

Module 7 : Antenna

Lecture 50 : Linear Antennas

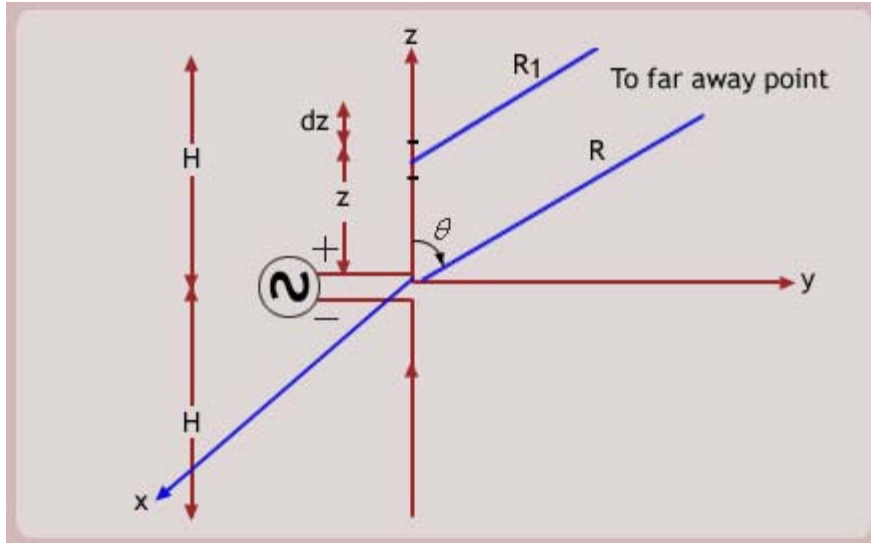
Objectives

In this course you will learn the following

- Dipole antenna.
- Radiation pattern of a dipole antenna.
- Input impedance of a dipole antenna.
- Half-wavelength dipole antenna.
- Monopole antenna.

Dipole Antenna

- The Hertz dipole has a limitation that its radiation resistance is too small and consequently is not a very efficient radiator.
- In practice dipole antennas of lengths comparable to the wavelength are used.
- A dipole antenna of length $2H$ oriented in the z -direction with its center at the origin of the coordinate system is shown in Fig.



- For these antennas since the length is comparable to the wavelength, the current distribution can not be uniform as we assumed for the Hertz dipole.
- However, as we mentioned, obtaining the current distribution is a difficult task and is beyond the scope of this course.
- The rigorous analysis show that the current distribution on a linear dipole antenna is sinusoidal with zero current at the ends of the antenna. The current distribution is given as

$$\begin{aligned}
 I(z) &= I_m \sin(\beta(H - |z|)) \\
 &= I_m \sin(\beta(H - |z|)) \quad \text{for } z > 0 \\
 &= I_m \sin(\beta(H + |z|)) \quad \text{for } z < 0
 \end{aligned}$$

- The radiation electric field due to the dipole can be obtained by dividing the dipole into small Hertz dipoles with appropriate currents and superposing their radiation fields with proper phase.

- Assuming that $R \gg H$, the total field at a point is given as

$$\begin{aligned}
 E_\theta &= j \frac{\beta^2 \sin \theta e^{-j\beta R}}{4\pi\omega \epsilon R} \int_{-H}^H I(z) e^{j\beta z \cos \theta} dz \\
 &= j60I_m \frac{e^{-j\beta R}}{R} F(\theta)
 \end{aligned}$$

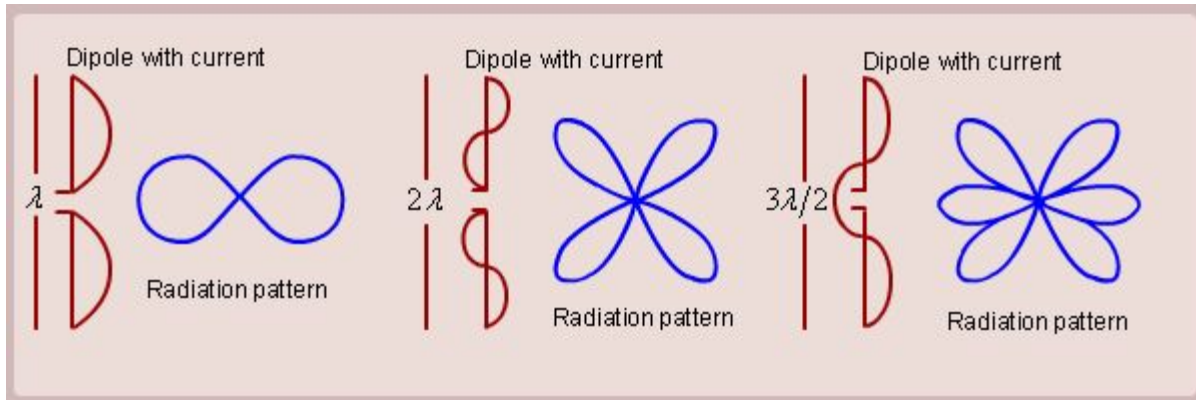
- Where we have defined

$$F(\theta) = \frac{\cos(\beta H \cos \theta) - \cos(\beta H)}{\sin \theta}$$

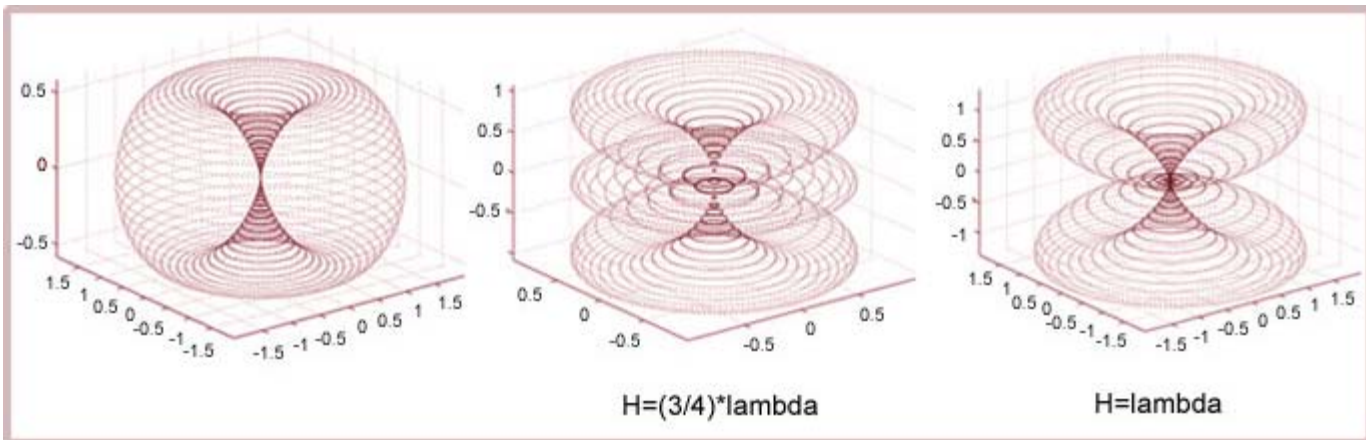
- The function $F(\theta)$ gives the variation of the electric field as a function of θ , and hence gives the E-plane radiation pattern of the dipole.

Radiation Pattern of a Dipole Antenna

- The current distribution and the radiation pattern of dipoles of different lengths are shown in Fig.



- Since the electric field is independent of ϕ , the H-plane radiation pattern is a circle which is same as that of the Hertz dipole.
- The three dimensional radiation patterns for the dipole antennas of length λ , $3\lambda/2$, 2λ are shown in Figs.



- In general a dipole antenna has multiple beams and multiple nulls. Generally, finding the directions of the nulls is easier compared to finding the directions of the maximum radiation. We therefore obtain the directions of the nulls and place one maximum approximately half way between two adjacent nulls.
- The directions of the nulls can be obtained by equating $F(\theta)$ to zero. The directions of the nulls are

$$\frac{\cos(\beta H \cos \theta_{null}) - \cos(\beta H)}{\sin \theta_{null}} = 0$$

$$\Rightarrow \cos(\beta H \cos \theta_{null}) = \cos(\beta H)$$

$$\Rightarrow \cos \theta_{null} = \pm 1 \pm \frac{2m\pi}{\beta H} = \pm 1 \pm \frac{m\lambda}{H}$$

Where $m = 0, 1, 2, 3, \dots$

Input Impedance of a Dipole Antenna

- Since the current has to be zero at the tip of the antenna, the current at the input of the antenna changes as the length of the dipole changes.

- In other words, the terminal impedance (input impedance) of the dipole is a function of length.

- The input impedance of the dipole is given as

$$Z_{in} = \frac{V}{I_{in}} = \frac{V}{I_m \sin \beta H}$$

- The input impedance is a function of the dipole length and can vary from $\frac{V}{I_m}$ to ∞ .

When $H = \text{odd multiple of } \frac{\lambda}{4}$, $|\beta H| = \pi/2$ and $\sin \beta H = 1$. In this case the input impedance is $\frac{V}{I_m}$.

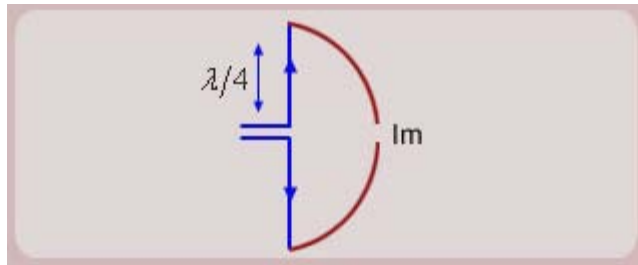
When $H = \text{even multiple of } \frac{\lambda}{4}$, (i.e., multiple of $\frac{\lambda}{2}$), $|\beta H| = m\pi$ and $\sin \beta H \rightarrow 0$ making impedance $Z_{in} \rightarrow \infty$.

- **NOTE**

The input impedance of a dipole antenna is not a monotonic function of length as it was in case of the Hertz dipole.

Half Wavelength Dipole antenna

- The most commonly used dipole is the half wavelength dipole ($\lambda/2$ -dipole).
- This antenna offers many advantages like
 - (1) Reasonable size
 - (2) Radiation pattern with single maximum
 - (3) Manageable input impedance
- A $\lambda/2$ -dipole is shown in Fig.



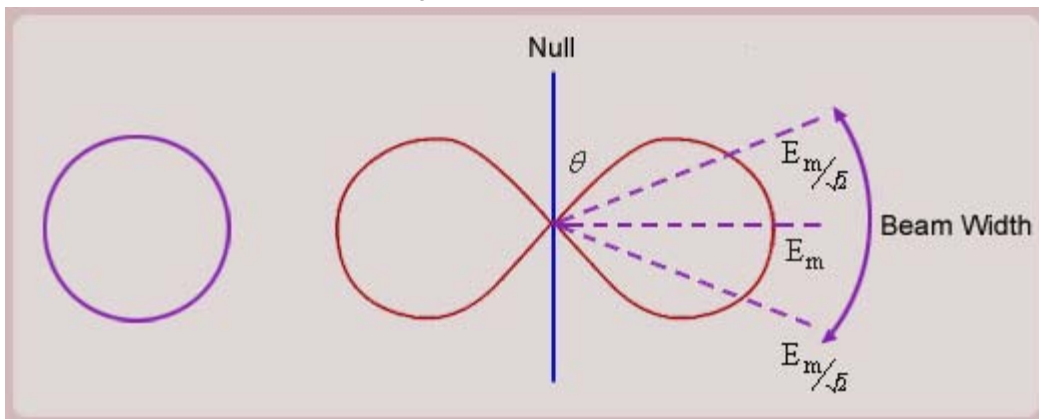
- For the $\lambda/2$ -dipole $H = \lambda/4$.
The **current distribution on the dipole** is

$$I(z) = I_m \cos \beta z$$

- The **radiation electric field** is given as

$$E_\theta = j60 \frac{I_m e^{-j\beta R}}{R} \frac{\cos\left(\frac{\pi}{2}\right) \cos \theta}{\sin \theta}$$

- The radiation pattern for the dipole is shown in Fig.



- The **total power radiated by the $\lambda/2$ -dipole** is

$$\begin{aligned} W &= \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} P_r R^2 \sin \theta d\theta d\phi \\ &= 2\pi \int_{\theta=0}^{\pi} \frac{15}{\pi} I_m^2 \frac{\cos^2\left(\frac{\pi}{2} \cos \theta\right)}{2} \sin \theta d\theta \end{aligned}$$

$$= 30I_m^2 \int_0^\pi \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} d\theta$$

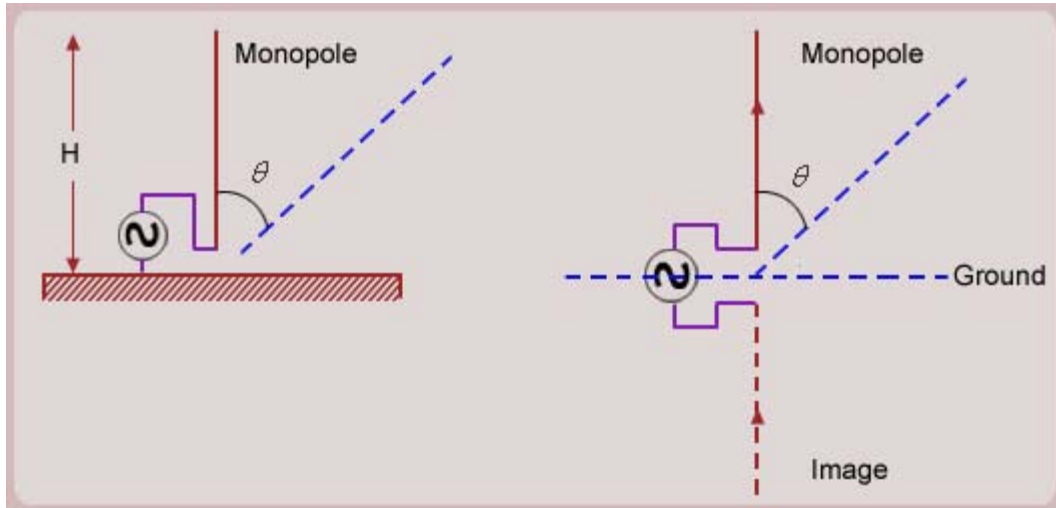
- Solving the integral numerically the total **radiated power and the radiation resistance** of the $\lambda/2$ -dipole are
- **The radiation resistance of the $\lambda/2$ -dipole is about 73 ohms.** The dipole due to the near fields has a reactance of about 34 ohms which can be removed by reducing the length of the dipole to about 0.47λ .
- The $\lambda/2$ -dipole dipole has an impedance which can be easily matched to 50 ohms using impedance transformers.
- For the $\lambda/2$ -dipole dipole we have following parameters:
 - Radiation pattern very similar to the Hertz dipole**
 - BWFN = 180 deg**
 - HPBW = 78 deg**
 - Directivity = 1.64 = 2.15 dB**
 - Input resistance = 73.1 ohm**
 - Effective Aperture = $1.125 \times 10^{-3} \lambda^2$**

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Monopole Antenna

- The monopole antennas are commonly used for the medium wave radio broadcasting. They also find application in walkie-talkies, other hand sets and cars.
- A monopole antenna is vertically mounted above the ground and is excited at the base as shown in Fig.



A monopole antenna is equivalent to a dipole as shown in the above Figure.

- The radiation characteristics of a monopole antenna and a dipole of double its length are identical except the radiation resistance and the radiated power.
- Since the monopole antenna radiates only in half space (above the ground), it radiates half the power compared to the corresponding dipole and consequently has the radiation resistance half of that of the corresponding dipole.
- The monopole antennas find applications at low frequencies where the wavelengths become excessively long.
- This antenna is also suited for medium wave transmission, because for that wavelength the earth behaves like a good conductor and therefore supports only vertical polarization.
- The monopole antenna naturally provides vertically polarized waves and an isotropic radiation pattern on the ground which is most suited for broadcasting applications.

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Recap

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