Chapter - 3

Information can be in the form of data, voice, picture and so on.. To be transmitted, information must be transformed into electromagnetic signals.

Both data and signals that represent them can take either analog or digital form.

ANALOG - refers to something that is continuous.

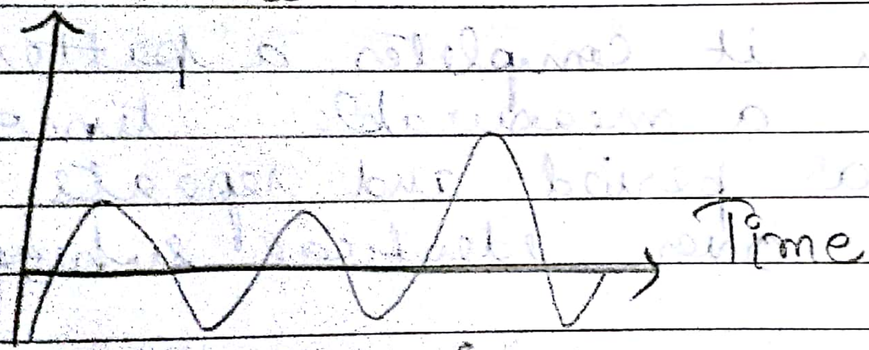
DIGITAL - refers to something that is discrete.

ANALOG SIGNAL - Analog signal is a continuous wave form that changes smoothly over time

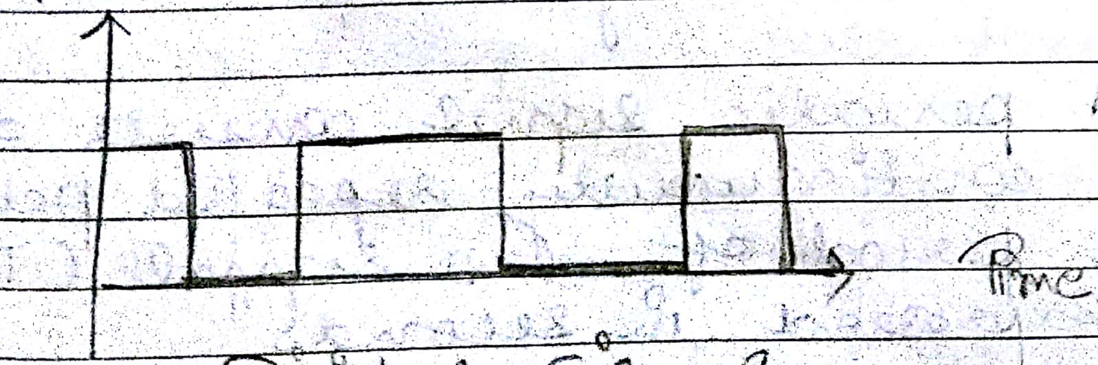
DIGITAL SIGNAL - Digital Signal on the other hand is discrete, It can have only a limited number of defined values. often as simple as 1 and 0. The transition of a digital signal from value to value is instantaneous, like a light being switched on and off.

SIGNALS

Analog   Digital



Analog Signal



Digital Signal

Both Analog and Digital signal can be of Periodic and Aperiodic signals.

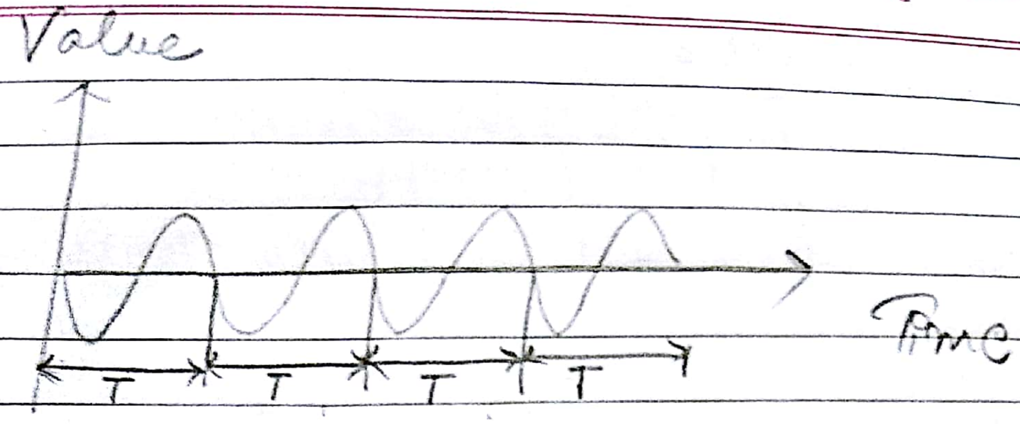
Analog
- Periodic
- Aperiodic

Digital
- Periodic
- Aperiodic

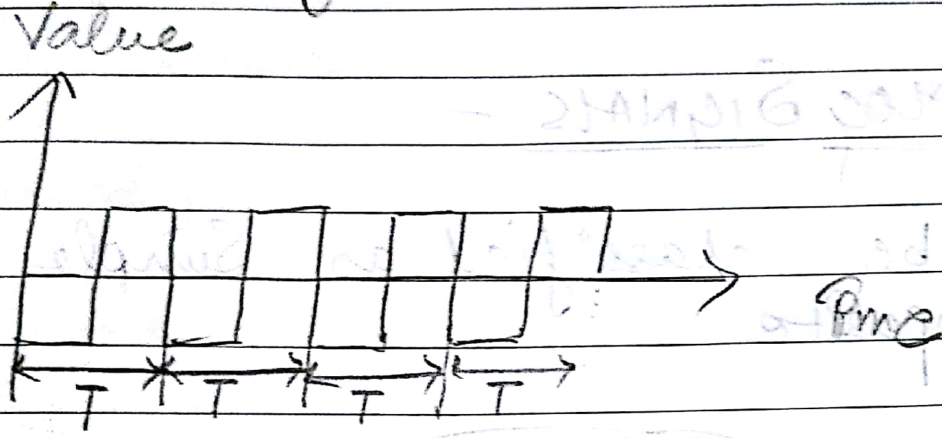
Periodic Signal — A periodic signal is when it completes a pattern within a measurable time frame, called a period and repeats that pattern over identical subsequent periods.

The completion of one full pattern is called a cycle.

"A periodic signal consists of a continuously repeated pattern. The period of a signal (T) is expressed in seconds",



Analog periodic Signals

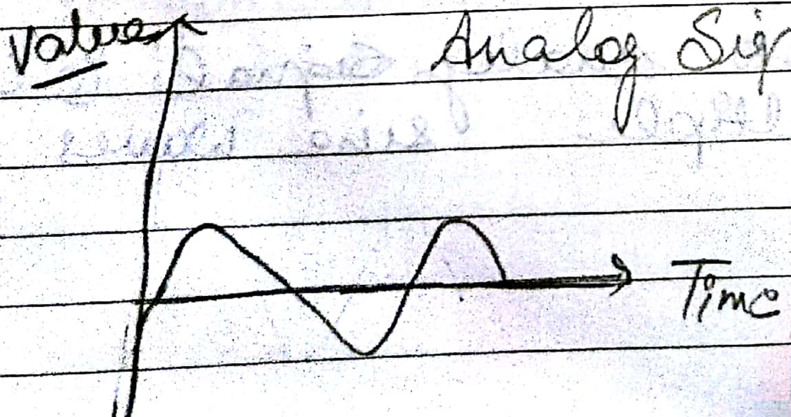


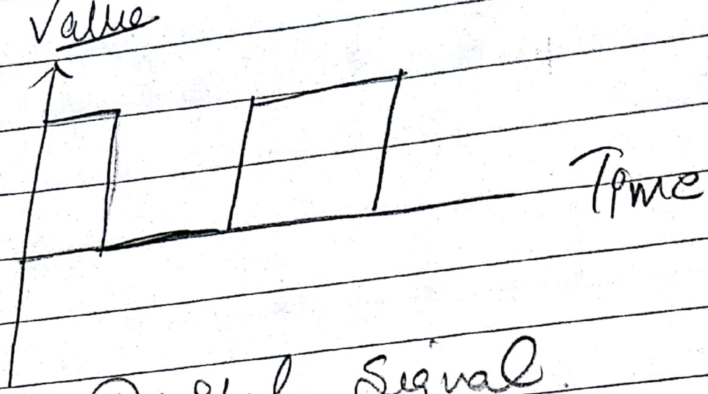
Digital periodic Signals.

Aperiodic Signals – An Aperiodic signal changes constantly without exhibiting a pattern or cycle that repeats over time.

" An Aperiodic or non-periodic signal has no repetitive pattern.

Analog Signal

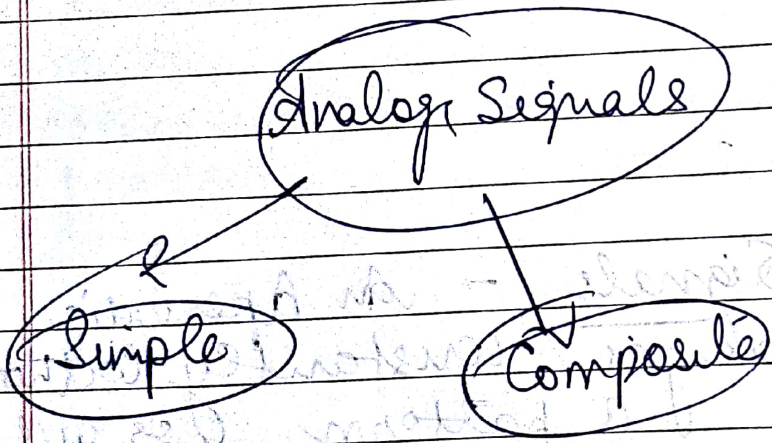




Digital Signal.

ANALOG SIGNALS -

can be classified as Simple or Composite



A simple analog signal or a "Sine Wave" can not be decomposed into simpler signals

A Composite analog signal is composed of multiple sine waves.

Simple Analog Signals

The sine wave is the most fundamental form of a periodic analog signal.

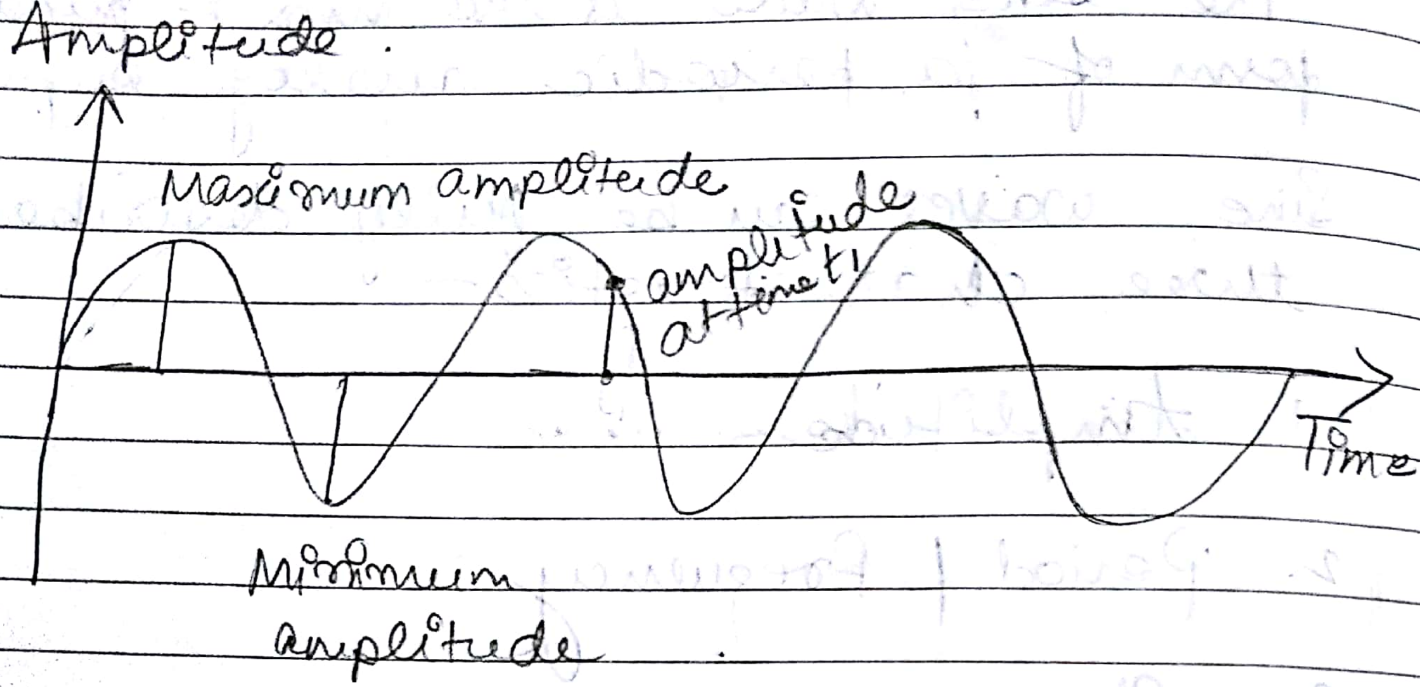
Sine waves can be fully described by three characteristics—

1. Amplitude
2. Period / Frequency
3. Phase.

Amplitude:— On a graph, the amplitude of a signal is the value of the signal at any point on the wave. It is equal to the vertical distance from a given point on the wave form to the horizontal axis.

The maximum amplitude of a sine wave is equal to the highest value it reaches on the vertical axis.

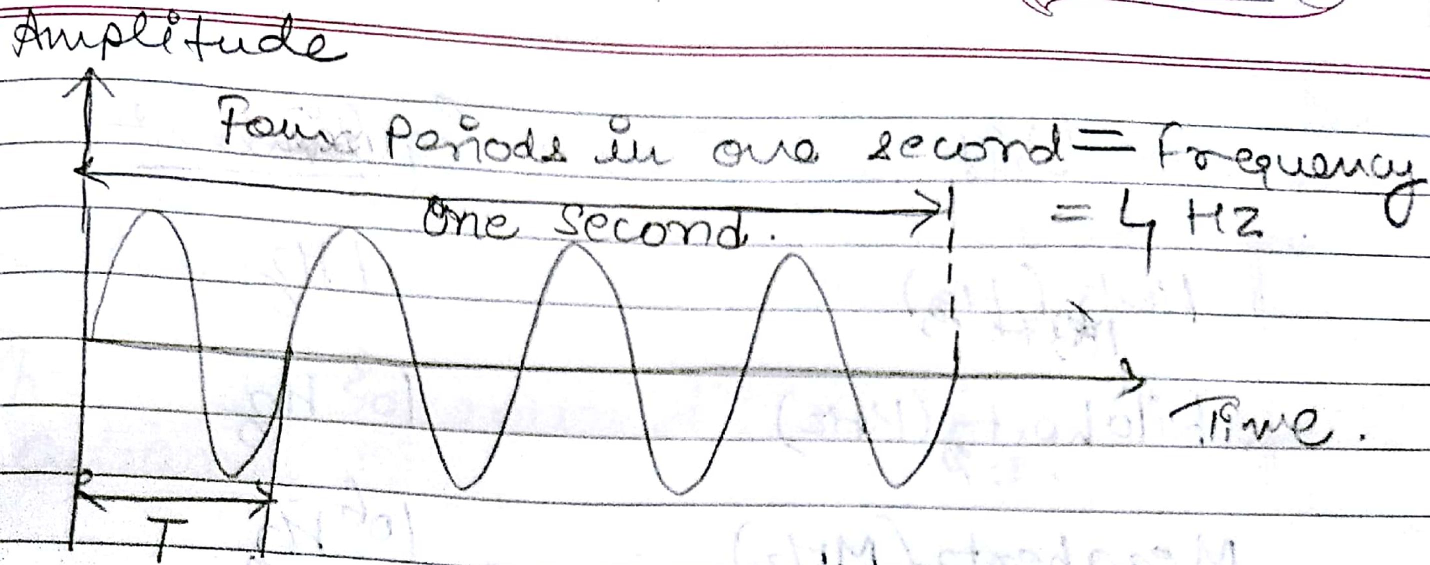
For electrical signals, the unit of amplitude is either Volts, amperes or Watts.



<u>Period</u> — Period refers to the amount of time, in seconds, a signal needs to complete one cycle.

<u>Frequency</u> — Refers to the number of periods in one second.

The frequency of a signal is the number of cycles per second.



Period = 1/4 second

Unit of Period = Period is expressed in seconds.

Units of Periods.

Unit	Equivalent
Seconds	1s
Milliseconds (ms)	10^{-3}s
Microseconds (μs)	10^{-6}s
Nano Seconds (ns)	10^{-9}s
Picoseconds (ps)	10^{-12}s

Units of Frequency :- frequency is expressed in hertz (Hz).

Unit	Equivalent
Hertz (Hz)	1 Hz
Kilohertz (KHz)	10^3 Hz
Megahertz (MHz)	10^6 Hz
Gigahertz (GHz)	10^9 Hz
Terahertz (THz)	10^{12} Hz

Q A sine wave completes one cycle in four seconds. What is its frequency?

$$f = \frac{1}{T} = \frac{1}{4} = 0.25 \text{ Hz}$$

Note: Frequency is the rate of change with respect to time. Change in a short span of time means high frequency. Change in a long span of time means low frequency.

Phase - The "term" "phase" describes the position of the waveform relative to time zero.

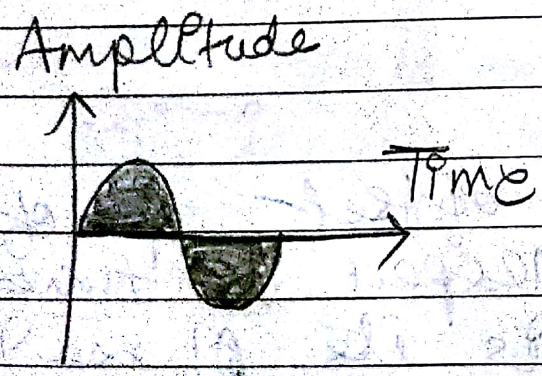
Phase is measured in degree or radians.

$360^\circ = 2\pi$ radians.

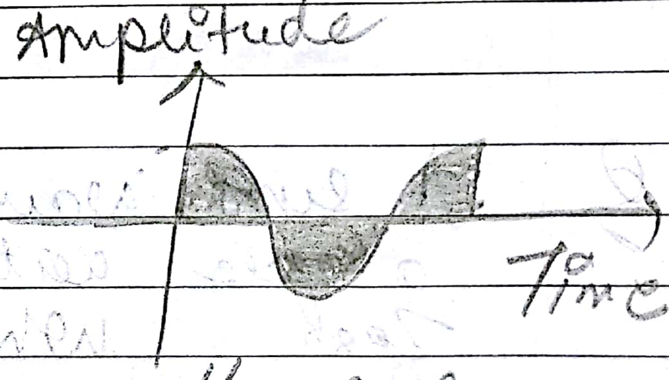
A phase of 360° corresponds to a shift of complete period.

A phase of shift of 180° corresponds to a shift of $1/2$ a period.

A phase of shift of 90° corresponds to a shift of quarter of a period.

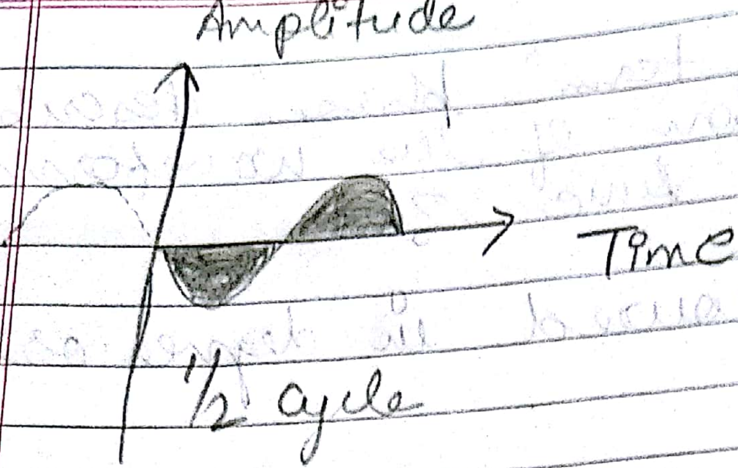


0 degrees



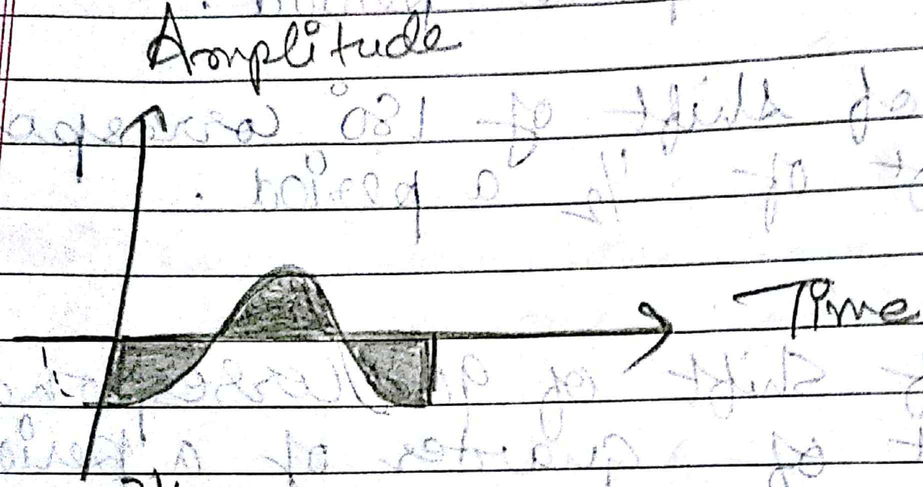
1/4 cycle

90° degrees



1/2 cycle

180° degrees.



3/4 cycle.

Q A sine wave is offset 1/6 of a cycle with respect to time zero. What is its phase?

Ans We know that one complete cycle is 360°. Therefore 1/6 of a cycle is

$$\frac{1}{6} \times 360 = 60^\circ.$$

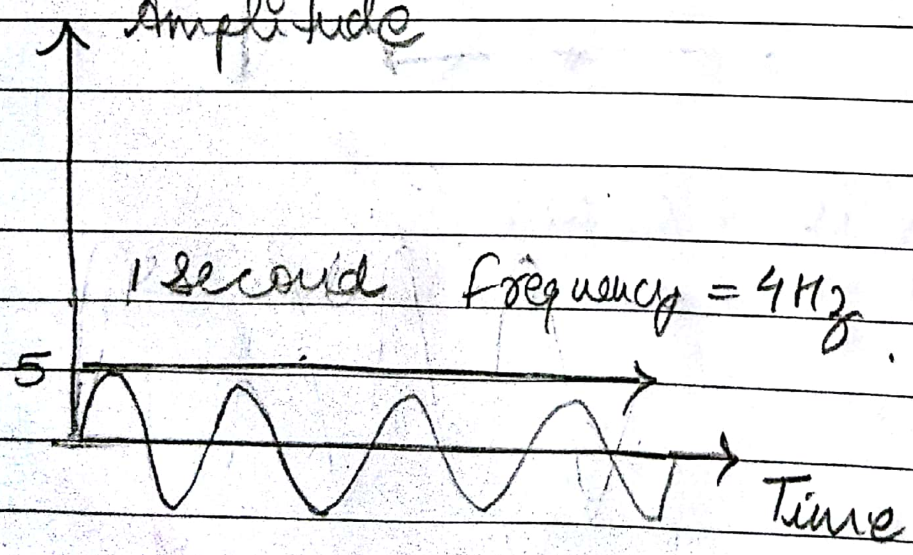
Chapter - 3

A sine wave is comprehensively defined by its amplitude, frequency & phase

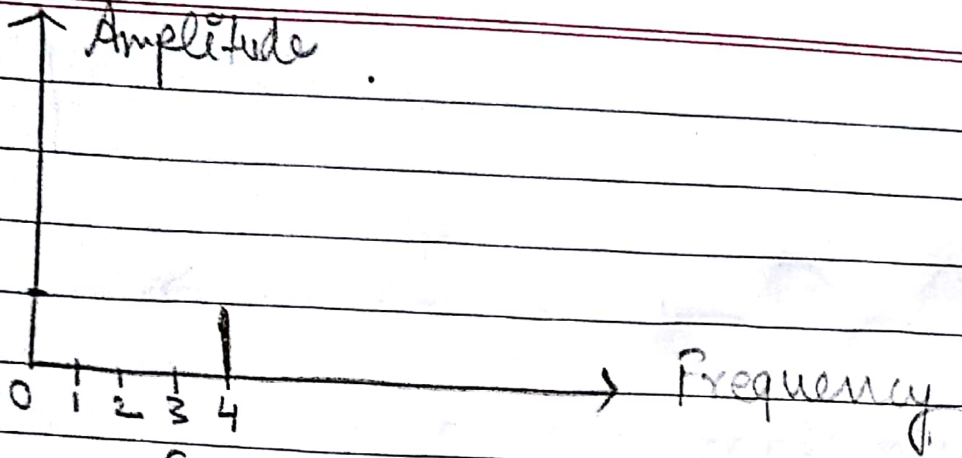
We have been showing a sine wave using what is called as time - domain plot

Time Domain plot shows changes in signal amplitude with respect to time (it is an amplitude v/s time plot)

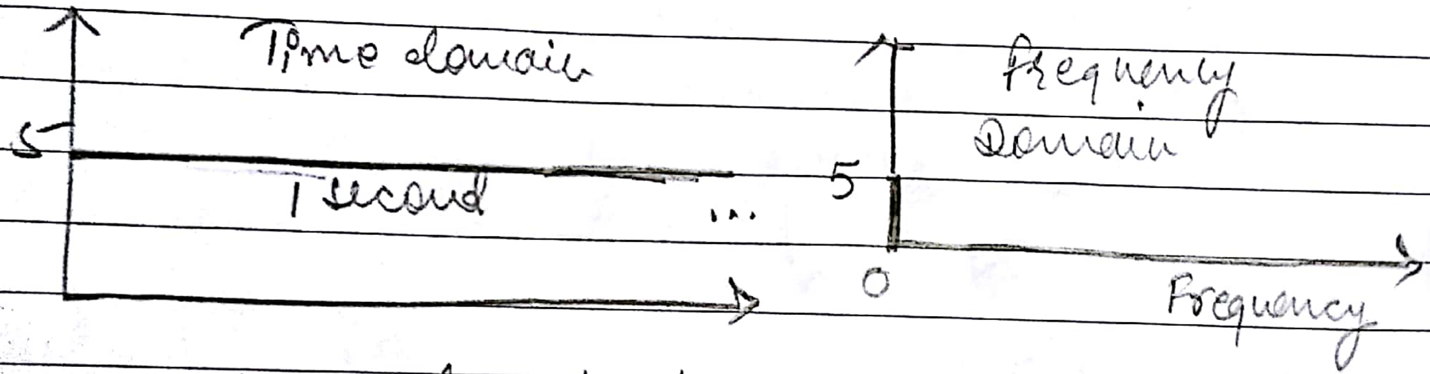
To show relationship b/w amplitude & frequency, we use frequency domain plot



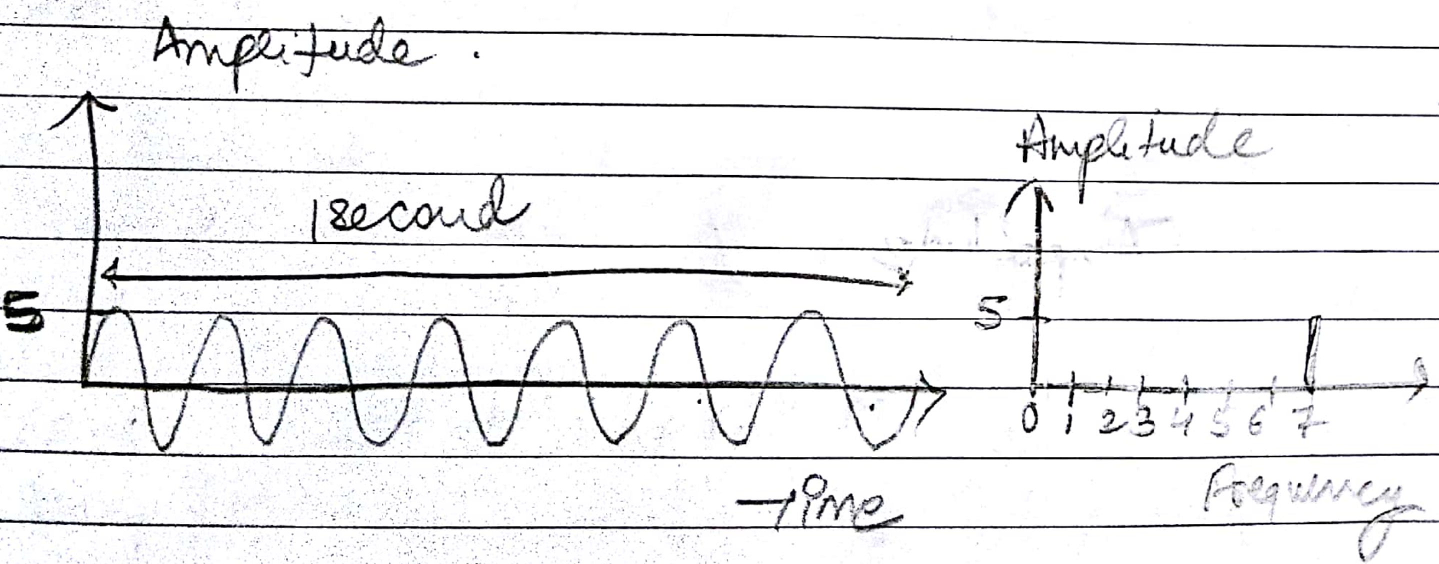
a. Time Domain

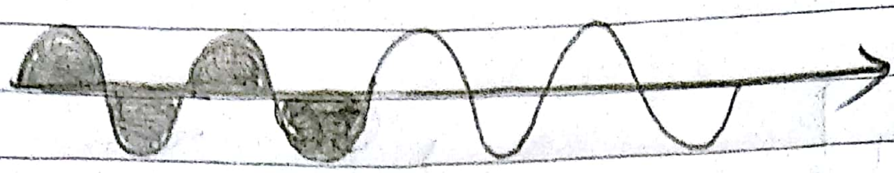


Frequency Domain

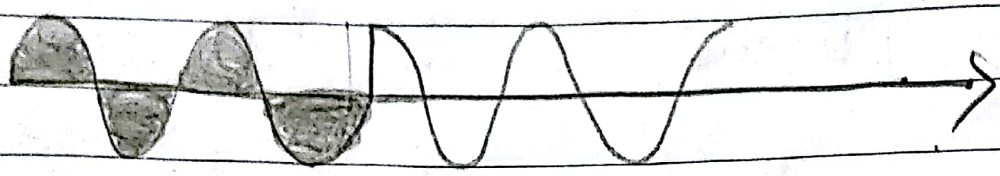


A signal with frequency 0.

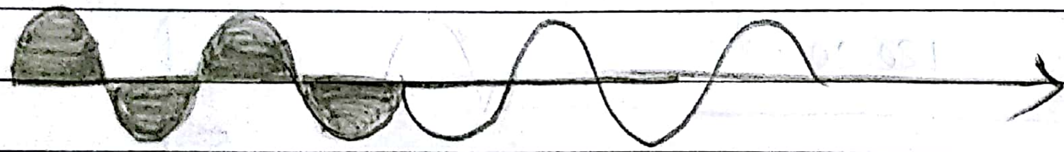




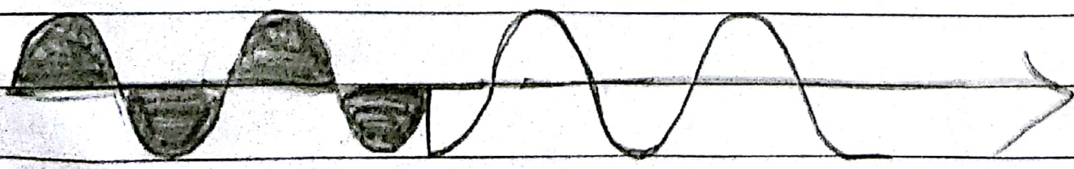
No phase change.



90° degree phase change.



180° phase change.



270° phase change.

COMPOSITE SIGNALS -

So far we have focused attention on simple periodic signals (sine waves). But what about periodic signals that are not sine waves?

Many useful wave forms, do not change in a single smooth curve, between a minimum & maximum amplitude, they jump, slide, wobble, spike and dip.

But as long as any irregularities are consistent, cycle after cycle a signal is still periodic and logically describable in same terms used for sine waves.

In fact it can be shown that any periodic signal no matter how complex, can be decomposed into a collection of sine waves, each having measurable amplitude, frequency & phase.

A single frequency sine wave is not useful in data communications we need to change one or more characteristics of a ~~sign~~ single, single frequency signal, it becomes a composite signal made of many frequencies.

Composite Signal

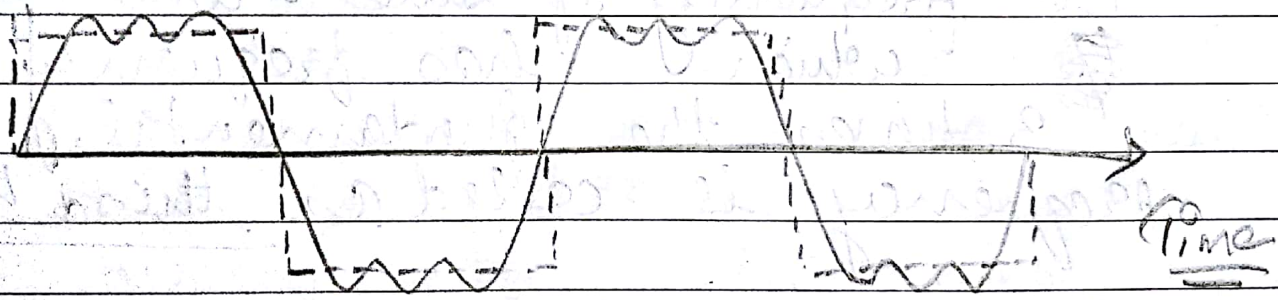
periodic

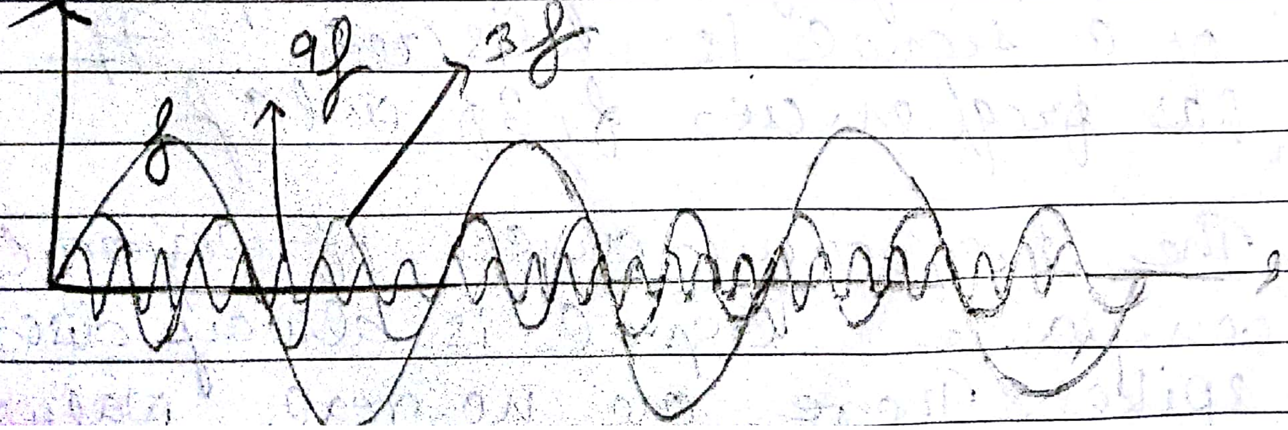
Non-periodic

A periodic composite signal can be decomposed into series of simple sine waves with discrete frequencies (frequencies that have integer value 1, 2, 3 & so on..)

A non periodic composite signal can be decomposed into a combination of infinite number of simple sine waves with continuous frequencies (frequencies that have real values)

The following figure shows a periodic composite signal with frequency f.





Decomposition of Composite Signal -

The amplitude of sine wave with frequency f is almost same as the peak amplitude of composite signal.

The amplitude of sine wave with frequency 3f ~~has~~ is one-third (1/3) of that of first. and amplitude of sine wave with frequency 9f is 1/9 of the first.

The frequency of first sine wave with frequency f is called as first harmonic or fundamental frequency.

The frequency of sine wave ~~with~~ which has frequency of 3 times the fundamental frequency is called as third harmonic

& the last one is called as ninth harmonic.

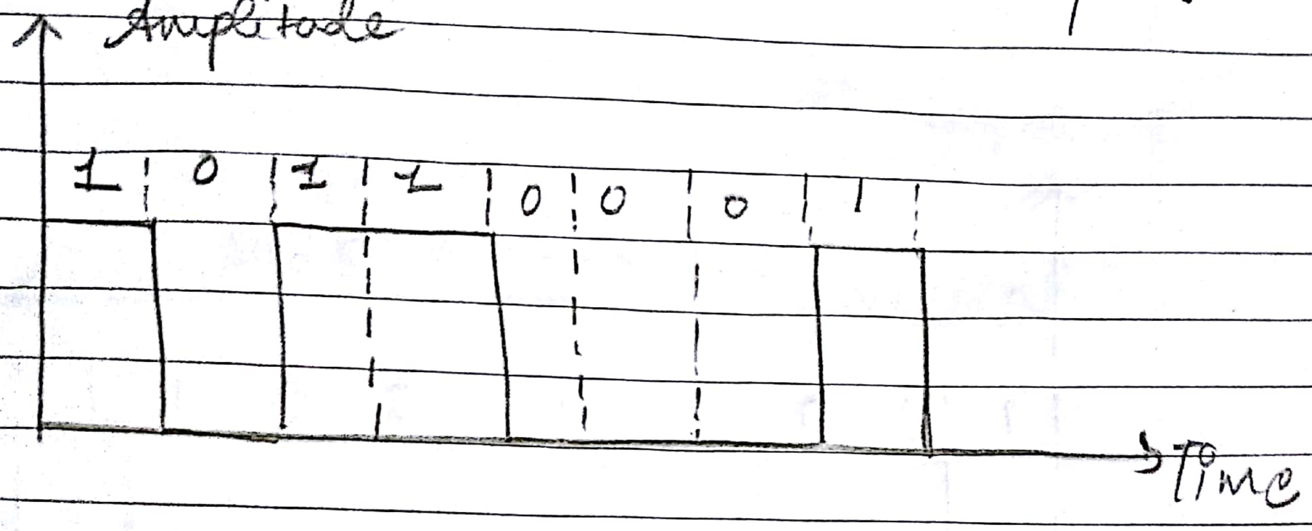
Note the frequency decomposition of a signal is discrete. It has frequencies f, 3f and 9f

The frequency domain of periodic composite signal is always discrete spikes. There are no real values like 1.2 f, 2.6 f . . . . .

DIGITAL SIGNAL -

In addition to being reprented by an analog signal, data can also be represented by digital signal.

1 can be encoded as positive voltage
0 can be encoded as -ve voltage.

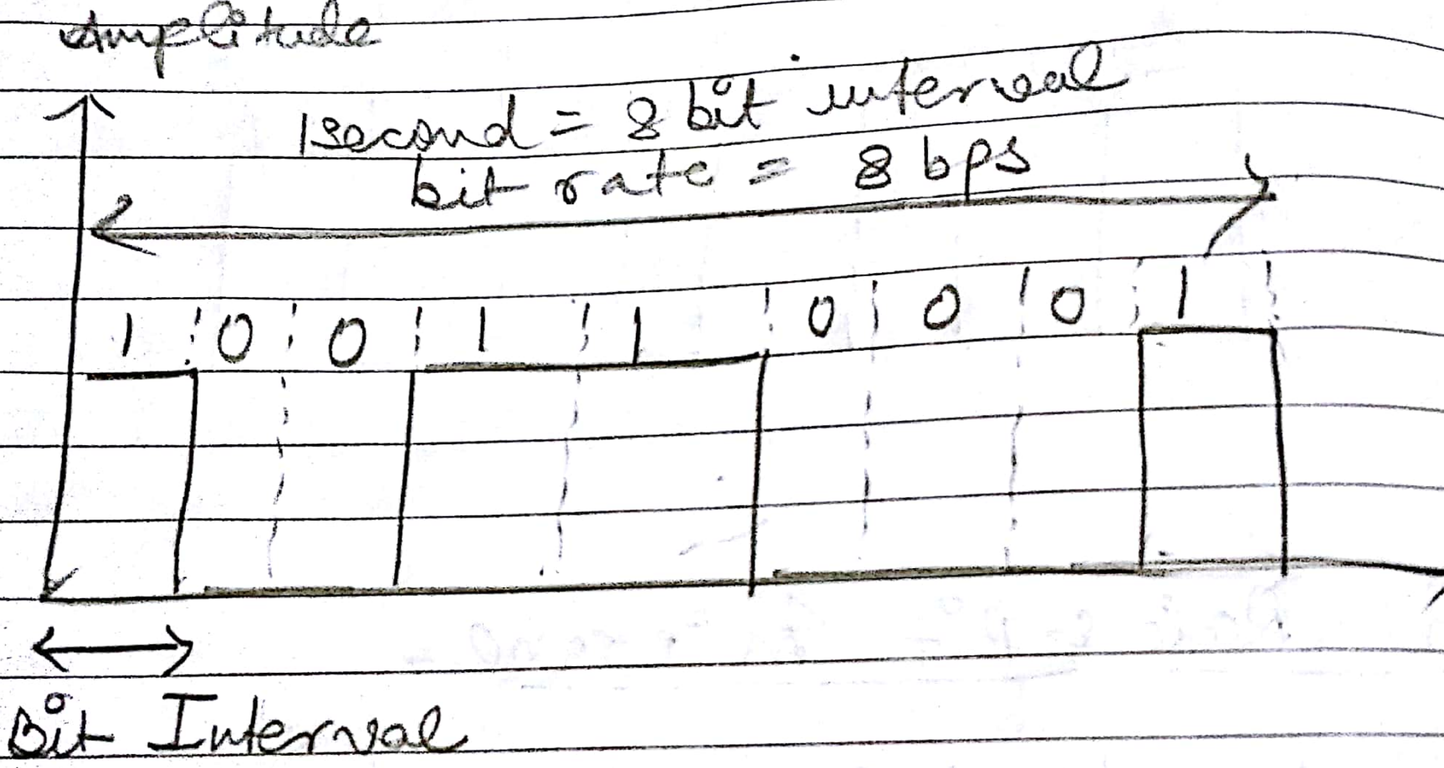


Bit Rate & Bit Interval -

Most digital signals are aperiodic and thus period or frequency is not appropriate. Two new terms bit interval (instead of period) and bit rate (instead of frequency) are used to describe digital signals.

Bit interval : Bit interval is the time required to send one single bit.

Bit Rate :- is the number of bit intervals per second.



Q A digital signal has a bit rate of 2000 bps. What is the duration of each bit (bit interval)?

Ans Bit interval is inverse of bit rate.

$$\text{bit interval} = \frac{1}{\text{Bit Rate}}$$

$$= \frac{1}{2000} = 0.000500 \text{ seconds}$$

Q A digital signal has a bit interval of 40 microseconds. What is the bit rate?

$$\text{bit rate} = \frac{1}{\text{bit interval}}$$

$$= \frac{1}{40 \times 10^{-6}} = 25{,}000 \text{ bits per second.}$$

$$= 25 \times 10^{3} \text{ bits / second}$$

$$= 25 \text{ Kbps}$$

Frequency Spectrum & Bandwidth :-

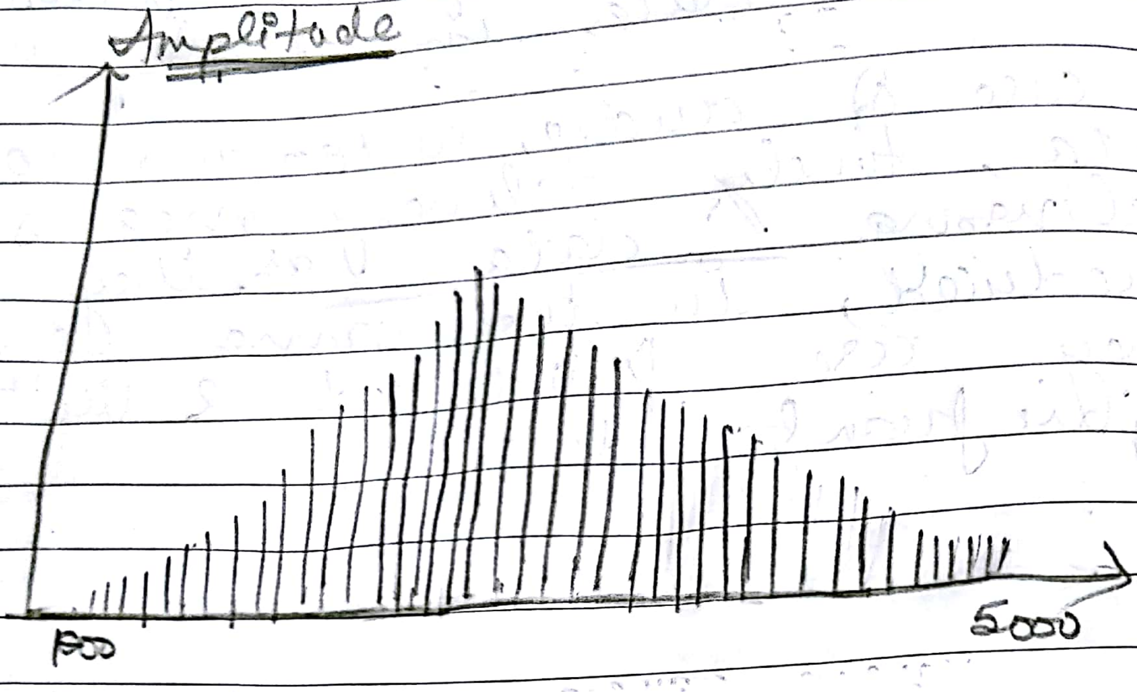
1. Frequency Spectrum of a signal is the collection of all the component frequencies it contains and shown using frequency domain graph.

2. **Bandwidth** - The bandwidth of the signal is the width of the frequency spectrum.

OR

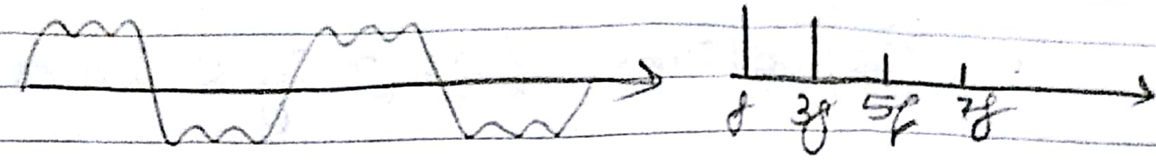
Bandwidth refers to the range of component frequencies and frequency Spectrum refers to the elements within that range

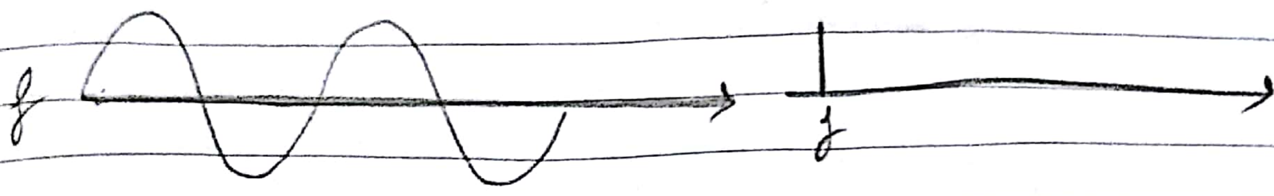
$$\boxed{\text{Bandwidth} = \text{Highest frequency} - \text{lowest frequency}}$$

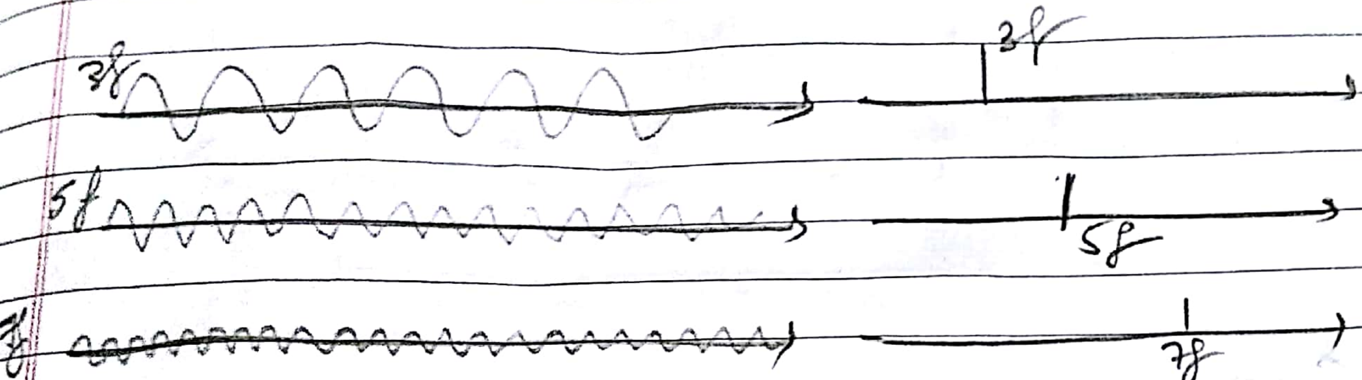


$B = 5000 - 1000 = 4000\,Hz$

Time Domain | Frequency Domain







Q. If a periodic signal is decomposed into 5 sine waves with frequencies of 100, 300, 500, 700 & 900 Hz. What is the bandwidth.

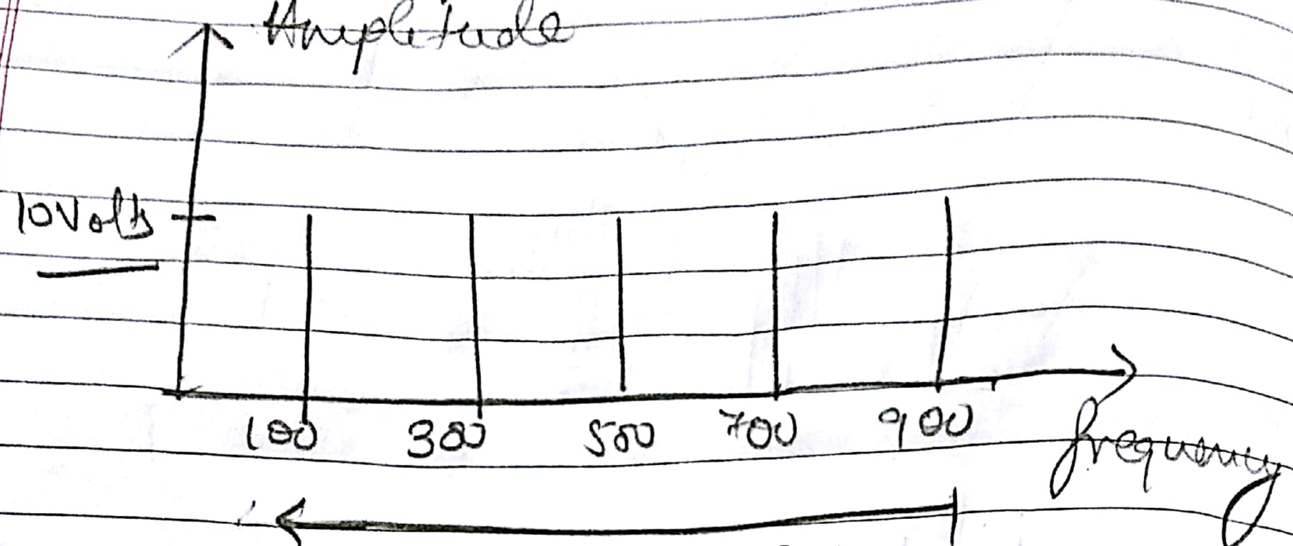
Draw the spectrum, assuming all components have max amplitude of 10 Volts.

Ans. Let f_h be the highest frequency and f_l is the lowest frequency

then Bandwidth $B = f_h - f_l$.

$900 - 100 = 800$ Hz

The spectrum has only 5 bars at 100, 300, 500, 700 & 900.



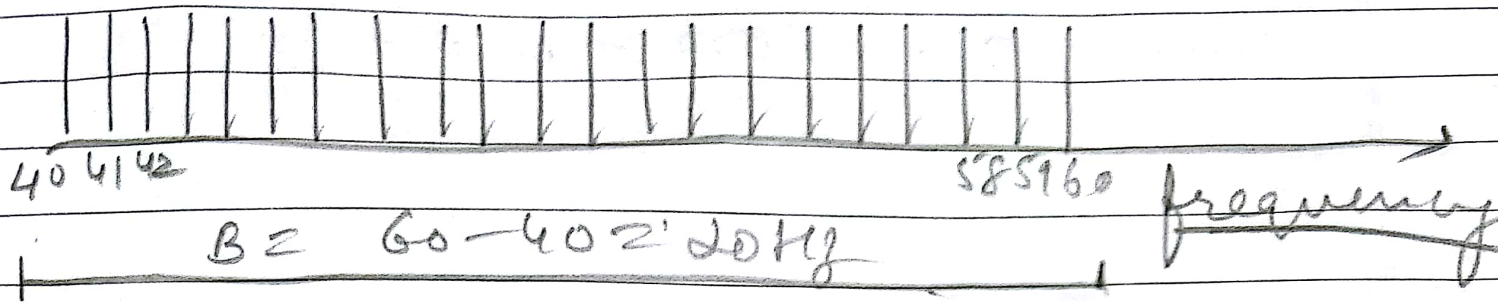
$B = 900 - 100 = 800$.

Eg. A signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency.

Draw the spectrum of the signal containing all integral frequencies of same amplitude.

$$B = f_h - f_l$$

$$f_l = 60 - 20 = 40\,Hz$$



$f_l = 40$ Hz

$f_h = 60$ Hz