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UGC-NET

Paper - 2

NATIONAL TESTING AGENCY (NTA)

ELECTRONIC SCIENCE

Paper 2 – Volume 6

SIERRA INNOVATIONS

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Unit – 7

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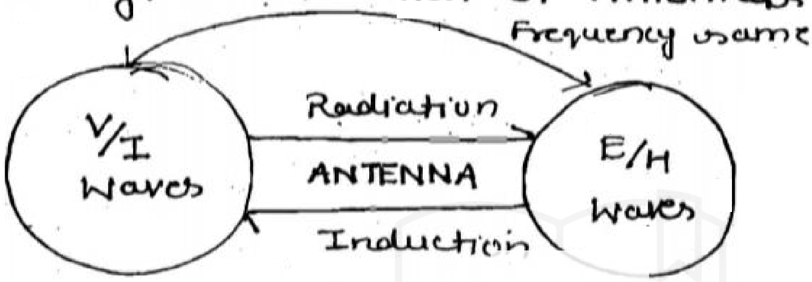
Unit – 7

-: ANTENNAS :-

- → Hertzian Dipole / Halfwave Dipole
- → Basic Terms and Definitions → 50%
- → Antenna Arrays
- → FRIIS - Free Space Propogation
- → Study / classification of Antennas



Hertzian Dipole as a Basic Radiating Element :-

It is a dl length $I(t) = I_m \sin \omega t$ (oscillatory or Harmonic) current element with $dl << \lambda$

(I) $A(t) = \dfrac{\mu I(t) dl}{4\pi r}$

(II) $B(t) = \mu H(t) = \nabla \times A$

(III) $\nabla \times H \Rightarrow \epsilon \dfrac{\partial E}{\partial t}$ (IV) $E(t) = \dfrac{1}{\epsilon} \int (\nabla \times H)\, dt$

Every harmonic current produces a time / space harmonic E & H around it. This EM wave generation is called as radiation

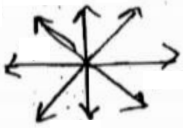
Expression for Radiated fields of Hertzian Dipole :-

W $\rightarrow E(z,t)_x = E_0 \; e^{j\omega t} \; e^{-\gamma z} \; a_x$

Properties of Radiated Waves:-

They travel radially outward and hence their amplitudes decrease as $\frac{1}{r}$ due to their power density decreases as $\frac{1}{r^2}$

$\longrightarrow$ Amplitude dec. but does not attenuate.



$$E_\theta \times H_\phi = P_r$$

$$\frac{E_\theta}{H_\phi} = \frac{1}{\epsilon C} = \frac{1}{\epsilon \sqrt{\frac{1}{\mu\epsilon}}} = \sqrt{\frac{\mu}{\epsilon}} = 120\pi \; \Omega$$

(II) The amplitude of the radiated wave is not omni-directional and depends on θ and ϕ

i.e. Radiation is directive in nature

(III) The amplitude of the radiated wave always depends on $\left(\frac{dl}{\lambda}\right)$ ratio

i.e. frequency decides radiated power

Total Power Radiated from a Hertzian Dipole:-

$$W_r = \oint P_{avg} \, ds$$

$$= \oint_{\text{Sphere}} \frac{1}{2} \frac{E_0^2}{\eta} a_r \; ds \cdot a_r$$

$$W_r = \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{1}{2} \left(\frac{I_m \, dl \sin\theta \, \omega}{4\pi\epsilon c^2 r} \right)^2 \frac{1}{120\pi} \; r^2 \sin\theta \, d\theta \, d\phi$$

$\left(\omega = \frac{2\pi c}{\lambda} \right)$

$$W_r = I^2_{rms} \; 80\pi^2 \left(\frac{dl}{\lambda}\right)^2$$

The expression is similar to a resistor dissipating power as heat i.e. every antenna radiates power in the form of EM wave

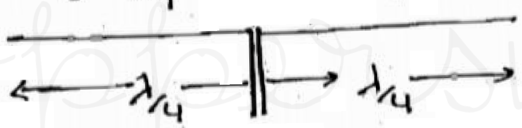
R_r = Radiation resistance of Hertzian Dipole

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

→ R_r is a measure of radiated power for a given input current i.e. it should be as possible for a practical antenna

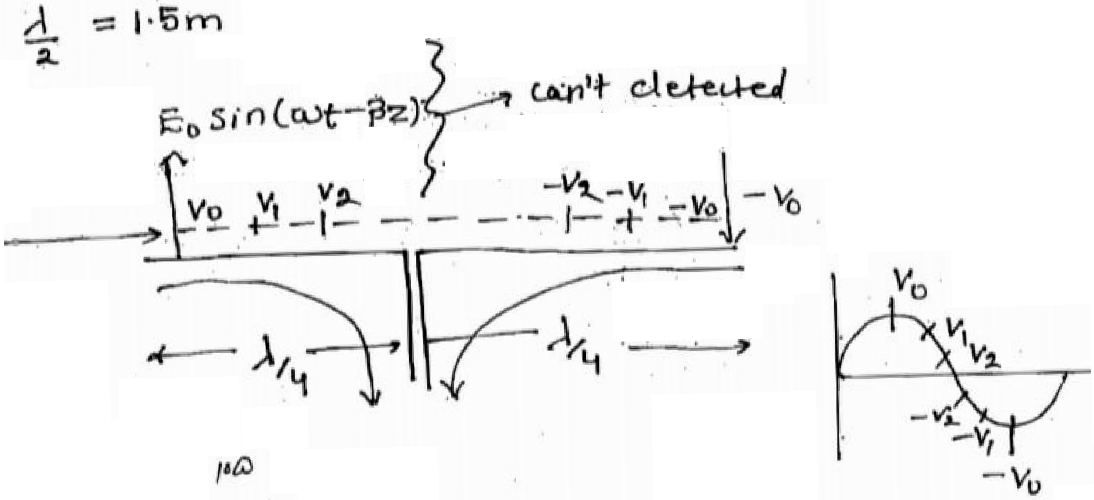
Halfwave dipole as a fundamental Antenna :-

→ A centre feed $\lambda/2$ - dipole is a transmission opened out by $\lambda/4$ on either sides



→ The length of antenna is strictly depends on the frequency of operation

FM	GSM
$f = 100\,MHz$	$f = 1800\,MHz$
$\lambda = 3m$	$\lambda =$ few cm
$\frac{\lambda}{2} = 1.5m$	



Note :-

When an EM waves having right frequency and right polarization travels along the axis of the antenna, it induced V_0 voltage at one end and progressively decrease voltage such that it is $-V_0$ at the other end Hence the word half wave dipole

> These voltages drive a current towards centre which is maximum in the line such that

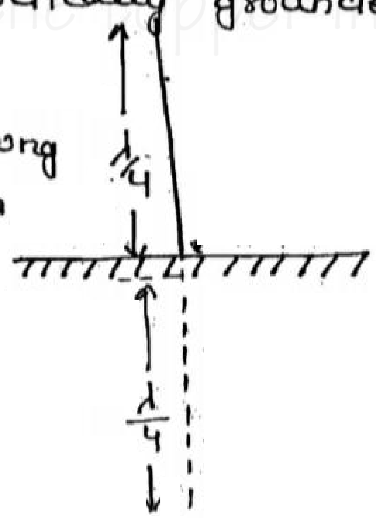
Assymptotic V/I distribution
$$\left.\begin{aligned} |V(z)| &= V_0 \sin \beta z \\ |I(z)| &= I_0 \cos \beta z \end{aligned}\right] \rightarrow z = -\frac{\lambda}{4} \text{ to } \frac{\lambda}{4}$$

* $V_0 = -ve$ at other end bec. of phase diff $= 180^\circ$

Quaterwave Monopole as a Practical Antenna :-

→ It is a low frequency vertically grounded single wire of $\lambda/4$ length

→ It is a base feed and along with its image works like a harmonic dipole



Summary :-

A halfway dipole is an array of Hertzian dipoles with dl from $-\lambda/4$ to $\lambda/4$ and
$\underline{I_m = |I(z)| = I_0 \cos \beta z}$
Assymptotic

Radiation Expressions for Halfwave Dipole :-

$$E(r,\theta,\phi,t)_\theta = \left(\frac{60 I_0}{r} \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right) \sin\omega t \; e^{-j\beta r} a_\theta$$

$$H(r,\theta,\phi,t)_\phi = \left(\frac{I_0}{2\pi r} \frac{\cos\left(\pi/2 \cos\theta\right)}{\sin\theta}\right) \sin\omega t \cdot e^{-j\beta r} a_\phi$$

Total power radiated from Halfwave Dipole

$$W_r = \int \frac{1}{2} \frac{E_0^2}{\eta} \, d_r$$

$$= \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{1}{2} \left(\frac{60 I_0}{r} \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right)^2 \frac{1}{120\pi} r^2 \sin\theta d\theta d\phi$$

$$= I_{rms}^2 \, (73)$$

R_r for a Halfwave Dipole $= 73\,\Omega$

R_r for Quarterwave monopole $= 36.5\,\Omega$

R_r for a folded dipole $= 2^2 \times 73\,\Omega = 292\,\Omega$

$\lambda/2$

R_r for n-Dipoles $= n^2 \times 73$

$(n^2 \times 273)$

Basic Terms and Definitions :-

Isotropic Antenna :-

It radiates power in all directions uniformly. Its E field pattern is independent of θ and ϕ

eg :- Broadcast antenna

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(II) Radiation Power Density :-

It is the strength of the radiated EM wave in any direction at any distance from the antenna

$$\frac{\text{Power}}{\text{Area}} \text{ or Watts}/m^2 = \frac{dW_r}{ds}$$

= Poynting vector of EM wave

$$= \frac{1}{2}\frac{E_0^2}{\eta}(r, \theta, \phi)$$

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

Imp

III) Radiation Power Intensity :-

It is the strength of the radiated EM wave in any direction from the antenna

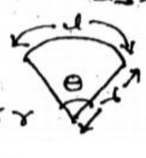
$$\frac{\text{Power}}{\text{direction}} = \frac{\text{Power/solid angle}}{}$$

$$= \text{with steradian} = \frac{dW_r}{d\Omega}$$

$l = \theta r$

If $\theta = 1$ then $l = r$

If $\theta = 6.28$ radian then $c = 6.28 r$

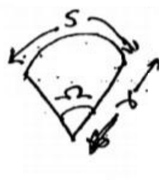


$s = \Omega r^2$

$\Omega = 1$ Steradian

$s = r^2$

$\Omega = 12.56$ steradian



Total surface area $= 12.56\, r^2$

Any small incremental area, $ds = r^2 d\Omega = r^2 \sin\theta \, d\theta \, d\phi$

$d\Omega = \sin\theta \, d\theta \, d\phi$

$$\frac{dW_r}{d\Omega} = \frac{dW_r}{ds} \cdot \frac{ds}{d\Omega}$$

$$= V(r, \theta, \phi) \, r^2 = \Psi(\theta, \phi)$$

eg:- Isotropic Antenna

$$\frac{dW_r}{ds} = \frac{W_r}{4\pi r^2} = V_{avg}$$

$$\frac{dW_r}{d\Omega} = \frac{W_r}{4\pi} = \Psi_{avg}$$

IV) <u>Gain of an Antenna</u>:-

$G_D \rightarrow$ Directive gain

$G_P \rightarrow$ Power gain

$D \rightarrow$ Directivity

(a) <u>Directive Gain (G_D)</u>:-

The radiation intensity of the antenna in a given direction to the radiation intensity of isotropic antenna

$$G_D = \frac{\Psi(\theta, \phi)}{\Psi_{avg}} = \frac{4\pi \Psi(\theta, \phi)}{W_r} = \frac{4\pi \Psi(\theta, \phi)}{\int \Psi(\theta, \phi) \, d\Omega}$$

$G_D > 1$ or $G_D < 1 \longrightarrow$ depends on direction

(b) <u>Power Gain</u>:-

$$G_P = \frac{4\pi \cdot \Psi(\theta, \phi)}{W_N}$$

W_r = Total o/p power

W_N = Total i/p power

$$G_p = \frac{4\pi\psi(\theta,\phi)}{W_r}\frac{W_r}{W_N}$$

$$= G_D \times \text{Efficiency of Radiation}$$

$$\text{Efficiency} = \frac{W_r}{W_r + W_l} = \frac{R_r}{R_r + R_l}$$

$$\text{Directivity} = G_D|_{max}$$

$\boxed{D \geq 1}$ → Always

$D = 1$ for isotropic antenna

<u>Radiation Pattern of an Antenna:-</u>

It is a polar plot of radiation intensity indicating various directions around the antenna where radiation is <u>finitely strong</u>

eg:- $|E| = \frac{k\sin\theta}{r}$

$\psi = \psi_0 \sin^2\theta$

HPBW — Half Power Beam width

BWFN — Beam Width Full Nulls

$\theta = 0°/180°$

$|E| = 0$ → Null points

→ θ_{NP}

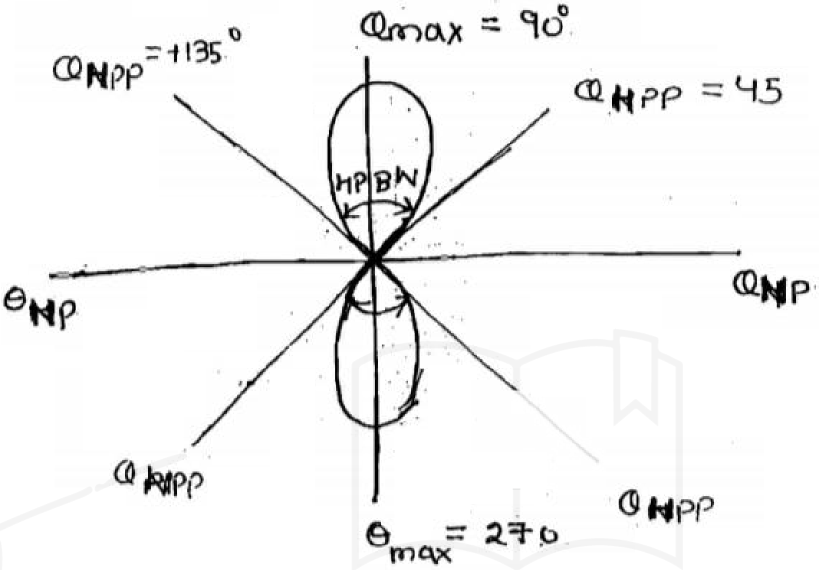
$\theta = 90^\circ/270^\circ$

$|E| = E_{max}$

$\rightarrow \theta_{max}$

$\theta = 45^\circ/135^\circ/225^\circ/315$

$|E| = \frac{E_{max}}{\sqrt{2}}$



θ_{HPBW} = HPP is next HPP in the maxima (Half power pt.)

$= 135^\circ - 45^\circ = 90^\circ$

The antenna considered has a ϕ independent pattern and hence a circular top view of the beam (for all ϕ)

In general

$$\theta_{HPBW} \times \phi_{HPBW} = \Omega_A \text{ Beam solid angle}$$

$$= \text{Steradian} = \text{radian}^2$$

In circular

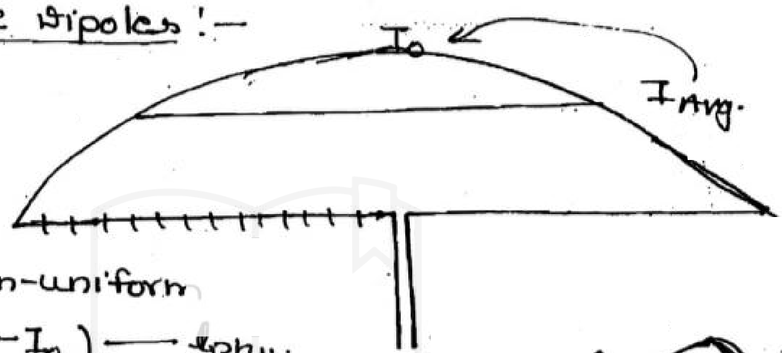
$$\left(\theta_{HPBW}\right)^2 = \Omega_A$$

$$D \propto \frac{1}{\Omega_A}$$

$$\Rightarrow \boxed{D = \frac{4\pi}{\Omega_A}}$$

(VI) Effective length of an antenna :-

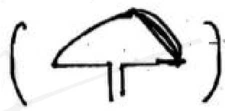
(a) For Halfwave Dipoles :-



Non-uniform

W_r ——— $(0 - I_0)$ ——— l_{phy}

W_r ——— I_{avg} ——— l_{eff}



Note :-

→ An antenna radiates W_r power over its physical length and non-uniform currents everywhere. Effective length is a length required to radiate same power assuming uniform currents everywhere.

$$I_{avg} = \frac{1}{\pi}\int_0^{\pi} I_0 \sin t \, dt = \frac{2I_0}{\pi}$$

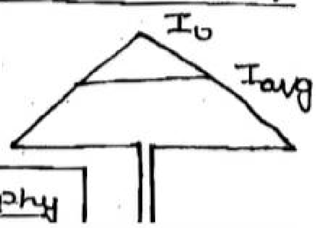
$$\boxed{l_{eff} = \frac{2 l_{phy}}{\pi}}$$

(b) For electrically short Dipoles $\left(l_{phy} < \frac{\lambda}{10}\right)$:-

$|I(z)| \propto z$

Linear current

$$I_{avg} = \frac{I_0}{2}$$



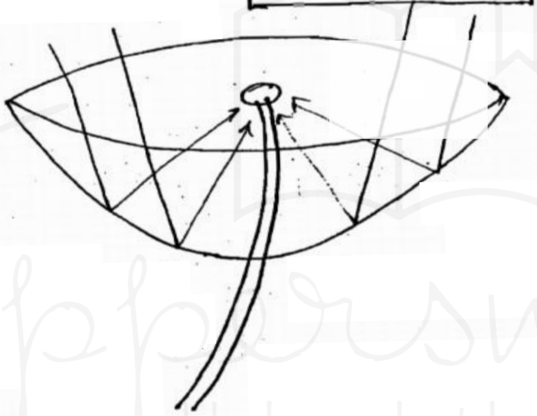
$$\boxed{l_{eff} = l_{phy}}$$

VII) Capture Area or Effecting Area (A_c) :–

In microwave antenna λ = few cm
r = few 1000km

$$A_c = \text{Capture Area} = \frac{\text{Power induced}}{\text{Poynting Vector}}$$

$$\boxed{A_c = \frac{\lambda^2}{4\pi} D}$$



Workbook :–

$$D \rightarrow G_D\big|_{max} \longrightarrow \Psi(\theta, \phi) \longrightarrow U(r, \theta, \phi) \longrightarrow E(r, \theta, \phi)$$

Hertzian Dipole , $|E| = \frac{k\sin\theta}{r}$

$$U(r, \theta, \phi) = \frac{1}{2} \frac{k^2 \sin^2\theta}{r^2 \cdot \eta}$$

$$\Psi(\theta, \phi) = \frac{1}{2} \frac{k^2 \sin^2\theta}{\eta}$$

$$G_D = 4\pi^2 \cdot \frac{1}{2} \frac{k^2 \sin^2\theta}{\eta}$$

$$\int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{1}{2} k^2 \frac{\sin^2\theta}{\eta} \sin\theta \, d\theta \cdot d\phi \qquad = \frac{2\sin^2\theta}{}$$

$$\int_{\theta=0}^{\pi} \sin^3\theta \, d\theta = \frac{4}{3}$$

$$\Leftarrow \qquad = \frac{3}{2} \sin^2\theta$$

$D = GD|_{max} = 1.5$

For Halfwave Dipole, $D = 1.63$

$4 - \frac{\lambda}{2}$ Dipoles

$$W_r = 4 I_{rms}^2 \cdot 73 = 4\left(\frac{0.5}{\sqrt{2}}\right)^2 73 = 36.5 \text{ Watts}$$

3. $D = \frac{4\pi}{\Omega_A}$

$\Rightarrow D = \frac{4\pi}{(\theta_{HPBW})^2}$

$10 \log D = 44 \text{ dB}$

$\Rightarrow D = 10^{4.4}$

$10^{4.4} = \frac{4 \times 3.14 \times (57)^2}{(\theta_{HPBW})^2}$

4. Efficiency $= \frac{R_r}{R_r + R_d}$

R_r for $\lambda/8$ Dipole

R_r $\lambda/2$ — 73Ω

R_r $\lambda/4$ — 36.5Ω

R_r $\lambda/8$ — 18.25Ω

Efficiency $= \frac{18.25}{19.75} = 89\%$

5. $\lambda \rightarrow 492 \text{ m}$

$d \rightarrow 124 \text{ m}$

$\frac{\lambda}{4} = 123 \text{ m}$

$R_r = 36.5\Omega$

6. $10 \log 4 = 6 \text{dB}$

$G = 4$

$W_{IN} = 1 \text{mW}$

lossless

$W_r = W_{IN}$

$\rightarrow$ Ans- (B)

7. (B)

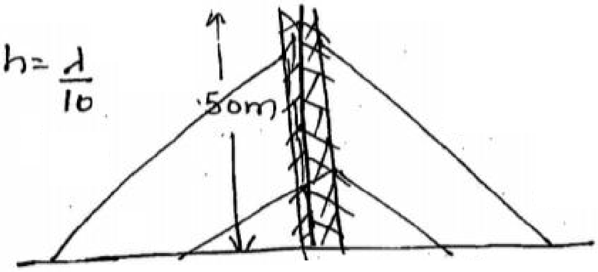
110

$h = 50m$

$f = 60\,kHz$

$\lambda = \frac{3\times10^8}{6\times10^5} = 500m$

$h = \frac{\lambda}{10}$



$R_r = 40\pi^2 \left(\frac{50}{500}\right)^2$

$\cong 4\Omega \quad = \frac{2\pi^2}{5}$

125 — $\lambda/4$ — 36.5Ω

50m — $\frac{\lambda}{10}$ — 4Ω

$W_r = I_{rms}^2 R_r$

7. $\Psi_{avg} = \frac{100}{4\pi} = \frac{25}{\pi} = 7.96$

$V_{avg} = \frac{100}{4\pi\times(10\times10^3)^2} = 7.96\times10^{-8}$

$= 0.08\,\mu W$

10. $\Psi \propto W_r \propto R_r \propto \frac{1}{\lambda^2} \times f^2$

strongly

$f' = f/2$

$\Psi' = \Psi/4$

11. $D = ?$ $\quad D = ?\,dB$

$D = \frac{4\pi\,\Psi(\theta,\phi)_{max}}{W_r}$

$= \frac{4\pi\cdot150}{0.9\,(W_{iN})} = \frac{4\pi\cdot150}{36\pi} = 16.67 = D$

$10\log 16.67 = 11.76\,dB$

$D = 11.76\,dB$

1 A — 1m — using

$\hookrightarrow$ Irms

$f = 10\,MHz$

$\lambda = \frac{3\times10^8}{10\times10^6} \times 30m$

$l = \frac{\lambda}{30}$

$W_r = I^2_{rms} R_r$

$R_r = 80\pi^2\left(\frac{1}{30}\right)^2 = 0.88\Omega$

$W_r = 0.88$

$$\left(\frac{dl}{\lambda}\right)\begin{cases} \lambda/2 \rightarrow 73\Omega \\ \frac{\lambda}{4} \rightarrow 36.5\Omega \\ \frac{\lambda}{10} \rightarrow 4\Omega \\ \frac{\lambda}{30} \rightarrow 0.88\Omega \end{cases}$$

13. $\theta_{HPBW} = 90^0$

14. A

15. Uniform currents $R_r = 80\pi^2\left(\frac{dl}{\lambda}\right)^2$

$l = 5m$

$\lambda = 100m$

$= 80\pi^2\left(\frac{\lambda}{20\lambda}\right)^2 \simeq 2\Omega$

16. A

18. $l = 1.5m$

$f = 100MHz$

$\lambda = 3m$

$l = \frac{\lambda}{2}$

$l = 15m$

$f = 10MHz$

$\lambda = 30m$

$l = \frac{\lambda}{2}$

Halfwave Dipole