COMMUNICATION SYSTEMS

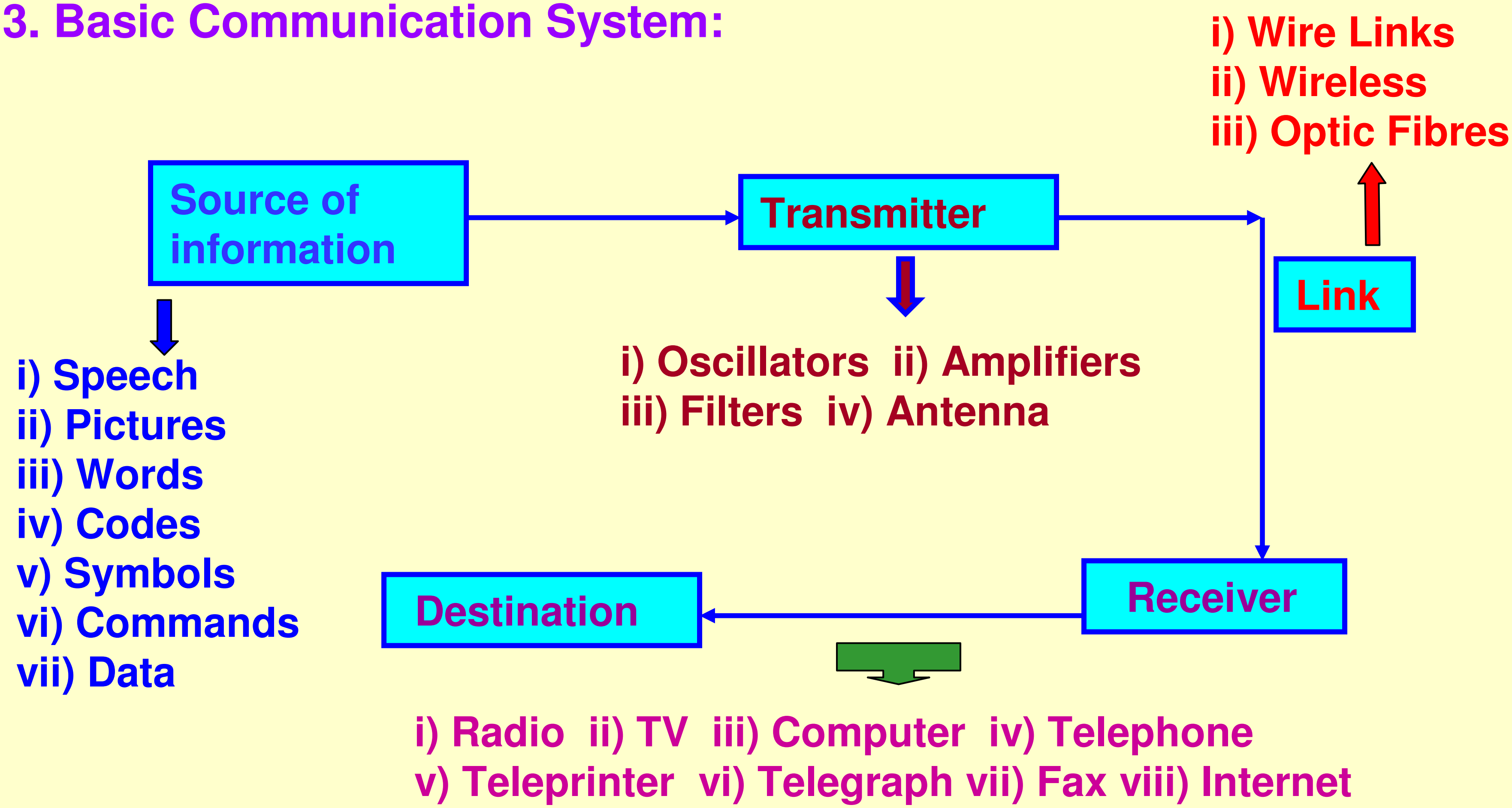
1. BASICS OF COMMUNICATION
2. AMPLITUDE MODULATION

BASICS OF COMMUNICATION

1. **Communication:** Processing, sending and receiving of information

2. **Information:** Intelligence, signal, data or any measurable physical quantity

3. **Basic Communication System:**



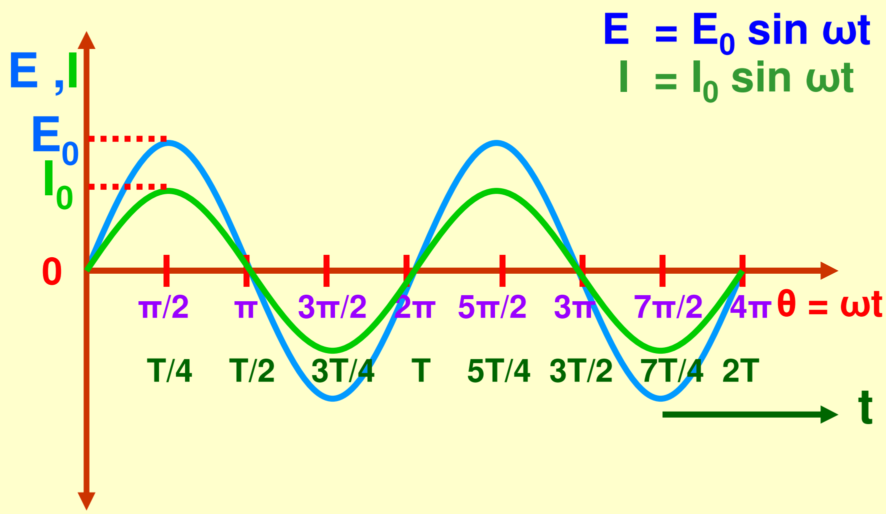
Forms of Communication:

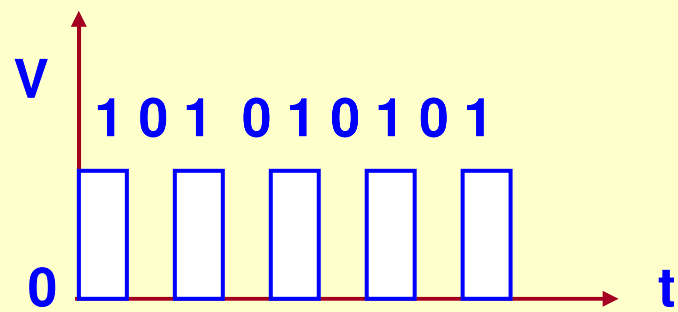
1. Radio Broadcast
2. Television Broadcast
3. Telephony
4. Telegraphy
5. Radar
6. Sonar
7. Fax (Facsimile Telegraphy)
8. E-mail
9. Teleprinting
10. Telemetering
11. Mobile Phones
12. Internet

Types of communication:

1. Cable communication
2. Ground wave communication
3. Sky wave communication
4. Satellite communication
5. Optic fibre communication

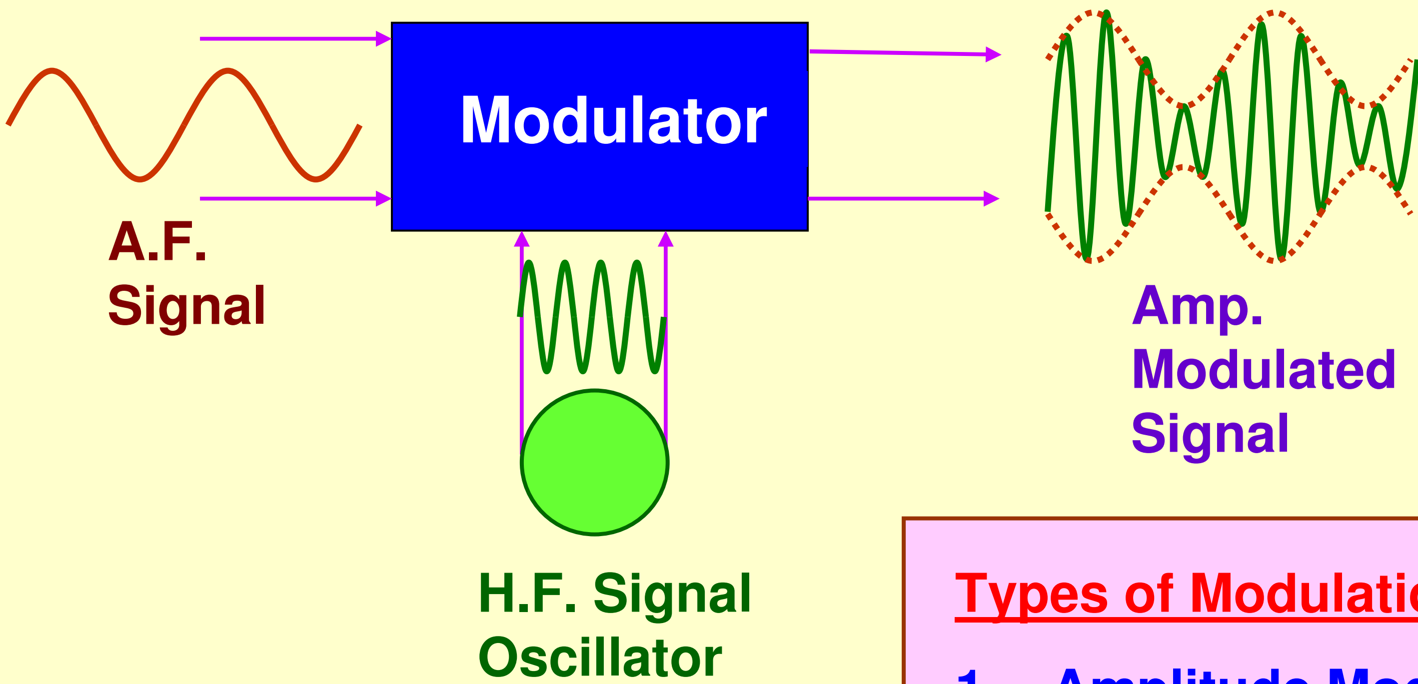
Analogue signal	Digital signal
A continuous signal value which at any instant lies within the range of a maximum and a minimum value.	A discontinuous signal value which appears in steps in pre-determined levels rather than having the continuous change.





MODULATION:

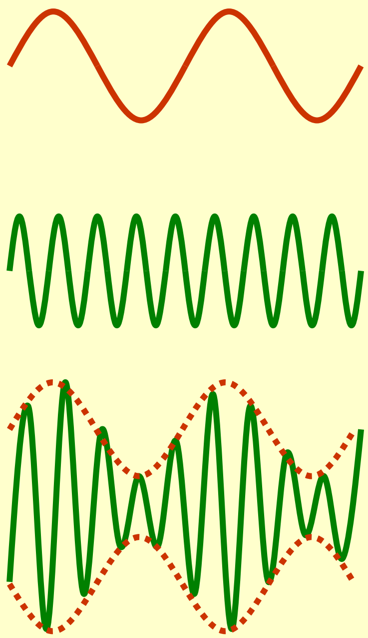
Modulation is the process of variation of some characteristic of a high frequency wave (carrier wave) in accordance with the instantaneous value of a modulating signal.

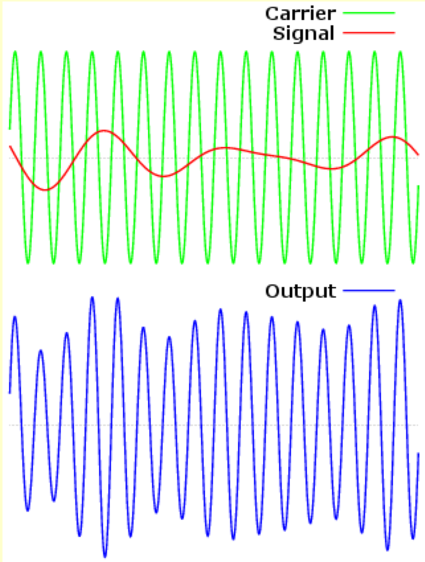


Types of Modulation:

1. **Amplitude Modulation**
2. **Frequency Modulation**
3. **Pulse Modulation**
4. **Phase Modulation**

AMPLITUDE MODULATION (AM):





(Courtesy: Internet)

$$e_m = E_m \sin \omega_m t$$

$$e_c = E_c \sin \omega_c t$$

$$e = (E_c + E_m \sin \omega_m t) \sin \omega_c t$$

$$e = E_c \sin \omega_c t + (m_a E_c/2) \cos (\omega_c - \omega_m)t - (m_a E_c/2) \cos (\omega_c + \omega_m)t$$

Modulation Index $(m_a) = k_a E_m / E_c$

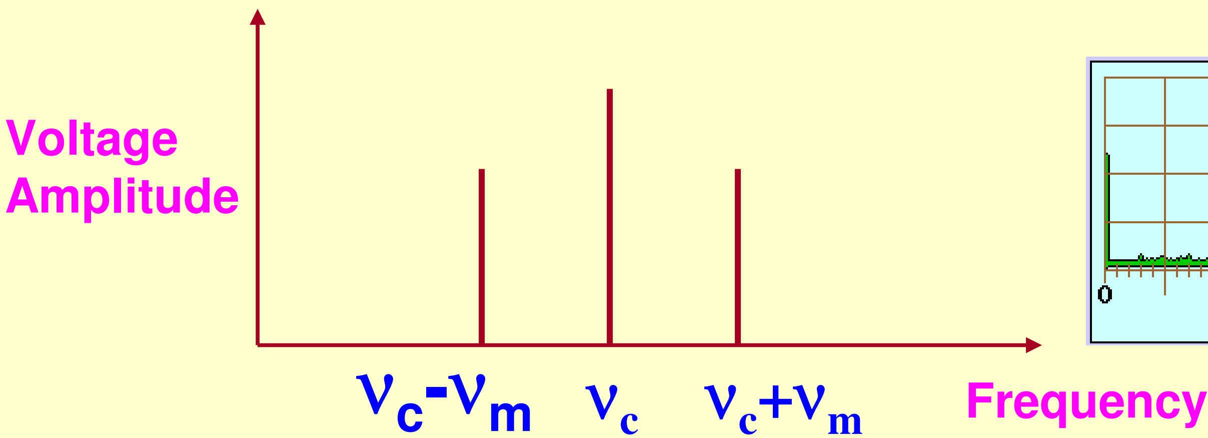
If $k_a = 1$, then $m_a = E_m / E_c$

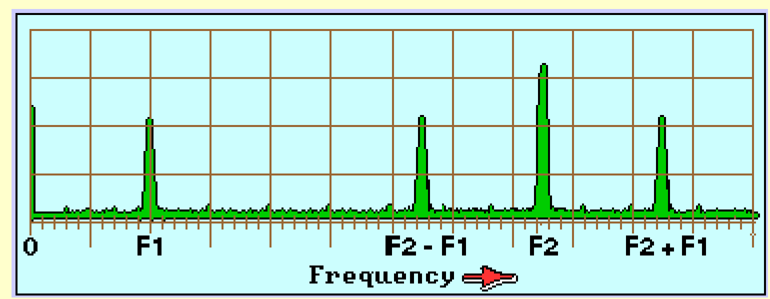
Inferences from equation for e:

1. The **Amplitude Modulated wave** is the summation of three sinusoidal waves with the frequencies ν_c, $\nu_c - \nu_m$ and $\nu_c + \nu_m$ namely Original frequency, Lower Side Band frequency and Upper Side Band frequency respectively.

2. The Bandwidth required for AM, BW = $2\,\nu_m$

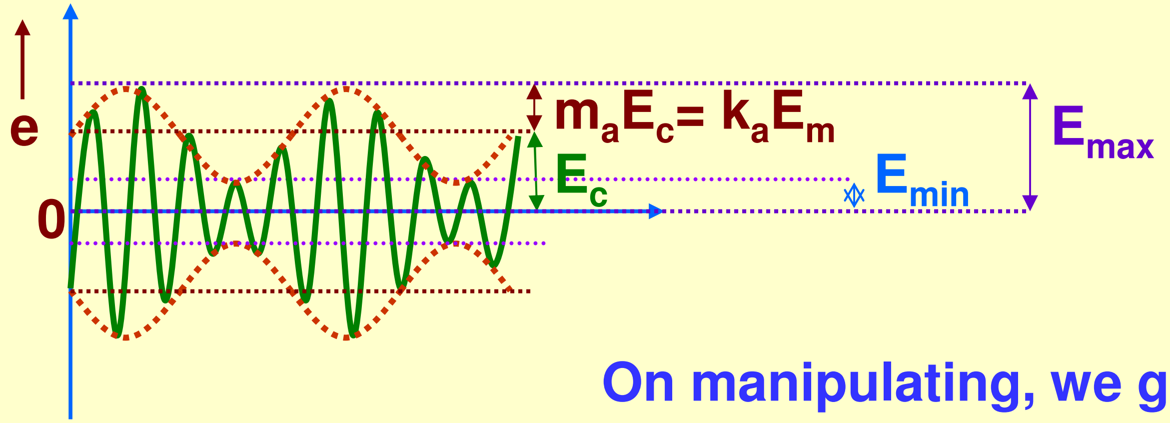
3. The amplitude E_c of the unmodulated carrier wave is made proportional to the instantaneous voltage ($e_m = E_m \sin \omega_m t$) of the modulating wave.





(Courtesy: Internet)

Significance of Modulation Index:

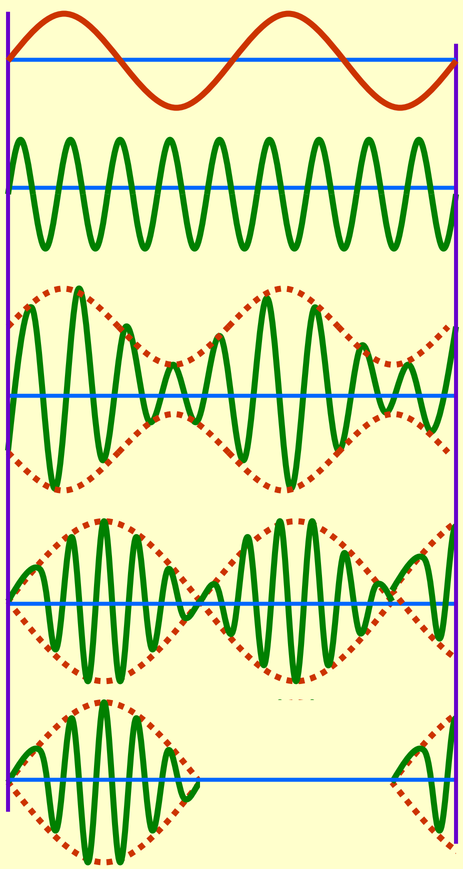


$$E_{max} = E_c + m_aE_c$$

$$E_{min} = E_c - m_aE_c$$

On manipulating, we get

$$m_a = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$



AF signal

$m_a = 0$ (No modulation)

$m_a = 0.5$ or 50%

$m_a = 1$ or 100%

$m_a > 1$ or 100%

Generally,

$0 < m_a < 1$

Power Relation in the AM wave:

If the modulated wave is applied to a resistor of resistance R (say antenna circuit), then the r.m.s. power dissipated in the form of heat is,

$$P_{r.m.s} = (1/R)[\{E_c /2\sqrt{2}\}^2 + \{m_a E_c /2\sqrt{2}\}^2 + \{m_a E_c /2\sqrt{2}\}^2]$$

$$P_{rms} = (E_c{}^2 /2R) [1 + (m_a{}^2 /2)] = P_c[1 + (m_a{}^2 /2)]$$

(where P_c is power dissipated by unmodulated carrier wave)

If $m_a = 1$, then $P_{rms} \rightarrow P_{max}$ and $P_{max} = 3 P_c /2$

Similarly, Power carried by both side bands $P_{SB} = P_{rms} / 3$ which is wasted.

Advantages:

1. AM is an easier method of transmitting and receiving speech signals.
2. It requires simple and inexpensive receivers.
3. It is a fairly efficient system of modulation.

Drawbacks:

1. AM is more likely to suffer from noise.
2. Appreciable energy is contained by three components of AM wave. Sufficient energy can be saved by suppressing carrier wave and one of the side bands. This process makes the equipment complex.
3. Cost of such transmitters and receivers becomes practically more.

Space Communication

This Chapter includes:

1. Space Communication
2. Power Density, Attenuation
3. Range of Electromagnetic Waves
4. Ground Wave Propagation
5. Sky Wave Propagation
6. Space Wave Propagation
7. TV Transmission and Height of TV Antenna
8. Satellite Communication
9. Remote Sensing Satellites

Space Communication:

Space Communication means free space communication.

A free space does not have solid particles or ionised particles and it has no gravitational or other fields of its own. When the frequency of transmitted wave is very high the actual space is considered nearly a free space.

Power Density:

Power density is radiated power per unit area and is inversely proportional to the square of distance from the source.

Antenna:

Antenna is a device which acts as an emitter of electromagnetic waves and it also acts as a first receiver of energy.

Attenuation:

Attenuation is the loss of power of radiation due to absorption of energy in space and power density goes on decreasing as the electromagnetic waves go away from their source.

It is proportional to the square of the distance travelled and is generally measured in decibel (dB).

Range of Electromagnetic Waves:

S. No.	Name of the frequency range (Band)	Short Form	Frequency Range
1	Very Low Frequency	VLF	3 kHz to 30 kHz
2	Low Frequency	LF	30 kHz to 300 kHz
3	Medium Frequency or Medium Wave	MF or MW	300 kHz to 3 MHz
4	High Frequency or Short Wave	HF or SW	3 MHz to 30 MHz
5	Very High Frequency	VHF	30 MHz to 300 MHz
6	Ultra High Frequency	UHF	300 MHz to 3,000 MHz
7	Super High Frequency or Micro Waves	SHF	3,000 MHz to 30,000 MHz (3 GHz to 30 GHz)
8	Extremely High Frequency	EHF	30 GHz to 300 GHz

Propagation of Electromagnetic Waves:

Depending on the frequency, radio waves and micro waves travel in space in different ways depending on the behaviour of these waves w.r.t. the earth and the atmosphere. They are:

1. Ground wave propagation
2. Sky (or ionospheric) wave propagation
3. Space (or tropospheric) wave propagation

1. Ground wave propagation: (AM Radio waves)

In ground wave propagation, the radio waves (AM) travel along the surface of the earth. These waves are called ground waves or surface waves.

In fact, these waves are not confined to surface of the earth but are guided along the earth's surface and they follow the curvature of the earth.

The energy of the radio waves decreases as they travel over the surface of the earth due to the conductivity and permittivity of the earth's surface.

Attenuation increases with the increase in frequency.

Therefore, the ground waves are limited to frequency of 1.5 MHz (1500 kHZ) or wavelength of 200 m.

Ground waves progress along the surface of the earth and must be vertically polarised to prevent from short-circuiting the electric component.

A wave induces currents in the earth over which it passes and thus loses some energy by absorption. This is made up by energy diffracted downward from the upper portions of the wavefront.

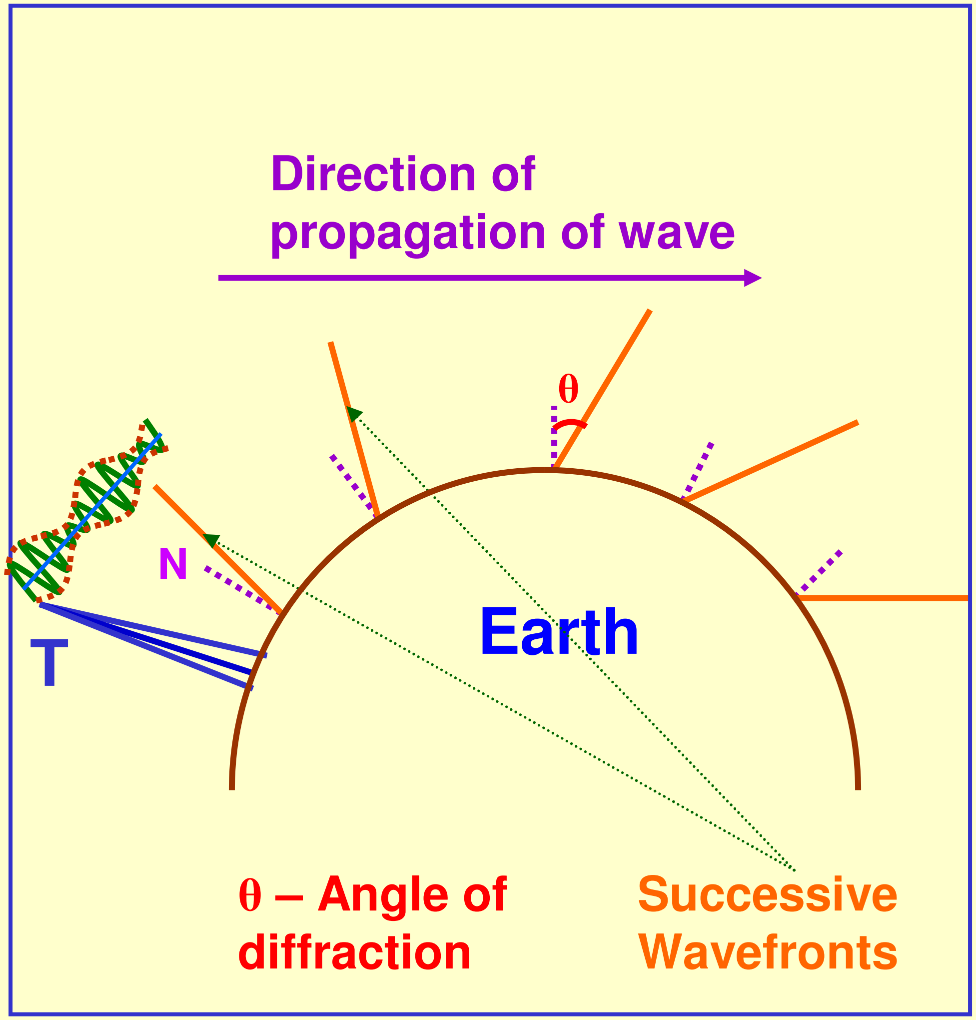
Another way of attenuation is due to diffraction and gradual tilting of the wavefront.

The increasing tilt of the wavefront causes greater short-circuiting of electric field components of the wave.

Eventually, at some distance from the antenna, the wave "lies down and dies".

The maximum range of a transmitter depends on its frequency as well as its power.

In MF band, the range can not be increased only by increasing its power because propagation is definitely limited by its tilt.



2. Sky wave propagation or Ionospheric wave propagation: (AM Radio waves)

Sky waves are the AM radio waves which are received after being reflected from ionosphere. The propagation of radio wave signals from one point to another via reflection from ionosphere is known as sky wave propagation.

The sky wave propagation is a consequence of the total internal reflection of radiowaves. Higher we go in the ionosphere, free electron density increases and refractive index decreases.

The UV and high energy radiations from the Sun are absorbed by the air molecules and they get ionised to form the ionised layer or electrons and ions. Ionosphere extends from 80 km to 300 km in the atmosphere above the earth's surface.

The oscillating electric field of electromagnetic wave (frequency ω) does not affect the velocity of the ions (negligible change because the em wave field is weak) in the ionosphere but changes the velocity of the electrons.

This changes the effective dielectric constant ε' and hence the refractive index n' as compared to the free space values ε_0 and n_0.

ε' and n' are related to ε_0 and n_0 as

$$n' = \sqrt{(\varepsilon' n_0)} \qquad \text{or} \qquad n' = n_0 \left[1 - (Ne^2 / \varepsilon_0 m \omega^2)\right]^{1/2}$$

where e is the electronic charge, m is the mass of the electron and N is the electron density in the ionosphere.

It is clear that the refractive index of ionosphere n’ is less than its free space value n_0. So, it acts as rarer medium. Therefore, for the angle of incidence above the critical angle, the electromagnetic waves undergo total internal reflection and reach the earth back.

Since n’ depends on ω and N, the waves of different frequencies will be reflected back from the different depths of ionosphere depending on electron density N in that region.

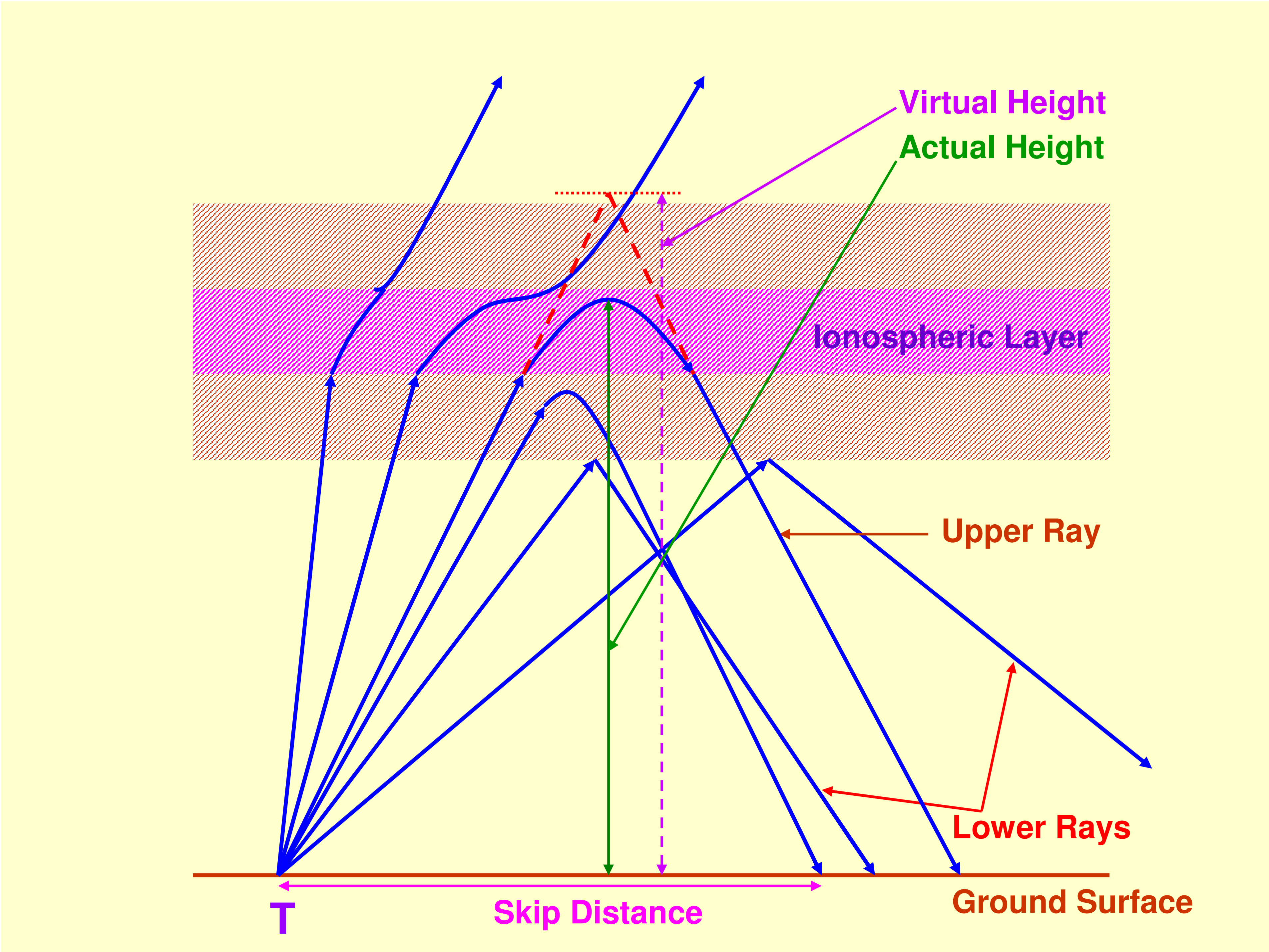
If the frequency ω is too high, then the electron density N may never be so high as to produce total internal reflection. This frequency is called ‘critical frequency’ (f_c). If the maximum electron density of the ionosphere is N_{max} per m^3, then the critical frequency is given by:

$$\boxed{f_c \approx 9(N_{max})^{1/2}}$$

The critical frequency ranges approximately from 5 to 10 MHz.
The frequencies higher than this cross the ionosphere and do not return back to the earth.

The sky wave propagation is limited to the range of 2 MHz to 30 MHz. This region is called ‘short wave band’.

The communication in AM band below 200 m wavelength is via the sky wave only.



Virtual Height
Actual Height
Ionospheric Layer
Upper Ray
Lower Rays
Ground Surface
T
Skip Distance

Important Terms used in Sky wave propagation:

Critical Frequency (f_c):

It is the highest frequency for a given ionospheric layer that can be returned down to the earth by that layer after having been beamed straight up at it.

$$\boxed{f_c \approx 9(N_{max})^{1/2}}$$

Maximum Usable Frequency (MUF):

It is the limiting frequency but for some specific angle of incidence other than the normal.

$$MUF = \frac{\text{Critical Frequency}}{\cos\theta} = f_c \sec\theta$$

This is called 'secant law' and is very useful in making preliminary calculations for a specific MUF. Strictly speaking, it applies only to the flat earth and the flat reflecting layer.

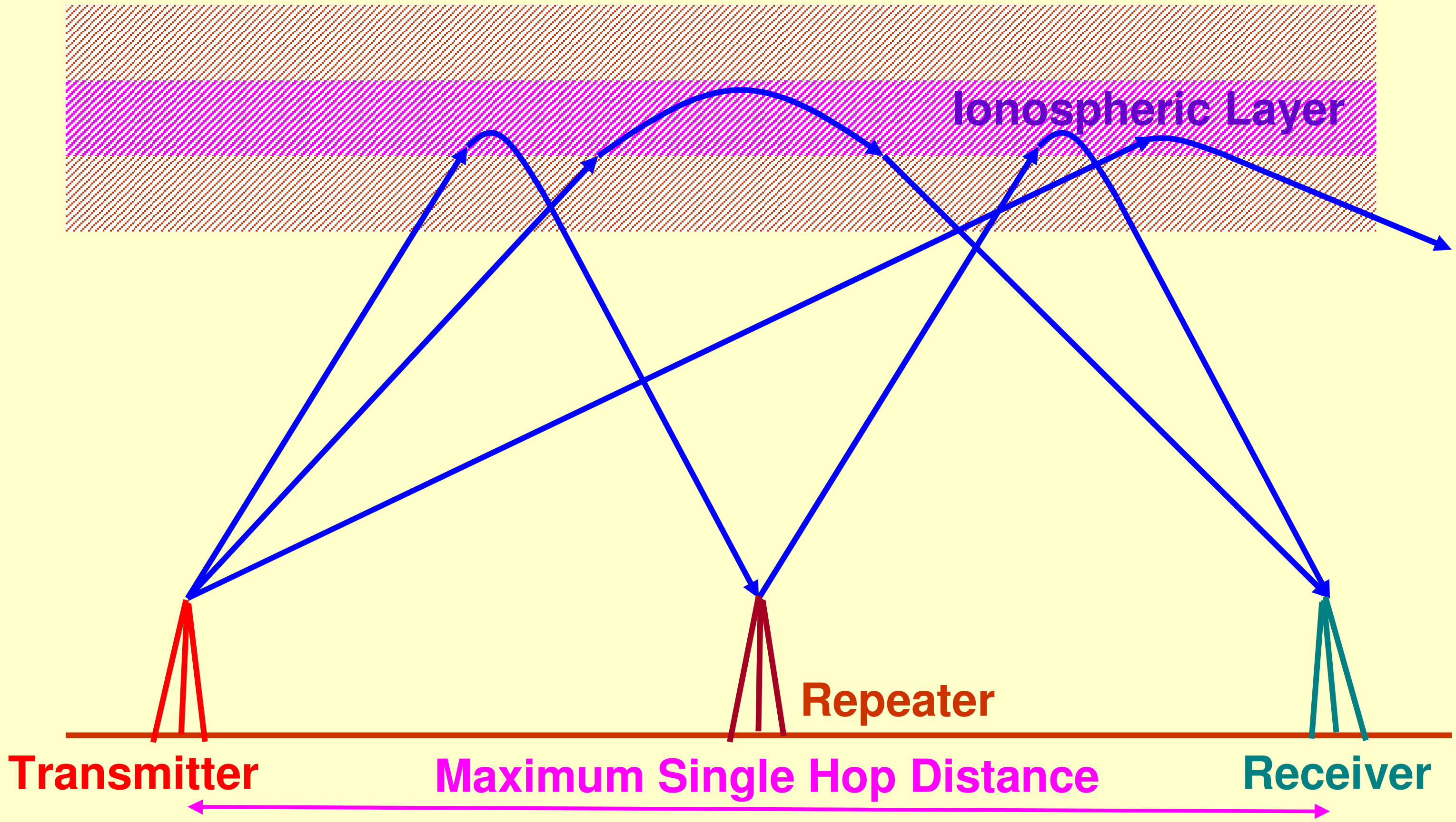
Skip Distance:

It is the shortest distance from a transmitter, measured along the surface of the earth, at which a sky wave of fixed frequency (more than f_c) will be returned to earth, but nevertheless a definite minimum also exists for any fixed transmitting frequency.

At the skip distance, only the normal or lower ray can reach the destination, whereas at greater distances, the upper ray can be received as well, causing interference. This is a reason why frequencies not much below the MUF are used for transmission.

Another reason is the lack of directionality of high-frequency antennas.

If the frequency used is low enough, it is possible to receive lower rays by two different paths after either one or two hops. But this will result in interference again.



3. Space wave propagation or Tropospheric wave propagation: (AM Radio waves)

Space waves travel in (more or less) straight lines. But they depend on line-of-sight conditions. So, they are limited in their propagation by the curvature of the earth.

They propagate very much like electromagnetic waves in free space.

This mode is forced on the waves because their wavelengths are too short for reflection from the ionosphere, and because the ground wave disappears very close to the transmitter, owing to tilt.

Radio Horizon:

The radio horizon for space waves is about four-thirds as far as the optical horizon. This beneficial effect is caused by the varying density of the atmosphere, and because of diffraction around the curvature of the earth.

It is given with good approximation, by the empirical formula

$$\boxed{d_t = 4\sqrt{h_t}}$$

where d_t = distance (in km) from the transmitting antenna,

h_t = height (in m) of transmitting antenna above the ground

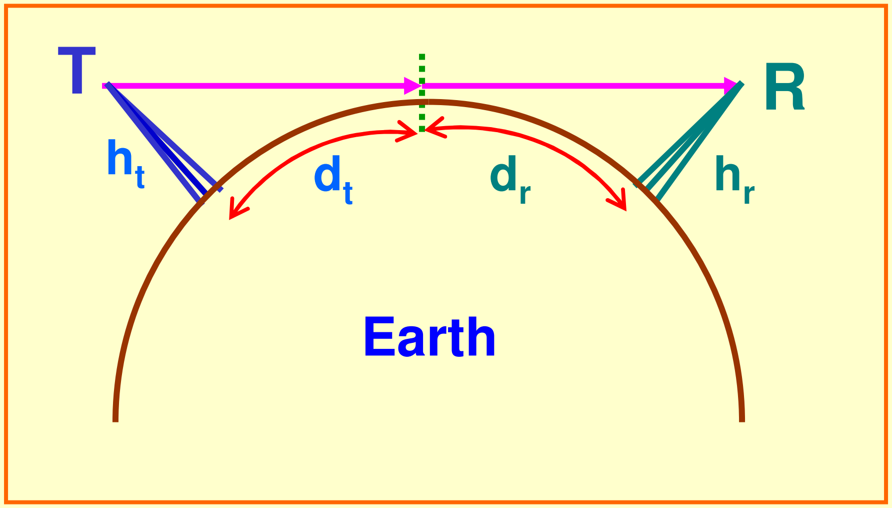
The same formula applies to the receiving antenna.

The distance between the Transmitter and the Receiver is

$$d = d_t + d_r = 4\sqrt{h_t} + 4\sqrt{h_r}$$

If the transmitting and receiving antennas are 225 m and 16 m above the ground, then the distance between them can be 76 km (= 60 + 16).

Commercially, links more than 100 km are hardly used.



Frequency Modulated Communication (TV Signals):

The TV signals are frequency – modulated. They employ frequency greater than 80 MHz.

They can not be propagated by ground wave because the signals get absorbed by ground due to their high frequency.

The propagation by sky wave is also not possible because the ionosphere can not reflect the frequencies higher than 40 MHz.

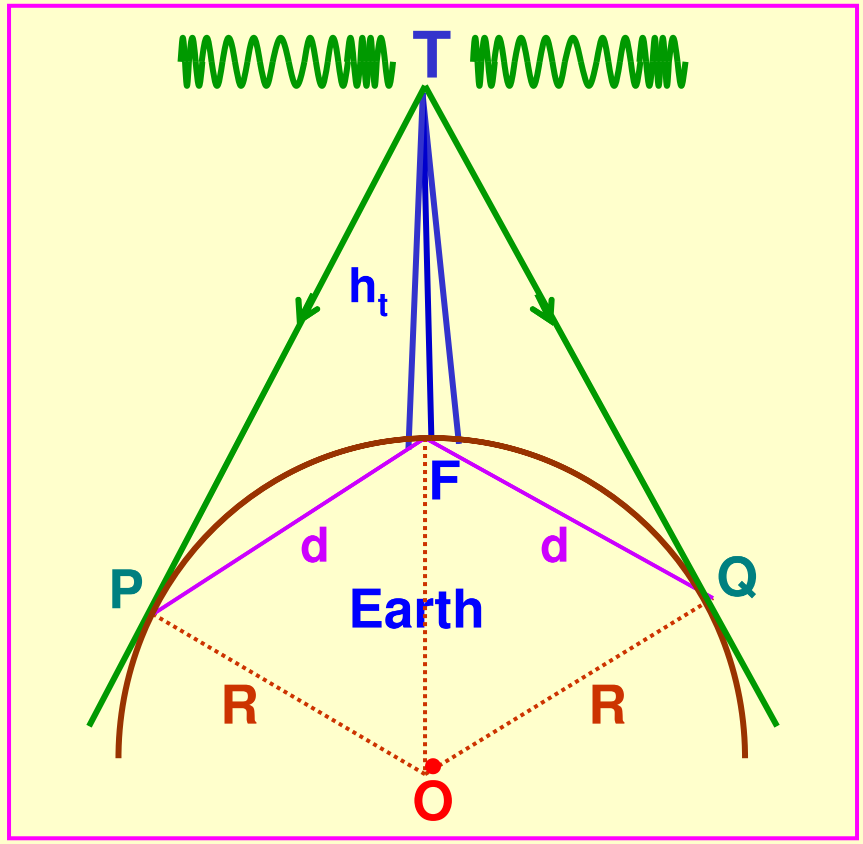
The only way for the transmission of TV signals is that the receiving antenna should directly intercept the signal from the transmitting antenna.
(Space-wave or line of sight propagation)

Height of TV Transmitting Antenna:

The TV signals (frequency modulated electromagnetic waves) travelling in a straight line directly reach the receiver end and are then picked up by the receiving antenna.

Due to the finite curvature of the earth, the waves cannot be seen beyond the tangent points P and Q.

The effective range of reception of the broadcast is essentially the region from P to Q which is covered by the line of sight.



Let h be the height of the transmitting antenna, d be the distance (radius) of coverage from the foot of the tower and R be the radius of the earth.

$$OT^2 = OQ^2 + QT^2$$

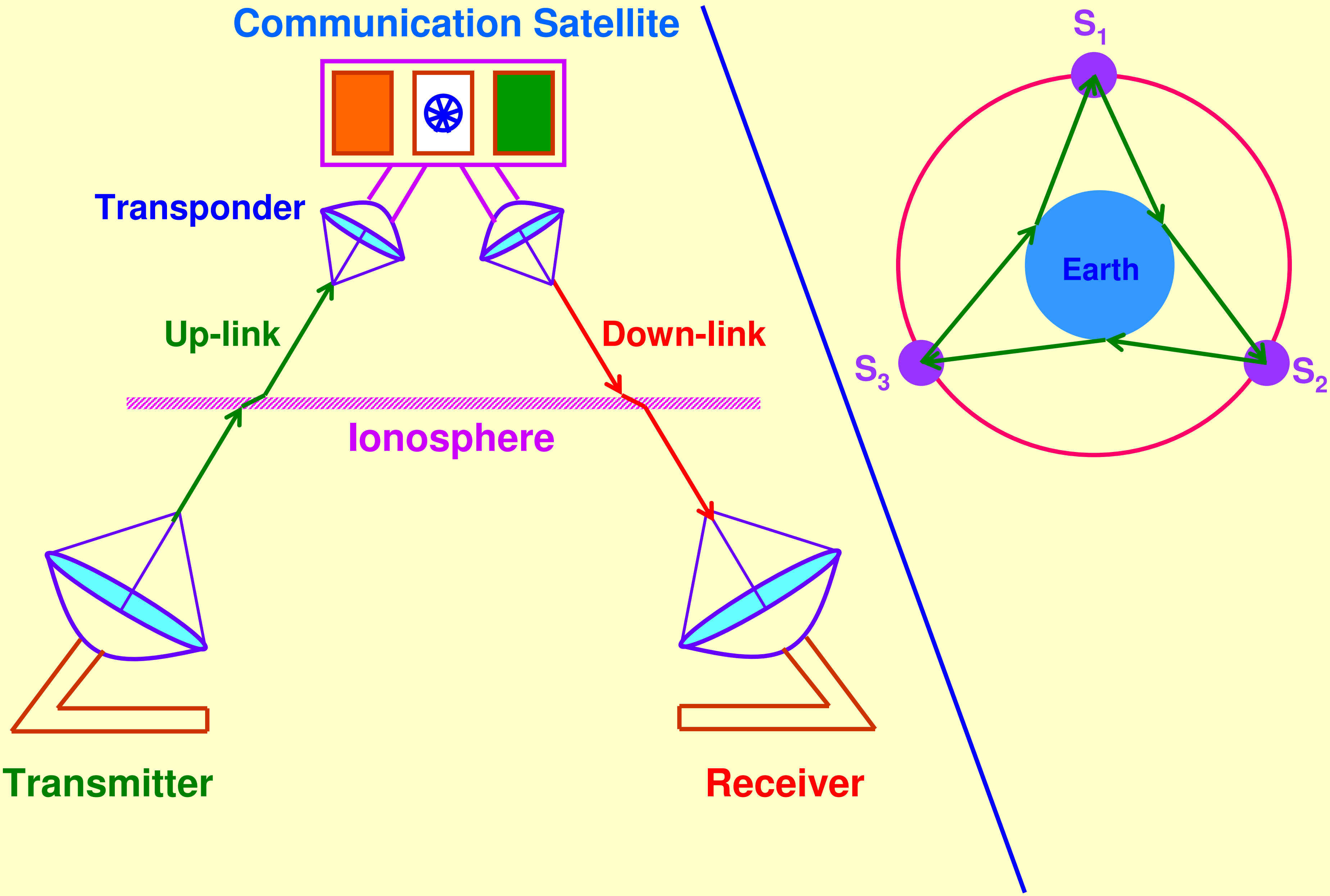
$$(R + h)^2 = R^2 + d^2 \qquad \text{(Note: } QT \approx FQ = d\text{)}$$

or $$d^2 = h^2 + 2hR$$

$$d = \sqrt{(h^2 + 2hR)} \qquad \text{or} \qquad \boxed{d \approx \sqrt{(2hR)}}$$

The antenna of height 80 m can transmit the signal with coverage radius of 32 km and area of 3217 sq. km.

Satellite Communication:



Satellite communication uses UHF / Microwave regions. Microwaves carrying audio, video, telephone, telex, FAX signals, etc. are transmitted from the earth to the satellites orbiting in the space and retransmitted from the satellites to different parts of the earth (world).

The special devices used for this purpose in satellites are called 'transponders'.

Satellite communication is mainly done through 'geostationary satellites'. Three geostationary satellites placed in equatorial orbits at 120° from one another can cover practically the whole populated land area of the world.

Frequency modulation is used for both 'up channel' and 'down channel' transmission. Though FM needs a larger bandwidth, it offers good immunity from interference and requires less power in the satellite transmitter.

Orbit of Communication Satellite:

For global communication, a satellite should move uniformly round a circular orbit with a period of $84.4[r / R]^{3/2}$ minutes, where r is the radius of the orbit of the satellite and R is the radius of the earth.

The circular orbit of the communication satellite is specified in terms of:

(i) The orbit radius (ii) The angle of inclination of the orbit's plane to the Earth's equatorial plane (iii) The position of the ascending mode
(iv) The phase angle of the satellite.

Height of Communication Satellite:

The area of the earth from which a satellite is visible increases with the altitude.

At altitudes below 10,000 km, the number of satellites required for global coverage would be excessive.

At altitudes above 20,000 km, the time taken by signals may be large enough to cause confusion in telephonic conversation.

If time-delay difficulties are ignored, then a synchronous satellite at 36,000 km height can be advantageously used.

Earth-Track Integral System for Communication Satellites:

If several satellites are spaced around the same orbit in space, the tracks of the satellites will be different due to Earth's rotation about its own axis.

If four satellites are placed into different orbits with their ascending modes displaced successively by 30° intervals to the east direction, the difference, in effects of Earth's rotation, can be counteracted and the paths of all the satellites relative to the Earth will be the same.

Such Earth-Track integral systems can be arranged to have the satellite period an integral factor of the sidereal day in order to have the same track repeated day after day.

Remote Sensing Satellites:

'Remote Sensing' is obtaining information about an object by observing it from a distance and without coming into actual contact with it.

The orbit of a remote sensing satellite is such that the satellite passes over a particular latitude at approximately the same local time. i.e. the position of the Sun with respect to a point on the Earth remains approximately the same as the satellite passes over it. Such orbits are called Sun-synchronous orbits.

A remote sensing satellite takes photographs of a particular region with nearly the same illumination every time it passes through that region.

Applications:

1. In Geology
2. In Agriculture
3. In Forestry
4. In Land Mapping
5. In Ocean and Coastal Data
6. In Monitoring Environmental Conditions
7. In Biodiversity
8. In Ground Water Management
9. In Flood Damage Assessment
10. In the Field of Defence
11. In Mapping Wastelands
12. In Early Warning Systems (Natural Calamities)
13. In Management of Water Resources
14. In Fisheries Sectors
15. In Tourism Industry
16. In Planning Pipeline Routs, Ring Roads and Urban Settlements

FREQUENCY MODULATION

“The process of changing the frequency of a carrier wave in accordance with the AF signal.”

The Chapter includes:

- **Wave Forms**
- **Theory**
- **Modulation Index**
- **Bandwidth & Bessel functions**
- **Merits & Demerits**

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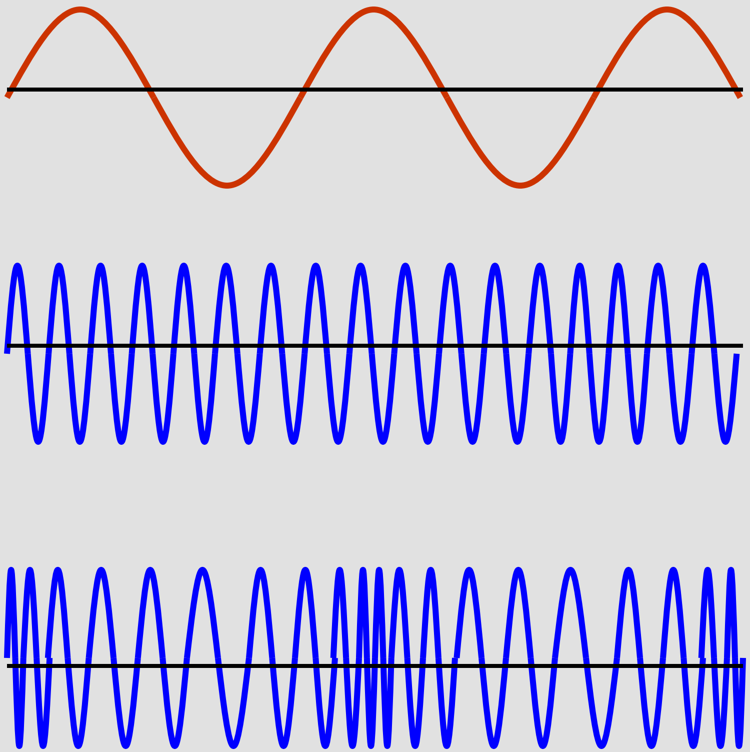
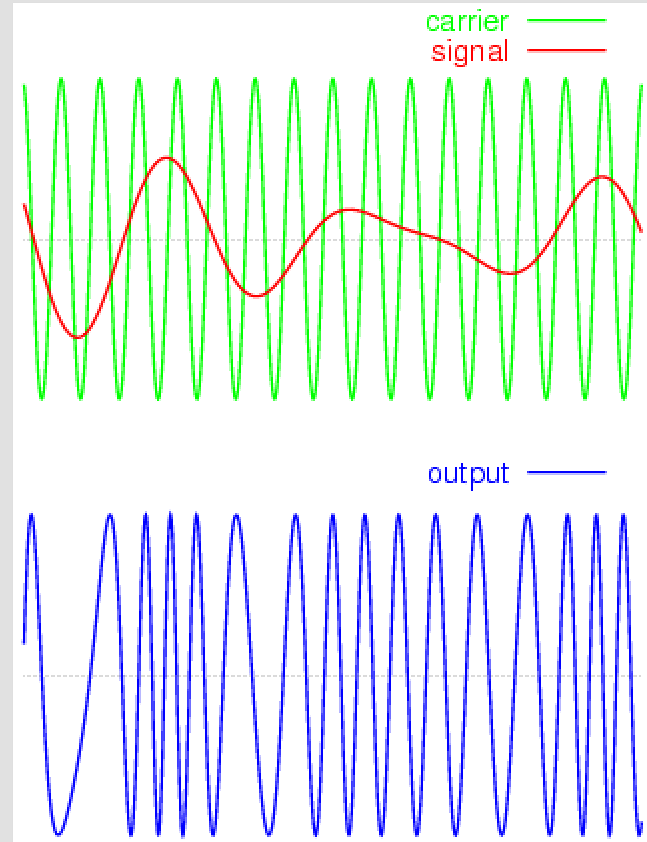
Wave Forms





(Courtesy: Internet)

Uniform AF signal modulating the Carrier wave frequency

Non-uniform AF signal modulating the Carrier wave frequency

Theory:

$$e_m = E_m \cos \omega_m t \qquad \& \qquad e_c = E_c \cos(\omega_c t + \phi)$$

The instantaneous frequency 'ν' of modulated wave is:

$$\nu = \nu_c + kE_m \cos \omega_m t$$

(where k is proportionality constant which depends on the modulating system)

If $\cos \omega_m t = \pm 1$, then $\nu = \nu_c \pm kE_m$

$$\text{or} \qquad \nu = \nu_c \pm \delta$$

(where $\delta = kE_m$ is maximum or peak deviation in carrier frequency)

Note that δ depends on the magnitude of E_m and not upon ν_c.

Instantaneous value of FM voltage is: $e = E_c \cos \theta$

θ is given by the following steps:

$$d\theta = \omega\, dt \Rightarrow d\theta = 2\pi \nu\, dt \Rightarrow d\theta = 2\pi(\nu_c + kE_m \cos \omega_m t)\, dt$$

On integration, we get

$$\theta = \omega_c t + (\delta / \nu_m) \sin \omega_m t$$

$$\therefore\ e = E_c \cos[\omega_c t + (\delta / \nu_m) \sin \omega_m t] = E_c \cos(\omega_c t + m_f \sin \omega_m t)$$

where $m_f = \delta / \nu_m$ is modulation index for FM

Deviation: The amount by which the frequency of the carrier wave is changed from its original unmodulated frequency.

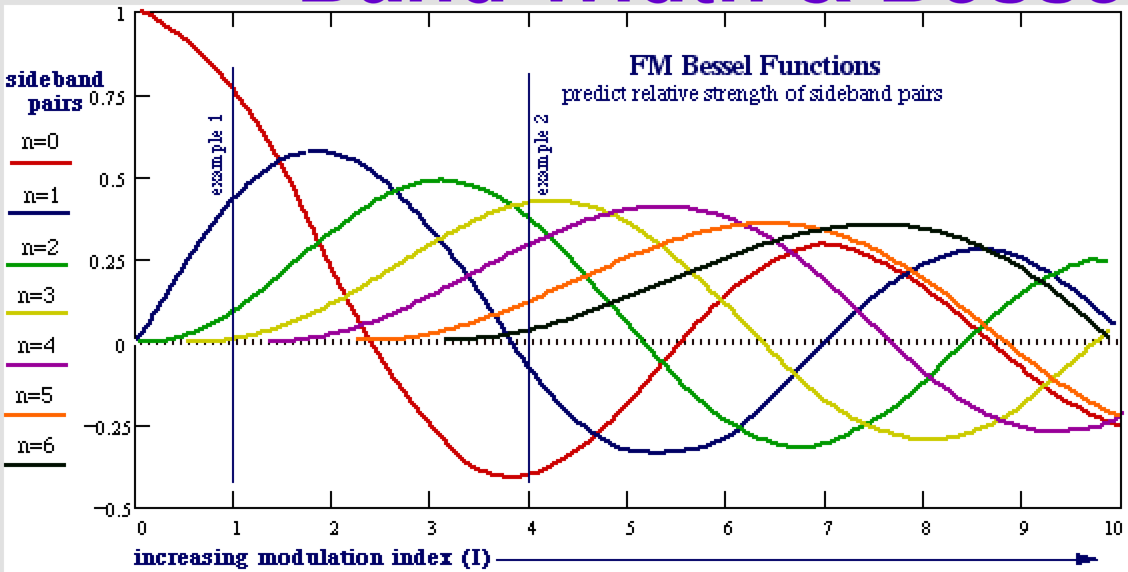
The rate at which this change occurs is equal to modulating frequency.

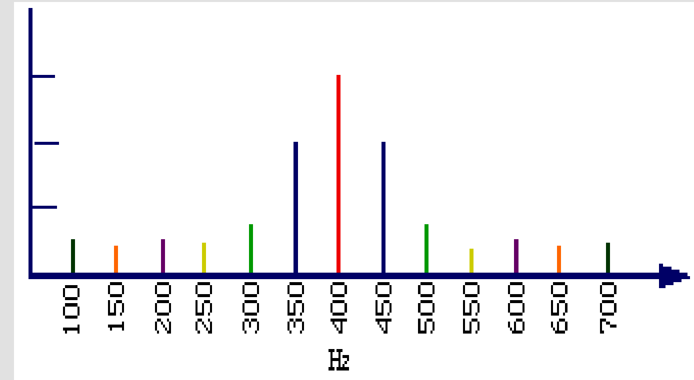
Modulation Index: M I for F M is the ratio of maximum frequency deviation to the modulating frequency. $\mathbf{m_f = \delta / \nu_m}$

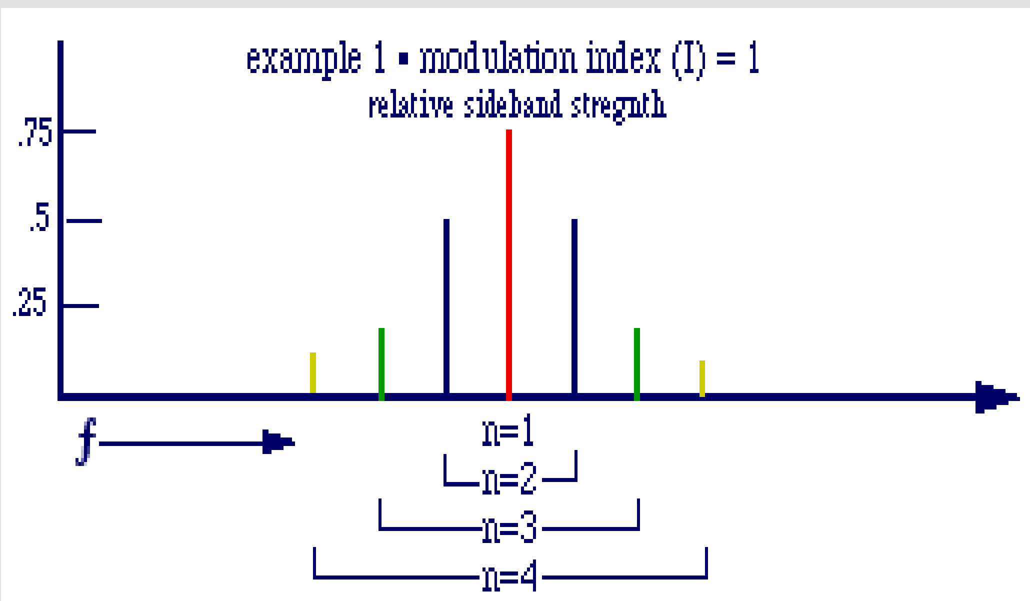
Observations:

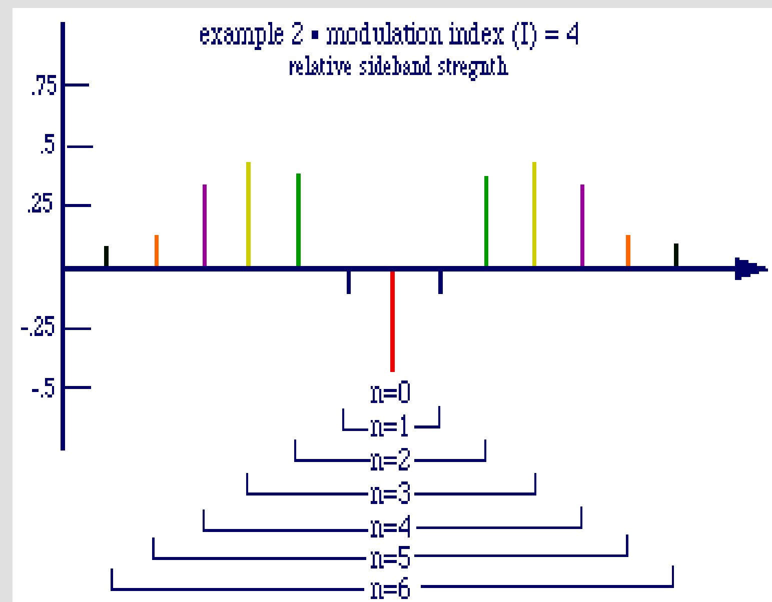
1. $\mathbf{m_f}$ is measured in radians.
2. Eqn. for frquency modulated wave is sine of sine function which gives a complex solution whereby the modulated wave consists of a carrier frequency and infinite number of pairs of side bands (Bessel functions).
3. In F M, the overall amplitude and hence the total transmitted power remains constant.

Band Width & Bessel Functions









(Courtesy: Internet)

Merits:

1. FM is inherently and practically free from noise.
2. Noise can be further reduced by increasing δ.
3. FM receivers can further be improved with the help of limiters to remove amplitude changes, if any.
4. All the transmitted power is useful in FM.
5. Many independent transmitters can be operated on same frequency without interference.

Demerits:

1. About 10 times wider channel is required by FM as compared to AM.
2. Area of reception for FM is much smaller than for AM.
3. FM receivers and transmitters are very complex and costly.

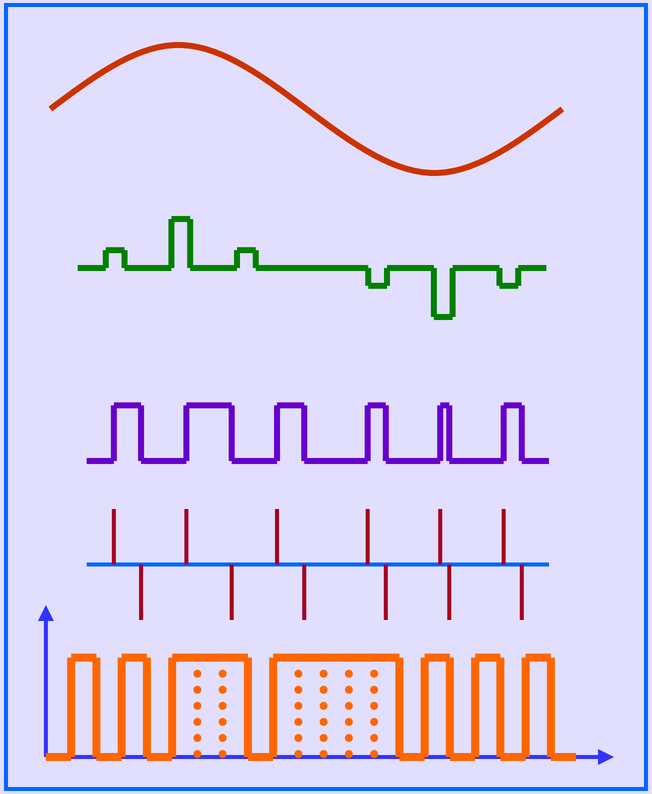
END

PULSE MODULATION

The process of transmitting signals in the form of pulses (discontinuous signals) by using special techniques.

The Chapter includes:

- Pulse Amplitude Modulation
- Pulse Width Modulation
- Pulse Position Modulation
- Pulse Code Modulation



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Pulse Modulation

Analog Pulse Modulation

- Pulse Amplitude (PAM)
- Pulse Width (PWM)
- Pulse Position (PPM)

Digital Pulse Modulation

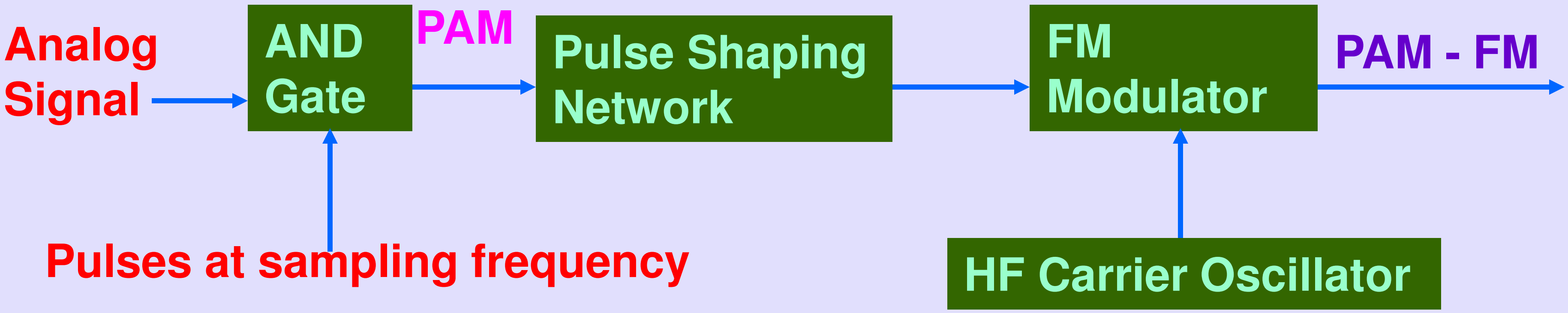
- Pulse Code (PCM)
- Delta (DM)

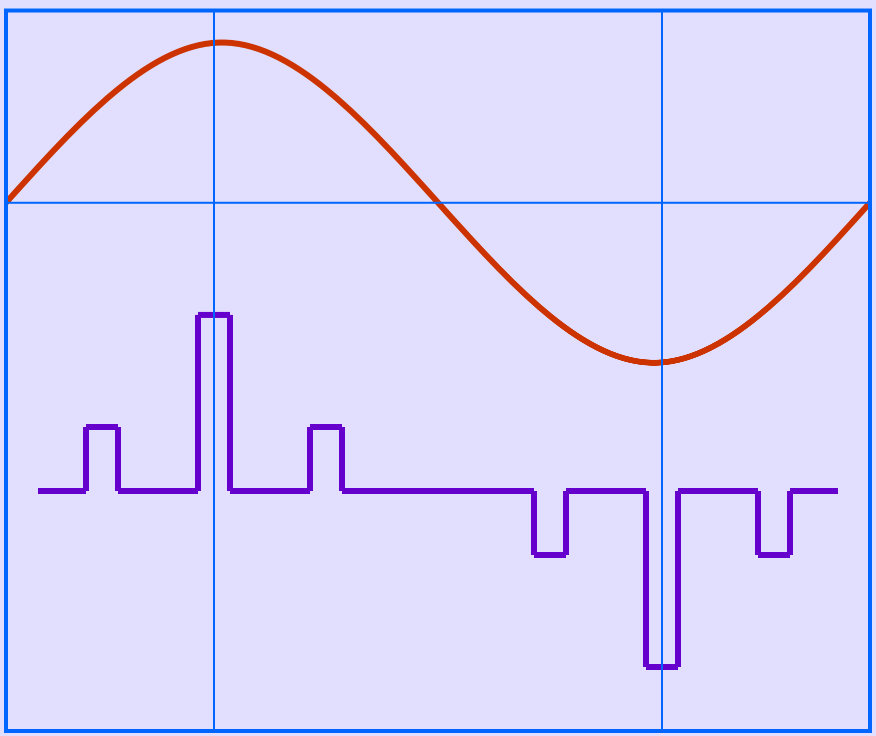
Pulse Amplitude Modulation (PAM):

*** The signal is sampled at regular intervals such that each sample is proportional to the amplitude of the signal at that sampling instant. This technique is called "sampling".**

**** For minimum distortion, the sampling rate should be more than twice the signal frequency.***

Pulse Amplitude Modulator





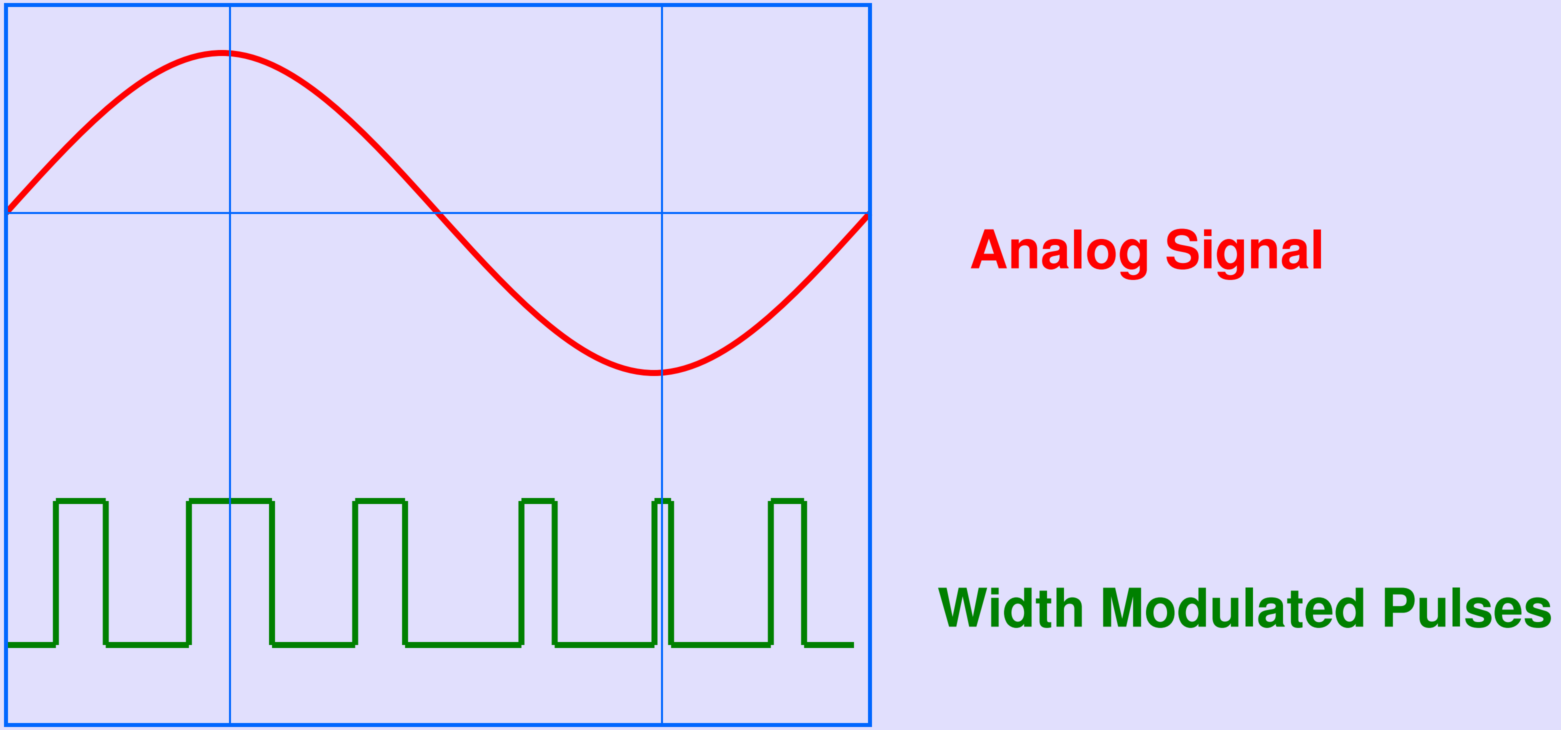
Analog Signal

Amplitude Modulated Pulses

Pulse Width Modulation (PWM or PLM or PDM):

* In this type, the amplitude is maintained constant but the duration or length or width of each pulse is varied in accordance with instantaneous value of the analog signal.

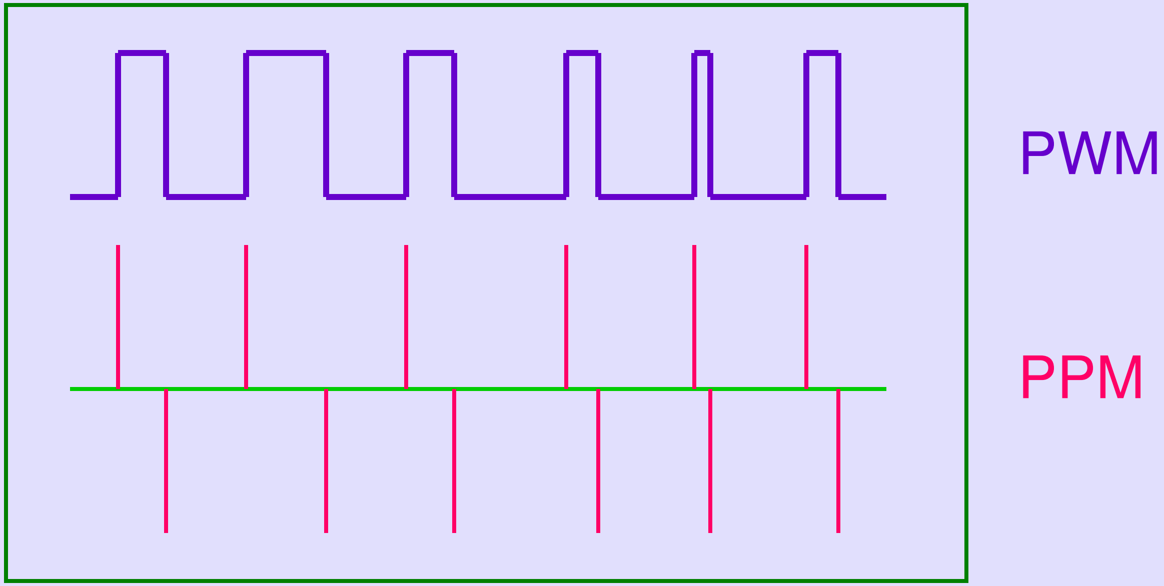
* The negative side of the signal is brought to the positive side by adding a fixed d.c. voltage.



Pulse Position Modulation (PPM):

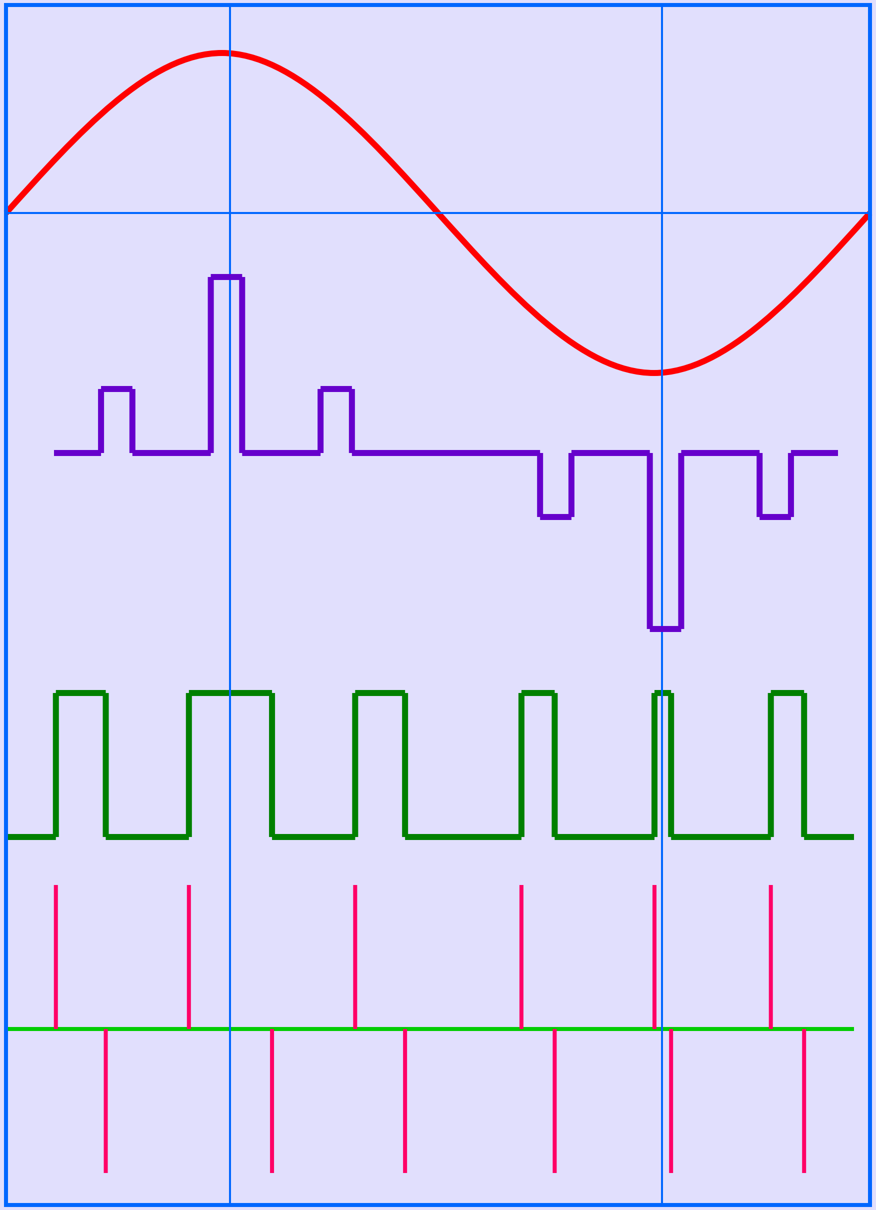
* In this type, the sampled waveform has fixed amplitude and width whereas the position of each pulse is varied as per instantaneous value of the analog signal.

* PPM signal is further modification of a PWM signal. It has positive thin pulses (zero time or width) corresponding to the starting edge of a PWM pulse and negative thin pulses corresponding to the ending edge of a pulse.



* This wave can be further amended by eliminating the whole positive narrow pulses. The remaining pulse is called clipped PPM.

PAM, PWM and PPM at a glance:



Analog Signal

Amplitude Modulated Pulses

Width Modulated Pulses

Position Modulated Pulses

Pulse Code Modulation (PCM):

* Analog signal is converted into digital signal by using a digital code.
* Analog to digital converter employs two techniques:

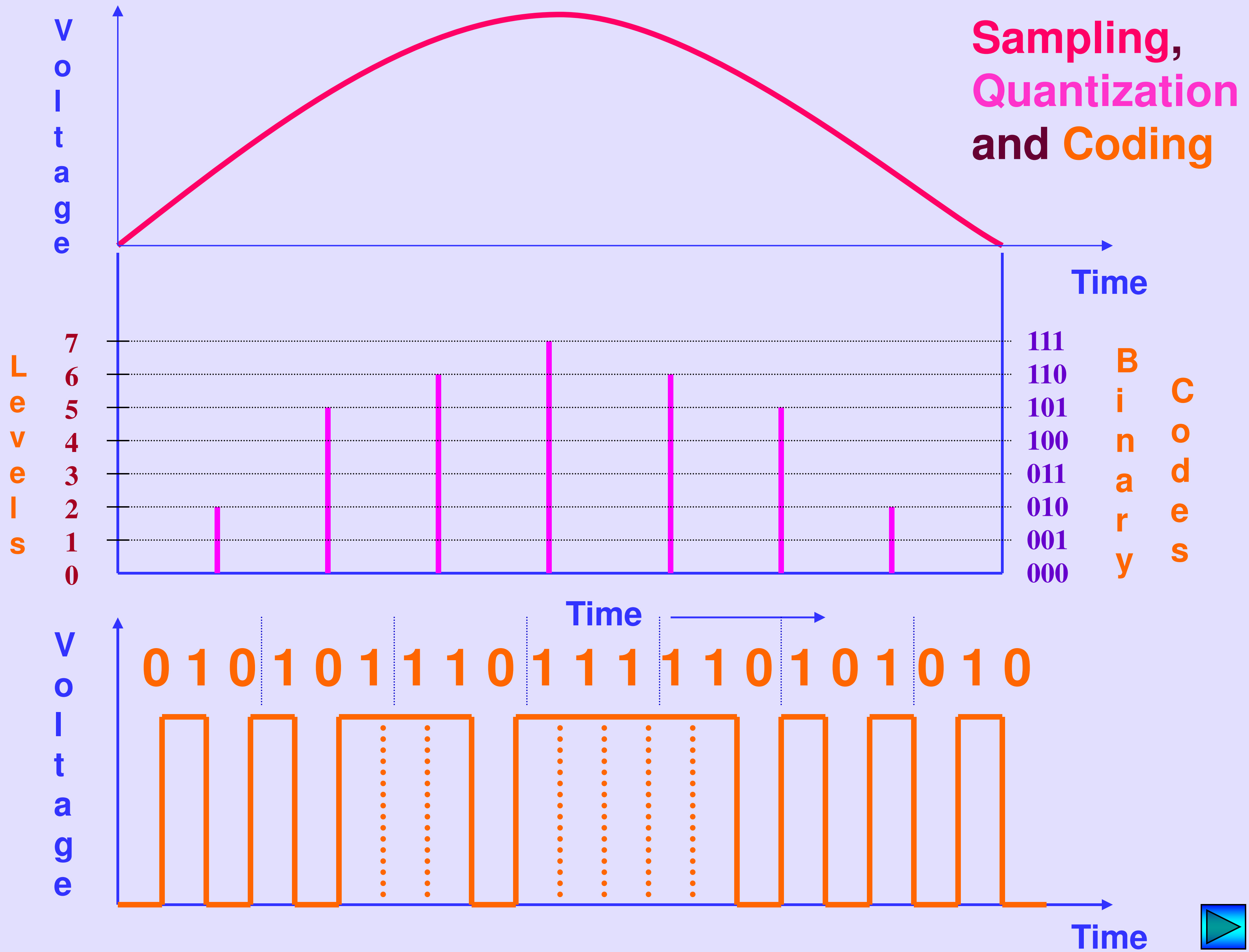
1. Sampling: The process of generating pulses of zero width and of amplitude equal to the instantaneous amplitude of the analog signal. The no. of pulses per second is called "sampling rate".

2. Quantization: The process of dividing the maximum value of the analog signal into a fixed no. of levels in order to convert the PAM into a Binary Code.
   The levels obtained are called "quanization levels".

* A digital signal is described by its 'bit rate' whereas analog signal is described by its 'frequency range'.

* Bit rate = sampling rate x no. of bits / sample

Sampling, Quantization and Coding



Merits of Digital Communication:

1. Digital signals are very easy to receive. The receiver has to just detect whether the pulse is low or high.
2. AM & FM signals become corrupted over much short distances as compared to digital signals. In digital signals, the original signal can be reproduced accurately.
3. The signals lose power as they travel, which is called attenuation. When AM and FM signals are amplified, the noise also get amplified. But the digital signals can be cleaned up to restore the quality and amplified by the regenerators.
4. The noise may change the shape of the pulses but not the pattern of the pulses.
5. AM and FM signals can be received by any one by suitable receiver. But digital signals can be coded so that only the person, who is intended for, can receive them.
6. AM and FM transmitters are ‘real time systems’. i.e. they can be received only at the time of transmission. But digital signals can be stored at the receiving end.
7. The digital signals can be stored, or used to produce a display on a computer monitor or converted back into analog signal to drive a loud speaker.

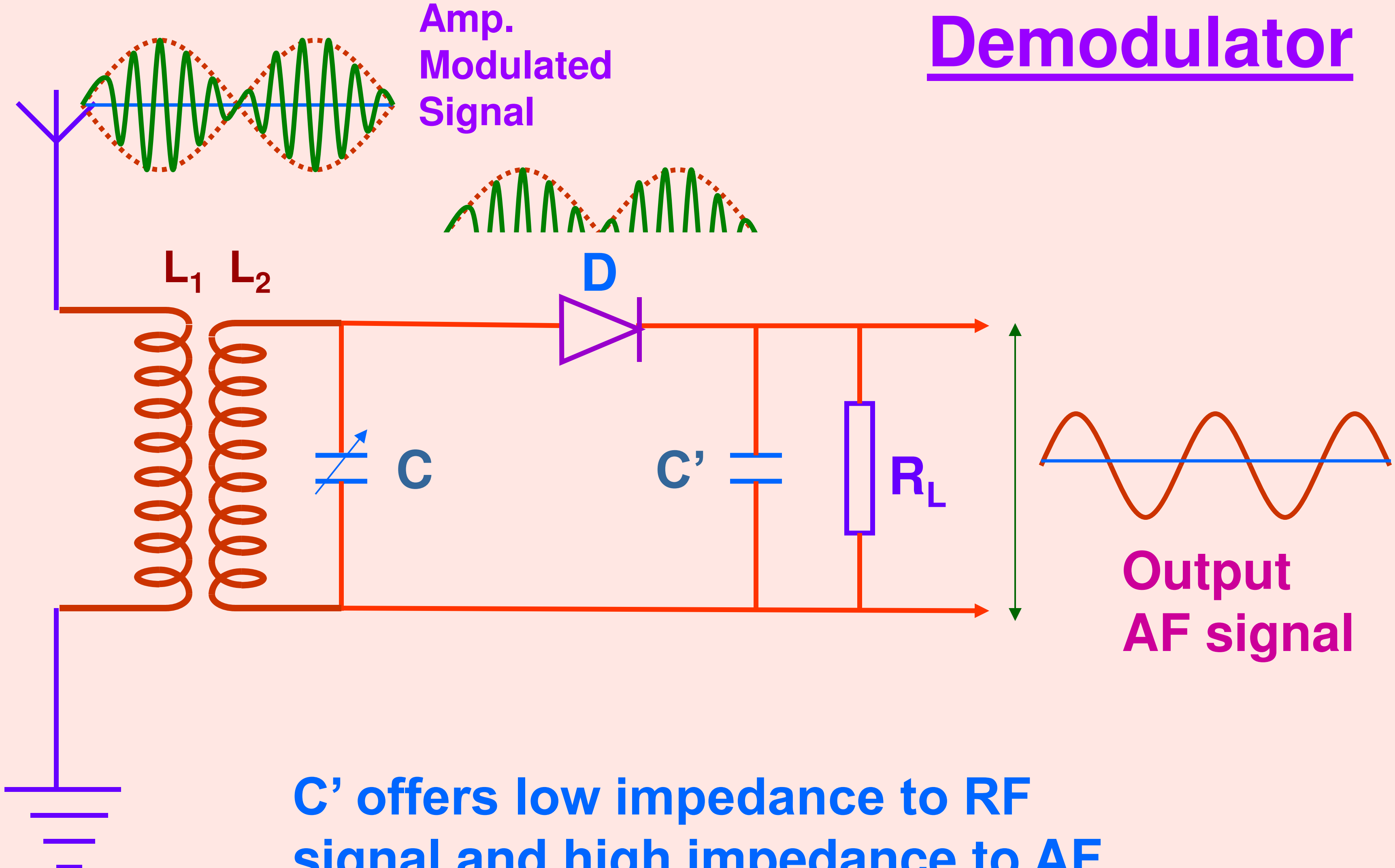
END

DATA TRANSMISSION AND RETRIEVAL

This Chapter includes

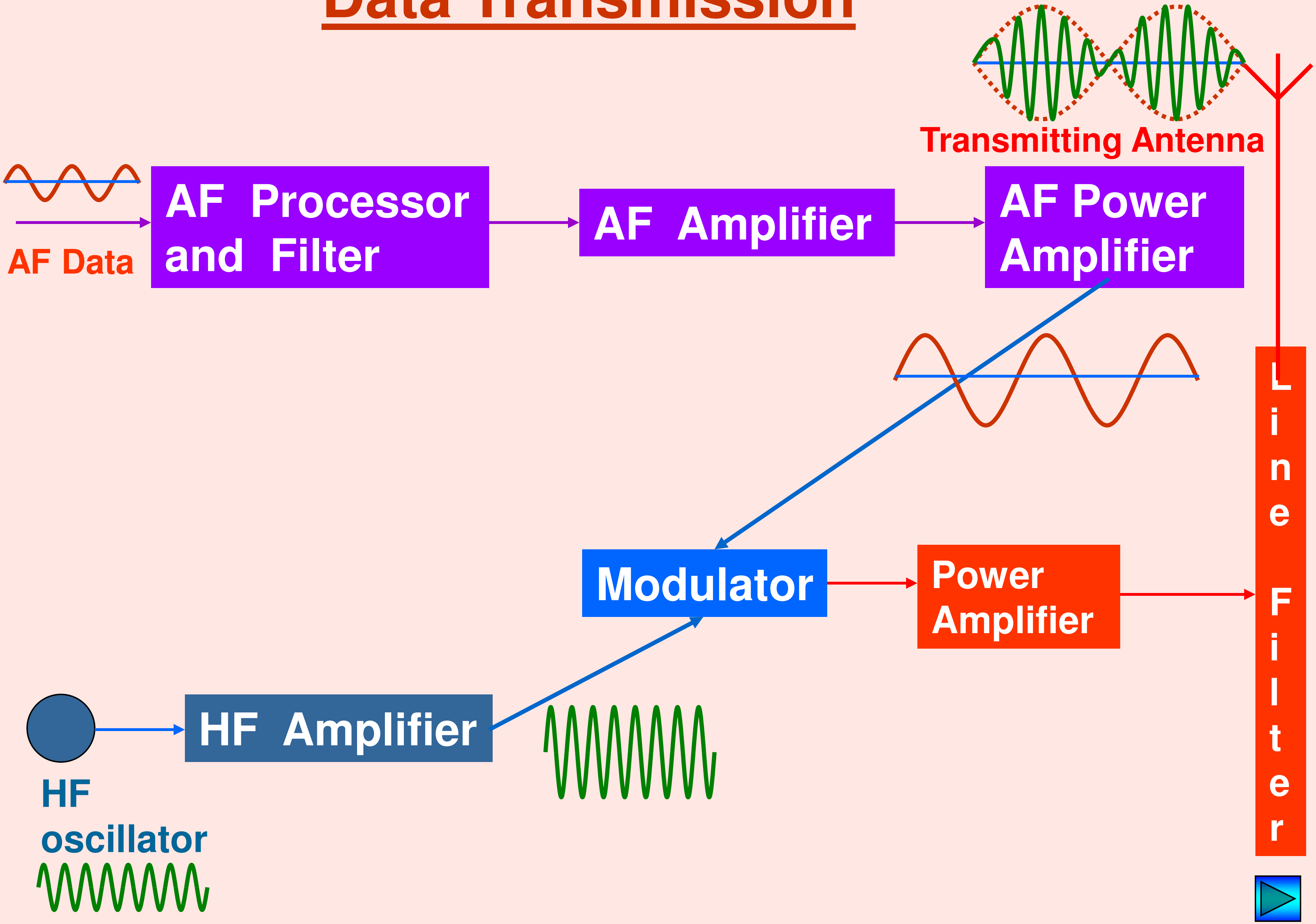
1. Demodulation
2. Data Transmission and Retrieval
3. FAX
4. Modem

Demodulator

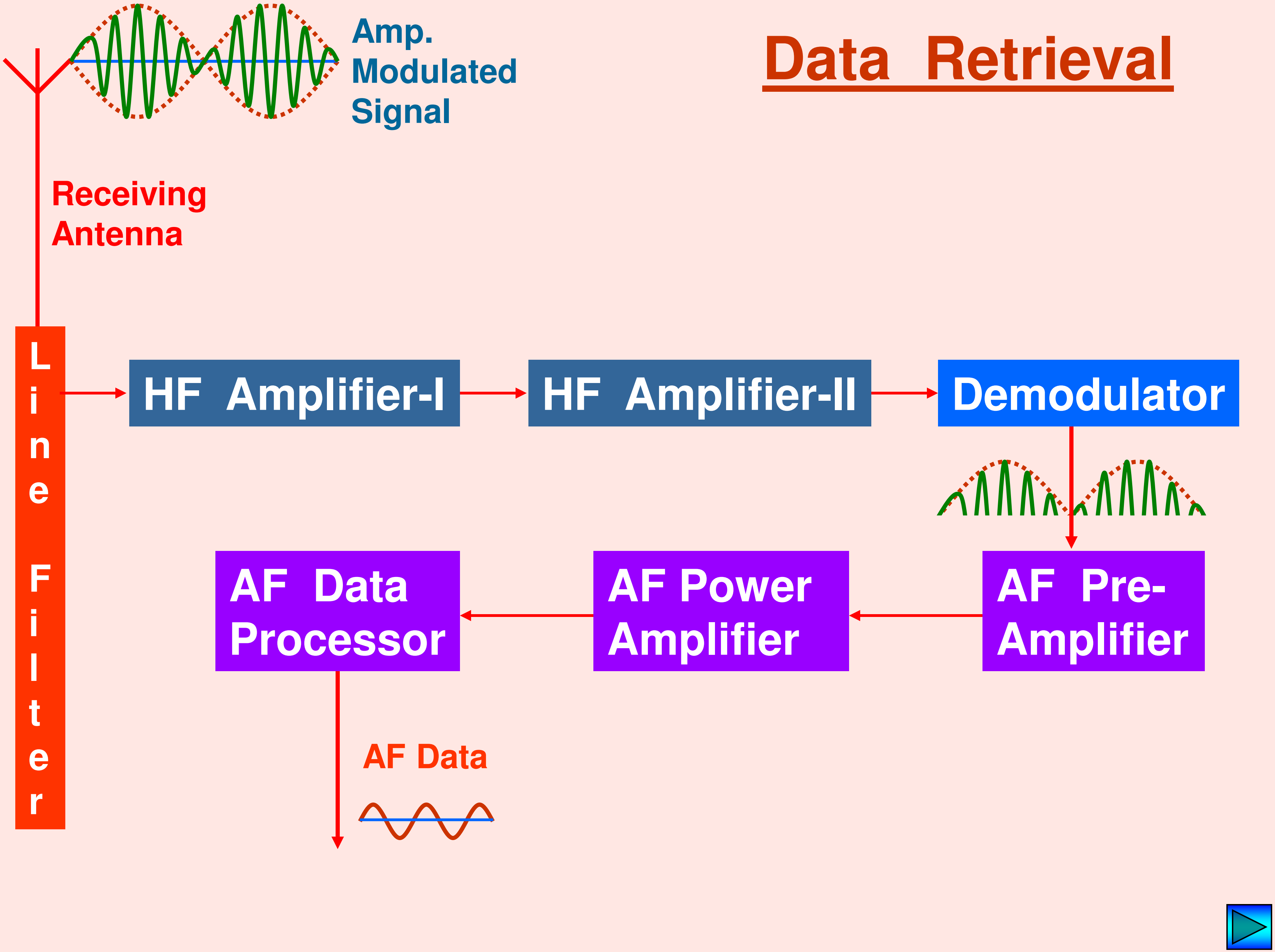


C' offers low impedance to RF signal and high impedance to AF signal since $X_c = 1/2\pi\nu C'$

Data Transmission

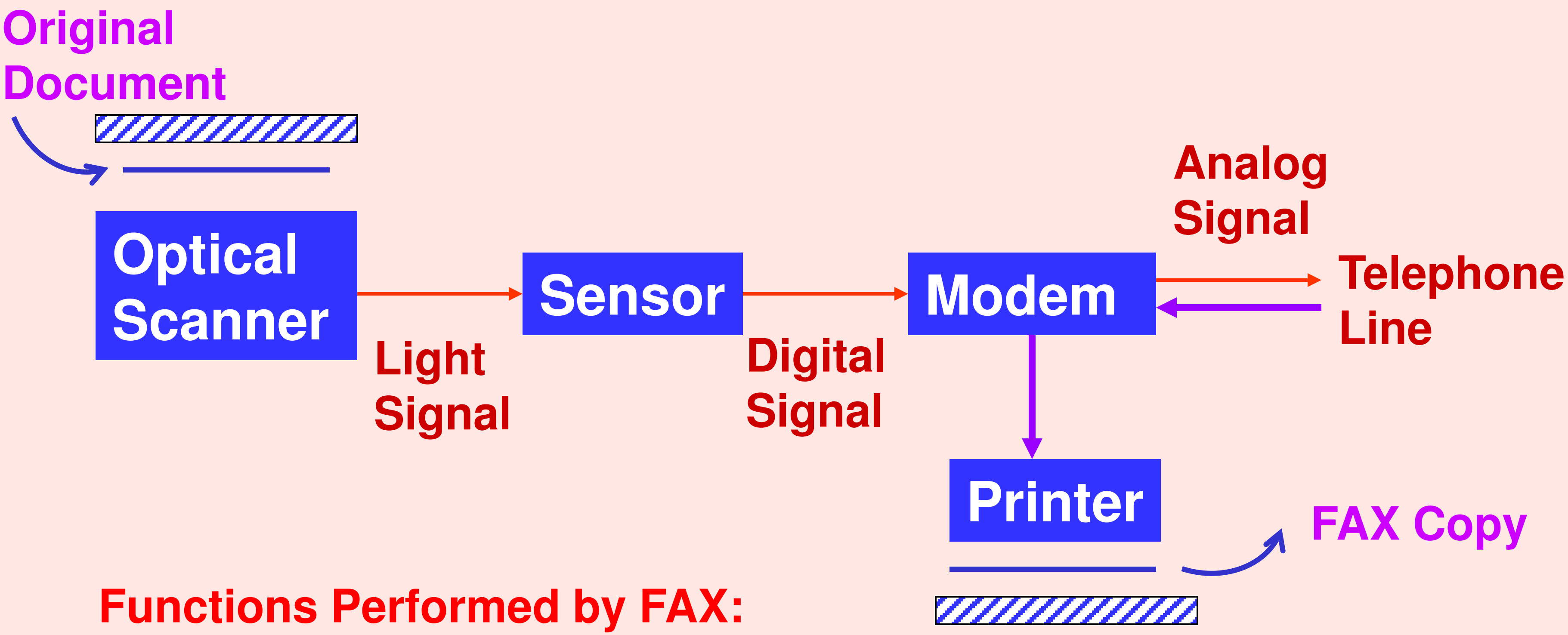


Data Retrieval



FAX (Facsimile Telegraphy)

* The electronic reproduction of a document at a distant place via Telephone line

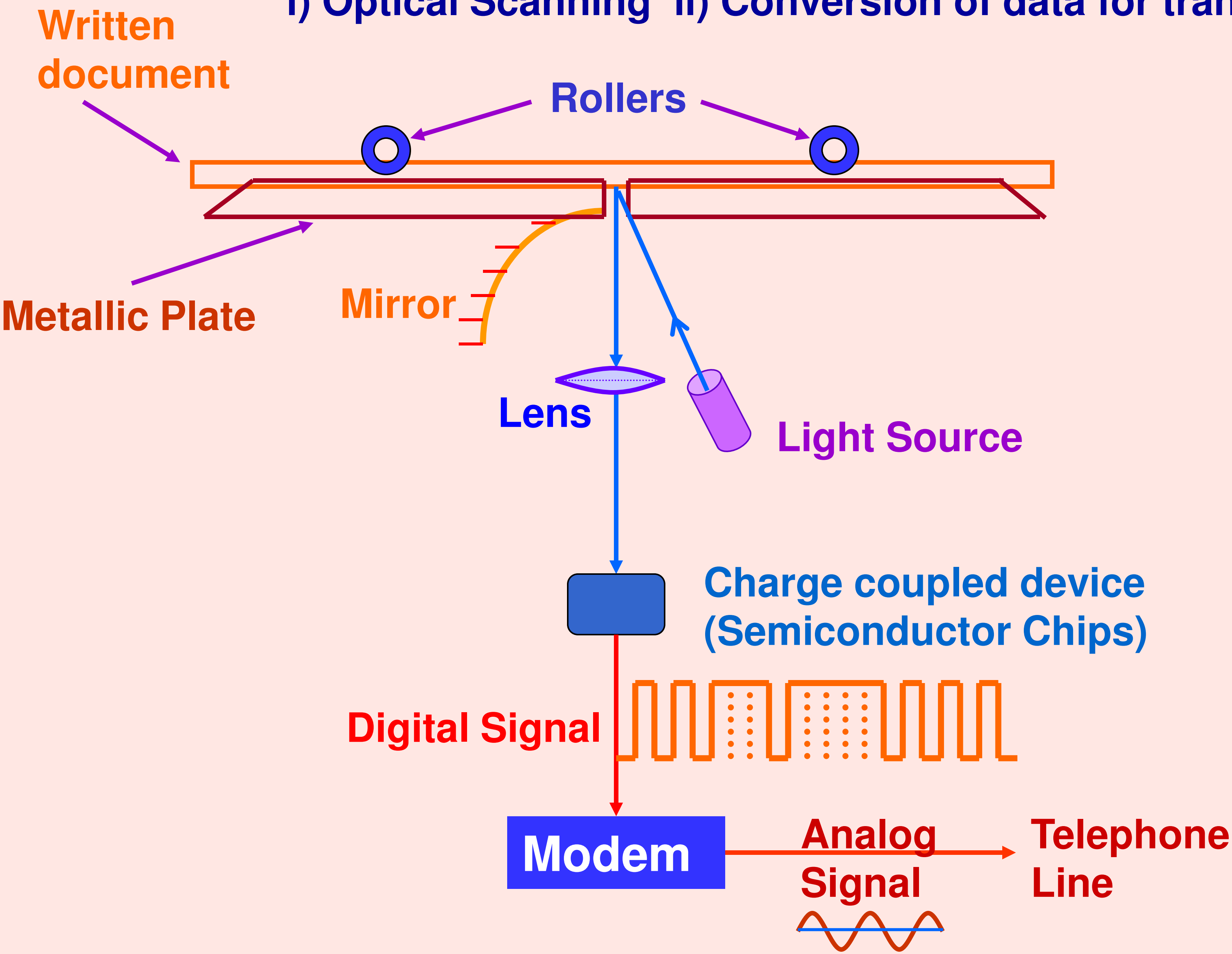


Functions Performed by FAX:

i) Optical Scanning   ii) Conversion of data for transmission and reception   iii) Printing a copy at the receiver's end

FAX

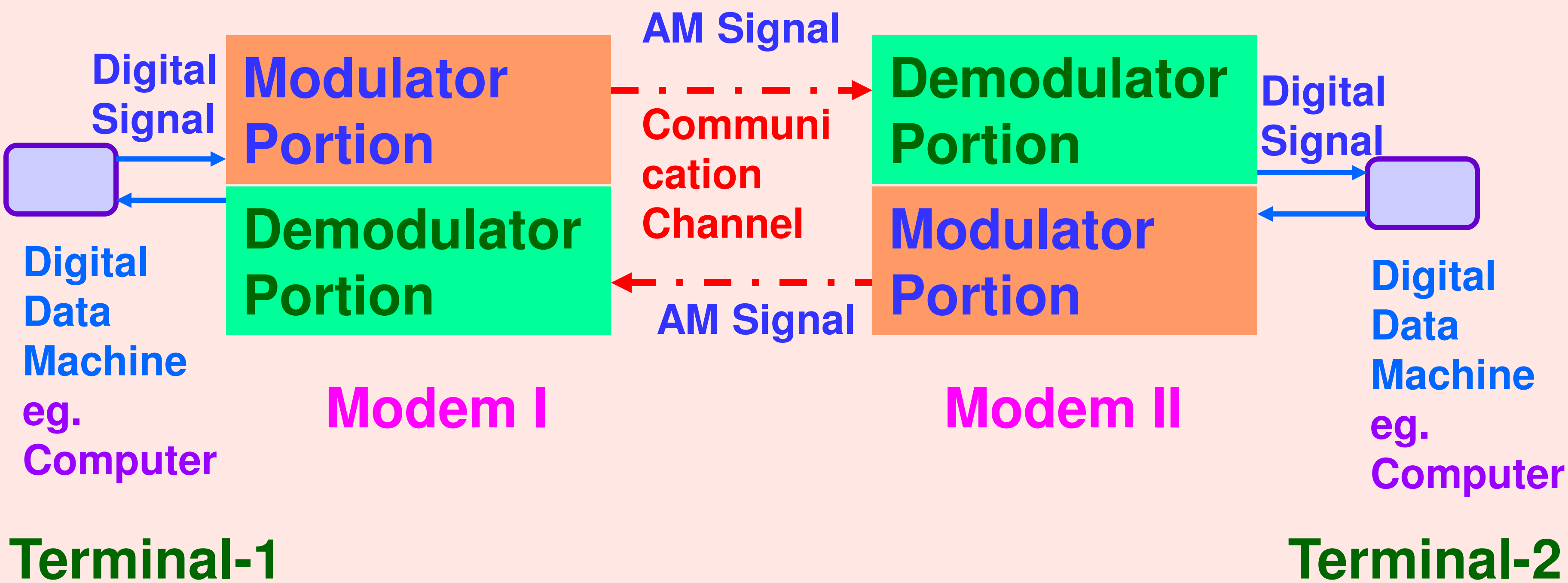
i) Optical Scanning ii) Conversion of data for transmission



MODEM (MOdulator and DEModulator)

DATA SET

* Converts digital signal to analog signal at the transmitting end and vice versa at the receiving end.



* Modem is also called as data set because it inter connects data source with a transmitter or receiver.

Modems differ in:

a) Speed of data transmission:

- i) low speed : upto 600 bits per sec (bps)
- ii) medium speed: 600 – 2400 bps
- iii) high speed : above 2400 bps

b) Modulation methods:

- i) frequency shift keying (FSK) which shifts a carrier frequency to indicate a space or mark
- ii) phase shift keying (PSK) which shifts the phase of a carrier wave

c) Bandwidth:

- i) low frequency range (below 4 kHz)
- ii) wide band (in multiples of 4 kHz)

Modes of Modems:

1) Simplex mode:

It operates as either send-only or receive-only device; i.e. data signals can be transmitted between Transmitter and Receiver only in one direction.

2) Half-duplex mode:

In this, data signals can be transmitted between Transmitter and Receiver in both the directions but only in one direction at a time.

3) Full-duplex mode:

In this, data signals can be transmitted between Transmitter and Receiver in both the directions simultaneously.

Line Communication

1. Two Wire Transmission Lines
   - Parallel Wire Line
   - Twisted Pair Wires
   - Coaxial Line
2. Equivalent Circuit of a Transmission Line
3. Velocity Factor in a Line
4. Losses in a Line
5. Cable System
6. Optic Fibre System & Components of Fibre Optic Equipment
7. Optical Fibre – Types of Optical Fibre
8. Principle of Optic Fibre
9. Important Aspects – Numerical Aperture, Attenuation and Dispersion
10. Advantages and Disadvantages of Optic Fibres

Created by C. Mani, Principal, K V No.1, AFS, Jalahalli West, Bangalore

Line Communication:

The simplest and the oldest mode of communication from point-to-point in contact through transmission lines or wires is called 'line communication'.

The main line communication channels are:

(i) Two wire transmission lines

(ii) Coaxial cables

(iii) Optical fibres

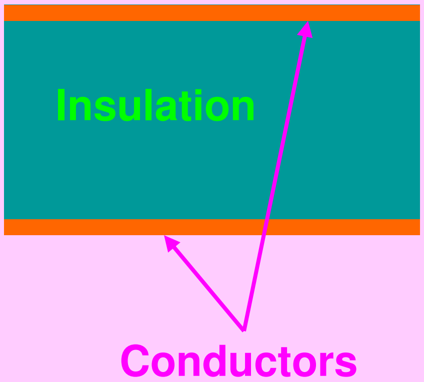
Two Wire Transmission Lines:

The most commonly used two wire lines are:

(a) Parallel wire line (b) Twisted pair of wires and (c) Coaxial line

Parallel Wire Line:

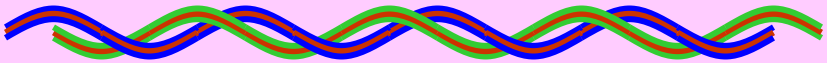
It is also known as balanced line. It resembles a ribbon. It is commonly used to connect an antenna with the TV receiver. It suffers from interferences and losses.



If the conductor separation is nearly equal to half wave length of the operating frequency of the signal, the system of wires may start radiating the signal.

Parallel wire lines are not suitable for microwaves.

Twisted Pair of Wires:



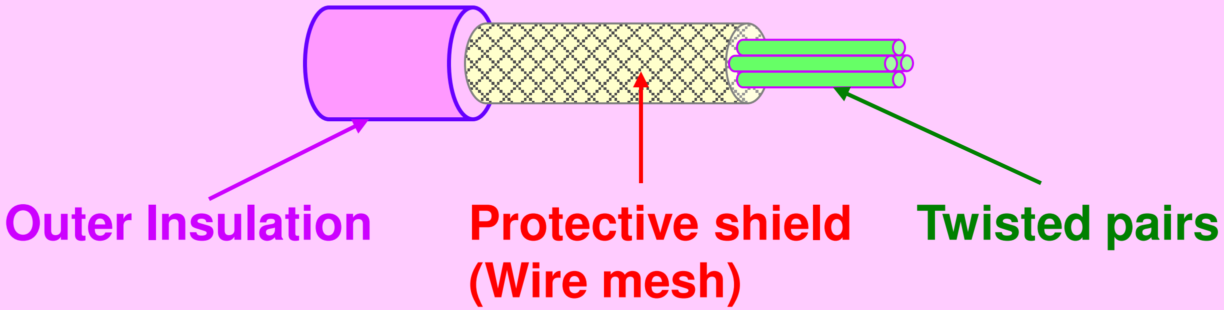
A twisted pair of wires consists of two insulated copper wires twisted around each other at regular intervals.

If the wires run parallel without twisting, then the electrical interference will be more for the wire close to the source of noise than the wire away from the source of noise. As a result of this, a distorted signal is available at the receiving end.

So, to minimize the electrical interference, two wires are twisted around each other.

Twisted pair wires are used to connect telephone systems. Usually many twisted pairs parallel to each other are grouped in the form of a bundle which is encased in a protective sheath.

In case of twisted pair wires, signals having frequency range 100 Hz to 5 MHz are transmitted.



Advantages:

(i) The signals can travel several kilometers without any amplification in a telephone system when twisted pair wires are used.

(ii) Both analogue and digital signals can be transmitted.

(iii) It is a cheap mode of communication.

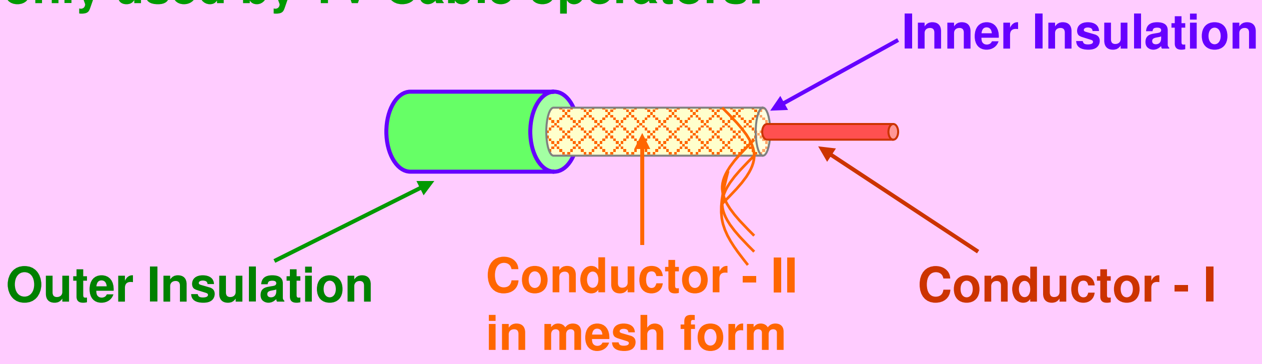
Disadvantages:

(i) The signal becomes weak when it travels a very large distance through a twisted pair of wires. As a result, transmission becomes faulty.

(ii) Telephone lines run overhead, so they can be broken during storm, etc.

Coaxial Line:

It is also called unbalanced line. Such a line resembles a rounded cable. It is commonly used by TV Cable operators.



It is also used to interconnect transmitter and an earthed antenna. Such cables are shielded i.e. outer conductor surrounds the insulated inner wire and the outer conductor is always earthed.

These cables do not suffer from radiation problems and be used for microwave and UHF region.

The inner and outer conductors are separated with the help of low dielectric. The common insulations are Polyethylene and Teflon.

Coaxial cables can be gas filled also. To reduce flash over between the conductor handling high power, nitrogen gas is used in the cable. Dry air can also be used under high pressure to avoid moisture in the cable.

These cables can find wide application for frequencies between 1 GHz and 20 GHz.

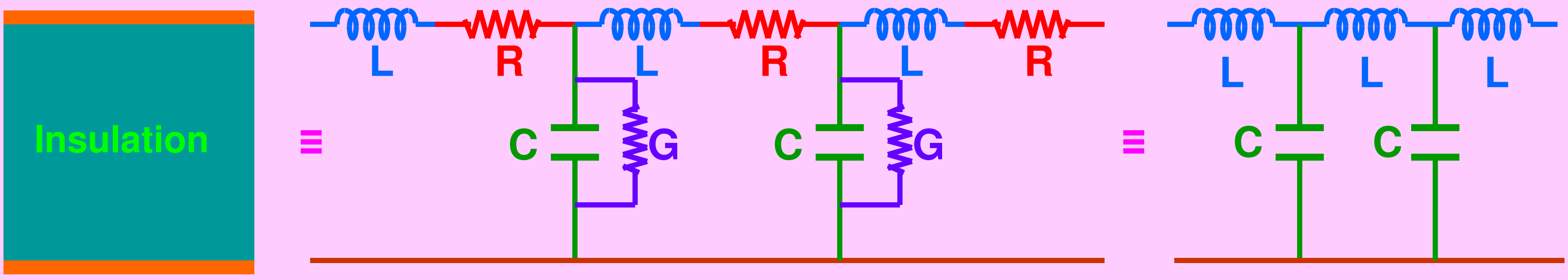
Advantages:

(i) Coaxial cable is well protected than an ordinary twisted pair of wires, so communication through cables is more efficient than through the twisted pairs.

(ii) The speed of transmission of signals is more than that of twisted pairs.

(iii) Electrical signals of higher frequencies (100 kHz to 500 kHZ) are transmitted through the cables than through the twisted pair wires.

Equivalent Circuit of a Transmission Line:



A two wire line consists of conductors and dielectric between them.

The line has some resistance (or conductance), inductive reactance and capacitive reactance (or susceptance). A dielectric can not be an ideal insulator and so some leakage current always flows through it which is considered to be due to shunt conductance G.

At radio frequency operations, the inductance of line is more effective than the resistance of line and capacitive susceptance is also significant than shunt conductance. So, at RF such resistances and shunt conductances can be ignored resulting into simple LC circuit.

A two wire line has some input impedance which depends upon type of line, length of line, termination at the other end, etc. This input impedance is known as 'reference impedance or characteristic impedance' (Z_0).

Characteristic impedance can be defined as the impedance measured at the input of a line of infinite length. Practically this impedance depends upon the size and spacing of the conductors as well as dielectric constant of the insulator separating them.

At voice frequency, expression for characteristic impedance is

$$\boxed{Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}}$$

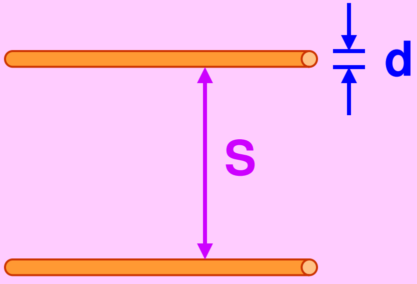
At radio frequency, expression for characteristic impedance is

$$\boxed{Z_0 = \sqrt{\frac{L}{C}}}$$

(R and G are insignificant)

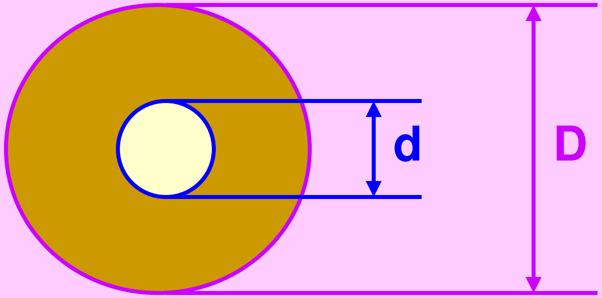
For a parallel – wire line,

$$Z_0 = \frac{276}{\sqrt{k}} \log \frac{2\,S}{d}$$



For a coaxial line,

$$Z_0 = \frac{138}{\sqrt{k}} \log \frac{D}{d}$$



Velocity Factor of a Line:

Velocity factor (v.f) of a cable is the ratio of reduction of speed of light in the dielectric of the cable.

$$v = \frac{c}{\sqrt{k}}$$

(where c is speed of light and k is dielectric constant)

By definition, $v = (v.f)\, c$ So, $v.f = 1 / \sqrt{k}$

For a line, velocity factor is generally of the order of 0.6 to 0.9

Losses in a Line:

Different types of lines cause different amount of energy losses. These losses can be due to Joule's heating in conductors, dielectric heating of insulation, radiation, etc.

Joule's Heating is given by $H = I^2Rt$

Current in the line depends upon frequency to be handled. Frequency alters the skin effect which changes the capacitive reactance ($1 / 2\pi vC$) and inductive reactance ($2\pi vL$) changing the circuit current and hence the energy losses change.

Dielectric losses are proportional to the voltage across the insulation. These losses increase with frequency. Dielectric heating is inversely proportional to the characteristic impedance for any power transmitted by the line.

Parallel lines cause radiation losses. Increase in frequency increases radiation losses. Coaxial cables have less radiation losses compared to parallel lines.

Cable System:

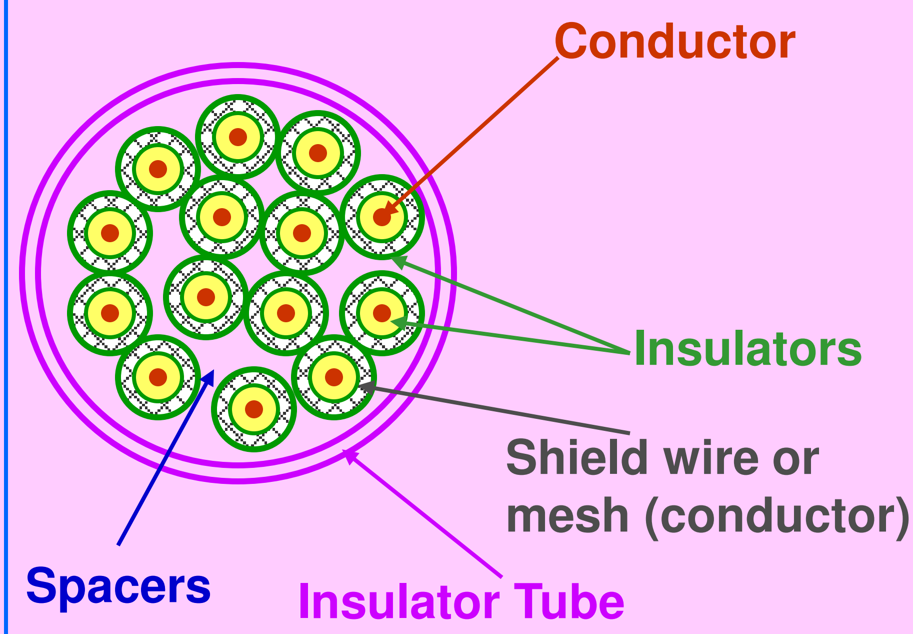
A practical cable system consists of a tube carrying many simple coaxial cables. They are more commonly used compared to flat cables.

A coaxial cable consists of a conductor covered with a suitable insulation. A shield wire is wrapped on this insulation which serves as the second conductor also. The shield wire is then again covered with a suitable insulation which also serves as a protection against mechanical injuries.

A typical cable used in communication system is used for multiple channels. A large channel system with 10,500 channels is much cheaper than equivalent number of small channel systems (say 3 x 3500 channels).

A cable is a source of loss of energy of a signal causing attenuation in signals as they travel along the cable. A signal booster i.e. amplifying repeater is placed at the required distance intervals.

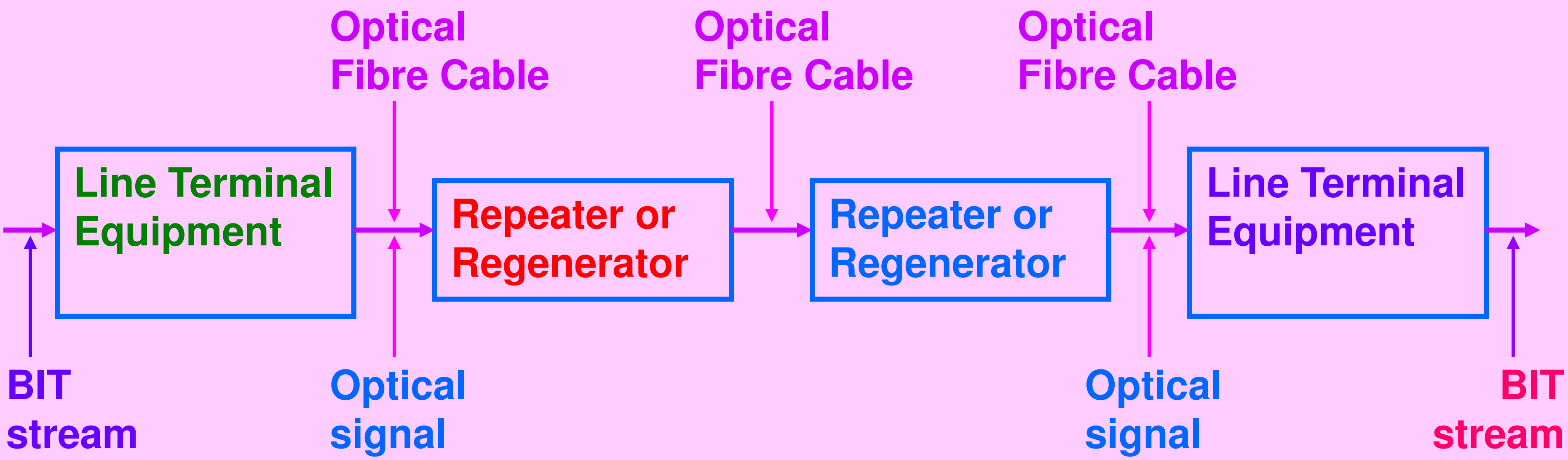
A cable further deviates the frequency and phase response of a signal. This deviation in signal has to be set right with the help of fixed type or variable type equalizers.



Optic Fibre System:

Optical communication is the mode of transmitting information in the form of a sort of light beam.

Optical fibre link like microwave link transmits the output from the digital source. The bit stream (zeros and ones) can be used directly to turn a laser or and off to send light pulses down the fibre cable.



Components of Fibre Optic Equipment:

1. **Light Source (LD or LED):** They are p-n junctions. Light from LED is produced by spontaneous emission whereas light from an LD is made by stimulated emission. LED has an incoherent output and wide spectrum but it has higher reliability, simpler drive circuit, lower temperature sensitivity, immunity to reflected light and low cost.

   LD has an output which is coherent and therefore has a very narrow spectrum. It has high output power and high coupling efficiency.

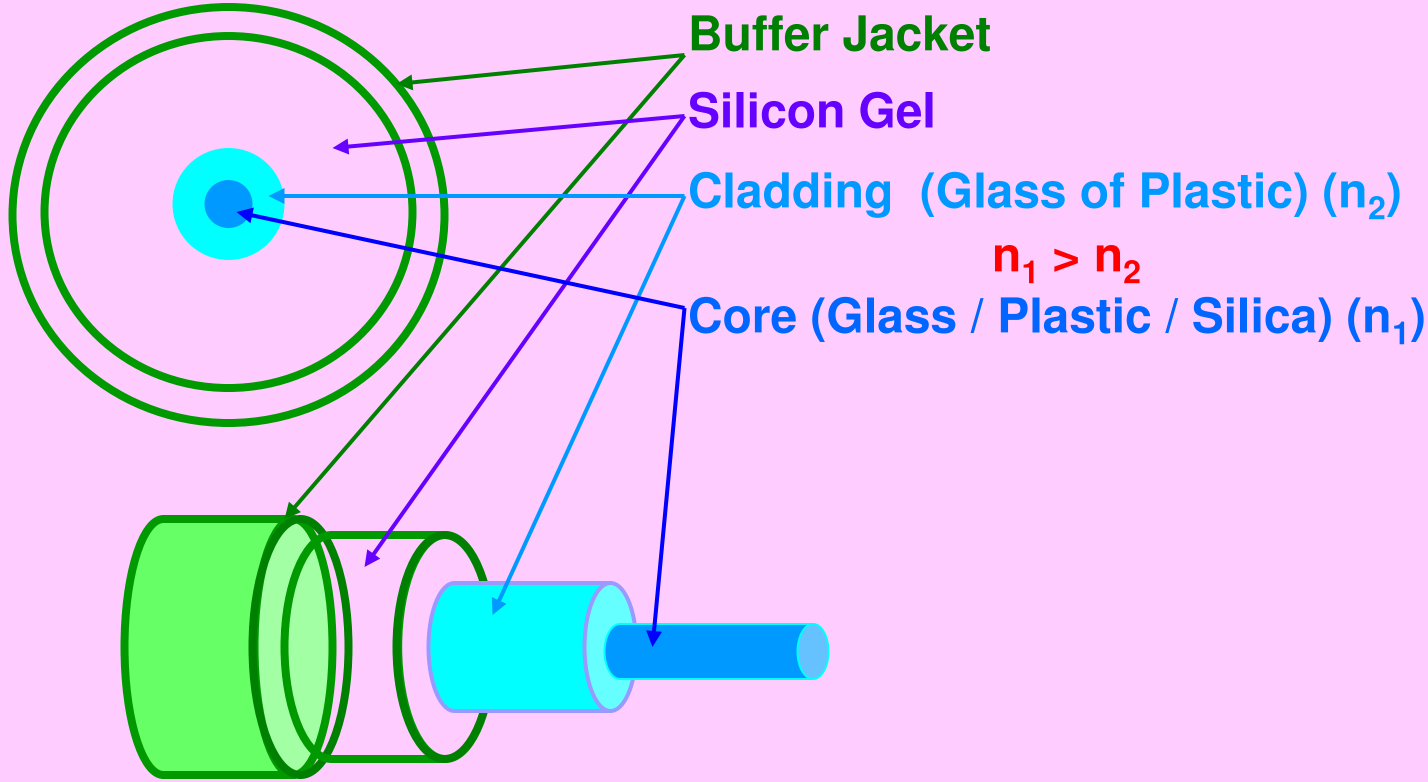
2. **Amplifiers:** Semiconductor amplifiers or doped fibre amplifiers are used to limit fibre losses and to increase repeater spacing. They are also known as repeaters because they can directly boost the signal just prior to detection.

3. **Modulators:** Modulation of a light source can be done by direct modulation of direct current supplying the source or by using an external modulator following the source. The simplest form of direct modulation is to change the light biasing current above and below the threshold value to turn the laser on and off to obtain digitalisation (0 and 1).

4. **Filters:** They are essential components to minimise the cross talk between channels.

5. **Light Detectors:** Light emerging from the end of an optical fibre link must be detected and converted in to electronic pulses for further processing so that the transmitted information can be received.

Optical Fibre:



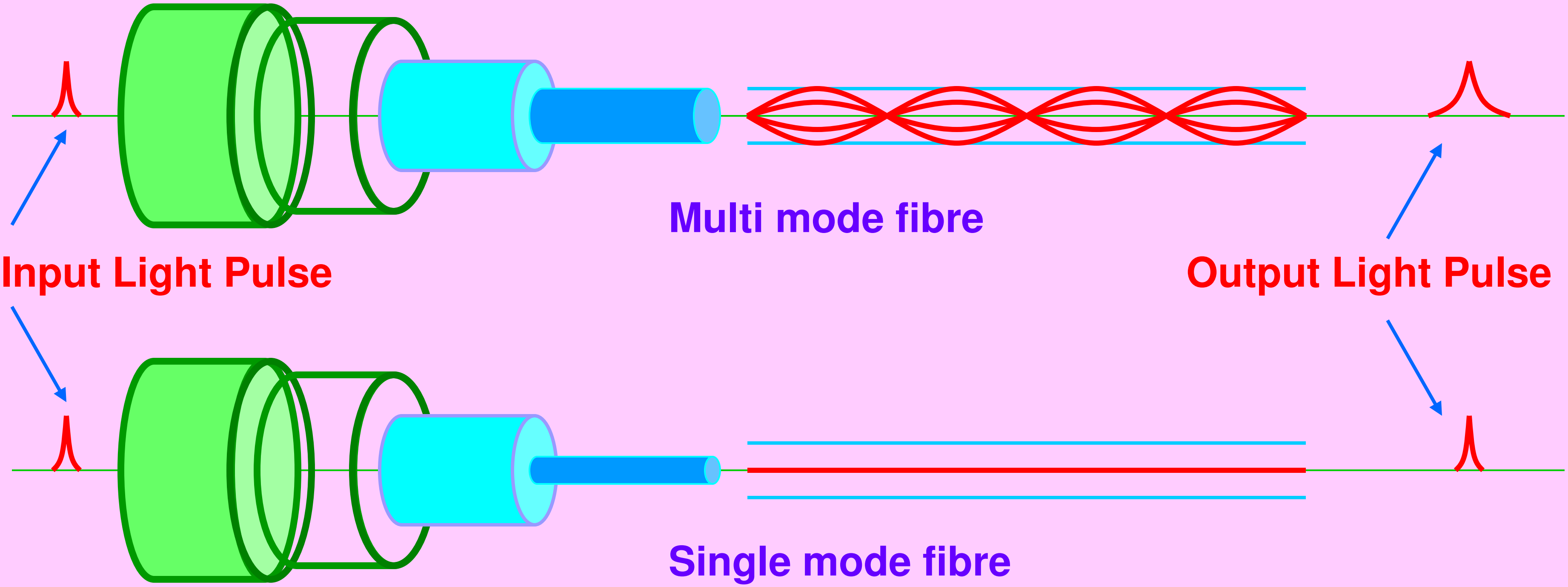
1. **Core:** It is made of glass / silica / plastic of refractive index (say n_1) with approximate diameter of 10 to 100 μm.

2. **Cladding:** It is made of glass or plastic with refractive index n_2 ($n_2 < n_1$) with approximate diameter of 100 to 400 μm. Cladding is of two types:

   Step-index fibre in which the refractive index changes abruptly;
   Graded-index fibre in which the refractive index changes gradually.

3. **Buffer Jacket:** It is plastic coating which houses the core-cladding and provides safety and strength.

Types of Optical Fibre:



1. In multi mode optical fibre, the core diameter is about 50 μm. The signal is transmitted in multiple modes. Attenuation is higher in this mode.

2. In single mode optical fibre, the core diameter is about 8 to 10 μm which is approximately same as the wavelength of the light used. Only one mode propagates in this fibre. Attenuation is lower and the maximum bit rate is higher.

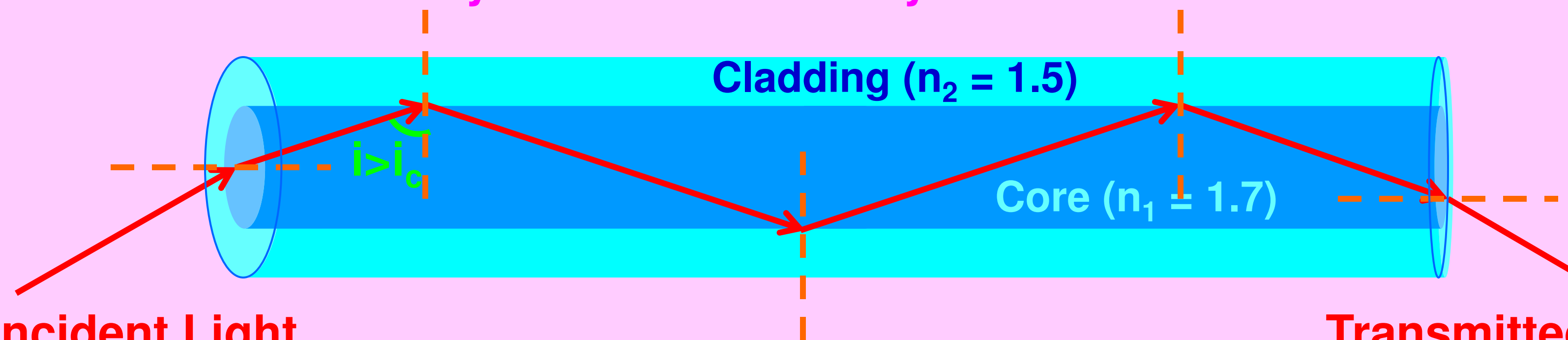
Fibre Bending: Whenever a fibre is bent, some of the energy with in the core can escape into region outside the fibre. This loss of energy increases as the radius of curvature of bend decreases.

Principle / Action of Optical Fibre:

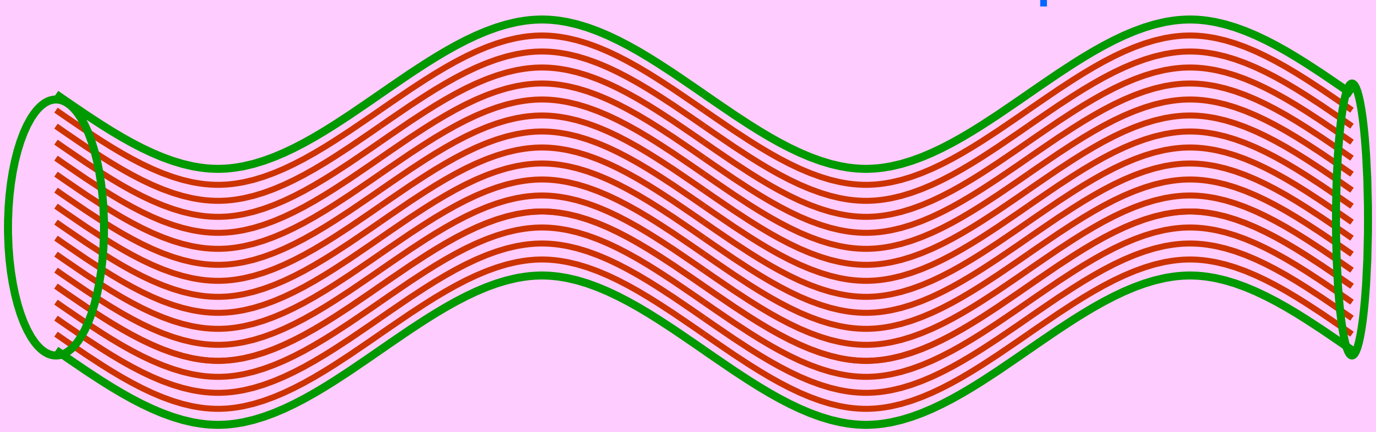
Optical fibre works on the principle of total internal reflection.

When light falls on the interface separating the fibre and coating at an angle which is greater than the critical angle, multiple total internal reflections take place.

The light travels the entire length of the fibre and comes out of the other end of the fibre without any loss in its intensity.



Optic Pipe: It is a bundle of thousands of optical fibres packed in such a way that the free ends on both sides are at the same relative positions.



Important Aspects of Fibre Optics:

1. Numerical Aperture (NA):

For Total Internal Reflection, light should enter the fibre at an angle θ in accordance with core of acceptance angle θ_c.

Numerical Aperture depends on diameter of the core. It decreases as the diameter of core decreases and vice versa.

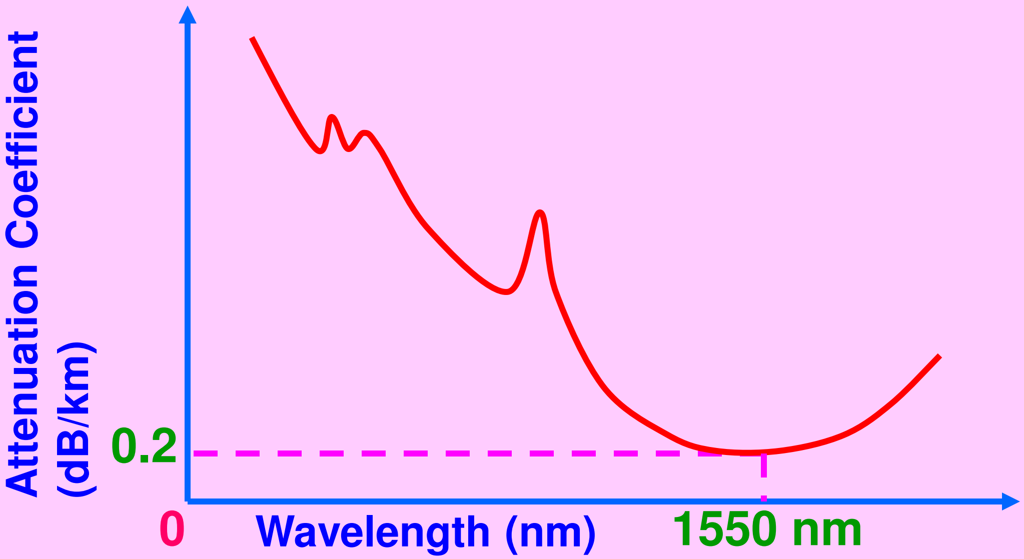
Typical value of NA for a 50 μm core cable is 0.2 and it is 0.1 for 10 μm cable.

$$\boxed{NA = \sin\theta_c = \sqrt{n_1^2 - n_2^2}}$$

2. Attenuation:

It basically means power loss or loss of information strength. Standard wavelengths of operation of optical fibres are 1.3 and 1.55 μm.

The lowest loss silica fibres operate at 1.55 μm with minimum attenuation of about 0.2 dB/km.



3. **Dispersion:**

As the optical pulses travel forward in the optical fibre, the pulses are broadened due to dispersion and the adjacent pulses may overlap. So, dispersion limits the distance of data transmission and transmission speed of data.

Laser has a narrower line width and hence dispersion will be the least.

Dispersion depends on fibre dimensions i.e. core diameter. It is also due to frequency dependence of refractive index of the fibre material.

Advantages of Optical Fibres:

1. **Optical fibres are the best for wavelength multiplexing i.e. innumerable signals of differing but nearby wavelengths can be sent along the same fibre.**

   A pair of optical fibres can carry 3000 telephone calls simultaneously whereas only dozens of telephone calls can be carried by a pair of copper wires and that also by special methods only.

2. **They are the best suited for digital transmission and switching systems.**
3. **A normal optic fibre cable is 1/6th in diameter as compared to coaxial cable.**
4. **Optic fibre communication is free from electromagntic interference and noise.**

5. Optical fibres are virtually free from losses. The intensity of the information transmitted by electric current flowing in copper wires become weak. But, the messages, data or picture sent through optical fibres remain undisturbed and hence can be transmitted through thousands of kilometers.

6. Optical communication can not be jammed as easily as radio waves can be jammed.

7. Light has higher frequency than electric current and so optical fibres can transmit higher band widths.

8. Optic fibres are becoming economical day by day.

Disadvantages of Optical Fibres:

1. Optical fibres are costly.

2. Only skilled engineers can handle the technology.

3. Glass fibres are easily broken when compared to copper wires, so they require extra care when installed.

LASER

1. LASER
2. Incoherent Light
3. Coherent Light
4. Atomic Interactions Related to LASER
   - Induced Absorption
   - Spontaneous Emission
   - Stimulated Emission
   - Population Inversion and Optical Pumping
5. Components of Laser Devices
6. Principle of Laser
7. Diode Laser
8. Characteristics of Laser Light
9. Applications of Laser
10. Elementary Principles of Light Modulation

LASER

LASER stands for Light Amplification by Stimulated Emission of Radiation.

Laser is a very intense, concentrated, highly parallel and monochromatic beam of light.

Coherence is very important property of Laser.

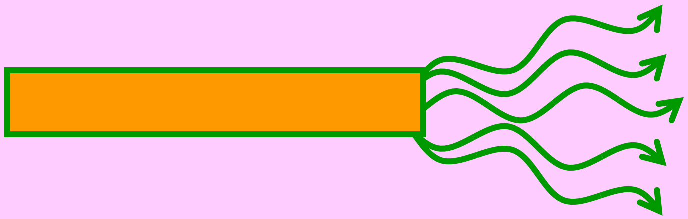
Incoherent Light:

The light emitted from the Sun or other ordinary light sources such as tungsten filament, neon and fluorescent tube lights is spread over a wide range of frequencies.

For eg. Sunlight is spread over Infra Red, Visible light and Ultra Violet spectrum. So, the amount of energy available at a particular frequency is very less and hence less intense.

Such light is irregular and mixed of different frequencies, directions and durations, and is incoherent.

Incoherent light is due to spontaneous and random emission of photons by the atoms in excited state. These photons will not be in phase with each other.

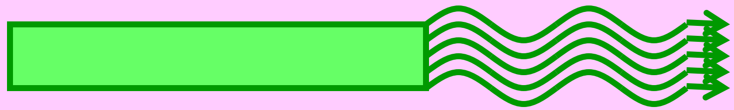


Incoherent Light

Coherent Light:

Coherent light is uniform in frequency, amplitude, continuity and constant initial phase difference.

Coherent beam of light is obtained due to stimulated emission of photons from the atoms jumping from meta-stable state to lower energy state.



Coherent Light

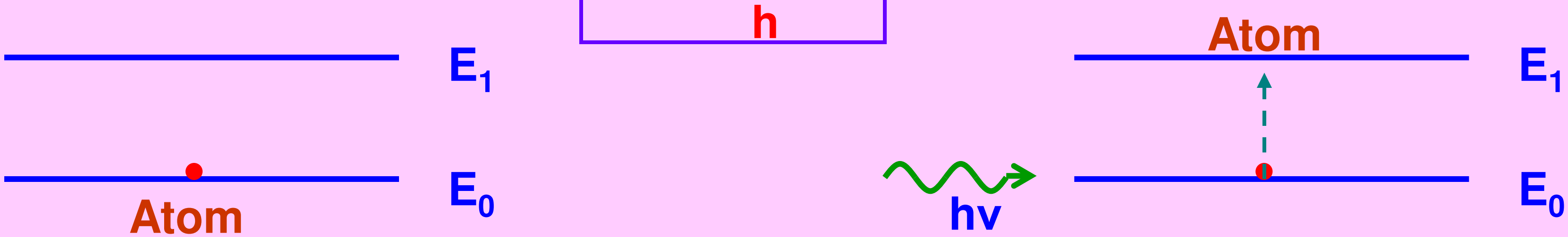
Various Atomic Interactions related to LASER:

a) Induced Absorption:

Photons of suitable size (energy) are supplied to the atoms in the ground state. These atoms absorb the supplied energy and go to the excited or higher energy state. IF E_i and E_j are energies of ground state (lower energy) land excited state (higher energy), then the frequency of required photon for absorption is

$$\boxed{\nu = \frac{E_j - E_i}{h}}$$

where 'h' is Planck's constant



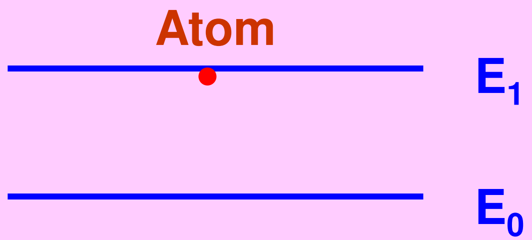
Before absorption

After absorption

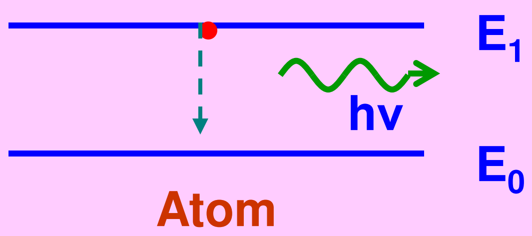
b) Spontaneous Emission:

An excited atom can stay in the higher energy state only for the time of 10^{-8} s. After this time, it returns back to the lower energy state by emitting a photon of energy $h\nu = E_1 - E_0$. This emission is called '**spontaneous emission**'.

During spontaneous emission, photons are emitted randomly and hence they will not be in phase with each other. Therefore, the beam of light emitted is **incoherent**.



Before emission

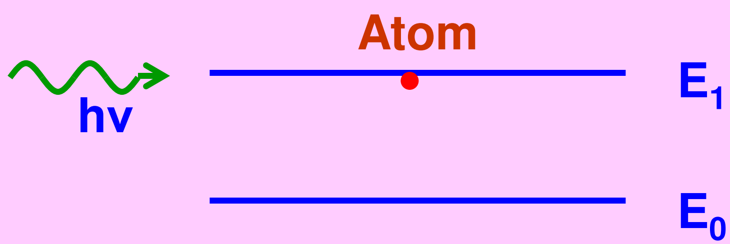


After emission

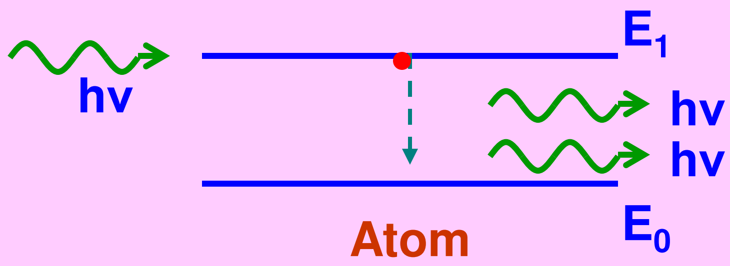
c) Stimulated Emission:

When photon of suitable size (energy) is showered (made to fall) on an excited atom in the higher energy state, the atom falls back to the ground state by emitting a photon of energy $h\nu = E_1 - E_0$ which is in phase with the stimulating (incident) photon.

Thus, it results in the appearance of one additional photon. This process is called 'stimulated or induced emission'.



Before emission



After emission

d) Population Inversion and Optical Pumping:

Usually , the number of atoms in the lower energy state is more than that in the excited state. According to Boltzmann, the ratio of atoms in the energy states j and i at a temperature T is given by

$$\frac{N_j}{N_i} = \frac{e^{-E_j / kT}}{e^{-E_i / kT}} = e^{-(E_j - E_i) / kT}$$

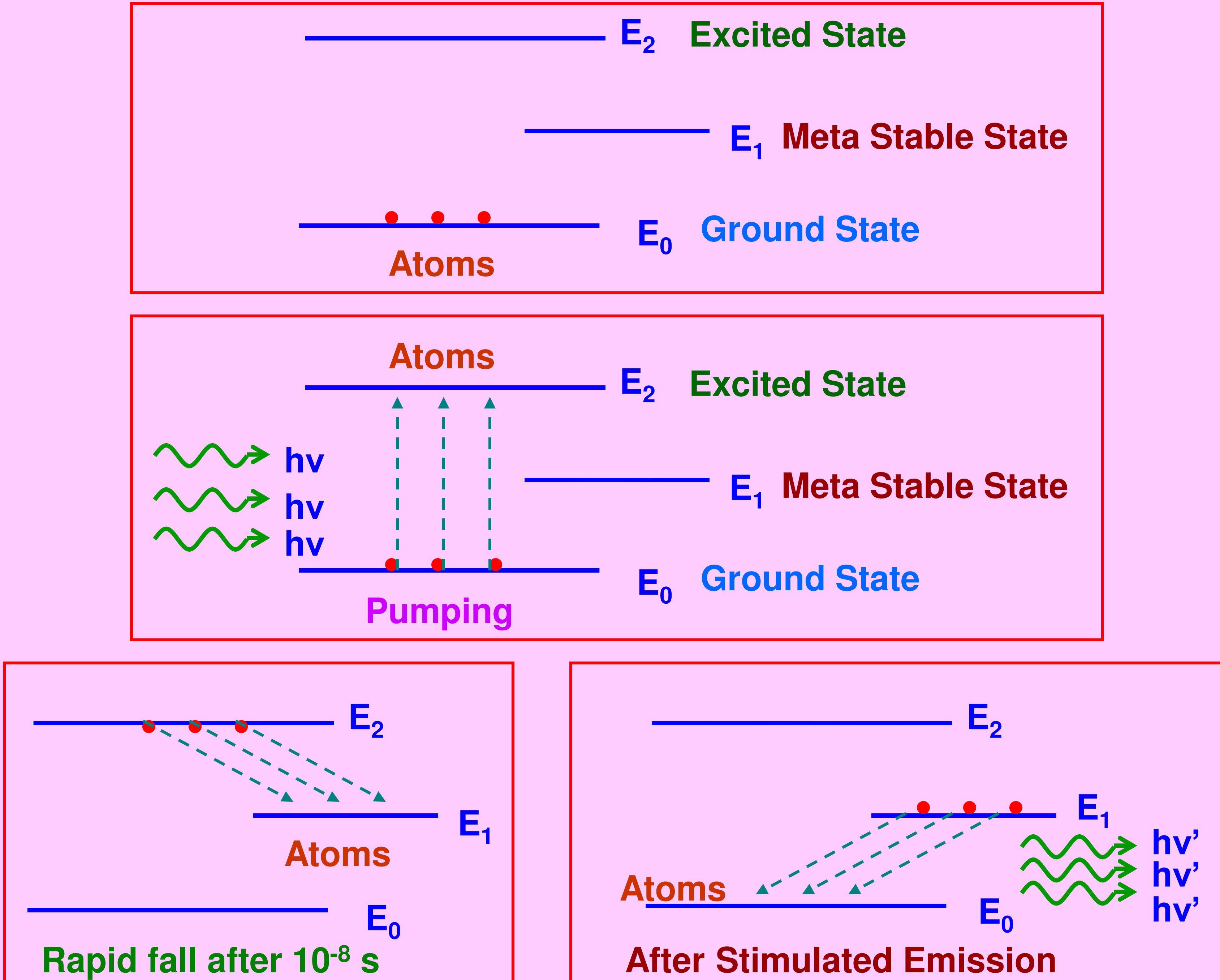
As $E_j > E_i$, $N_j < N_i$

To emit photons which are coherent (in same phase), the number of atoms in the higher energy state must be greater than that in the ground state (lower energy).

The process of making population of atoms in the higher energy state more than that in the lower energy state is known as 'population inversion'.

The method by which a population inversion is affected is called 'optical pumping'. In this process atoms are raised to an excited state by injecting into system photon of frequency different from the stimulating frequency.

Population inversion can be understood with the help of 3-energy level atomic systems.


E2
Excited State
E1
Meta Stable State
E0
Ground State
Atoms
Atoms
E2
Excited State
hv
hv
hv
E1
Meta Stable State
E0
Ground State
Pumping
E2
E1
Atoms
E0
Rapid fall after 10-8 s
E2
E1
hv'
hv'
hv'
Atoms
E0
After Stimulated Emission

In the figures, E_0, E_1 and E_2 represent ground state, meta-stable state (temporarily stable state) and excited state respectively.

The atoms by induced absorption reach excited state E_2 from E_0. They stay there only for 10^{-8} seconds.

After this time they fall to met-stable state where they stay for quite a longer time (10^{-3} seconds). Within this longer time more number of atoms get collected in the meta-stable state which is large than that at lower energy level. Thus population inversion is achieved.

In atomic systems such as chromium, neon, etc, meta-stable states exist.

Three Components of Laser Devices:

1. **The Pump:** It is an external source which supplies energy to obtain population inversion. The pump can be optical, electrical or thermal.
   In Ruby Laser, we use optical pumping and in He - Ne Laser, we use electric discharge pumping.

2. **The Laser Medium:** It is material in which the laser action is made to take place. It may be solid, liquid or gas. The very important characteristic requirement for the medium is that optical inversion should be possible in it.

3. **The Resonator:** It consists of a pair of plane or spherical mirrors having common principal axis. The reflection coefficient of one of the mirrors is very near to 1 and that of the other is kept less than 1. The resonator is basically a feed-back device, that directs the photons back and forth through the laser medium.

Principle of Laser:

An atomic system having one or two **meta-stable states** is chosen. Normally, the number of atoms in the lower energy state is greater than that in the meta-stable state.

This population is inverted by a technique known as **optical pumping**. It is made induced absorption of incident photons of suitable frequency.

The atoms are made to fall from meta-stable state to lower energy state and photons are emitted by **stimulated emission**.

The photons are reflected back and forth in the active medium to excite the other atoms.

Thus a large number of photons are emitted simultaneously which possess the same energy, phase and direction. This process is called 'amplification of light'.

To produce laser beam, the following two conditions must be fulfilled:

1. The meta-stable state should all the time have larger number of atoms than the number of atoms in lower energy state.
2. The photons emitted due to stimulated emission should stimulate other atoms to multiply the photons in the active medium.

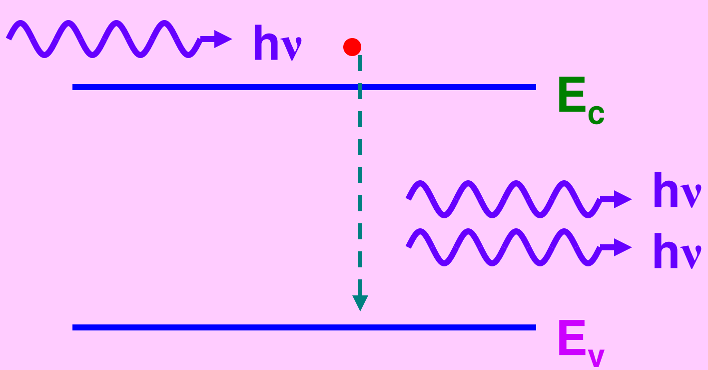
Diode Laser:

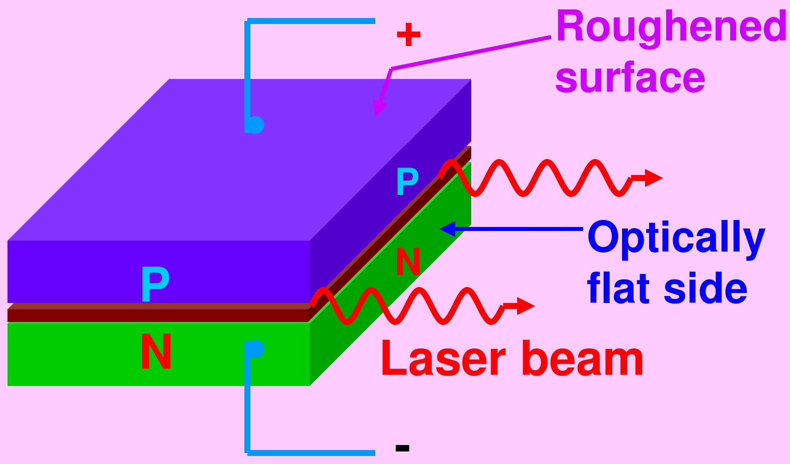
Laser Diode is an interesting variant of LED in which its special construction help to produce stimulated radiation as in laser.

In conventional solid state or gas laser, discrete atomic energy levels are involved whereas in semiconductor lasers, the transitions are associated with the energy bands.

In forward biased p-n junction of LED, the higher energy level (conduction band) is more populated than the lower energy level (valence band), which is the primary requirement for the population inversion.

When a photon of energy $h\nu = E_g$ impinges the device, while it is still in the excited state due to the applied bias, the system is immediately stimulated to make its transition to the valence band and gives an additional photon of energy $h\nu$ which is in phase with the incident photon.





The perpendicular to the plane of the junction are polished. The remaining sides of the diode are roughened.

When a forward bias is applied, a current flows. Initially at low current, there is spontaneous emission (as in LED) in all the directions. Further, as the bias is increased, a threshold current is reached at which the stimulated emission occurs.

Due to the plane polished surfaces, the stimulated radiation in the plane perpendicular to the depletion layer builds up due to multiple reflections in the cavity formed by these surfaces and a highly directional coherent radiation is emitted.

Diode lasers are low power lasers used as optical light source in optical communication.

Characteristics of Laser Light:

1. Laser light is highly directional.

   A laser beam departs from strict plarallelism only because of diffraction effects. Light from other sources can be made into an approximately parallel beam by a lens or a mirror, but the beam divergence is much greater than for laser light.

2. **Laser light is highly coherent.**

Wave trains for laser light may be several hundred kilometre long. Interference fringes can be set up by combining two beams that have followed separate paths whose lengths differ by as much as this amount. The corresponding coherence length for light from a tungsten filament lamp or a gas discharge tube is typically considerably less than 1 m.

3. **Laser light is highly monochromatic.**

Tungsten light, spread over a continuous spectrum, gives us no basis for comparison. The light from selected lines in a gas discharge tube, however, can have wavelengths in the visible region that are precise to about 1 part in 10^6. The sharpness of laser light can easily be thousand times greater, or 1 part in 10^9.

4. **Laser light can be sharply focussed.** Flux densities for focussed laser light of 10^{15} W cm^{-2} are readily achieved. An oxyacetylene flame, by contrast, has a flux density of only 10^3 W cm^{-2}.

5. **Tuning:** Some lasers can be used to emit radiation over a range of wavelengths. Laser tunability leads to applications in photochemistry, high resolution and Raman spectroscopy.

6. **Brightness:** The primary characteristic of laser radiation is that lasers have a higher brightness than any other light source. Brightness is defined as the power emitted per unit area per unit solid angle.

Applications of Laser Light:

1. The smallest lasers used for telephone communication over optical fibres have as their active medium a semiconducting gallium arsenide crystal about the size of the pin-head.
2. The lasers are used for laser fusion research. They can generate pulses of laser light of 10^{-10} s duration which have a power level of 10^{14} W.
3. It is used for drilling tiny holes in diamonds for drawing fine wires.
4. It is used in precision surveying.
5. It is used for cutting cloth (50 layers at a time, with no frayed edges).
6. It is used in precise fluid-flow velocity measurements using the Doppler effect.
7. It is used precise length measurements by interferometry.
8. It is used in the generation of holograms.
9. It is used to measure the x, y and z co-ordinates of a point by laser interference techniques with a precision of $\pm$ 2 x 10^{-8} m. It is used in measuring the dimensions of special three-dimensional gauges which, in turn are used to check the dimensional accuracy of machine parts.
10. Medical applications: It has been used successfully in the treatment of detached retinas and cancer. A single pulse of laser beam of duration of a thousandth of a second only is needed for welding the retina.

Elementary Principles of Light Modulation:

Suppose we increase / decrease the amplitude of an electromagnetic wave passing though an ionised gas. These modulations can contain coded information.

If we add sine waves of different frequencies, but close to each other, the sine waves would get increasingly out of phase with each other.

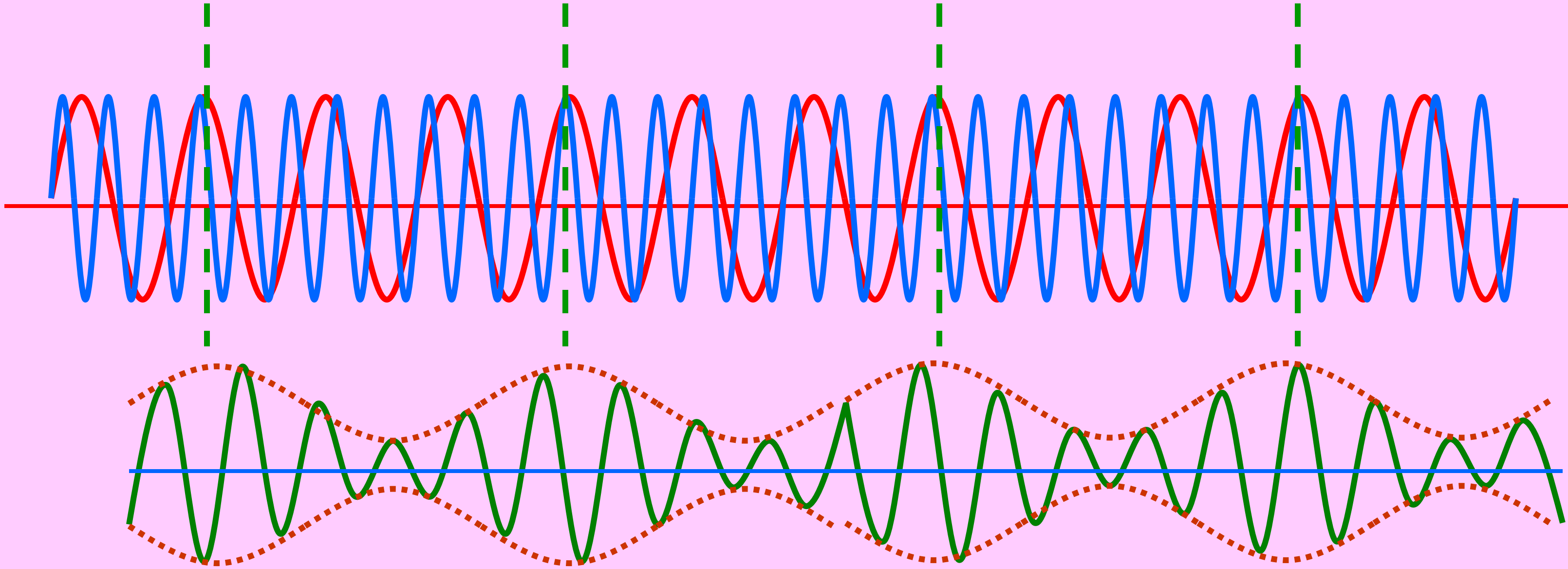
The simplest case would be the sum of two equal sine waves of frequencies ω_1 and ω_2.

The sum of the waves is given by

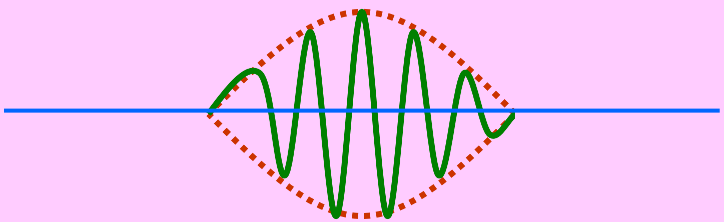
$$S(t) = \cos(\omega' + \Delta\omega)\, t + \cos(\omega' - \Delta\omega)\, t$$

where $\omega' = (\omega_1 + \omega_2) / 2$ and $\Delta\omega = (\omega_1 - \omega_2) / 2$

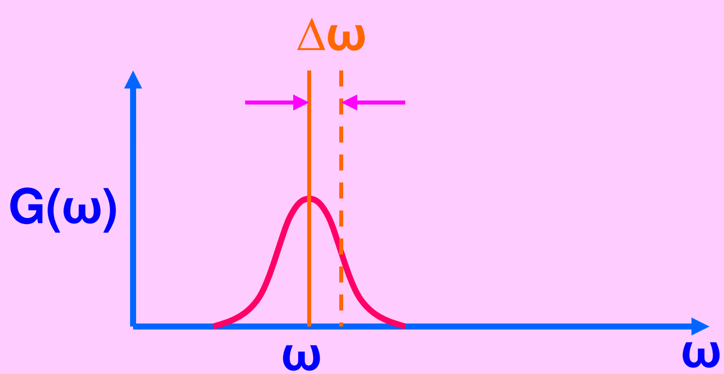
$S(t) = A(t) \cos \omega' t$ where $A(t) = 2 \cos (\Delta\omega)\, t$



The sum of two sine waves of slightly different frequency



The sum of an infinite number of sine waves



End of Principles of Communication