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UNIT-III

ANTENNA ARRAYS:

Antenna Array:

The group of antenna elements which are similar is Called as an Antenna Array.

To Improve the radiation characteristics of antenna characteristics like Directivity the Antenna Arrays are designed.

The Antenna Array Improvem radiations are Improved and these are depend on

(i) length of A Individual Antenna elements

(ii) No. of Antenna elements in Antenna Array

(iii) The current magnitude & phase provided with each element

(iv) Material used for each Antenna element

(v) Seperate b/w the individual Antenna elements in Antenna Array.

By, using the Antenna arrays, the concentration of radiations in particular direction ↑ and forms a beam of line radiation and this beam is used in point to point Commⁿ bcz point to point is

These are ~~two~~ types of Antenna Arrays.

Linear Antenna Array:

In this, each Antenna element is seperated with the same distance in Antenna Array.

Uniform Antenna Array:

In this, each Antenna elements Seperation will be equal & has a uniform magnitude of Current is provided for all the Antenna element and has a progressive phaseshift.

Non-Uniform Antenna Array.

These are having unequal seperation b/w Antenna elements & unequal magnitude of current for Antenna element

Based on construction & direction of max. radiations Antenna Arrays are classified as

1) Broad side Antenna Array (BSA)
2) Endfire " " (EFA)
3) Collinear " " (or)
Omnidirectional " " (AA)

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$$\vec{E_T} = \vec{E_1} + \vec{E_2} + \vec{E_3} + \dots + \vec{E_n} \ V/m$$

BROADSIDE ANTENNA ARRAY:

Construction:

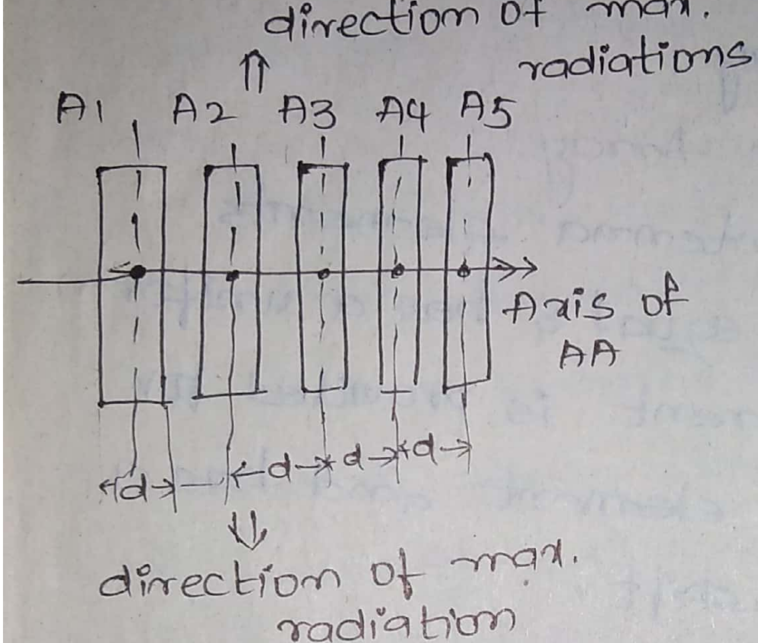

fig (a) Broadside with 5 elements Equally Spaced

Radiation pattern of AA

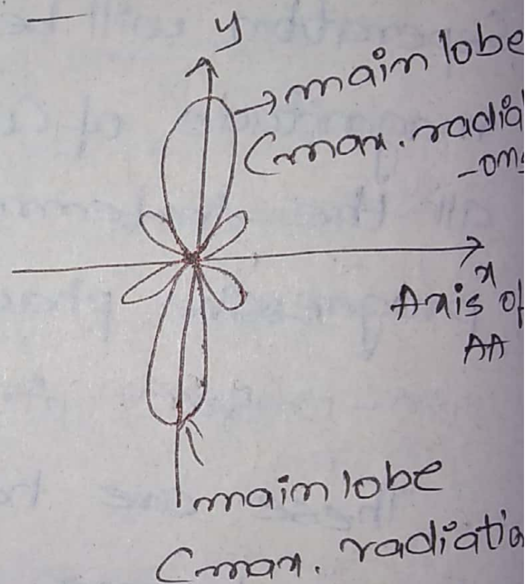

fig: Bidirectional R.P of BSA.

1. All elements are ||al to each other.
2. All elements are Equally spaced.
3. All elements are Equally arranged along the dir^n of Antenna Array.
4. All elements are excited with uniform magnitude of current space & phase
5. Radiation pattern is Bidirectional & wider, than max radiation's $\perp^{lar}$ to Axis of AA.

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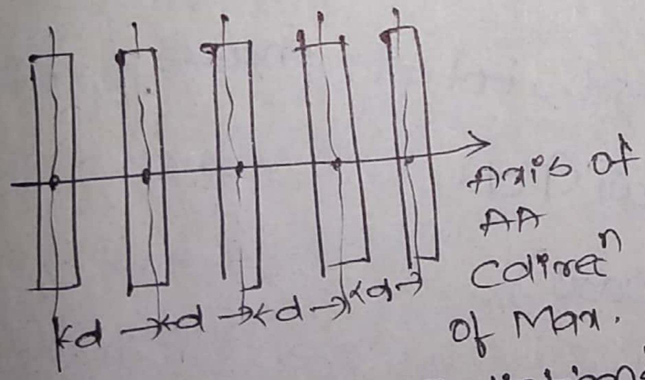
2) ENDFIRE ANTENNA ARRAY

construction of Endfire Antenna array it is similar to Broadside Antenna Array.

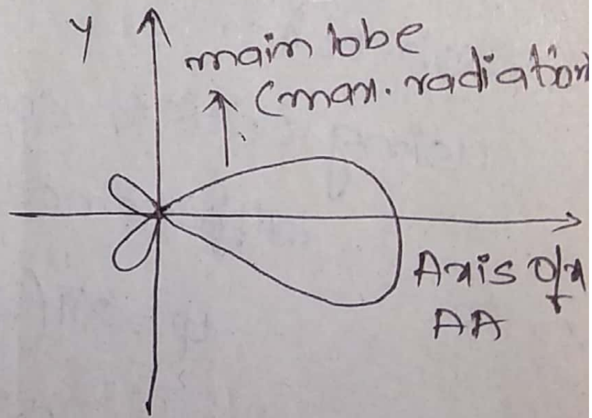
1, 2, 3, 4, points are same.

(5) ~~Radiation is Bidi~~ All elements are excited with uniform magnitude of current but variable phase.

So, the dire^n of Max. Radiations are along the axis. So, the Radiations are ||lal to the axis. & Radiation pattern is unidirectional.

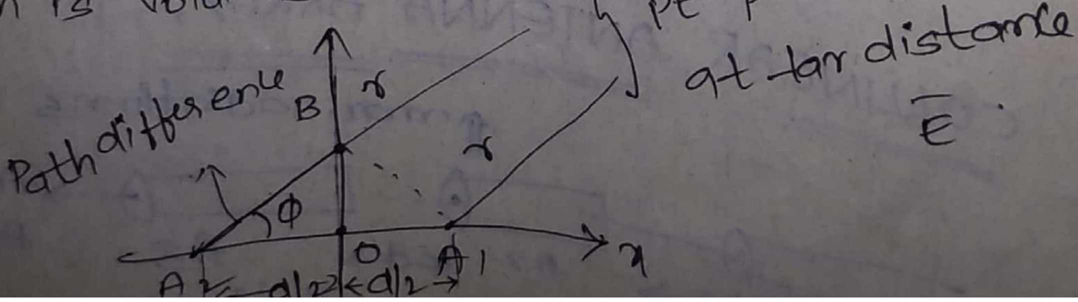


Radiation Pattern of AA



→ BSA WITH TWO ISOTROPIC POINTS SOURCES

Point source is the part of Antenna which is Volumeless.



Here, the A_1 radiations will reach faster than A_2 radiatiations, this is bcz A_2 is having extra differen distance than A_1, and this distance is called Path difference.

From figure $\angle ABA_2$, $\cos\phi = \frac{A_2B}{d} = \frac{A_2B}{A_1A_2}$

$$\boxed{A_2B = d\cos\phi}$$

Path difference expressed interms of λ

$$\rightarrow \boxed{AB = \frac{d}{\lambda}\cos\phi = Pd} \text{ meters.}$$

Here, the two point sources are Equally spaced & the two radiations are ||lal to each other.

Using optics concept, total phase difference $= 2\pi(Pd)$

$$\psi = 2\pi\left(\frac{d}{\lambda}\cos\phi\right)$$

$$= \frac{2\pi}{\lambda} \cdot d\cos\phi$$

$$\boxed{\psi = \beta \cdot d\cos\phi}$$

3 COLLINEAR ANTENNA ARRAY:

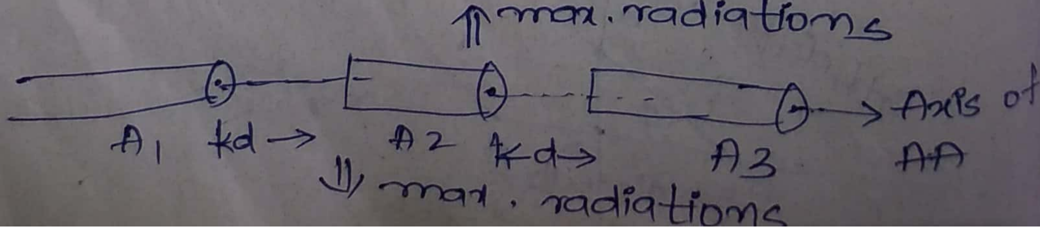


fig: Collinear AA with 2 ele

d should be 0.3λ to 0.5λ (practically)

The Antenna elements are connected with Insulating material & these should be finite, if it is not there, the Antenna elements doesn't acts as an Antenna Array. The max. radiations are in θ=90° & 270° (same as BSA). The drawback is that a feeding problems ~~ar~~ takes place. In BSA, dipoles are used but in Collinear circular elements are used.

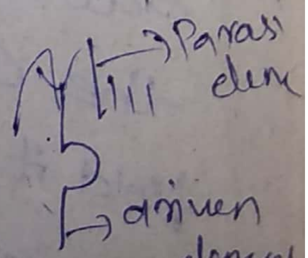
④ PARASITIC ANTENNA ARRAY

In all the BSA, EFA and collinear all the Antennas ~~are~~ elements are excited by the Individual inputs. & the I/p's are by transmission line.

Parasitic Antenna Array is having two elements. They are:

① Parasitic element ② Driven element.

The i/p is given to the driven element by the transmission line. The Parasitic element is without ~~q~~ taken any wire & due to Electromagnetic Coupling b/w driven element & parasitic element, radiation takes place.



The radiation pattern due to parasitic elements depends upon

(i) length of driven element.

(ii) length " " Parasitic element

(iii) Seperation b/w " & Driven element

The direction of Antenna Array is unidirectional & the max. radiations takes place along the parasitic element when it satisfies the conditions below.

(i) When the seperation b/w the Parasitic & driven element is $d = \lambda/4$. | turning of parasitic elem to H

Reason | When the i/p is given to the driven element by the transmission lin " " produces electromagnetic field. So, when the Parasitic element (Antenna i.e Conductor) is ~~not~~ placed near the field, the Current produces, bcz according to the Faradays law, when the Conductor ~~pro~~ is placed in magnetic field it produces a current. So, that the Parasitic elements will radiate.

(ii) The ~~relative phased~~ phase difference b/w relative Currents produced by driven element & parasitic element is $\pi/2$.

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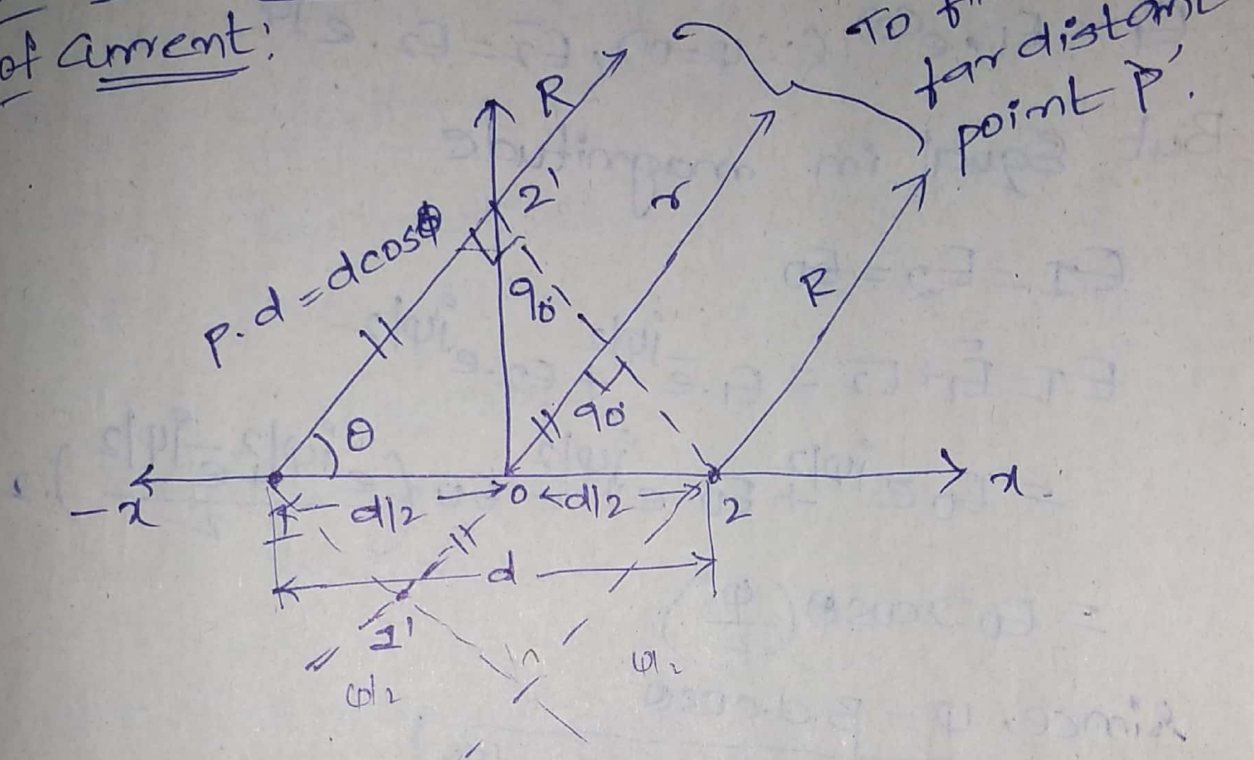
ARRAY OF 2 POINT SOURCES

case: I, Array of two point sources fed with Equal amplitude and same phase of current:



Path difference = d cos θ

Interms of Wavelengths $P_d = \frac{d}{\lambda}\cos\theta$

using optics concept,

total phase difference b/w 2 element

$= 2\pi$ (path difference) $= 2\pi\left(\frac{d}{\lambda}\right).\cos\theta$

$\varphi = \beta d \cos\theta$ —— (1)

According to superposition concept.

$\bar{E_T} = \bar{E_1} + \bar{E_2}$

Since, $\bar{E_1} = E_1 . e^{-j\varphi/2}$, $\bar{E_2} = E_2 . e^{j\varphi/2}$

$(\bar{v} = |v| . \hat{a_v})$

vector = magnitude . unit vector

Note: Origin of system is taken as reference for phase calculation

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$E_{nor} = \cos(\pi/2 \cos\theta)$ —— (B)

Since, $d = \lambda/2$, $\beta = 2\pi/\lambda$.

Let us find the direction of max. radiations, min. radiations using above Equation.

Case i) Direction of Maxima:

When $E_{normalised}$ = maximum in the direction of θ, there will be max. radiations.

$E_{nor} = \cos(\pi/2 \cos\theta) = \pm 1$ (max)

$\pi/2 \cos\theta_{max} = n\pi$

where $n = 0, 1, 2 \ldots$

if $n = 0$,

$\pi/2 \cos\theta_{max} = 0$

$$\boxed{\theta_{max} = 90^\circ \text{ \& } 270^\circ}$$

Case ii) Direction of Minima:

When $E_{normalised}$ = min. in the direction of θ, there will be min. radiations.

$E_{nor} = \cos(\pi/2 \cos\theta) = 0$

$(\pi/2 \cos\theta_{min}) = \pm(2n+1)\pi/2$

where $n = 0, 1, 2, 3 \ldots$

$\pi/2 \cos\theta_{min} = \frac{\pm\pi}{2}$

$\cos\theta_{min} = \pm 1 \Rightarrow \theta_{min} = \cos^{-1}(\pm 1)$

$$\boxed{\theta_{min} = 0^\circ \text{ \& } 180^\circ}$$

iii) Half Power Point:

At Half Power point, $E_{nor} = \pm \frac{1}{\sqrt{2}}$

$$\cos(\pi/_2 \cos\theta) = \pm(2n+1)\pi/4$$

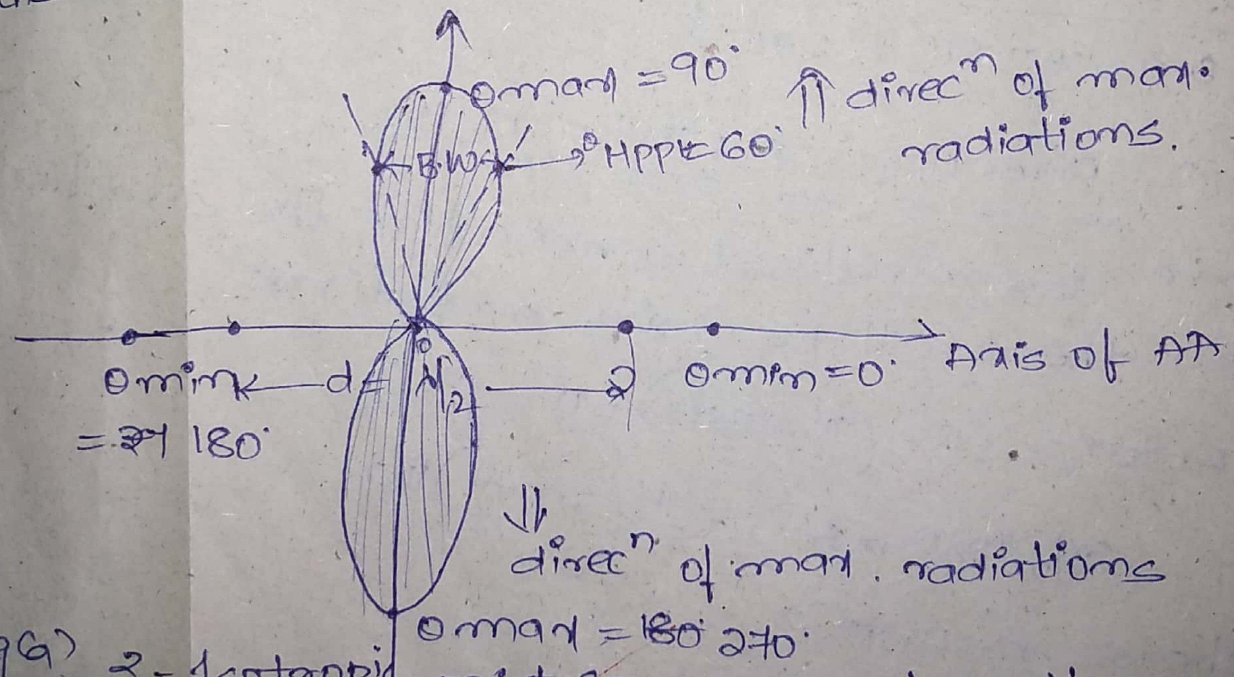
When $n = 0$.

$$\cos(\pi/_2 \cos\theta) = \pm \frac{\pi}{4}$$

$$\cos\theta = \pm \frac{1}{2}$$

$$\boxed{\theta_{HPP} = 60^\circ \; \& \; 120^\circ}$$

Using above data Radiation Pattern will be, Radiations in minimum direction is 0. Therefore there is no lobe.



fig(a) 2-Isotropic point source spaced by $\lambda/2$ apart.

The three-dimensional vertical pattern is Doenut shape

The above is the two Isotropic point source with equal Amplitude & op same phase.

Case:ii) 2- Isotropic point sources with equal Amplitude, unequal phase.

Consider fig(a) of case:i)

$\psi = \beta d \cos\theta \longrightarrow (i)$

opposite phase means if $\theta = 0°$ max. radiations occurs, then at 180°, min. radiations ~~occur~~ should occur. The max. radiations should be unidirectional

According to superposition $\bar{E} = \bar{E_1} + \bar{E_2}$

$E_1 = -E_1 e^{-j\psi/2}$, $E_2 = E_2 e^{j\psi/2}$, Since, equal ~~Amp~~

E_1 is taken as -ve bcz opposite phase mean at left side, Amplitude is $-E_1$ ($\because$ at this ψ is lo

Since, $E_1 = E_2 = E_0$

$\bar{E} = -E_1 e^{-j\psi/2} + E_2 \cdot e^{j\psi/2} = -E_0 e^{-j\psi/2} + E_0 e^{j\psi/2} = E_0 (e^{j\psi/2} - e^{-j\psi/2})$

$= E_0 \cdot 2 \cdot \left(\frac{e^{j\psi/2} - e^{-j\psi/2}}{2} \right) = 2E_0 \cdot j\sin\left(\frac{\psi}{2}\right)$

$\psi = \beta d \cos\theta$

$\bar{E} = 2E_0 \cdot j \sin\left(\frac{\beta d \cos\theta}{2}\right)$, ($j$ indicates the 2 point sources are opposite phase;

From eq (i) considering the max radiations occurs, $2jE_0 = 1$, if $d = \lambda/2$, $\beta = 2\pi/\lambda$

~~E_{max}~~ $= \pm$ ~~$\sin$~~ $(\pi/2$ ~~$\cos\theta$~~$)$

$\sin(\cancel{\pi/2 \cos\theta}) = \pm 1$

$\Rightarrow \pi/2$ ~~$\cos\theta_{max}$~~ $= \pm(2n+1)\frac{\pi}{2}$

$\sin\theta$ ~~max~~ $(2n+1)$

α $\sin\theta_{max} = \pm(2n+1)\frac{\pi}{2}$

When $\theta = n = 0$

$\sin\theta_{max} = \pm\frac{\pi}{2} \rightarrow \sin\theta_{max} = \pm\frac{\pi}{2}$

$\theta_{max} = 90°$ or $180°$

$$\boxed{E_{nor} = \sin\left(\frac{\pi\cos\theta}{2}\right)}$$

Max. radiations

$\pi/2 \cos$ ($\sin(\pi/2\cos\theta) = \pm 1$

$\Rightarrow \sin(\pi/2\cos\theta) = \pm\sin(2n+1)\pi/2$

$\pi/2\cos\theta = \pm(2n+1)\frac{\pi}{2}$

$\cos\theta_{max} = (2n+1)$

When $n=0$

$\Rightarrow \cos\theta_{max} = 1$

$\theta_{max} = \cos^{-1}(1) = \cos^{-1}(1)$

$$\boxed{\theta_{max} = 0° \text{ or } 180°}$$

Min. radiations

$\sin(\pi/2\cos\theta) = 0$

$\sin(\pi/2\cos\theta) = \pm\sin n\pi$

$\cancel{\pi}/2\cos\theta_{min} = n\cancel{\pi}$

$\cos\theta_{min} = 2n$

if $n=0$, $\cos\theta_{min} = 0 \Rightarrow \theta_{min} = \cos^{-1}(0)$

$\theta_{min} = \cos^{-1}(0)$

$$\boxed{\theta_{min} = \cancel{0} \; 90° \text{ or } 270°}$$

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Half Power Point

$$\sin\left(\frac{\pi}{2}\cos\theta\right) = \pm\sin(2n+1)\frac{\pi}{4}$$

$$\frac{\pi}{2}\cos\theta_{HPP} = (2n+1)\frac{\pi}{4}$$

$$\cos\theta_{HPP} = (2n+1)\frac{1}{2}$$

when $n=0$

$$\cos\theta_{HPP} = \frac{1}{2} \rightarrow \boxed{\theta_{HPP} = 60^\circ \text{ (or) } 12}$$

Radiation Pattern

Consider the max. radiations are

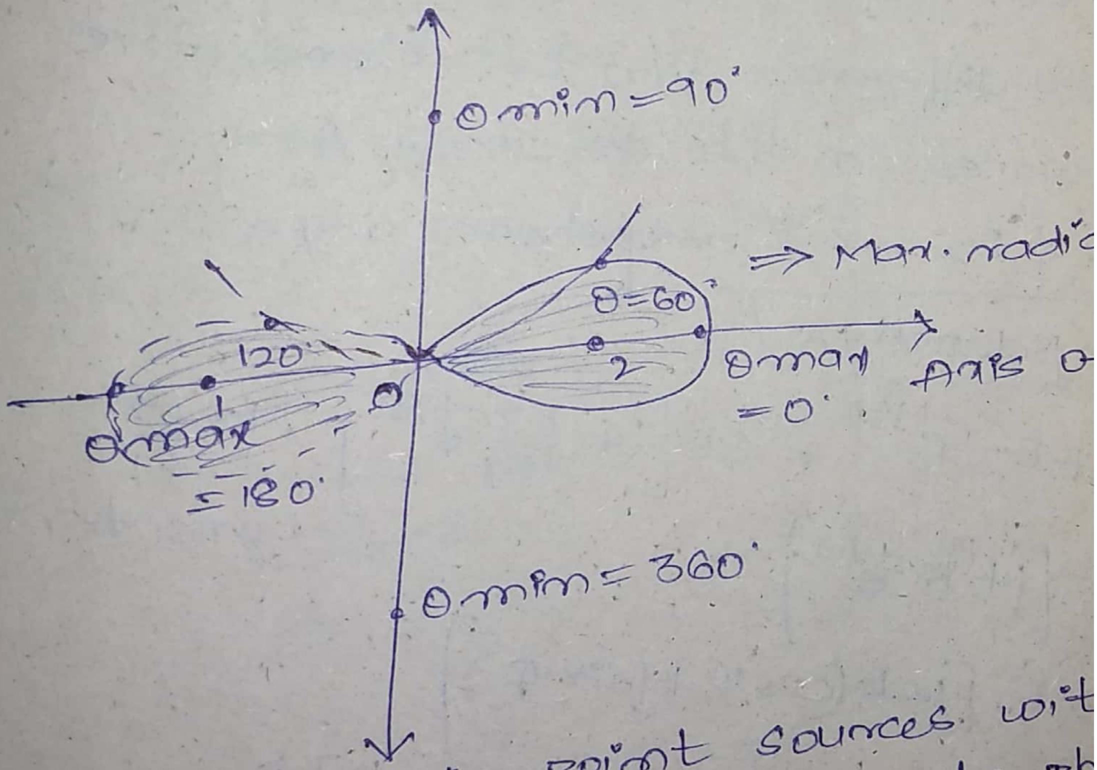
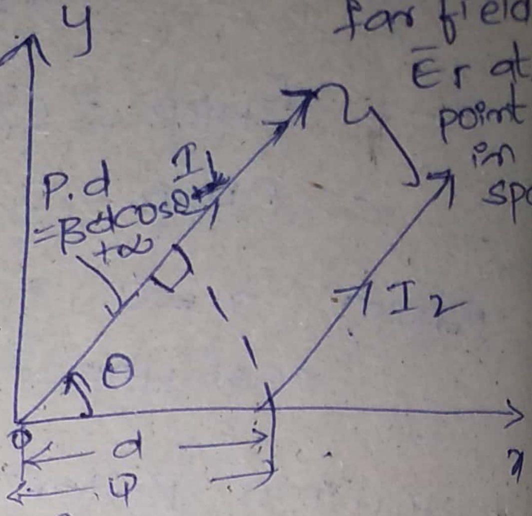


fig (2) 2-Isotropic point sources wit spaced with $d=\lambda/2$ and opposite ph This Radiation Pattern is Endfire Ant Array bcz the max. radiations ar unidirectional.

Case: iii) 2 point sources fed with unequal amplitude & any phase:



I_2 leads the current I_1

Now, taking 1 as reference,

then $E_1 = E_1 . e^{j\psi(0)}$

$E_2 = E_2 . e^{\pm j\psi}$

$E = E_1 + E_2$

$= E_1 . e^0 + E_2 . e^{\pm j\psi} = E_1 + E_2 e^{\pm j\psi}$

α = phase difference b/w two consecutive point sources in the Antenna Array

Say $E_1 \neq E_2$, α & anywhere say α.

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

$\bar{E}_T = E_1 + E_2 . e^{\pm j\psi} = E_1\left[1 + \frac{E_2}{E_1} e^{\pm j\psi}\right]$, $k = \frac{E_2}{E_1}$

Consider $E_1 >> E_2$

$\bar{E}_T = E_1\left[1 + k . e^{\pm j\psi}\right]$

$= E_1\left[1 + k(\cos\psi + j\sin\psi)\right]$

$|E_T| = |E_1\left[1 + k\cos\psi + j\sin\psi k\right]|$

$|E_T| = E_1\sqrt{(1+k\cos\psi)^2 + \sin^2\psi k^2} \angle\alpha$

$|E_T|$ where $\alpha = \tan^{-1}\left(\frac{k\sin\psi}{1+\cos\psi . k}\right)$

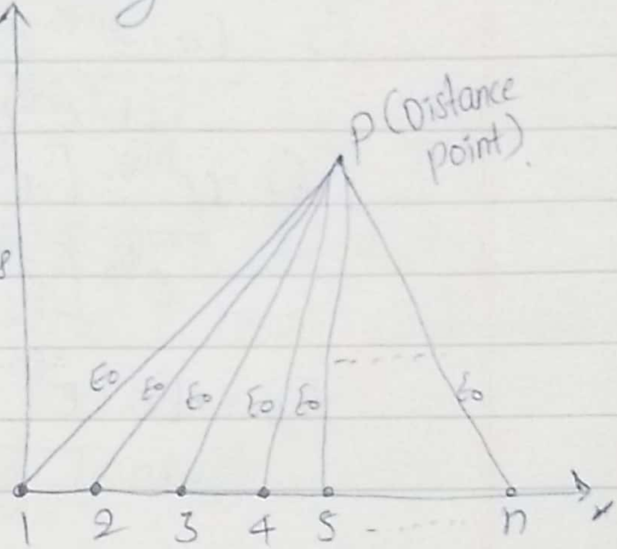
Note: If $\alpha = 0°$ (or) $180°$, $E_1 = E_2$, we can obtain radiation patterns of first two earlier cases

N-element uniform Linear Array:-

→ If the individual elements of the array are equally spaced along a line is called as Linear array

→ If the elements are fed with currents of equal amplitude and having an uniform progressive phase shift along the line is called as uniform linear array.

→ consider a linear array of 'n' isotropic point sources in which point sources are spaced equally and are fed with in-phase currents of equal amplitude 'E_0'.



→ The total far-field value at a distance point 'p' is obtained by adding the fields of individual sources.

$$E_t = E_0 e^{0j\psi} + E_0 e^{j\psi} + E_0 e^{2j\psi} + \dots + E_0 e^{j(n-1)\psi}$$

$$E_t = E_0 + E_0 e^{j\psi} + E_0 e^{j2\psi} + \dots + E_0 e^{j(n-1)\psi}$$

$$E_t = E_0 (1 + e^{j\psi} + e^{j2\psi} + \dots \dots e^{j(n-1)\psi}] \quad \text{---} (1)$$

Where $\psi = \beta d \cos\theta + \alpha$.

ψ → Total phase difference of the fields at point 'p'.

β → phase shift constant

α → phase difference b/w adjacent elements.

eqn (1) multiplied by $e^{j\psi}$.

$$E_t e^{j\psi} = E_0 [e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots + e^{jn\psi}] \quad \text{---} (2)$$

subtracting eq (2) from (1)

$$E_t - E e^{j\psi} = E_0[1 + e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots + e^{j(n-1)\psi}] - E_0[e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \dots + e^{j(n-1)\psi} + e^{jn\psi}]$$

$$= E_t[1 - e^{j\psi}] = E_0[1 - e^{jn\psi}]$$

$$E_t = \frac{E_0[1 - e^{jn\psi}]}{[1 - e^{j\psi}]}$$

$$E_t = \frac{E_0[e^{jn\psi/2} \cdot e^{-jn\psi/2} - e^{jn\psi/2} \cdot e^{jn\psi/2}]}{[1 - e^{j\psi/2} \cdot e^{j\psi/2}]}$$

$$\left[\because \frac{e^{j\theta} + e^{-j\theta}}{2j} = \sin\theta\right.$$

$$E_t = \frac{E_0 e^{jn\psi/2}[e^{-jn\psi/2} - e^{jn\psi/2}]}{e^{j\psi/2}[e^{-j\psi/2} - e^{j\psi/2}]}$$

$$E_t = E_0 \cdot \frac{e^{j(n-1)\psi/2}[e^{jn\psi/2} - e^{-jn\psi/2}]}{[e^{j\psi/2} - e^{-j\psi/2}]}$$

$$E_t = E_0 \cdot \frac{e^{j(n-1)\psi/2}\, 2j\sin(n\psi/2)}{2j\sin(\psi/2)}$$

$$E_t = E_0 \cdot e^{j(n-1)\psi/2} \cdot \frac{\sin(n\psi/2)}{\sin(\psi/2)}$$

$$E_t = \frac{E_0 \sin(n\psi/2)}{\sin(\psi/2)} \angle e^{j\phi} \qquad \phi = (n-1)\psi/2.$$

$$E_t = E_0 \cdot \frac{\sin(n\psi/2)}{\sin(\psi/2)}[\cos\phi + j\sin\phi]$$

The total field pattern of Linear array of n-isotropic point Source is given as,

$$E_t = E_0 \frac{\sin(n\psi/2)}{\sin(\psi/2)} \angle\phi$$

Array factor $\boxed{\frac{E_t}{E_0} = \frac{\sin(n\psi/2)}{\sin(\psi/2)}}$

Maximum Electric field:-

→ In the total field vector, if $\psi = 0$ the equation becomes indeterminant. Hence 'L' hospital rule must be applied to evaluate the function

$$\lim_{\psi \to 0} E_t = E_0 \frac{\lim_{\psi=0} \frac{d}{d\psi}[\sin(n\psi/2)]}{\lim_{\psi=0} \frac{d}{d\psi}(\sin(\psi/2))}$$

$$E_{tmax} \Rightarrow E_0 \lim_{\psi=0} \frac{\frac{n}{2}\cos(n\psi/2)}{\frac{1}{2}\cos(\psi/2)}$$

$$= E_0 \cdot \frac{\frac{n}{2} \cdot \cos 0^\circ}{\frac{1}{2}\cos 0^\circ}$$

$$= E_0 \cdot n$$

$$\boxed{E_{tmax} = E_0 \cdot n}$$

The maximum value of E_t is 'n' times the field from a single source.

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Normalized field:-

$$E_{norm} = \frac{E_t}{E_{t\,max}}$$

$$E_{norm} = \frac{E_0\left(\frac{\sin(n\psi/2)}{\sin(\psi/2)}\right)}{E_0 \cdot n}$$

$$\boxed{E_{norm} = \frac{\sin(n\psi/2)}{n\,\sin(\psi/2)} = (\text{Array factor})/n}$$

Characteristics of Broadside Array:-

→ In broadside array, the maximum radiation is in perpendicular to array axis i.e. 90° & 270°

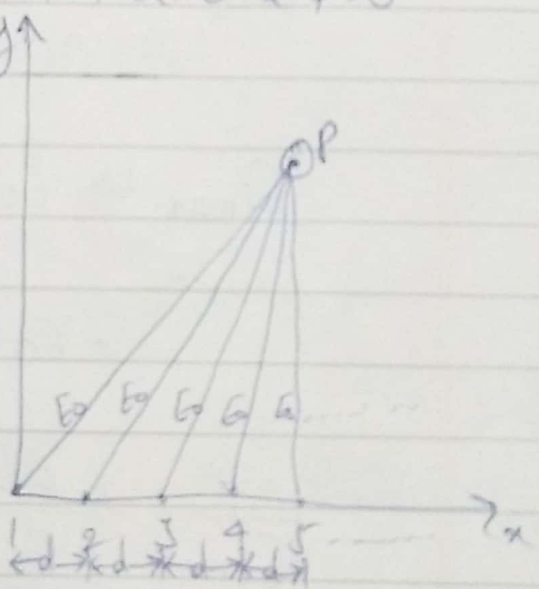
→ sources are in-phase. i.e, $\alpha=0$ & $\psi=0$

ψ = Total phase difference of the field at point 'p'

α → phase difference in adjacent point sources.

$\psi = \beta d\cos\theta + \alpha$ [$\because \psi = \alpha = 0$]

$\beta d\cos\theta = 0$



Maximum Radiation:-

$\beta d\cos\theta_{max} = 0$

$\cos\theta_{max} = 0$

$\theta_{max} = \cos^{-1}(0)$

$\theta_{max} = 90°$ & $270°$