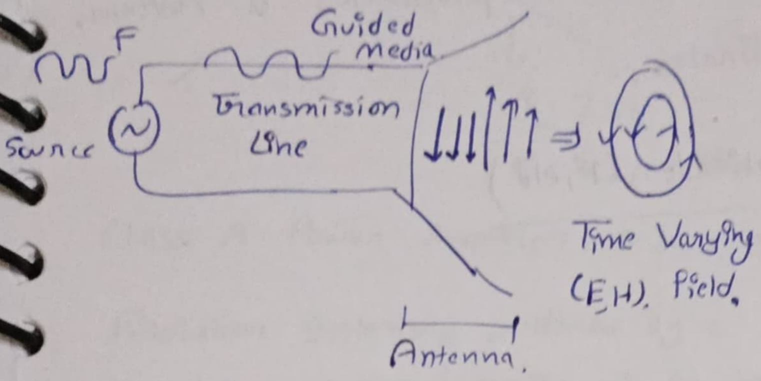
Antenna & Propagation

Wave

→ What is an Antenna?

→ It is a metallic device used to transmit or recieve waves
electromagnetic



Mid Term	30
End Term	50
Class Work & Presentation	10 + 10.

2 Books

→ Balanis → John Wiley (Antennas)

→ Antenna → John D Krauss ~~Meg~~ Mc Graw Hill.

→ wave travels in coaxial cable as E or H ~~plan~~ waves.

→ Antenna Converts guided wave to unguided wave (free space/ wireless)

→ Same antenna works as Transmitted & Reciever.

① Wire Antenna
- ↳ Monopole
- ↳ Dipole
- ↳ Helical Ant..
- ↳ Loop Ante...

② Apertura Antenna
- ↳ Reflector ,,
- ↳ Horn ,,
  - Circular
  - Rectangular

③ Microstrip ↓ Mobile, WiFi

④ Array

⑤ Lens Antenna ↳ Millimeter wave

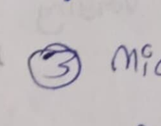
→ Any Antenna has to have impedance matching to prevent reflection and Standing wave Formation.

→ Why Radiation ~~A~~ Happen?

$I_z = q_e V_z$

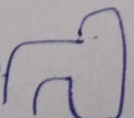
$\frac{e\,dI_z}{dt} = l\,q_e \frac{dV_z}{dt}$ (Charge accele or decceleration ↳ Responsible for Radiation)

Impedance of Dipole



$Z = 73 + j41.5\,\Omega$

Yagi Antenna



→ No charges or charges with const velocity → No radiation.

→ Microstrip Antennas → Mobile, WiFi

Wave Propagation
→ K. D. Prasad

→ Phased Array Antenna

→ Graphical representation of the radiation properties of Antenna with respective to space coordinates.

→ Power Flux Density Amplitude (Field)

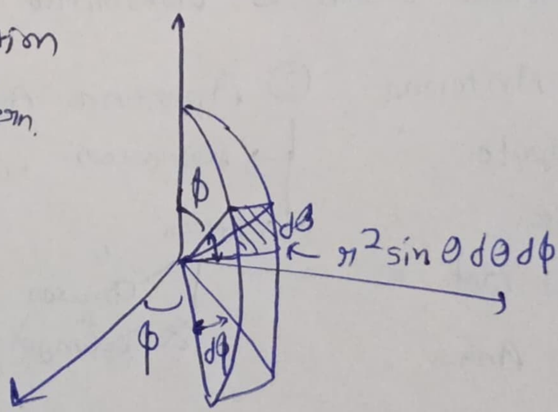
→ Polarization

→ Phase

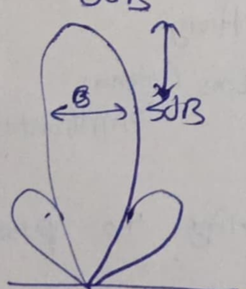
→ Spherical coordinates are used for radiation pattern.

→ r θ constant, ϕ varying → called Azimuthal radiation pattern.

ϕ const, θ varying → Elevation radiation pattern.



→ Beam width



HPBW

FNBW
First Null Band width.

Never happens.

Equal radiation in all directions

① Isotropic

Equal Radiation in one plane ← ② Omnidirectional

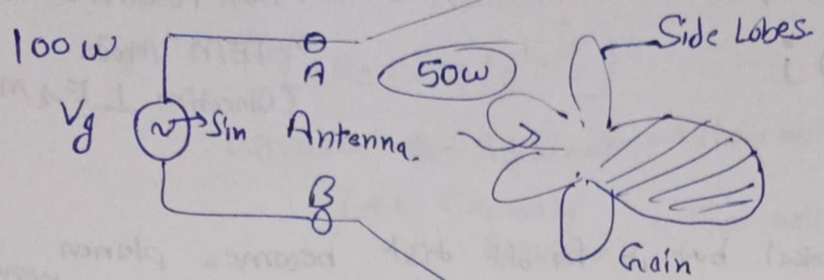
③ Directional
↓
Radiates in a particular direction

Gain :-

1. Reactive Field
2. Near Field
3. Far Field

↓

Radiation Pattern remains constant irrespective of distance.



Gain

$G = \frac{V_o}{V_i}$

Find gain at maximum radiation direction

↓

R_L 25%

R_V 25%. (Radiation)

Class A Power Amplifier → 25% efficiency.

Radiation Intensity produced by a antenna at maximum radiation direction by the radiation Intensity of a test antenna with same Input power

$$G = \frac{4\pi U}{P_{in}}$$

17 chapter of Balanis (Measurement).

Gain of Dipole antenna → 1.5 - 2.1 dB. ~~1.2 - 2.1 dB~~

Horn " → 12–25 dB

$$(G_{ot})_{dB} + (G_{or})_{dB} = 20\log \frac{4\pi R}{\lambda} + 10\log\left(\frac{P_r}{P_t}\right)$$

$(G_{ot})_{dB}$ → Gain of Transmitter

$(G_{or})_{dB}$ → Gain of reciever

R → Dist b/w Antennas

λ → Operating wavelength

$$(G_T)_{dB} = (G_S)_{dB} + 10\log\left(\frac{P_T}{P_S}\right)$$

P_T → Test Antenna

P_S → ~~[illegible]~~/Standard.

→ Power meter → Borometer or Holometer (Based on heat)

→ For high Freq measurement

Horn & Dipole Antenna → Linearly Polarized ← Yagi Antenna

$$\vec{E} = E_0 \cos(\omega t - kz)\ \hat{i}$$

$$\vec{H} = H_0 \cos(\omega t - kz)\ \hat{j}$$

$$\frac{E_0}{H_0} = \mu C.$$

Sunlight
→ Non Polarized
→ TEM mode
(Direction ⊥ E & M)

→ Initially wave is spherical but at far-off dist becomes planar wave

→ Polarization property is found based on the curve traced by the wave when moving away from Observer.

Eg Linear, Elliptical

Linear ↓ Oscillations are only in 1 plane

$\phi_x - \phi_y = n\pi$

Elliptical ↘ $\phi_y - \phi_x = (\frac{1}{2} + n)$ CW

$-(\frac{1}{2} + n)$ CCW

$E_x = E_y$ (Trace out Circle)

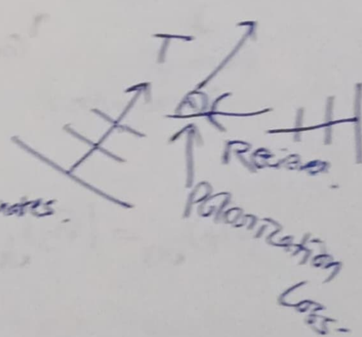
else elliptical

→ Station has vertical polarization because earth is a conductor and tan $\vec{E} = 0$

→ Satellite Communicate → Elliptical or Circular polarization, Cant use Linear polarization due to atmosphere.

→ By varying the power difference, phase can be varied to produce elliptical polarization

→ Poincare Sphere



$$\rightarrow E = \{ \hat{a}_\theta E_\theta + \hat{a}_\phi E_\phi \} e^{j\omega t} \quad (r, \theta, \phi)$$

↳ Spherical Coordinates.

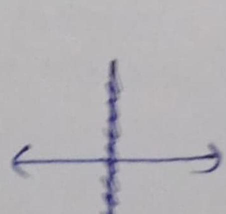
$E_\theta = Ae^{j\alpha}$, $E_\phi = Be^{j\beta}$

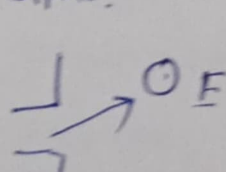
$$= Re\{ E_0 Ae^{j\alpha} e^{j\omega t} + Be^{j\beta} e^{j\omega t} \}$$

$$E = \frac{jn\, I_0 e^{j\alpha}\, dl \sin\theta}{4\pi} \frac{e^{-jkr}}{r}$$

(Linearly polarized)

→ Electric field produced by a vertical dipole.





$\vec{E} = a_\theta + j a_\phi$

→ ? Find Polarization ← SOME PROBLEMS REGARDING THIS.

$Re[(a_\theta + j a_\phi) e^{j\omega t}]$

$a_\theta \cos\omega t - a_\phi \sin\omega t$ → How will this expression move with time? That will provide its polarization

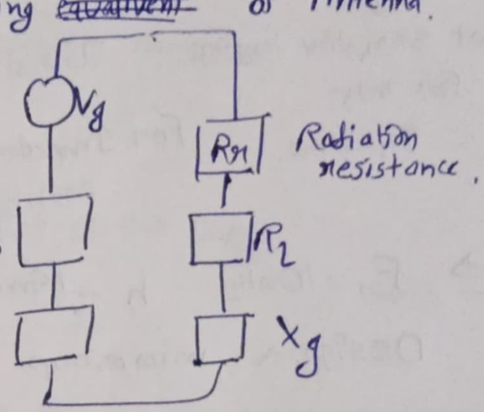
Left Circularly Polarized.

→ Bandwidth of Antennas:

→ Bandwidth is finite due to the parasitic capacitances, (In Amplifiers).

→ When Frequency Increases, X_g changes so impedance matching is disturbed
↓
More reflection.
(Less Power Transferred)
↓
Gain Changing
(Thus B.W is finite).

Thevening ~~equivalent~~ equivalent of Antenna.



→ If any parameter changes, so till it remains in an admissible limit

→ Horn Antenna has maximum Bandwidth (1 to 40 - 50 GHz).

→ Dish Antenna → 1 GHz - 40 GHz

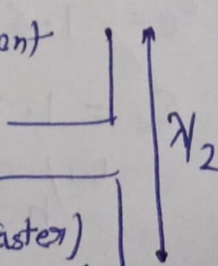
Sometimes Bandwidth is defined in percent →

$$B.W = \frac{f_U - f_L}{f_0} \times 100\%.$$

f_0 ↳ Resonance Frequency.
(Frequency at which circuit has maximum gain).

→ FM channel B.W (200 kHz)
$\beta = 5$

Mobile Antenna, Dipole is resonant Antenna

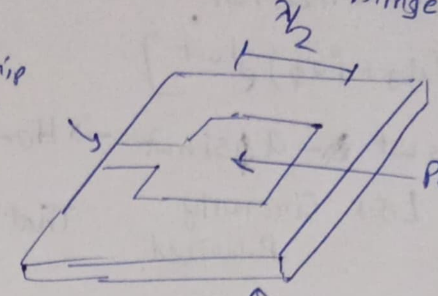


→ Information carrying capacity depends on B.W.
(Thats why optical comm. is faster)

Microstrip Antenna :

Responsible for radiation in Microstrip Antenna

fringe field



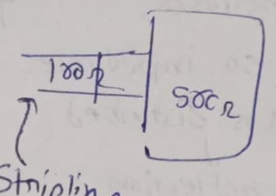
$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2}$$

$\sqrt{100 \times 500}$

Get stripline length for this impedance.

Quarter wave Transformer

For Impedance Matching.



→ $f_r = 10GHz$ $h = 15mm$ $\varepsilon_r = 2.2$ $L = \lambda/2$

Design a microstrip antenna using these

$$W = \frac{V_0}{2f_r}\sqrt{\frac{1}{1+\varepsilon_r}} \qquad V_0 = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

$$\frac{\Delta L}{h} = \frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.259)\left(\frac{W}{h} + 0.8\right)} \times 0.412$$

$$W = \frac{3\times 10^8}{2\times 10\times 10^9}\sqrt{\frac{1}{1+2.2}} = 8.385\times 10^{-3}$$

$$\varepsilon_e = 1.6 + 0.6\left(1 + \frac{12\times 15\times 10^{-3}}{8.385\times 10^{-3}}\right)^{-1/2}$$

$$\varepsilon_e = 1.726$$

$$W/h = \frac{8.385\times 10^{-3}}{15\times 10^{-3}} = 0.559$$

$$\frac{\Delta L}{15\times 10^{-3}} = \frac{(1.726+0.3)(0.559+0.264)}{(1.726-0.259)(0.559+0.8)} \times 0.412$$

$\Delta L = 5.168 \times 10^{-3}$

$L_{EFF} = L + 2\Delta L$

$Y_1 = G_1 + jB_1$

$Y_2 = G_2 + jB_2$

→ Poynting vector represents real power.

$Y = 2G_1 (R) = \frac{1}{2}$

$G_1 = \frac{2 P_{rad}}{V_0^2}$

↳ Voltage Generated Across Slot.

→ Transmission Line Model

→ Analytical Method

↳ Certain assumptions to simplify things

→ Numerical Method / Rigorous Model

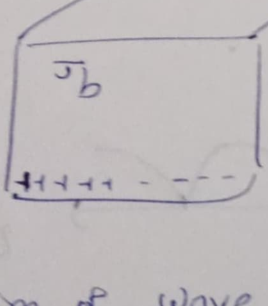
↳ CST, HFSS

① Method of moments
② Finite elemental metric
③ Integral Method.

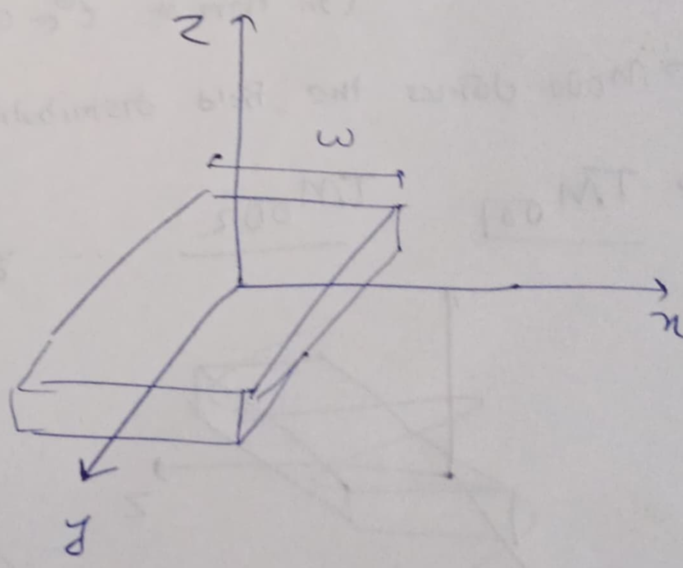
Out of our scope.

→ Cavity Model

$E_i \; E_j \; E_k \quad H_i \; H_j \; H_k$



tangential electric Field 0. (on metal).



→ Solution of wave Equation

$E_x = \frac{-j}{}\left(\frac{\partial^2}{\partial H} + k^2\right) A_x$ Generalized soln in terms of sin, cos.

$E_y =$ 〃

$E_z =$ 〃

Use boundary condition to solve equations.

E_y ($x=0$ $0 \le y \le L$ $0 \le z \le w$] $= 0$ → Gives $A_1 = 0$

Similarly for H_y and all that.

$$A_x = A_1 \cos k_x x + B_1 \sin k_x x$$

$$k^2 = k_x^2 + k_y^2 + k_z^2 = \omega^2 \mu \varepsilon$$

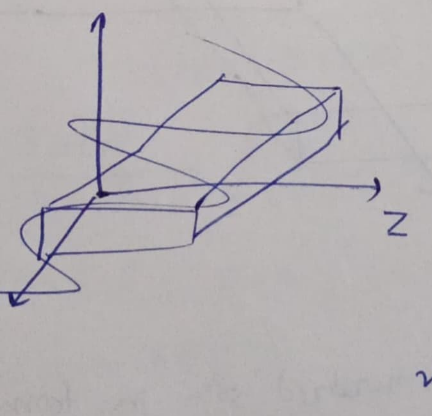
$$(2\pi f)^2 \mu \varepsilon$$

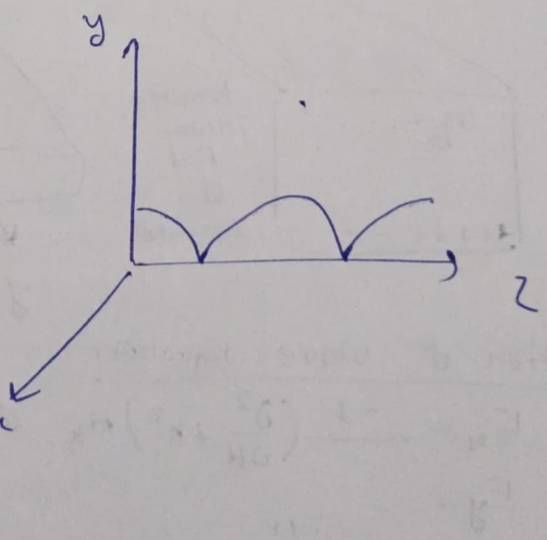
$$f_T = \frac{1}{2\pi\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{L}\right)^2 +}$$

→ Based on this we have modes.

- → Dominant mode operates at lowest frequency.
- → Only the imaginary part moves in waveguide
  ↓ (In form of $e^{j\theta}$ ← contains oscillation which get propagated through waveguide
- → Mode defines the field distribution.

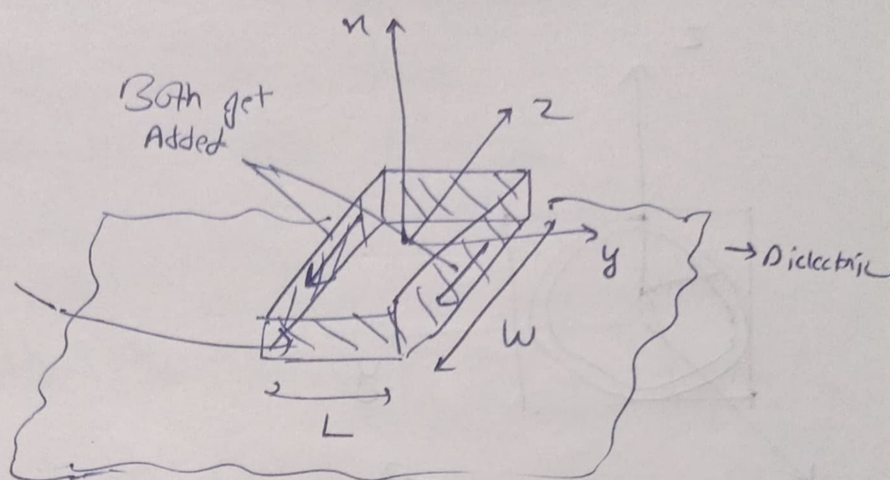
→ <u>TM_{001}</u> <u>TM_{002}</u>





what is the reason behind radiation ?

Cavity Model : Equivalent Current Density :-



E-plane

H-plane

Electric current Density $J_s = \hat{n} \times H_a$

Magnetic field in Slot

xy plane → E plane

xz plane → H plane.

Magnetic Current Density $M_s = -\hat{n} \times E_a$

→ Current across edges is very small thus $J_s = \hat{n} \times H_a = 0$

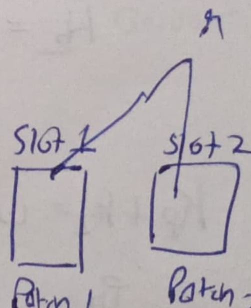
$E_r = E_\theta = 0$

$$E_\phi = +j \frac{k_0 h w E_0 e^{-jkr}}{2\pi r} \left[\sin\theta \frac{\sin X}{X} \frac{\sin Z}{Z} \right]$$

Dist.

$X = \frac{k_0 h}{2} \sin\theta \cos\phi.$

$Z = \frac{k_0 w}{2} \cos\phi.$



Array Factor $= 2\cos\left(\frac{k_0 L_e}{2} \sin\theta \sin\phi\right)$ [If suppose there are 2 slots]

Resultant $E = E_\phi \times$ Array Factor

E-plane

↳ $0 \le \phi \le 90°$

$270 \le \phi \le 360°$

H-plane

$\phi = 0$

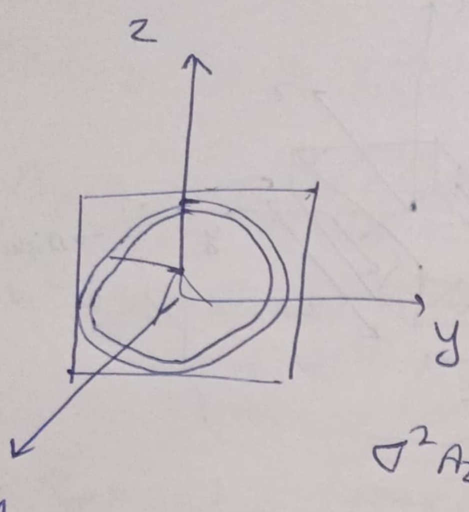
$0° \le \theta \le 180°$

* Circular Patch

→ Circular Microstrip Antenna.

10) Biomedical Antenna.
(Cancer Detection).

10-15 page report.
15 days before end term.
Presentation.



$$\nabla^2 A_z(\rho,\phi,z) + k^2 A_z(\rho,\phi,z) = 0.$$

$$E_\rho = \frac{-j}{\omega\mu\varepsilon} \frac{\partial^2 A_z}{\partial\rho\,\partial z} \qquad E_z = \frac{-j}{\omega\mu\varepsilon}\left(\frac{\partial^2}{\partial z^2} + k^2\right) A_z$$

$$E_\phi = \frac{-j}{\omega\mu\varepsilon} \frac{\partial^2 A_z}{\partial\rho\,\partial z}$$

Bessel Function.

$$H_\rho = \frac{-1}{\mu}\frac{1}{\rho}\frac{\partial A_z}{\partial\phi} \qquad A_z = B_{mnp} J_m(k_\rho \rho')$$

$$H_\phi = \frac{1}{\mu}\frac{\partial A_z}{\partial\rho} \qquad (A_2 \cos m\phi + B_2 \sin m\phi')$$

$$\cos(k_z z')$$

$$H_z = 0.$$

Boundary Conditions.
$$\left\{\begin{array}{l} E_\rho(0 \le \rho \le a,\ 0 \le \phi < 2\pi,\ z=0) = 0. \\ E_\phi(\qquad) = 0 \\ H_\phi(\qquad) = 0. \end{array}\right.$$

$$K_\rho + k_z = \omega^2\mu\varepsilon$$

$$f_r = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\left(\frac{X_{mn}}{a}\right)$$

Zeros of the derivative of the Bessel Function.

$$X'_{11} = 1.8412$$

$$X_{21} = 3$$

High Frequency → Losses ↑↑ → Efficiency ↓↓

BW → 5 - 7%.

→ What is the band of Frequency that the cell phone operates on ?

5G operates at < 6GHz . .   2G at 950MHz.

3G at 1.8-2.1 GHz.

→ How to Increase the Bandwidth ?

→ If antenna bandwidth is more, ∴ can send more information.

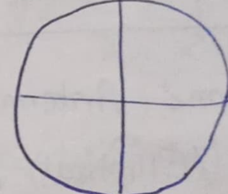
magnetic current density $M_s = -2\hat{n} \times \vec{E}_a \Big|_{a=a_i} = 2\hat{\phi} E_0 [J'_{0z}] \cos\phi'$

$$f = \frac{V_0}{2\pi\sqrt{\epsilon_r}}\left(\frac{\chi'_{mn}}{a}\right)$$

$E_r = 0, \; E_\phi = 0$

$$E_\theta = j\frac{2a_e V_0 e^{-jkr}}{2r} J_{02}$$

E plane $\phi = 0, 180°$ $0 \le \theta \le 90$



$E_\theta = 0$

$$E_\phi = j\frac{2a_e V_0 e^{jkr}}{2r} J_{02}$$

Everything From Balanis

$\phi = 270°, 360°, \; 0 \le \theta \le 90$

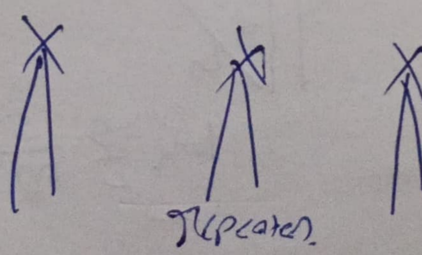
Television 1970 ← Terrestrial Transmission.

Yagi Uda Antenna

Translated to english

1920

Line of Sight Communication

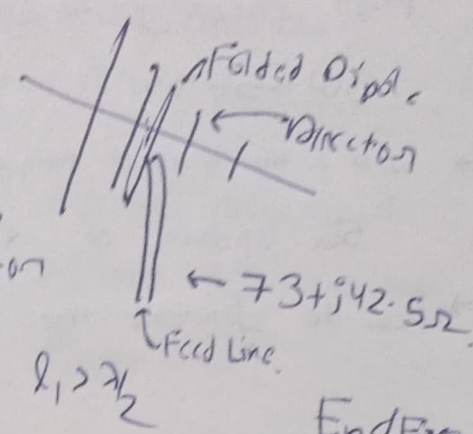


Repeater

Broad Side radiation → Perpendicular to Plane.

↑

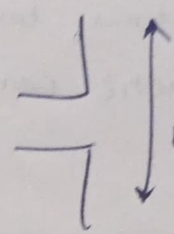
Microstrip Antenna radiation



Minimum impedance of cable available during time of Yagi Antenna was 250Ω

→ Impedance when Folded dipole gets $n^2 \times$ Impedance
↳ No. of folds

End Fire radiation



→ Folded dipole has better directivity.

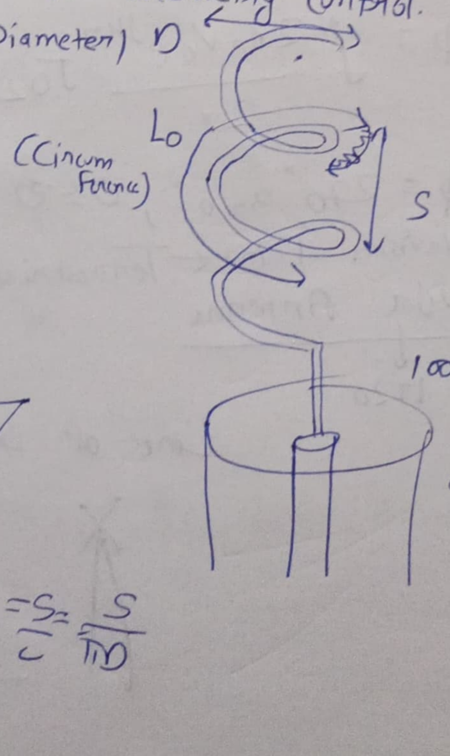
Gain of Dipole → 1.5

G = efficiency × Directivity
↳ Gain.

* Helical Antenna

→ Broadband Antenna
→ Circular / Elliptical / Linear polarization
→ Early sattelites used this antenna for telemetry control.

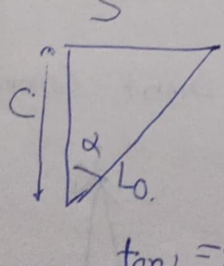
→ Normal Mode
$NL_0 < \lambda$
No. of turns ↙ ↳ Length of wire.



100 to 200 cm

Gain is around 10-12dB

→ End fire
$NL_0 \sim \lambda$



$\alpha = 90°$ ⇒ Wire Antenna

$\alpha = 0°$ ⇒ Loop Antenna.

$\tan\alpha = \frac{S}{C} = \frac{S}{\pi D}$

$$E_\theta = \frac{jy\, k I_o e^{-jkr} \sin\theta}{4\pi r}$$

$$E_\phi = \frac{\eta k^2 (a/2)^2 I_o e^{-jkr} \sin\theta}{4\pi r}$$

Not in same phase but quadrature.

When two electric fields are 90° then we have circular polarization (elliptical.

$$\frac{E_\theta}{E_\phi} = \frac{2\lambda S}{(\pi D)^2} = 1$$ ← If 1 the implies circular polarization

$$\Rightarrow C = \sqrt{2\lambda S}$$

→ End Fire is normally used in radiation

→ ~~Used~~ Range 100 MHz to 2000 MHz

→ Ground Plane → metalized surface at other side of PCB.

→ In end direction, radiation is along the axis and

$$3 < \frac{C}{\lambda} < \frac{\lambda}{4}$$

→ why this 90 phase difference?

$$HPBW = 52\, \lambda_0^{3/2}$$

Directivity (Gain)

$$D_0 = 15N\frac{C^2}{\lambda^2}$$

$$FNBW = \frac{115\lambda^{3/2}}{C\sqrt{NS}}$$

$$G = \eta \times D$$

η → Efficiency

$$AR = \frac{2N+1}{2N}$$

(Axial Ratio) → Parameter to level of polarization.

Feed Value $= E = \sin(\pi/2N)$

$\cos\theta \cdot \sin(\psi N \cos\theta)$

$$\psi = k_0 l \cos\theta - \frac{f_0}{R}$$

→ All formulas are in book.

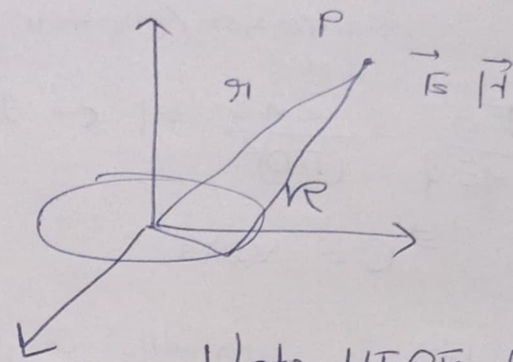
$P =$

Neccesary condition for end ~~dire~~ fire radiation

$kd\cos\theta + \beta = 0$

$kd = \pm\beta$

→ Hansen-wood



→ Calculate Polarization, Gain, Directivity etc

30-40%. Numericals

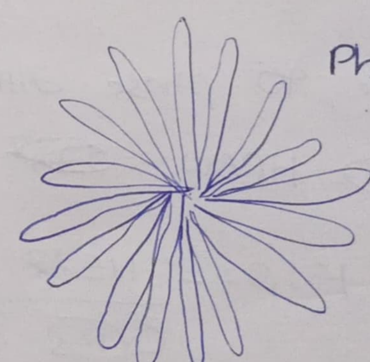
Upto HERE Midterm

---

* Array:

Linear, Circular, Polygonal.

→ Necessary to increase Gain, Beamwidth
↳ Scanning. Better



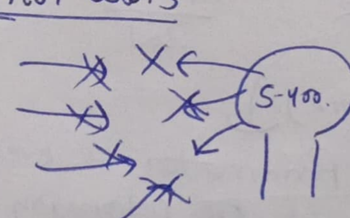
Phased Array Antenna.

→ Electronic warfare

→ Fixed beam array (Produce beam in fixed direction)

1. Geometric Configuration
2. Seperation b/w elements
3. Phase b/w elements
4. Input Amplitude.
5. Element (Antenna) Radiation properties.

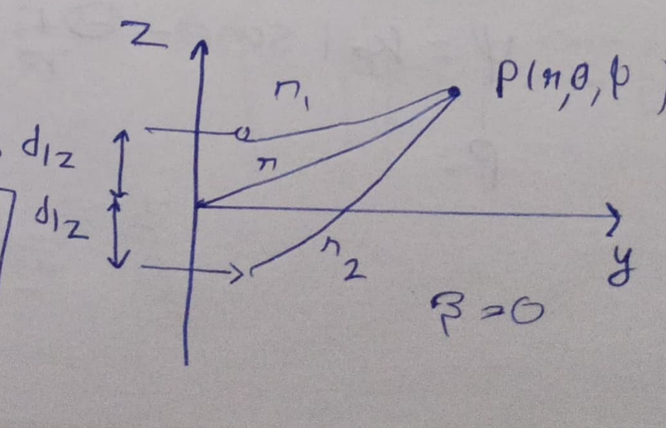
Star wars



$$E_t = E_1 + E_2$$

$$= \hat{a}_\theta \frac{j\eta k I_0 l}{4\pi}\left[e^{-j(kr_1 - \beta/2)}\cos\theta_1 + e^{-j(kr_2 + \beta/2)}\cos\theta_2\right]$$

For dipole there is only E_θ, H_ϕ.



$r_1 = r - \frac{d}{2}\cos\theta$

$\theta_1 \simeq \theta_2$

$r_2 = r + \frac{d}{2}\cos\theta$

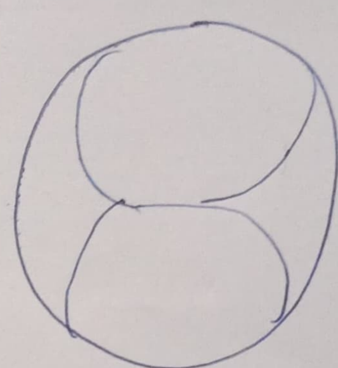
$$e^{-j\left(kr - \frac{kd\cos\theta}{2} - \beta_r\right)} + e^{-j\left(kr + \frac{kd\cos\theta}{2} + \beta_r\right)}$$

By substituting we get

$$= \underbrace{a_\theta[\quad]\cos\theta}_{\text{Represent single element radiation}} \times \underbrace{\cos\left[\frac{1}{2}(kd\cos\theta + \beta)\right]}_{\text{Array factor}}$$

Let $d = \lambda/4$, $\beta = 0$

$$= a_{\hat\theta}[\quad]\cos\theta\cos\left(\frac{\pi}{4}\cos\theta\right)$$

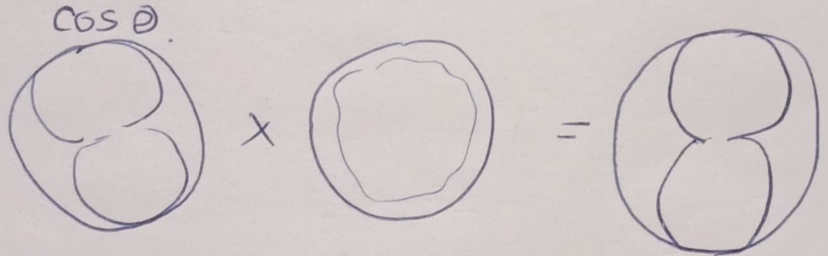


Minima

$\frac{\pi}{4}\cos\theta = \pi/2$ (for zero)

$\boxed{\cos\theta = 2} \to$ Not Possible

$\cos\theta$.



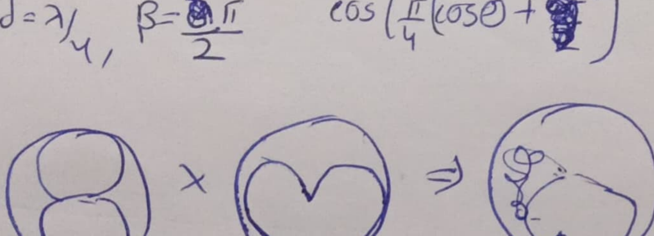
Individual element radiation   Array factor.

Let $d = \lambda/4$, $\beta = \frac{\pi}{2}$ $\cos\left[\frac{\pi}{4}(\cos\theta + 1)\right]$

$\frac{\pi}{4}(\cos\theta + 1) = \frac{\pi}{2}$

$\cos\theta = 1$

$\theta = 0$ ← Minima at $\theta = 0$.



Only lower

$\beta = -\frac{\pi}{2}$

$\frac{\pi}{4}(\cos\theta - 1) = \frac{\pi}{2}$

$\cos\theta = 3$

$\frac{\pi}{4}(\cos\theta - 1) = -\frac{\pi}{2}$

$\cos\theta = -1$

$\boxed{\theta = 180}$

→ Two Element Array

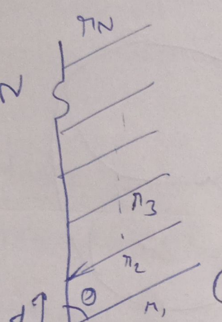
Array Factor

$$E_t = \hat{a}_0 \frac{\eta k I_0 l e^{-jkr}}{4\pi r} \cos\theta \cos\left[\frac{1}{2}(kd\cos\theta + \beta)\right]$$

↓

Corresponding to Single element

→ N-element Uniform Array



$$AF = 1 + e^{j(kd\cos\theta + \beta)} + e^{2j(kd\cos\theta + \beta)} + \dots - e^{j(N-1)(kd\cos\theta + \beta)}$$

Array Factor

(1) – $AF = 1 + e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots e^{j(N-1)\psi}$

(2) – $e^{j\psi} AF = e^{j\psi} + e^{2j\psi} + \dots e^{jN\psi}$ (Multiply Both Sides by $e^{j\psi}$)

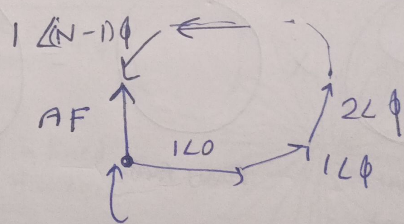
Subtract (1) from (2).

~~$(1 - e^{j\psi}) AF = ||$~~

$e^{j\psi} AF - AF = e^{jN\psi} - 1$

$AF(e^{j\psi} - 1) = e^{jN\psi} - 1$

$$\boxed{AF = \frac{e^{jN\psi} - 1}{e^{j\psi} - 1}}$$



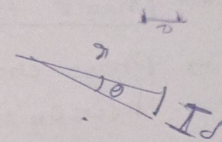
They are vectorly added to give AF (Array Factor).

$$AF = \frac{e^{j\frac{N\psi}{2}}}{e^{j\frac{\psi}{2}}} \left[\frac{e^{j\frac{N\psi}{2}} - e^{-j\frac{N\psi}{2}}}{e^{j\frac{\psi}{2}} - e^{-j\frac{\psi}{2}}}\right] = e^{j(N-1)\frac{\psi}{2}} \left[\frac{\sin(N\psi/2)}{\sin(\psi/2)}\right]$$ → what kind of Pattern it is

where will be the minima of this AF.

$$AF \simeq \left(\frac{\sin N\psi/2}{N\psi/2}\right)$$ → Normalized (Approximately equal)

At $\psi = \infty$, minimal.



$\frac{N\psi}{2} = \pm n\pi$

$\psi = kd\cos\theta + \beta = \frac{\pm 2n\pi}{N}$

$\cos\theta = \frac{1}{kd}\left(-\beta \pm \frac{2n\pi}{N}\right)$

$\theta = \cos^{-1}\left(\frac{1}{kd}\left(-\beta \pm \frac{2n\pi}{N}\right)\right)$

$n \neq N, 2N, 3N$ ... → will become maxima

$n = 1, 2, 3, ...$

This kind of Array, find beam only (Produce Pattern in fixed direction).

① Broadside Array

② Endfire Array.

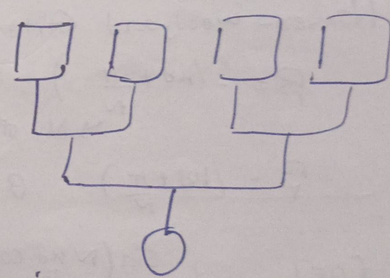
$kd\cos\theta + \beta = 0$ (For Broadside)

$\theta = 90°$

$0 + \beta = 0 \Rightarrow \beta = 0.$ → All elements have same phase angle

→ All ψ have same Path Difference so leading to same Phase.

as $\boxed{\frac{2\pi}{\lambda} \times \text{Path Diff.} = \phi.}$



~~$d\sin\theta$~~ λ

Endfire
- ~~Broadside~~ Array

$kd\cos\theta + \beta$ $\qquad$ $\theta = 0°$ as radiation in same direction

$kd + \beta = 0$

$\boxed{\beta = -kd}$

Separation

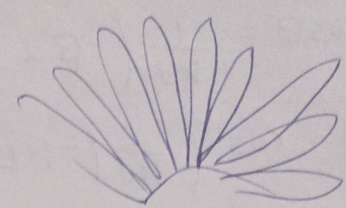
Propagation constant.

Phased Array Antenna

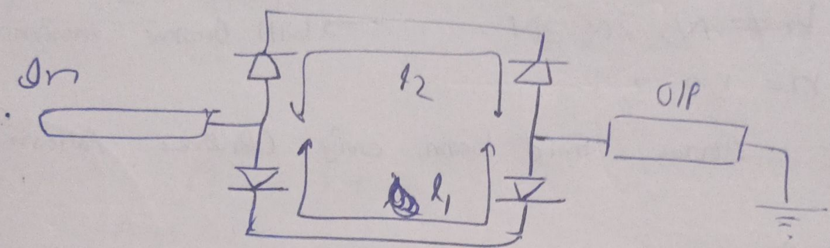
→ Phase changes continuously, Beam keeps on changing (like scanning).

$kd\cos\theta_n + \beta = 0.$

$\cos\theta_n = \frac{-\beta}{kd}$



$\phi = k(l_2 - l_1)$



→ N-element uniform array

→ Phased Array

→ Broadside Array ($\beta = 0$)

→ Endfire Array ($\beta = \pm kd$)

Hansen-woodyard Criteria

$\beta = -\left(kd + \frac{\pi}{N}\right) \quad \theta = 0$ → Gives Better Directivity

N → No. of elements

$\beta = \left(kd + \frac{\pi}{N}\right) \quad \theta = 180$

$$[AF]_n = \frac{1}{N} \frac{\sin\left(N\frac{kd}{2}\cos\theta + \beta\right)}{\sin\left(\frac{kd\cos\theta}{2} + \beta\right)}$$

$\beta = -pd.$

$$= \frac{\sin\left(\frac{Nkd}{2}\cos\theta - pd\right)}{\sin\left(\frac{kd}{2}\cos\theta - pd\right)} = \frac{\sin\left[\left(\frac{Nd}{2}\right)(k\cos\theta - p)\right]}{\frac{Nd}{2}(k\cos\theta - p)}$$

$q = \frac{Nd}{2}$

$$D = \frac{U_{max}}{U_0}, \quad U_0 = \frac{P_{rad}}{4\pi} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\left[\frac{\sin\left[q(\cos\theta - p)\right]}{q(k\cos\theta - p)}\right]^2 \sin\theta\, d\theta\, d\phi$$

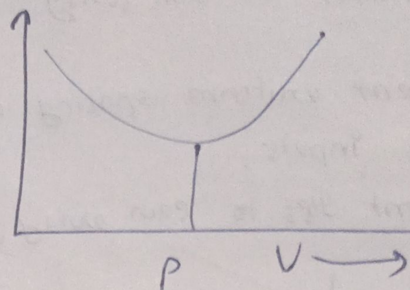
{General expression

$\theta = 0$ for maximum directivity (for endfire array).

$U_0 =$

$\frac{U}{U_0}$ → Maximum, U_0 needs to be minimum

Endfire characteristics will improve if we use Hansen woodyard criteria.



→ Broadside Array

$$AF \simeq \frac{\sin N\left(\frac{kd\cos\theta}{2}\right)}{\frac{Nkd\cos\theta}{2}}$$

$$D = \frac{U_{max}}{U_0} \qquad \theta = 90^\circ$$

$$U_0 = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\left[\frac{\sin Z}{Z}\right]^2 \sin\theta\, d\theta\, d\phi$$

$$\boxed{Z = \frac{Nkd\cos\theta}{2}} \qquad dZ = \frac{Nkd}{2}(-\sin\theta\, d\theta)$$

$$\frac{Nkd}{2} \qquad -\frac{Nkd}{2} \qquad d\theta = \frac{-2dZ}{Nkd}$$

$$U_0 = \frac{1}{4\pi}\int_0^{2\pi}\int_{-\frac{Nkd}{2}}^{+\frac{Nkd}{2}} \frac{+2dZ}{Nkd}\, dZ\, d\phi$$

$$= \frac{1}{2}\int_{-\frac{Nkd}{2}}^{+\frac{Nkd}{2}}\left[\frac{\sin Z}{Z}\right]^2 dZ$$

N is large

$$= \frac{1}{2}\int_{-\infty}^{\infty}\left(\frac{\sin Z}{Z}\right)^2 dZ$$

$$D \simeq \frac{Nkd}{\pi} = \frac{2Nd}{\lambda}$$

2M N-element array.

(3.4-5.6GHz) Reliable

5G → Massive MIMO

from Smiths 1024 (multiple i/p multiple o/p)

↓

Receiver 1024

Arrays :-

① Fixed Beam

② Phased Array

③ N Element Uniform array

Why Array ?

High Gain

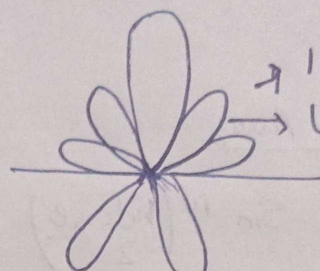
Beamwidth (Radiation Pattern).

Configuration

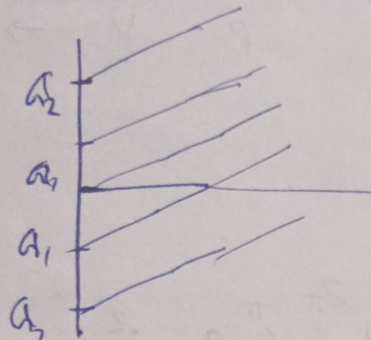
Reduced Sideband

→ N-element uniform spacing with non-uniform inputs.

→ Different i/ps to each array.



2M



$$[AF]_n = a_1 e^{\frac{jhd\cos\theta}{2}} + a_2 e^{\frac{3jhd\cos\theta}{2}} + a_- \text{———} \; a_{M-1} e^{j\frac{(n-1)}{2} hd\cos\theta}$$

$$+ a_1 e^{-\frac{jhd\cos\theta}{2}} + a_2 e^{-j\ldots}$$

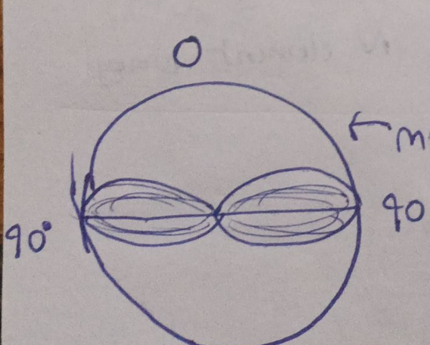
$$= 2\sum_{n=1}^{M} \cos\left(\frac{(2n-1)}{2} hd\cos\theta\right)$$

→ **Binomial Arrays :**

↳ Broadside Array

Calculate corresponding weight factors of different antennas in array.

m = 1	1
2	1 1
3	1 2 1
4	1 3 3 1
5	1 4 6 4 1



$d = \lambda/4$

$\lambda/2$

λ

$3\lambda/4$

More d, more side lobes
↓
Seperation

Dolph - Tschebyscheff (Non Uniform Array)

↓

Polynomial.

Eg. I want 10 element array then I will make use of 9th order Polynomial to calculate weights.

All Tschebyscheff polynomial pass through (1,1).

~~All values b/w +1 and -1.~~

<u>10 element</u>

$$[AF]_n = \sum_{n=1}^{5} a_n \cos((2m-1)u)$$

$u = \frac{\pi d \cos\theta}{\lambda}$

$$= a_1\cos u + a_2\cos 3u + a_3\cos 5u + a_4\cos 7u + a_5\cos 9u$$

$4\cos^3 u - 3\cos u$.

Substitute

Normalize.

$m=0 \quad \cos mu = 1$

$m=1 \quad \cos u \; - \; T_1(z)$

$m=2 \quad \cos 2u \; = 2\cos^2 u - 1$

$= 2z^2 - \; T_2(z)$

Substitute

$m=3 \quad \cos 3u =$

$$T_9(z) = 9z - 120z^3 + 432z^5 - 576z^7 + 256z^9$$

z_0 → How much seperation of sideband I want

Compare $[AF]_n$ and $(T_9)(z)$ to get the a_1, a_2 ---- values.

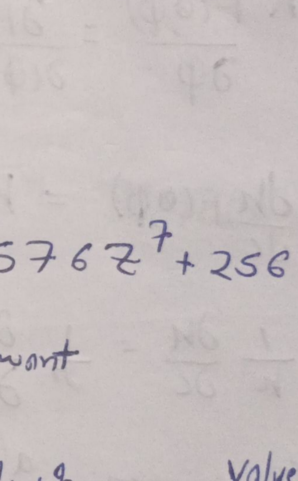
* Frequency Independent Antennas

↑BW (10MHz to 10000MHz) (2:1) ratio

10GHz.

↳ Lower cutoff

↳ Upper cutoff.



Most of the impedance of antenna is complex impedance, so if change freq → Impedance change → Matching changes → Antenna not performing as efficient.

In Frequency Independent Antennas you get 40:1 even 100:1

So larger range is covered.

Freq Indep. Antennas :

→ Antennas which are defined by angular configuration (θ,ϕ) rather than radial configuration (r).

$$r = F(\theta,\phi)$$

→ r is decreased by 1/2, f increased to 2f same thing, this is scaling ?

$$r' = kF(\theta,\phi)$$

$$kF(\theta,\phi) = F(\theta,\phi+c)$$ [To match both of them, to make em congruent]

$$\frac{dk}{dc}F(\theta,\phi) = \frac{\partial}{\partial(\phi+c)}F(\theta,\phi+c) \quad \text{— (1)}$$

Angle

$$k\frac{F(\theta,\phi)}{\partial\phi} = \frac{\partial F}{\partial(\phi+c)}(\theta,\phi+c) \quad \text{— (2)}$$

$$\frac{dk}{dc}F(\theta,\phi) = k\frac{F(\theta,\phi)}{\partial\phi}$$

$$\frac{1}{k}\frac{\partial k}{\partial c} = \frac{1}{r}\frac{\partial r}{\partial\phi}$$

Soln is $r = e^{a\phi}f(\theta)$

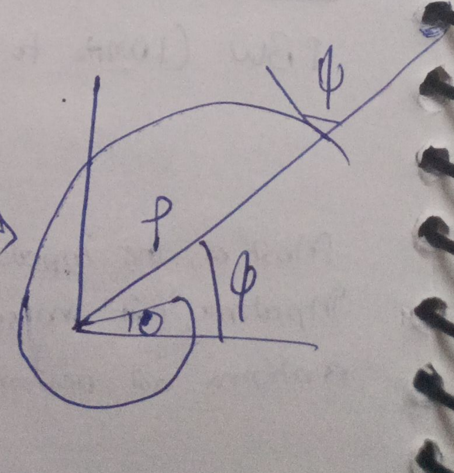
$$f' = A\delta(\pi/2 - \theta)$$

$\theta = \pi/2$

Equiangular antenna

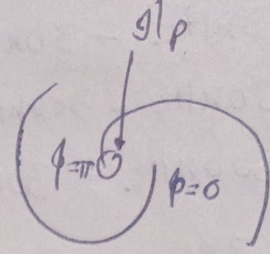
$$\frac{df}{d\theta} = f' = \begin{cases} A_e{}^{a\phi} & \theta = \pi/2 \\ 0 & \end{cases}$$

$$a = \frac{1}{k}\frac{dk}{dc}$$



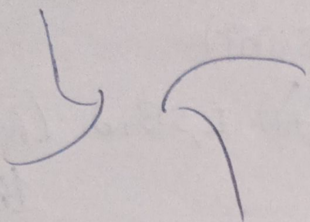
Prepare metal of spiral shape

Define spirals of different shapes, different ϕ's



Broadside radiation

Spiral.



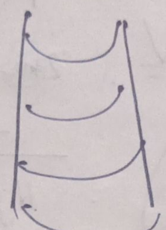
Planar Configuration

$G = 10dB$ (by doing this)

→ Conical Antenna

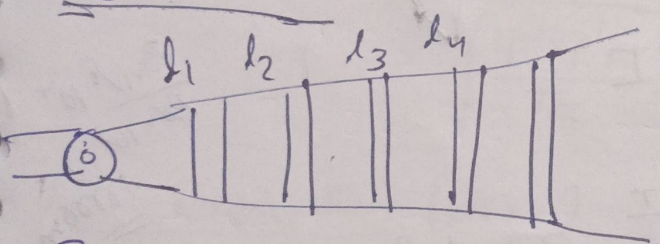
$$\boxed{f' = A\delta(\beta - \phi)}$$

β: 0 to π



3D Configuration

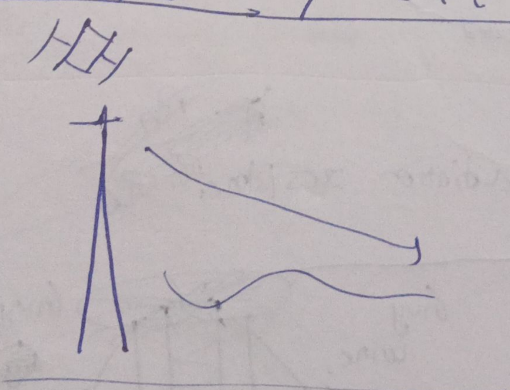
→ Log Periodic



FM - 88 - 108 MHz

→ Response is some log function of frequency.

* Signal Propogation / Wave Propogation



VLF → 3kHz – 30kHz (SONAR, Sea Communication, Navigation)

LF → 30kHz – 300kHz Low Bandwidth Applications

MF → 300kHz – 3000kHz AM, Broadcasting Applications

HF → 3MHz – 30MHz → FM

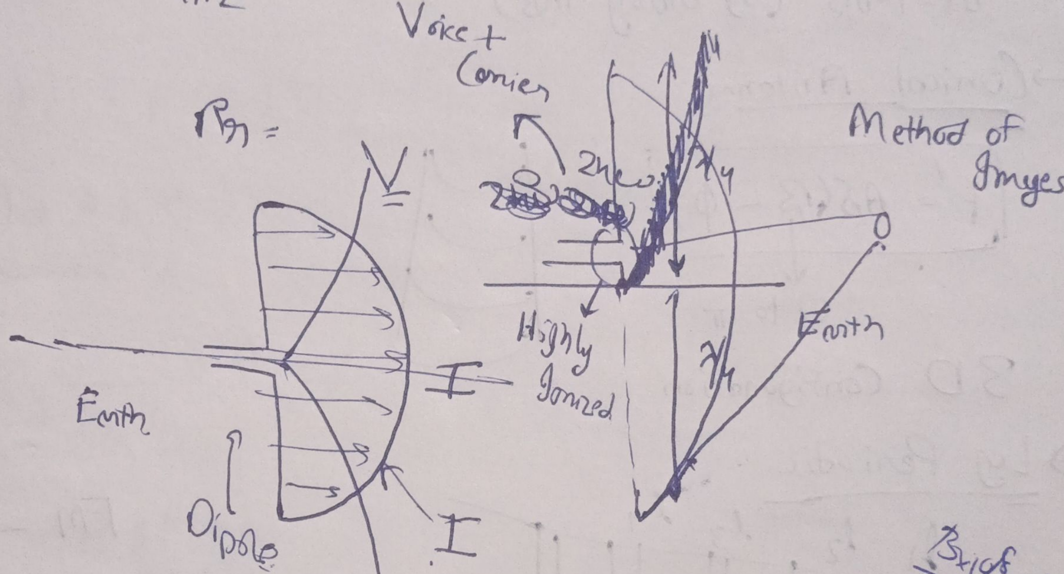
VHF → 30MHz – 300MHz LOS (Line of Sight)

VHF → 300MHz – 3000MHz ~~LOS (Line of Sight)~~ L, S Band (GPS) 1GHz

SHF → 3GHz – 300GHz (Satellite Communication)

– THz

$R_r =$

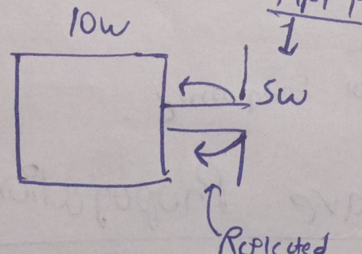


$\frac{3\times10^8}{30\times10^3}$ 10^4

10000 m

* Radiation resistance

MPTT



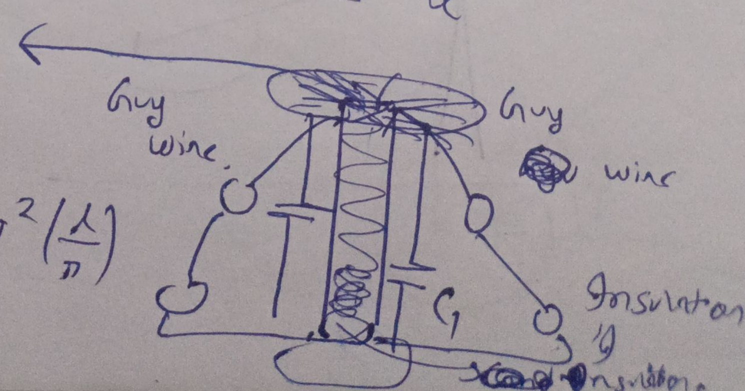
Radiated Power $\xrightarrow{\text{Equivalent}}$ Radiation resistance.

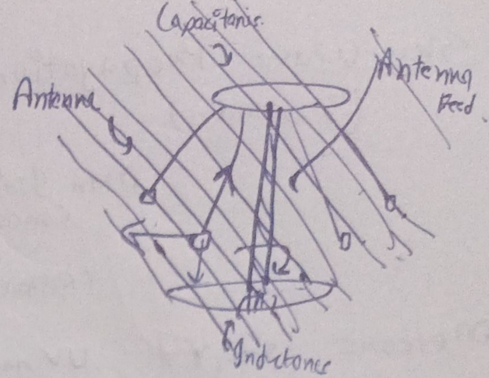
→ ~~Vacuum Tube~~

Increase hight, Increase radiation resistance

if $y_{\lambda/4}$

$R_r = 80\pi^2\left(\frac{\lambda}{\pi}\right)$





Ground Wave / Surface Wave

Q) A vertically polarized plain wave of power density $10 W/m^2$ propogates at $2 MHz$ as surface wave along smooth surface of the earth having dielectric constant of 16, and conductivity as 10^{-2} mho/m. Find the wave tilt and Power loss per m^2 of the ground.

$$d = \sqrt{2R}\,(\sqrt{h_t} + \sqrt{h_r})$$

↳ height of reciever.

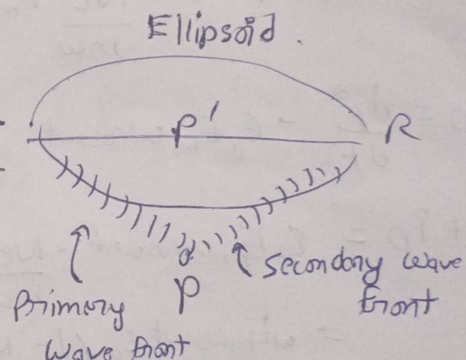
↳ heigh of transmitter

↓ Radius of earth.

→ Waves will be getting refracted in air as, as we move up in air the refractive index changes (decreases)

→ LOS is very reliable

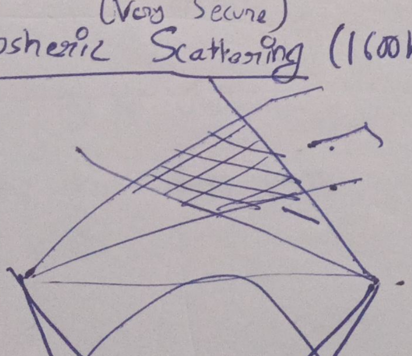
$$d = \sqrt{\frac{Tp' \times p'R}{TR} \times \lambda}$$

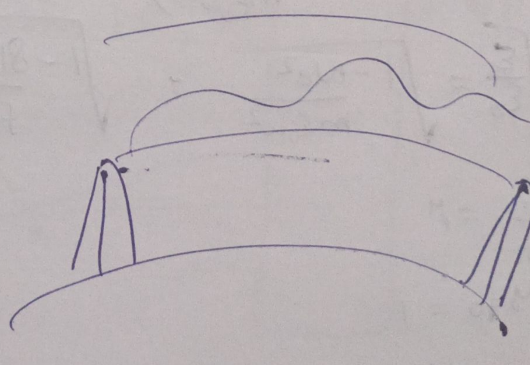


Duct Propagation (1000 km)

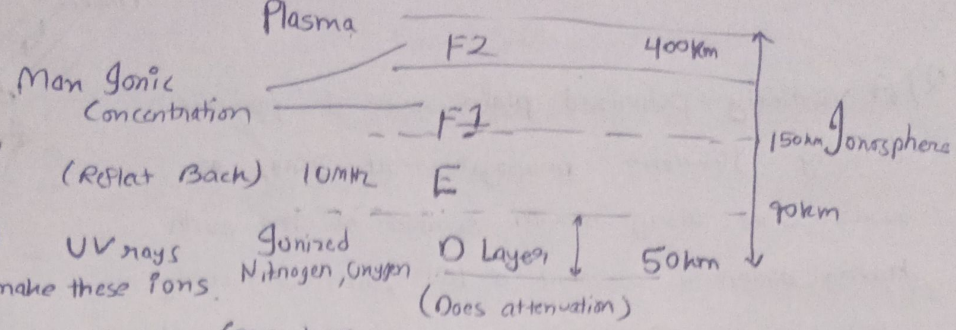
→ Space duct where the signal will be propogated

* Troposheric Scattering (1600 km) (Very Secure)





Sky Wave Propagation - Ionosphere
(3-30MHz)



Meteors (α, β, γ) UV rays make these ions

Concentration $10^{10}-10^{11}$

Solar Cycle

HEm Radio

$$F = eE_m \sin\omega t$$

$$m\frac{dv}{dt} = -eE_m \sin\omega t$$

$$v = +\frac{eE_m}{m\omega}\cos\omega t$$

$$i_e = -Nev = -\frac{Ne^2}{m\omega}E_m\cos\omega t$$

$$i_D = \frac{d\vec{p}}{dt} = \epsilon_0 E_m \omega\cos\omega t$$

$$i_e + i_D = \epsilon_0 E_m \omega\cos\omega t - \frac{Ne^2}{m\omega}E_m\cos\omega t$$

$$= \omega E_m \cos\omega t\, \epsilon_0\left(1 - \frac{Ne^2}{m\epsilon_0\omega^2}\right)$$

$$\epsilon = \epsilon_0\left(1 - \frac{Ne^2}{m\epsilon_0\omega^2}\right)$$

$$\mu = \sqrt{\frac{\epsilon}{\epsilon_0}} = \sqrt{1 - \frac{Ne^2}{m\epsilon_0\omega^2}} = \sqrt{1 - \frac{81N_m}{f^2}}$$

$$\frac{\sin i}{\sin r} = \mu$$

$$r_{90^\circ} = 1$$

$$\mu = \sin i_m$$

If $\mu = 0$ $\quad f_c = 9\sqrt{N}$ ← Cuttoff frequency

$f_{MUF} = f_c \sec i$

→ Numericals on this

* Reflector Antenna (Satellite Comm. Radar Deep Space Communication Astronomy)

Gain of Reflector Antenna

↳ 60-70 dB

↳ like 10^3

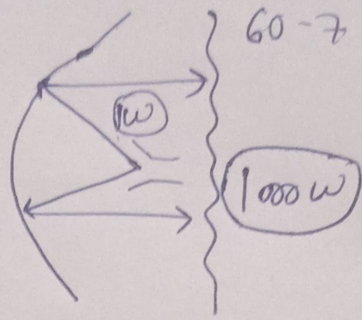
So 1W → 1000W

$r' + r'\cos\theta' = 2f$

$r'(1+\cos\theta) = 2f$

$r' = 2f\sec^2\theta/2$

$\boxed{r' = f\sec^2(\theta/2)}$



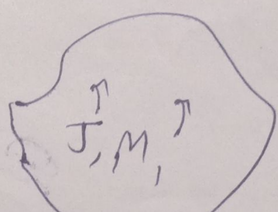
Same phase

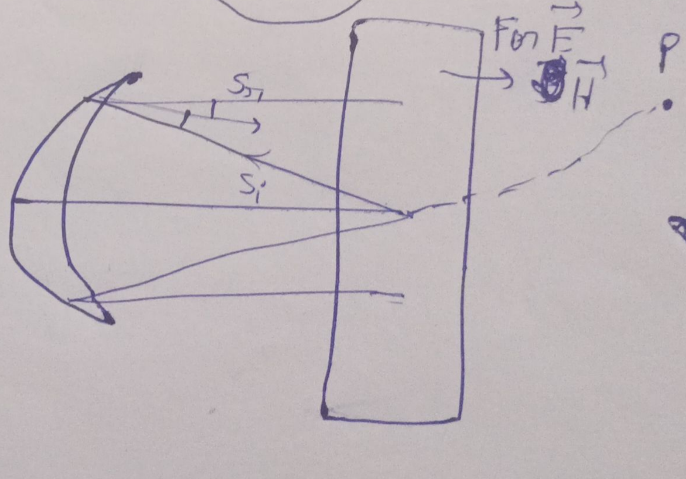
* Field Equivalence Principle

Translating problem from complex to simple terms

$J_s = \hat{n} \times \vec{H} = \hat{n} \times (H_i + H_r)$
$= 2\hat{n} \times H$

$M_s = -\hat{n} \times \vec{E}$
$= -\hat{n}\,(\vec{E}_i + \vec{E}_r)$
$= -2\hat{n} \times \vec{E}$





→ Directivity ∝ Gain

→ More the Area, more the gain

→

For Military Application, Beam width should be narrow.