Data and Signals

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Analog and Digital Signals

- For transmission, data must be transformed to electromagnetic signals.
- Data can be analog or digital.
  - ✓ The term analog data refers to information that is continuous; analog data take on continuous values. Analog signals can have an infinite number of values in a range.
  - ✓ Digital data refers to information that has discrete states. Digital data take on discrete values. Digital signals can have only a limited number of values.

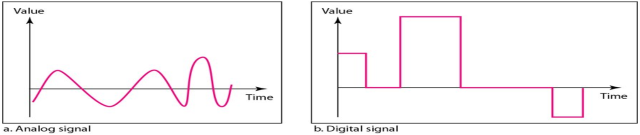
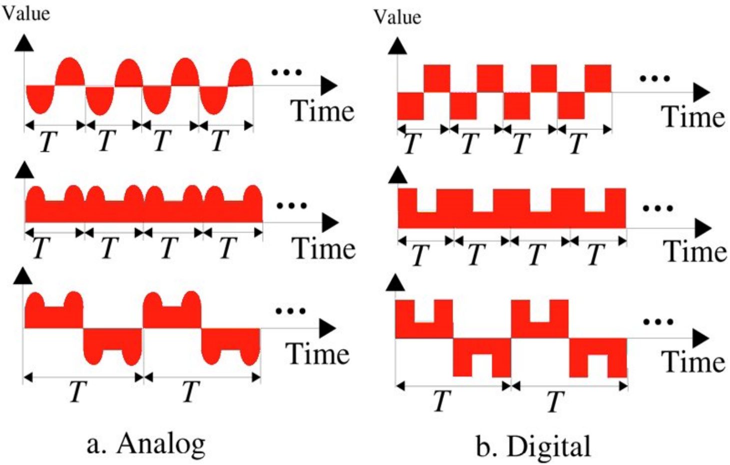


Figure: Five components of data communication

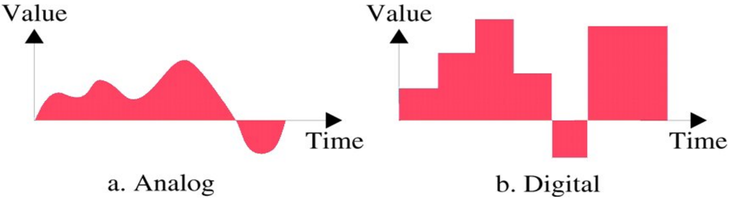
Periodic and Aperiodic Signals

- Periodic Signals:
  - A periodic signal completes a pattern within a measurable time frame called a period, and repeats that pattern over identical subsequent periods.
  - The period is expressed in seconds.
  - 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.
- Aperiodic Signals:
  - An aperiodic signal changes constant without exhibiting a pattern or cycle that repeats over time.

Periodic Signals

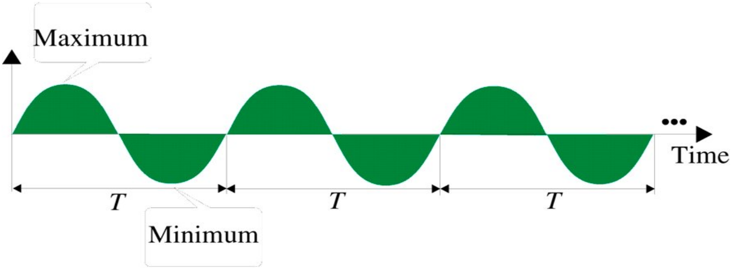


Aperiodic Signals



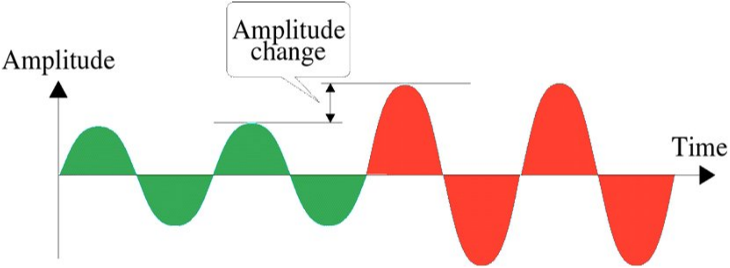
Simple Periodic Analog Signals

- A Sine wave is the simplest periodic signal, i.e., it can not be decomposed into simpler signals.
- A sine wave can be fully described by three characteristics:
  - ✓ Amplitude, Period or Frequency and Phase.



Amplitude

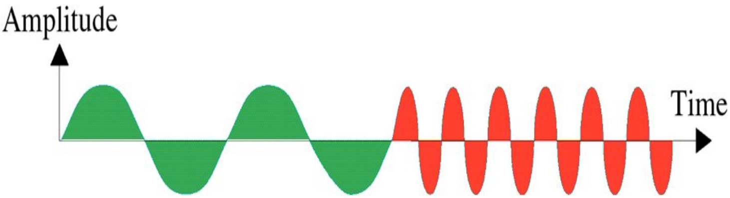
- ∝ Amplitude is the value of the signal at any point on the wave.
- ∝ Maximum amplitude is the highest value



Period and Frequency

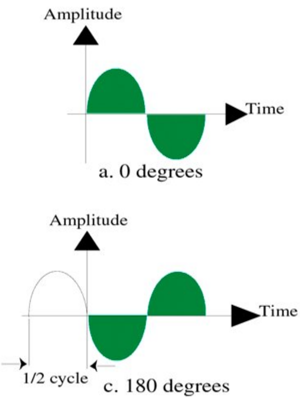
- Period is the time a signal needs to complete one cycle.
- Frequency is the number of cycles per second.
- Frequency is expressed in hertz (Hz).

$$\mathit{Frequency} = \frac{1}{\mathit{Period}}$$

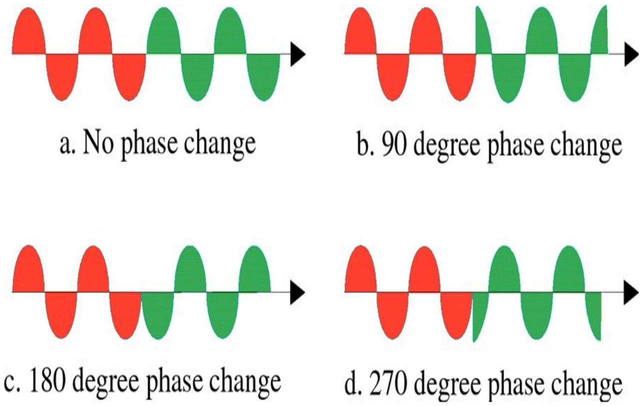


Phase

- Phase describes the position of the waveform relative to the time zero.
- Phase describes the amount of shift along the time axis.
- Phase is measured in degree or radian.

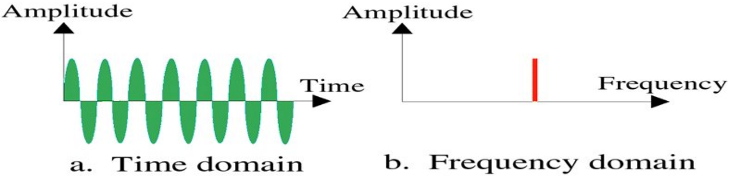


Phase Change

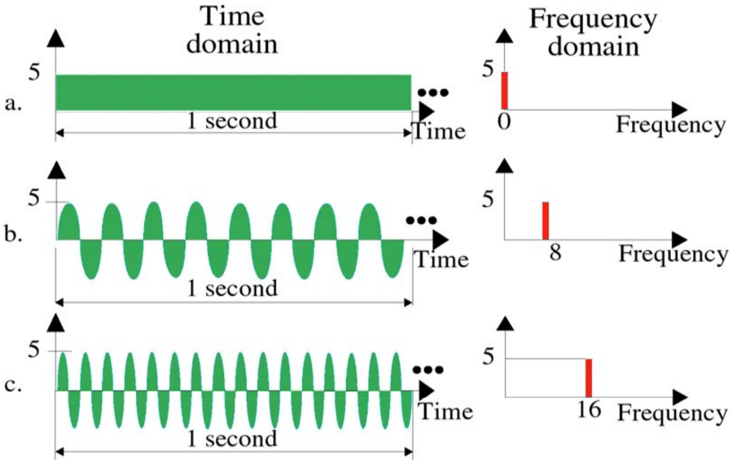


Time and Frequency Domains

- Time-domain plot shows the change in amplitude w.r.t. time.
- A frequency domain plot shows the relationship between amplitude and frequency.



Time and Frequency Domains: Example



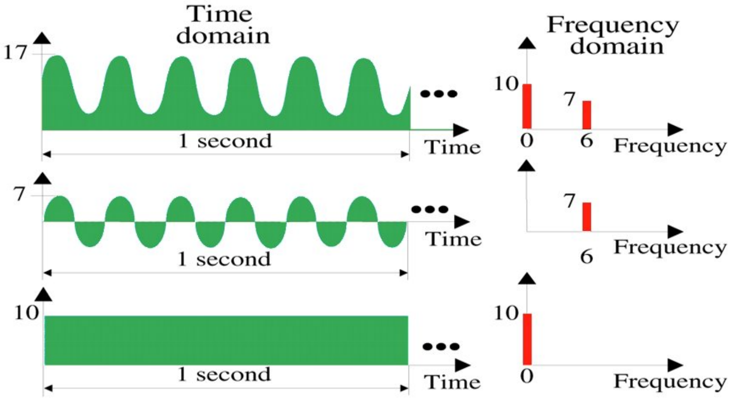
Composite Signal

- What about wave forms that are not simple or periodic (sine waves)
- For composite signals, we use Fourier transformation to decompose it into its components.
- French Mathematician, Jean-Baptiste Fourier proved that any reasonably behaved periodic fuction, g(t) with period T can be constructed as the sum of a number of sines and cosines:

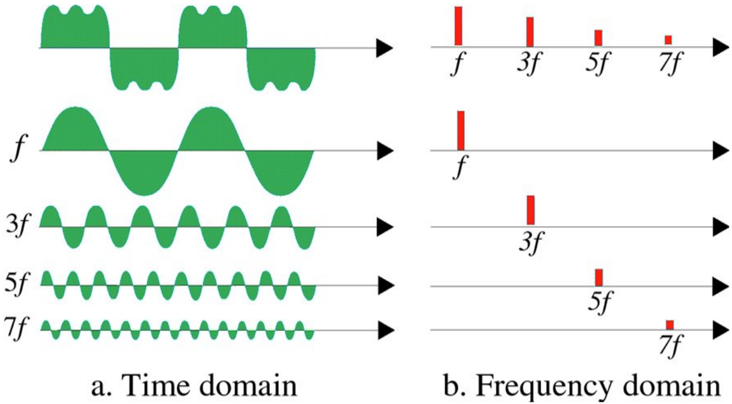
$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

c = constant.
a_n and b_n are the sine and cosine amplitude of the nth harmonics.
$f = 1/T$ is the fundamental frequency.

Composite Signal: Example



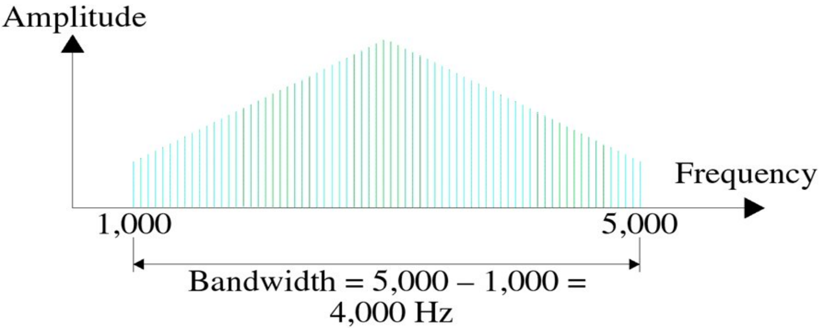
Composite Signal: Example



Frequency Spectrum and Bandwidth

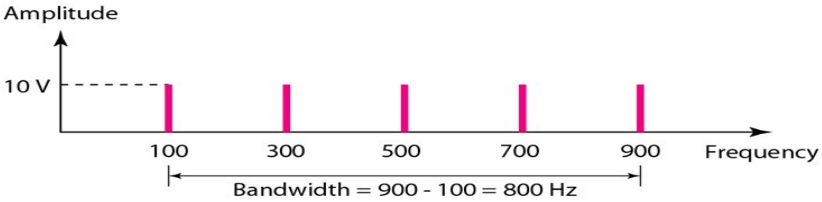
- The frequency spectrum of a signal is the collection of all the component frequencies it contains.
- That is, the combination of all sine waves that forms the signals.
- The bandwidth of a signal is the width of the frequency spectrum.
- To calculate bandwidth: subtract the lowest and highest frequency of a signal.

Bandwidth



Bandwidth: Example

- If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.



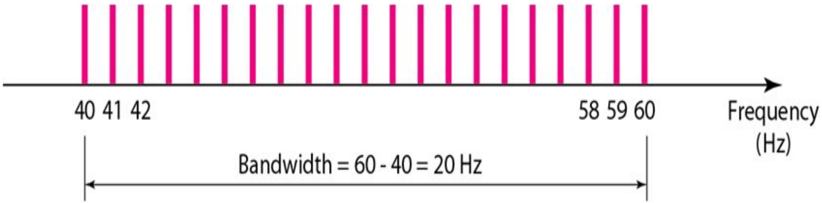
Solution: Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800Hz$$

Bandwidth: Example

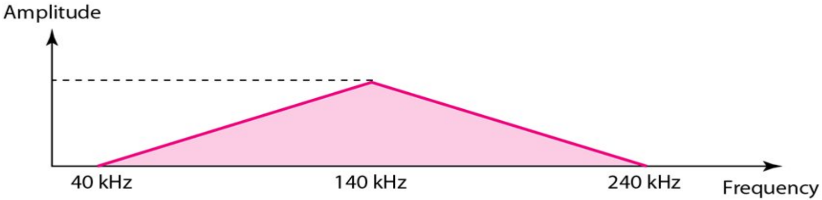
- A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.
- Solution: Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \Longrightarrow 20 = 60 - f_l \Longrightarrow f_l = 40Hz$$

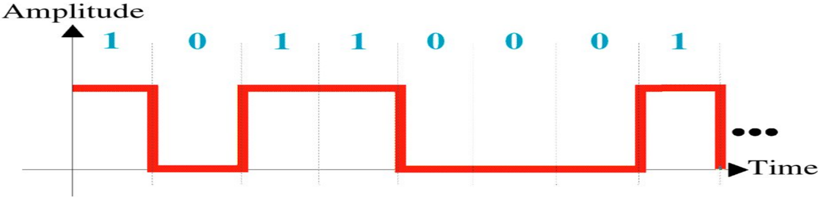


Bandwidth: Example

- A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.
- Solution: The lowest frequency must be at 40 kHz and the highest at 240 kHz.

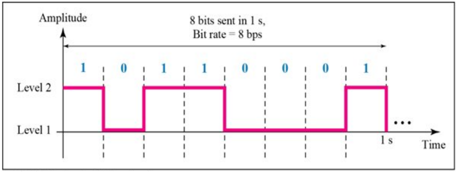


Digital Signals

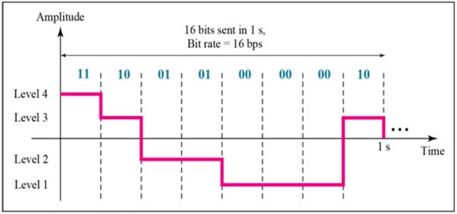


Digital Signals

- A digital data, e.g., a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- Moreover, a digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.



a. A digital signal with two levels



b. A digital signal with four levels

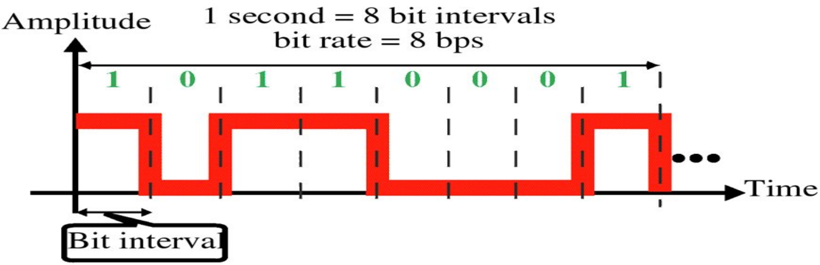
Digital Signals

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

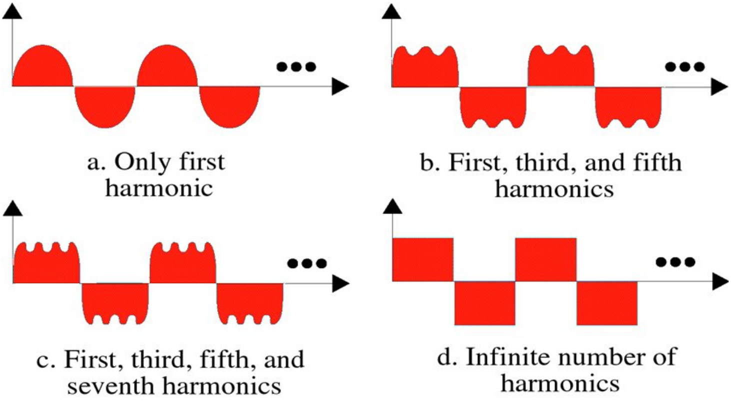
$$Number\ of\ bits\ per\ level = \log_2 8 = 3$$

Digital Signals

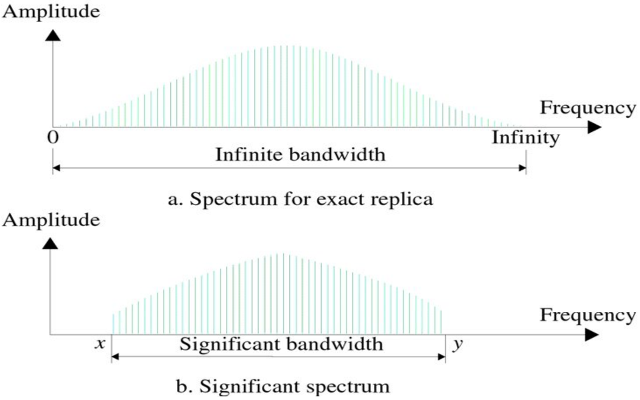
- Bit Interval (like period) is the time required to send one single bit.
- Bit Rate (like frequency) is the number of bit intervals per seconds or bits per second (bps).



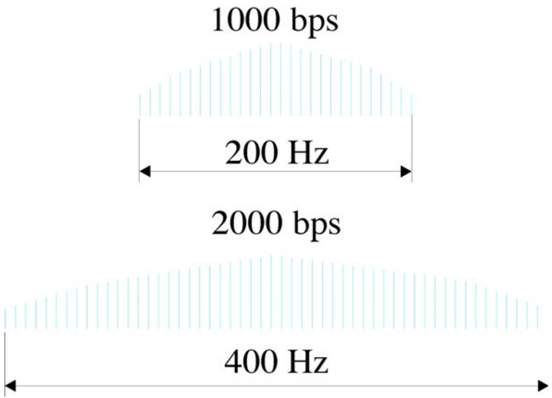
Harmonics of a Digital Signal



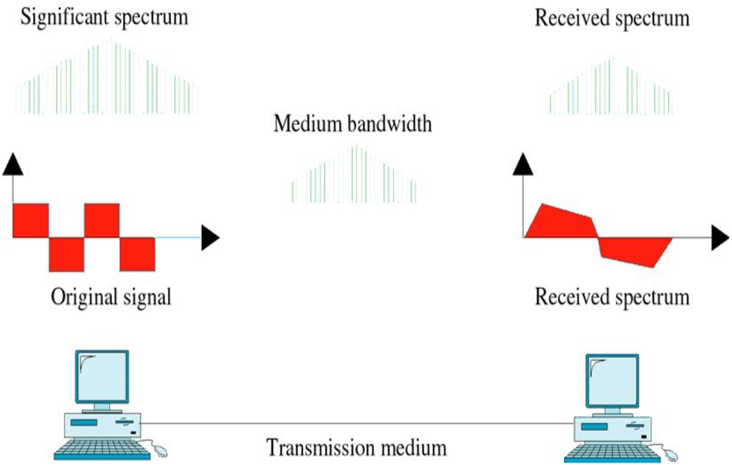
Exact and Significant Spectrums



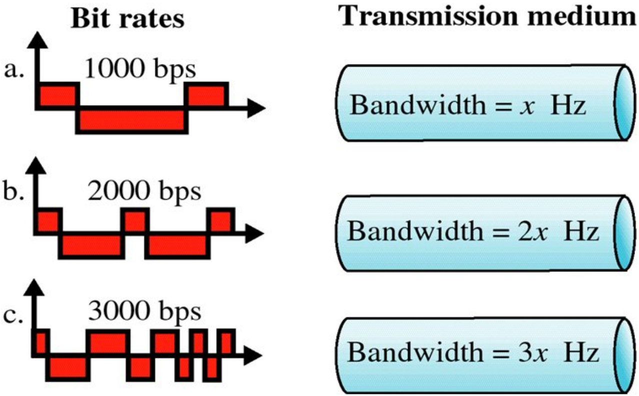
Bit Rates and Significant Spectrums



Corruption Due to Insufficient Bandwidth



Bandwidth and Data Rate

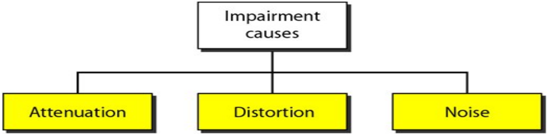


Bandwidth

- 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. Often referred to as Capacity.
- An increase in bandwidth in Hz means an increase in bandwidth in bps.

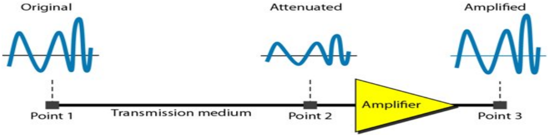
Transmission Impairment

- Signals traveling through a medium may get corrupted.
- This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.
- Three causes of impairment are:
  - ✓ Attenuation
  - ✓ Distortion
  - ✓ Noise



Attenuation

- Means loss of energy – weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.



Measurement of Attenuation

- To show the loss or gain of energy the unit "decibel" is used.
- The decibel is -ve if the signal is attenuated and +ve if a signal is amplified.

$$dB = 10 \log_{10} P_2/P_1$$

where, P_1 - power of input signal. P_2 - power of output signal.

$$OR$$

$$dB = 20 \log_{10} V_2/V_1$$

where, V_1 - voltage of input signal. V_2 - voltage of output signal.

Measurement of Attenuation: Example

- Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as:

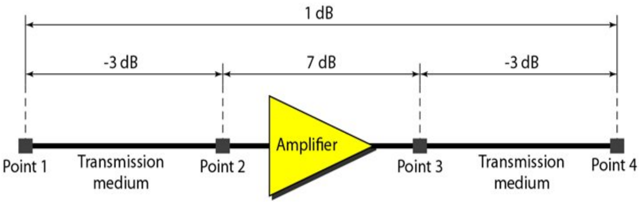
$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3dB$$

- A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1 . In this case, the amplification (gain of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10 P_1}{P_1} = 10 \log_{10} 10 = 10(1) = 10dB$$

Measurement of Attenuation: 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.



$$dB = -3 + 7 - 3 = +1$$

Measurement of Attenuation: Example

- 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 2 mW, what is the power of the signal at 5 km?
- Solution: The loss in the cable in decibels is $5 \times (-0.3) = -1.5$ dB. We can calculate the power as:

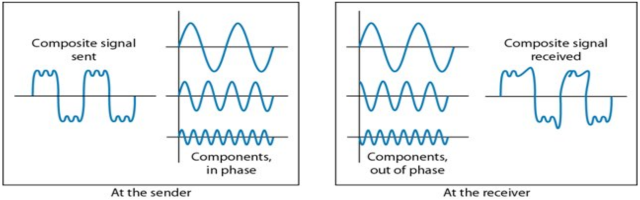
$$dB = 10\log_{10}\frac{P_2}{P_1} = -1.5$$

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

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 mW$$

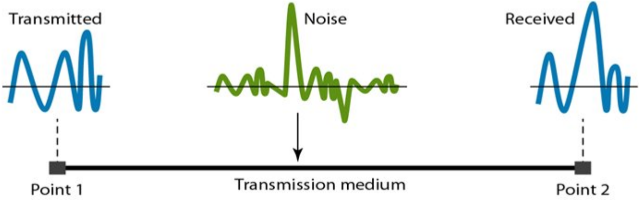
Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.



Noise

- There are different types of noise
  - Thermal: random noise of electrons in the wire creates an extra signal
  - Induced: from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk: same as above but between two wires.
  - Impulse: Spikes that result from power lines, lightning, etc.



Signal to Noise Ratio (SNR)

- It indicates the strength of the signal w.r.t. the noise power in the system.
- It is the ratio between two powers:

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

- A high SNR means the signal is less corrupt by noise and vice versa.
- Since SNR is the ratio of two power, it is usually given in dB and referred to as SNR_{dB}.

$$SNR_{dB} = 10 \log_{10} SNR$$

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

$$SNR = \frac{signalpower}{0} = \infty$$

$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

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