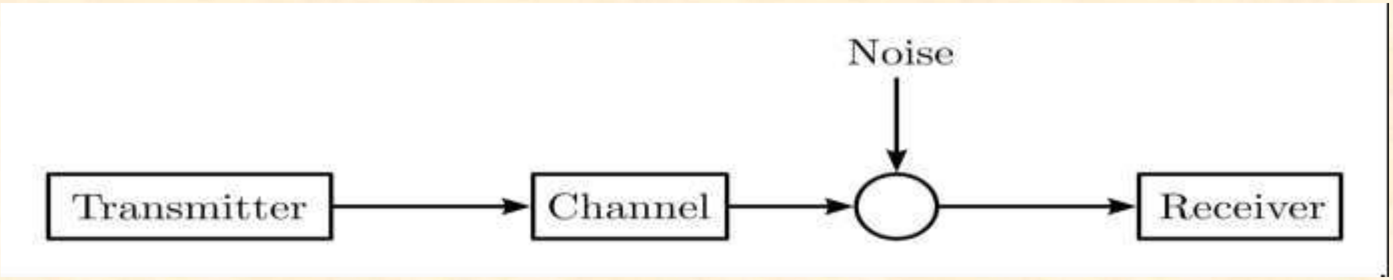
# Communication System

# Introduction

- **Communication system** is a system which describes the **exchange of information or data between two stations**, i.e. between **transmitter and receiver.**

- To transmit signals in communication system, it must be first processed by several stages, beginning from signal representation, to signal shaping until encoding and modulation.



# Application Areas

- Telephone/ Mobile
- Telegraph
- TV cable/ Radio
- Computer
- Defense/ military application
- Broadcasting, Mass Media or Journalism
- Satellite/ Space Communication
- Digital Signal Processing
- Image Processing
- And many more.....

# Essentials of Communication System

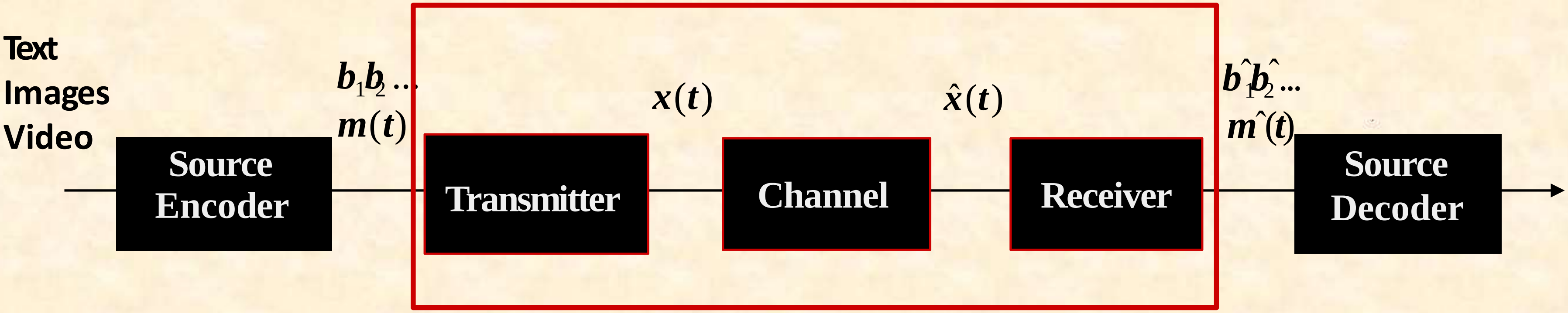
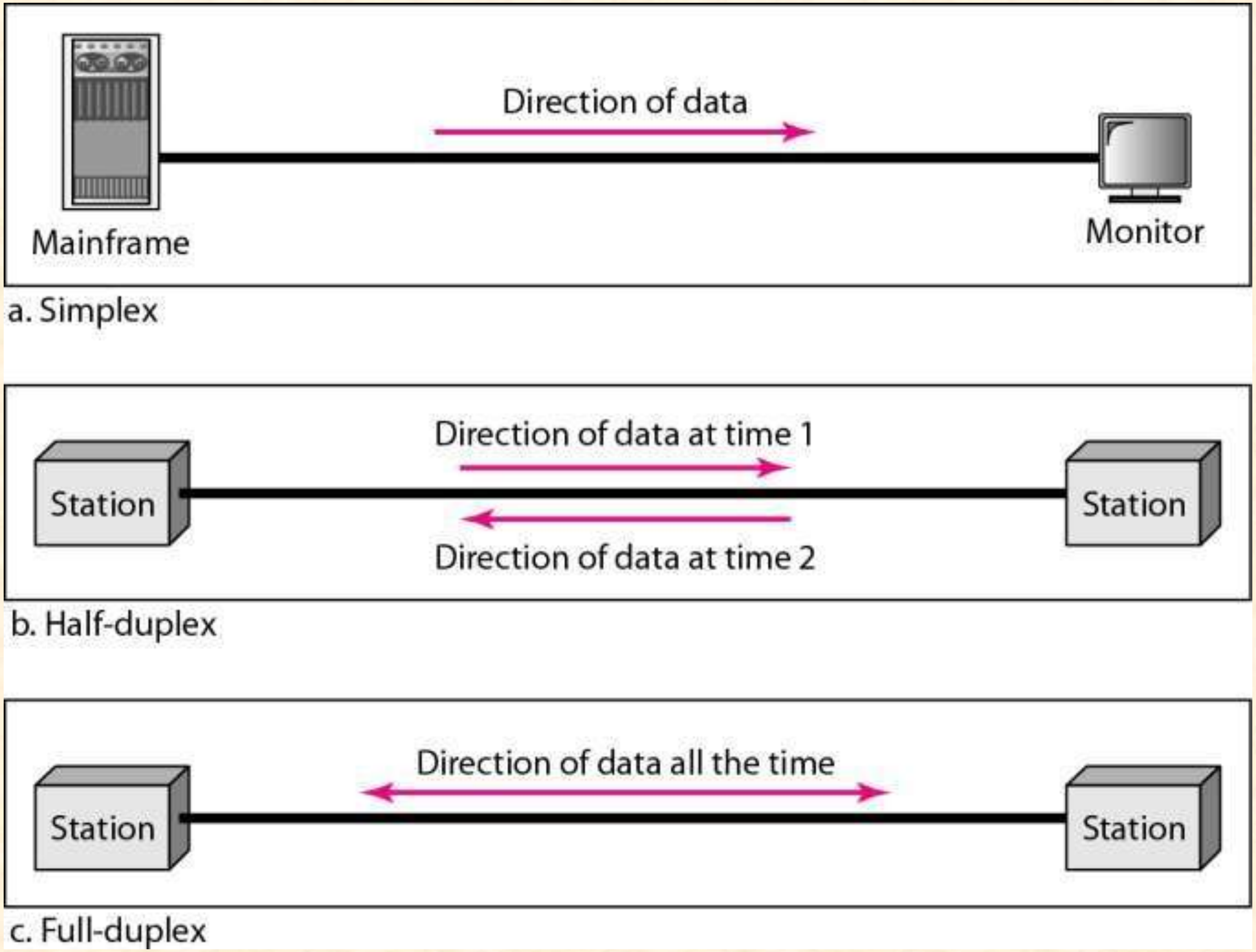



Figure: Block Diagram of Digital Communication System

- Source encoder converts message into message signal or bits.
- Transmitter converts message signal or bits into format appropriate for channel transmission (analog/digital signal).
- Channel introduces distortion, noise, and interference.
- Receiver decodes received signal back to message signal.
- Source decoder decodes message signal back into original message.

# Modes of Communication: S*implex, Half-Duplex and Full-Duplex)*



- **Simplex (SX) –** one direction only, e.g. TV
- **Half Duplex (HDX) –** both directions but not at the same time, e.g. CB radio
- **Full Duplex (FDX) –** transmit and receive simultaneously between two stations, e.g. standard telephone system.
- **Full/Full Duplex (F/FDX) -** transmit and receive simultaneously but not necessarily just between two stations,

  e.g. data communications circuits

# Medias for Communication

- Telephone Channel
- Mobile Radio Channel
- Optical Fiber Cable
- Satellite Channel

# Unit 1

- **Introduction To Communication System**: Modulation, Demodulation, Radio Frequency Spectrum, Signals & their classification, Limitations & Advantages of a Communication System, Comparison of Analog & Digital Communication Systems, Historical Perspectives.
- **Noise**: Sources of Noise, External & Internal Noise, Noise Calculations, Noise Figure, Noise Figure Calculation, Noise Temperature, Noise in Communication Systems, Band Pass Noise Model, Cascaded States & its Noise Figure Calculation, Signal in presence of Noise, Pre-Emphasis & De- Emphasis, Noise Quieting Effect, Capture Effect, Noise in Modulation Systems.

# Introduction to Communication System

- Modulation
- Demodulation
- Radio Frequency Spectrum
- Signals & their classification
- Systems & their classification
- Limitations & Advantages of a Communication System
- Comparison of Analog & Digital Communication Systems
- Historical Perspective

# What is Modulation?

In modulation, a <u>message</u> signal, which contains the <u>information</u> is used to control the parameters of a <u>carrier</u> signal, so as to impress the information onto the carrier.

**<u>The Messages</u>**

The message or modulating signal may be either:

analogue – denoted by $m(t)$

digital – denoted by $d(t)$ – *i.e.* sequences of 1's and 0's

The message signal could also be a multilevel signal, rather than binary; this is not considered further at this stage.

**<u>The Carrier</u>**

The carrier could be a 'sine wave' or a 'pulse train'.

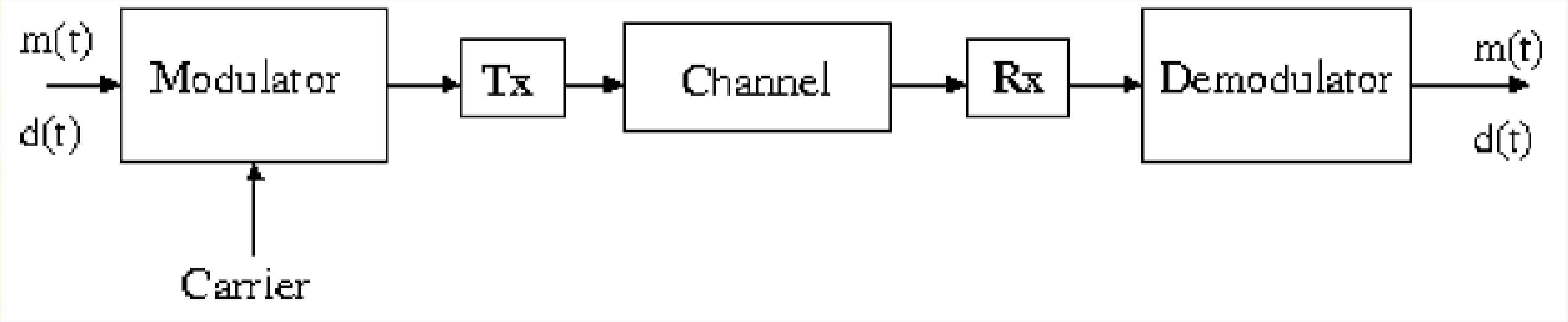
<u>Consider a 'sine wave' carrier:</u>

$$v_c(t) = V_c \cos(\omega_c t + \varphi_c)$$

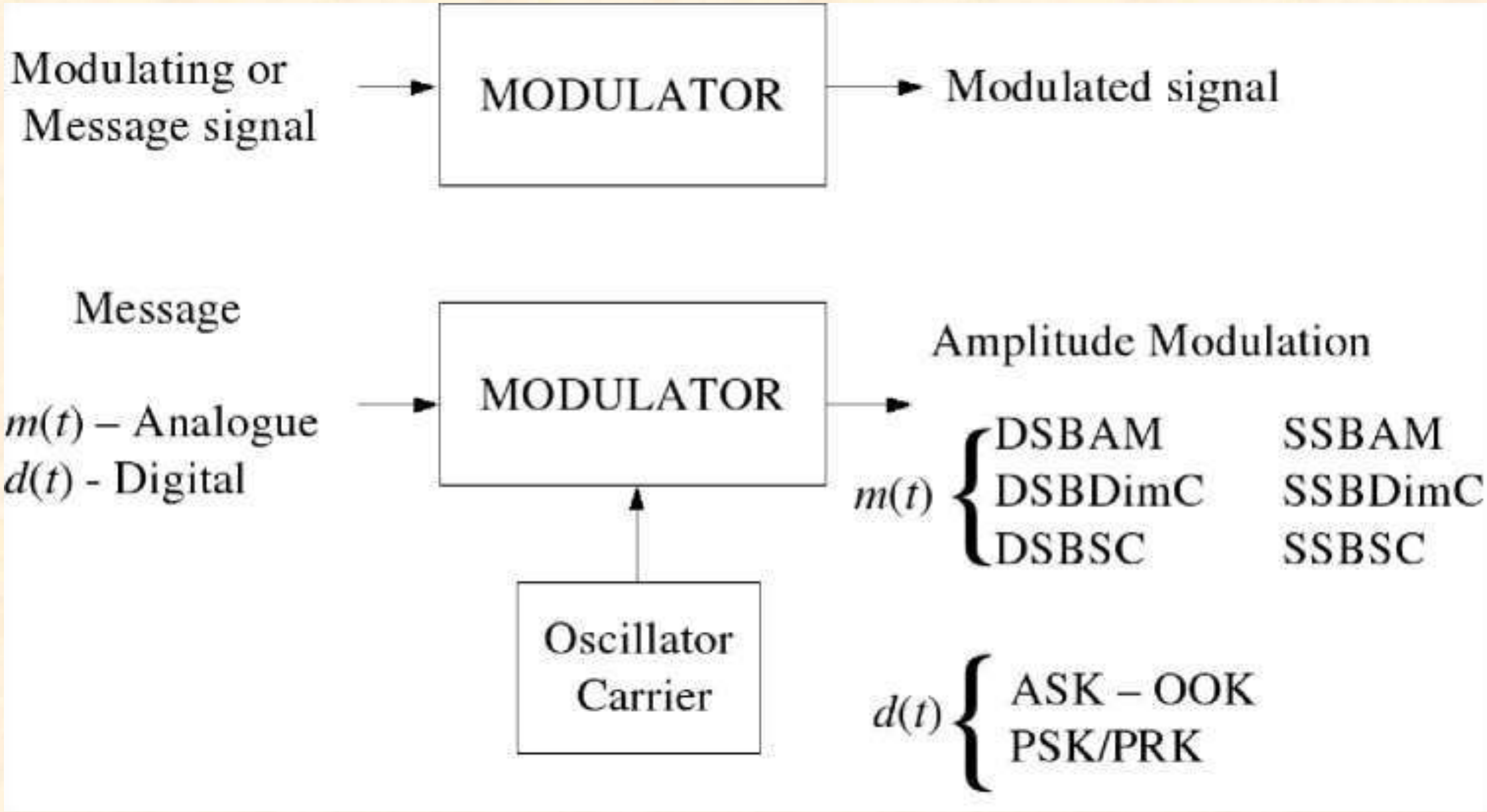
- If the message signal $m(t)$ controls amplitude – gives AMPLITUDE MODULATION AM
- If the message signal $m(t)$ controls frequency – gives FREQUENCY MODULATION FM
- If the message signal $m(t)$ controls phase- gives PHASE MODULATION PM or $\phi$M

# What is Demodulation?

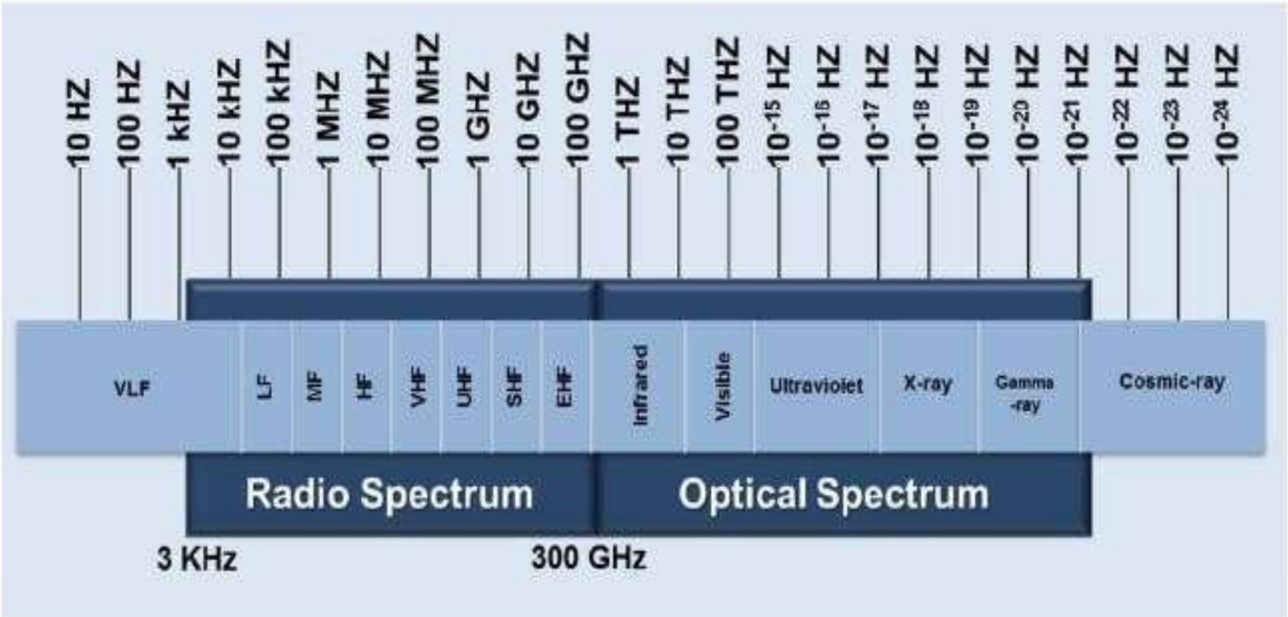
Demodulation is the reverse process (to modulation) to recover the message signal *m*(*t*) or *d*(*t*) at the receiver.



# Summary of Modulation Technique.

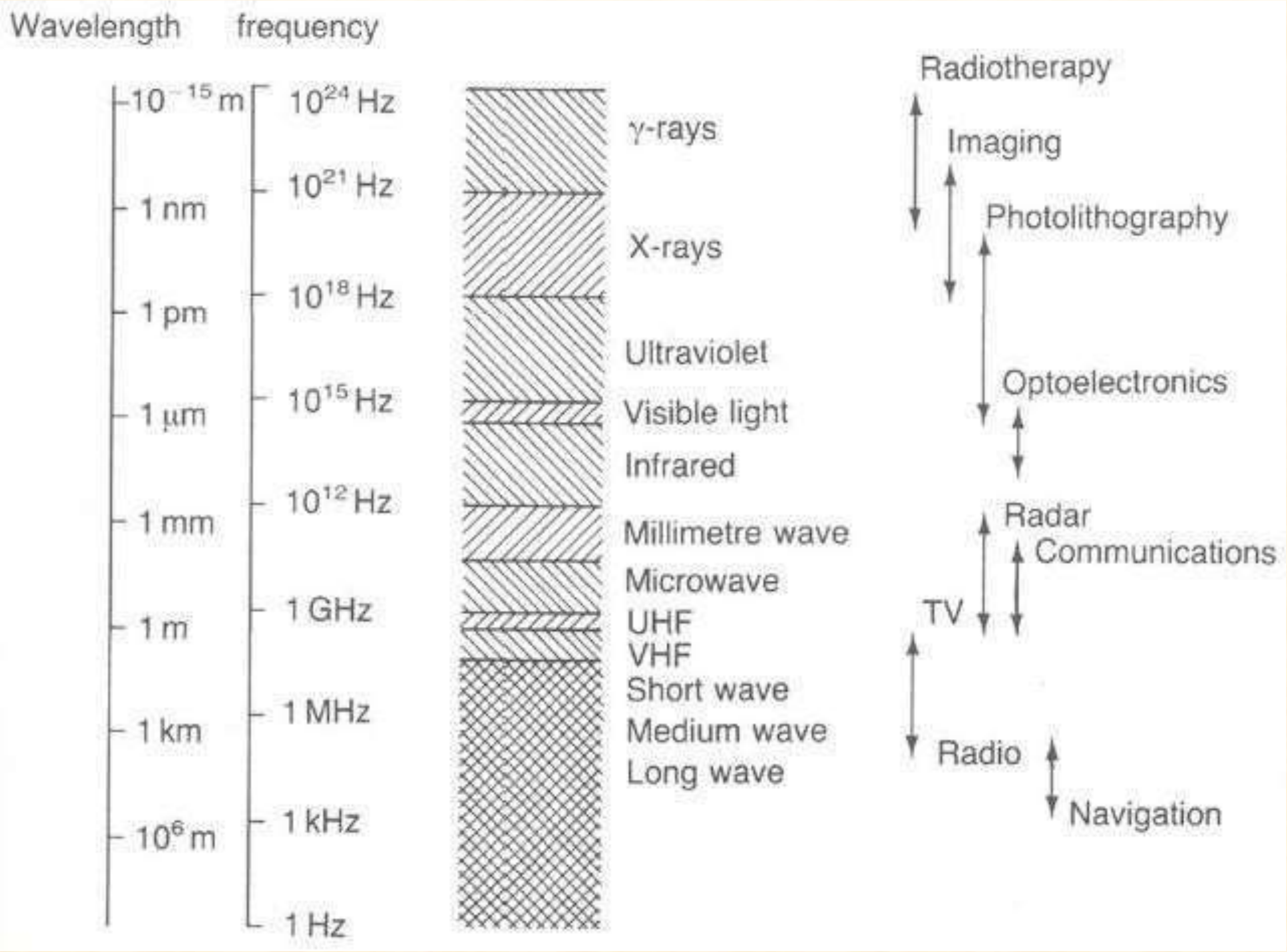


# What is Frequency or Spectrum 'Band'




- Bands are group of frequencies, defined to make it easier to remember
- Bandwidth (BW) is the difference between max and min of any defined or undefined band.
  - For example you have a band from 700MHz to 800MHz, BW = 100MHz

# Frequency Spectrum



- The electromagnetic spectrum is a collective term to refer to the entire range and scope of frequencies of electromagnetic radiation, from 3 Hertz (written as Hz) to 300 Exahertz (300,000,000,000,000,000,000 Hz)

- 1000 Hz = 1 kilo Hz (kHz)
- 1000 kHz = 1 Mega Hz (MHz)
- 1000 MHz = 1 Giga Hz (GHz)
- 1000 GHz = 1 Tera Hz (THz)
- 1000 THz = 1 Peta Hz (PHz)
- 1000 PHz = 1 Exa Hz (EHz)

The **Radio Spectrum** is part of spectrum from 3Hz to 3000GHz (3 THz)

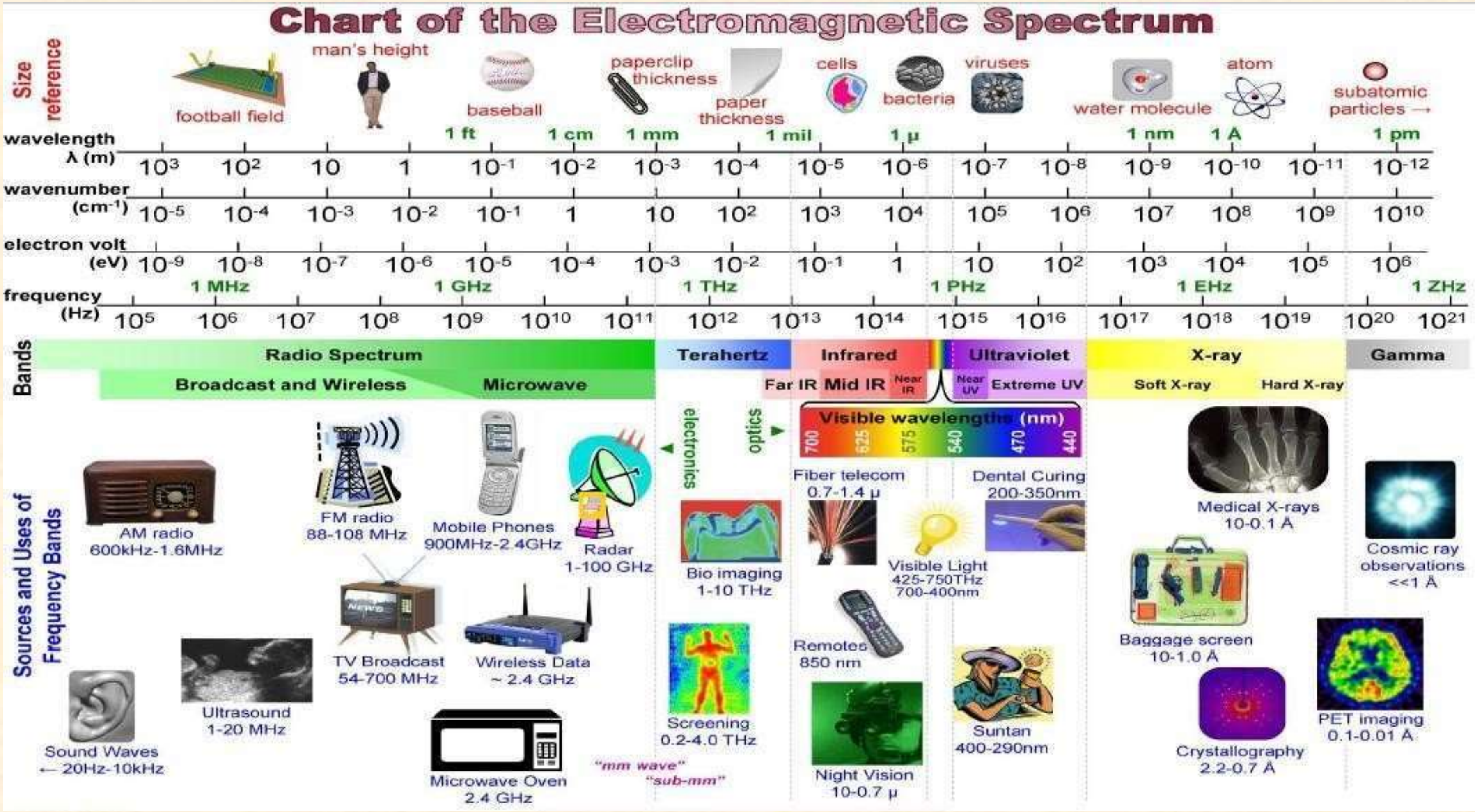
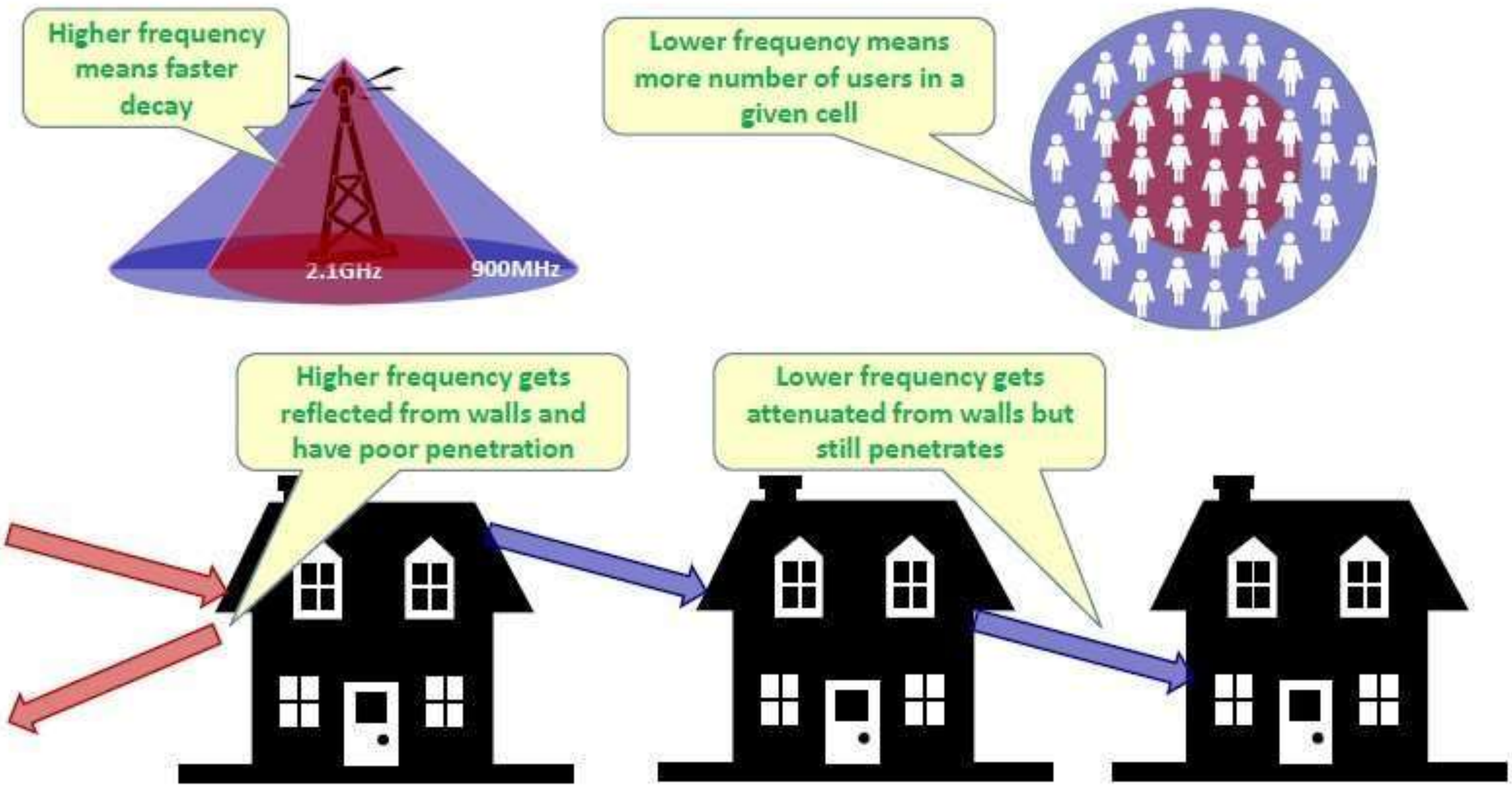
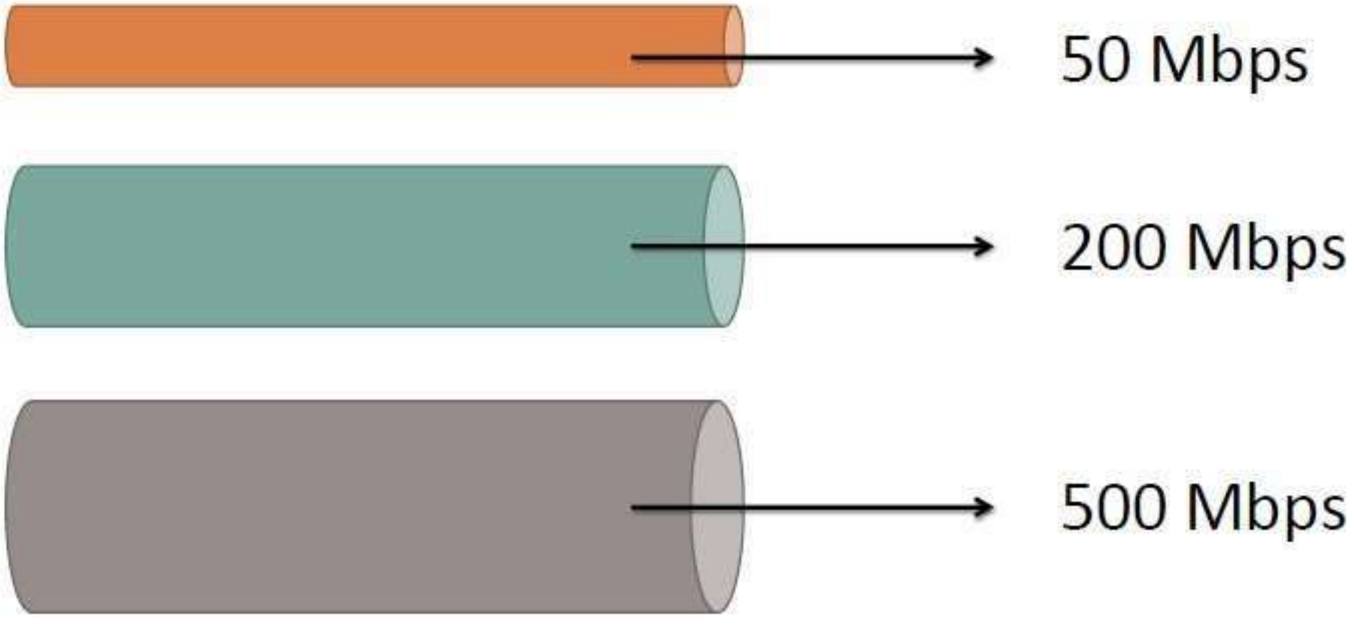


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 Å
1 pm
$10^3$ $10^2$ 10 1 $10^{-1}$ $10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$ $10^{-11}$ $10^{-12}$
wavenumber ($cm^{-1}$)
$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ 1 10 $10^2$ $10^3$ $10^4$ $10^5$ $10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$
electron volt (eV)
$10^{-9}$ $10^{-8}$ $10^{-7}$ $10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ 1 10 $10^2$ $10^3$ $10^4$ $10^5$ $10^6$
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
$10^5$ $10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$ $10^{17}$ $10^{18}$ $10^{19}$ $10^{20}$ $10^{21}$
Bands
Radio Spectrum
Broadcast and Wireless
Microwave
Terahertz
Infrared
Far IR
Mid IR
Near IR
Ultraviolet
Near UV
Extreme UV
X-ray
Soft X-ray
Hard X-ray
Gamma
electronics
optics
Visible wavelengths (nm)
700 625 575 540 470 440
Sources and Uses of Frequency Bands
AM radio 600kHz-1.6MHz
FM radio 88-108 MHz
Mobile Phones 900MHz-2.4GHz
Radar 1-100 GHz
TV Broadcast 54-700 MHz
Wireless Data ~ 2.4 GHz
Sound Waves ← 20Hz-10kHz
Ultrasound 1-20 MHz
Microwave Oven 2.4 GHz
"mm wave"
"sub-mm"
Bio imaging 1-10 THz
Screening 0.2-4.0 THz
Fiber telecom 0.7-1.4 μ
Remotes 850 nm
Night Vision 10-0.7 μ
Visible Light 425-750THz 700-400nm
Dental Curing 200-350nm
Suntan 400-290nm
Medical X-rays 10-0.1 Å
Baggage screen 10-1.0 Å
Crystallography 2.2-0.7 Å
Cosmic ray observations <<1 Å
PET imaging 0.1-0.01 Å

# Importance of Frequency selection



# Larger Bandwidth means more data flow




Visualise bandwidth as pipes carrying water. The fatter the pipe, the more water can flow through it

# Signals

- **A Signal** is the function of one or more independent variables that carries some information to represent a physical phenomenon. e.g. ECG, EEG

- **Classification of signals:**
  1. Continuous & Discrete Signals
  2. Randam & Diterminstic Signals
  3. Periodic & Non Periodic Signals
  4. Causal & Non Causal Signals
  5. Energy & Power signals
  6. Even & Odd signals

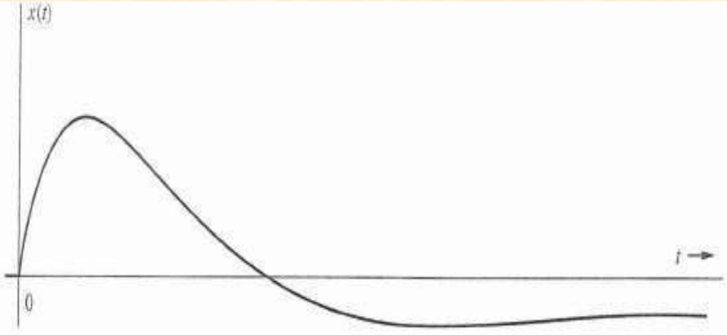
# Classification of Signals

**Continuous-time Sinal:** Signal which is defined at every instant of time, this means that the signal is analog or continuous in nature.

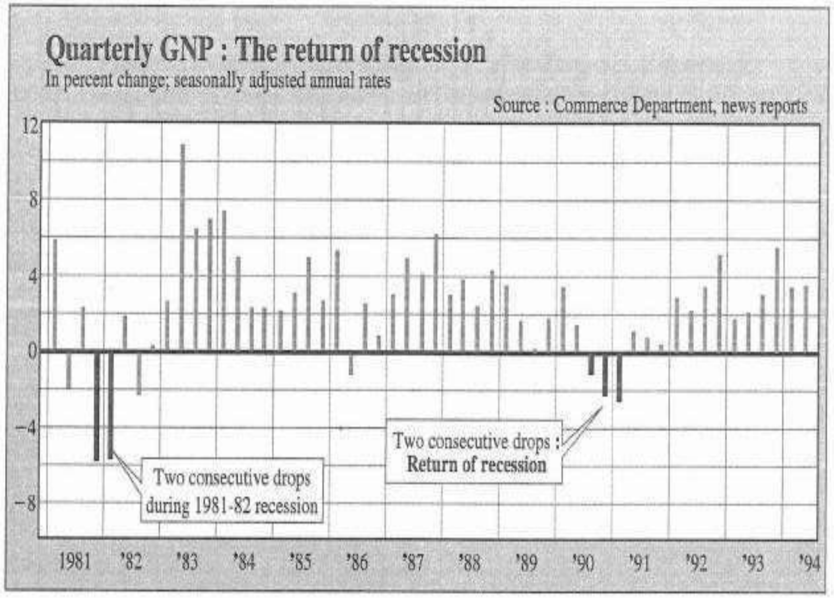
**Discrete-time Sinal:**

The Signal which is defined at some instant of time, not at every instant.

These signals are also known as sampled signals.




(a)




(b)

# Examples: CT vs. DT Signals

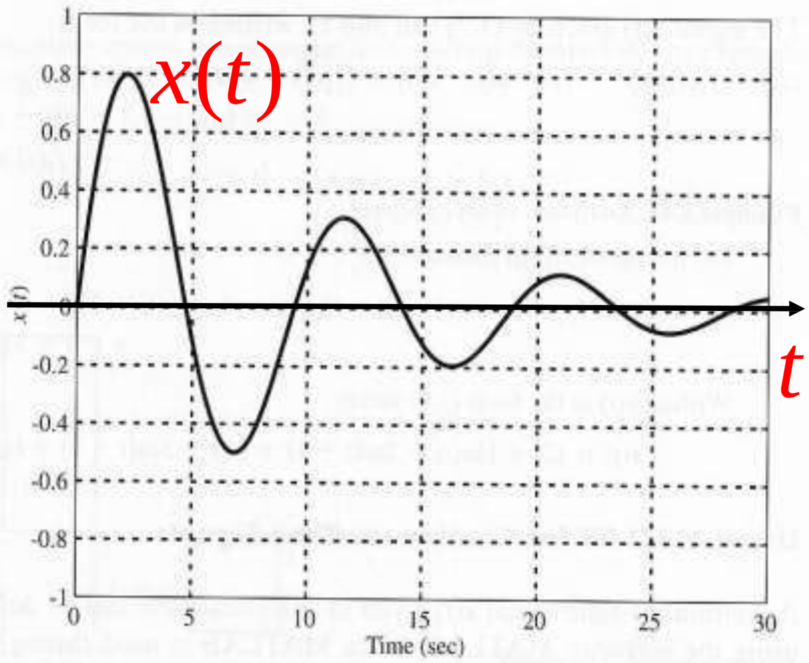



**Figure 1.13** MATLAB plot of the signal $x(t) = e^{-0.1t} \sin \frac{2}{3} t$.

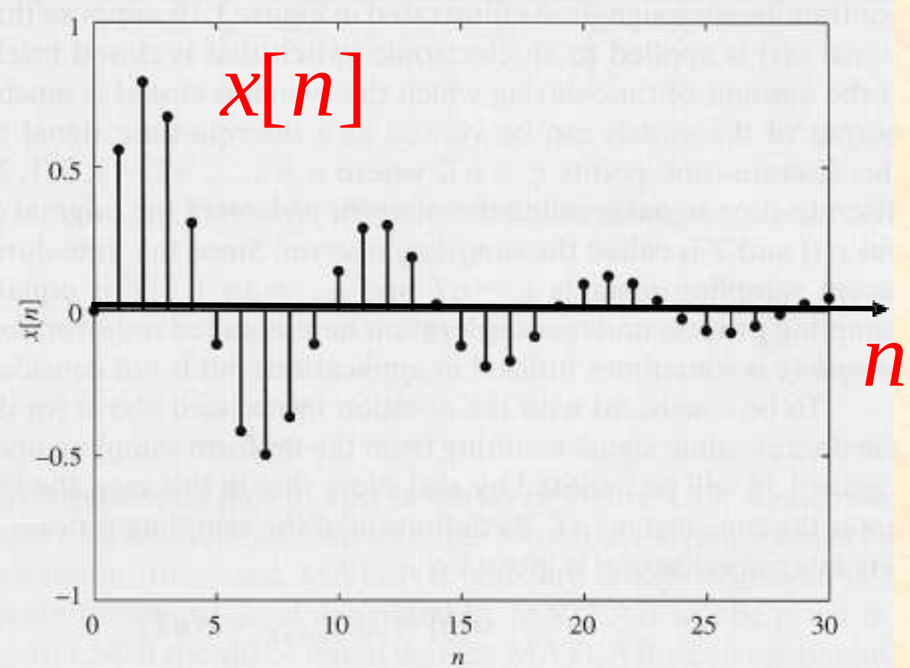


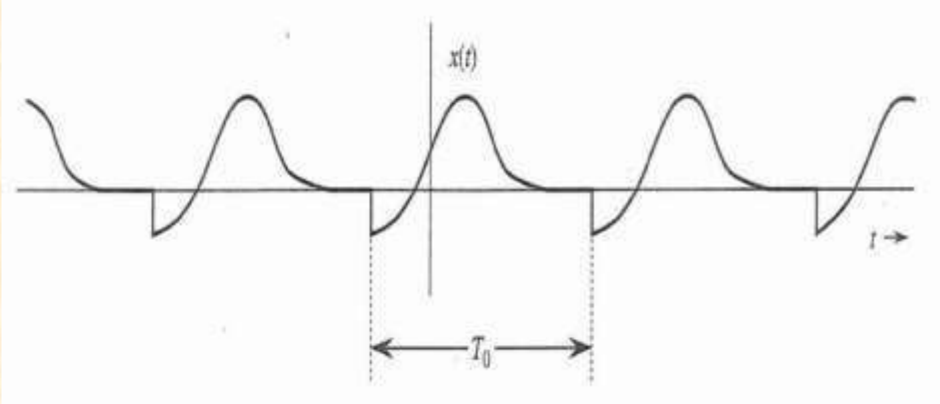

**Figure 1.17** Sampled continuous-time signal.

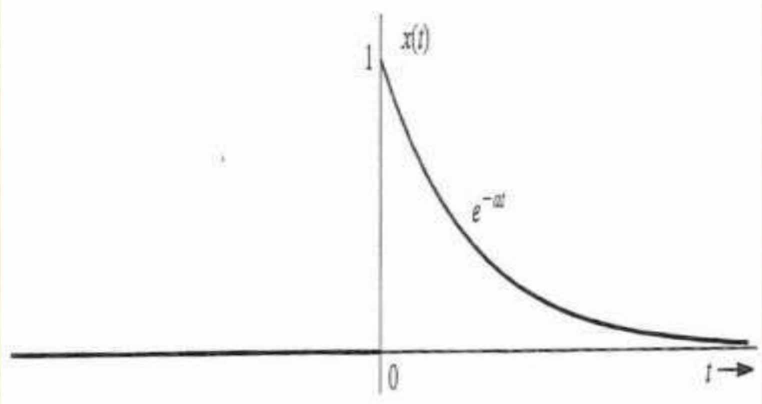
# Periodic vs Aperiodic

- A signal *x(t) is said to be* ***periodic*** *if for some positive constant* $T_o$ *i.e* $x(t) = x(t+T_o)$ *for all t*
- *A signal x(t) is said to be* ***non periodic****:*

  if $x(t) \neq x(t+T_o)$ *for all t*

The smallest value of $T_o$ *that satisfies the periodicity condition of this* equation is the *fundamental period of x(t).*




Periodic Signal

Non Periodic Signal

# Energy and Power Signals

## Energy Signal

- A signal with finite energy and zero power is called Energy Signal i.e.for energy signal

$$0<E<\infty \text{ and } P=0$$

- Signal energy of a signal is defined as the *area under the square of the magnitude of the signal*.

$$E_x = \int_{-\infty}^{\infty} \left| x(t) \right|^2 dt$$

- The units of signal energy depends on the unit of the signal.

# Energy and Power Signals Contd.

## Power Signal

- Some signals have infinite signal energy. In that case it is more convenient to deal with **average signal power.**
- For power signals

$$0<P<\infty \text{ and } E = \infty$$

- Average power of the signal is given by

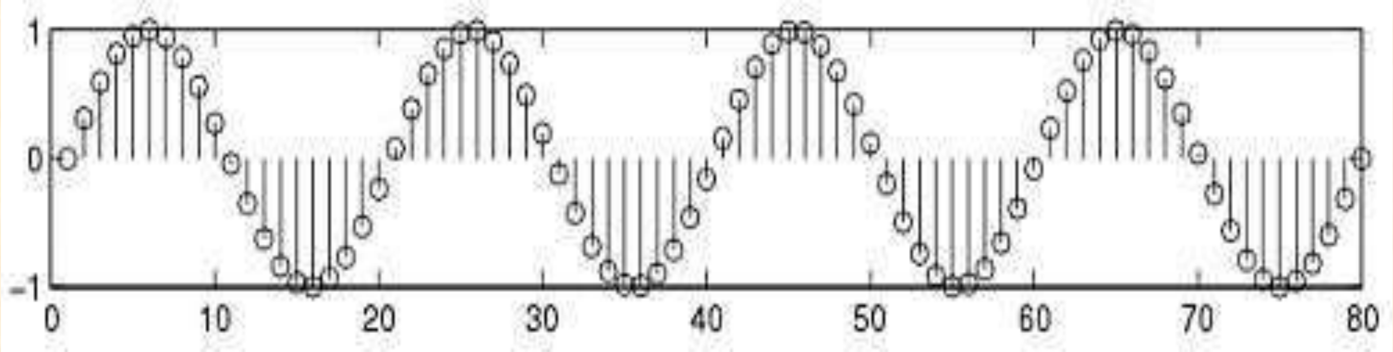
$$P_x = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} |x(t)|^2 \, dt$$

# Deterministic & Non Deterministic Signals

## Deterministic signals

- Behavior of these signals is predictable w.r.t time
- There is no uncertainty with respect to its value at any time.
- These signals can be expressed mathematically.

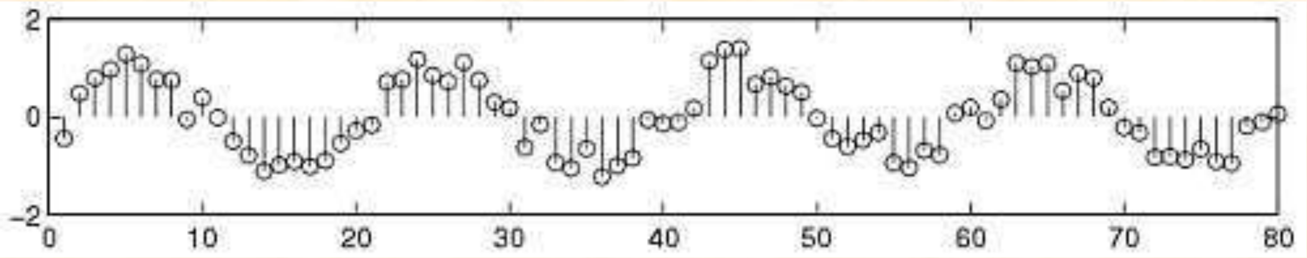
  For example $x(t) = \sin(3t)$ is deterministic signal.



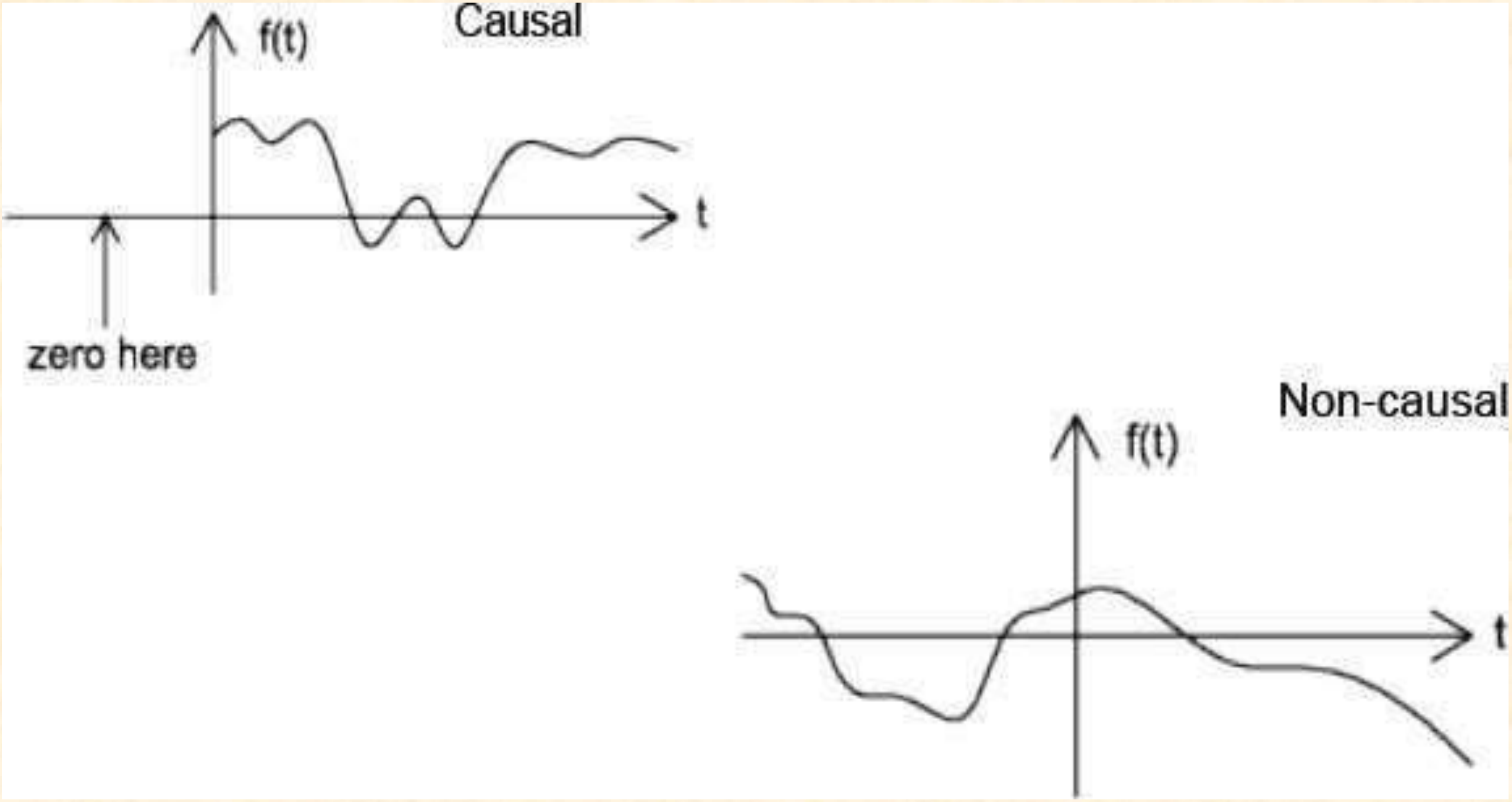
# Deterministic & Non Deterministic Signals Contd.

## Non Deterministic or Random signals

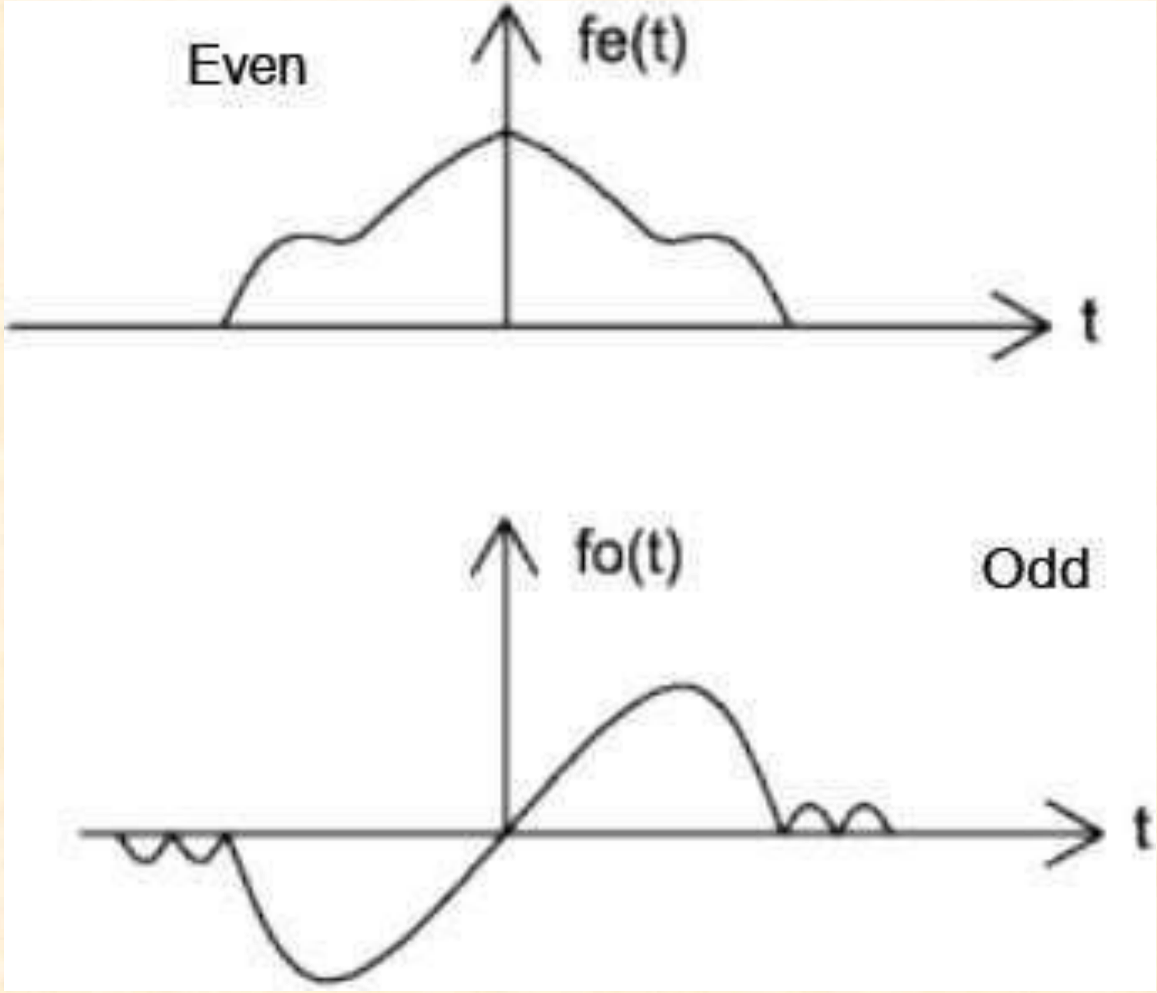
- Behavior of these signals is random i.e. not predictable w.r.t time.
- There is an uncertainty with respect to its value at any time.
- These signals can't be expressed mathematically.
- For example Thermal Noise generated is non deterministic signal.



# Causal vs Non-causal



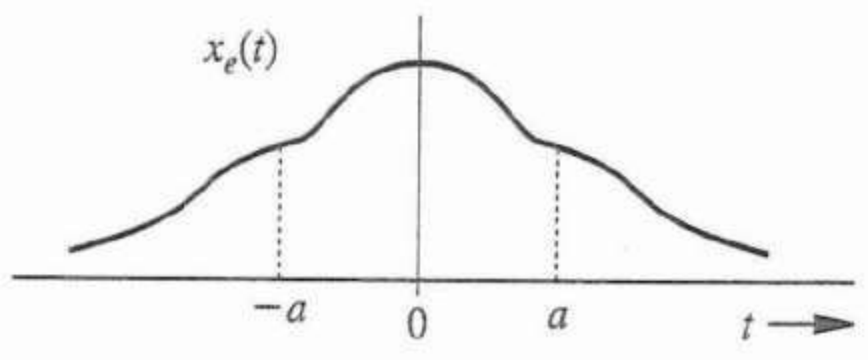
# Even vs Odd Signal



# Even and Odd Signal

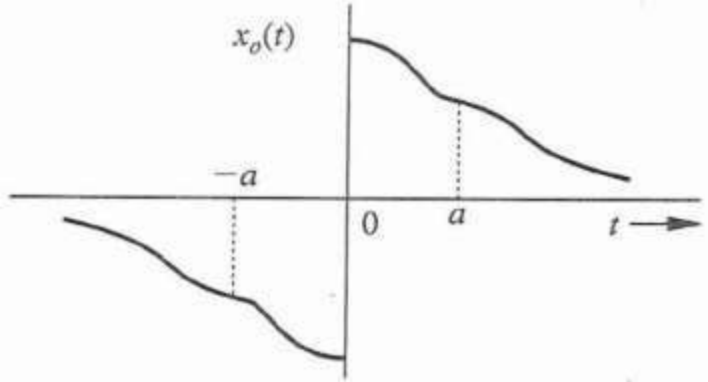
A real function $x_e(t)$ *is said to be an even function of t if*

$$x_e(t) = x_e(-t)$$




A real function $x_o(t)$ *is said to be an odd function of t if*

$$x_o(t) = -x_o(-t)$$



# Systems

**A system (plant)** is a combination of components, interrelated, independent elements that are organized for a specific purpose or task.

**Classification of Systems:**

1. Linear Time Invariant System (LTI System)
2. Linear Time Variant System (LTV System)
3. Continuous and Discrete time system
4. Causal and Non Causal Systems

# Classification of Systems

## Linear Time Invarient System **(LTI System)**/ Linear Time Varient System **(LTV System):**

**Linear:** The system that satisfies both superposition & homogeniety principle are said to be linear system.

**Time Invarient:** The output due to input x(t) is y(t) then the output due to input x(t+T) is y(t+T) is identical or same irrespective to the delay T in the input of the system.

**Linear+ Time Invarient= LTI System**

If the system does not obey's the Time Invarient Principle are known as Linear Time varient system.

# Continuous and Discrete time system:

Continuous System (Analog System): A continuous-time system is a device that operates on a continuous-time input and output signals.

Discrete time system : A discrete system is a system with a countable number of states.

A discrete-time system is a device that operates on a discrete-time input and output signals.

# Causal and Non Causal Systems:

Causal system : A system is said to be causal system if its output depends on present and past inputs only and not on future inputs.

Non Causal system: A system whose present response depends on future values of the inputs is called as a non-causal system.

# Advantages of a Communication System

**1.Speedy transmission:** It requires only a few seconds to communicate through electronic media because it supports quick transmission.

**2.Wide coverage:** World has become a global village and communication around the globe requires a second only.

**3. Low cost:** Electronic communication saves time and money. For example, Text SMS is cheaper than the traditional letter.

**4.Exchange of feedback:** Electronic communication allows the instant exchange of feedback. So communication becomes perfect using electronic media.

**5.Managing global operation:** Due to the advancement of electronic media, business managers can easily control operation across the globe. Video or teleconferencing e-mail and mobile communication are helping managers in this regard

# Disadvantages of a Communication System

1. **The volume of data:** The volume of telecommunication information is increasing at such a fast rate that business people are unable to absorb it within the relevant time limit.

**2.The cost of development:** Electronic communication requires huge investment for infrastructural development. Frequent change in technology also demands further investment.

**3.Legal status:** Data or information, if faxed, may be distorted and will cause zero value in the eye of law.

**4. Undelivered data:** Data may not be retrieved due to system error or fault with the technology. Hence required service will be delayed

# Advantages of a Digital Communication

- Digital communication can be done over large distances though internet and other things.
- Digital communication gives facilities like video conferencing which save a lot of time, money and effort.
- It is easy to mix signals and data using digital techniques.
- The digital communication is fast, easier and cheaper.
- It can tolerat the noise interference.
- It can be detect and correct error easily because of channel coding.
- Used in military application.
- It has excellent processing techniques are available for digital signals such as data compression, image processing, channel coding and equalization.

# Disadvantages of a Digital Communication

- Digital communication needs synchronization in synchronous modulation.
- High power consumption.
- It required more bandwidth as compared to analog systems.
- It has sampling error.
- Complex circuit, more sophisticated device making is also disadvantage of digital system.

# Historical Perspective

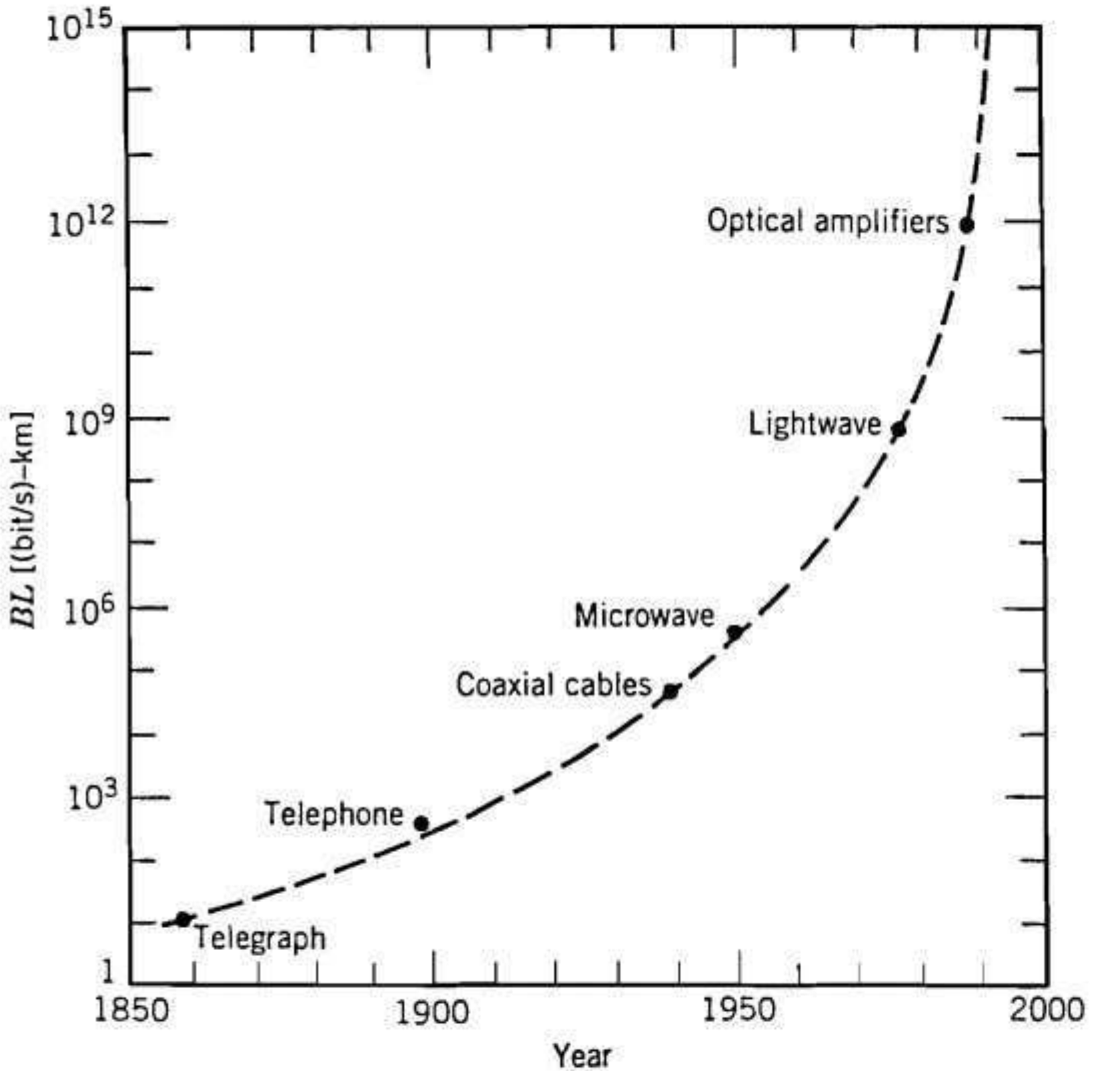



**Figure 1.1** Increase in bit rate–distance product $BL$ during the period 1850–2000. The emergence of a new technology is marked by a solid circle.

# History of Communication

- Early Optical Communications (circa 1700-1800)
  i. **Fire** or **smoke signals, signaling lamps**, and **semaphore flags**
  ii. Conveyed a single piece of information.
  iii. The bit rate of these systems is much less than 1 b/s.
  iv. Relay or regeneration systems were proposed by Claude Chappe in 1792 to transmit coded messages over distance of 100 km.

- **Morse Code keying techniques** (1830's)
  i. Electrical communications increased the bit rate to ~ 10 b/s.
  ii. Intermediate *relay stations* increased the transmission distances to ~1000 km.
  iii. *1866 first transatlantic cable.* These coding techniques were essentially a *digital code.*

- **Telephone** (1876)
  - i. Primarily an analog signal system.
  - ii. Dominated communication transmission for nearly a century.
  - iii. The development of worldwide telephone networks led to many advances in electrical communications systems.

- **Coaxial Cable** (1940)
  - i. Used in place of wire pairs as a transmission medium.
  - ii. Greatly increased system capacity.
  - iii. The first coax cable system - 3 MHz carrier frequency
  - iv. Capable of carrying 300 voice channels or one television channel.
  - v. This type of transmission medium is limited by frequency dependent cable losses that increase rapidly with frequencies above 10 MHz.

- **Microwave Systems** (1948)

  **i.** Extended the carrier frequency to about 4GHz

  **ii.** *Carrier frequency* and *attenuation* limit the performance of both microwave and coax systems.

- **Figure of Merit**

  i. *Bit Rate-Distance* product (B-L).

  ii. The large improvement offered by the high carrier frequency of optical transmission fibers is the motivation for optical communications system development.

- **Fiber Optic Systems**

i. (1960's) the main drawback of optical fibers were their loss. ~ 1000 dB/km.

ii. (1970) losses were reduced to 20 dB/km by using refined fiber fabrication techniques.

iii. (~1970) GaAs semiconductor lasers were able to operate at room temperatur

iv. This combination of developments led to development of a world-wide fiber optic systems.

# Introduction to Noise

- Sources of Noise
- External Noise
- Internal Noise
- S/N Ratio, Noise Figure
- Introduction
- Thermal Noise
- Shot Noise

# 1. Introduction

Noise is a general term which is used to describe an unwanted signal which affects a wanted signal. These unwanted signals arise from a variety of sources which may be considered in one of two main categories:-

- *Interference, usually from a human source (man made)*
- *Naturally occurring random noise*

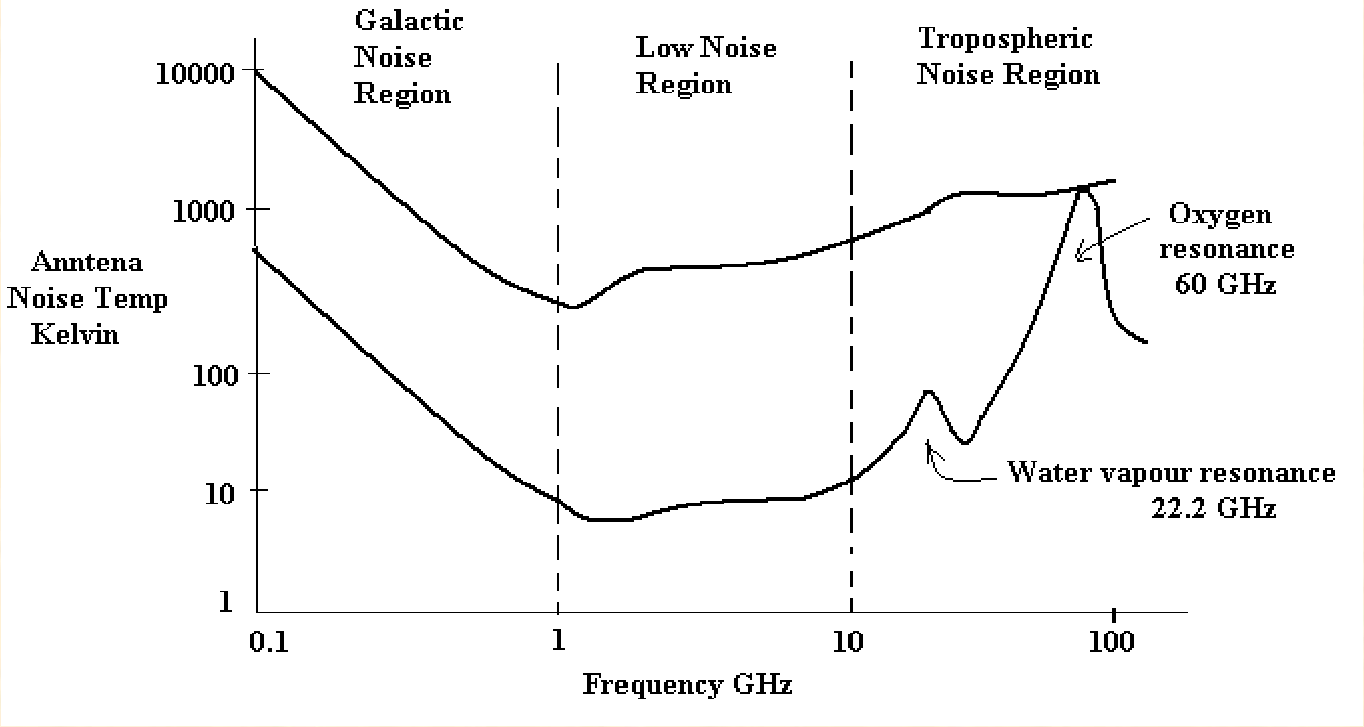
**Interference**

Interference arises for example, from other communication systems (cross talk), 50 Hz supplies (hum) and harmonics, switched mode power supplies, thyristor circuits, ignition (car spark plugs) motors … etc.

# 1. Introduction (Cont'd)

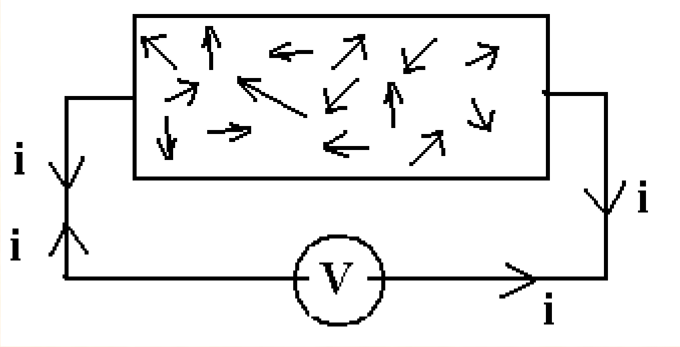
## Natural Noise

Naturally occurring external noise sources include atmosphere disturbance (e.g. electric storms, lighting, ionospheric effect etc), so called 'Sky Noise' or Cosmic noise which includes noise from galaxy, solar noise and 'hot spot' due to oxygen and water vapour resonance in the earth's atmosphere.



# 2. Thermal Noise (Johnson Noise)

This type of noise is generated by all resistances (e.g. a resistor, semiconductor, the resistance of a resonant circuit, i.e. the real part of the impedance, cable etc).




Experimental results (by Johnson) and theoretical studies (by Nyquist) give the mean square noise voltage as

$$\overline{V}^2 = 4kTBR \ (volt^2)$$

Where k = Boltzmann's constant = 1.38 x $10^{-23}$ Joules per K

T = absolute temperature

B = bandwidth noise measured in (Hz)

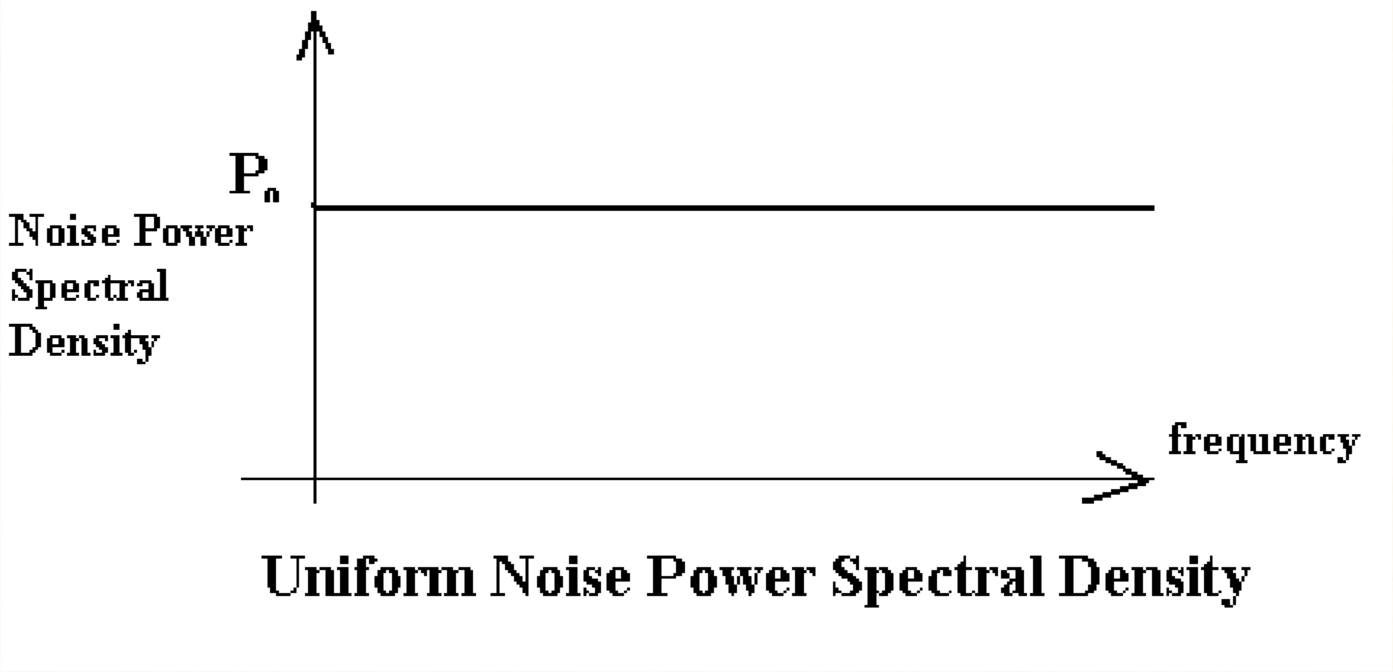
R = resistance (ohms)

# 2. Thermal Noise (Johnson Noise) (Cont'd)

The law relating noise power, N, to the temperature and bandwidth is

**N = k TB watts**

Thermal noise is often referred to as 'white noise'because it has a uniform 'spectral density'.



# 3. Shot Noise

- Shot noise was originally used to describe noise due to random fluctuations in electron emission from cathodes in vacuum tubes (called shot noise by analogy with lead shot).
- Shot noise also occurs in semiconductors due to the liberation of charge carriers.
- For *pn* junctions the mean square shot noise current is

$$I_n^2 = 2\left(I_{DC} + 2I_o\right)q_e B \qquad (amps)^2$$

Where

is the direct current as the *pn* junction (amps)

is the reverse saturation current (amps)

is the electron charge = 1.6 x 10-19 coulombs

B is the effective noise bandwidth (Hz)

- Shot noise is found to have a uniform spectral density as for thermal noise

# 4. Low Frequency or Flicker Noise

Active devices, integrated circuit, diodes, transistors etc also exhibits a low frequency noise, which is frequency dependent (i.e. non uniform) known as flicker noise or ‘one – over – f ’ noise.

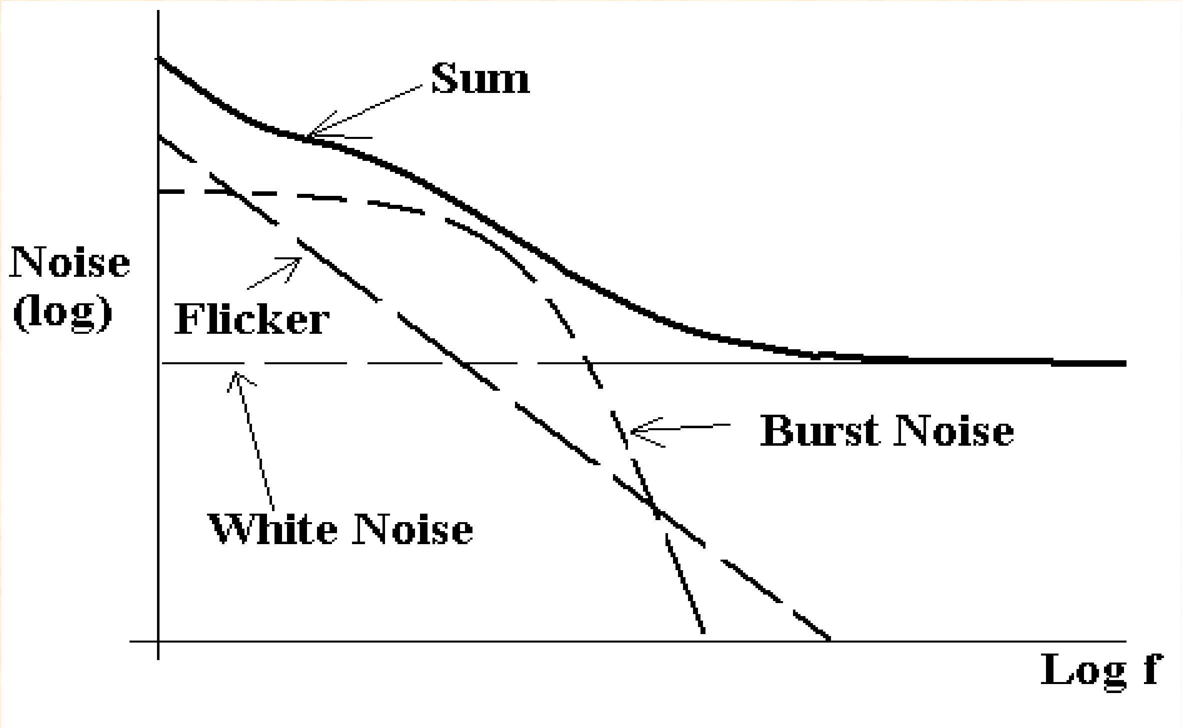
# 5. Excess Resistor Noise

Thermal noise in resistors does not vary with frequency, as previously noted, by many resistors also generates as additional frequency dependent noise referred to as excess noise.

# 6. Burst Noise or Popcorn Noise

Some semiconductors also produce burst or popcorn noise with a spectral density which is proportional to $\left(\frac{1}{f}\right)^2$

# 7. General Comments




For frequencies below a few KHz (low frequency systems), flicker and popcorn noise are the most significant, but these may be ignored at higher frequencies where ‘white’noise predominates.

# 8. Noise Evaluation

The essence of calculations and measurements is to determine the signal power to Noise power ratio, i.e. the (S/N) ratio or (S/N) expression in dB.

$$\left(\frac{S}{N}\right)_{ratio} = \frac{S}{N}$$

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

*Also recall that*

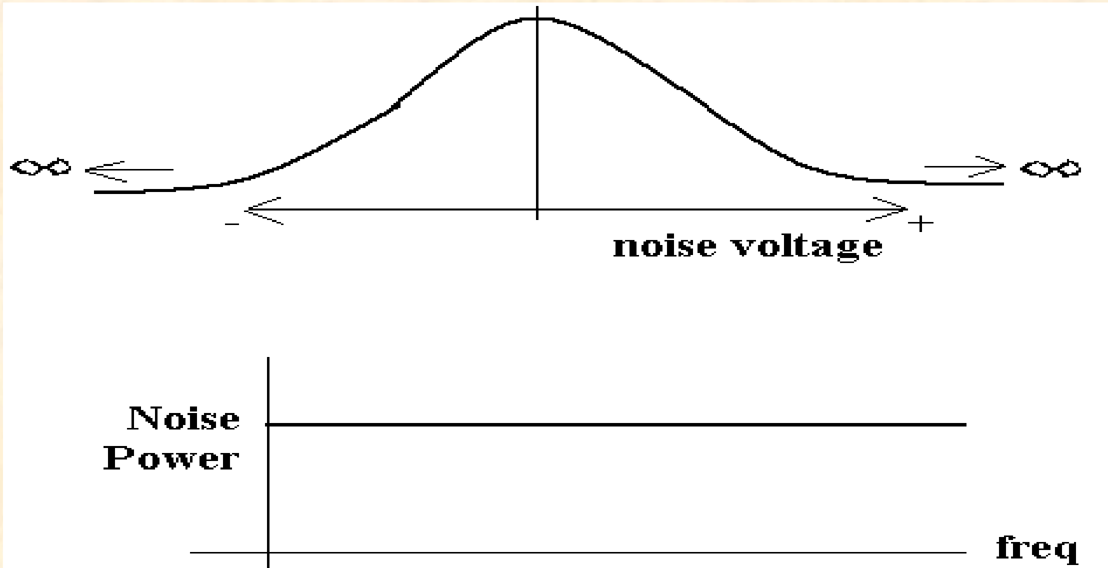
$$S_{dBm} = 10\log_{10}\left(\frac{S(mW)}{1mW}\right)$$

$$and\quad N_{dBm} = 10\log_{10}\left(\frac{N(mW)}{1mW}\right)$$

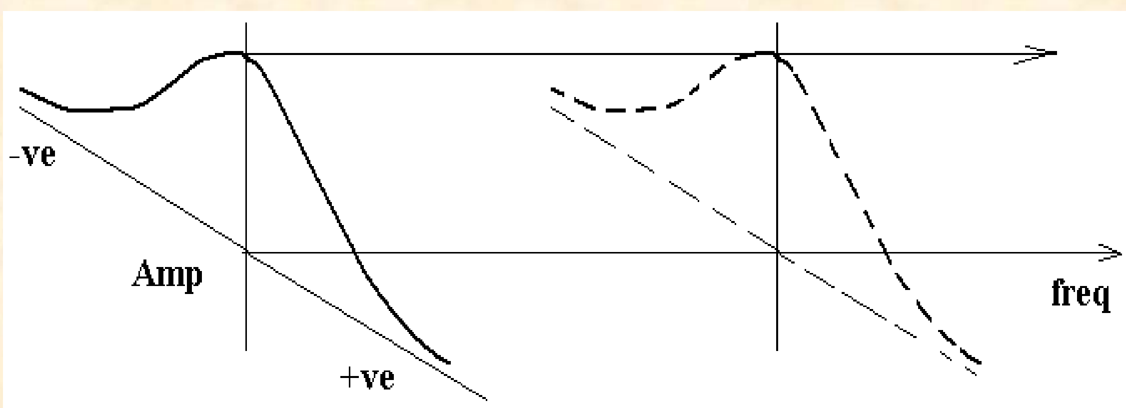
$$i.e.\ \left(\frac{S}{N}\right)_{dB} = 10\log_{10} S - 10\log_{10} N$$

$$\left(\frac{S}{N}\right)_{dB} = S_{dBm} - N_{dBm}$$

# 8. Noise Evaluation (Cont'd)



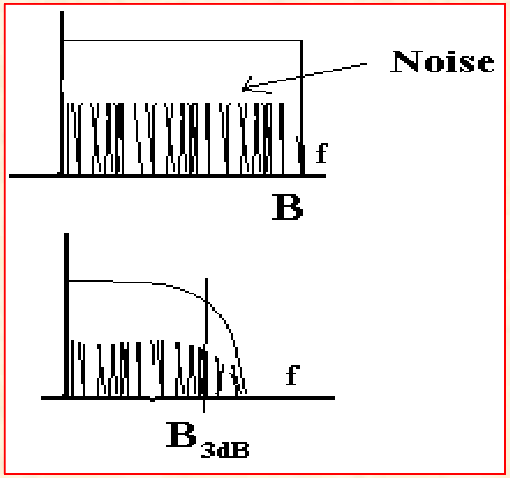

The probability of amplitude of noise at any frequency or in any band of frequencies (e.g. 1 Hz, 10Hz… 100 KHz .etc) is a Gaussian distribution.



# 8. Noise Evaluation (Cont'd)

Noise may be quantified in terms of noise power spectral density, $p_o$ watts per Hz, from which Noise power N may be expressed as

$$N = p_o B_n \text{ watts}$$




Ideal low pass filter

Bandwidth B Hz = $B_n$

$N = p_o B_n$ watts

Practical LPF

3 dB bandwidth shown, but noise does not suddenly cease at $B_{3dB}$

Therefore, $Bn > B_{3dB}$, Bn depends on actual filter.

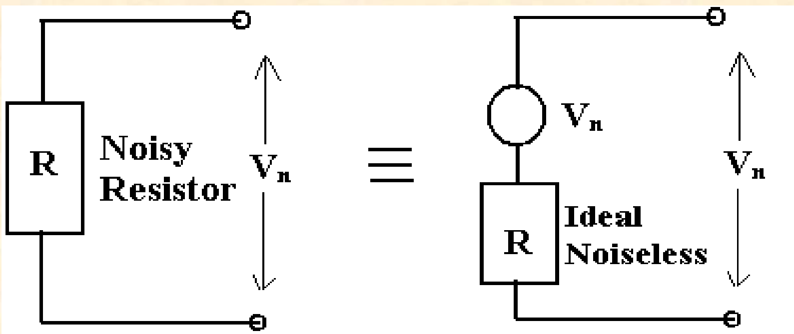
$N = p0\ B_n$

In general the equivalent noise bandwidth is $> B_{3dB}$.

# 9. Analysis of Noise In Communication Systems

## Thermal Noise (Johnson noise)

This thermal noise may be represented by an equivalent circuit as shown below




$$\overline{V^2} = 4kTBR \ (volt^2)$$

(mean square value , power)

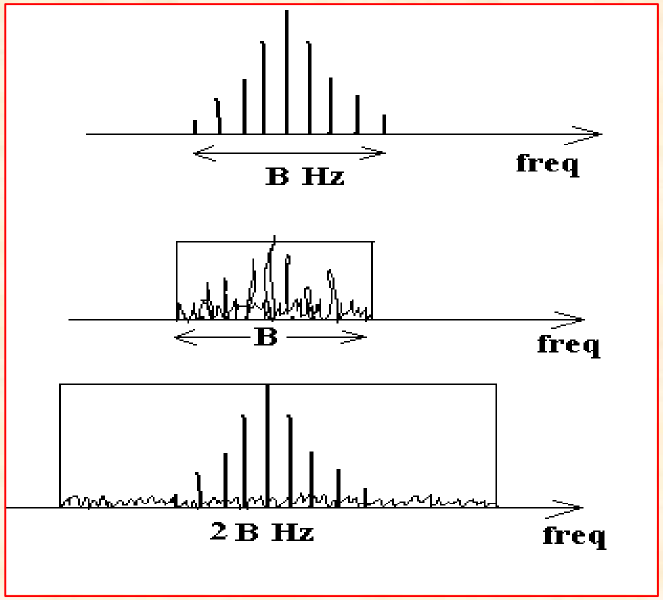
then $V_{RMS} = \sqrt{\overline{V^2}} = 2\sqrt{kTBR} = V_n$

i.e. $V_n$ is the RMS noise voltage.

A) System BW = B Hz
N= Constant B (watts) = KB
B) System BW
N= Constant 2B (watts) = K2B

For A, $\frac{S}{N} = \frac{S}{KB}$

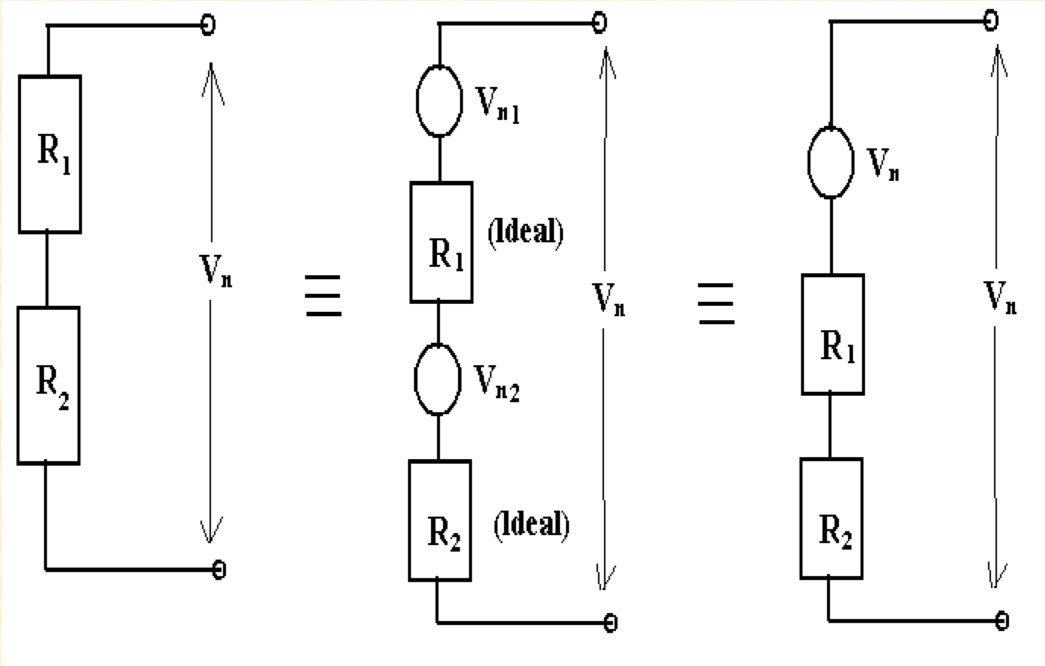
For B, $\frac{S}{N} = \frac{S}{K2B}$



# 9. Analysis of Noise In Communication Systems (Cont'd)

## Resistors in Series

Assume that $R_1$ at temperature $T_1$ and $R_2$ at temperature $T_2$, then




$$\overline{V_n^2} = \overline{V_{n1}^2} + \overline{V_{n2}^2}$$

$$\overline{V_{n1}^2} = 4kT_1BR_1$$

$$\overline{V_{n2}^2} = 4kT_2BR_2$$

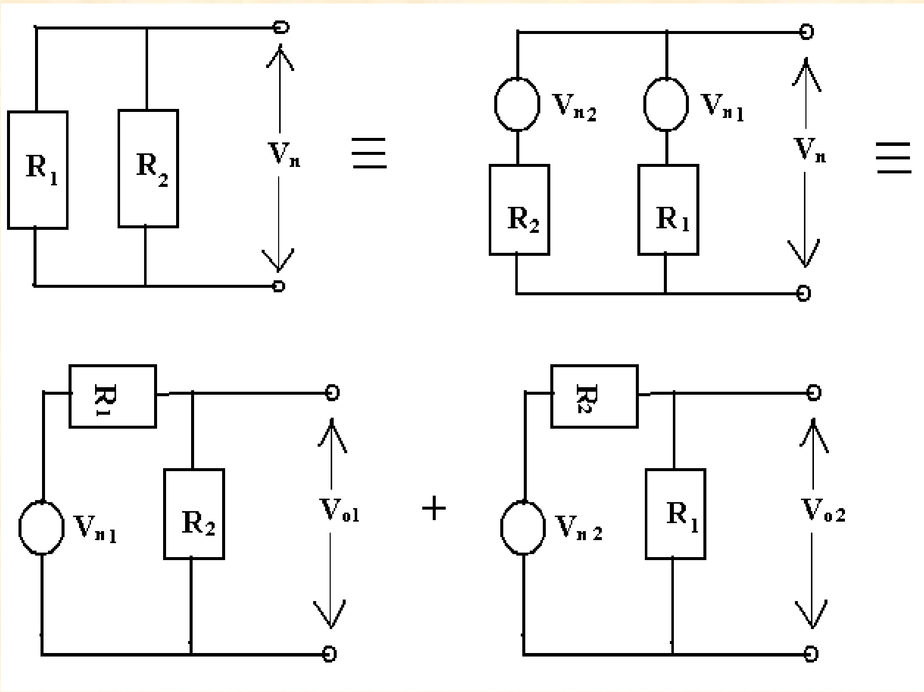
$$\therefore \overline{V_n^2} = 4kB(T_1R_1 + T_2R_2)$$

$$\overline{V_n^2} = 4kTB(R_1 + R_2)$$

i.e. The resistor in series at same temperature behave as a single resistor

# 9. Analysis of Noise In Communication Systems (Cont'd)

## Resistance in Parallel




$$V_{o1} = V_{n1}\frac{R_2}{R_1+R_2} \qquad V_{o2} = V_{n2}\frac{R_1}{R_1+R_2}$$

$$\overline{V_n^{\,2}} = \overline{V_{o1}^{\,2}} + \overline{V_{o2}^{\,2}}$$

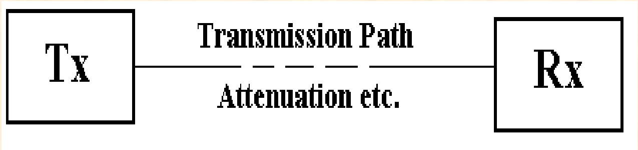
$$\overline{V_n^{\,2}} = \frac{4kB}{(R_1+R_2)^2}\left[R_2^2\,T_1R_1 + R_1^2\,T_2R_2\right] \times \left(\frac{R_1R_2}{R_1R_2}\right)$$

$$\overline{V_n^{\,2}} = \frac{4kBR_1R_2(T_1R_1+T_2R_2)}{(R_1+R_2)^2}$$

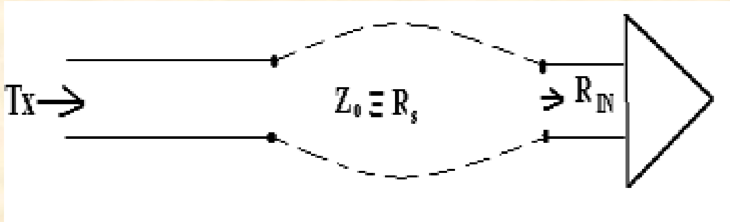
$$\overline{V_n^{\,2}} = 4kTB\left(\frac{R_1R_2}{R_1+R_2}\right)$$

# 10. Matched Communication Systems

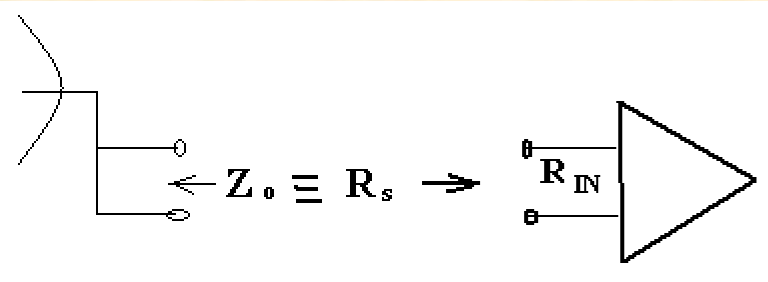
In communication systems we are usually concerned with the noise (i.e. S/N) at the receiver end of the system.



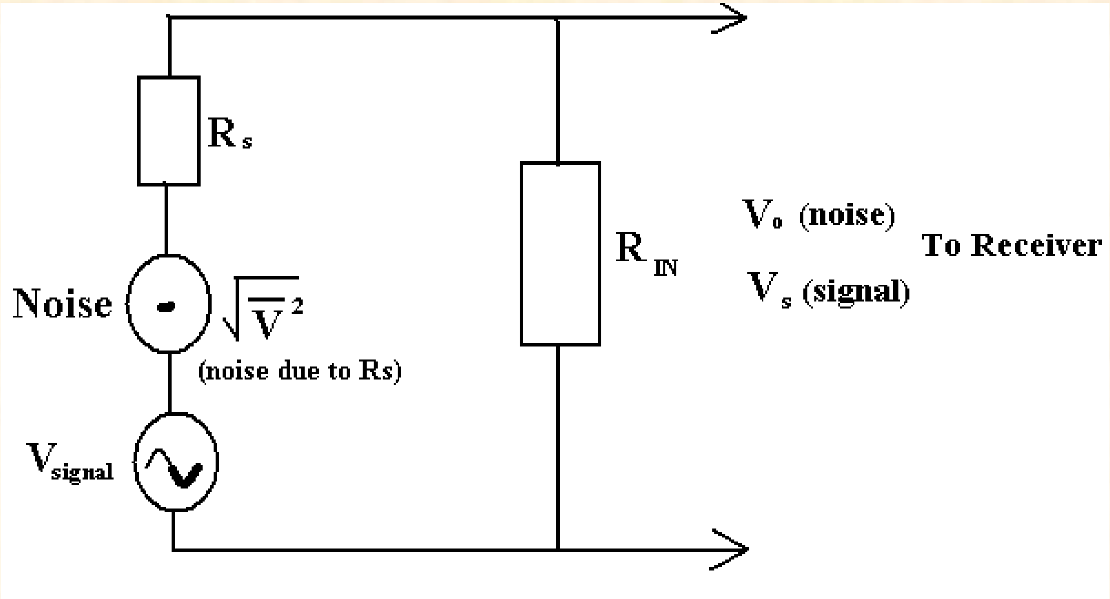

The transmission path may be for example:-




**Or**




An equivalent circuit, when the line is connected to the receiver is shown below.



# 10. Matched Communication Systems (Cont'd)

The RMS voltage output, $V_o$ (noise) is

$$V_o(noise) = \sqrt{\overline{v^2}}\left(\frac{R_{IN}}{R_{IN}+R_S}\right)$$

Similarly, the signal voltage output due to $V_{signal}$ at input is

$$Vs(_{signal}) = (V_{signal})\left(\frac{R_{IN}}{R_{IN}+R_s}\right)$$

For maximum power transfer, the input $R_{IN}$ is matched to the source $R_S$, i.e. $R_{IN}$ $= R_S$ = R (say)

Then $$V_o(noise) = \sqrt{\overline{v^2}}\left(\frac{R}{2R}\right) = \frac{\sqrt{\overline{v^2}}}{2} \quad (RMS\ \ Value)$$

And signal, $V_{S(signal)} = \dfrac{V_{signal}}{2}$

# 11. Signal to Noise

The signal to noise ratio is given by

$$\frac{S}{N} = \frac{Signal\ Power}{Noise\ Power}$$

The signal to noise in dB is expressed by

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

$$\left(\frac{S}{N}\right)_{dB} = S_{dBm} - N_{dBm}$$ for S and N measured in mW.

# 12. Noise Factor- Noise Figure

Consider the network shown below,

# 12. Noise Factor- Noise Figure (Cont’d)

•The amount of noise added by the network is embodied in the Noise Factor F, which is defined by

$$\text{Noise factor F} = \frac{\left(S/N\right)_{IN}}{\left(S/N\right)_{OUT}}$$

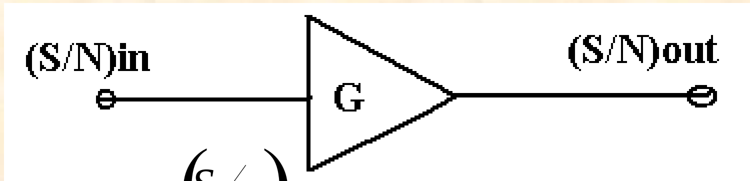
•F equals to 1 for noiseless network and in general F > 1. The noise figure in the noise factor quoted in dB

i.e. Noise Figure F dB = 10 log10 F $\quad\quad$ $F \geq 0$ dB

•The noise figure / factor is the measure of how much a network degrades the (S/N)IN, the lower the value of F, the better the network.

# 13. Noise Figure – Noise Factor for Active Elements

For active elements with power gain G>1, we have

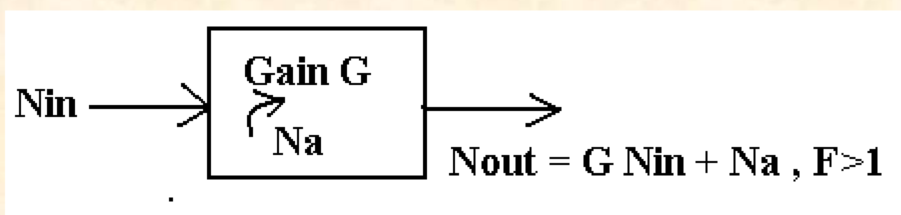



$$F = \frac{\left(S/N\right)_{IN}}{\left(S/N\right)_{OUT}} = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{S_{OUT}}$$ But $S_{OUT} = G\, S_{IN}$

Therefore

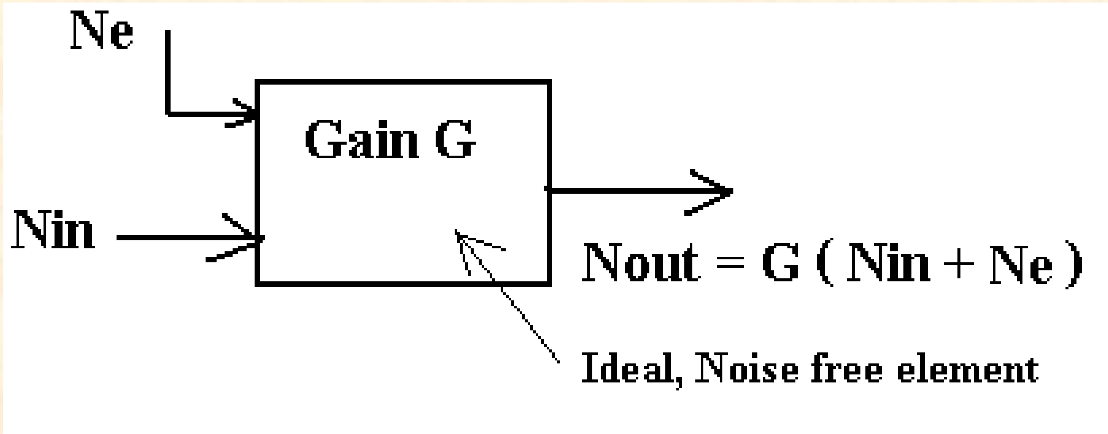
$$F = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{G\, S_{IN}} = \frac{N_{OUT}}{G\, N_{IN}}$$

Since in general F v> 1 , then $N_{OUT}$ is increased by noise due to the active element i.e.




Na represents 'added' noise measured at the output. This added noise may be referred to the input as extra noise, i.e. as equivalent diagram is

# 13. Noise Figure – Noise Factor for Active Elements (Cont'd)




Ne is extra noise due to active elements referred to the input; the element is thus effectively noiseless.

$$\text{Hence } F = \frac{N_{OUT}}{G\,N_{IN}} = F = \frac{G(N_{IN} + N_e)}{G\,N_{IN}}$$

Rearranging gives,

$$N_e = (F - 1)\,N_{IN}$$

# 14. Noise Temperature

$N_{IN}$ is the 'external' noise from the source i.e. $N_{IN} = kT_S B_n$

$T_S$ is the equivalent noise temperature of the source (usually 290K).

We may also write $N_e = kT_e B_n$, where $T_e$ is the equivalent noise temperature of the element i.e. with noise factor F and with source temperature $T_S$.

$$\text{i.e. } kT_e B_n = (F-1)\, kT_S B_n$$

$$\text{or } T_e = (F-1) T_S$$

# 15. Noise Figure – Noise Factor for Passive Elements

Since $F = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{S_{OUT}}$ and $N_{OUT} = N_{IN}$.

$$F = \frac{S_{IN}}{G\,S_{IN}} = \frac{1}{G}$$

If we let L denote the insertion loss (ratio) of the network i.e. insertion loss

$$L_{dB} = 10 \log L$$

Then

$L = \frac{1}{G}$ and hence for passive network

$$F = L$$

Also, since $T_e = (F\text{-}1)T_S$

Then for passive network

$$T_e = (L\text{-}1)T_S$$

Where $T_e$ is the equivalent noise temperature of a passive device referred to its input.

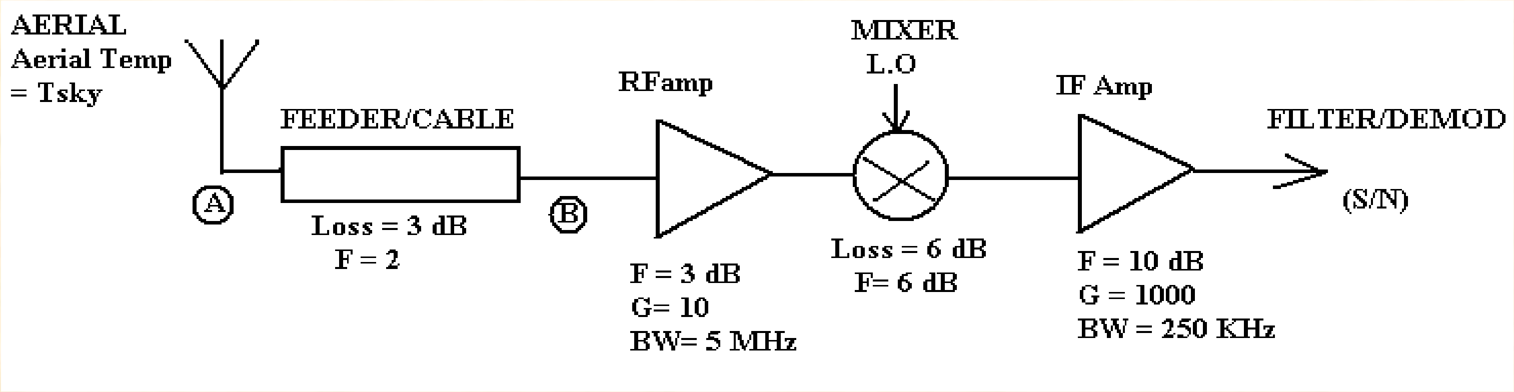
# 16. Review of Noise Factor – Noise Figure –Temperature

Typical values of noise temperature, noise figure and gain for various amplifiers and attenuators are given below:

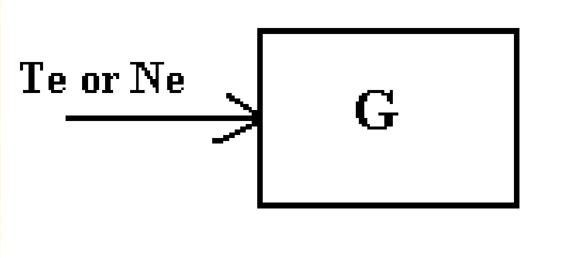
| **Device** | **Frequency** | $T_e$ **(K)** | $F_{dB}$ **(dB)** | **Gain (dB)** |
|---|---|---|---|---|
| *Maser Amplifier* | 9 GHz | 4 | 0.06 | 20 |
| *Ga As Fet amp* | 9 GHz | 330 | 303 | 6 |
| *Ga As Fet amp* | 1 GHz | 110 | 1.4 | 12 |
| *Silicon Transistor* | 400 MHz | 420 | 3.9 | 13 |
| *L C Amp* | 10 MHz | 1160 | 7.0 | 50 |
| *Type N cable* | 1 GHz | | 2.0 | 2.0 |

# 17. Cascaded Network

A receiver systems usually consists of a number of passive or active elements connected in series. A typical receiver block diagram is shown below, with example



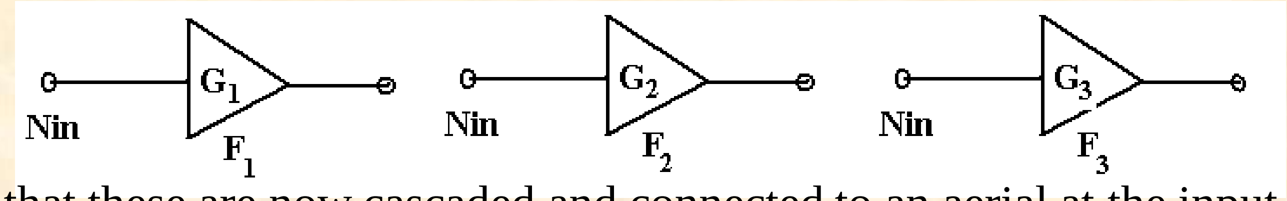

In order to determine the (S/N) at the input, the overall receiver noise figure or noise temperature must be determined. In order to do this all the noise must be referred to the same point in the receiver, for example to A, the feeder input or B, the input to the first amplifier.



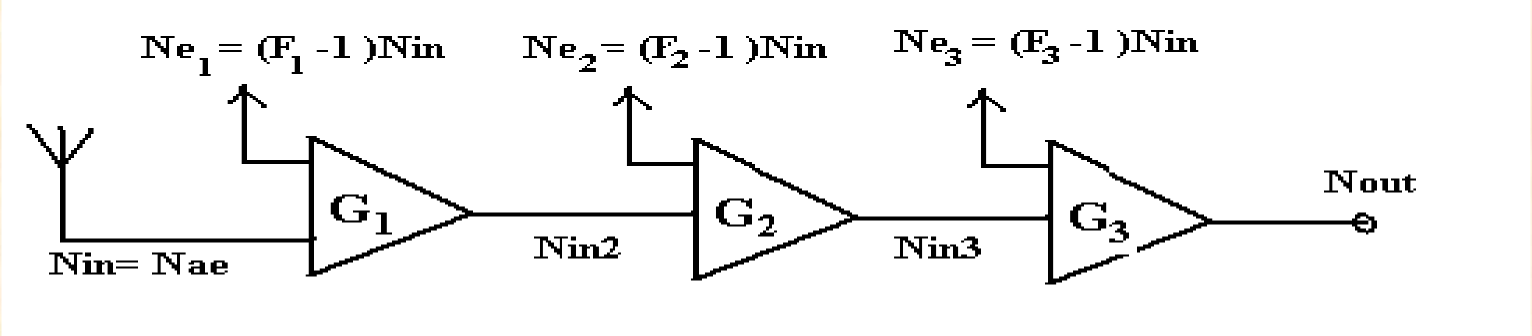

$T_e$ or $N_e$ is the noise referred to the input.

# 18. System Noise Figure

Assume that a system comprises the elements shown below,




Assume that these are now cascaded and connected to an aerial at the input, with $N_{IN} = N_{ae}$ from the aerial.




Now,
$$N_{OUT} = G_3\left(N_{IN3} + N_{e3}\right)$$
$$= G_3\left(N_{IN3} + \left(F_3 - 1\right)N_{IN}\right)$$

Since
$$N_{IN3} = G_2\left(N_{IN2} + N_{e2}\right) = G_2\left(N_{IN2} + \left(F_2 - 1\right)N_{IN}\right)$$

similarly
$$N_{IN2} = G_1\left(N_{ae} + \left(F_1 - 1\right)N_{IN}\right)$$

# 18. System Noise Figure (Cont'd)

$$N_{OUT} = G_3\left[G_2\left[G_1 N_{ae} + G_1(F_1-1)N_{IN}\right] + G_2(F_2-1)N_{IN}\right] + G_3(F_3-1)N_{IN}$$

The overall system Noise Factor is

$$F_{sys} = \frac{N_{OUT}}{GN_{IN}} = \frac{N_{OUT}}{G_1 G_2 G_3 N_{ae}}$$

$$= 1 + (F_1-1)\frac{N_{IN}}{N_{ae}} + \frac{(F_2-1)}{G_1}\frac{N_{IN}}{N_{ae}} + \frac{(F_3-1)}{G_1 G_2}\frac{N_{IN}}{N_{ae}}$$

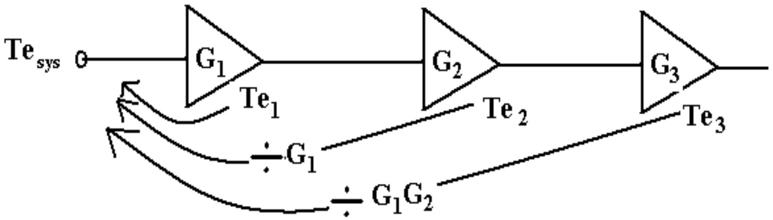
If we assume $N_{ae}$ is $\approx N_{IN}$, i.e. we would measure and specify $F_{sys}$ under similar conditions as $F_1, F_2$ etc (i.e. at 290 K), then for *n* elements in cascade.

$$F_{sys} = F_1 + \frac{(F_2-1)}{G_1} + \frac{(F_3-1)}{G_1 G_2} + \frac{(F_4-1)}{G_1 G_2 G_3} + \dots\dots\dots\dots + \frac{(F_n-1)}{G_1 G_2 \dots\dots\dots G_{n-1}}$$

The equation is called FRIIS Formula.

# 19. System Noise Temperature

Since $T_e = (L-1)T_S$, i.e. $F = 1 + \dfrac{T_e}{T_s}$




Then

$$F_{sys} = 1 + \frac{T_{e\,sys}}{T_s} \qquad \begin{cases} \text{where } T_{e\ sys} \text{ is the equivalent Noise temperature of the system} \\ \text{and } T_s \text{ is the noise temperature of the source} \end{cases}$$

and

$$\left(1 + \frac{T_{e\,sys}}{T_s}\right) = \left(1 + \frac{T_{e1}}{T_s}\right) + \frac{\left(1 + \dfrac{T_{e2}}{T_s} - 1\right)}{G_1} + \ldots etc$$

$$i.e.\ from\, F_{sys} = F_1 + \frac{(F_2 - 1)}{G_1} + \ldots\ldots etc$$

*which gives*

$$T_{e\,sys} = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1G_2} + \frac{T_{e4}}{G_1G_2G_3} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

# Online Links

- https://nptel.ac.in/courses/117102059/
- https://onlinecourses.nptel.ac.in/noc18_ee03/preview