

Campi Elettromagnetici

**Corso di Laurea in Ingegneria Informatica,
Biomedica e delle Telecomunicazioni**

a.a. 2019-2020 - Laurea "Triennale" – Secondo semestre - Secondo anno

Università degli Studi di Napoli "Parthenope"

Stefano Perna

Color legend

New formulas, important considerations,
important formulas, important concepts

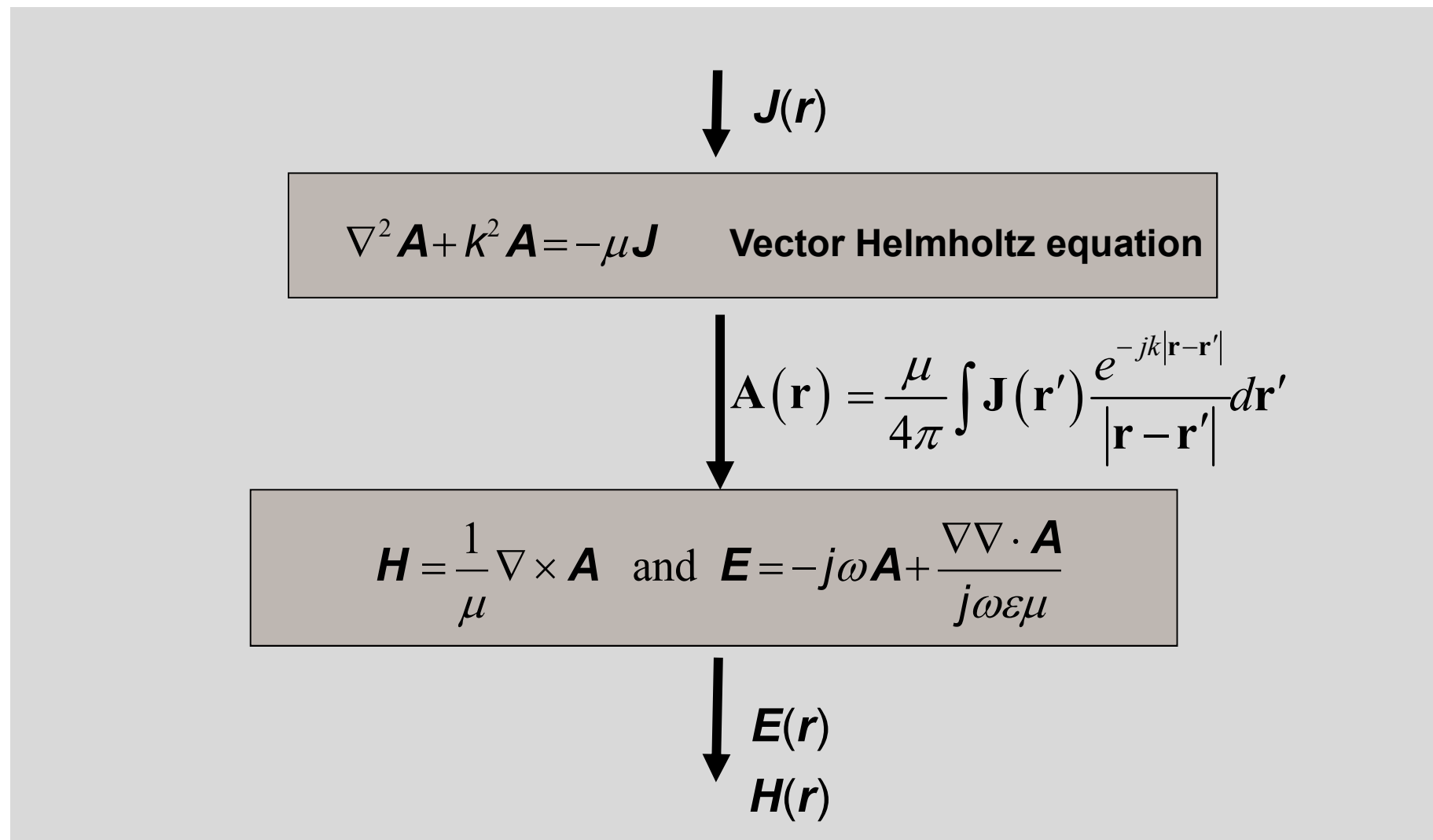
Very important for the discussion

Memo

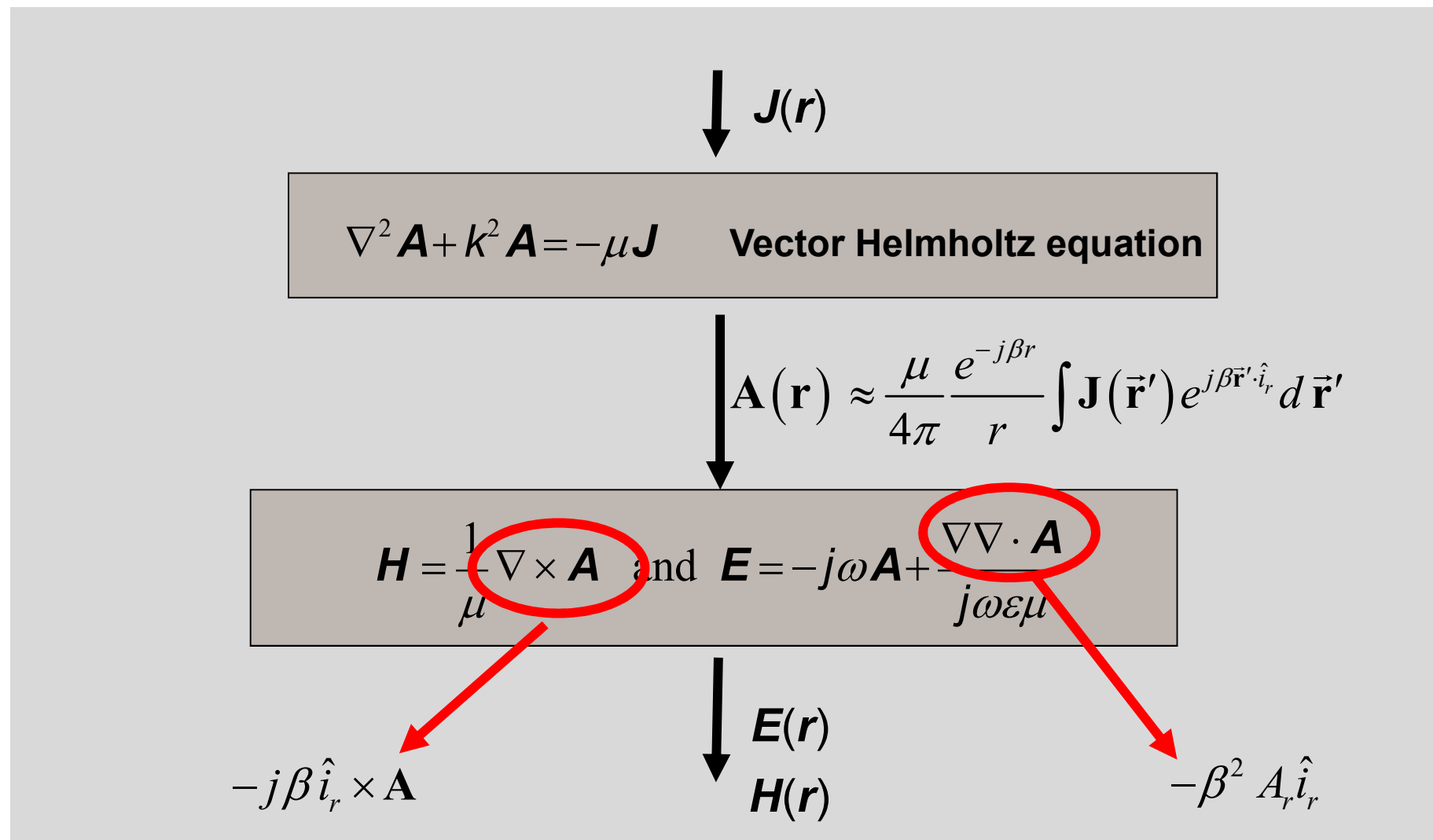
Mathematical tools to be exploited

Mathematics

Radiation problem for extended antennas



Radiation problem for extended antennas



Fraunhofer region

$$r \gg D$$

$$r > \frac{2D^2}{\lambda}$$

$$r \gg \lambda$$

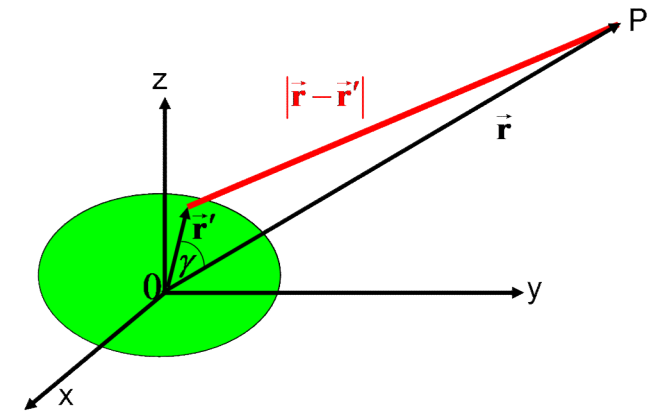
Fraunhofer region

$$\mathbf{E}(\vec{\mathbf{r}}) = \mathbf{E}(r, \vartheta, \varphi) = -\frac{j\omega\mu}{4\pi} \frac{e^{-j\beta r}}{r} \left[\mathbf{M}(\vartheta, \varphi) - M_r(\vartheta, \varphi) \hat{i}_r \right] = -\frac{j\omega\mu}{4\pi} \frac{e^{-j\beta r}}{r} \left[M_\vartheta(\vartheta, \varphi) \hat{i}_\vartheta + M_\varphi(\vartheta, \varphi) \hat{i}_\varphi \right]$$

$$\zeta \mathbf{H}(\vec{\mathbf{r}}) = \hat{i}_r \times \mathbf{E}(\vec{\mathbf{r}})$$

- the e.m. field propagates along \hat{i}_r
- the e.m. field lies on the plane orthogonal to the propagation direction
- $|E|$ and $|H|$ exhibit the decaying factor $1/r$
- $|E|$ and $|H|$ are proportional through ζ

$$\mathbf{M}(\vartheta, \varphi) = \int \mathbf{J}(\vec{\mathbf{r}}') e^{j\beta \vec{\mathbf{r}}' \cdot \hat{i}_r} d\vec{\mathbf{r}}'$$



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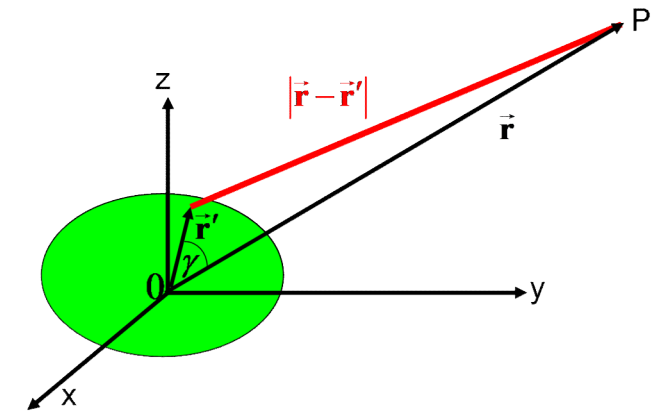
$$\mathbf{M}(\vartheta, \varphi) = \int \mathbf{J}(\vec{r}') e^{j\beta \vec{r}' \cdot \hat{i}_r} d\vec{r}'$$

Fraunhofer region

$$\vec{\mathbf{S}} = \frac{1}{2} \vec{\mathbf{E}} \times \vec{\mathbf{H}}^* = \frac{1}{2\zeta} \vec{\mathbf{E}} \times (\hat{i}_r \times \vec{\mathbf{E}})^* = \frac{1}{2\zeta} \vec{\mathbf{E}} \times (\hat{i}_r \times \vec{\mathbf{E}}^*) = \frac{1}{2\zeta} \left[|\vec{\mathbf{E}}|^2 \hat{i}_r - (\hat{i}_r \times \vec{\mathbf{E}}) \vec{\mathbf{E}}^* \right] = \frac{1}{2\zeta} |\vec{\mathbf{E}}|^2 \hat{i}_r$$

$$\vec{\mathbf{S}} = \frac{1}{2} \vec{\mathbf{E}} \times \vec{\mathbf{H}}^* = \frac{\zeta}{2} |\vec{\mathbf{H}}|^2 \hat{i}_r$$

$$\vec{\mathbf{A}} \times (\vec{\mathbf{B}} \times \vec{\mathbf{C}}) = \vec{\mathbf{B}}(\vec{\mathbf{A}} \cdot \vec{\mathbf{C}}) - \vec{\mathbf{C}}(\vec{\mathbf{A}} \cdot \vec{\mathbf{B}})$$



Fraunhofer region

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$$r > \frac{2D^2}{\lambda}$$

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Fraunhofer region

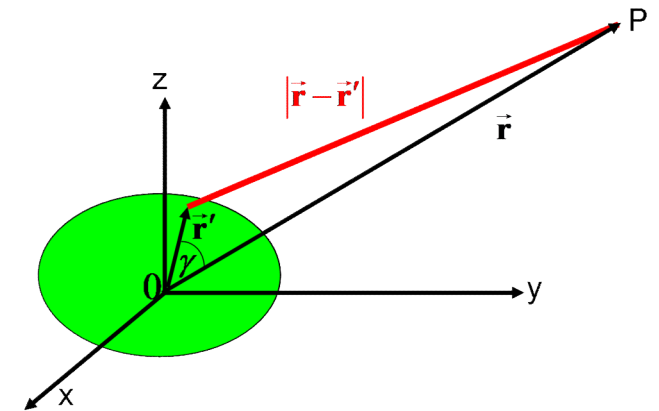
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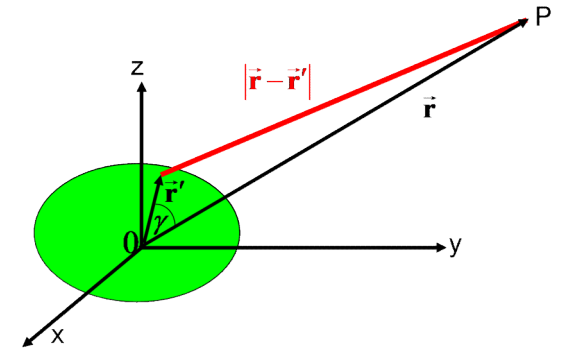
$$\mathbf{M}(\vartheta, \varphi) = \int \mathbf{J}(\vec{\mathbf{r}}') e^{j\beta \vec{\mathbf{r}}' \cdot \hat{i}_r} d\vec{\mathbf{r}}'$$



Fraunhofer region

$$\mathbf{A}(\vec{\mathbf{r}}) = \frac{\mu}{4\pi} \int \mathbf{J}(\vec{\mathbf{r}}') \frac{e^{-j\beta|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|}}{|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|} d\vec{\mathbf{r}}'$$

$$|\vec{\mathbf{r}}-\vec{\mathbf{r}}'| = r - \vec{\mathbf{r}}' \cdot \hat{\mathbf{i}}_r + \frac{(r')^2}{2r} \sin^2 \gamma + \dots$$



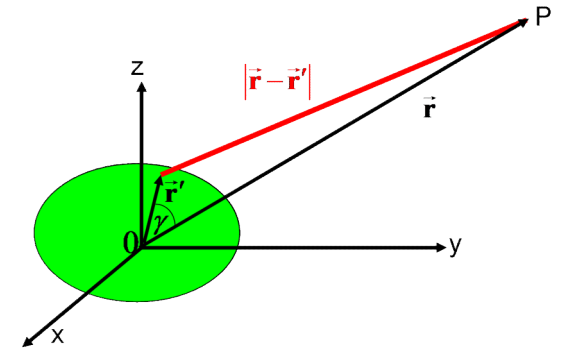
$$\frac{1}{|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|} = \frac{1}{r - r' \cos \gamma + \frac{(r')^2}{2r} \sin^2 \gamma + \dots} \approx \frac{1}{r} \quad \text{if } D \ll r$$

$$e^{-j\beta|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|} = e^{-j\beta r} e^{j\beta \vec{\mathbf{r}}' \cdot \hat{\mathbf{i}}_r} e^{-j\beta \frac{(r')^2}{2r} \sin^2 \gamma} \dots \approx e^{-j\beta r} e^{j\beta \vec{\mathbf{r}}' \cdot \hat{\mathbf{i}}_r} \quad \text{if } r > \frac{2D^2}{\lambda}$$

Fresnel region

$$\mathbf{A}(\vec{\mathbf{r}}) = \frac{\mu}{4\pi} \int \mathbf{J}(\vec{\mathbf{r}}') \frac{e^{-j\beta|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|}}{|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|} d\vec{\mathbf{r}}'$$

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$$e^{-j\beta|\vec{\mathbf{r}}-\vec{\mathbf{r}}'|} \approx e^{-j\beta r} e^{j\beta \vec{\mathbf{r}}' \cdot \hat{\mathbf{i}}_r} e^{-j\beta \frac{(r')^2}{2r} \sin^2 \gamma} \dots \quad \text{if } r > 0.62 \sqrt{\frac{D^3}{\lambda}}$$

Fresnel region

Fraunhofer region

$$r \gg D$$

$$r > \frac{2D^2}{\lambda}$$

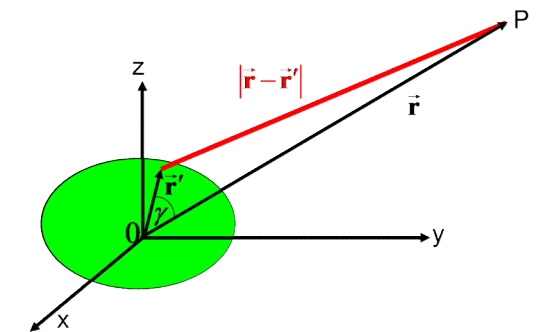
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$$\mathbf{M}(\vartheta, \varphi) = \int \mathbf{J}(\vec{r}') e^{j\beta \vec{r}' \cdot \hat{i}_r} d\vec{r}'$$



Fraunhofer region

$$\frac{j\omega\mu}{4\pi} = \frac{j\omega\sqrt{\mu}\sqrt{\mu}}{4\pi} \frac{\sqrt{\varepsilon}}{\sqrt{\varepsilon}} = \frac{j\zeta}{4\pi} \beta = \frac{j\zeta}{4\pi} \frac{2\pi}{\lambda} = \frac{j\zeta}{2\lambda}$$

$$\omega\sqrt{\mu\varepsilon} = \beta = \frac{2\pi}{\lambda}$$

$$\zeta = \sqrt{\frac{\mu}{\varepsilon}}$$

Fraunhofer region

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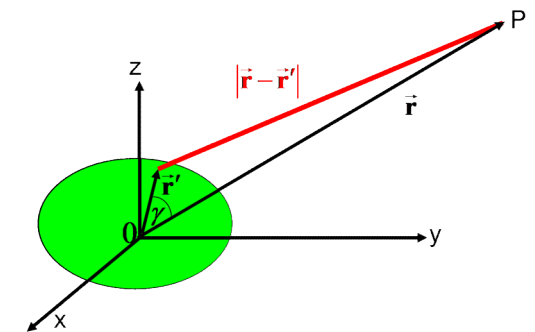
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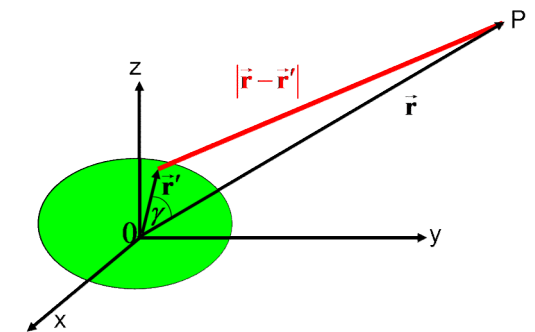
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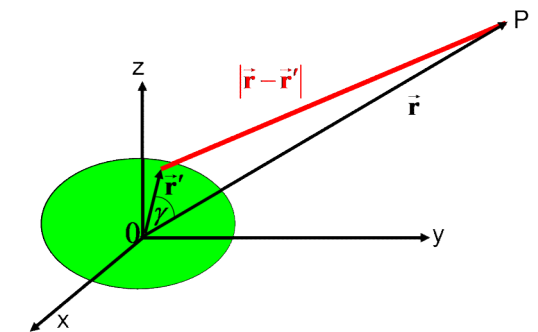
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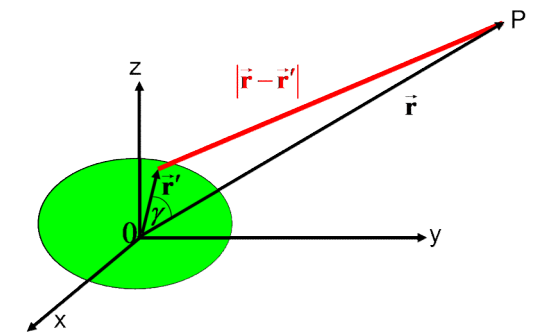
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I is the phasor associated to the input current at the antenna input terminals

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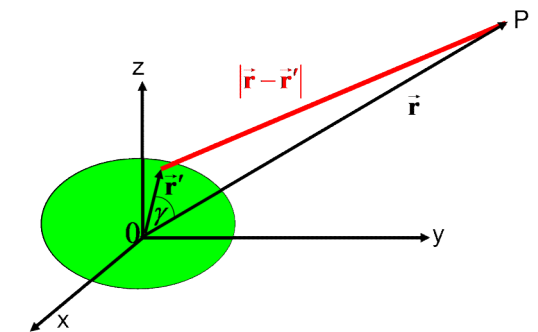
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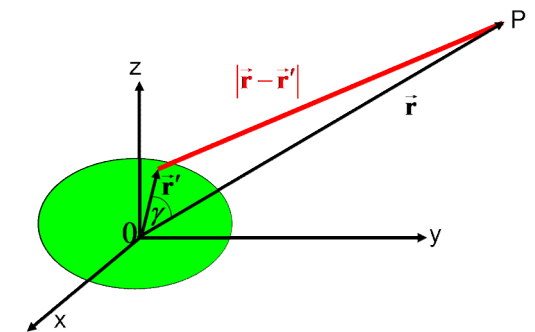
$$\mathbf{E}(\vec{\mathbf{r}}) = \mathbf{E}(r, \vartheta, \varphi) = \frac{j\zeta I e^{-j\beta r}}{2\lambda r} \frac{-M_\vartheta(\vartheta, \varphi)\hat{\mathbf{i}}_\vartheta - M_\varphi(\vartheta, \varphi)\hat{\mathbf{i}}_\varphi}{I} = \frac{j\zeta I e^{-j\beta r}}{2\lambda r} \mathbf{l}(\vartheta, \varphi)$$

$$\zeta \mathbf{H}(\vec{\mathbf{r}}) = \hat{\mathbf{i}}_r \times \mathbf{E}(\vec{\mathbf{r}})$$

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$$\mathbf{M}(\vartheta, \varphi) = \int \mathbf{J}(\vec{\mathbf{r}}') e^{j\beta \vec{\mathbf{r}}' \cdot \hat{\mathbf{i}}_r} d\vec{\mathbf{r}}'$$



$$[\mathbf{M}] = \frac{\text{Ampere}}{m^2} \times m^3 = \text{Ampere} \times m$$

$$\frac{-M_\vartheta(\vartheta, \varphi)\hat{\mathbf{i}}_\vartheta - M_\varphi(\vartheta, \varphi)\hat{\mathbf{i}}_\varphi}{I} = \mathbf{l}(\vartheta, \varphi) = l_\vartheta(\vartheta, \varphi)\hat{\mathbf{i}}_\vartheta + l_\varphi(\vartheta, \varphi)\hat{\mathbf{i}}_\varphi$$

is said **effective length** of the antenna

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Antenna Parameters

Introduction

- To describe the performance of an antenna, definitions of various parameters are necessary.
- Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance.

Antenna Parameters

Parameters of the Tx Antenna

Parameters of the Rx Antenna

Parameters of the Tx Antenna

- Effective length
 - Radiation pattern
 - Radiation pattern lobes
 - Beamwidth
- Directivity
- Gain
- Radiation Resistance
- Equivalent circuit of the tx antenna
- Input Impedance and Input Resistance



Effective Length

$$r \gg D$$

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$$\mathbf{l}(\vartheta, \varphi) = l_g(\vartheta, \varphi) \hat{i}_g + l_\varphi(\vartheta, \varphi) \hat{i}_\varphi$$

$$\vec{\mathbf{S}} = \frac{1}{2\zeta} |\vec{\mathbf{E}}|^2 \hat{i}_r = \frac{\zeta}{2} |\vec{\mathbf{H}}|^2 \hat{i}_r$$

$$\mathbf{l}(\vartheta, \varphi) = l_g(\vartheta, \varphi) \hat{i}_g + l_\varphi(\vartheta, \varphi) \hat{i}_\varphi \quad \text{effective length of the antenna}$$

Effective Length

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$$\vec{\mathbf{S}} = \frac{1}{2\zeta} |\vec{\mathbf{E}}|^2 \hat{\mathbf{i}}_r = \frac{\zeta}{2} |\vec{\mathbf{H}}|^2 \hat{\mathbf{i}}_r$$

Elementary electrical dipole

$$\mathbf{E}(\vec{\mathbf{r}}) = \frac{j\zeta I e^{-j\beta r}}{2\lambda r} \Delta z \sin \vartheta \hat{\mathbf{i}}_\vartheta$$

$$\zeta \mathbf{H}(\vec{\mathbf{r}}) = \hat{\mathbf{i}}_r \times \mathbf{E}(\vec{\mathbf{r}})$$

$$\mathbf{l}(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{\mathbf{i}}_\vartheta$$

Small loop antenna

$$\mathbf{E}(\vec{\mathbf{r}}) = \frac{j\zeta I e^{-j\beta r}}{2\lambda r} (-j\beta \Delta S) \sin \vartheta \hat{\mathbf{i}}_\varphi$$

$$\zeta \mathbf{H}(\vec{\mathbf{r}}) = \hat{\mathbf{i}}_r \times \mathbf{E}(\vec{\mathbf{r}})$$

$$\mathbf{l}(\vartheta, \varphi) = -j\beta \Delta S \sin \vartheta \hat{\mathbf{i}}_\varphi$$

Parameters of the Tx Antenna

- Effective length
 - Radiation pattern
 - Radiation pattern lobes
 - Beamwidth
- Directivity
- Gain
- Radiation Resistance
- Equivalent circuit of the tx antenna
- Input Impedance and Input Resistance



Radiation pattern

$$r \gg D$$

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$$\mathbf{l}(\vartheta, \varphi) = l_\vartheta(\vartheta, \varphi) \hat{i}_\vartheta + l_\varphi(\vartheta, \varphi) \hat{i}_\varphi$$

$$\vec{\mathbf{S}} = \frac{1}{2\zeta} |\vec{\mathbf{E}}|^2 \hat{i}_r = \frac{\zeta}{2} |\vec{\mathbf{H}}|^2 \hat{i}_r$$

An antenna *radiation pattern* or *antenna pattern* is defined as “a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates”.

In most cases, the radiation pattern is determined in the *far-field region* and is represented as a function of the directional coordinates.

We can describe the angular behavior of the field radiated by the antenna by representing its effective length.

Radiation pattern

- a. *field pattern (in linear scale)* typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.
- b. *power pattern (in linear scale)* typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space.
- c. *power pattern (in dB)* represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.

Often the *field* and *power* patterns are properly normalized, yielding *normalized field* and *power patterns*

Radiation pattern

an example: the electrical elementary dipole

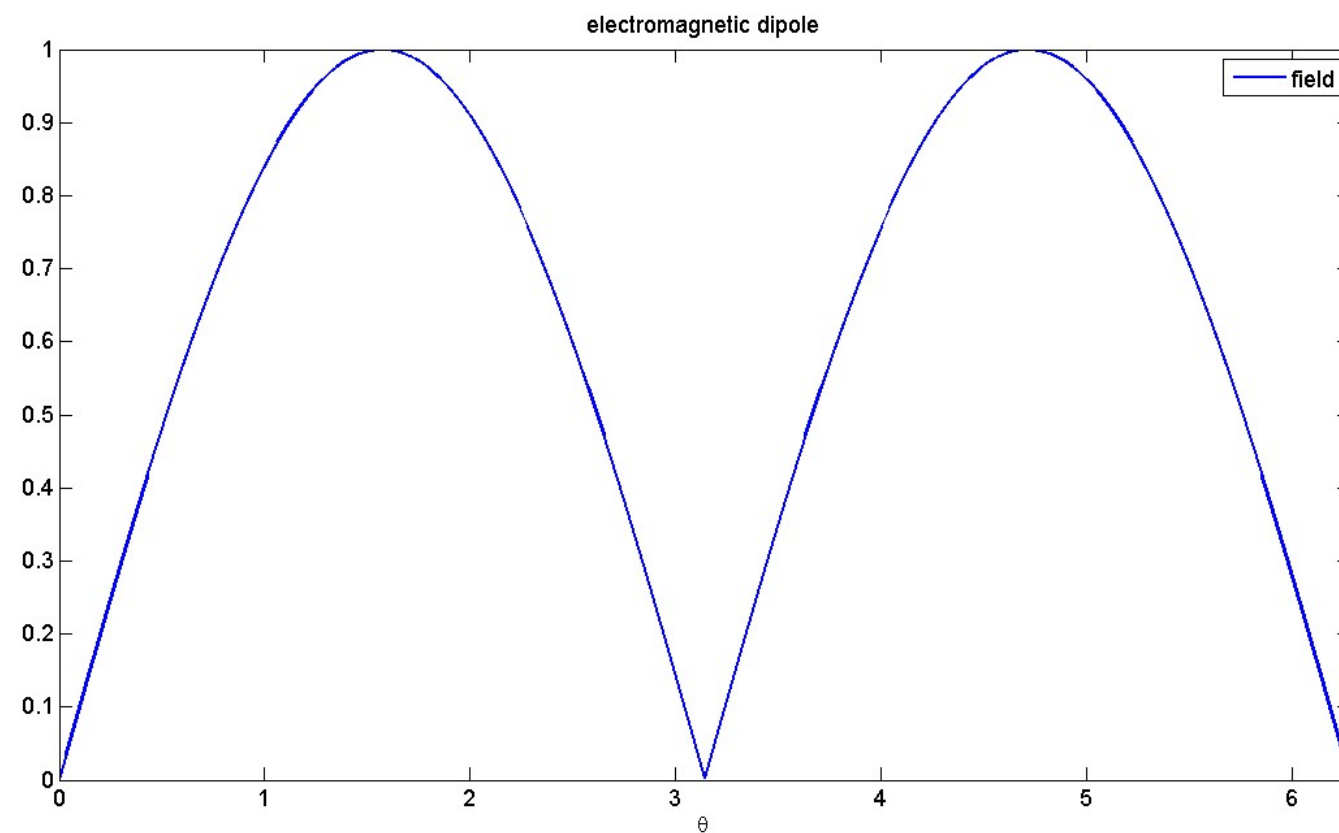
$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\varphi$$

Vertical plane ($\varphi=0$)

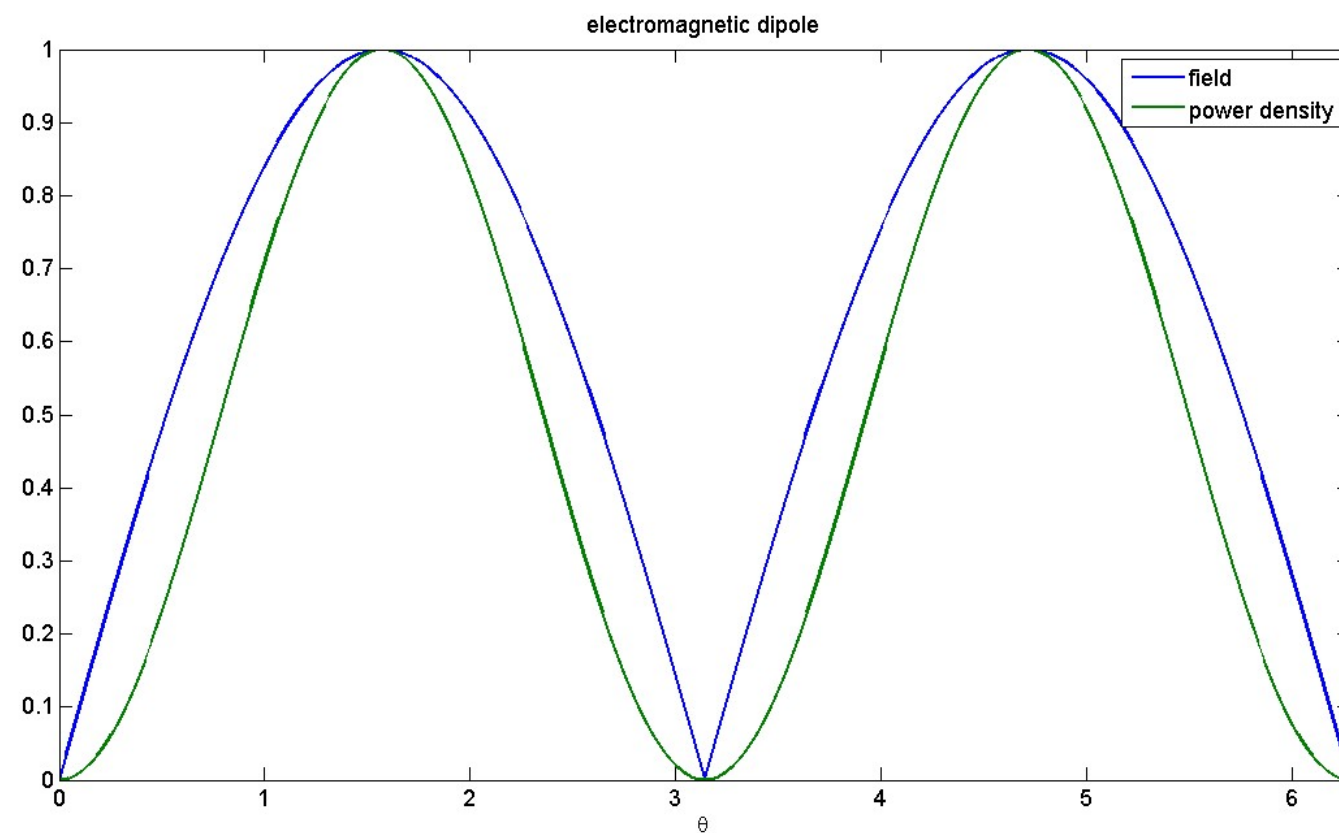


Radiation pattern

an example: the electrical elementary dipole

$$\mathbf{I}(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)

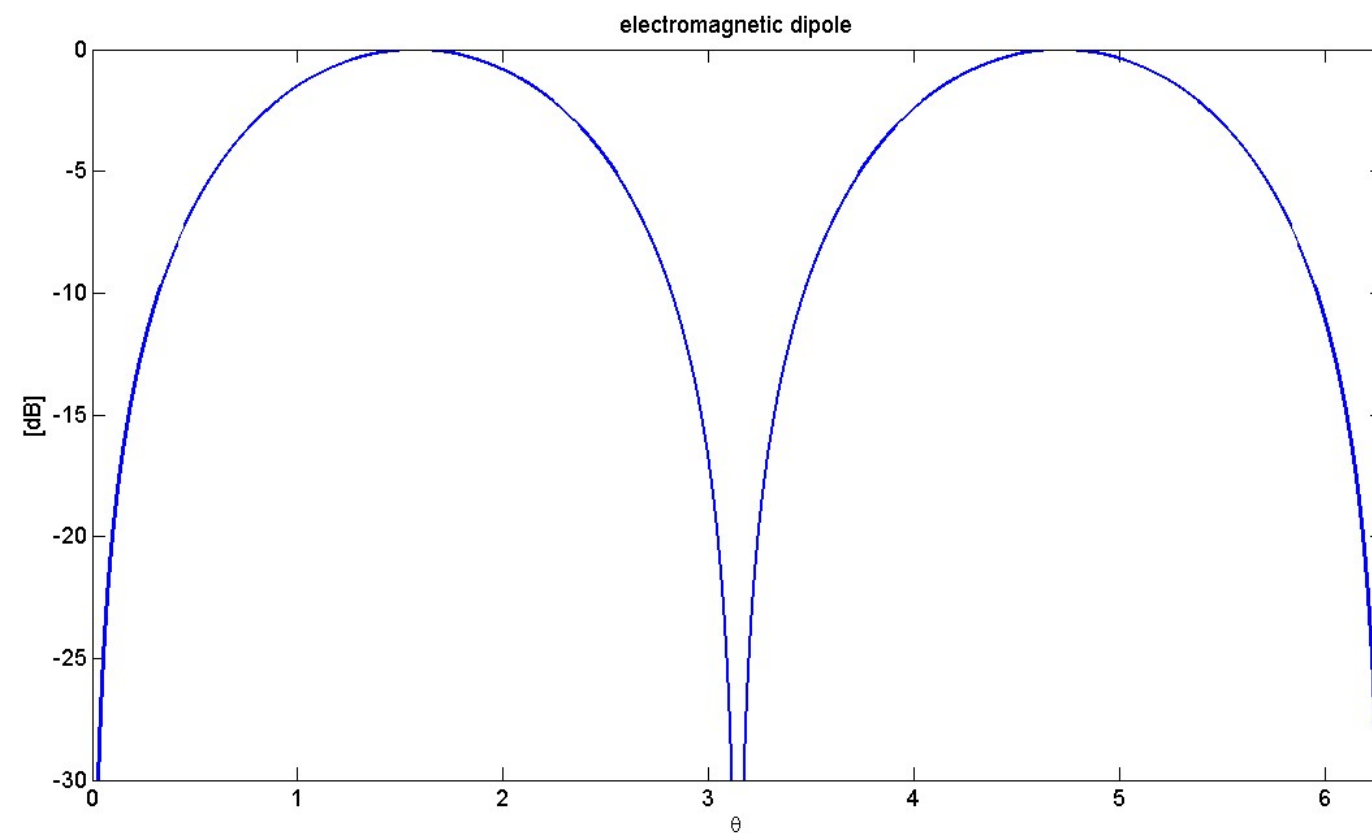


Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)

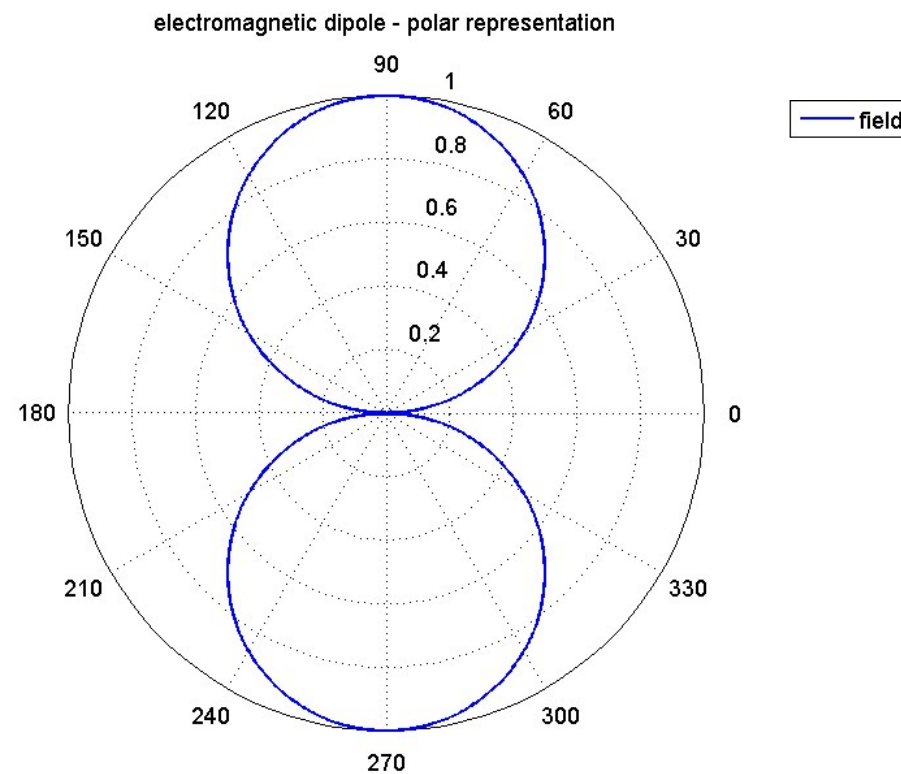


Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)

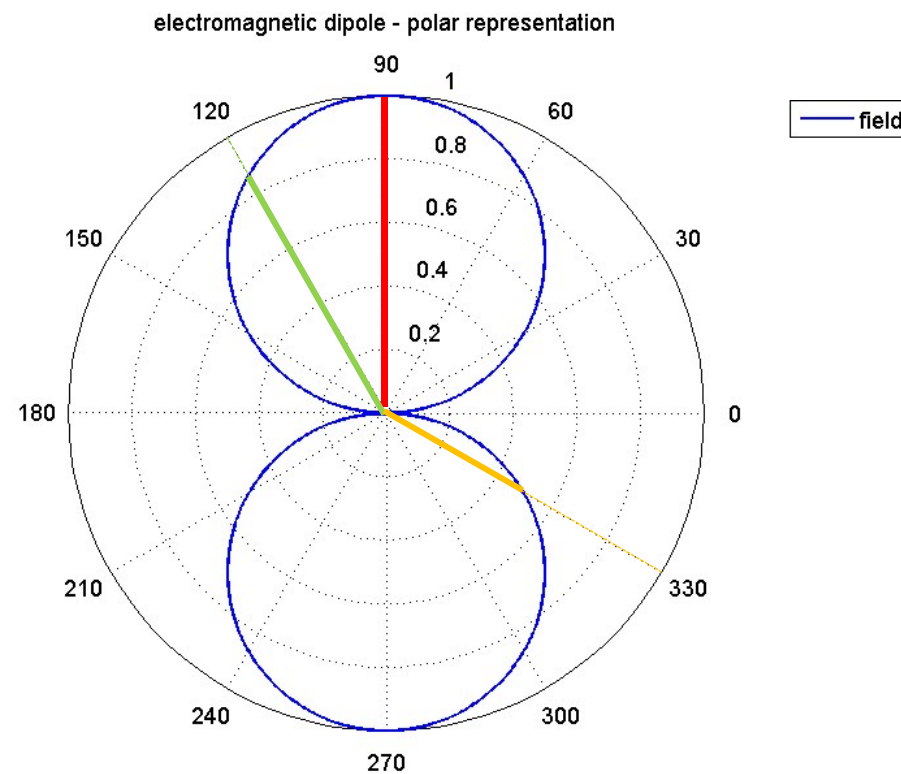


Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)



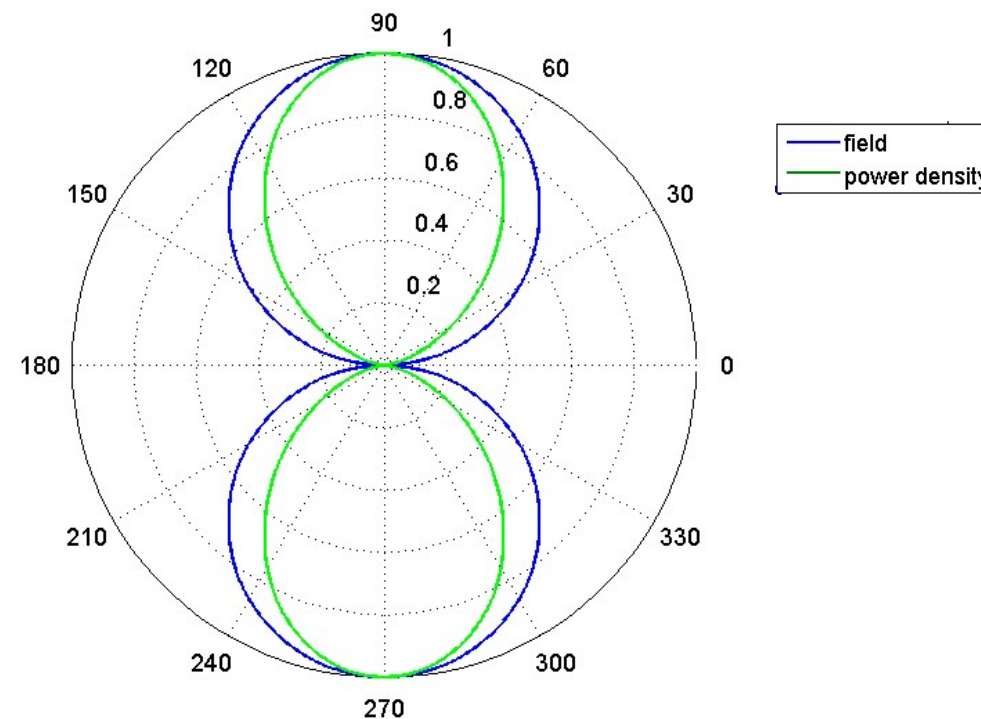
Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)

electromagnetic dipole - polar representation blue:field green: power density

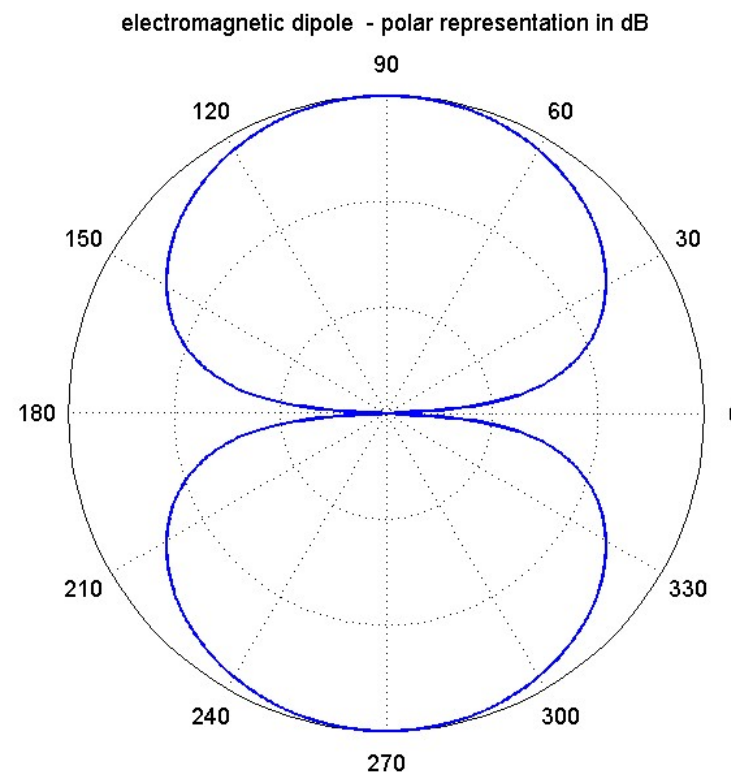


Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Vertical plane ($\varphi=0$)

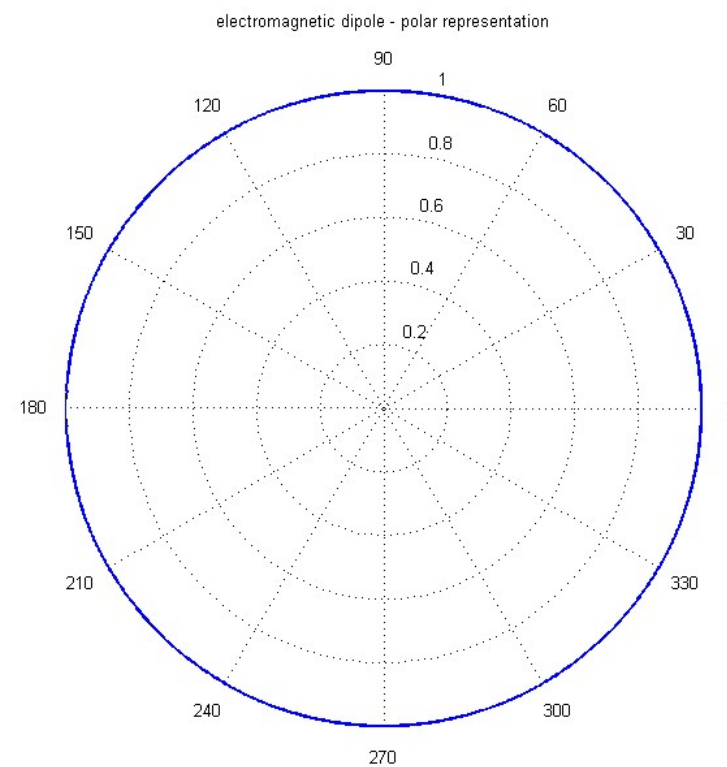
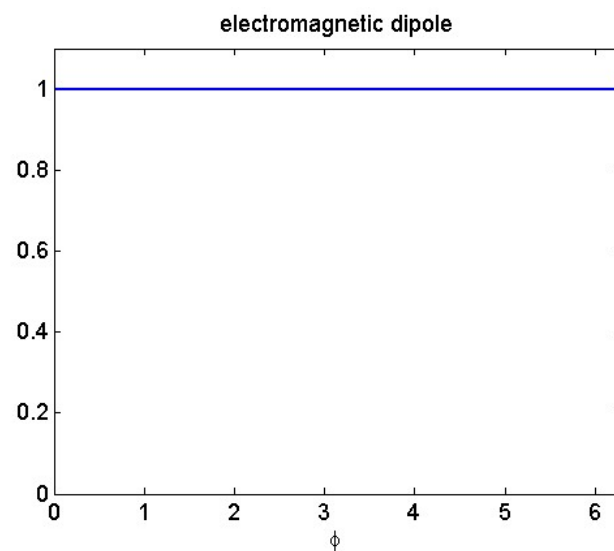


Radiation pattern

an example: the electrical elementary dipole

$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Horizontal plane ($\theta = \pi/2$)



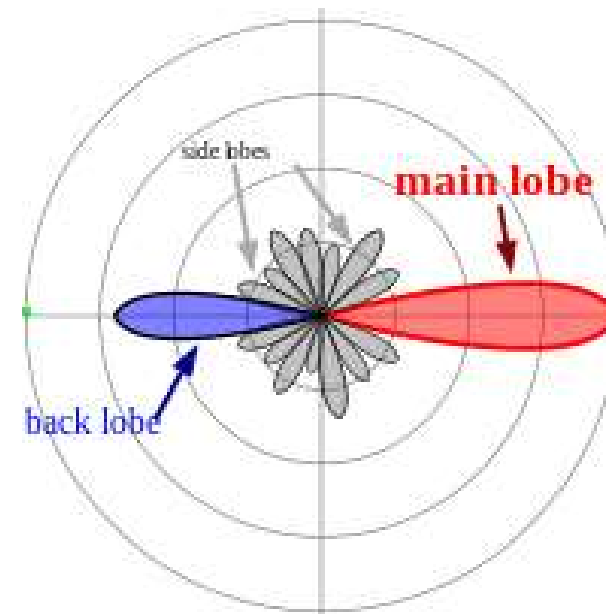
Parameters of the Tx Antenna

- Effective length
 - Radiation pattern
 - Radiation pattern lobes
 - Beamwidth
- Directivity
- Gain
- Radiation Resistance
- Equivalent circuit of the tx antenna
- Input Impedance and Input Resistance



Radiation pattern lobes

- In some very specific directions there are zeros, or *nulls*, in the pattern indicating no radiation.
 - The protuberances between the nulls are referred to as *lobes*, and the main, or major, lobe is in the direction of maximum radiation.
- There are also *side lobes* and *back lobes*.
- A *back lobe* is “a radiation lobe whose axis makes an angle of approximately 180° with respect to the beam of an antenna.” Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.
 - *Side lobes* and *back lobes* divert power away from the main beam and are desired as small as possible.



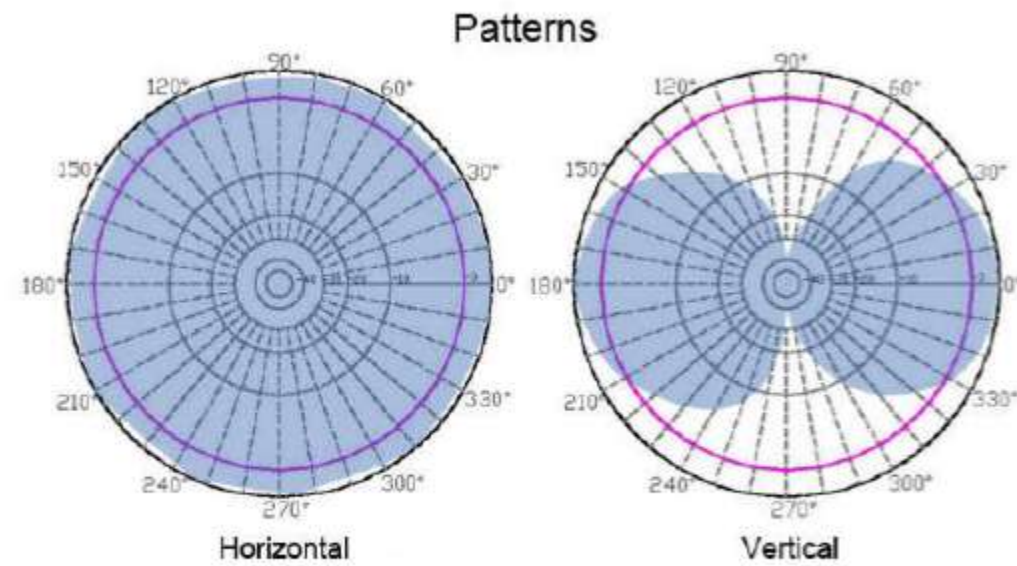
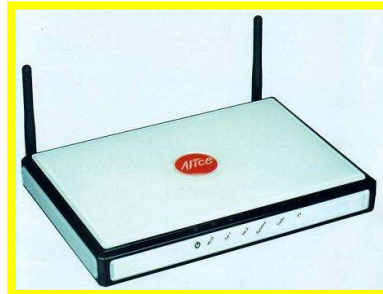
Radiation pattern

three examples from the real life



Radiation pattern

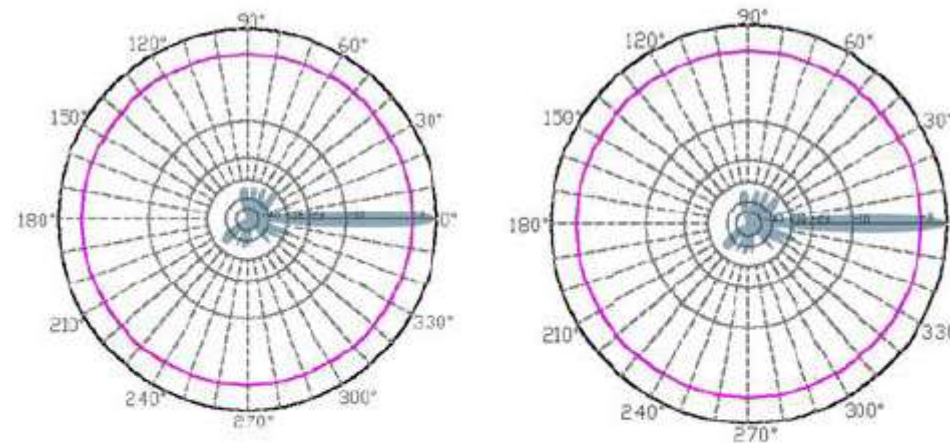
three examples from the real life



ZDAEW1900-3 Patterns

Radiation pattern

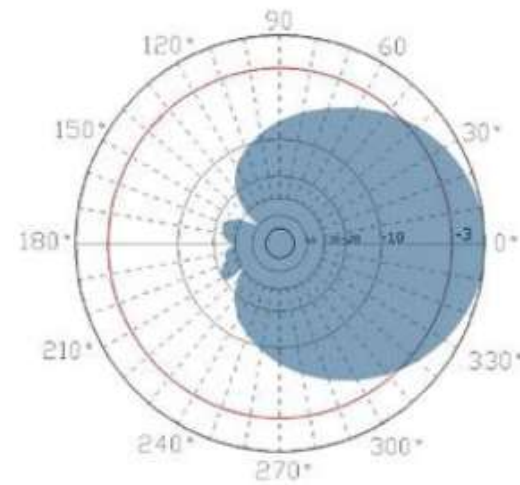
three examples from the real life



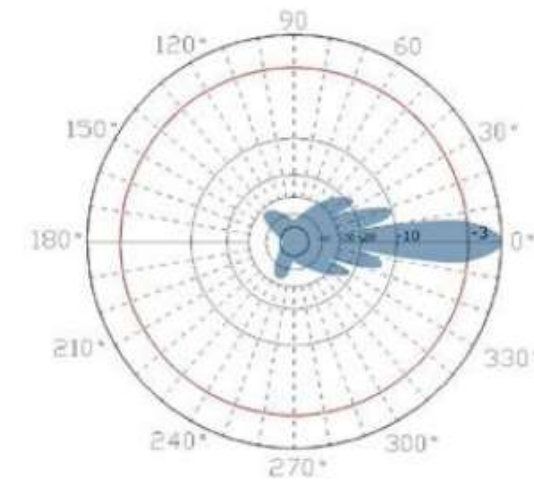
Horizontal Vertical
ZDASP5400-29-6 Patterns

Radiation pattern

three examples from the real life



Horizontal



Vertical

ZDADJ800-13-90 Patterns