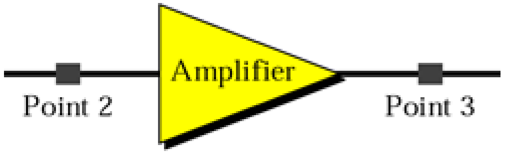
Transmission Impairments: Attenuation (cont.)

how many times the output signal has attenuated relative to the input signal – **should be ≥1**

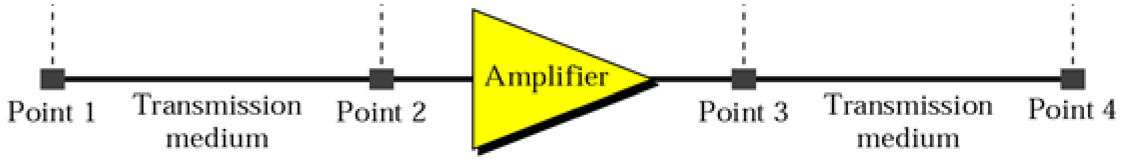
$$L(f) = \frac{P_{in}(f)}{P_{out}(f)} = \frac{A_{in}(f)^2}{A_{out}(f)^2}$$

how many times the output signal has been amplified relative to the input signal – **should be ≥1**

$$G(f) = \frac{P_{out}(f)}{P_{in}(f)} = \frac{1}{L(f)}$$



In multi-cascade system



$$L(f) = L_1(f) \cdot L_2(f) \cdot L_2(f) \cdot \ldots$$

$$L(f)[dB] = L_1(f)[dB] + L_2(f)[dB] + L_2(f)[dB] + \ldots$$

Transmission Impairments: Attenuation (cont.)

$$L\,[dB] \leftrightarrow G\,[dB]$$

$$L[dB] = 10 \cdot \log \frac{P_{in}}{P_{out}}\,[dB] = 10 \cdot \log \left(\frac{P_{out}}{P_{in}}\right)^{-1}\,[dB] = -10\log \frac{P_{out}}{P_{in}} = -G[db]$$

$$G\,[dB] = -L\,[dB]$$

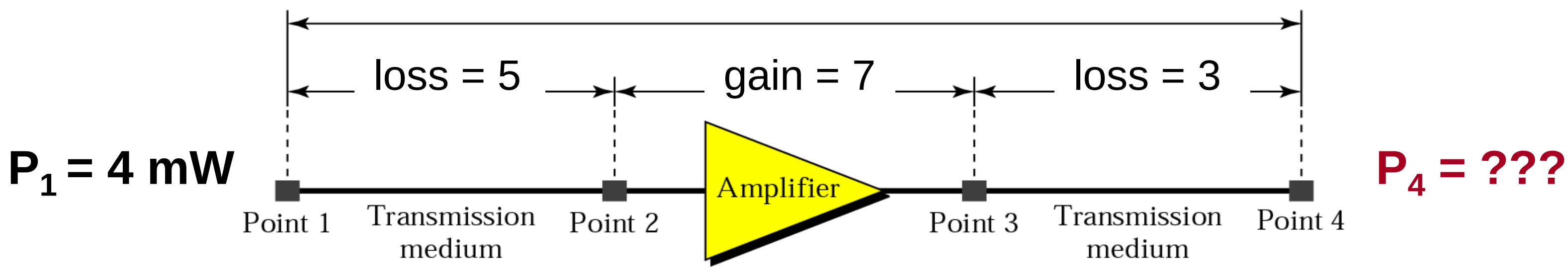
Transmission Impairments: Attenuation (cont.)

Example [attenuation]

Consider a series of transmission elements as shown in the figure below.

The input signal has the power of P_1 = 4 mW. The 1st element is a transmission line with a loss of **5 (x)**, the 2nd element is an amplifier with a gain of **7 (x)**, and the 3rd element is a transmission line with a loss of **3 (x)**.

Calculate the output power P_4.



$$G = \frac{1}{L} = \frac{P_4}{P_1} = \frac{P_4}{P_3} \cdot \frac{P_3}{P_2} \cdot \frac{P_2}{P_1} = \frac{1}{5} \cdot \frac{7}{1} \cdot \frac{1}{3} = 0.47$$

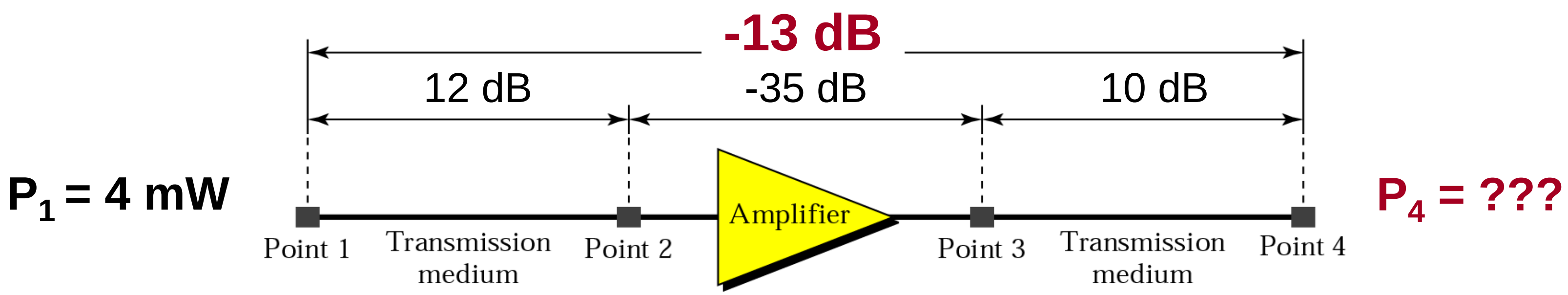
$$P_4 = G \cdot P_1 = 0.47 \cdot 4\,[\text{mW}] = 1.88\,[\text{mW}]$$

Example [attenuation]

Consider a series of transmission elements as shown in the figure below.

The input signal has the power of P_1 = 4 mW. The 1st element is a transmission line with a 12 dB loss, the 2nd element is an amplifier with a 35 dB gain, and the 3rd element is a transmission line with a 10 dB loss.

Calculate the output power P_4.



$$10 \cdot \log \frac{P_{in}}{P_{out}} = -13 \text{ [dB]} \qquad \frac{P_{in}}{P_{out}} = 10^{-1.3} \text{ [dB]}$$

$$P_{out} = \frac{P_{in}}{10^{-1.3}} = P_{in} \cdot 10^{1.3} = 4 \cdot 19.95 = 79.8 \text{ [mW]}$$

Example [attenuation]

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

If the signal at the beginning of a cable with 0.3 dB/km has a power of P_1 = 2 mW, what is the power of the signal at 5km?

$$L_{total=5km} = 5 \cdot L_{1km} = 1.5 \text{ [dB]}$$

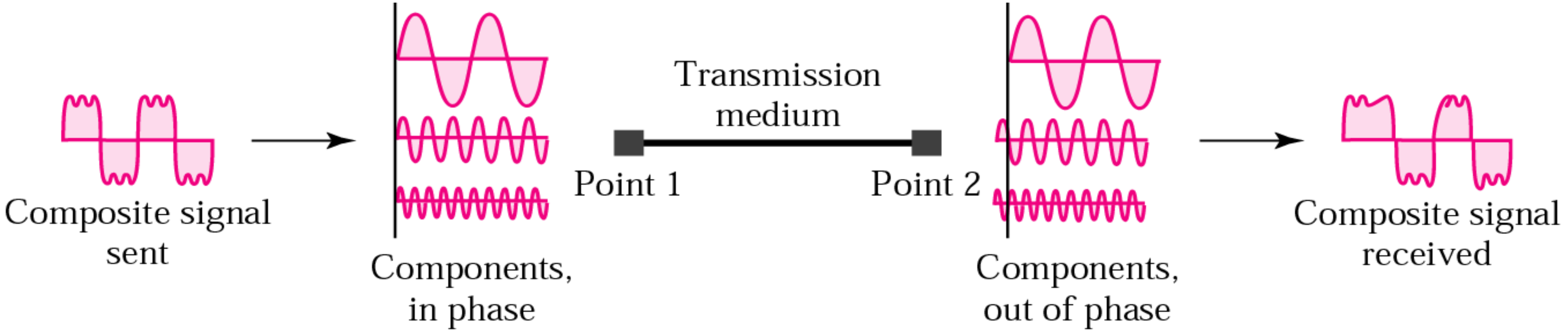
$$10 \cdot \log \frac{P_{in}}{P_{out}} = 1.5 \text{ [dB]} \qquad \frac{P_{in}}{P_{out}} = 10^{0.15} \text{ [dB]}$$

$$P_{out} = \frac{P_{in}}{10^{0.15}} = \frac{2 \text{ [mW]}}{1.41} = 1.41 \text{[mW]}$$

Transmission Impairments: Delay Distortion

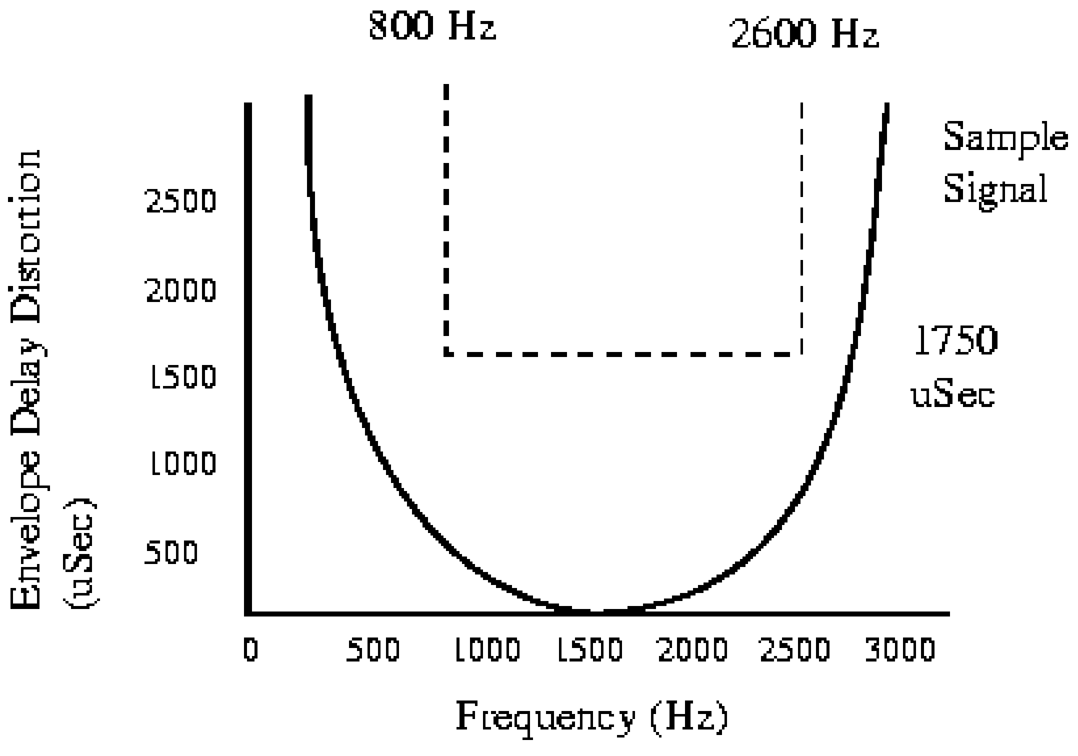
Delay Distortion – **change in signal's form / shape**

- **each signal component has its own <u>propagation speed</u> through a medium, and therefore, its own delay in arriving at the final destination**
- **critical for composite-analog and digital signals – some of the signal components of one bit position will spill over into other bit position, contributing to 'intersymbol interference'**
  - **one of major limitation to achieving high bit rates**
- **in bandlimited channels, <u>velocity tends to be highest near the center frequency and fall off towards the edges of the band</u>**



Transmission Impairments: Delay Distortion

Example **[delay distortion in telephone lines – measured in μsec]**



http://www.techbooksforfree.com/intro_to_data_com/page83.html

Transmission Impairments: Noise

Noise – **unwanted signals that get inserted / generated somewhere between transmitter and receiver**

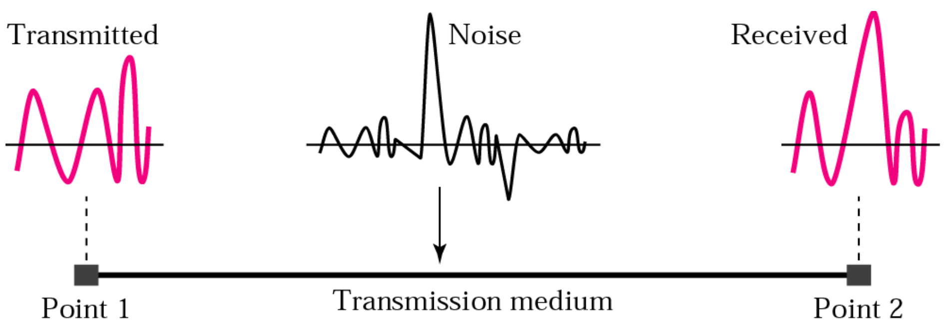
- **major limiting factor in communications system performance**
  - **cannot be predicted – appears at random!**
- **the presence of noise limits the reliability with which the receiver can correctly determine the information that was transmitted**
- **main categories of noise:**

  (1) thermal noise

  (2) intermodulation noise

  (3) crosstalk

  (4) impulse noise



Transmission Impairments: Noise (cont.)

(1) Thermal Noise – **result of random motion of electrons – appears in all electronic devices and transmission media – cannot be eliminated**

- **function of temperature**
- **uniformly distributed across frequency spectrum ⇒ aka white noise**
- **noise power density (N_o) = amount of thermal noise to be found in a bandwidth of 1Hz**

$$N_o = k \cdot T \text{ [W/Hz]}$$

where k = Boltzmann's constant = $1.3803 \cdot 10^{-23}$ [J/K]
T = temperature [K]

- **thermal noise (N) in [W] present in a bandwidth of B [Hz]**

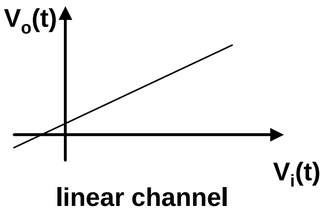
$$N = k \cdot T \cdot B \text{ [W]}$$

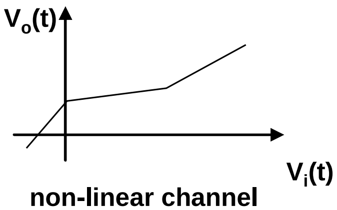
Example **Calculate N on 20C and 1GHz: N = k*(273+20)*10^9 = 3.8*10^{-12} .**

Transmission Impairments: Noise (cont.)

(2) Intermodulation Noise – signals that are sum / difference of original frequencies sharing a medium

- result of nonlinearity in transmission medium – output signal is a complex function of the input





(3) Crosstalk – effect of one wire on the other – one wire acts as a sending antenna and the other as the receiving antenna

- can be reduced by careful shielding and using twisted pairs
- of the same magnitude, or less, than thermal noise

(4) Impulse Noise – non-continuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude

- induced by external electromagnetic disturbances, such as lightening, faults and flaws in communication system

Transmission Impairments: Noise (cont.)

$$s_{in}(t) = \sin(2\pi f_1 t) + \sin(2\pi f_2 t)$$

Example [linear channel]

$$s_{out}(t) = k \cdot s_{in}(t)$$

$$s_{out}(t) = k \cdot \sin(2\pi f_1 t) + k \cdot \sin(2\pi f_2 t)$$

Example [non-linear channel]

$$s_{out}(t) = k \cdot \left(s_{in}(t)\right)^2$$

$$s_{out}(t) = k \cdot \left(\sin(2\pi f_1 t) + \sin(2\pi f_2 t)\right)^2 =$$

$$= k \cdot \left[\sin^2(2\pi f_1 t) + 2\sin(2\pi f_1 t)\sin(2\pi f_2 t) + \sin^2(2\pi f_2 t)\right] =$$

$$= k \cdot \left[\frac{1 - \cos(4\pi f_1 t)}{2} + \cos(2\pi(f_1 - f_2)t)) - \cos(2\pi(f_1 + f_2)t)) + \frac{1 - \cos(4\pi f_2 t)}{2}\right]$$

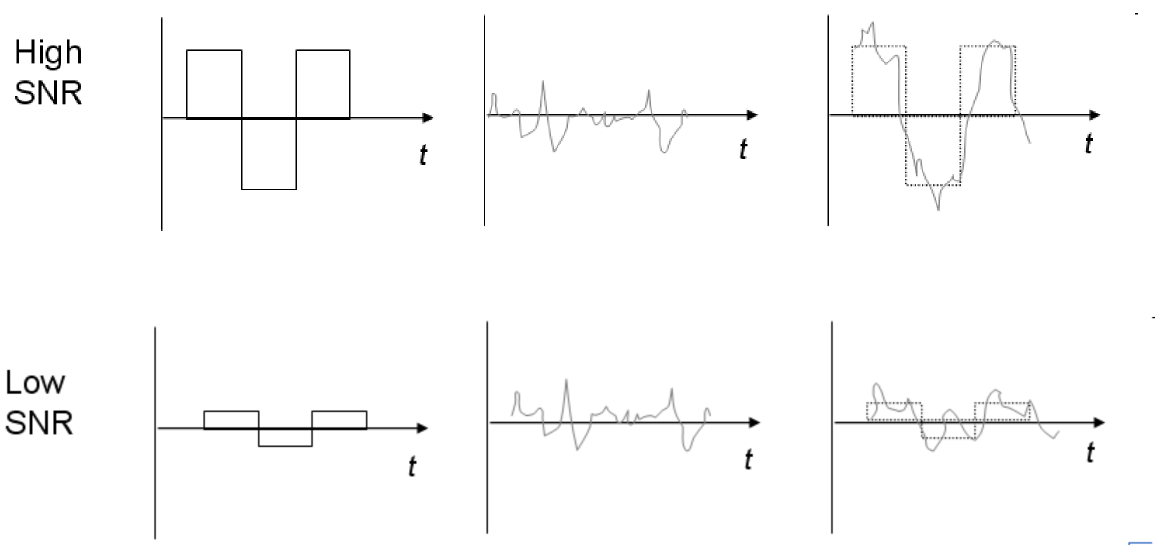
Transmission Impairments: Noise (cont.)

Signal to Noise Ratio (SNR) – **ratio of the power in the <u>desired</u> signal to the power in the superimposed noise**

$$\mathrm{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

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

- **high SNR ⇒ high-quality signal and low number of required amplifiers / repeaters**

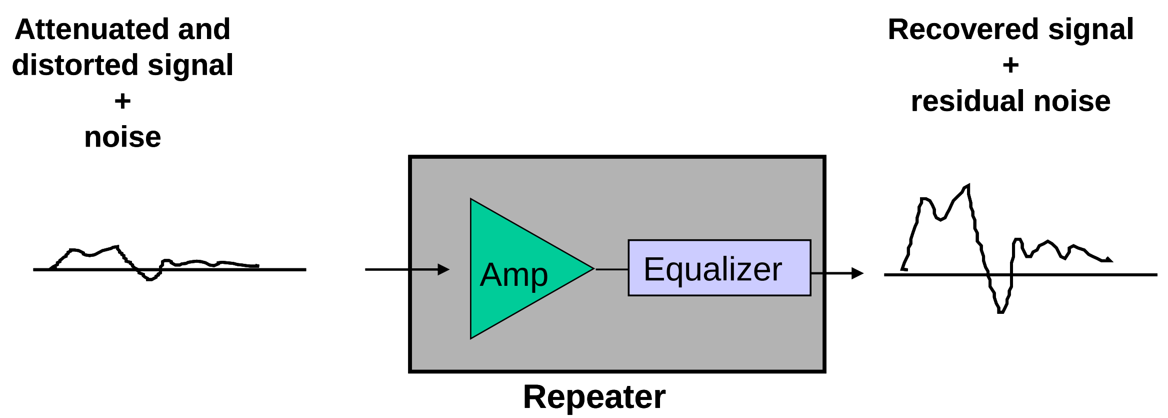


Analog Transmission

Analog Long-Distance Communications

Goals:
1) restore amplitude
2) remove delay distortion
3) remove noise

- each repeater attempts to restore analog signal to its original form
- restoration (noise removal) is imperfect – noise gets amplified too !
  - if signal only had components in certain frequency band, repeater could remove noise components outside signal band – but, not those inside ☹
- signal quality decreases with # of repeaters ⇒ communications is distance-limited
- analogy: copy a song using a cassette recorder



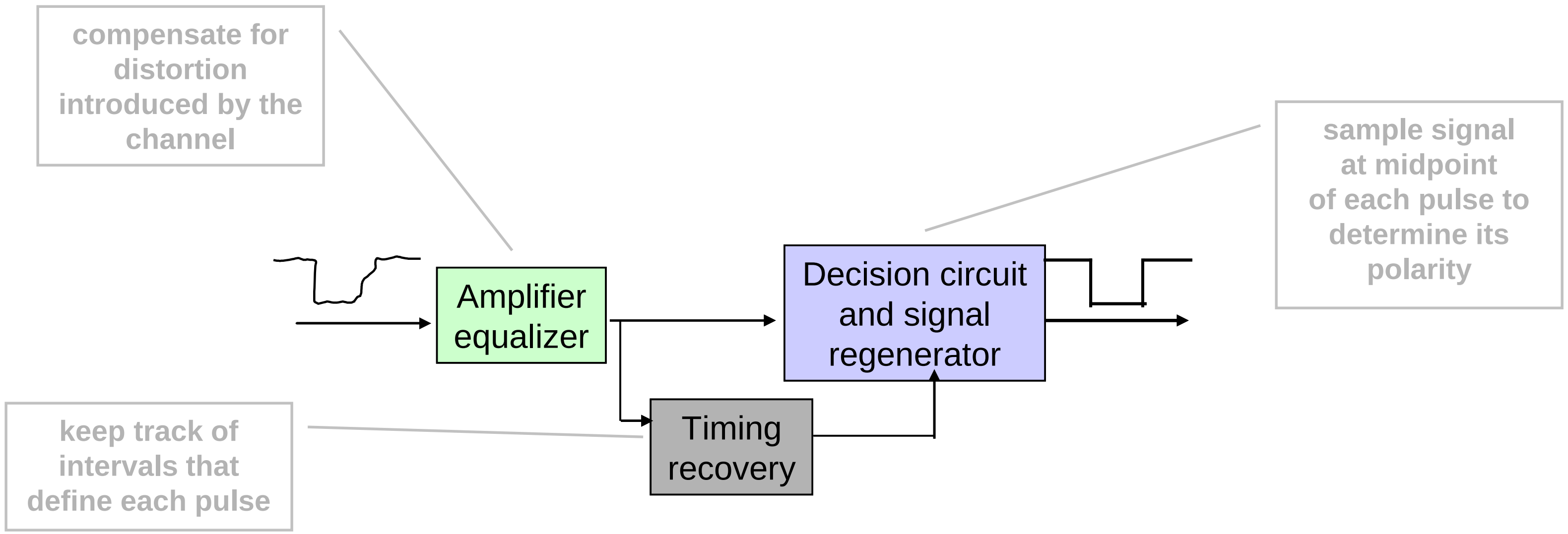

MEGA BASS
A


B
90

Digital Transmission

Digital Long-Distance Communications

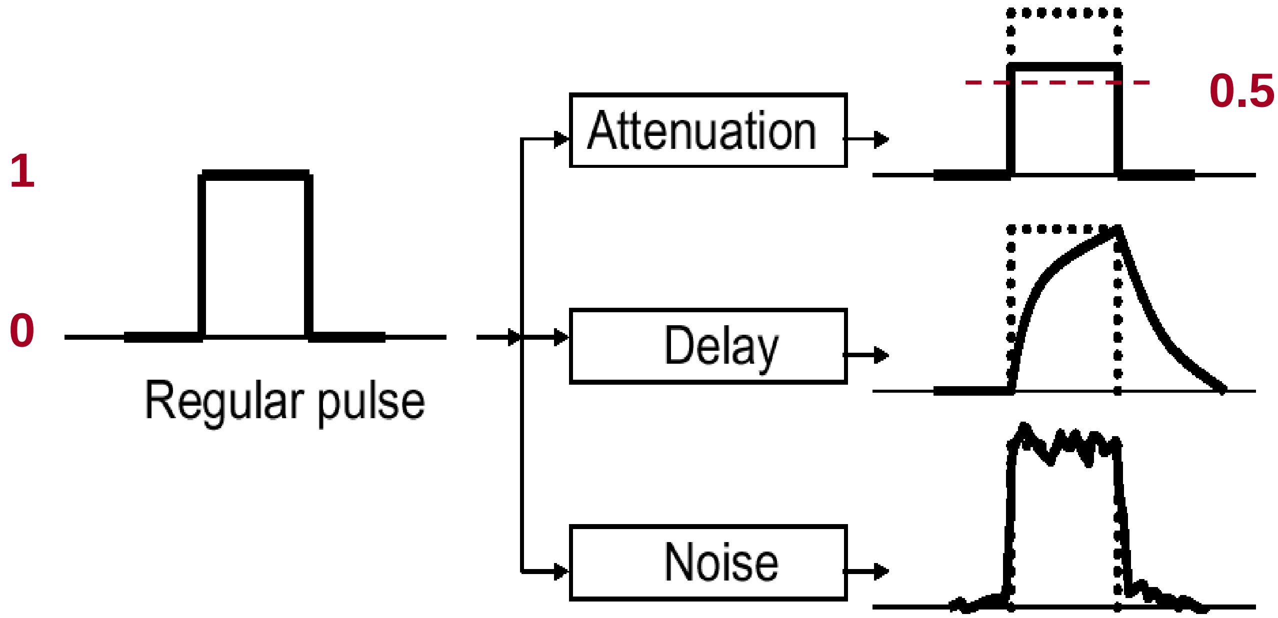
- regenerator does not need to completely recover the original shape of the transmitted signal – it only needs to determine whether the original pulse was positive or negative
- original signal can be completely recovered each time $\Rightarrow$ communication over very long distance is possible
- analogy: copy an MP3 file



Digital Transmission (cont.)

Example **[transmission impairments in digital transmission]**

Digital transmission can easily recover from various types of channel impairments.



So, is digital transmission the ultimate winner?!

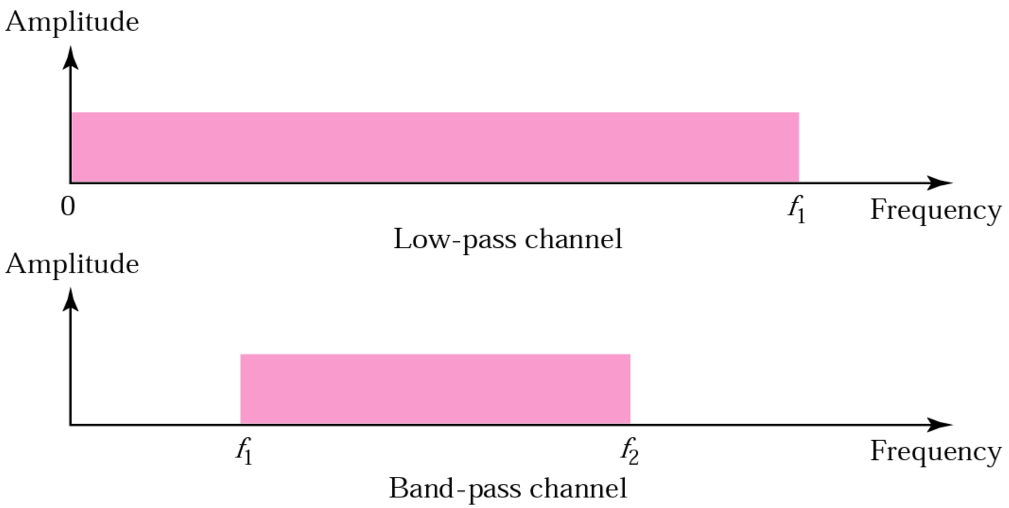
Analog vs. Digital Transmission

Low-pass Channel – bandwidth = $[0, f_1)$

- entire medium (bandwidth) is dedicated to two devices
- devices alternate in transmission

Band-pass Channel – bandwidth = $[f_1, f_2)$

- medium is shared among multiple users
- each pair of users gets a portion of overall bandwidth



Analog vs. Digital Transmission (cont.)

Digital Transmission Advantages

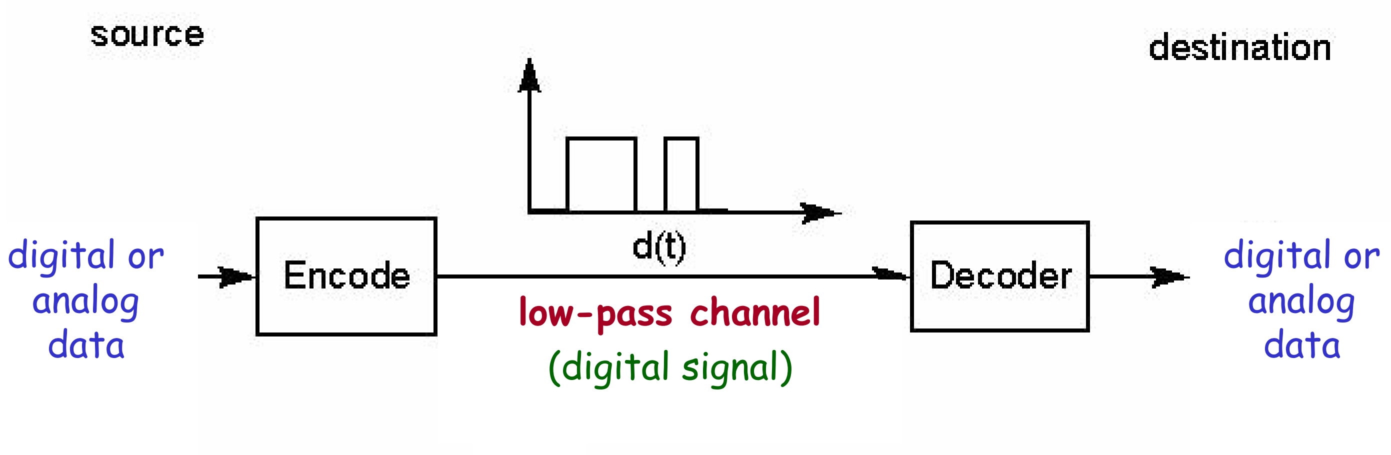
- **signal can be transmitted over long-distance without loosing any quality**
- **can operate with lower signal levels ⇒ lower system cost**
- **easier to apply encryption**
- **easier integration of voice, video and data**

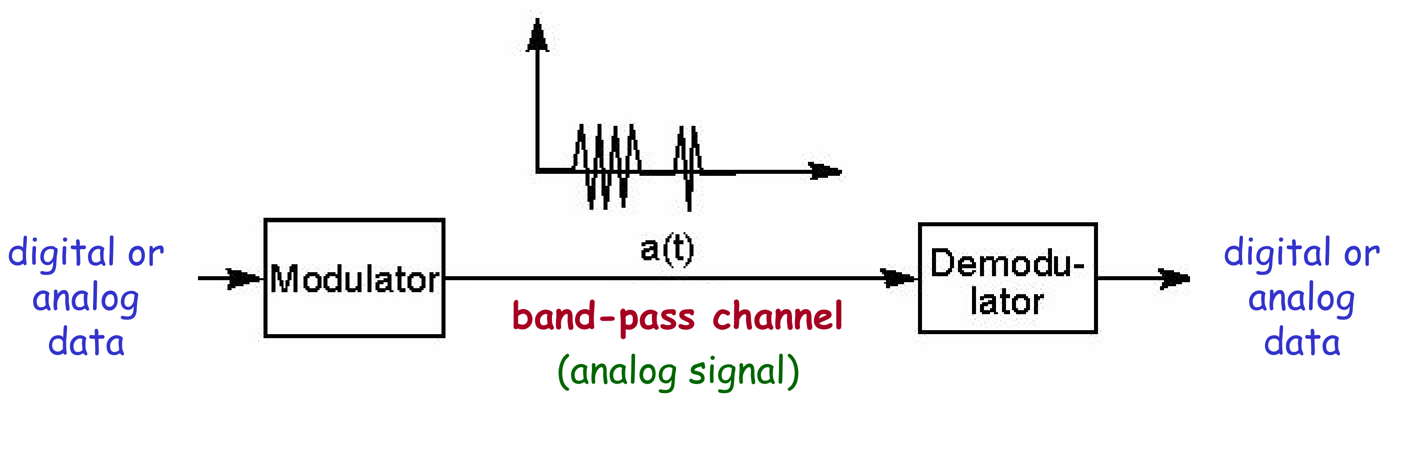
Digital Transmission Disadvantages

- **digital signal theoretically needs a bandwidth [0, ∞) – upper limit can be relaxed if we decide to work with a limited number of harmonics ⇒ digital transmission needs a low-pass channel**
- **analog transmission can use a band-pass channel**

Both analog and digital data may be transmitted on suitable transmission media using either digital coding or analog modulation.

Analog vs. Digital Transmission (cont.)

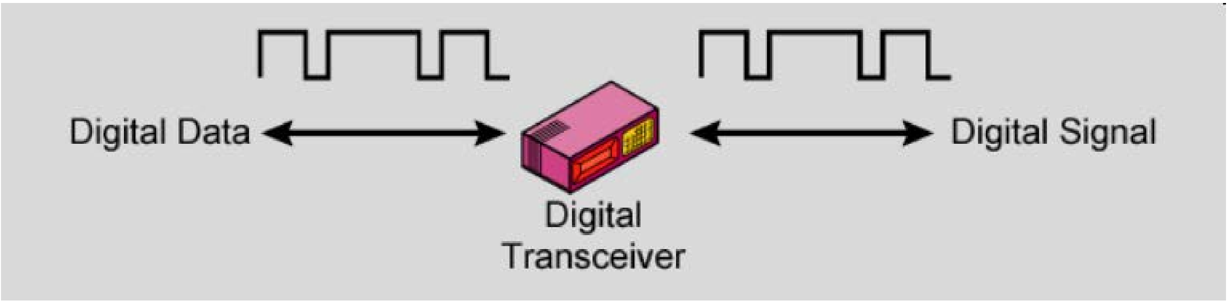




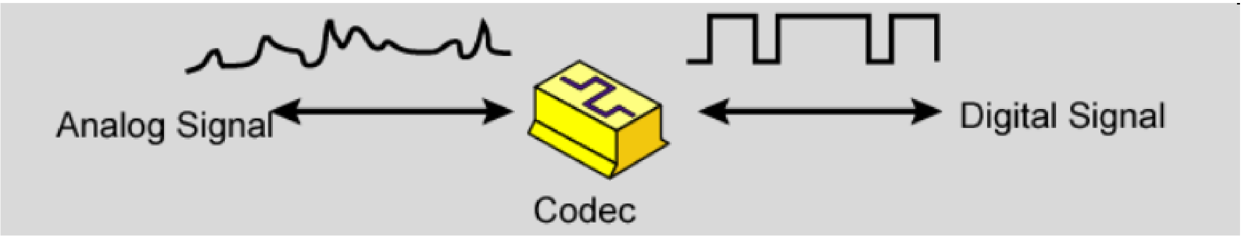
Analog vs. Digital Transmission (cont.)

Example **[digital transmission of digital and analog data]**

Digital Data → Digital Signal: Line Coding



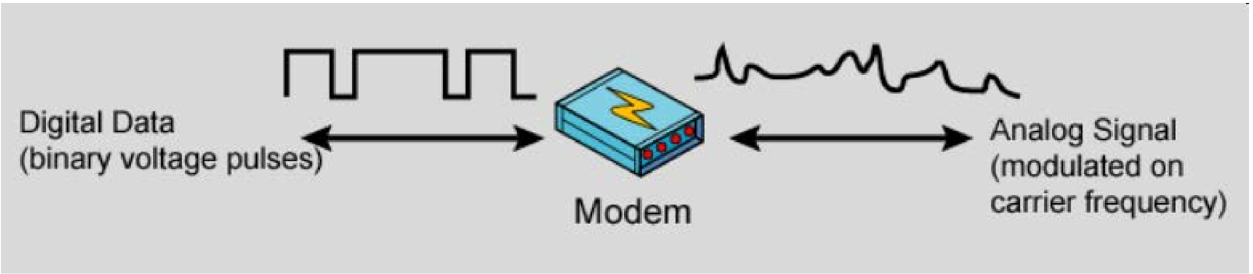
Analog Data → Digital Signal: PCM (Pulse Code Modul.) or Delta Modulation



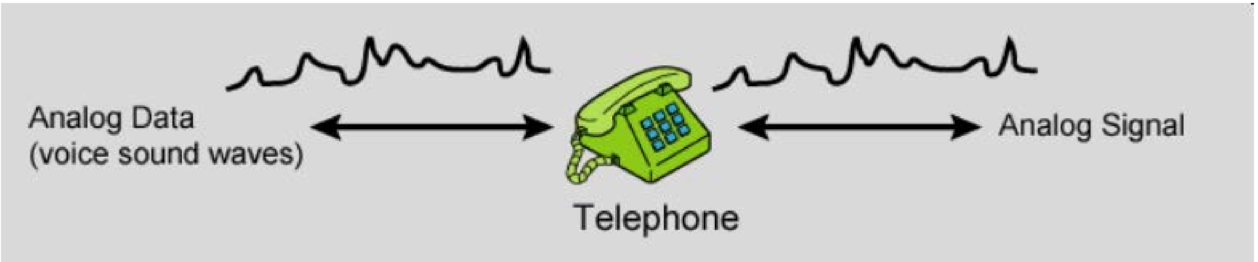
Analog vs. Digital Transmission (cont.)

Example **[analog transmission of digital and analog data]**

Digital data → Analog Signal: Digital Modulation



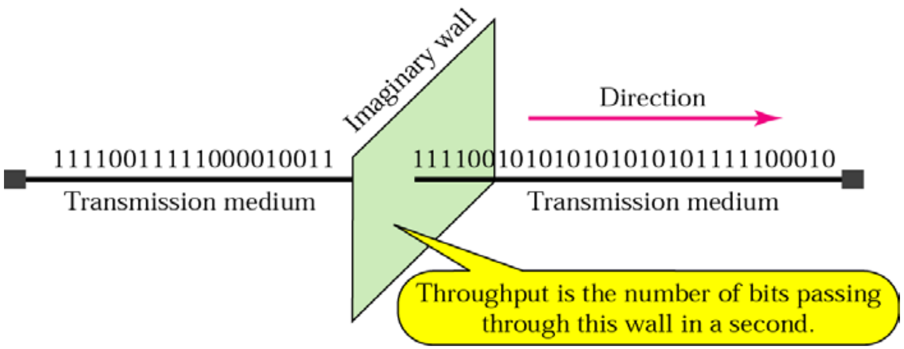
Analog data → Analog Signal: Analog Modulation



Last Note about Signals …

Throughput – **measurement of how fast data can pass through an entity in the network (computer, router, channel, etc.)**

- **if we consider this entity as a wall through which bits pass, throughput is the number of bits that can pass this wall in one second**



e.g. R=56 kbps

Example **[throughput]**

If the throughput at the connection between a device and the transmission medium is 56 kbps, how long does it take to send 100,000 bits out of this device?

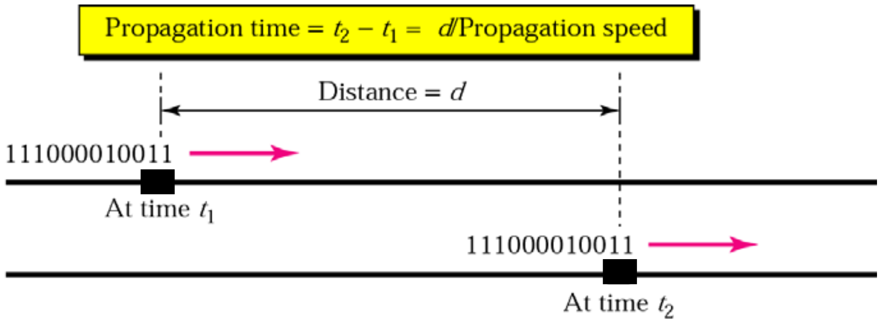
$$t = \frac{N\,[bits]}{R\,[bps]} = \frac{100000\,[\text{bit}]}{56000\,[\text{bps}]} = 1{,}786\,[\text{sec}]$$

Last Note about Signals … (cont.)

Propagation Time – **measures the time required for a signal (or a bit) to travel from one point of the transmission medium to another**

$$p = \frac{d}{c}\ [\text{sec}]$$

- **d – length of physical link [m]**
- **c – signal propagation speed in medium ~ 2*10^8 [m/s]**



Example [propagation time]

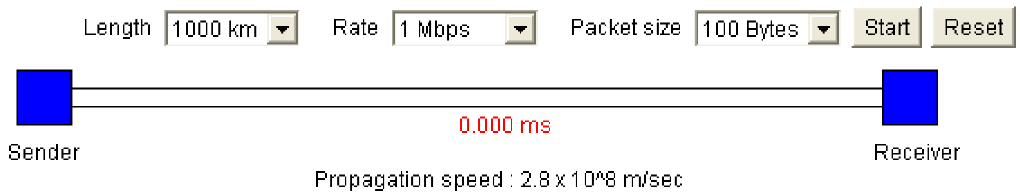
The light of the Sun takes approximately 8 minutes to reach the Earth? What is the distance between the Sun and the Earth?

$$d = p\,[\text{sec}]\cdot c\,[\frac{m}{\text{sec}}] = 8*60\,[\text{sec}]\cdot 3\cdot 10^8 [\frac{m}{\text{sec}}] = 144\cdot 10^9 [m] = 144\cdot 10^6 [km]$$

Last Note about Signals … (cont.)

Overall Delay

- *L* [bits] number of bits in message
- *R* [bps] speed of digital transmission system
- *d* [m] distance in meters
- *c* [m/s] speed of light ($3x10^8$ m/s in vacuum)



Time to deliver a block of L bits:

$$\text{Delay} = t_{\text{propagation}} + t_{\text{transmission}} = \frac{d}{c}[\text{sec}] + \frac{L}{R}[\text{sec}]$$

Use data compression to reduce L.

Use higher speed modem/cable to increase R.

Place server closer to reduce d.

http://www.ccs-labs.org/teaching/rn/animations/propagation/