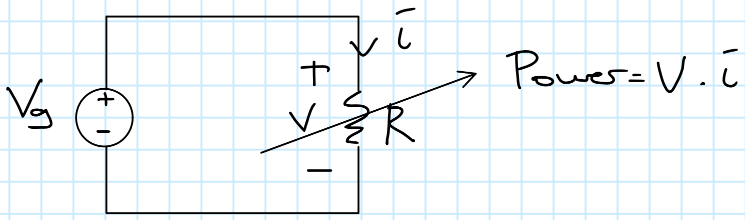
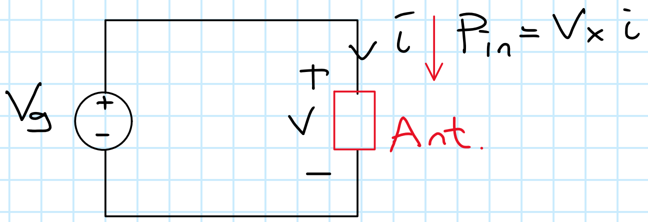
EE 451
ANTENNA THEORY

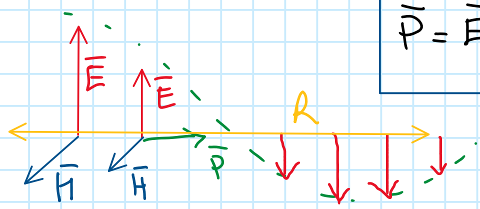
P1

Thursday, February 22, 2024 2:47 PM

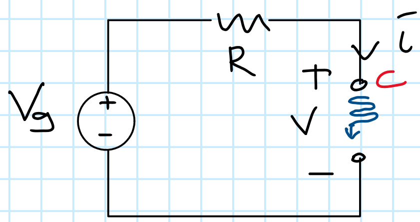
Antenna: is a device that converts electrical energy into electromagnetic waves energy.

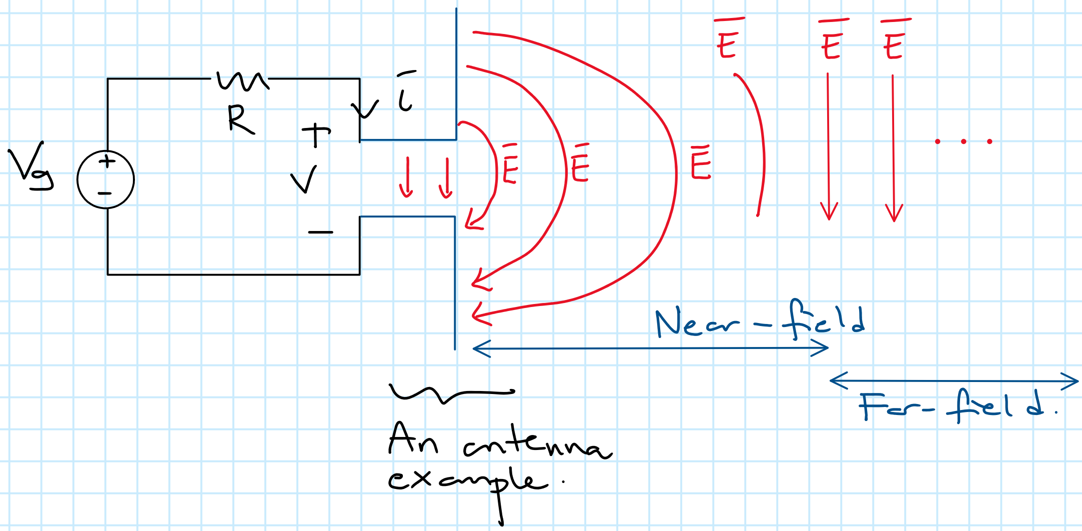






$$\boxed{\bar{P} = \bar{E} \times \bar{H} \quad \left(\frac{W}{m^2}\right)}$$



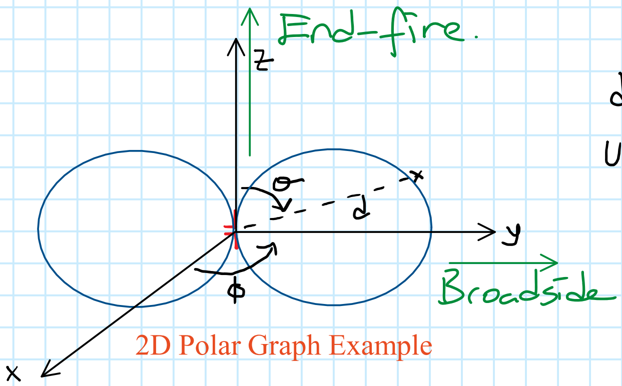


EE 451 ANTENNA THEORY
ANTENNA PROPERTIES

Sunday, November 12, 2023 8:03 PM

1-) Radiation Pattern: (Işıma Örüntüsü)

- 2D or 3D space distribution of radiated E.M. energy.
- Usually, rectangular or spherical coordinates are used.
- Mostly, 2D polar or 3D polar graphs are used.



2D Polar Graph Example

d = Magnitude of the radiated energy.

Usually,

$d = E_0$ E-field rad. pattern

$d = P_0$ Power density rad. pattern

yz-plane = Elevation plane. (θ)

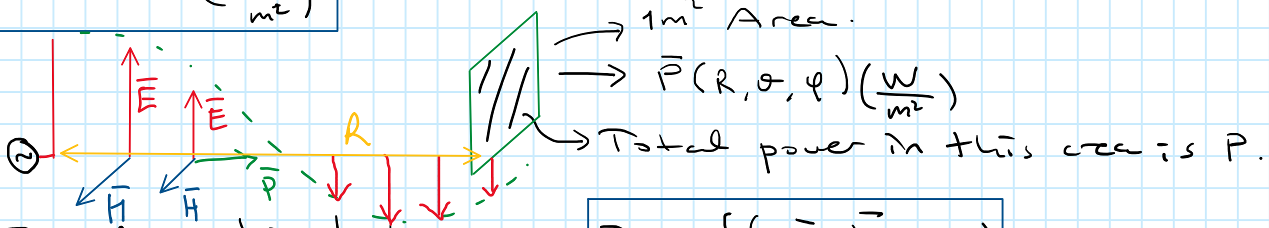
xy-plane = Azimuth plane (ϕ)

and θ = Angle from the z-axis.

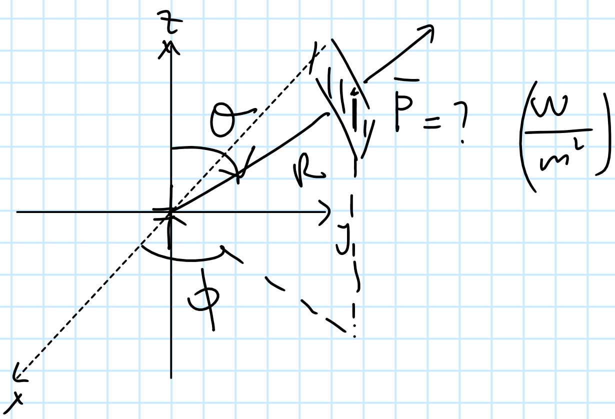
For 3D Polar Plots: ϕ = Angle made with the x-axis.

2-) Power Density $\left(\frac{W}{m^2}\right)$ = Poynting vector:

$$\boxed{\bar{P} = \bar{E} \times \bar{H} \quad \left(\frac{W}{m^2}\right)}$$



Total radiated power = $\boxed{P_t = \iint_{Sphere} \bar{P} \cdot \bar{ds} \ (W)}$



P3

Tuesday, February 20, 2024 7:38 PM

Ex:

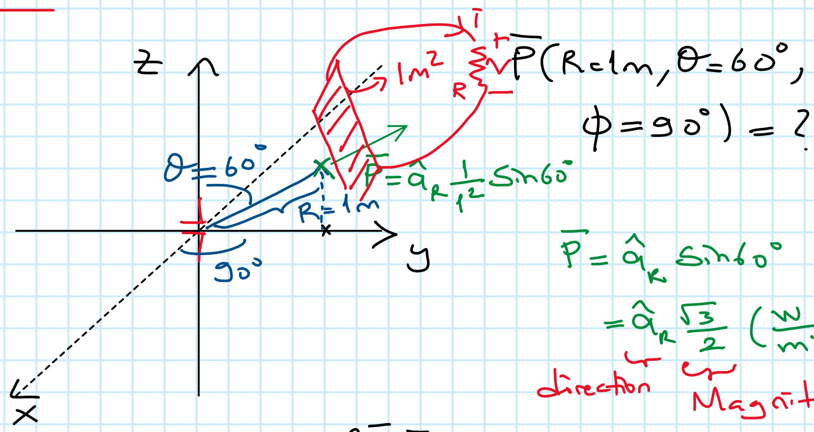
Given $\bar{P} = \hat{a}_R \frac{1}{R^2} \sin\theta$ (W/m^2),

a-) Find $\bar{P}$ at $(R, \theta, \varphi) = (1m, 60°, 90°)$.

b-) Find the total power radiated by this antenna.

Ans:

a-)



$$\bar{P} = \hat{a}_R \sin 60°$$

$$= \underbrace{\hat{a}_R}_{\text{direction}} \underbrace{\frac{\sqrt{3}}{2}}_{\text{Magnitude}} \left(\frac{W}{m^2}\right)$$

b-) $$P_t = \iint_{\text{sphere}} \bar{P} \cdot \bar{ds} = \int_0^{2\pi}\int_0^{\pi} \hat{a}_R \frac{1}{\cancel{R^2}} \sin\theta \cdot \underbrace{\hat{a}_R \cancel{R^2} \sin\theta \, d\theta \, d\phi}_{\bar{ds} \text{ in spherical coord.}}$$

$$= \int_0^{2\pi}\int_0^{\pi} \sin^2\theta \, d\theta \, d\phi$$

$$= \int_0^{2\pi}\int_0^{\pi} \frac{1}{2}(1 - \cos 2\theta) \, d\theta \, d\phi$$

$$= \frac{1}{2}\int_0^{2\pi}\int_0^{\pi} d\theta \, d\phi - \frac{1}{2}\int_0^{2\pi}\int_0^{\pi} \cos 2\theta \, d\theta \, d\phi$$

$$= \frac{1}{2}(2\pi)(\pi) - \frac{2\pi}{2}\int_0^{\pi} \cos 2\theta \, d\theta$$

$$= \pi^2 - \pi \underbrace{\frac{1}{2}\sin 2\theta \Big|_0^{\pi}}_{0} = \pi^2 \, (W) = 9.87 \approx 10W.$$

Note: The part of the power density function $\bar{P}$ that is a function of directions (θ and/or ϕ) is called the "radiation pattern".

In this question, the radiation pattern is

$$f(\theta) = \sin\theta.$$

P4

Friday, January 12, 2024 10:35 AM

3-) Directivity:

By definition $\boxed{D(\theta,\varphi) = \frac{P(\theta,\varphi)}{P_o}}$, where $P(\theta,\varphi)$ = Power density of the antenna at a constant R.

and

P_o = Power density of an $\underbrace{\text{isotropic antenna}}_{\text{The antenna that radiates}}$.

equal energy in all directions. $\Rightarrow$ $\boxed{P_o = \frac{P_t}{4\pi R^2} \left(\frac{W}{m^2}\right)}$ $4\pi R^2$ = Area of a sphere.

Thus, the directivity is the ratio of a power density in a certain direction with respect to the isotropic antenna.

$$\Rightarrow \boxed{D = \frac{P(\theta,\varphi)}{\frac{P_t}{4\pi R^2}} = 4\pi R^2 \frac{P}{P_t}}.$$

Usually, $P(\theta,\varphi)$ is used for θ and φ that make $P(\theta,\varphi)$ maximum. Thus $D(\theta,\varphi)$ becomes D.

Ex:

Given $\bar{P} = \hat{a}_R \frac{1}{R^2} A_o \sin\theta \left(\frac{W}{m^2}\right)$ for an antenna. Find its directivity.

<u>Ans:</u>

$$D = 4\pi R^2 \frac{P}{P_t}$$

Power density at θ, ϕ for which P is max.

$$\Rightarrow P = P\Big|_{\theta=90^\circ} = \frac{1}{R^2} A_o \overset{1}{\cancel{\sin 90^\circ}} = \frac{A_o}{R^2} \left(\frac{W}{m^2}\right)$$

$$P_t = \iint_{\text{sphere}} \bar{P} \cdot \bar{ds} = A_o \pi^2 \ (W)$$

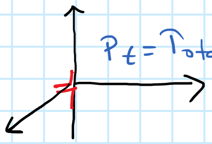
$$\Rightarrow D = 4\cancel{\pi}\cancel{R^2} \frac{\cancel{A_o}}{\cancel{R^2}} \frac{1}{\cancel{A_o}\pi^{\cancel{2}}} = \frac{4}{\pi} = 1.27$$

4-7 Antenna Gain:

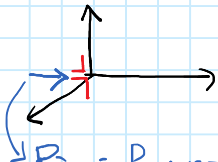
$$D = \frac{P}{P_o}, \quad \text{Gain} = G = \frac{P}{\frac{P_{in}}{4\pi R^2}} = 4\pi R^2 \cdot \frac{P}{P_{in}}$$

$$P_o \rightarrow \frac{P_t}{4\pi R^2}$$

$P_{in} > P_t$ ✓ or $\cancel{P_t > P_{in}}$



P_t = Total power radiated



P_{in} = Power fed to the antenna from the transmitter.

$\Rightarrow D > G$

$P_{in} - P_t$ is the loss power in the antenna itself as heat dissipation.

$\boxed{P_t = \epsilon P_{in}}$, ϵ = Antenna Efficiency, $0 < \epsilon < 1$.

Ideally, we want $\epsilon = 1$. In reality, $\epsilon < 1$. But for many antennas ϵ is very close to 1.

$\Rightarrow \boxed{G = \epsilon D.}$

P6

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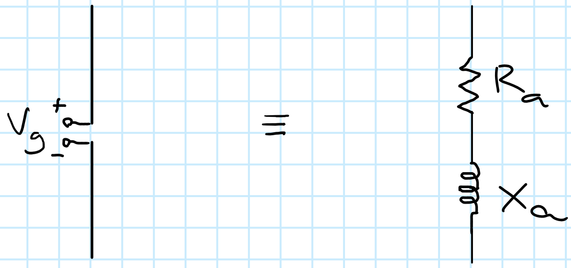
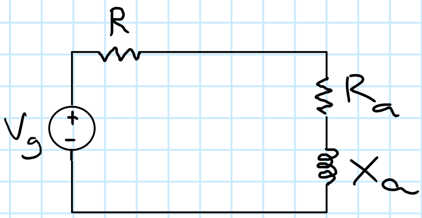
5- Antenna Impedance:

An antenna can be modelled by a resistor and a reactance:



$Z_A = R_a + jX_a$
(Antenna input impedance)

When the antenna is connected to a voltage source like a function generator;



$R_a = R$ (for max. power transfer)

$P_{R_a} = P_{rad} = P_t$ (W)

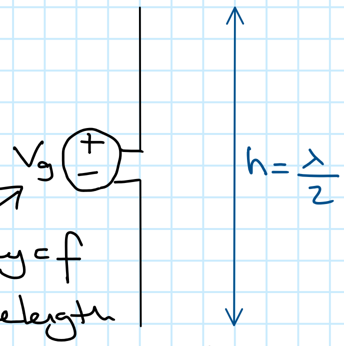
P_R = Power used by the transmitter.

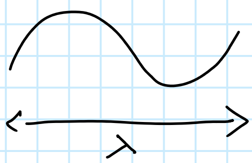
The best is

$$P_R = \frac{P_{total}}{2}, \quad P_{R_a} = \frac{P_{total}}{2} \text{ (W)}.$$

Q_a is the reactive power that corresponds to stored energy around the antenna. This is unwanted. Thus, we insert a component opposite to the antenna reactance.

Half Wave Dipole Antenna:





frequency = f

λ = Wavelength

$\lambda = \frac{c}{f}$, $c = 3 \times 10^8$ m/s.

P7

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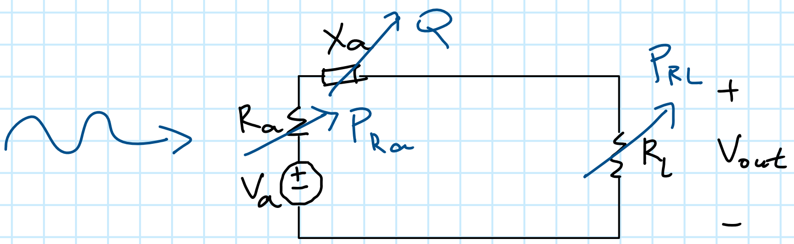
$- \text{At } f = 433\,\text{MHz}, \quad \lambda = \frac{c}{f} = \frac{3\times 10^{\cancel{8}\,2}}{433\times 10^{\cancel{6}}} = \frac{300}{433} = 0.69\,\text{m}$

$\approx 68\,\text{cm}$

$\Rightarrow \frac{\lambda}{2} = \text{Antenna height} = 34\,\text{cm}.$

Receiver Antenna Circuit Model:



- $R_L = R_a$ for maximum power reception.
- $X_a = 0$ is ideal.

P_{R_L} = Received power by the receiver.

Q = Stored energy around the antenna.

P_{R_a} = Re-radiated power.

Assignment 2 (due as presentation on 22/10/2025)

Design a half wave dipole antenna, and simulate it in Ansys HFSS for its radiation pattern, gain, and the input impedance.
Take measurement of these three parameters as wavelength is decreased slightly. For example from 34 cm down to 30 cm in steps of 0.5 cm.