① Discuss the Radiation Mechanism of Single wire & Two-wire Antenna.

Ans. • The Radiation mechanism represents the, how the radiation obtained.

• It represents, how the EM energy generated from the source which is connected to transmission line and the antenna into the free space

• Consider, the basic type of source for radiation.

① Single wire:

• Let us consider a thin conductor with total charges, Q which is moving along the z-direction with uniform velocity, V_z i.e. (m/sec).

• Let the line charge density, ρ_L which is uniformly distributed along the line i.e, $I_z = \rho_L V_z$ (c/sec).

• If the current is time varying then, $\frac{dI}{dt} = \rho_L \frac{dV_z}{dt}$.

• The length of the wire is l, then it represents,

$$\boxed{l\frac{dI}{dt} = l\rho_L \frac{dV_z}{dt} = l\rho_L a_z}$$

• The above equation represents the relation b/w current & charge.

• It states that to create a radiation there must be time varying current or acceleration (deceleration) of charge.

Consider a single wire source,

	Q	V	I	EM
(i)	✓	×	×	×
(ii) ①	✓	✓	✓	×
②	✓	✓	✓	✓
(iii)	✓	$\frac{dV}{dt}$	$\frac{dI}{dt}$	✓

Case(i):

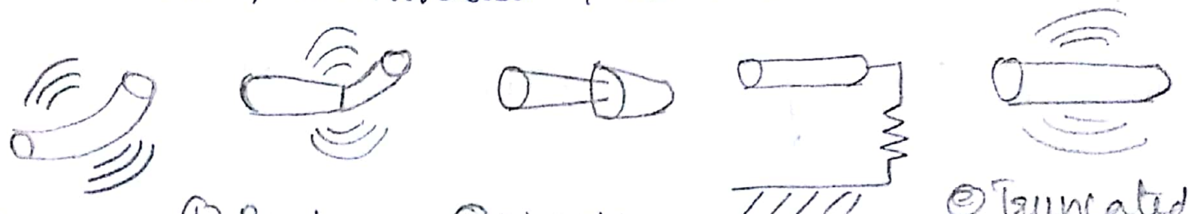
If the charge is not moving then there is no current so there is no radiation.

Case(ii)

If the charge is moving with uniform velocity,

① There is no radiation, if the wire is straight, infinite in extent.

② There is a radiation, if the wire is curved, bent, discontinous, terminated & truncated.

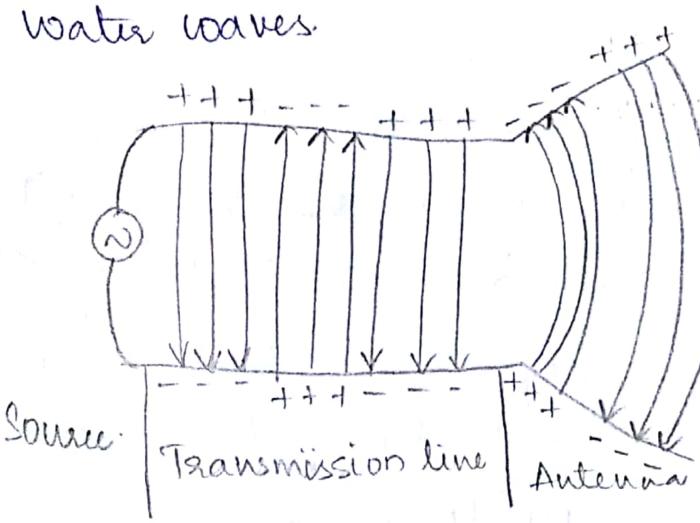


ⓐ Curved ⓑ Bent ⓒ Discontinous ⓓ Terminated ⓔ Truncated

② Two wires:

- Let us consider an antenna with a transmission line which is connected by the external source.
- When the external voltage is applied to the conductor wire, then it creates electric field.
- The electric field in the form of electric line force.
- The electric line forces are proportional to the electric field intensity
- These electric line forces are applied to the conductors then the flow of e^-'s starts & it creates current.
- Due to this current, magnetic field will be created.
- The creation of electric field & magnetic field in b/w the conductor it forms the EM waves.
- These EM waves are transfered to the antenna through a transmission line.

- If the external voltage is sinusoidal & periodic, then the EM waves in b/w the conductor are also sinusoidal & periodic.
- The free space waves are also periodic but a phase constant. Point, P_0 moves outwardly with a light speed (3×10^8 m/sec) to the point, $P_1(\lambda/2)$.
- The remaining EM waves (P_1 to P_2) forms like a greater water waves.



② ⓐ **Beam Area:**

The beam area represents the solid angle of the sphere ie, 4π (Sr) Steradian.

$1 Sr = 1(rad)^2 = \left(\frac{180}{\pi}\right)^2 = 3282^{\square}$

Beam area $= 4\pi Sr = 4\pi\,(1r)^2 = 4\pi\left(\frac{180}{\pi}\right)^2 = 41253^{\square} = \Omega_A$

The approx. beam area, $\Omega_A = \oiint_{\Omega} \underbrace{P_n(\theta,\phi)}_{\text{Normalised power}} d\Omega$

ⓑ **Radiation Intensity:**

The radiation intensity is the product of power density & r^2, ie, $\boxed{U(\theta,\phi) = W_{rad}\cdot r^2}$

The total power is the integration of power density over a 'n' times of solid angle, ie,

$P_{rad} = \oiint_{\Omega} W_{rad}\cdot r^2 d\Omega = \oiint_{\Omega} U(\theta,\phi)\, d\Omega$

For isotropic antenna, the total radiated power is,

$$P_{rad} = \oint\!\!\oint_{\Omega} U_0\, d\Omega = \int_0^{2\pi}\int_0^{\pi} U_0 \sin\theta\, d\theta\, d\phi = U_0 \int_0^{2\pi}\int_0^{\pi} \sin\theta\, d\theta\, d\phi$$

$$\Rightarrow P_{rad} = U_0(4\pi)$$

$$\boxed{U_0 = \frac{P_{rad}}{4\pi}}$$

$$W_0 = \frac{P_{rad}}{4\pi r^2} \Rightarrow P_{rad} = W_0 4\pi r^2$$

$$U_0 = \frac{W_0 4\pi r^2}{4\pi} \Rightarrow \boxed{U_0 = W_0 r^2}$$

© Directivity:

- The directivity is defined as the ratio of radiation intensity in a particular direction to the average of the radiation intensity of overall directions ie; $D = \frac{U(\theta,\phi)}{U_0}$.
- The average radiation intensity is represented as total radiated power divided by '4π'. ie; $U_0 = \frac{P_{rad}}{4\pi}$. then directivity is,

$$D = \frac{U(\theta,\phi)}{U_0} = \frac{U(\theta,\phi)}{P_{rad}/4\pi} = \frac{4\pi U(\theta,\phi)}{P_{rad}} \quad \text{—(1)}$$

- If the direction is not specified, then the radiation intensity describes the max. value i.e; $D_0 = \frac{U_{max}}{U_0} = \frac{U_{max}}{P_{rad}/4\pi} = 4\pi \frac{U_{max}}{P_{rad}}$ —(2)
- The directivity of the isotropic antenna is unity because the isotropic antenna radiates equally in all directions.
- For non-isotropic antenna, the directivity is greater than equal to 1. ie; $\boxed{0 \leq D \leq D_0}$ $\left(D = \frac{U_{max}}{U_0} \geq 1\right)$

Ⓓ Gain:

- Gain is similar to the directivity.
- While considering the gain, take the directivity in addition to that consider the radiation efficiency.

- The gain is defined as ratio of radiation intensity in a particular direction to the obtained radiation intensity.
- The obtained radiation intensity is the total i/p accepted power $\frac{Power}{4\pi} = \frac{P_{in}}{4\pi}$ i.e.,

$$\text{Gain} = \frac{\text{radiation intensity in given direction}}{\underbrace{\text{obtained radiation intensity}}_{\hookrightarrow \frac{P_{in}}{4\pi}}}$$

$$G(\theta,\phi) = 4\pi \frac{U(\theta,\phi)}{P_{in}} \quad (1)$$

Consider the efficiency, $e_{cd} = \frac{P_{rad}}{P_{in}} \Rightarrow P_{rad} = e_{cd} \cdot P_{in}$

from eq (1), $G(\theta,\phi) = e_{cd} \cdot 4\pi \frac{U(\theta,\phi)}{P_{rad}} \Rightarrow G(\theta,\phi) = e_{cd}\, D(\theta,\phi)$

$$\boxed{G = e_{cd} \cdot D}$$

(E) Antenna Aperture:

- It is related to the receiving antenna.
- The antenna aperture is the ability of the antenna to extract the energy from EM wave.
- The effective / Aperture area is defined as the ratio of the power delievered to the load to the incident power density i.e.,

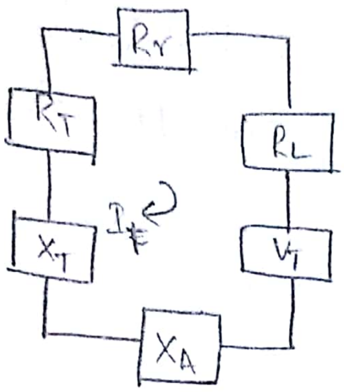
$$\underset{\substack{\downarrow \\ \text{Effective aperture}}}{A_e} = \frac{P_T}{W_i}$$

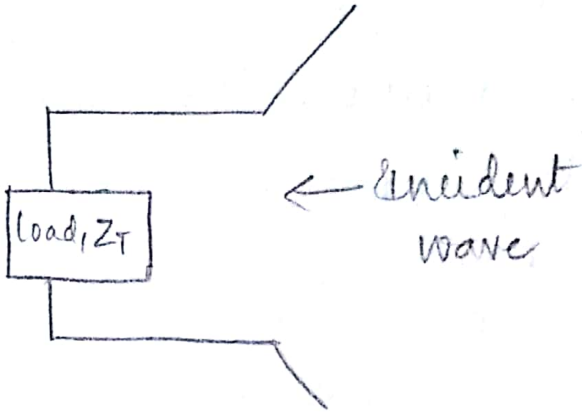
$P_T \rightarrow$ Power delievered to the load.

$W_i \rightarrow$ Power density of incident wave

- To calculate the effective area we require load power, i.e.,

$P_T = \frac{1}{2}|I_T|^2 R_T.$





$$I_T = \frac{V_T}{(R_r+R_L+R_T)+j(X_T+X_A)}$$

For the max. power, magnitude of I_T is,

$$|I_T| = \frac{|V_T|}{\sqrt{(R_r+R_L+R_T)^2+(X_L+X_A)^2}} \Rightarrow P_T = \frac{1}{2}|I_T|^2 R_T$$

$$= \frac{1}{2}\frac{|V_T|^2 R_T}{(R_r+R_L+R_T)^2+(X_A+X_T)^2}$$

To get the max. power the condition under conjugate matching, i.e., $R_r+R_L = R_T$; $X_A = -X_T$

$$A_{em} = \frac{1}{2W_i}\frac{|V_T|^2 R_T}{4(R_r+R_L)^2} = \frac{1}{8W_i}\frac{|V_T|^2 R_T}{(R_r+R_L)^2} \Rightarrow A_{em} = \frac{1}{8W_i}\frac{|V_T|^2}{(R_r+R_L)} \quad (1)$$

- The total power, which is captured by the antenna is not completely delievered to the load.
- Only half of the power is delievered to the load and the remaining half of the power is scattered and dissipated as heat.
- For the above consideration we should calculate scattered area A_s or A_r, loss area A_L and total captured area A_c.
- To calculate the A_s, A_L, A_c we require P_c, P_L, P_r.
- WKT, under conjugate matching,

$$P_s \text{ or } P_r = \frac{1}{8}\frac{|V_T|^2 R_r}{(R_r+R_L)^2} ; \quad P_L = \frac{|V_T|^2 R_L}{8(R_r+R_L)^2} ; \quad P_c = \frac{1}{4}\frac{|V_T|^2}{(R_r+R_L)}$$

- The areas of the scattered, loss and captured of the eq ckt., is similar to the, $A = \frac{P}{W_i}$

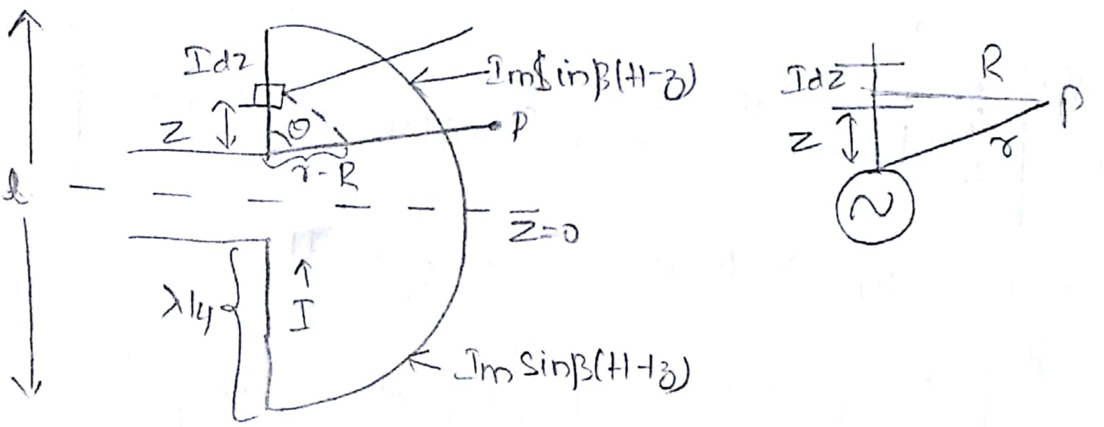
$$A_s = \frac{P_r}{W_i} = \frac{1}{8W_i}\frac{|V_T|^2 R_r}{(R_r+R_L)^2} \quad -(2) \; ; \; A_L = \frac{P_L}{W_i} = \frac{1}{8W_i}\frac{|V_T|^2 R_L}{(R_r+R_L)^2} \quad -(3)$$

$$A_c = \frac{P_c}{W_i} = \frac{1}{8W_i}\frac{|V_T|^2(R_r+R_L+R_T)}{(R_r+R_L)^2} = \frac{1}{4W_i}\frac{|V_T|^2}{(R_r+R_L)} \quad -(4)$$

- The max. Conjugate area is, $A_c = A_{em} + A_s + A_L$

3) Derive the far field components of Half wave dipole Antenna.

Ans:



$\cos\theta = \frac{r-R}{z}$

$R = r - z\cos\theta$.

- Let us consider the current element $I\,dz$ placed at distance z from $z=0$.
- Assuming that the current distribution is sinusoidal then,

$I = I_m \sin\beta(H-z) \; ; \; z > 0 \{0 \text{ to } \lambda/4\} \quad H = l/2 = \lambda/4$

$= I_m \sin\beta(H+z) \; ; \; z < 0 \{-\lambda/4 \text{ to } 0\}$

- ~~Assuming that the current distribution~~
- length of half wave dipole is $\lambda/2$. Here the I_m is peak value of current, the vector magnetic potential at point P due to the current element $I\,dz$.

WKT, $A_z = \frac{\mu I_0 l\, e^{-j\beta r}}{4\pi r} \Rightarrow dA_z = \frac{\mu e^{-j\beta r}}{4\pi r} I\,dz$.

• Where R is distance from current element to point P.

$$A = \frac{\mu}{4\pi}\int_{-H}^{H} \frac{I dz\, e^{-j\beta r}}{R}$$

• The denominator R is approx. as $R \approx r$. In numerator,

$$R = r - z\cos\theta$$

$$A_z = \frac{\mu}{4\pi}\left[\int_{-\lambda/4}^{0} \frac{I_m \sin\beta(H+z)\, e^{-j\beta(r - z\cos\theta)}}{r} dz\right]$$

$$+ \frac{\mu}{4\pi}\left[\int_{0}^{\lambda/4} \frac{I_m \sin\beta(H-z)\, e^{-j\beta(r - z\cos\theta)}}{r} dz\right]$$

$$= \frac{I_m \mu e^{-j\beta r}}{4\pi r}\left[\int_{-H}^{0} \sin\beta(H+z) e^{j\beta z\cos\theta} dz + \int_{0}^{H} \sin\beta(H-z)\, e^{j\beta z\cos\theta} dz\right]$$

$$\beta = \frac{2\pi}{\lambda},\ H = \lambda/4 \Rightarrow \beta \cdot H = \frac{2\pi}{\lambda}\cdot \lambda/4 = \pi/2$$

$$A_z = \frac{I_m \mu e^{-j\beta r}}{4\pi r}\left[\int_{-H}^{0} \cos\beta z\, e^{j\beta z\cos\theta} dz + \int_{0}^{H} \cos\beta\, e^{j\beta z\cos\theta} dz\right]$$

$$= \frac{I_m \mu e^{-j\beta r}}{4\pi r}\left[\int_{0}^{H} \cos\beta z (2\cos(\beta z\cos\theta))\right]$$

$$\boxed{A_z = \frac{I_m \mu e^{-j\beta r}}{2\pi r\beta}\left[\frac{\cos(\pi/2\cos\theta)}{\sin^2\theta}\right]}$$

* $\overline{H}$: $\mu \overline{H}_\phi = \nabla \times \overline{A}$ [Conversion of rectangular to sphere].

$$\overline{H}_\phi = \frac{1}{\mu}(\nabla \times \overline{A})$$

WKT, $\overline{H}_\phi = \frac{1}{\mu}\left[\frac{1}{r}\left(\frac{\partial}{\partial r}(rA_\theta) - \frac{\partial}{\partial\theta}(A_r)\right)\right] \Rightarrow \boxed{A_r = 0}$

In this consider only A_θ value. In this r is not taken into account of a halfwave dipole

WKT, $A_\theta = -A_z \sin\theta$

$$\mu H_\phi = \frac{1}{r}\left(\frac{\partial}{\partial r}(-rA_z\sin\theta)\right) \Rightarrow \mu H_\phi = -\frac{\sin\theta}{r}\cdot\frac{\partial}{\partial r}(rA_z)$$

$$\Rightarrow \mu H_\phi = -\frac{\sin\theta}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\frac{I_m \mu e^{-j\beta r}}{2\pi r\beta}\left(\frac{\cos(\pi/_2\cos\theta)}{\sin^2\theta}\right)\right)$$

$$\boxed{H_\phi = \frac{jI_m \cos(\pi/_2\cos\theta)}{2\pi r\sin\theta}e^{-j\beta r}} - ⑤$$

E: WKT, $E_\theta = \eta H_\phi$, $\eta = 120\pi$

$$\boxed{E_\theta = \frac{j60 I_m e^{-j\beta r}}{r}\times\frac{\cos(\pi/_2\cos\theta)}{\sin\theta}} - ⑤$$

P_{rad}: E_θ & H_ϕ

$$P_{rad} = \int_s W_r\,ds \qquad W_r = \frac{1}{2}\mathrm{Re}\left[E_\theta \times H_\phi^*\right]$$

$$P_{rad} = \frac{\eta I_m^2}{4\pi}\int_0^\pi \frac{\cos^2(\pi/_2\cos\theta)}{\sin\theta}d\theta \qquad \left(\because \int_0^\pi \frac{\cos^2(\pi/_2\cos\theta)}{\sin\theta}d\theta = 1.218\right)$$

$$P_{rad} = \frac{\eta I_m^2}{4\pi}(1.218) = \frac{120\pi I_m^2(1.218)}{4\pi} \qquad (\because I_m = \sqrt{2}I_{eff})$$

$$P_{rad} = 36.54 I_m^2$$

$$\boxed{P_{rad} = 73 I_{eff}^2}$$

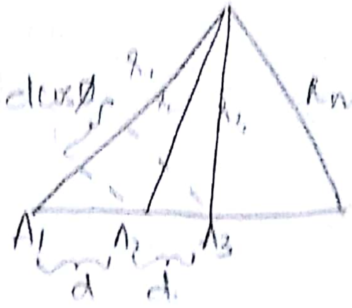
The radiated resistance of the dipole is, $R_r = 73\Omega$

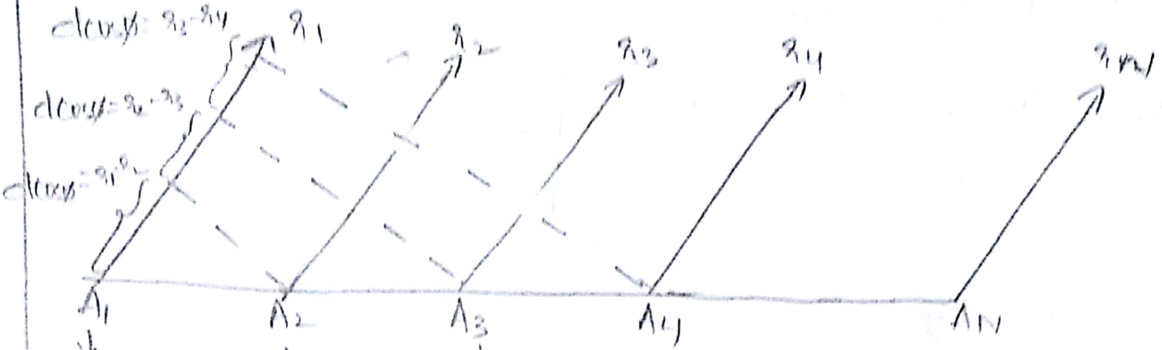
(4) Describe the N element uniform linear array (BSA) with any 3 properties.

Sol) $\cos\phi = \frac{r_1 - r_2}{d}$

$\frac{r_1 - r_2}{P_d} = d\cos\theta$

$P_d = \frac{d\cos\theta}{\lambda}$





$I_1 = I_0 e^{j\beta(0)}$

$I_2 = I_0 e^{-j\beta d}$

$I_3 = I_0 e^{-2j\beta d}$

$A_1 \rightarrow P.A = 0$

$A_2 \rightarrow P.A = \beta$

$A_3 \rightarrow P.A = 2\beta$

- The n-element uniform linear array is used for point to point communications.
- It is used to obtain single beam radiation pattern.
- To get the single beam radiation pattern the two point source array increases to 'n' no. of point sources array.
- Linear Array: If the elements are equally space with same distance 'd'.
- Uniform Array: If the currents are equal in magnitudes, then phase shift uniformly progressive along the line.
- In this case consider an array with 'n' elements which are spaced equally with a distance 'd' and also fed with.

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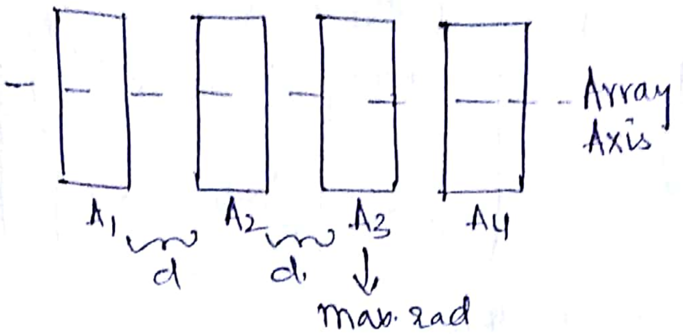
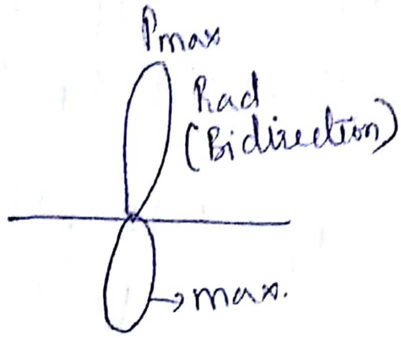
a distance 'd' and also fed with current in equal magnitude & uniform progressive phase shift i.e,

$A_1 = I_1 = I_0 e^{j0}$, $A_2 = I_2 = I_0 e^{-j\beta d}$, $A_3 = I_3 = I_0 e^{-j\beta 2d}$.

- The resultant field at point 'p' is obtained by adding the fields due to individual sources.





- In this case all elements are placed parallely
- The direction of max. radiation is always $\perp^{lar}$ array axis.

The radiation pattern is bidirectional.

- The total field at point 'p' is, $E_T = E_1 + E_2 + E_3 + \dots + E_N$.

$A_1 \rightarrow E_1$, $A_2 \rightarrow E_2$, $A_3 \rightarrow E_3$
$(\psi = 0)$ $\quad (\psi) \quad (2\psi)$

$$E_1 = E_1 e^{j(0)} \; ; \; E_2 = E_1 e^{j(\psi)}, \; E_3 = E_1 e^{j(2\psi)}$$

$$E_T = E_1 + E_1 e^{j\psi} + E_2 e^{j(\psi)2} + E_1 e^{3j\psi} + \dots + E_1 e^{j(N-1)\psi}$$

$$E_T = E_1 \left[1 + e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots + e^{j(N-1)\psi} \right] \quad \text{-①}$$

$$\boxed{\psi = \beta d \cos\phi + \alpha}$$

- The above equation indicates the phase difference of fields from adjacent sources. Here 'α' is progressive phase shift b/w two adjacent sources. $(0 \le \alpha \le 100)$.

→ If $\alpha = 0$, N-element uniform linear array $\psi = \beta d \cos\phi$.

→ If $\alpha = 180°$, N-element uniform linear end fire array.

Multiply eq ① with $e^{j\psi}$ then,

$$E_T \cdot e^{j\psi} = E_1 \left[e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \cdots + e^{jN\psi} \right] \quad -②$$

$$① - ② \Rightarrow E_T - E_T e^{j\psi} = E_1 \left\{ \left(1 + e^{j\psi} + e^{j2\psi} + \cdots + e^{j(N-1)\psi}\right) - \left(e^{j\psi} + e^{j2\psi} + \cdots + e^{jN\psi}\right) \right\}$$

$$\Rightarrow E_T = \frac{E_1 \left[1 - e^{jN\psi}\right]}{\left[1 - e^{jN\psi}\right]} = E_1 \left[\frac{e^{jN\psi/2}\left[e^{-jN\psi/2} - e^{jN\psi/2}\right]}{e^{j\psi/2}\left[e^{-j\psi/2} - e^{j\psi/2}\right]} \right]$$

WKT, $e^{-j\theta} - e^{j\theta} = -2j\sin\theta$, $\theta = \psi/2$

$$E_T = E_1 \left[\frac{(-2j\sin N\psi/2)e^{jN\psi/2}}{(-2j\sin\psi/2)e^{j\psi/2}} \right] = \frac{E_1 \sin(N\psi/2)}{\sin(\psi/2)} \cdot e^{(j(N-1)\psi)/2}$$

$$E_T = \underbrace{E_1 \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin(\psi/2)}}_{\text{mag}} \quad \underbrace{\left[\frac{\psi(N-1)}{2}\right.}_{\text{phase}}$$

$$\boxed{|E_T| = E_1 \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin(\psi/2)}} \quad -③$$

Properties:

① Major lobe:

- In case of BSA the field is max. in direction normal to axis of array.

- The conditions for max. field at point 'P' is,

$\psi = \beta d \cos\phi + \alpha$.

- $\psi = 0$, all sources are in phase for max. direction.

$\beta d \cos\phi = 0 \Rightarrow \phi_{max} = 90^\circ$.

- The direction of radiation is max.

② NULLs (or) minor lobes:

$$E_T = E_1 \frac{\sin \frac{N\psi}{2}}{\sin \frac{\psi}{2}} \Rightarrow \min \to 0$$

$\Rightarrow \sin \frac{N\psi}{2} = 0$ but $\sin \frac{\psi}{2} \neq 0$

$\Rightarrow \frac{N\psi}{2} = \sin^{-1}(0) = \pm m\pi$; $m = 0, 1, 2, 3 \ldots$

$\psi = \beta d \cos\phi = \pm m\pi$

$\beta = \frac{2\pi}{\lambda} \Rightarrow \frac{N}{2} \times \frac{2\pi}{\lambda} \times d \cos\phi_{min} = \pm m\pi$

$$\Rightarrow \boxed{\phi_{min} = \cos^{-1}\left(\frac{\pm m\lambda}{Nd}\right)}$$

③ Minor lobe (side lobes):

WKT, $E_T = E_1 \frac{\sin \frac{N\psi}{2}}{\sin \frac{\psi}{2}}$

$\rightarrow E_T$ is max when numerator is max.

ie, $\sin \frac{N\psi}{2} = \pm 1$.

$\frac{N\psi}{2} = \sin^{-1}(\pm 1)$

$\Rightarrow \frac{N\psi}{2} = \pm(2m+1)\pi/2$; $m = 0, 2, 3 \ldots$