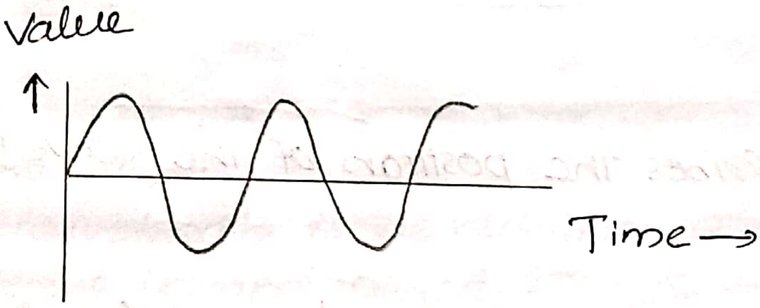
Periodic Analog Signals

- 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.

→ **Sine Wave**

- The sine wave is the most fundamental form of a periodic analog signal.
- When we visualize it as a simple oscillating curve its change over the course of a cycle is smooth and consistent, a continuous, rolling value



→ **Peak Amplitude**

The peak amplitude of the signal is the absolute value of its highest intensity, proportional to the energy it carries.

For electric signals, peak amplitude is normally measured in volts.

* Two signals with the same phase and frequency for different amplitude.

Period and Frequency

- Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.

- Frequency refers to the number of periods in 1sec.

- Frequency is the rate of change with respect to time.

  - Change in a short span of time means high frequency. Change over a long span of time means low frequency.

- Frequency and period are the inverse of eachother

$f = 1/t$ $t = 1/f$

Period - seconds

Frequency - Hertz - cycles per second

Phase

- Phase describes the position of the waveform relative to time 0.

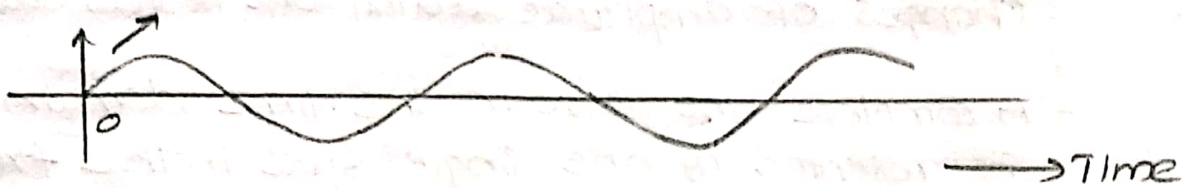
- Phase measured in degrees / radians.

- A phase shift of 360° corresponds to a shift of a complete period.

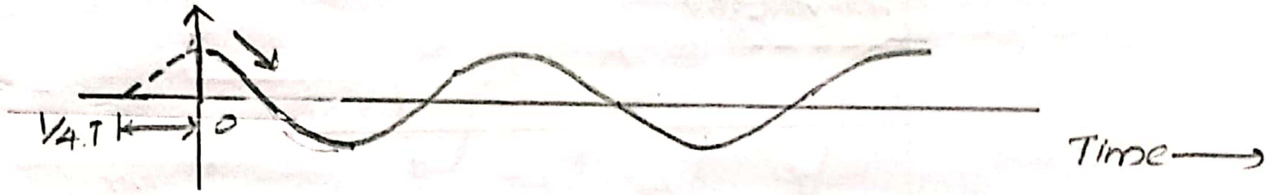
- A phase shift of 180° corresponds to a shift of one-half ~~po~~ of a period

- A phase shift of 90° corresponds to a shift of ~~sp~~ one-quarter of period.

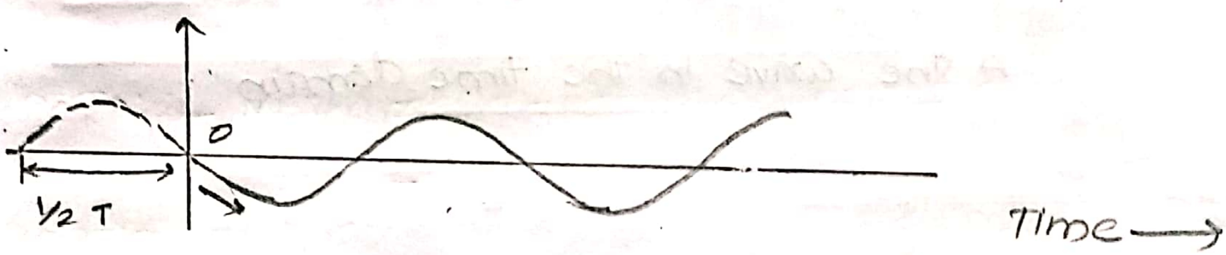
Wavelength!!



0 degree



-90 degree



180 degree

Wave length

- The wavelength is the distance a simple signal can travel in one period.
- The wavelength depends on both the frequency & the medium.

(c)

wavelength = propagation speed x period

= propagation speed / frequency

(c) (f)

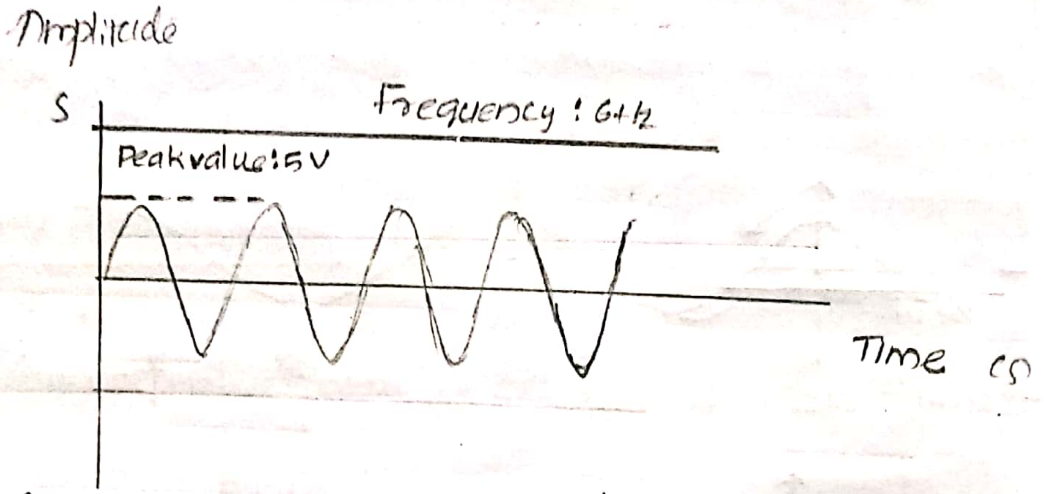
Time & Frequency Domains

- The time-domain plot shows changes in signal amplitude with respect to time.

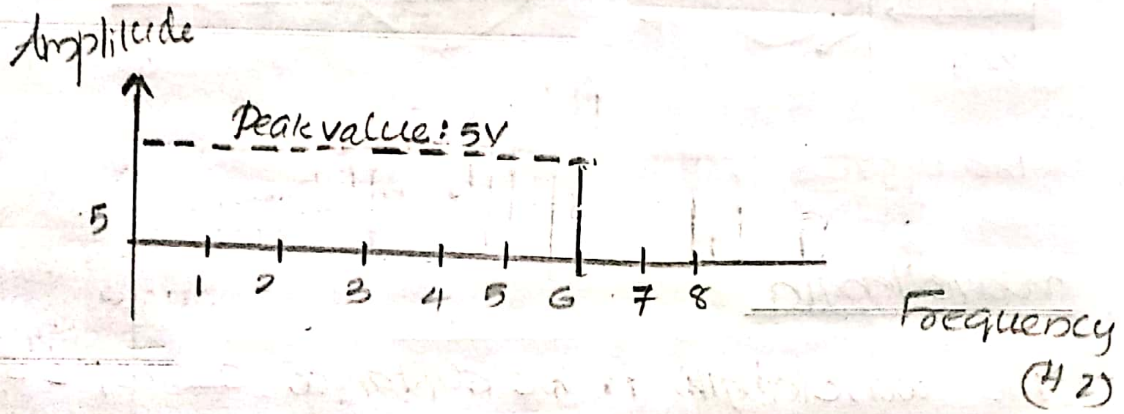
Scanned by CamScanner

- A frequency-domain plot is ~~connected~~ concerned with only the peak value and the frequency. Changes of amplitude during one period are not shown

- A complete sine wave in the time domain can be represented by one single spike in the frequency domain.



A Sine wave in the time domain.

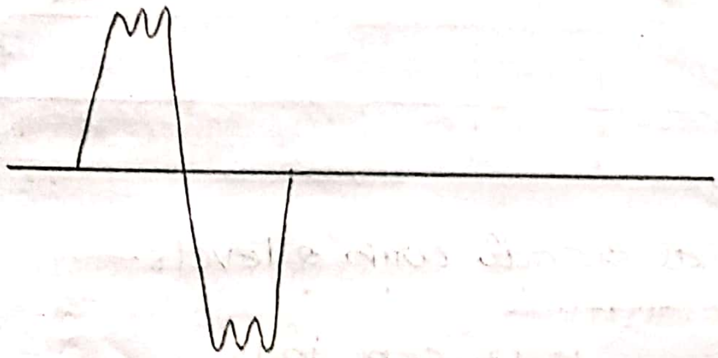


Composite signals

- If we had only one single sine wave to convey a conversation over the phone, it would make no sense and carry no information. We would just hear a buzz.

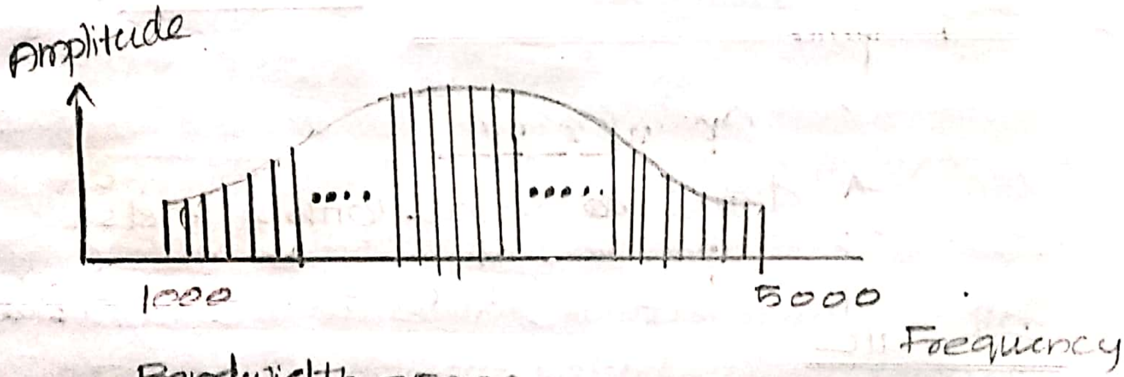
- A single a frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.

→ According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes & phases.



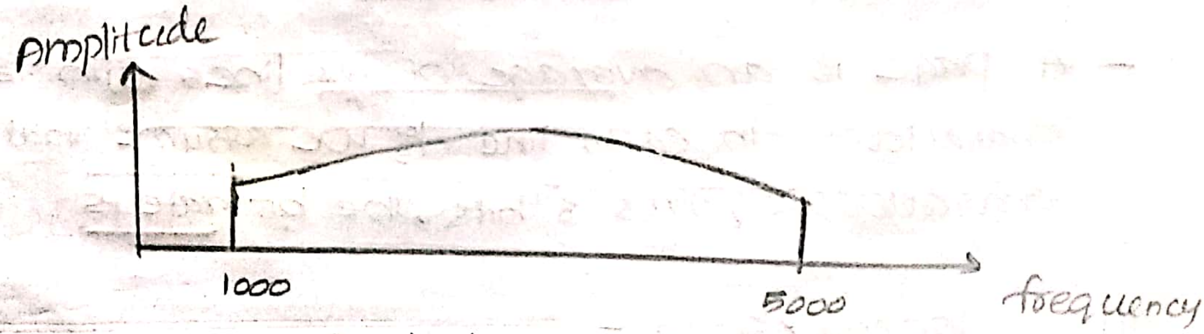
Bandwidth

The bandwidth of a composite signal is the difference b/w the highest & the lowest frequencies contained in that signal.



Bandwidth = 5000 − 1000
= 4000 Hz.

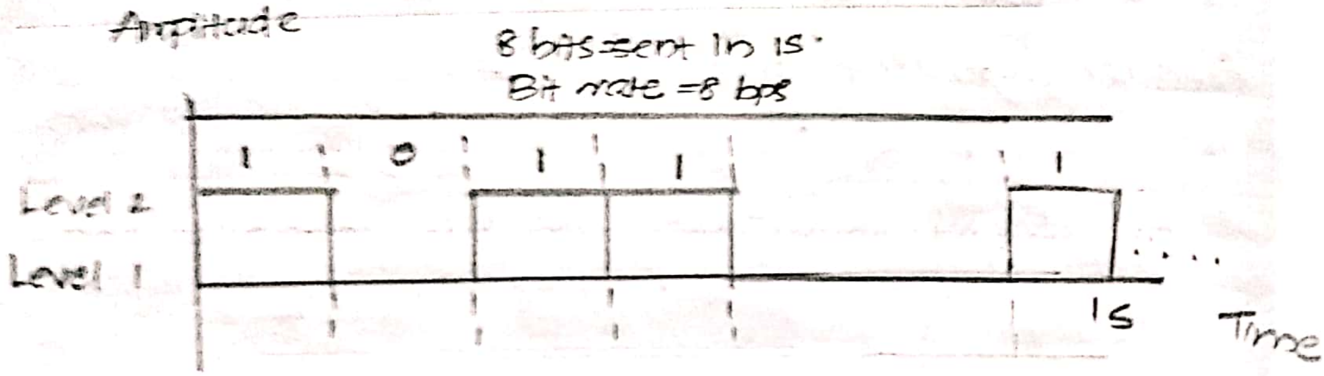
Bandwidth of a periodic signal.



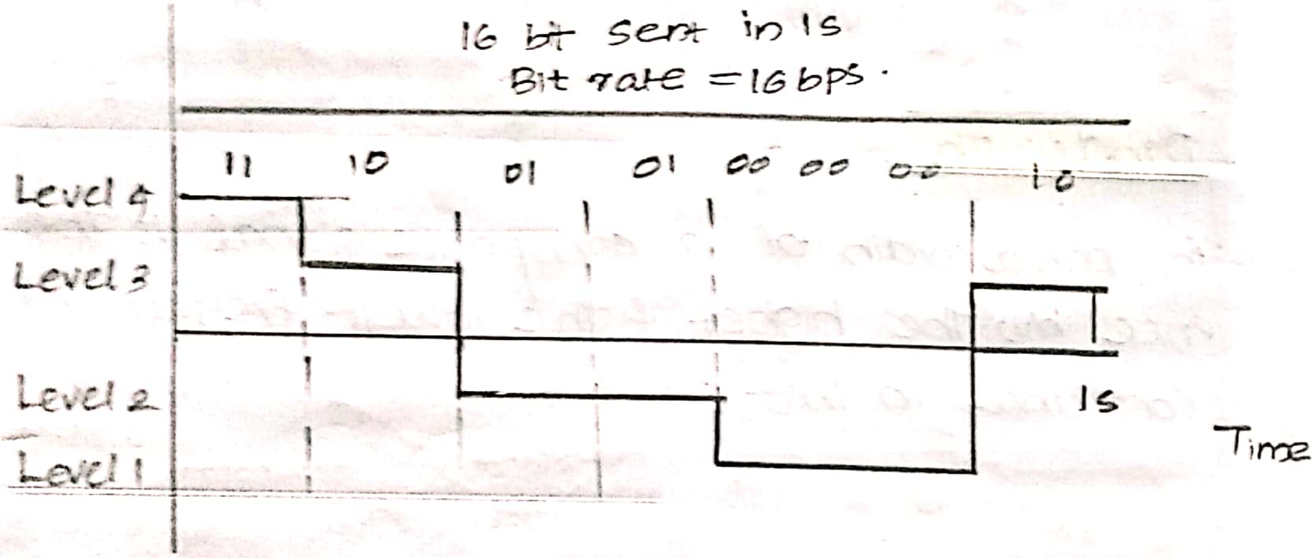
Bandwidth = 5000 − 1000
= 4000 Hz

Bandwidth of a non-periodic signal

Digital Signal



A digital signal with 2 levels.



A digital ~~at~~ signal with 4 levels.

Bit Rate

- Bit rate is the number of bits sent in 1s, expressed in bits per second (bps)

- A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$100 \times 24 \times 80 \times 8 =$

Bit Length

- Bit length is the distance one bit occupies on the transmission medium.

$$\boxed{\text{Bit length} = \text{propagation speed} \times \text{bit duration}}$$

Bandwidth utilization

- Sometimes we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth.
- Sometimes we need to expand the bandwidth of a channel to achieve goals such as privacy and antijamming.

Data and signals

Analog data

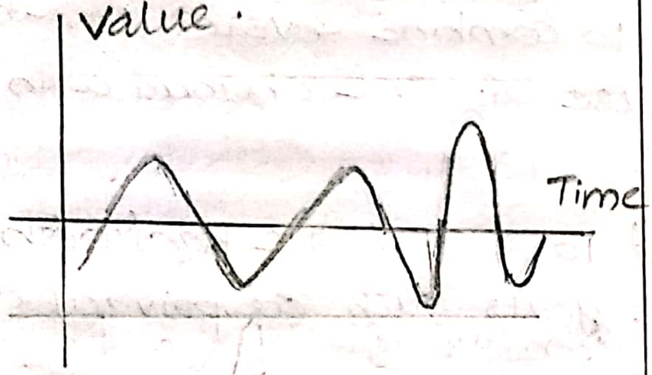
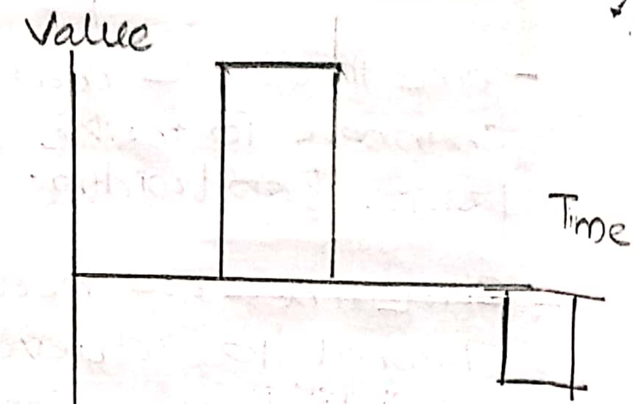
- The term analog ~~to~~ data refers to information that is continuous.
- Analog data, such as the sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled & converted to a digital signal.

Digital data

- Digital data refers to information that has discrete states.
- It take on discrete values.

Eg, data are stored in computer memory in the form of 0's & 1's. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

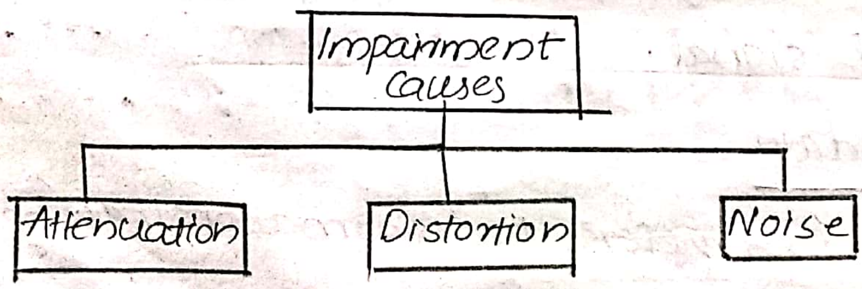
Comparison of analog & digital signals.

Analog signal	Digital signal
• Analog signals can have an infinite numbers of values in a range	• Digital signals can have only a limited number of values.
	

Imp TRANSMISSION IMPAIRMENT

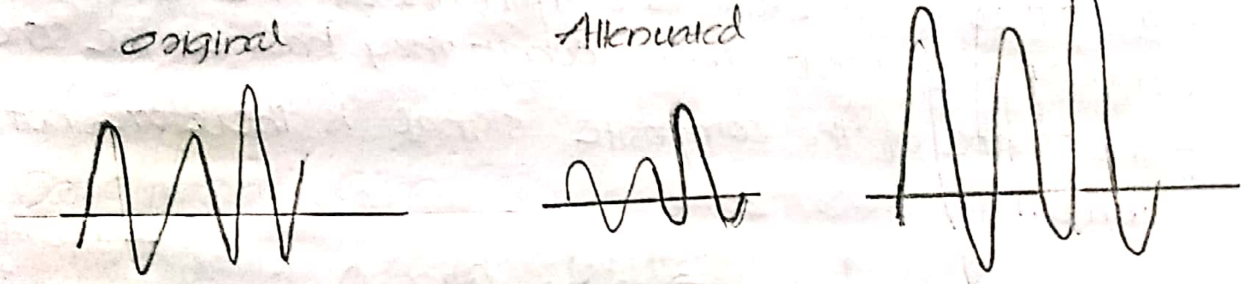
Signals travel through transmission media, which are not perfect. The impetfection Causes signal impairment.

- 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

- Attenuation means loss of energy.
- When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
- That is why a wire carrying electric signals gets warm, if not hot, after a while.
- Some of the electrical energy in the signal is converted to heat.
- To compensate for this loss, amplifiers are uses to amplify the signal.



decibel (dB)

- To show that a signal has lost or gained strength, engineers use the unit of the decibel.
- The decibel (dB) measures the relative strengths of 2 signals or one signal at 2 diff. point.
- Note that the decibel is -ve if a signal is attenuated & +ve if a signal is amplified.

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

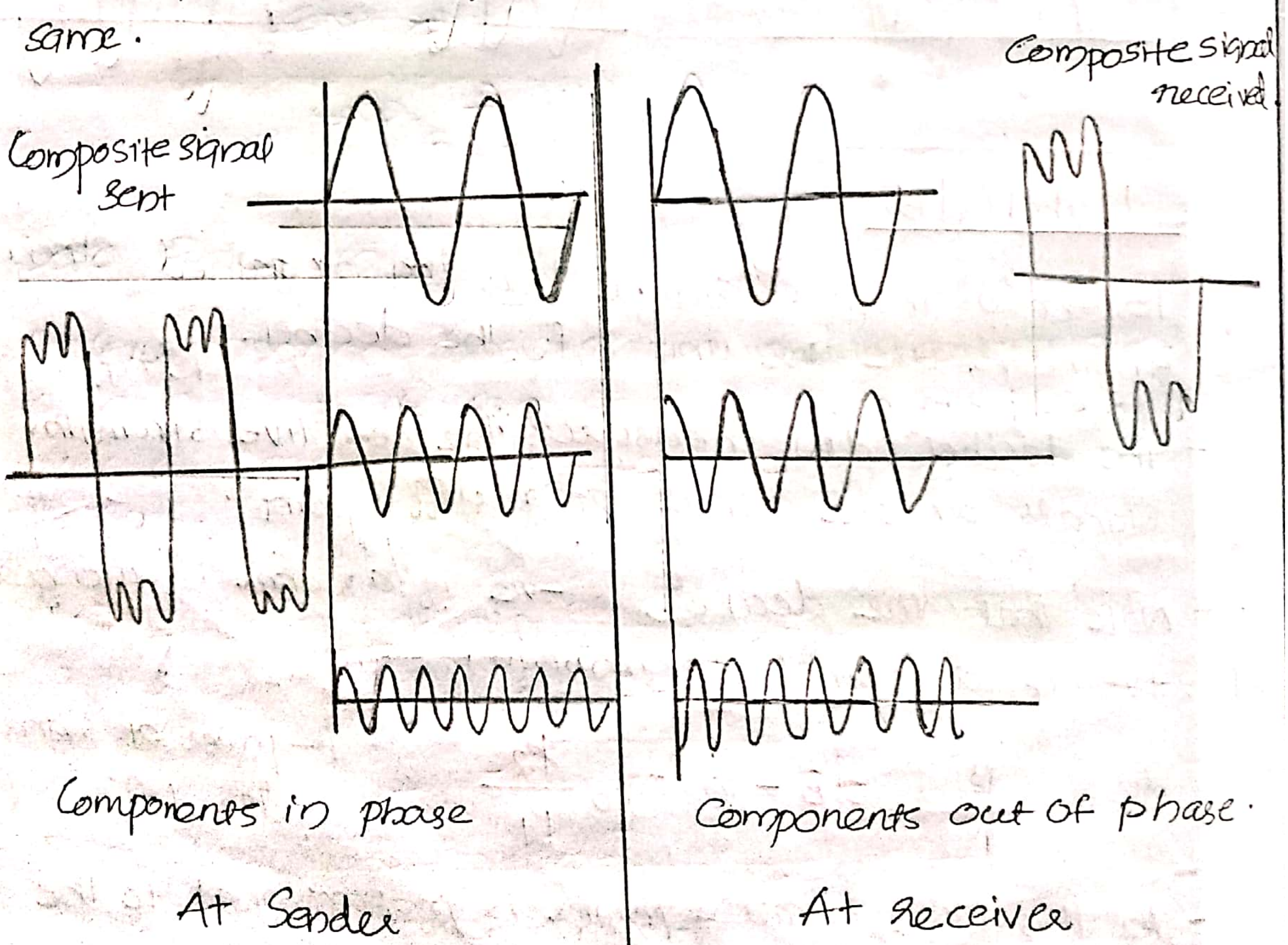
P – power of signal at Pts 1 & 2 respectively.

- In this case, because power is proportional to the square of the voltage, the formula is.

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

Distortion

- Distortion means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies.
- Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination.
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
- In other words, signal components at the receiver have phases different from what they had at the sender.
- The shape of the composite signal is therefore not the same.



Noise

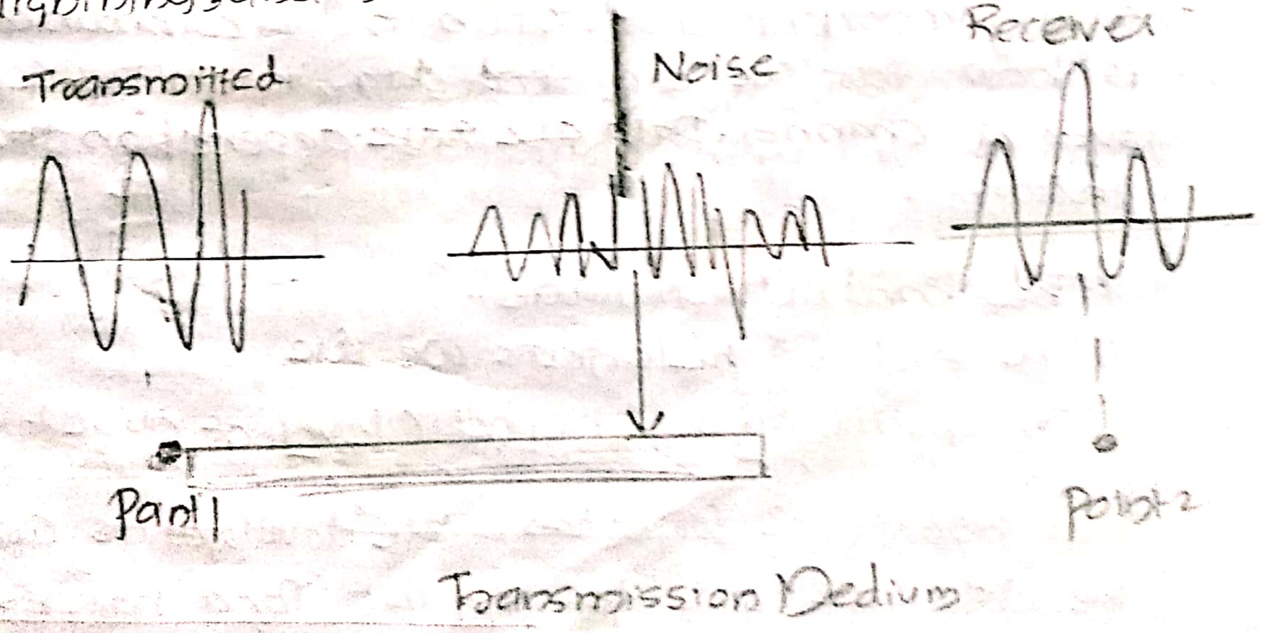
- Noise is another cause of impairment. Several types of noise, such as ~~ter~~ thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.

- Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.

- Induced noise comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium act as the receiving antenna.

- Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.

- Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.



Signal-to-Noise Radio (SNR)

- ~~To find the the the~~

- SNR is the ratio of ~~the~~ what is wanted (signal) to what is not wanted (noise).

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

- A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

- Because SNR is the ratio of two powers, it is often described in decibel units.

~~SNR dB~~

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

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 ~~are~~ rate depends on three factors.

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

- Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel. another by shannon for noisy channel

Noiseless Channel : Nyquist Bit Rate

- For a noiseless channel, the Nyquist bit rate formula defines the theoretical maxi. bit rate.

$$\text{Bit Rate} = 2 \times \text{bandwidth} \times \log_2 L$$

Bandwidth – Bandwidth of the channel

L — No. of signal levels used to represent data.

* Bit Rate is the bit rate in bits per second.

~~Noiseless~~ Channel : ~~Ny~~

- According to the formula, we can have any bit rate theoretically, by increasing the no. of signal levels, but practically there is a limit.
- When we increase the no. of signal levels, we impose a burden on the receiver.
- If the no. of levels in a signal is just 2, the receiver can easily distinguish b/w 0 & 1.
- If the level of a signal is 64, the receiver must be very sophisticated to distinguish b/w 64 diff. levels.

or rising the level of a signal reduces the reliability of the system.

Noisy Channel : Shannon Capacity

- We cannot have a noiseless channel; the channel is always noisy.
- In 1944, Claude Shannon introduced a formula called the shannon capacity, to determine the theoretical highest data rate for a noisy channel:

$$\text{Capacity} = \text{bandwidth} * \log_2(1+\text{SNR})$$

Bandwidth = bandwidth of the channel.

SNR = signal to noise ratio.

Capacity - Capacity of the channel in bits per second.

Shannon Capacity

- ~~The form~~

~~Capacity~~

- The formula defines a characteristic of the channel, not the method of transmission.

In other words, ~~AB~~ In the Shannon formula there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel.

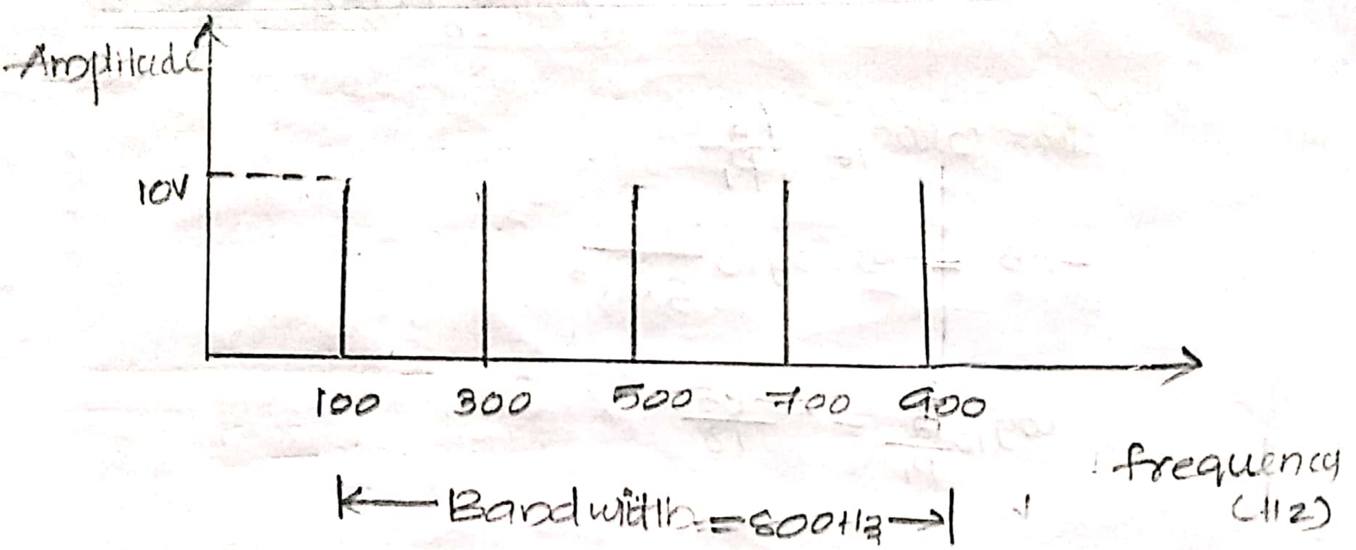
8/08/19 Q) If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum ~~of~~ amplitude of 10V.

Bandwidth = highest frequency - lowest frequency

$= 900 - 100$

$= \underline{\underline{800\ Hz}}$

Amplitude = 10V



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

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

$$P_2 = 10 \times P_1$$

$$10 \log_{10} = \frac{\log 10}{\log 10} = 1$$

$$dB = 10 \log_{10} \frac{10 \times P_1}{P_1}$$

$$= 10 \log_{10} 10$$

$$= \underline{\underline{10 dB}}$$

? The loss in a cable is usually defined in decibels per km (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 signal at 5km?

Beginning

loss in a cable $= -0.3 dB/km$

power $= 2 mW$

At 5km

loss in a cable $= 5 \times -0.3 = \underline{\underline{-1.5}} dB/km$

$$\boxed{Antilog_b(x) = b^x}$$

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

$$-1.5 = 10\log_{10}\frac{P_2}{2\times10^{-3}}$$

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

$$\log_{10}\frac{P_2}{2\times10^{-3}} = \frac{-1.5}{10} = -.15$$

$$\frac{P_2}{2\times10^{-3}} = antilog_{10}(-.15)$$

$$\frac{P_2}{2\times10^{-3}} = 10^{-(.15)}$$

$$= .7079$$

$$P_2 = .7079\times2\times10^{-3}$$

$$= 1.415\times10^{-3}W$$

$$= \underline{1.415\,mW}$$

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

$1\,mW = 1000\,\mu W$

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

$$= \frac{10\times1000}{1} = \underline{10,000}$$

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

$$= 10\log_{10} 10{,}000$$

$$= \frac{\log 10000}{\log 10} \times 10$$

$$= 4 \times 10$$

$$= \underline{40}$$

? Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with 2 signal levels. The maximum bit ~~rate~~ can be calculated as.

$$\text{Bit rate} = 2 \times \text{bandwidth} \times \log_2 L$$

$$= 2 \times 3000 \times \log_2 2 \qquad \frac{\log 2}{\log 2} = 1$$

$$= \underline{6000} \text{ bits per second}$$

? We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300-3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$\text{Capacity} = \text{bandwidth} \times \log 2(1+SNR)$$

$$SNR = 3162$$

$$\text{bandwidth} = 3000$$

$$\text{Capacity} = 3000 \times \log 2\,(3163)$$

$$= \underline{\underline{34881.23}} \text{ bps}$$

? If a TV picture is to be transmitted over a 45 MHz channel with a 35dB SNR. Find the capacity of the channel?

19/08/19

~~Capacity = bandwidth * $\log_2(1+SNR)$~~

~~$= 45\times10^6 * \log_2(1+35)$~~

~~$= 232.64\times10^6$ bps~~

$B = 45\times10^6$ Hz

$SNR_{dB} = 35$

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

~~SNR =~~ ~~antilog~~$_{10}$ ~~(35)~~

=

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

$SNR = \text{antilog}_{10}(35/10)$

$= 10^{3.5}$

$= 3162.28$

Capacity = bandwidth * $\log_2(1+SNR)$

$= 45\times10^6 * \log_2(1+\cancel{350}\ 3162.28)$

$= 45\times10^6 * 11.627$

$= 52.322\times10^6$ bps

$= 52.322$ Mbps

Scanned by CamScanner

? A telephone line with a bandwidth 100KHz is known to have a attenuation of 20dB. The i/p signal power is .5W & o/p noise level is 2.5μW. Calculate the o/p SNR.

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

$B = 100\ KHz$

$P_1 = .5W$

~~dB =~~ $2.5\mu W$

$dB = -20dB$

$$-20 = 10\log_{10}\frac{P_2}{.5}$$

$$\frac{P_2}{.5} = \text{antilog}_{10}(-2)$$

$$= 10^{-2}$$

$$P_2 = .01 \times .5$$

$$= \underline{5 \times 10^{-3}\ W}$$

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

$$= \frac{5\times10^{-3}}{2.5\times10^{-6}} = \underline{\underline{2000}}$$

? What is the channel capacity for a telephone channel with a 3000 Hz band width & a SNR of 6dB:

Capacity = bandwidth * log2 (1+SNR)

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

$$SNR = \text{antilog}_{10}(6/10)$$

$$= 10^{(.6)} = \underline{3.98}$$

Scanned by CamScanner

$$Capacity = 3000 \times \log_2(1+3.98)$$

$$= 6948.43\ W$$

$$= 6.948 \times 10^{-3}\ bps$$

$$= 6.948\ \mu bps$$

? What is the channel capacity for a teleprinter channel with 300 Hz bandwidth and a SNR of 3 dB.

$$Bandwidth = 300\ Hz$$

$$SNR_{dB} = 3$$

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

$$SNR = antilog_{10}(.3)$$

$$= 10^{-3}$$

$$= 1.995$$

$$Capacity = 300 \times \log_2(1 + 1.995)$$

$$= 474.76\ bps$$

? A digital signaling system is required to operate 9600 bps. If a signal elt encode a 4 bit / 8 bit words. What is the minimum required Bandwidth of the channel?

Bit Rate / Capacity = 9600 bps

$$\log_2 L = 4 / 8$$

$$Bit\ rate = 2 \times bandwidth \times \log_2 L$$

4 bit word ($\log_2 L = 4$)

$$\text{Bandwidth} = \frac{\text{Bitrate}}{2 \times \log_2 L}$$

$$= \frac{9600}{2 \times \cancel{\log} 4} = \underline{1200 \text{ Hz}}$$

8 bit word ($\log_2 L = 8$)

$$\text{Bandwith} = \frac{9600}{2 \times 8} = \underline{600 \text{ Hz}}$$

Minimum required bandwidth of the channel is 600 Hz. (8 bit word).

Important Questions

1. Communication models
2. Shannon capacity formula (problem)
3. find bandwidth with spectrum question.
4. Transmission impairments.
5. We have a channel with 5 Hz bandwidth. if you want to send data at 150 ~~Hz~~ Kbps. What is the minimum SNRdB & What is SNR.
6. Explain Nyquist Bit rate formula (Nyquist theorem)
7.