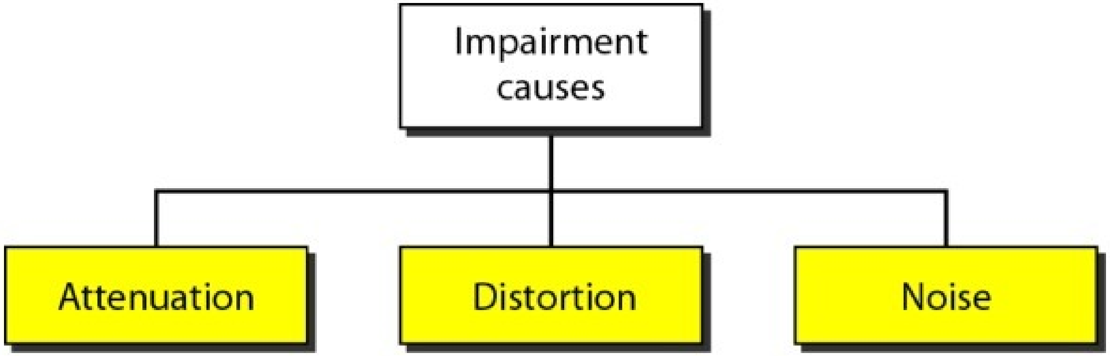
# Chapter 3: Data and Signals

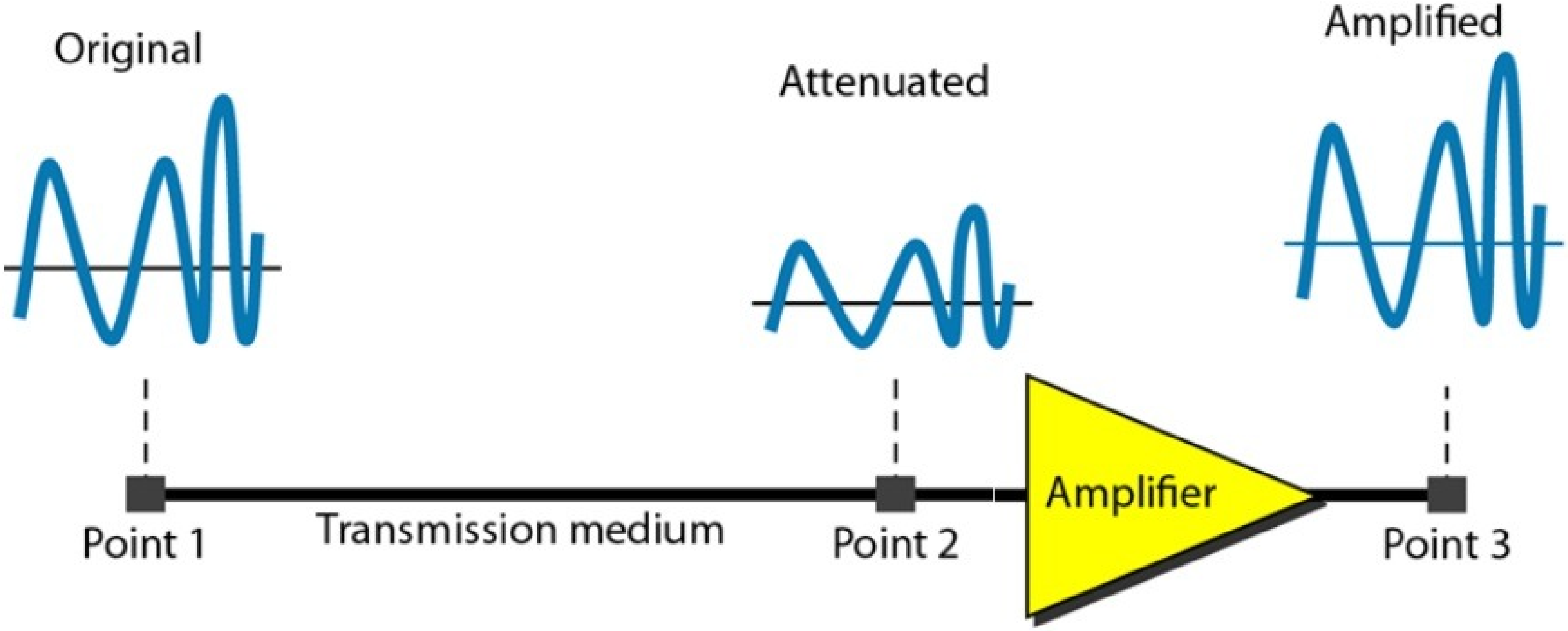
- 3.1 Analog and Digital
- 3.2 Periodic Analog Signals
- 3.3 Digital Signals
- 3.4 Transmission Impairment
- 3.5 Data-rate Limits
- 3.6 Performance

# 3-4 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.



# Attenuation



# Example

Suppose a signal travels through a transmission medium and its power is reduced to one-half.

This means that $P_2$ is $(1/2)P_1$.

In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

# Example

A signal travels through an amplifier, and its power is increased 10 times.

This means that $P_2 = 10P_1$.

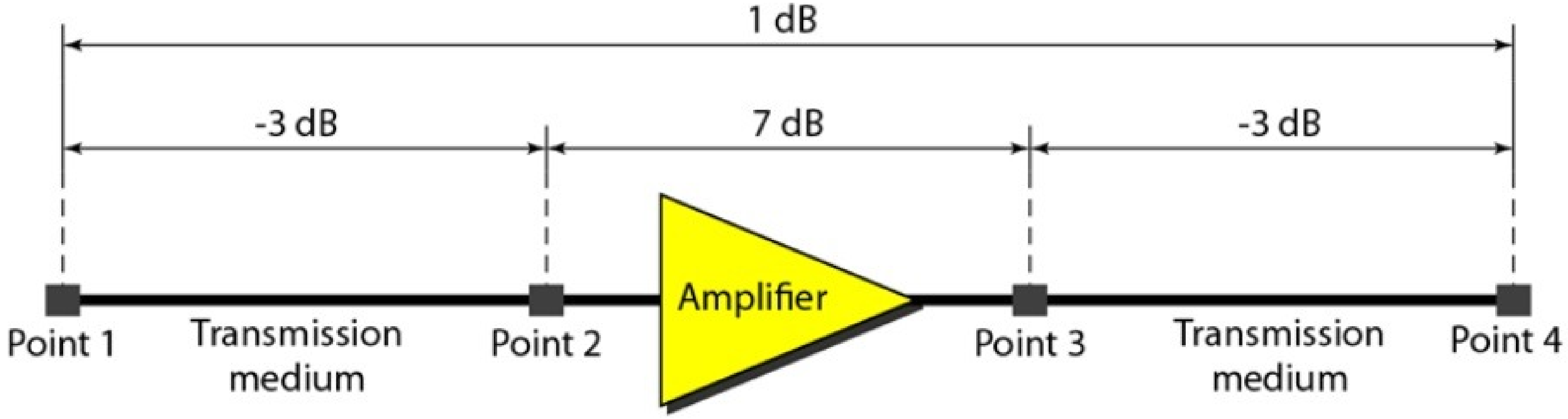
What is the amplification (gain of power)?

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}}$$

$$\boxed{= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}}$$

# Example

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two.
A signal travels from point 1 to point 4.




In this case, the decibel value can be calculated as

$$\boxed{dB = -3 + 7 - 3 = +1}$$

# Example

Sometimes the decibel is used to measure signal power in milliwatts.

In this case, it is referred to as $dB_m$ and is calculated as $dB_m$ = 10 log10 $P_m$ , where $P_m$ is the power in milliwatts.

Calculate the power of a signal with $dB_m = -30$.

Solution

We can calculate the power in the signal as

$$\mathrm{dB_m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW}$$

# Example

The loss in a cable is usually defined in decibels per kilometer (dB/km).

If the signal at beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

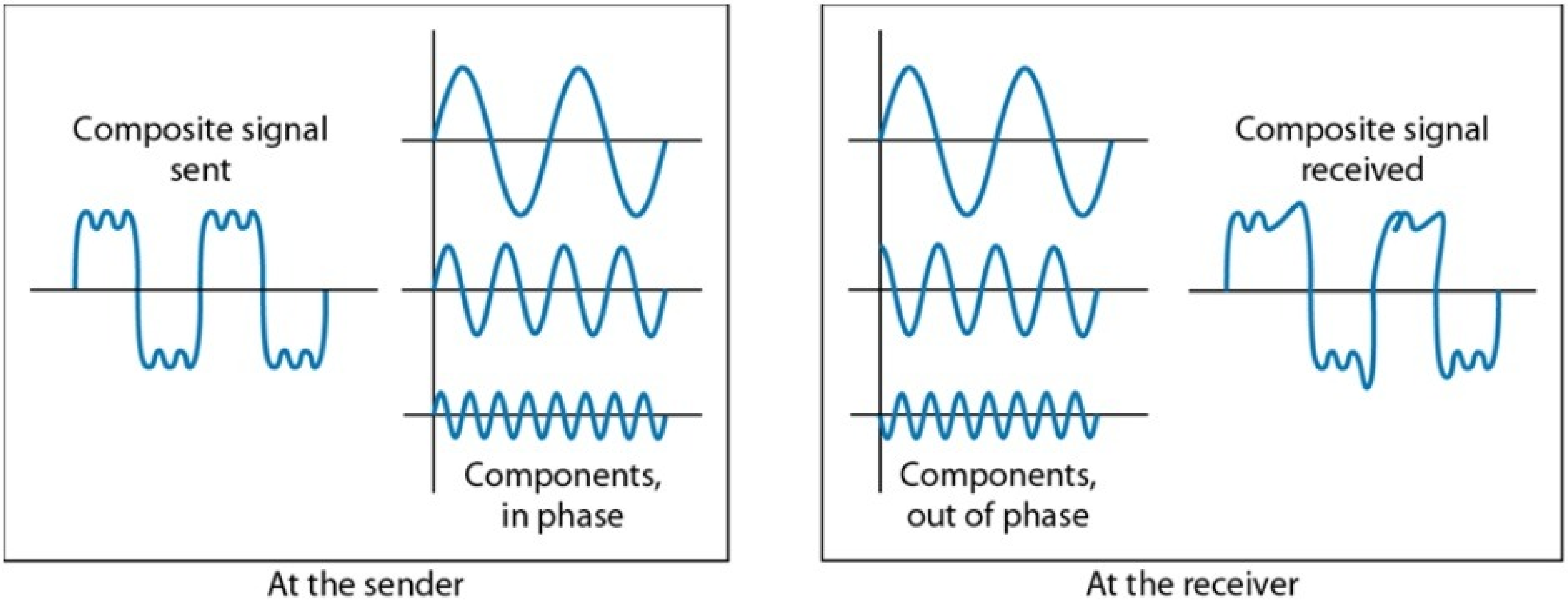
The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

$$\mathrm{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

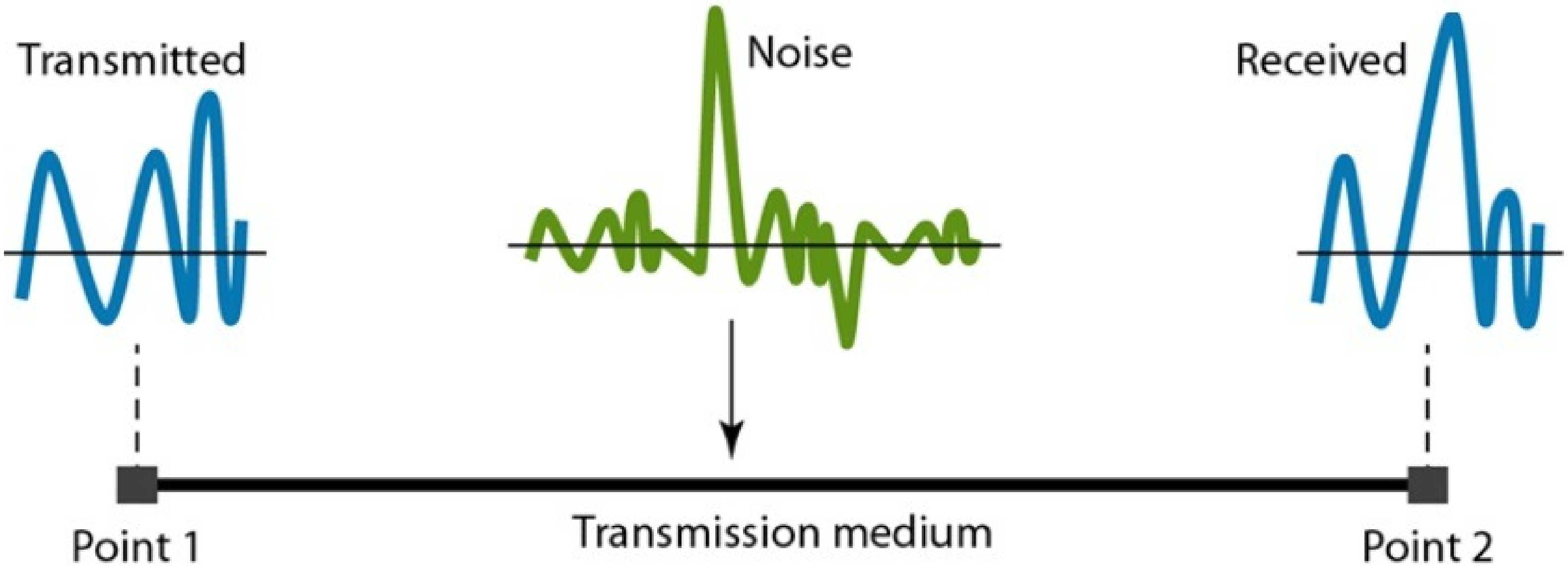
$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

# Distortion

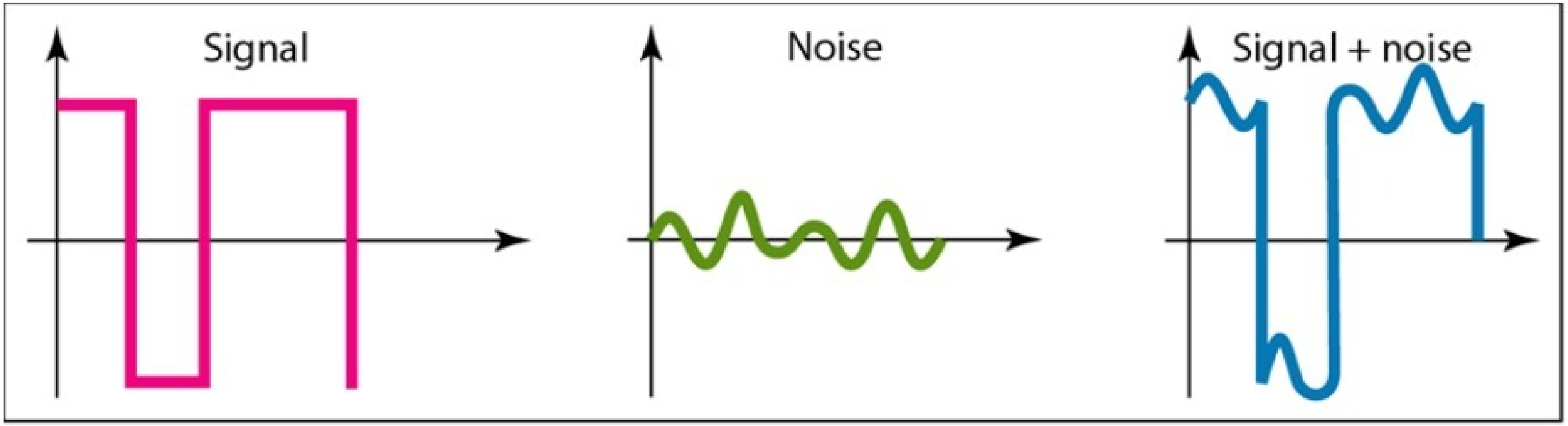

Composite signal
sent
Components,
in phase
At the sender
Components,
out of phase
Composite signal
received
At the receiver

# Noise

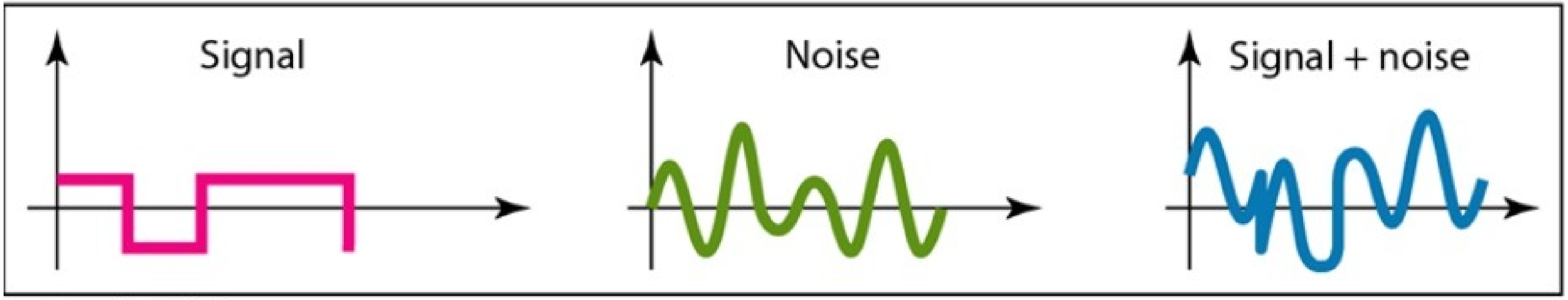


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

# *Signal-to-Noise Ratio (SNR): high vs. low*




a. Large SNR




b. Small SNR

# *Example*

The power of a signal is 10 mW and the power of the noise is 1 μW;
what are the values of SNR and $SNR_{dB}$?

Solution
The values of SNR and SNRdB can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ \mu W} = 10{,}000$$
$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

# Example

The values of SNR and $SNR_{dB}$ for a noiseless channel are

$$\boxed{\begin{aligned} SNR &= \frac{\text{signal power}}{0} = \infty \\ SNR_{dB} &= 10 \log_{10} \infty = \infty \end{aligned}}$$

We can never achieve this ratio in real life;
it is an ideal.

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# 3-5 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)

Increasing the levels of a signal may reduce the reliability of the system.

# Nyquist Theorem

For noiseless channel,

$$\text{BitRate} = 2 \times \text{Bandwith} \times \log_2 \text{Levels}$$

In baseband transmission, we said the bit rate is 2 times the bandwidth if we use only the first harmonic in the worst case.

However, the Nyquist formula is more general than what we derived intuitively;

It can be applied to baseband transmission and modulation.

Also, it can be applied when we have two or more levels of signals.

# Examples

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels.
What is the maximum bit rate?

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits).
What is the maximum bit rate?

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

# Example

We need to send 265 Kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate.

If we have 128 levels, the bit rate is 280 Kbps.

If we have 64 levels, the bit rate is 240 Kbps.

# Shannon Capacity

In reality, we can not have a noiseless channel

For noisy channel,

$$\text{Capacity} = \text{Bandwith} \times \log_2(1+\text{SNR})$$

The Shannon capacity gives us the upper limit;
the Nyquist formula tells us how many signal levels we need.

# Example

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero.

In other words, the noise is so strong that the signal is faint.

What is the channel capacity?

Solution

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0$$

This means that the capacity of this channel is zero regardless of the bandwidth.

We cannot receive any data through this channel.

# Example

Let's calculate the theoretical highest bit rate of a regular telephone line.

A telephone line normally has a bandwidth of 3000 Hz.

The signal-to-noise ratio is usually 3162.

What is the channel capacity?

Solution

$$C = B \log_2 (1 + \mathrm{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 Kbps.

If we want to send data faster than this,

we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

# Example

The signal-to-noise ratio is often given in decibels.

Assume that $SNR_{dB}$ = 36 and

the channel bandwidth is 2 MHz.

What is the theoretical channel capacity?

Solution

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

# Example

For practical purposes, when the SNR is very high, we can assume that SNR + 1 is almost the same as SNR.
In these cases, the theoretical channel capacity can be simplified to

$$C = B \times \frac{\mathrm{SNR_{dB}}}{3}$$

For example, we can calculate the theoretical capacity of the previous example as

$$C = 2\ \mathrm{MHz} \times \frac{36}{3} = 24\ \mathrm{Mbps}$$

# Example

We have a channel with a 1-MHz bandwidth.
The SNR for this channel is 63.
What are the appropriate bit rate and signal level?

Solution
First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

The Shannon formula gives us 6 Mbps, the upper limit.
For better performance we choose something lower,
4 Mbps, for example.
Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \longrightarrow \quad L = 4$$

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# 3-6 PERFORMANCE

One important issue in networking is the performance of the network

— how good is it?

*In networking, we use the term bandwidth in two contexts*

The first, bandwidth in hertz,
refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.

The second, bandwidth in bits per second,
refers to the speed of bit transmission in a channel or link.

# Examples

The bandwidth of a subscriber line is 4 kHz for voice or data.

The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog.

If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz,
we can send 112,000 bps.

# Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits.

What is the throughput of this network?

**Solution**

We can calculate the throughput as

$$\boxed{\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}}$$

The throughput is almost one-fifth of the bandwidth in this case.

# Example

What is the propagation time if the distance between two points is 12,000 km?

Assume the propagation speed to be $2.4 \times 10^8$ m/s in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

# Example

What are the *propagation time* and the *transmission time* for a 2.5-kbyte message if the bandwidth of the network is 1 Gbps?

Assume that the distance is 12,000 km and that light travels at $2.4 \times 10^8$ m/s.

**Solution**

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Note that in this case, the dominant factor is the propagation time, not the transmission time.

because the message is short and the bandwidth is high

The transmission time can be ignored.

# *Example*

What are the *propagation time* and the *transmission time* for a 5-Mbyte message if the bandwidth of the network is 1 Mbps?

Assume that the distance is 12,000 km and that light travels at $2.4 \times 10^8$ m/s.

Solution

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

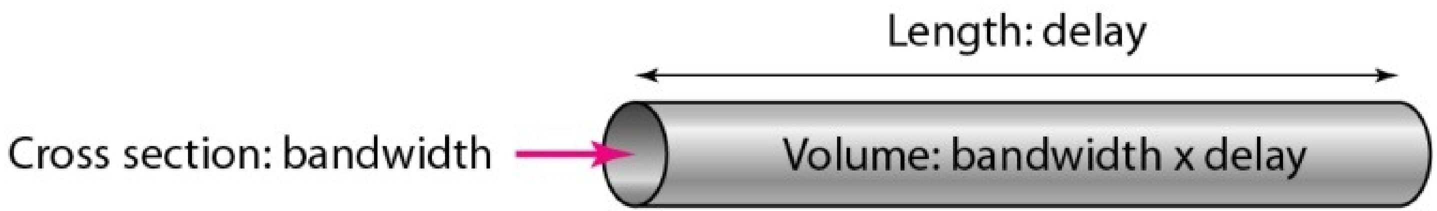
Note that in this case, the dominant factor is the transmission time, not the propagation time.

because the message is very long and the bandwidth is not very high

The propagation time can be ignored.

# *Concept of bandwidth-delay product*

The bandwidth-delay product defines the number of bits that can fill the link.

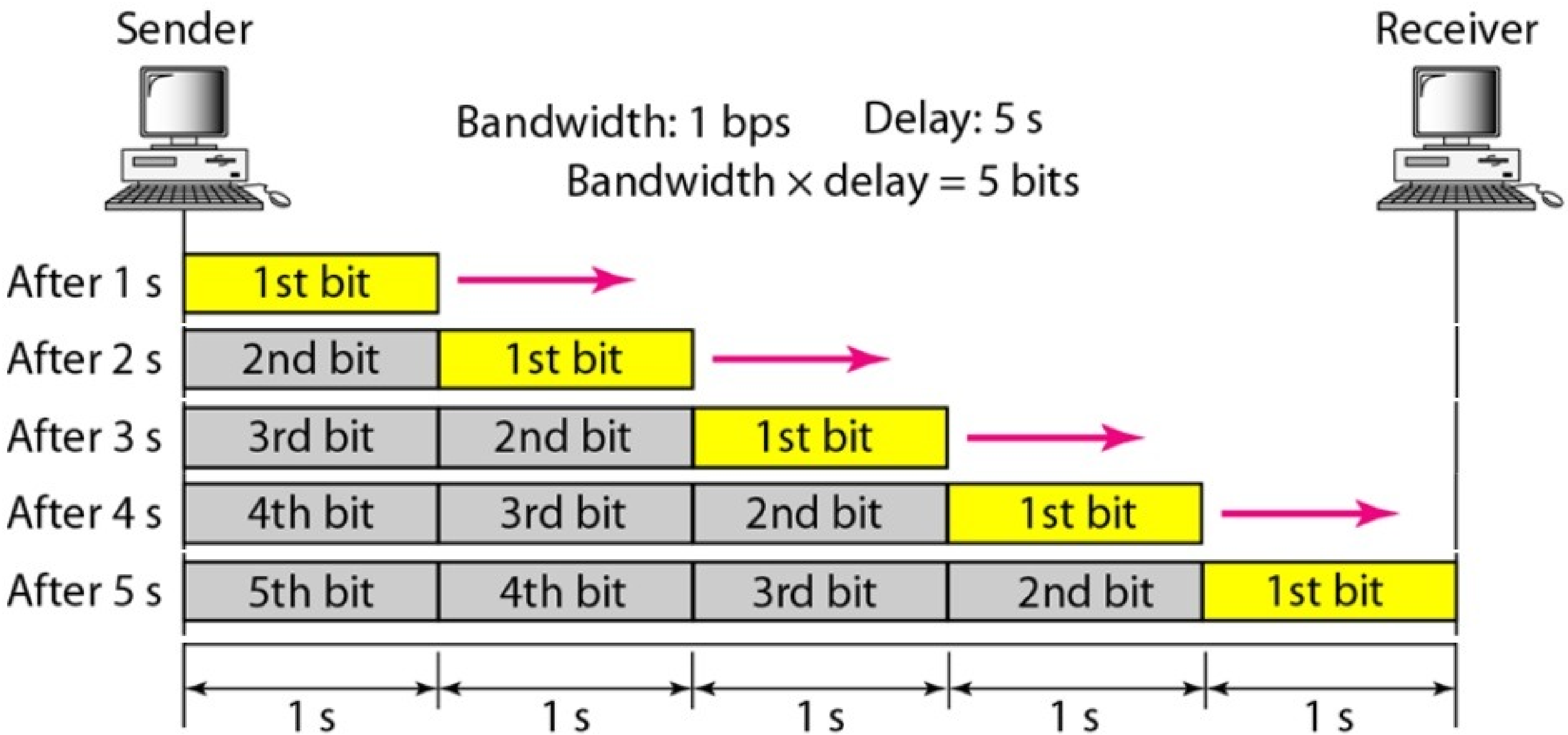



We can think about the link between two points as a pipe.

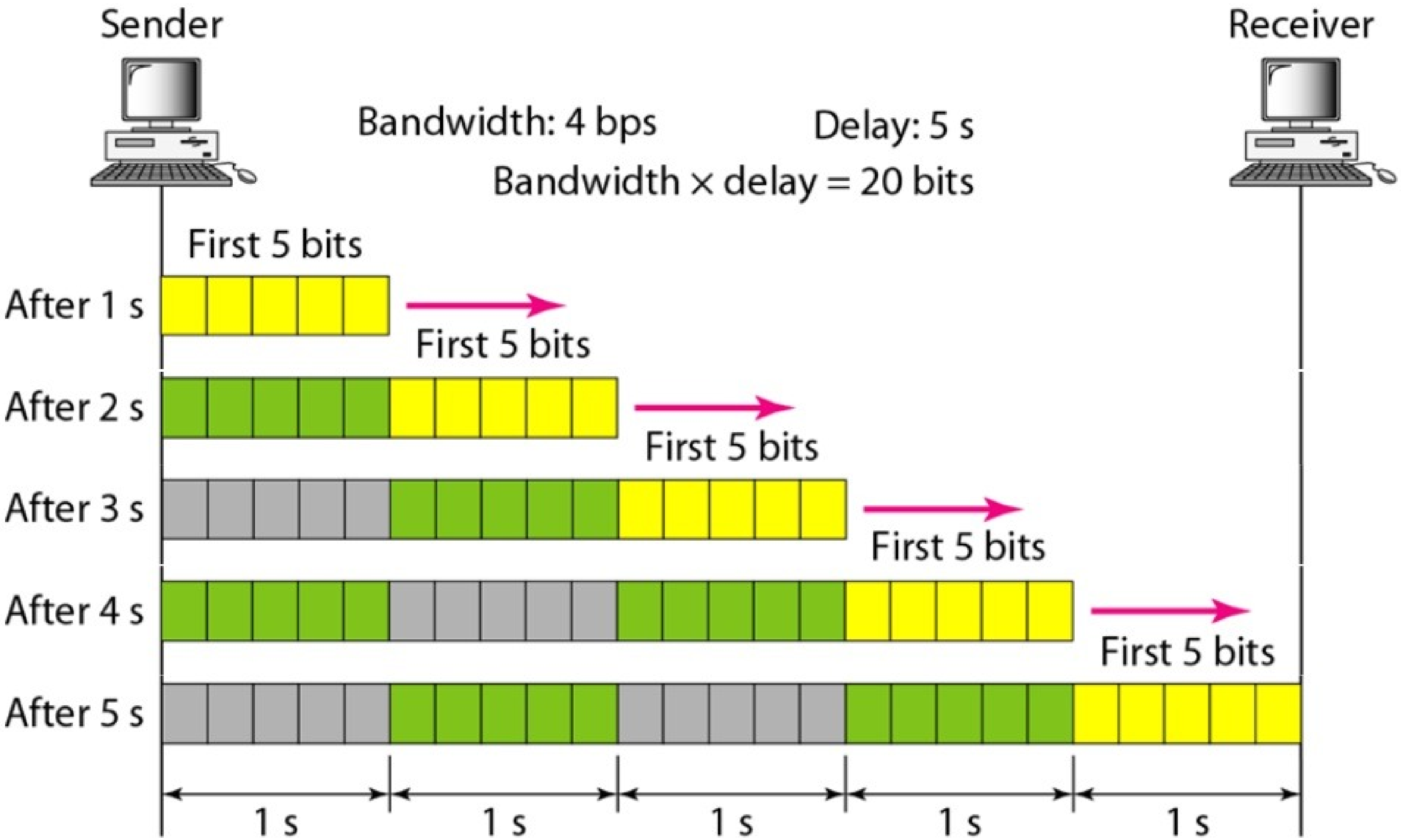
The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay.

We can say the volume of the pipe defines the bandwidth-delay product.

# *Filling the link with bits in case 1*

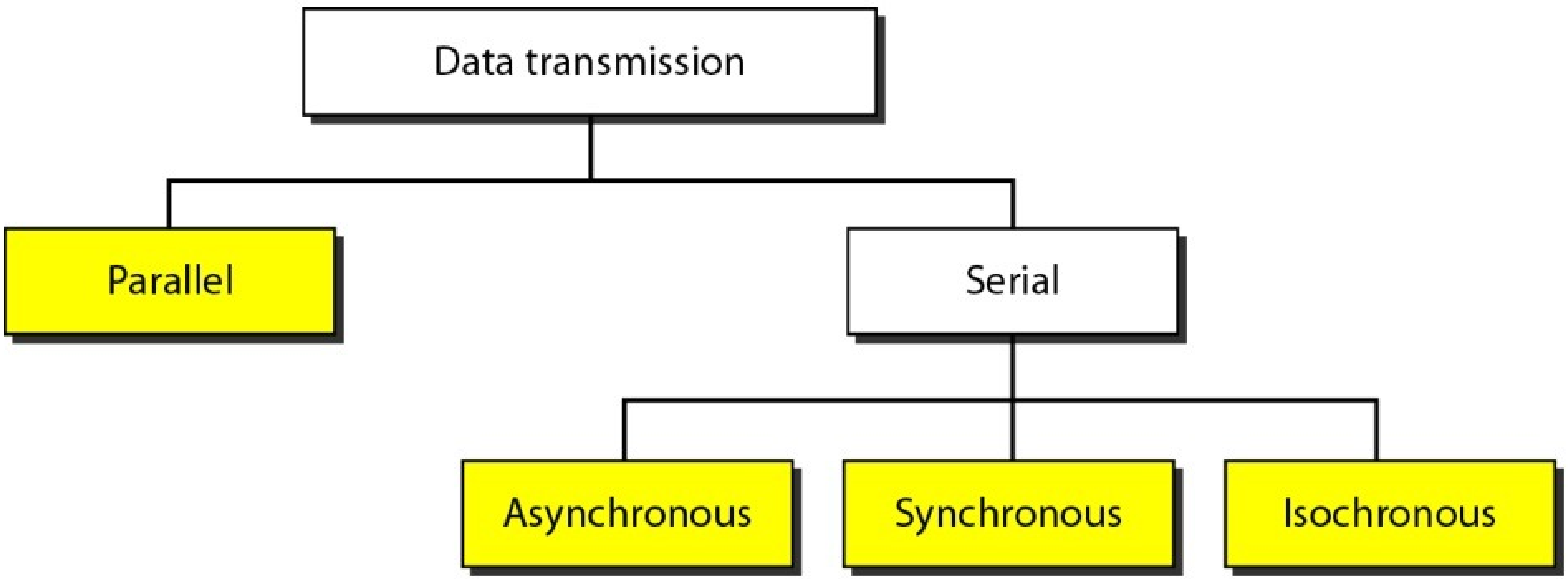


# Filling the link with bits in case 2



# Chapter 4

- 4.3 Transmission Modes
  - Parallel Transmission
  - Serial Transmission



# *4-3 TRANSMISSION MODES*

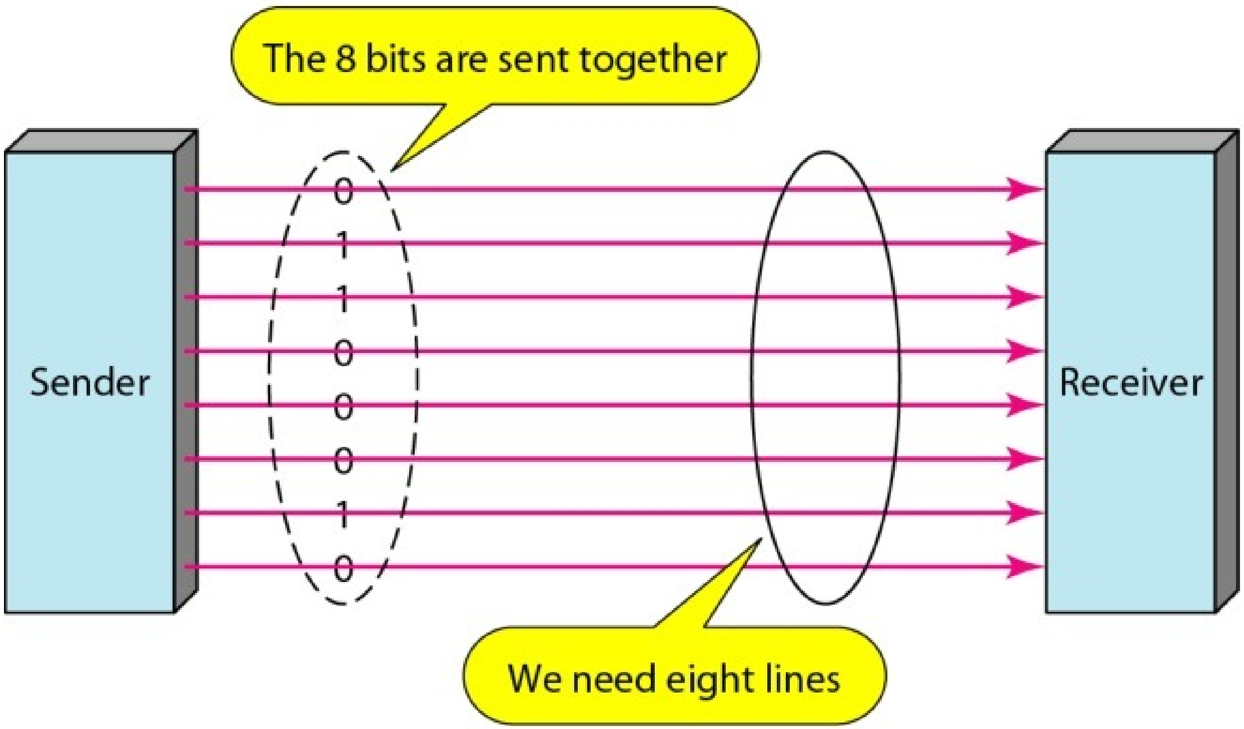
- The transmission of binary data across a link can be accomplished in either parallel or serial mode.

- In parallel mode, multiple bits are sent with each clock tick.

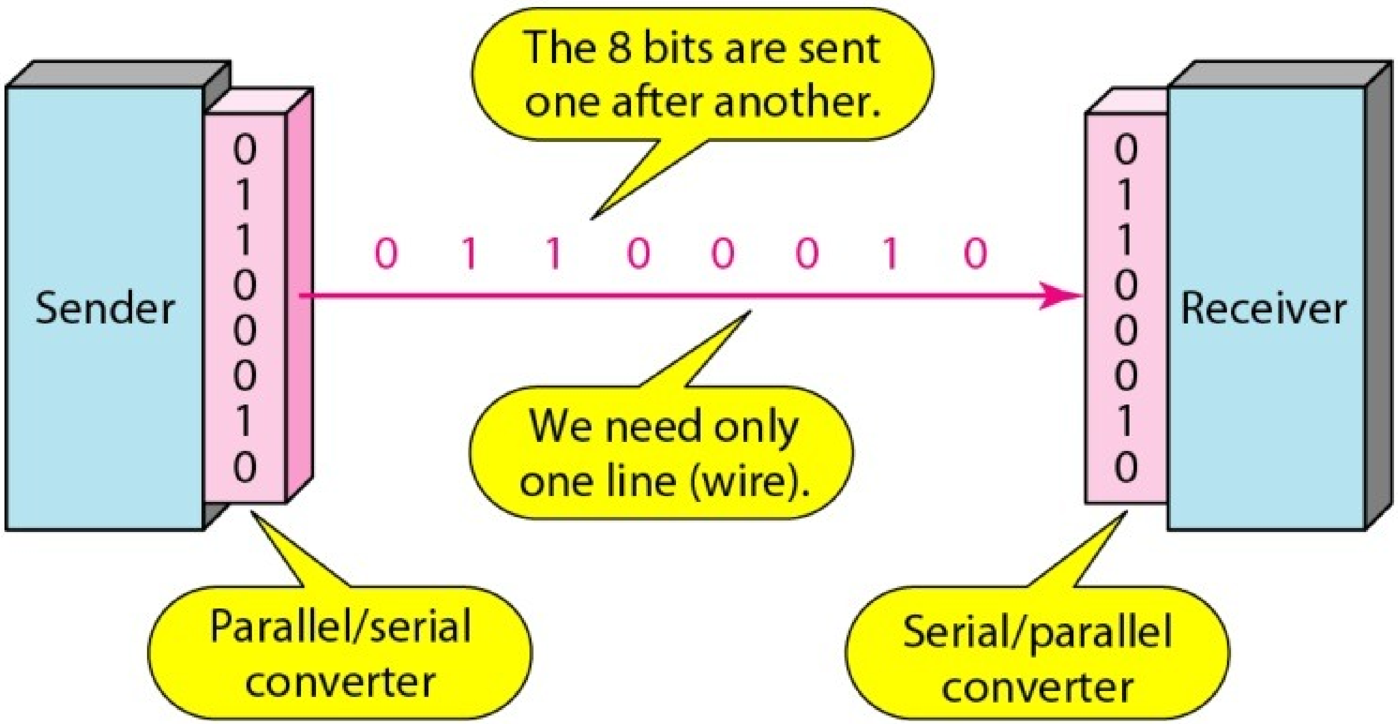
- In serial mode, 1 bit is sent with each clock tick.

- While there is only one way to send parallel data, there are three subclasses of serial transmission: *asynchronous*, *synchronous*, and *isochronous*.

# *Parallel transmission*

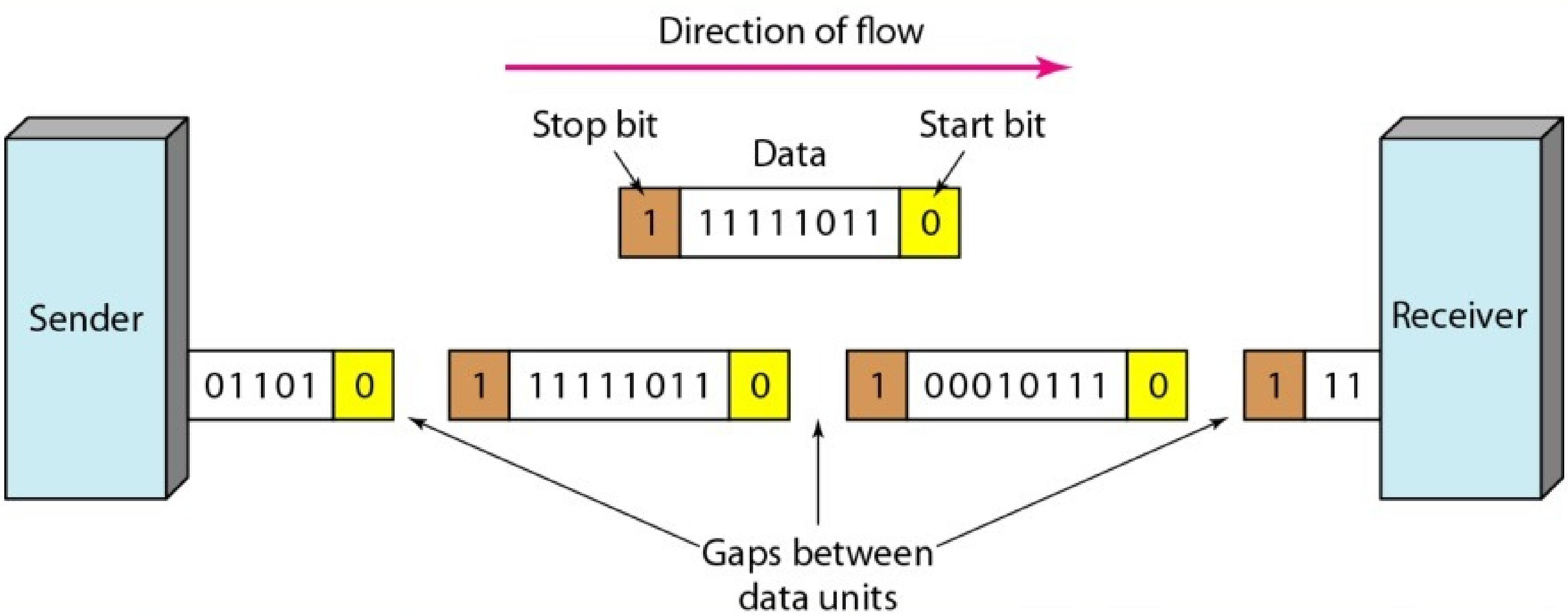


# *Serial transmission*



## *Asynchronous transmission*

We send 1 start bit (0) at the beginning and
1 or more stop bits (1s) at the end of each byte.
There may be a gap between each byte.




*It is "asynchronous at the byte level," bits are still synchronized; their durations are the same.*

# *Synchronous transmission*

We send bits one after another without start or stop bits or gaps.
It is the responsibility of the receiver to group the bits.