EE 407
Microwave Engineering

Lecture 1 & 2

Introduction to Microwave Engineering and EM wave Propagation

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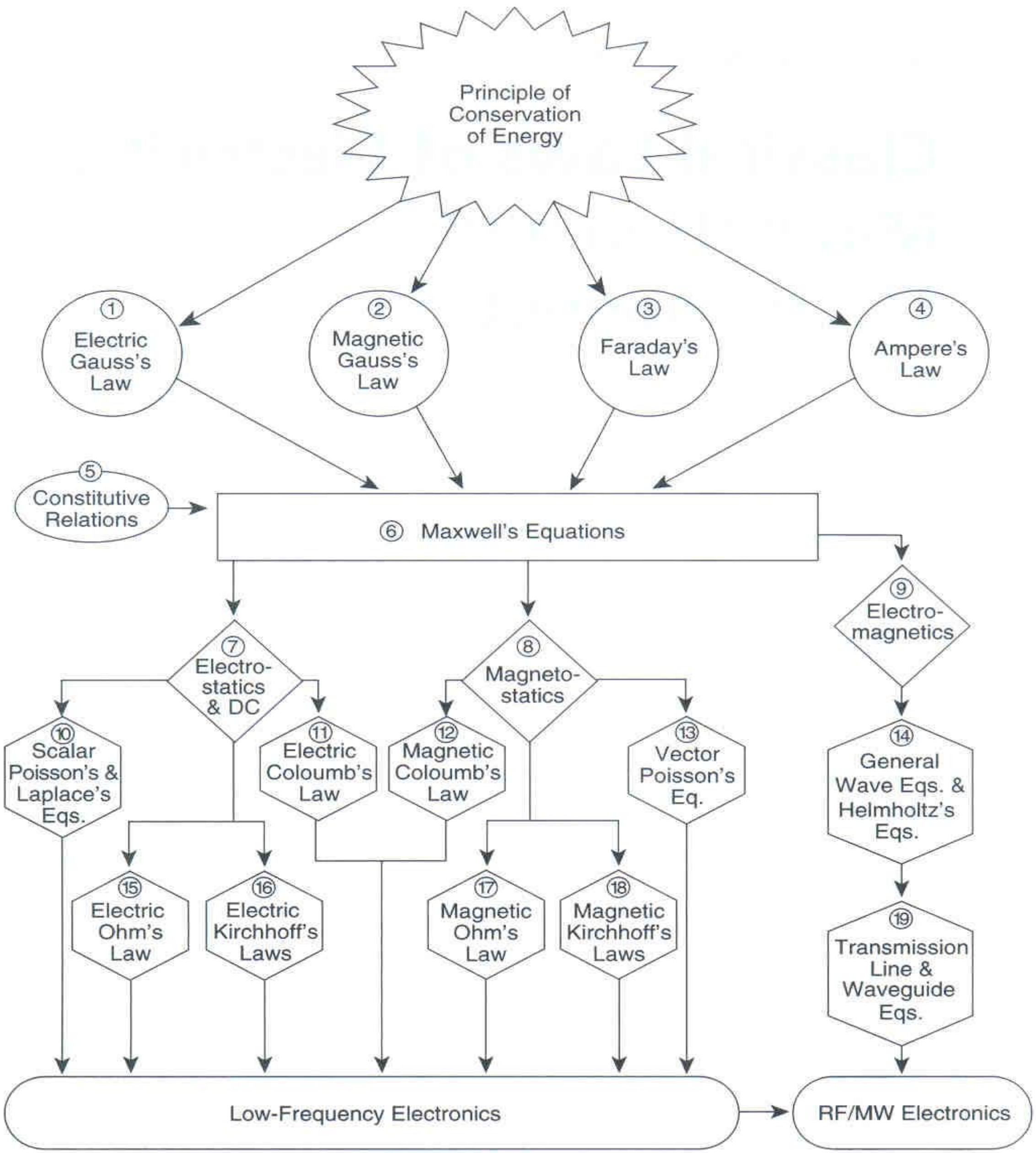
References: Text books

Laws of Electricity and Magnetism



1. E. flux & enclosed charge
2. M.flux & enclosed charge
3. EMF induced $\propto$ time varying magnetic flux
4. DC current flow generate H.flux
5. $D=\varepsilon E$; $B=\mu H$; $J=\sigma E$
6. Behavior of EM fields/wave
7. Static E.field (char. capacitor)
8. Static M.field (magnet/DC 'I')
9. E.field->M.field->E.field->..
10. Potential function in charged region & free-space
11. Force bet. charged particles
12. Force between Mag. Poles
13. Mag. potetial function due to current distribution.
14. Time varying fields/waves
15. Linear resistor law
16. Voltage and current law
17. Linear reluctance law
18. Magnetic flux & MMF laws
19. Time harmonic fields/waves

Maxwell's equations

- For **Static fields** ($\delta/\delta t=0$) Maxwell's equations are:

  $\nabla \bullet \underline{D} = \rho$; $\nabla \bullet \underline{B} = 0$; $\nabla \times \underline{E} = 0$; $\nabla \times \underline{H} = \underline{J}$;

  where, $\underline{D} = \varepsilon \, \underline{E}$ and $\underline{B} = \mu \, \underline{H}$ (ρ, $\underline{J}$ *are the charge, current Densities*)

- For **Time varying fields** Maxwell's equations are:

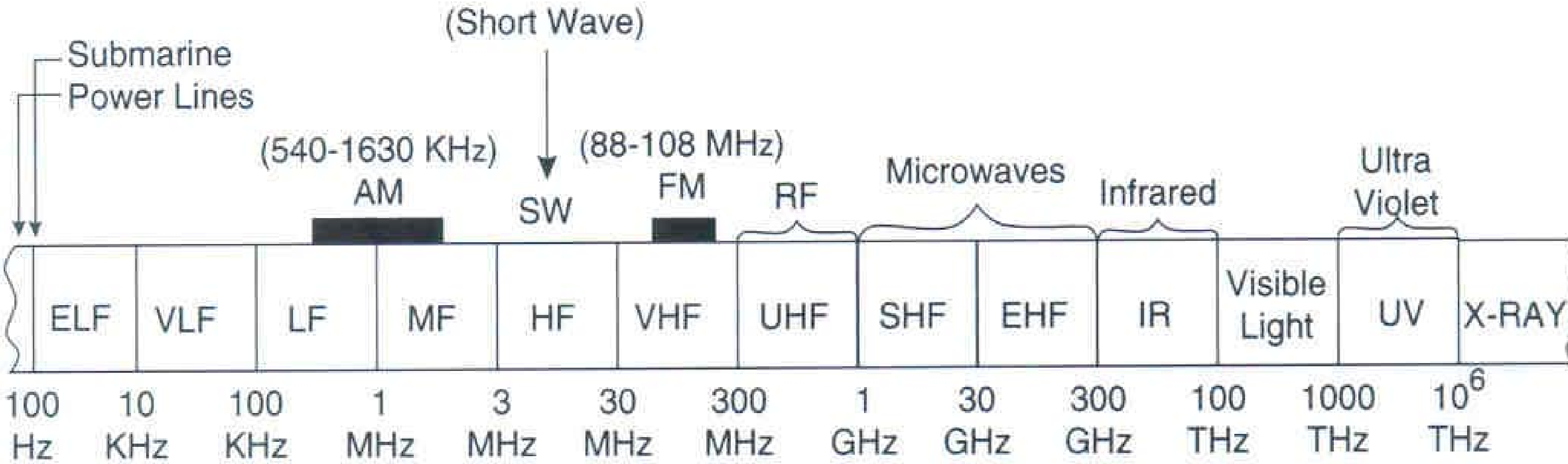
  $\nabla \bullet \underline{D} = \rho$; $\nabla \bullet \underline{B} = 0$; $\nabla \times \underline{E} = - \delta\underline{B}/\delta t$; $\nabla \times \underline{H} = \underline{J} + \delta\underline{D}/\delta t$;

- o Faradays Law ($\nabla \times \underline{E} = - \delta\underline{B}/\delta t$) shows that time-varying magnetic field ($\delta\underline{B}/\delta t$) is a source of electric field ($\underline{E}$).
- o Ampere's Law ($\nabla\times\underline{H}=\underline{J}+\delta\underline{D}/\delta t$) shows that both electric-current ($\underline{J}$) or time-varying E-field ($\delta D/\delta t$) are sources for the magnetic field (H).

- Thus, in source-free region ($\rho=0$ and $\underline{J}=0$), time varying electric and magnetic fields can generate each other.

- Consequently, EM fields are self sustaining, thus predicting the phenomenon of EM wave propagation.

Electromagnetic (EM) signal spectrum:



Signal wavelength, $\lambda=\lambda_0 /\sqrt{(\varepsilon_r\mu_r)}$; $\lambda_0=c/f$; velocity, $v=c /\sqrt{(\varepsilon_r\mu_r)}$ and $\beta=\omega/v$

RF/MW versus DC/Low-AC signals: **MW engg.?**

- In LF, mostly $l<<\lambda$, thus I & V are constant in line. (l=device length)

  In HF, mostly $l>>\lambda$, thus I & V are not constant in the line.
- Unwanted HF affects of component insulating-shell & wire-lead
- Current distribution within the conductor [Skin Depth, $\delta_s=\sqrt{(2/\omega\mu\sigma)}$ and Surface resistance, $R_s=1/(\delta_s\sigma)=\sqrt{(\omega\mu/2\sigma)}$]

A few reasons for using RF/Microwaves:

- Wider bandwidth due to higher frequency
- Smaller component size leading to smaller systems
- More available frequency spectrum with low interference.
- Better resolution for radars due to smaller wavelengths
- High antenna gain possible in a smaller space

Some Disadvantages in using RF/Microwaves:

- More expensive components
- Existence of higher signal losses
- Use of high-speed semiconductor devices

RF/Microwave Applications :

- Medical: Imaging, selective heating, sterilization etc.
- Domestic/industrial: Cooking, traffic & toll management, sensor

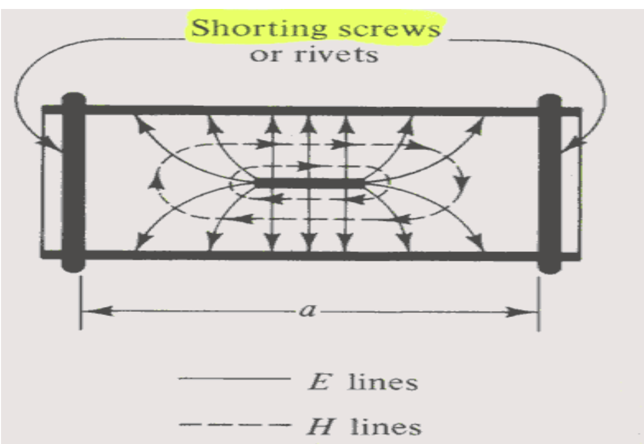
- Surveillance: Electronic warfare, security system etc.
- Radar: Air defense, guided weapon, collision avoidance, weather
- Astronomy & Space exploration: Monitor and collect data.
- Communication: Satellite, Space, Long distance telephone, etc

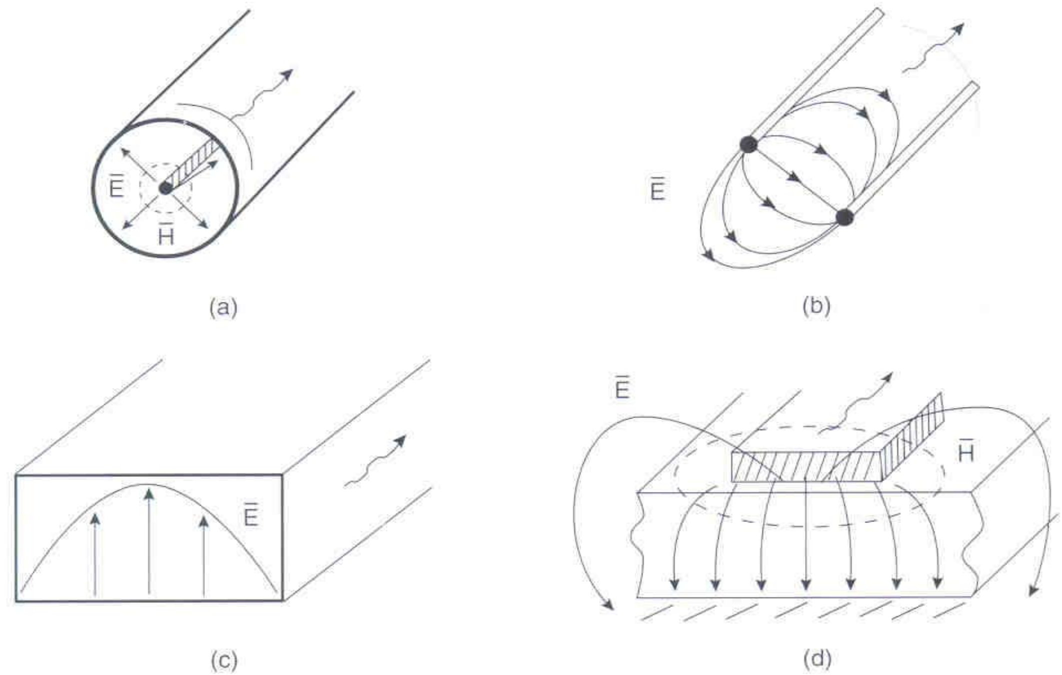
Introduction to RF/Microwave Communication:

- In 1960's: Microwave was 1st used for wireless communication between Europe and America. It required repeater stations for approximately every 30 to 50 miles .
- In 1970~1980's: Fiber-optic link was introduced and repeaters were used for approximately every 2000 miles.
- In 1990's: Microwave Satellite links were introduced. The High-orbit and Low-orbit satellites were used since then.

Guided Transmission Media

- Coaxial TL: Low radiation, freq. range up to 3GHz, support TEM mode
- Two-wire TL: Low radiation, freq. up to 300 MHz, support TEM mode
- Waveguide: For high freq./power signals, Support **TE/TM** modes.
- Microstrip: Losy, quasi-TEM modes, high bandwidth, easy integration
- Stripline: Less losy, **TEM**, high bandwidth, low power capacity, Fair’’

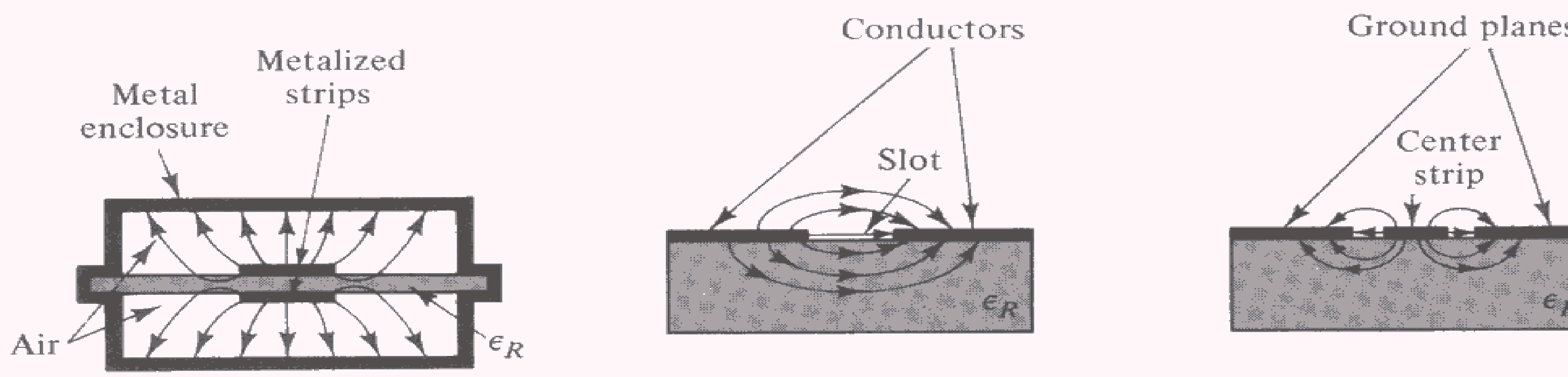




TEM: E.& H.field comp. are ⊥ to each other and also to direc. of prop.

More on guided Transmission Media

- Suspended-substrate stripline, easy for device integration.
- Slot line: very useful for specific applications.
- Coplanar line: Conductor and GND is in the same plane



(a) Suspended-substrate stripline (b) Slot line (c) Coplanar line

Feature	Coaxial	Stripline	Microstrip	Waveguide
1.) Propagating Mode	Main: TEM Other: TM, TE	Main: TEM Other: TM, TE	Main: Quasi-TEM Other: TM, TE	Main: TE_{10} Other: TM, TE
2.) Dispersion	None	None	Low	Medium
3.) Bandwidth	High	High	High	Low
4.) Power loss	Medium	High	High	Low
5.) Power capacity	Medium	Low	Low	High
6.) Size	Large	Medium	Small	Large
7.) Ease of fabrication	Medium	Easy	Easy	Medium
8.) Ease of integration	Hard	Fair	Easy	Hard

Free space propagation (Plane Waves)

- Plane wave fronts (**circular**, **spherical** **or** **rectangular** **plane**)
- Uniform Plane wave; E & H fields are uniform in plane-wave-front.
- P.Wave conditions; $\delta \underline{E}/\delta x = \delta \underline{E}/\delta y = \delta \underline{H}/\delta x = \delta \underline{H}/\delta y = 0$ *(as prop in z-dir)*
- Solution of Maxwell's equations for a uniform plane wave in a source-free-region results in the expressions of $\underline{E}$ & $\underline{H}$ field intensities as;
  $E_x = E_o\, e^{(j\omega t-\gamma z)} = E_o \cos(\omega t-\beta z)$ ***OR*** $H_y = H_o\, e^{(j\omega t-\gamma z)} = H_o \cos(\omega t-\beta z)$;
  where E_o & H_o are E & H field magnitudes; $\gamma = \alpha + j\beta = j\omega\sqrt{\varepsilon\mu}$ *$\{as\ \alpha = 0\}$*
- Plane waves in air/vacuum ($\varepsilon_r = \mu_r = 1$) ; the phase constant $\beta_o = \omega\sqrt{\varepsilon_o \mu_o}$; the intrinsic wave impedance $\eta_o = E_o/H_o = \sqrt{\mu_o/\varepsilon_o} = 377\Omega$ *$\{\lambda_o = 2\pi/\beta_o = c/f\}$*

Basic characteristics of uniform plane wave in a source free region ;

(a) There is **no E or H field** component along the direction of prop. (z)

(b) Two pairs of the $\underline{E}$ & $\underline{H}$ fields $\{(E_x, H_y)$ *OR* $(H_x, E_y)\}$ produces two independent plane waves, which can exist and propagate by itself.

(c) E and H field components are always ⊥ to each other; (E_x,H_y) or (H_x,E_y)

(d) Ratio of E and H field components are constant (intrinsic wave imp)

If reflection of the wave occurs due to some obstacles in the propagating path: **Standing wave** is generated from incident and reflected waves.

Polarization of waves : Polarization of wave depends on magnitude and phase relationship between existing E-field components (E_x and E_y)

Linear polarization occurs when E_x and/or E_y are in phase regardless of their relative magnitudes(**direction** of L.P. wave is the same as E- field)

E-field of a L.P. EM wave: $\mathbf{\underline{E}}(z,t) = [A\,\underline{a}_x + B\,\underline{a}_y] \cos(\omega t - \beta z - \phi)$

Circular polarization occurs when E_x & E_y are out of phase by 90° but both components have equal magnitude. E-fields of a L.P. EM wave are:

$E_x = A \cos(\omega t + \phi_y + \pi/2 + \beta z)$ and $E_y = A \cos(\omega t + \phi_y + \beta z)$

Elliptical polarization occurs when E_x and E_y are out of phase by 90° and both components have different magnitudes. E-fields of E.P. wave:

$$E_x = A\cos(\omega t + \phi_y + \pi/2 + \beta z) \quad \text{and} \quad E_y = B\cos(\omega t + \phi_y + \beta z)$$

Example: use a probe to measure E & H fields of L. polarized EM wave

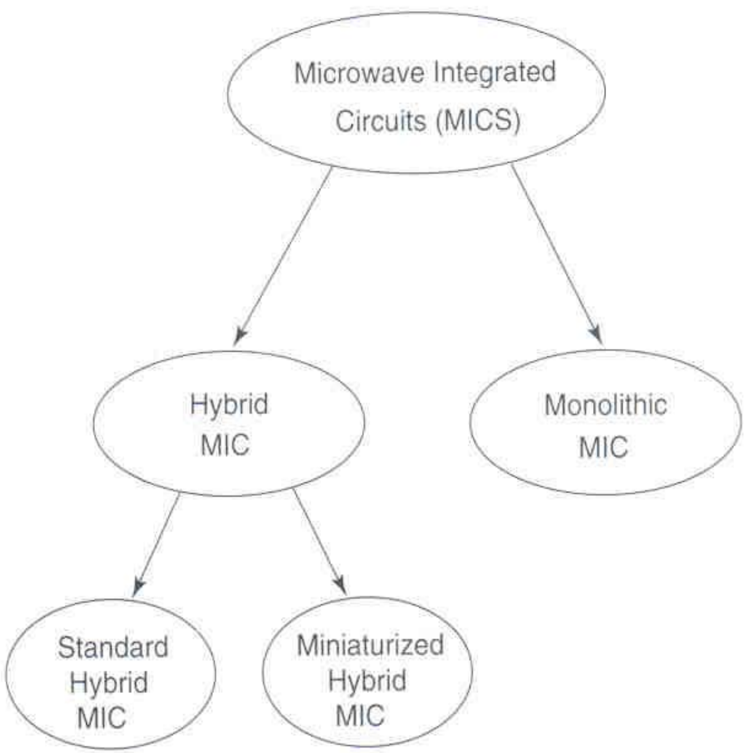
- EM wave propagation and attenuation : Use two horn antennas, one connected with the source (mW power and 9GHz) and the other one is connected with a speaker (load). By moving the receiving Horns, we can show the power radiation pattern of the load (attinu. and main-loab)

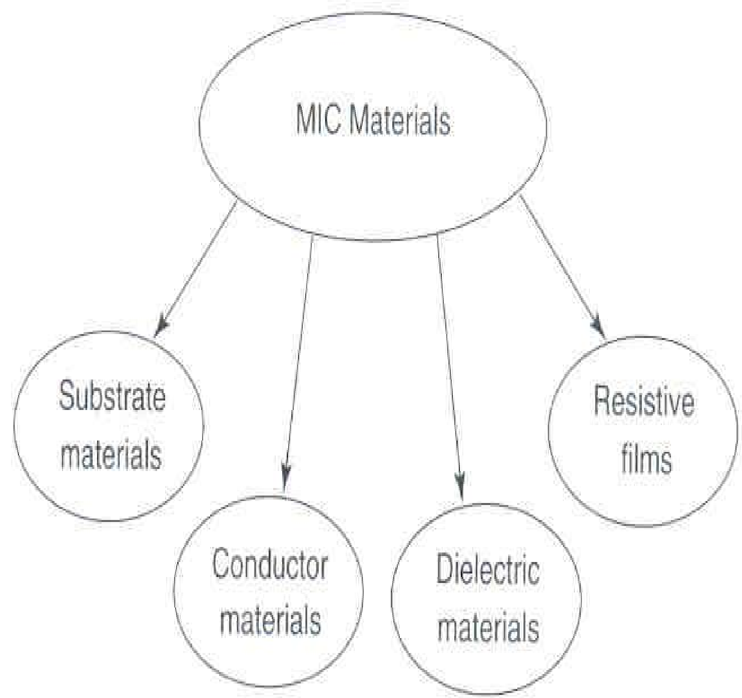
- Reflection of EM wave: Microwave reflects from metal plates with a reflected wave angle equal to the incident wave angle. This is due to the acceleration of the free electrons in the metal (caused by the incident EM wave), which in-turn produce a EM wave traveling away from the metal plate (called reflected EM wave). Since in a semiconductor material, the amount of free electrons are less, less amount of reflection occurs and more incident EM wave is absorbed.

-Interference in EM wave propagation :The constructive and destructive interference in the receiver is shown (~height of the receiver)

- Guided EM wave propagation: in rectangular waveguide: correct guide size is important for guiding EM waves properly.

Microwave Integrated Circuits (MICs):





Microwave frequency bands Designation Frequency range

- **L band 1 to 2 GHz**
- **S band 2 to 4 GHz**
- **C band 4 to 8 GHz**
- **X band 8 to 12 GHz**
- **Ku band 12 to 18 GHz**
- **K band 18 to 26.5 GHz**
- **Ka band 26.5 to 40 GHz**
- **Q band 30 to 50 GHz**
- **U band 40 to 60 GHz**
- **V band 50 to 75 GHz**
- **E band 60 to 90 GHz**
- **W band 75 to 110 GHz**
- **F band 90 to 140 GHz and D band 110 to 170 GHz**