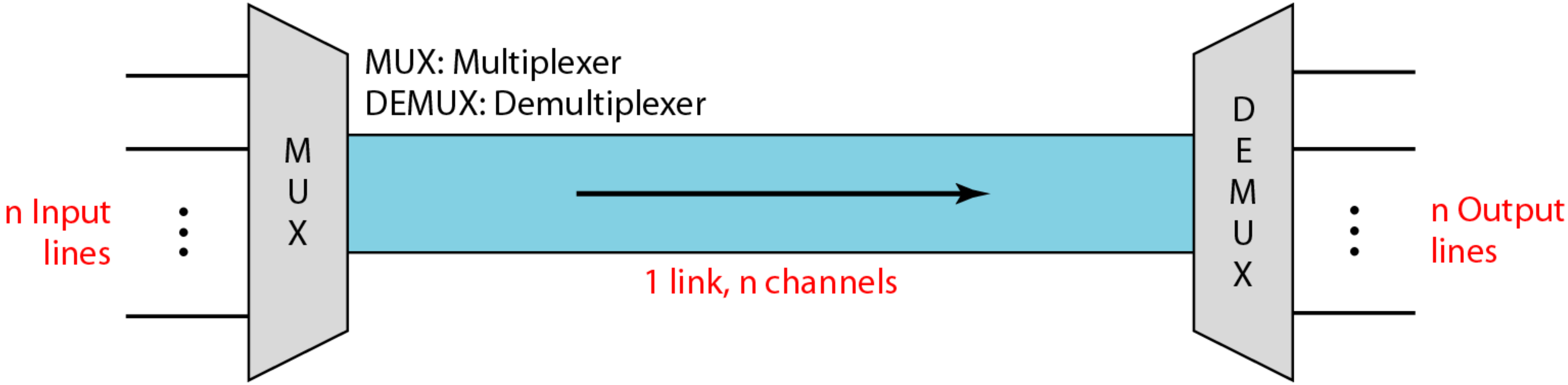
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

Bandwidth Utilization: Multiplexing

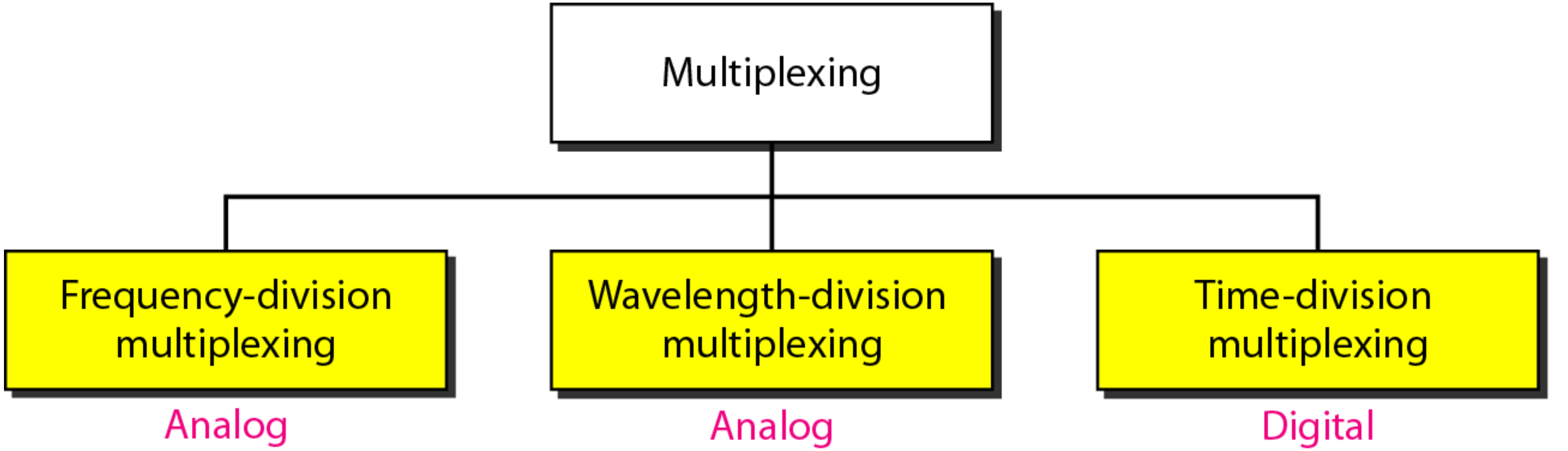
MULTIPLEXING

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.

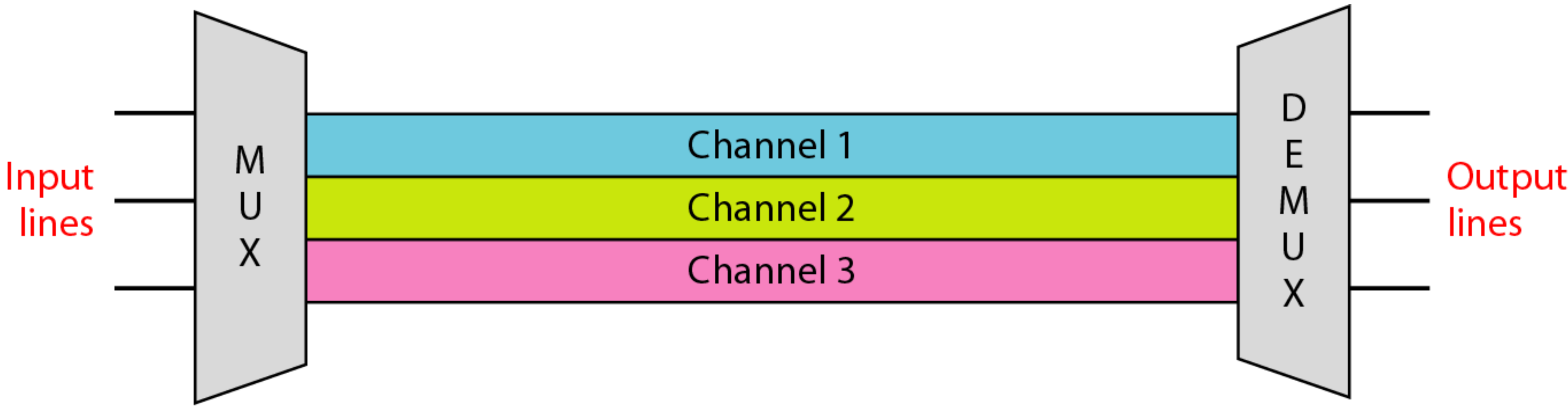
Dividing a link into channels



Categories of multiplexing

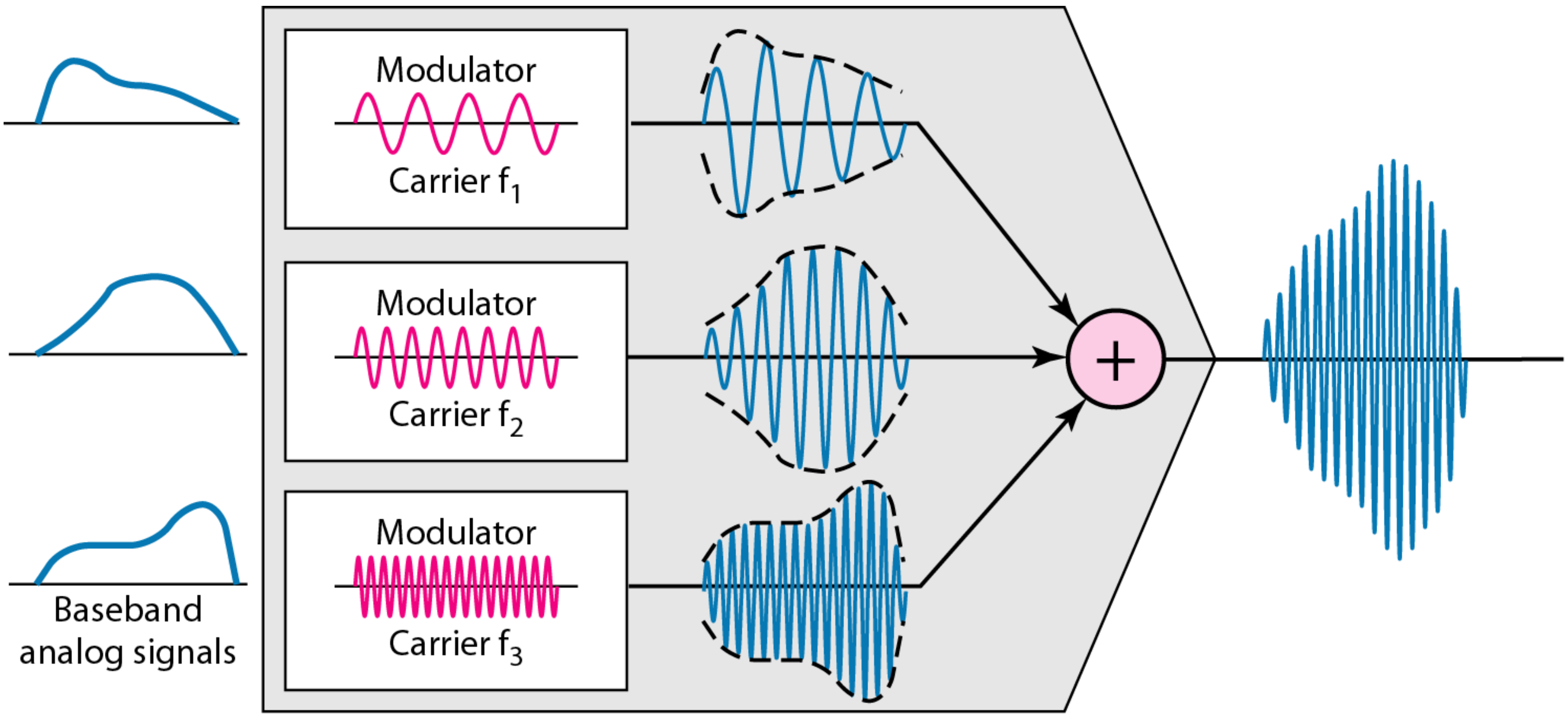


Frequency-division multiplexing

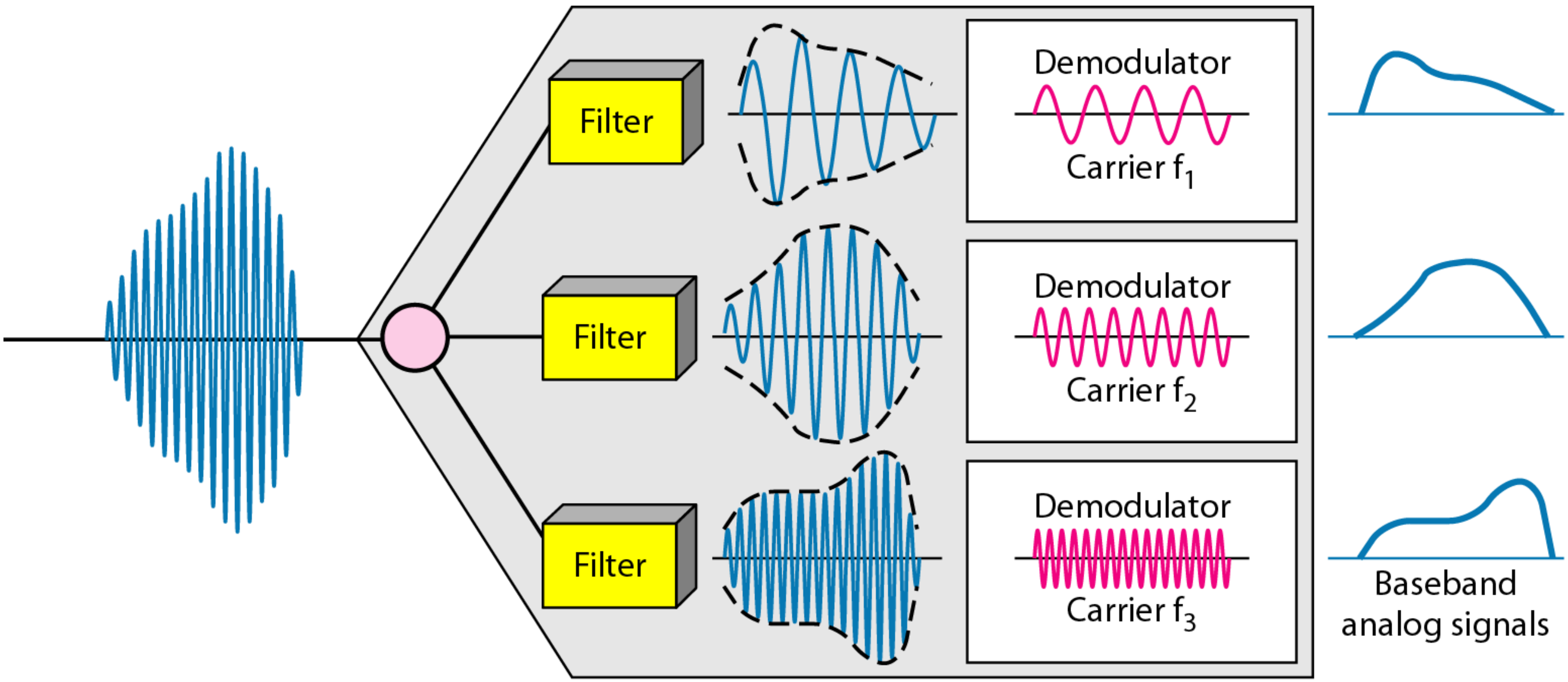


FDM is an analog multiplexing technique that combines analog signals

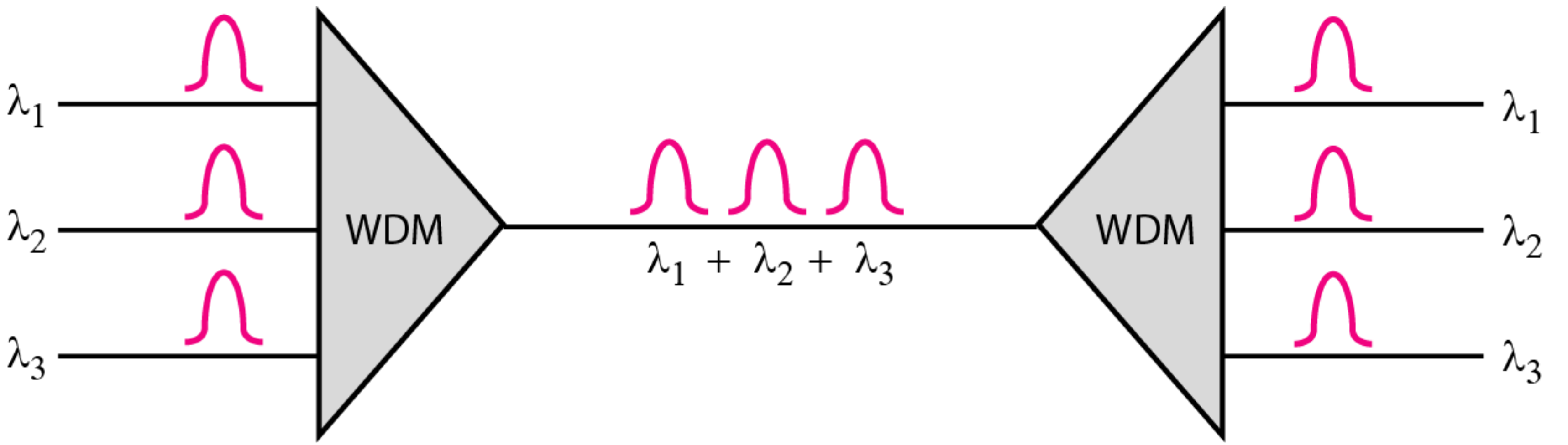
FDM process


Modulator
Carrier f1
Modulator
Carrier f2
Modulator
Carrier f3
+
Baseband
analog signals

FDM demultiplexing example

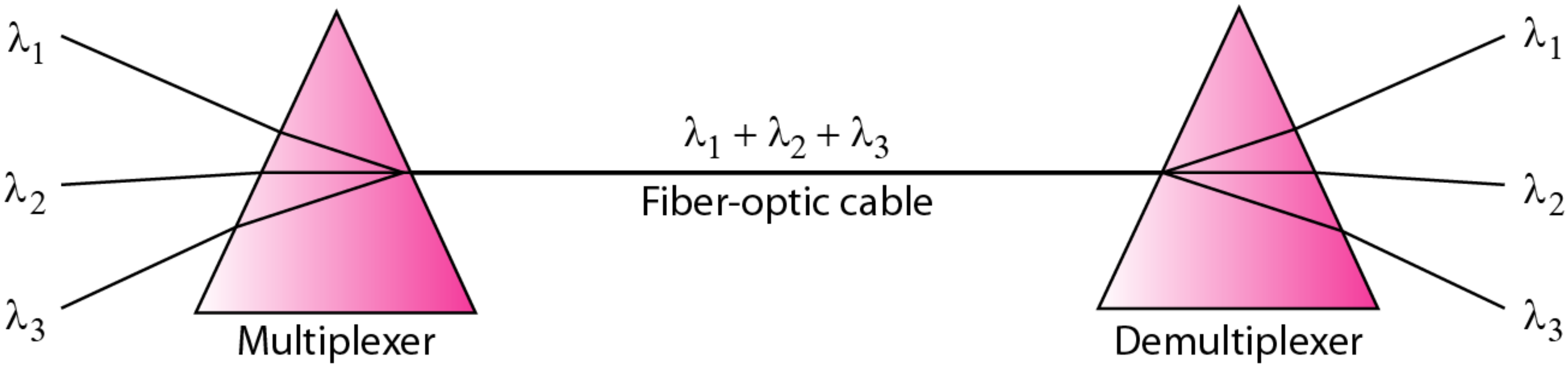


Wavelength-division multiplexing

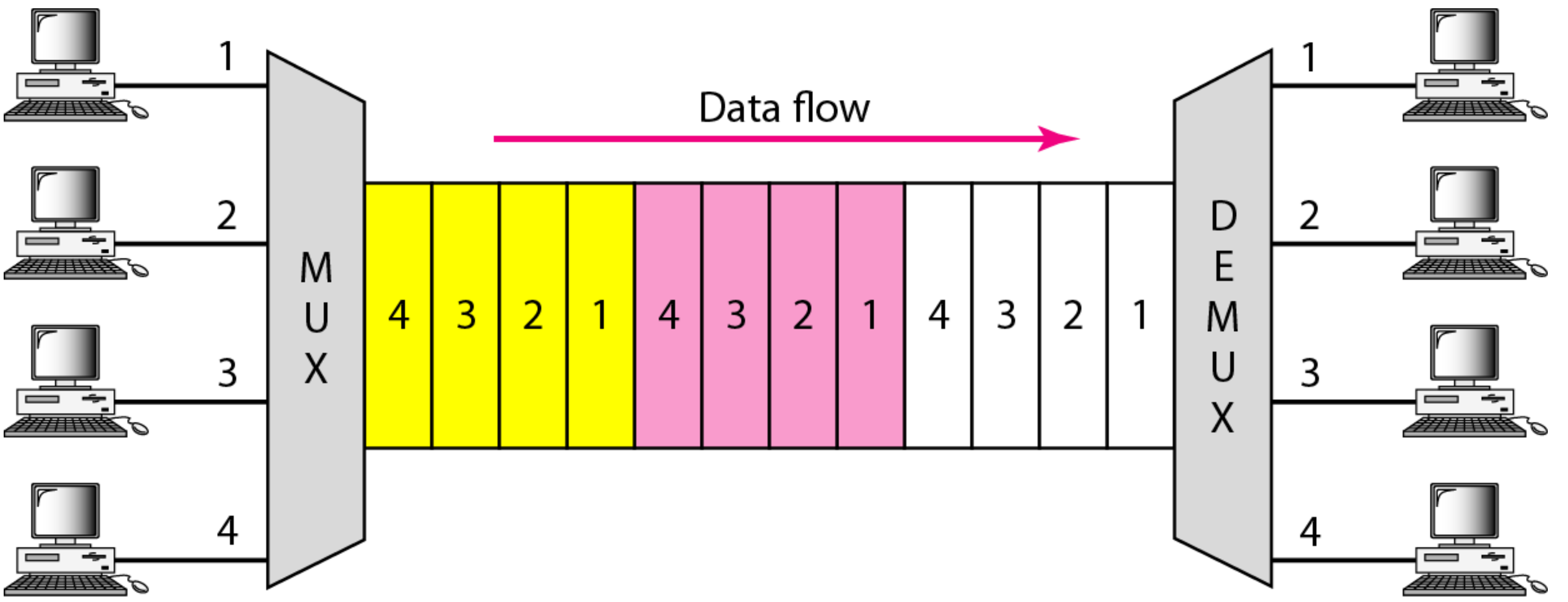


WDM is an analog multiplexing technique to combine optical signals.

Prisms in wavelength-division multiplexing and demultiplexing



TDM



TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.