Antennas and Wave Propagation

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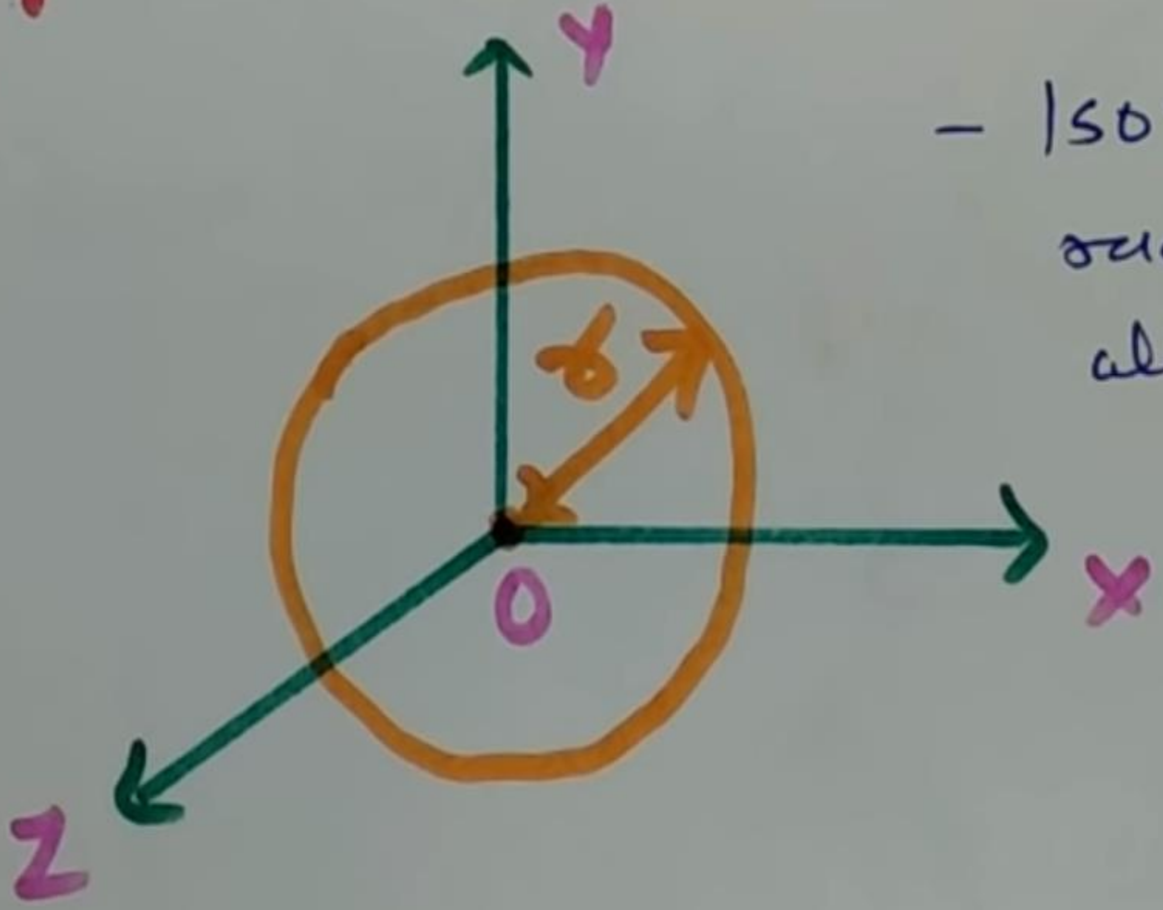
Book: Antenna theory: Analysis & Design (3^{rd} edition)

Antenna & Wave Propagation

Radiation Pattern

[Isotropic Antenna]
[Directional Antenna]
[Omnidirectional Antenna]

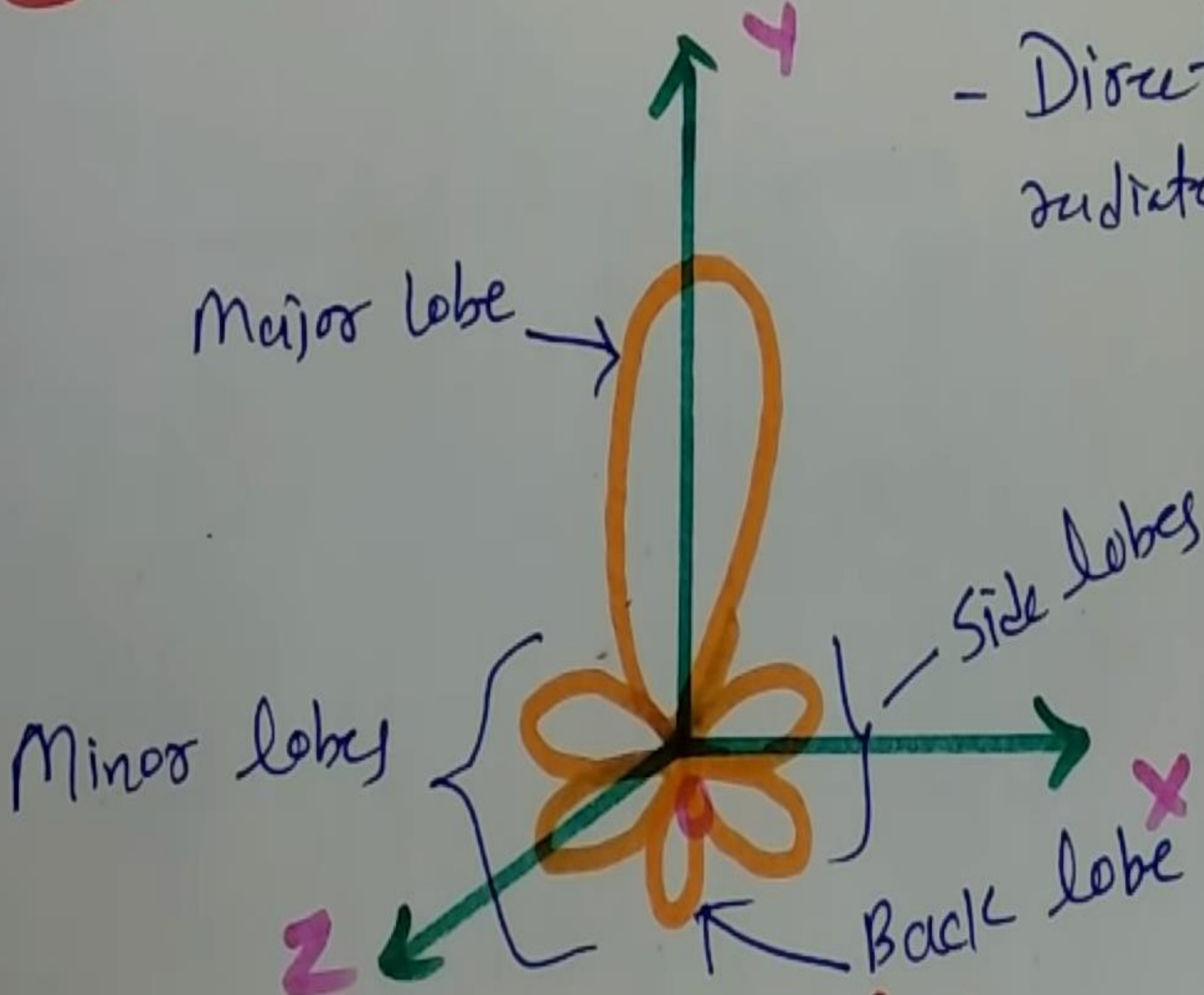
Isotropic Antenna



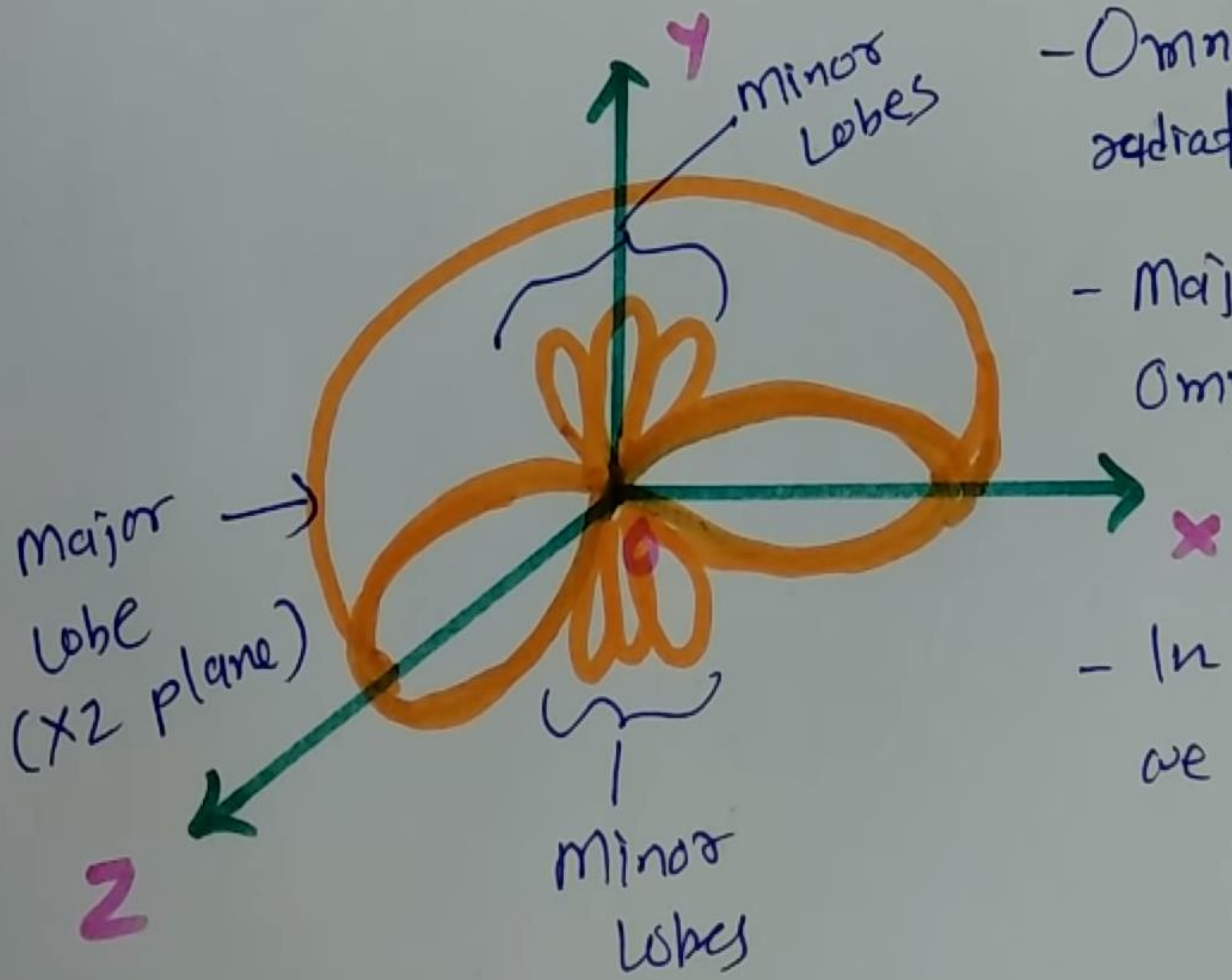
- Isotropic antenna radiates equally in all the direction.
- It's radiation pattern will be sphere

Directional Antenna

- Directional antenna radiates in particular direction

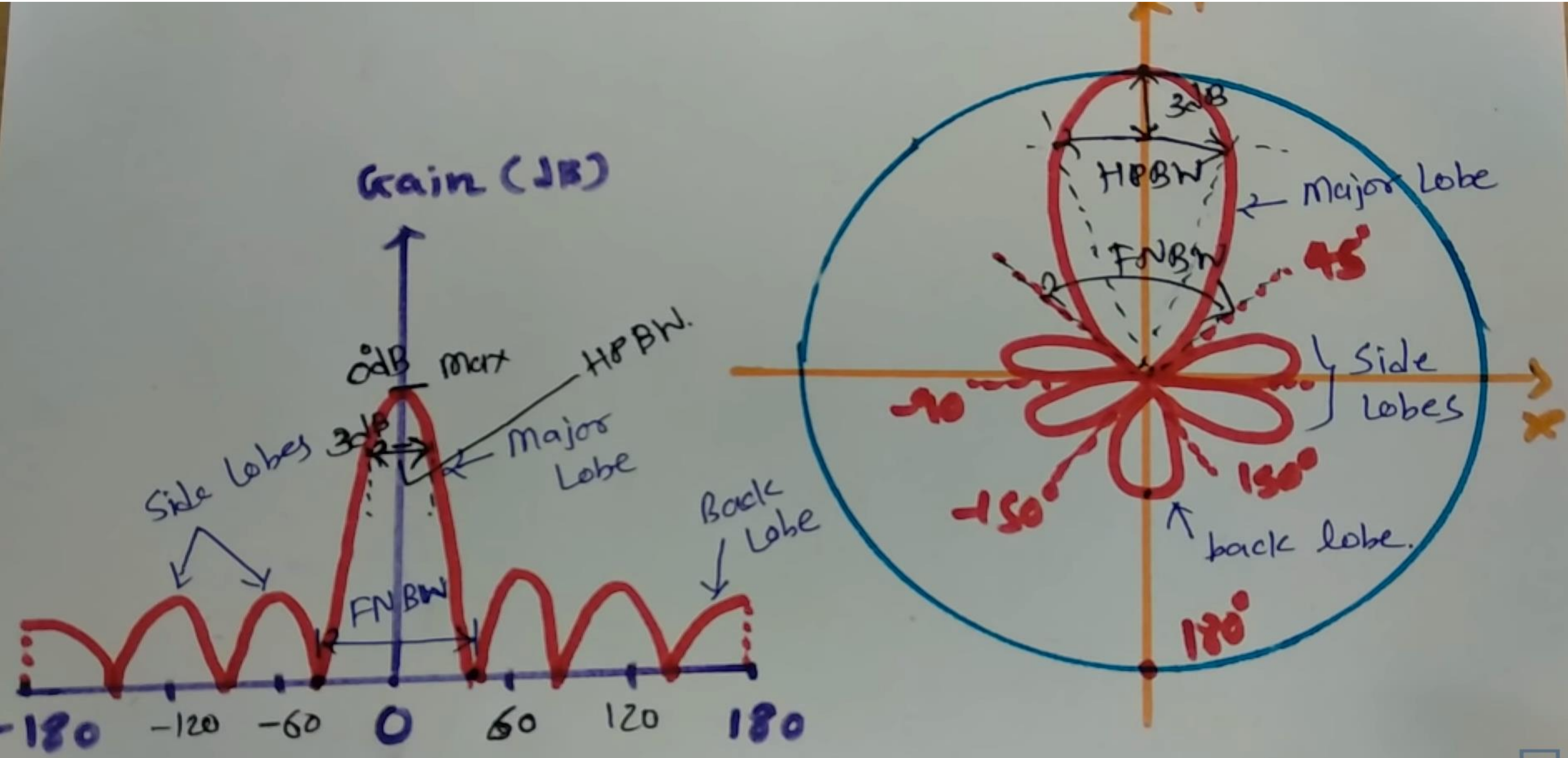


Omnidirectional Antenna



- Omnidirectional antenna radiates in plane.
- Major Lobe of Omnidirectional antenna is in plane.
- In Omnidirectional antenna we don't have back lobe

Basic Parameters of Radiation Pattern



HPBW (half power Beam width)

It is a angular width of major lobe, from max to 3-dB down.

FNBW (First Null Beam width).

It is a width of major lobe.

Front to back ratio.

It is a ratio of gain from major lobe to back lobe.

Radiation Density and Radiated Power

→ when electromagnetic wave travels in space. The power density of radiation by antenna related to electric and magnetic field is given by

$$\vec{W} = \vec{E} \times \vec{H} \quad (W/m^2)$$

→ So for Instantaneous power

$$P_{int} = \oint \vec{W} \cdot \vec{ds}$$

→ Average power density

$$W_{avg} = \frac{1}{2} Re [\vec{E} \times \vec{H}]$$

so, radiated (Avg) power by antenna

$$P_{rad} = \oint_S \vec{\omega}_{avg} \cdot \vec{ds}$$

$$= \oint_S \left(\frac{1}{2} Re(\vec{E} \times \vec{H}) \right) \cdot \vec{ds}$$

$$= \frac{1}{2} \oint_S Re(\vec{E} \times \vec{H}) \cdot \vec{ds}$$

Beam Efficiency

→ Ω_m = Solid angle for major lobe

Ω_{m} = Solid angle for minor lobes

→ total Solid angle

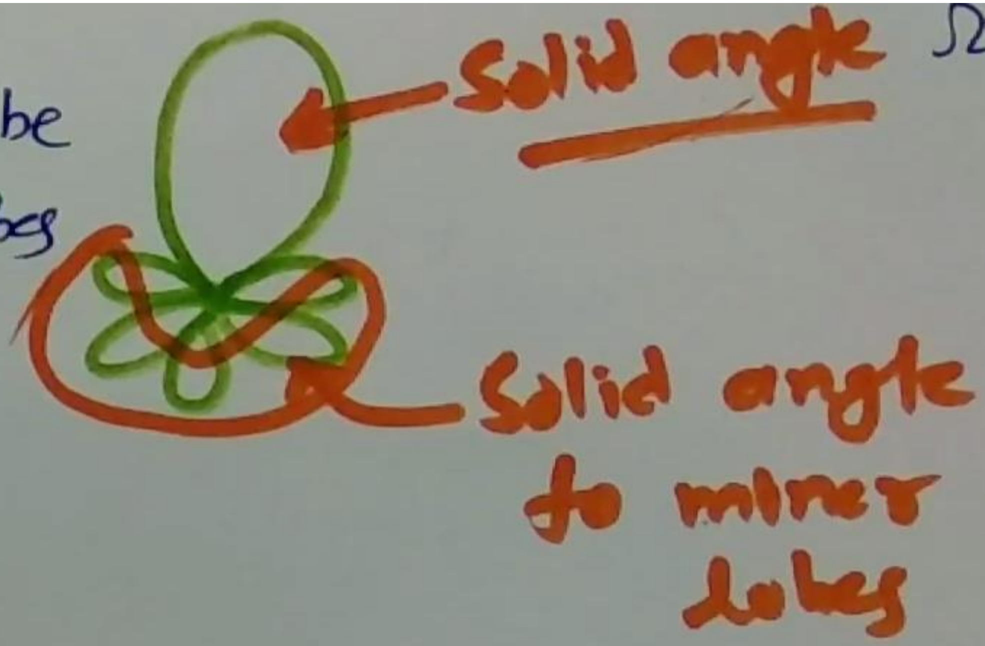
$$\Omega_A = \Omega_m + \Omega_{m}$$

→ Beam efficiency

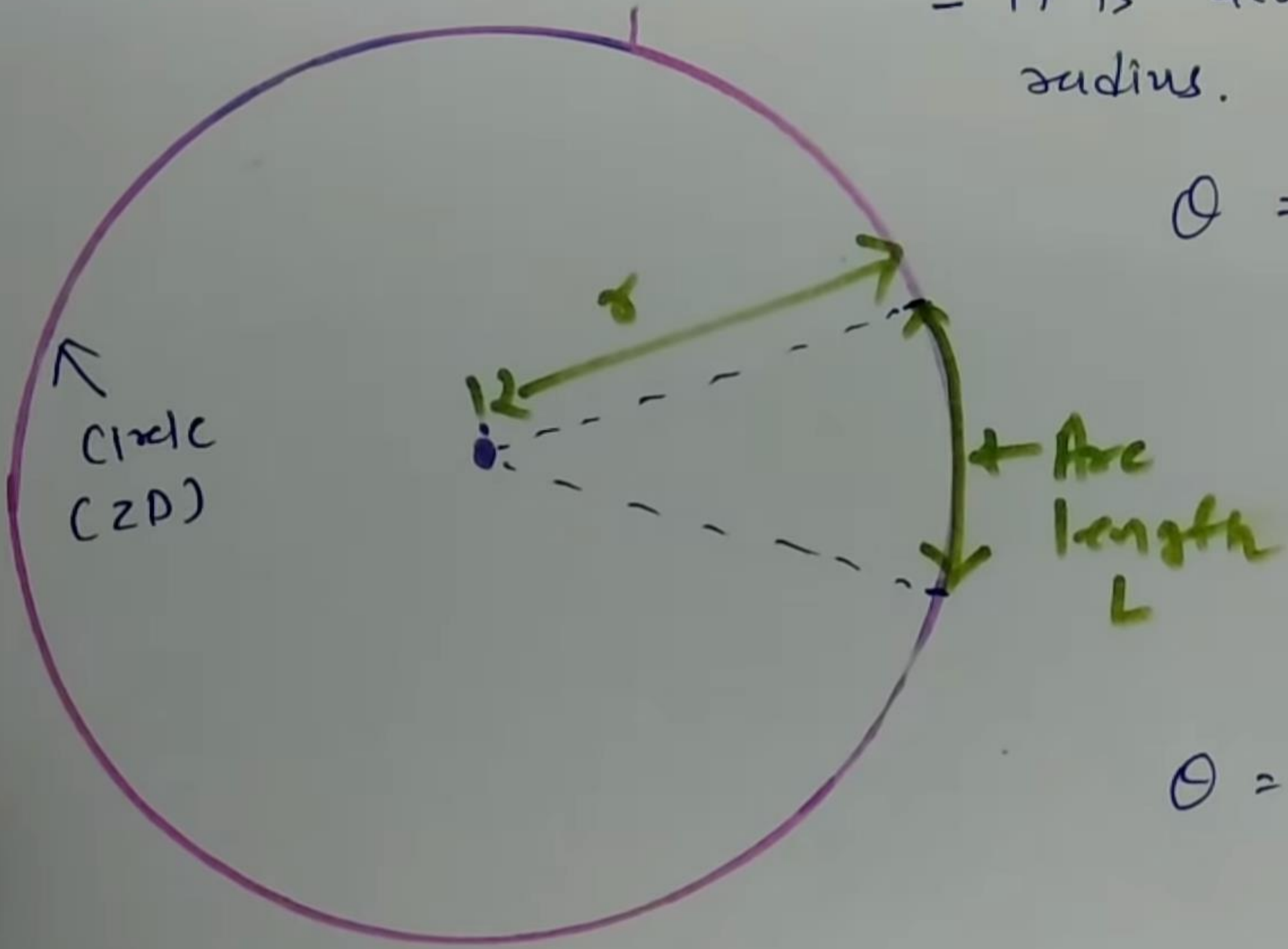
$$\varepsilon_m = \frac{\Omega_m}{\Omega_A}$$

→ Stray factor

$$\varepsilon_{m} = \frac{\Omega_{m}}{\Omega_A}$$



- Angle [Radian]



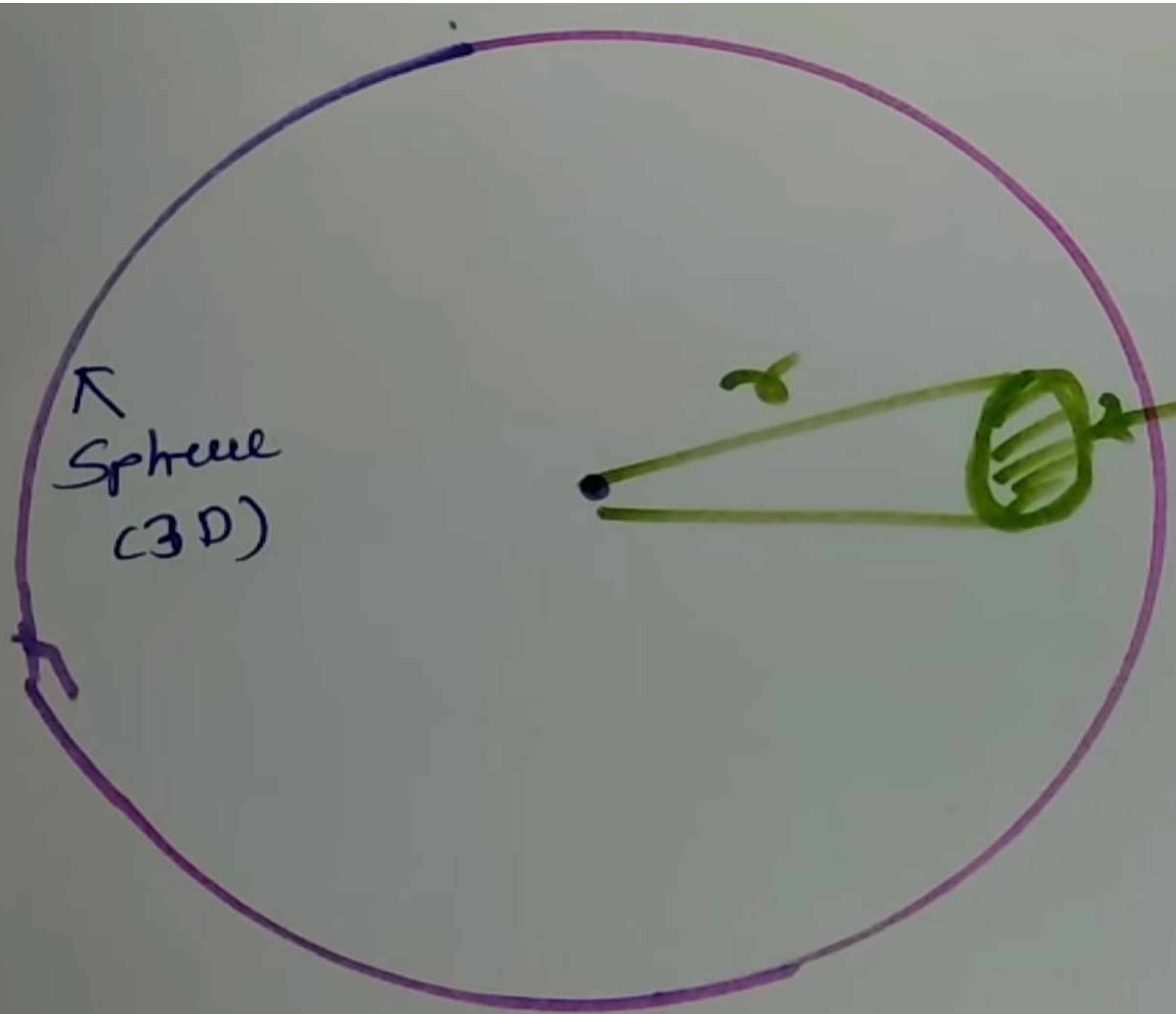
- It is arc length per unit radius.

$$\theta = \frac{\text{Arc length}}{\text{Radius}} = \frac{L}{r} \text{ (Rad}$$

→ for complete circle, arc length $= 2\pi r$

$$\theta = \frac{2\pi r}{r} = 2\pi \text{ (Rad)}.$$

Solid Angle (steradian)



- It is amount of area per square of radius.

$$\phi = \frac{Area}{radius^2} \ (Sr)$$

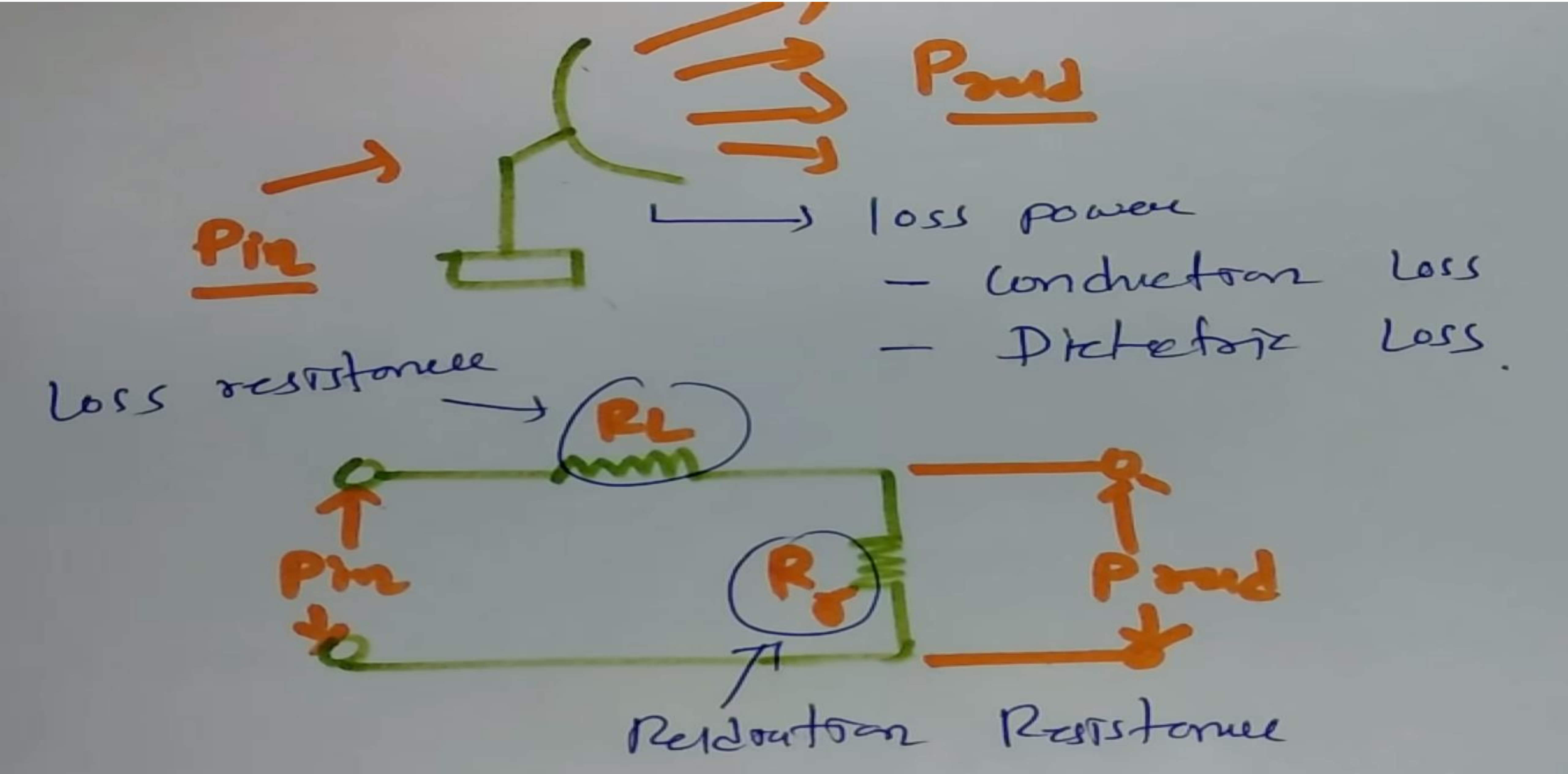
- for complete sphere, surface area is

$$= 4\pi r^2$$

$$\phi = \frac{4\pi r^2}{r^2} = 4\pi \ (Sr).$$

Solid angle is angle measurement in 3D.

Antenna Radiation Efficiency



→ Radiation efficiency

$$= \frac{P_{rad}}{P_{in}} = \frac{R_r}{R_r + R_L}$$

→ By Increasing radiation resistance, we can Increase radiation efficiency..

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→ $R_L = 10\Omega$

$R_r = 10\Omega$

→ $\epsilon_{rad} = \frac{R_r}{R_r + R_L}$

$= 0.5$

→ $R_L = 10\Omega$

$R_r = 40\Omega$

→ $\epsilon_{rad} = \frac{40}{40+10}$

$= 0.8$

Examples on Antenna Radiation Efficiency

- The antenna supplied with a power of 10 Watts. Calculate the power radiated when the efficiency of antenna is 90%.

$P_{in} = 10\,W$

$\eta = 90\% = 0.9$

$\rightarrow \eta = \dfrac{P_{rad}}{P_{in}} \Rightarrow P_{rad} = \eta P_{in}$

$\Rightarrow P_{rad} = 0.9 \times 10$

$= 9\,W$

Radiation Resistance of an antenna is 80 Ω and loss resistance is 10 Ω. Calculate antenna radiation efficiency.

$R_{rad} = 80\,\Omega$

$R_{Loss} = 10\,\Omega$

$$\eta = \frac{R_{rad}}{R_{rad} + R_{Loss}}$$

$$= \frac{80}{80 + 10}$$

$$= \frac{80}{90} = \frac{8}{9}$$

Directivity

- The directivity of an antenna is defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity avg. over all direction.

$$D = \frac{U_{\text{given direction}}}{U_{\text{avg}}}$$

avg. over all direction.

$$D = \frac{U_{\text{given direction}}}{U_{avg}}$$

- Average radiation Intensity

$$U_{avg} = \frac{P_{rad}}{4\pi}$$

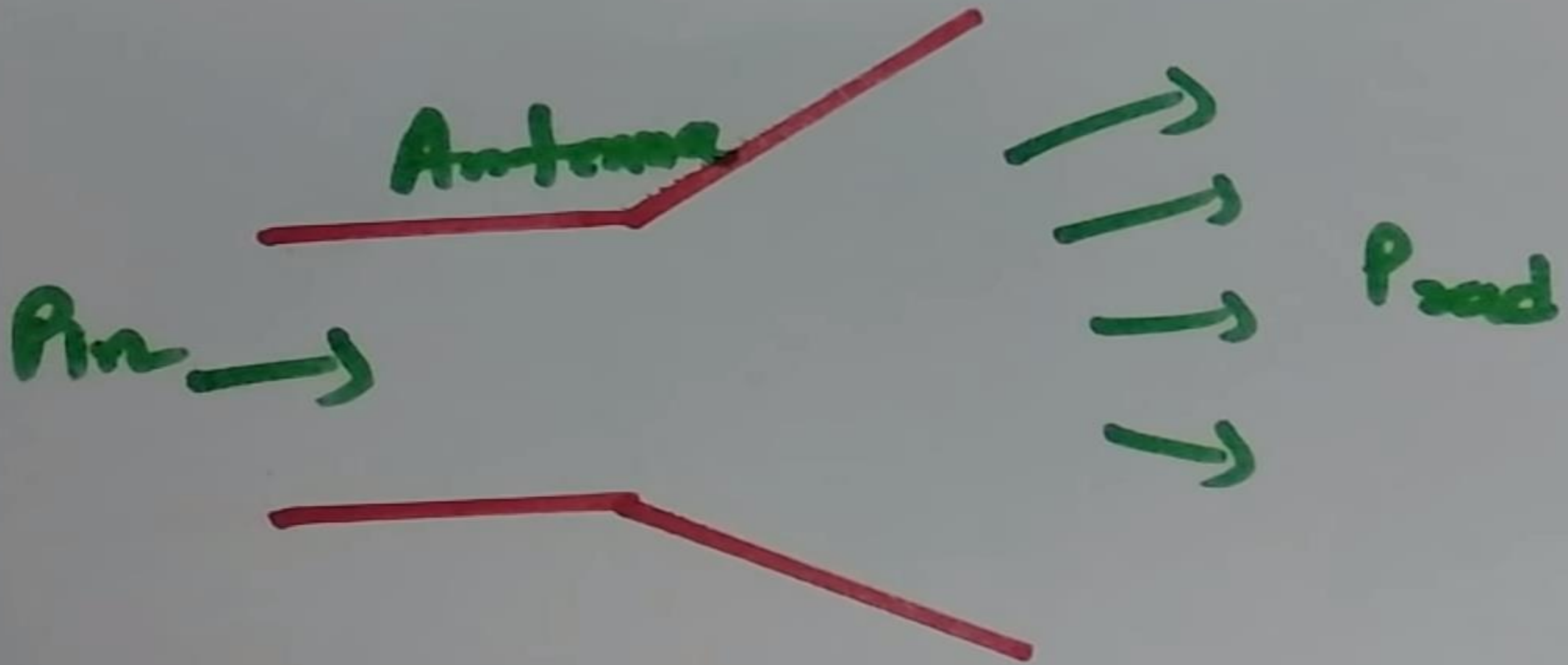
- Directivity,

$$D = \frac{4\pi U}{P_{rad}}$$

Antenna Gain

→ We have seen directivity of Antenna

$$D = \frac{4\pi U_m}{P_{rad}}$$



→ for Gain of antenna we need to use Pin instead of Prad in directivity.

$$G = \frac{4\pi U_m}{P_{in}} \quad — (2)$$

→ efficiency of antenna

$$K = \frac{P_{rad}}{P_{in}}$$

→ (2)/(1)

$$\Rightarrow \frac{G}{D} = \frac{4\pi U_m / P_{in}}{4\pi U_m / P_{rad}} = \frac{P_{rad}}{P_{in}} = K$$

$$\Rightarrow G = KD$$

→ ② / ① ⇒ $\frac{G}{D} = \frac{4\pi U_m / P_{in}}{4\pi U_m / P_{rad}} = \frac{P_{rad}}{P_{in}} = K$

$$\Rightarrow \boxed{G = KD}$$

Gain of antenna can be measured by AUT with respect to reference antenna. (isotropic antenna)

$$\Rightarrow \boxed{G = \frac{U_{AUT}}{U_{Ref}}}$$

U_{AUT} → **Rad intensity of antenna under test**

$U_{Ref} = \frac{P_{in}}{4\pi}$ | → $G = \frac{U_{AUT}}{P_{in}/4\pi} = \boxed{\frac{4\pi U_{AUT}}{P_{in}}}$

The radiation resistance of an Antenna is 72 Ω and the loss resistance is 8 Ω. What is the directivity If antenna power Gain is 16.

$$R_r = 72\,\Omega$$
$$R_L = 8\,\Omega$$
$$G = 16$$

$$\rightarrow K = \frac{R_r}{R_r + R_L}$$
$$= \frac{72}{72+8}$$
$$= \frac{72}{80}$$
$$= 0.9$$

$$\Rightarrow G = KD$$
$$\Rightarrow 16 = 0.9 \times D$$
$$\Rightarrow D = 16/0.9$$
$$= 17.77$$
$$= 10 \log 17.77$$
$$= 12.498\ dB$$

An Antenna has a loss resistance of 10Ω, power gain of 20 and directivity 22. Calculate the radiation resistance.

→ $R_L = 10\Omega$

$G = 20$

$D = 22$

$\Rightarrow G = KD$

$\Rightarrow K = G/D$

$= 20/22$

$= 10/11$

$= 0.909$

$\Rightarrow K = \dfrac{R_r}{R_r + R_L}$

$\Rightarrow \dfrac{10}{11} = \dfrac{R_r}{R_r + 10}$

$\Rightarrow 10 R_r + 100 = 11 R_r$

$\Rightarrow \boxed{R_r = 100\,\Omega}$