

Campi Elettromagnetici

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

a.a. 2020-2021 - Laurea "Triennale" – Secondo semestre - Secondo anno

Università degli Studi di Napoli "Parthenope"

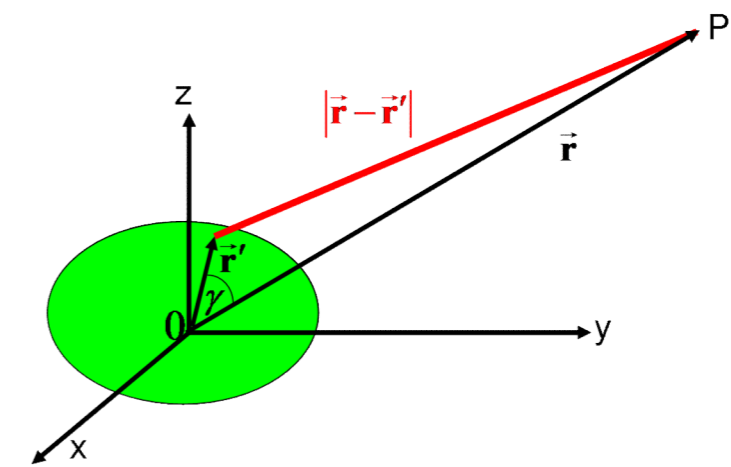
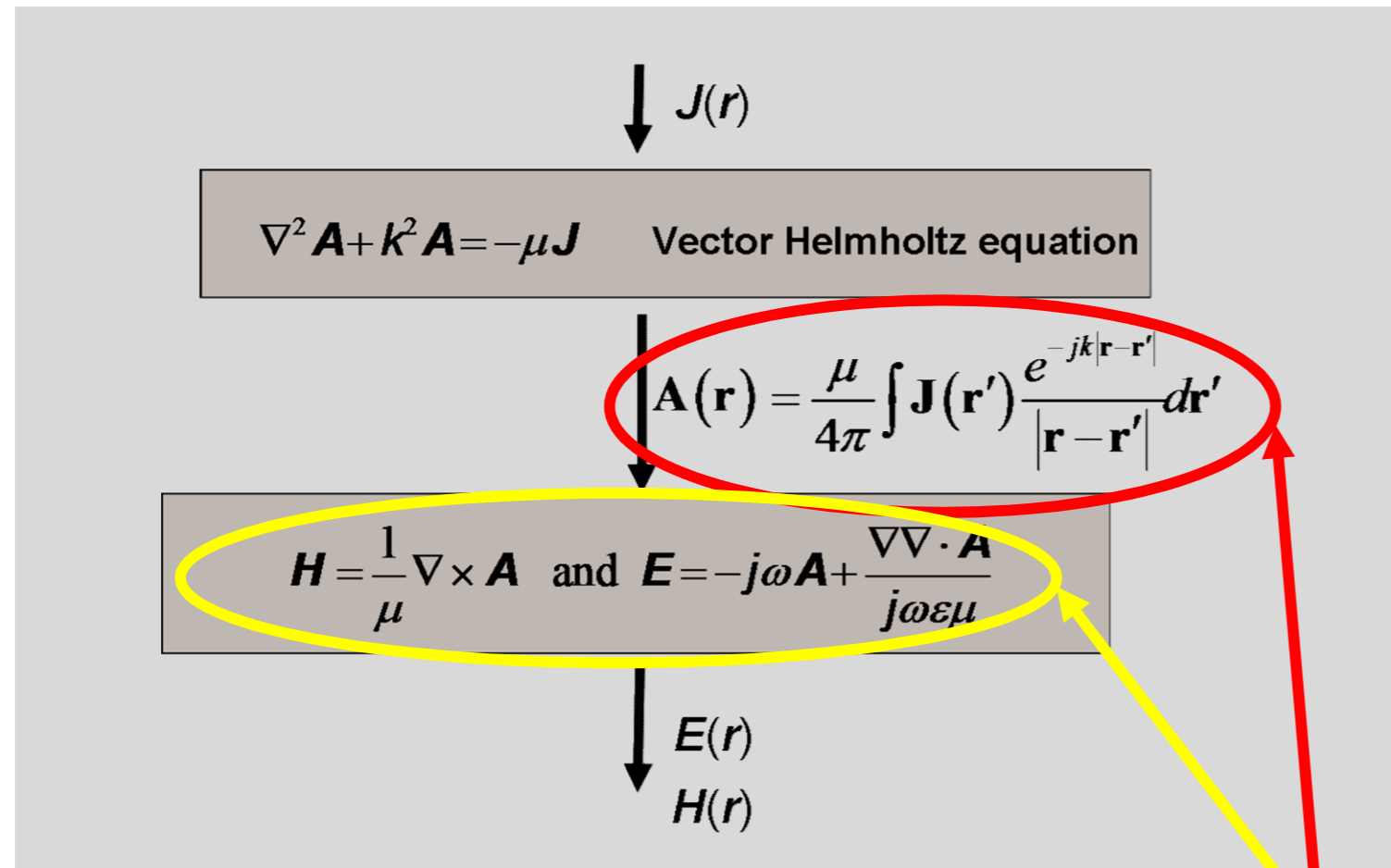
Stefano Perna

Outline

- Radiation problem for extended antennas
- Field regions



Extended antennas



Is it possible to simplify the expressions of the fields, possibly via proper approximation of the vector potential \mathbf{A} ?

Fraunhofer region

Fraunhofer region

$$r \gg D$$

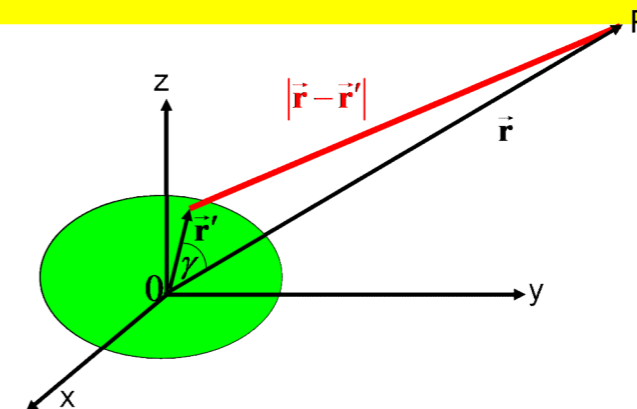
$$r > \frac{2D^2}{\lambda}$$

$$r \gg \lambda$$

$$\mathbf{A}(\vec{r}) \approx \frac{\mu}{4\pi} \frac{e^{-j\beta r}}{r} \mathbf{M}(\vartheta, \varphi)$$

$$\begin{cases} \nabla \nabla \cdot \mathbf{A}(\vec{r}) \approx -\beta^2 A_r(\vec{r}) \hat{i}_r \\ \nabla \times \mathbf{A}(\vec{r}) \approx -j\beta \hat{i}_r \times \mathbf{A}(\vec{r}) \end{cases}$$

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



$$\mathbf{E}(r, \vartheta, \varphi) = -\frac{j\omega\mu}{4\pi} \frac{e^{-j\beta r}}{r} [\mathbf{M}(\vartheta, \varphi) - M_r(\vartheta, \varphi) \hat{i}_r] = \frac{j\zeta I}{2\lambda} \frac{e^{-j\beta r}}{r} \mathbf{l}(\vartheta, \varphi)$$

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

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

$$\mathbf{l}(\vartheta, \varphi) = l_\vartheta(\vartheta, \varphi) \hat{i}_\vartheta + l_\varphi(\vartheta, \varphi) \hat{i}_\varphi = \frac{-M_\vartheta(\vartheta, \varphi) \hat{i}_\vartheta - M_\varphi(\vartheta, \varphi) \hat{i}_\varphi}{I} \quad \text{is said effective length of the antenna}$$

Fraunhofer region

Fraunhofer region

$$r \gg D$$

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

$$r \gg \lambda$$

- 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

$$\mathbf{E}(r, \vartheta, \varphi) = -\frac{j\omega\mu}{4\pi} \frac{e^{-j\beta r}}{r} [\mathbf{M}(\vartheta, \varphi) - M_r(\vartheta, \varphi)\hat{i}_r] = \frac{j\zeta I}{2\lambda} \frac{e^{-j\beta r}}{r} \mathbf{I}(\vartheta, \varphi)$$

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

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

$$\mathbf{I}(\vartheta, \varphi) = l_\vartheta(\vartheta, \varphi)\hat{i}_\vartheta + l_\varphi(\vartheta, \varphi)\hat{i}_\varphi = \frac{-M_\vartheta(\vartheta, \varphi)\hat{i}_\vartheta - M_\varphi(\vartheta, \varphi)\hat{i}_\varphi}{I} \quad \text{is said effective length of the antenna}$$

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

$$r \gg D$$

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

$$r \gg \lambda$$

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

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

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

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

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

Effective Length

$$r \gg D$$

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

$$r \gg \lambda$$

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

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

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

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

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
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- Gain
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Radiation pattern

$$r \gg D$$

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

$$r \gg \lambda$$

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

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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

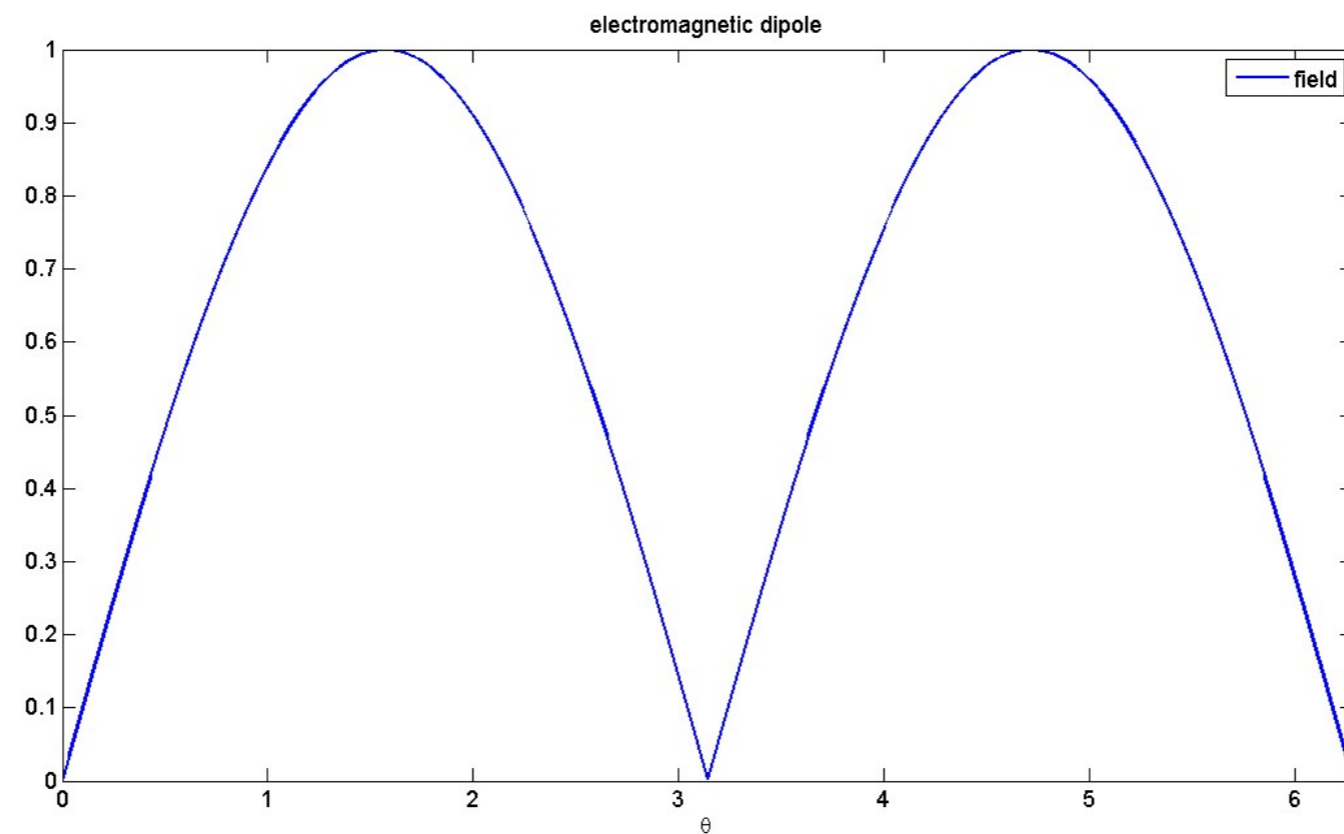
$$I(\vartheta, \varphi) = \Delta z \sin \vartheta \hat{i}_\vartheta$$

Radiation pattern

an example: the electrical elementary dipole

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

Vertical plane ($\varphi=0$)

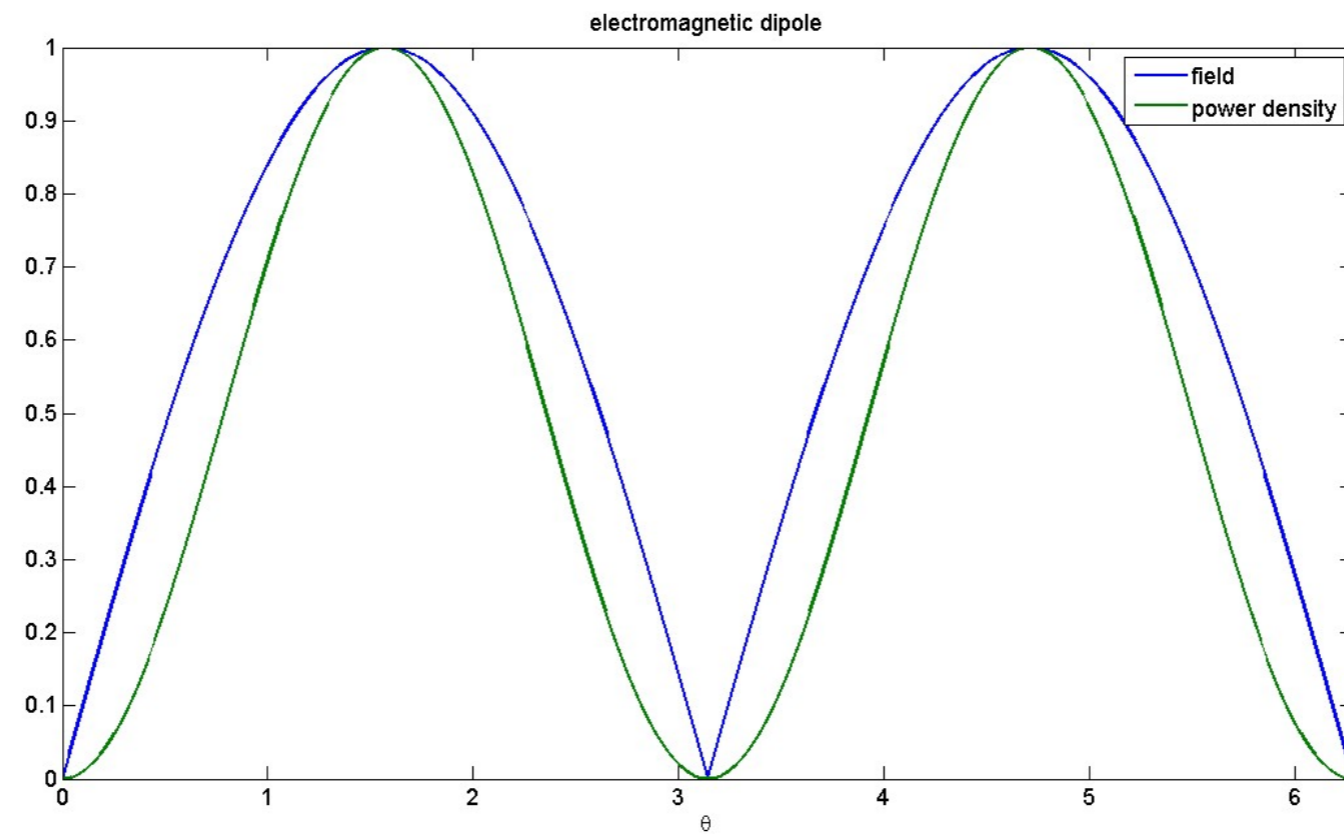


Radiation pattern

an example: the electrical elementary dipole

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

Vertical plane ($\varphi=0$)

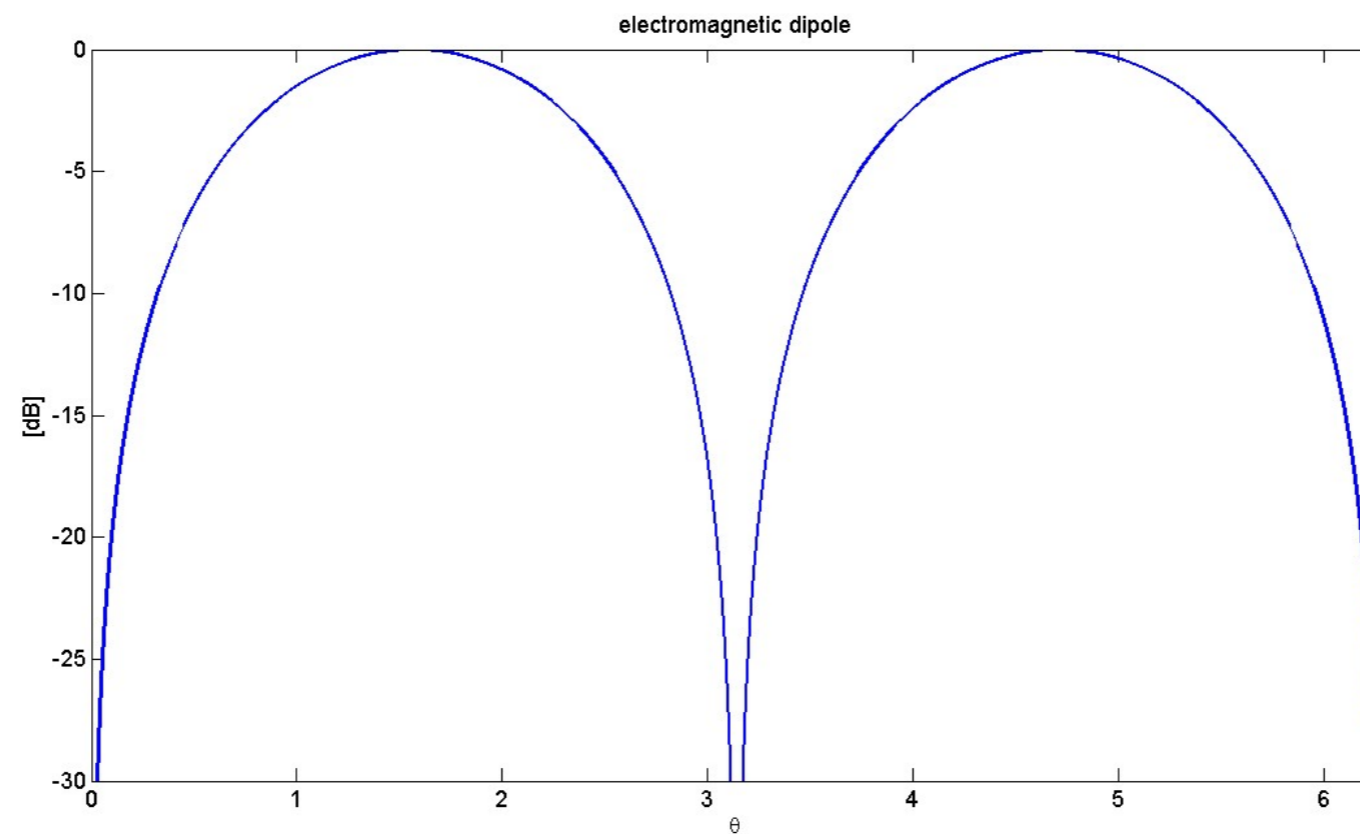


Radiation pattern

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

Vertical plane ($\varphi=0$)

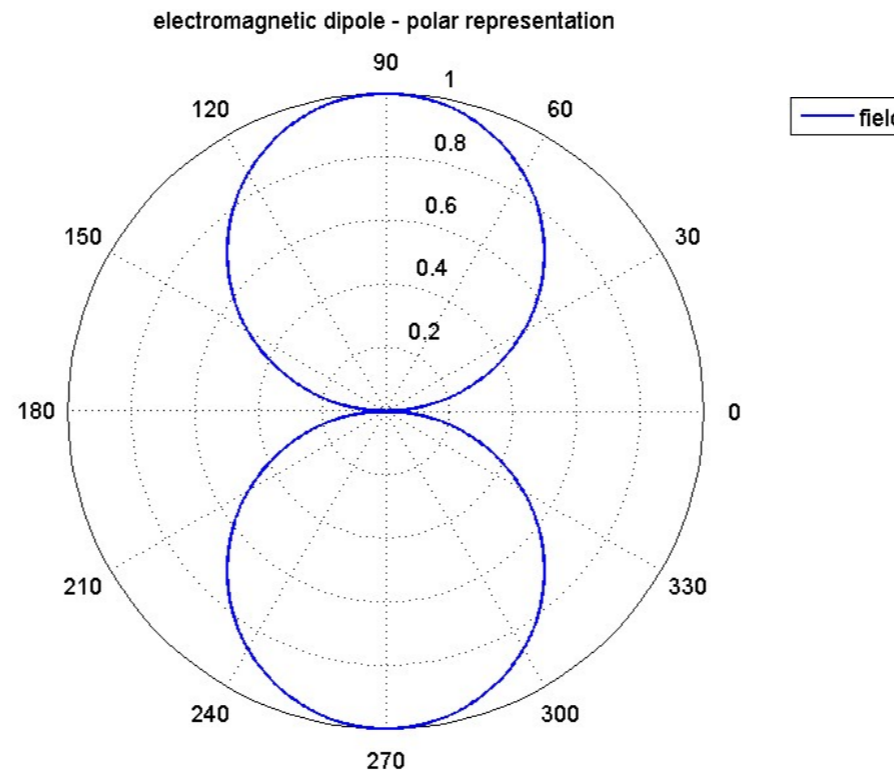


Radiation pattern

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

Vertical plane ($\varphi=0$)

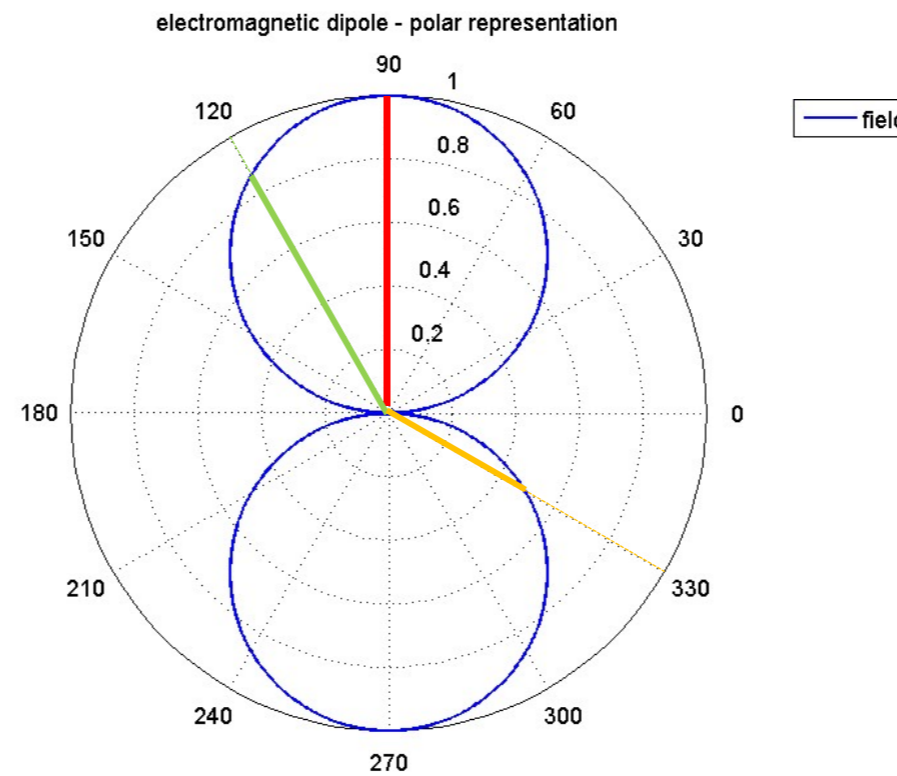


Radiation pattern

an example: the electrical elementary dipole

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

Vertical plane ($\varphi=0$)



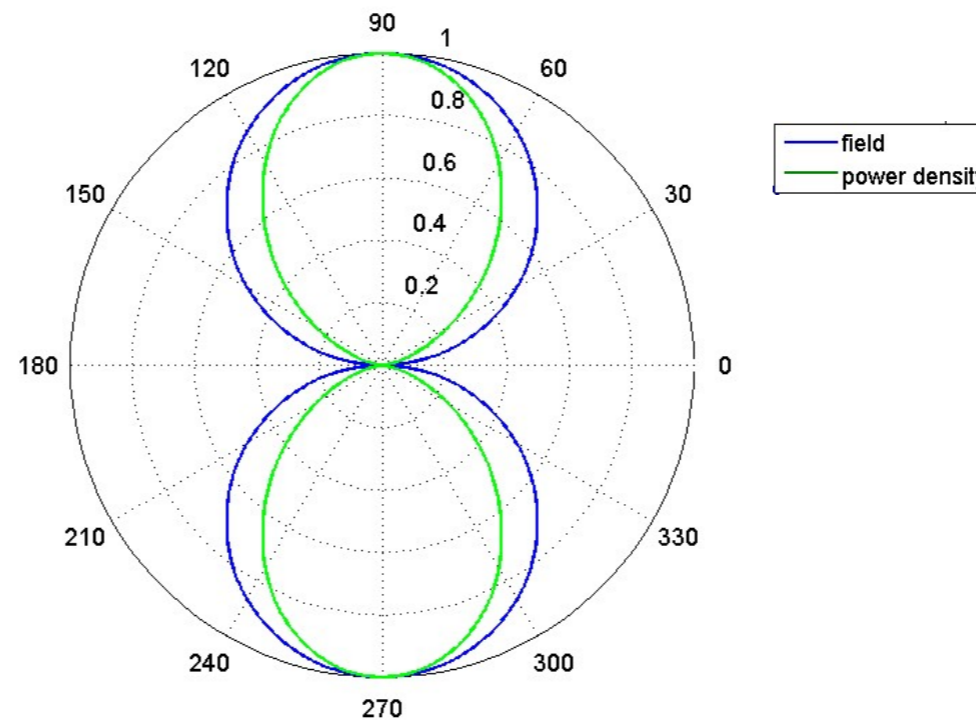
Radiation pattern

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

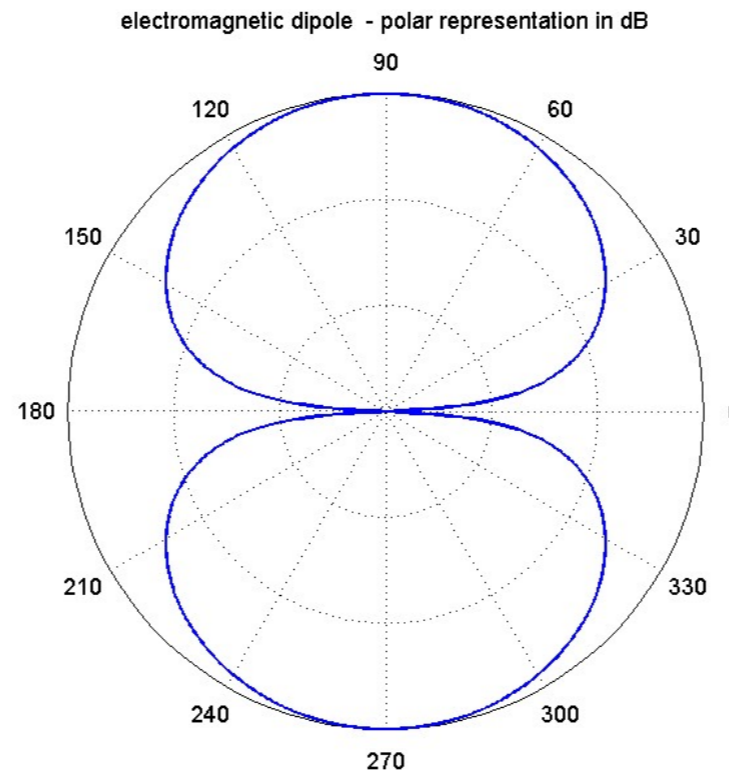


Radiation pattern

an example: the electrical elementary dipole

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

Vertical plane ($\varphi=0$)

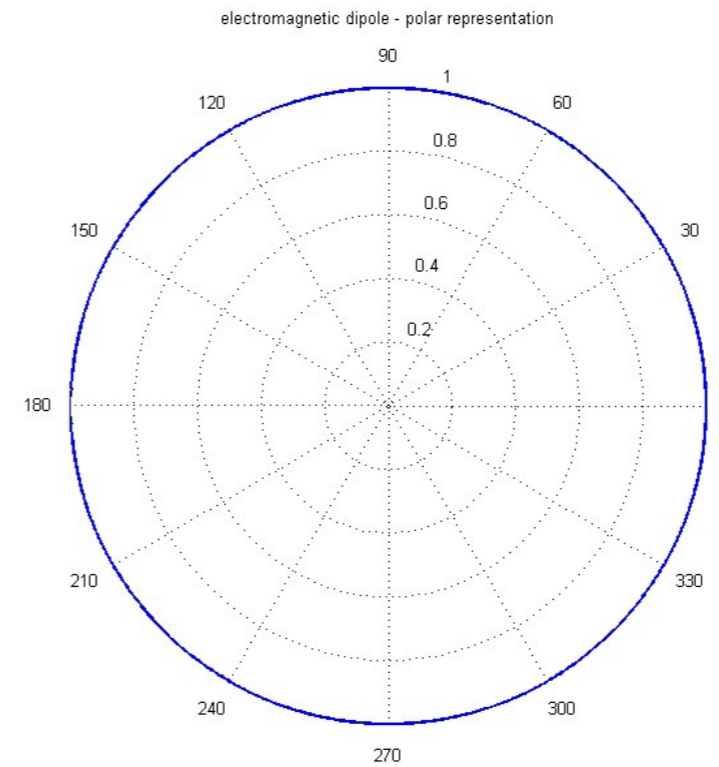
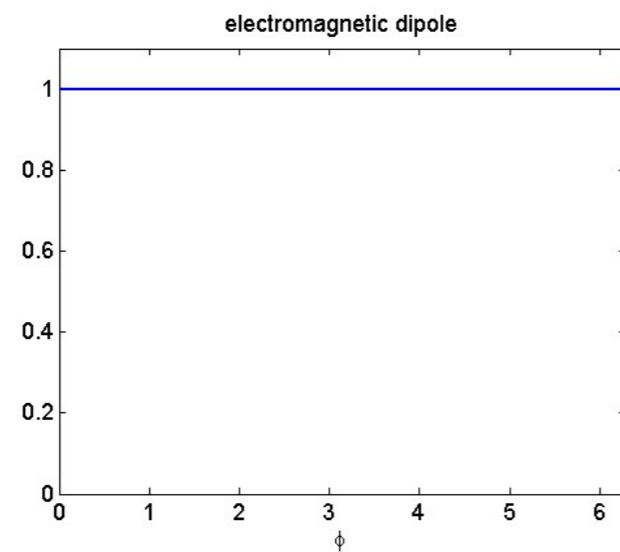


Radiation pattern

an example: the electrical elementary dipole

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

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



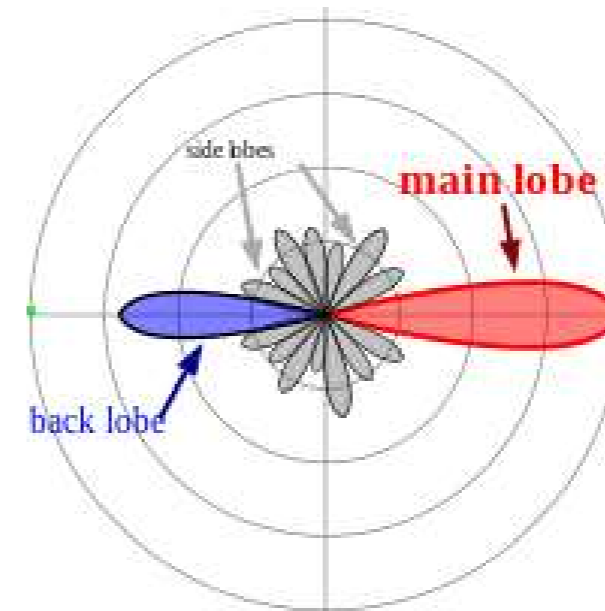
Parameters of the Tx Antenna

- 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.



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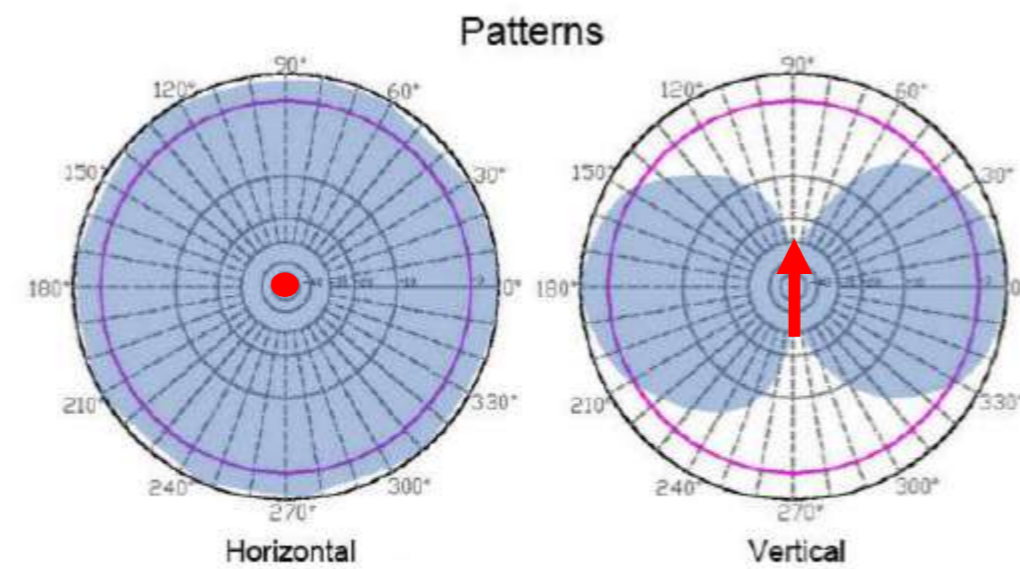
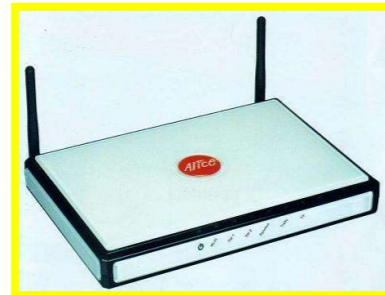
Radiation pattern

three examples from the real life



Radiation pattern

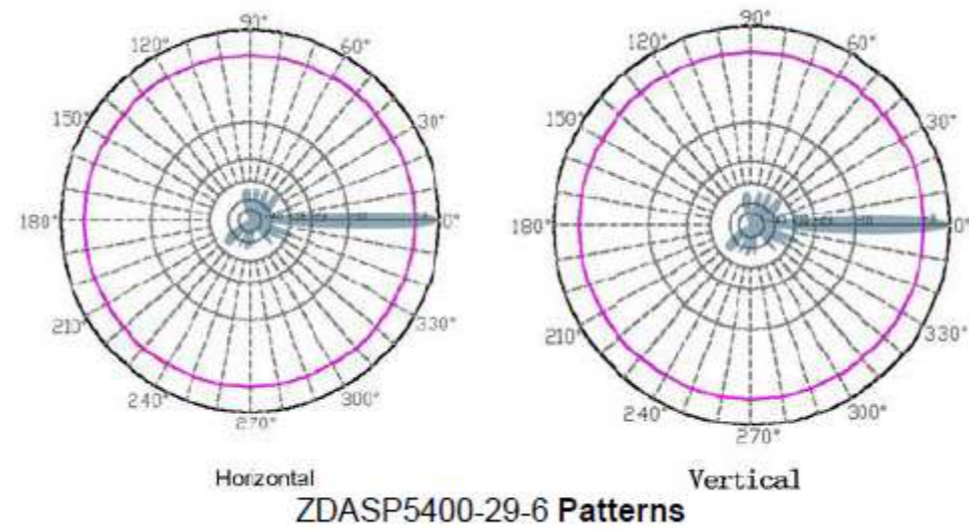
three examples from the real life



ZDAEW1900-3 Patterns

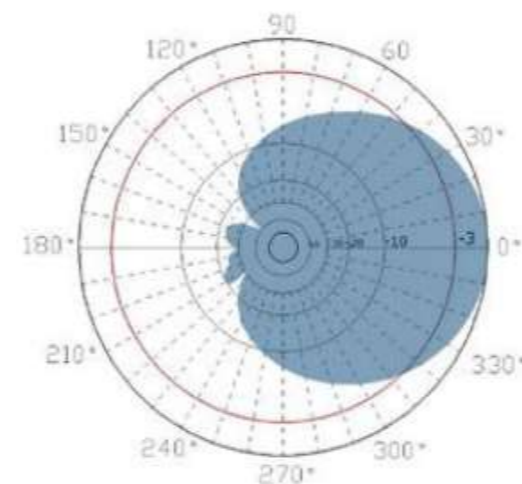
Radiation pattern

three examples from the real life

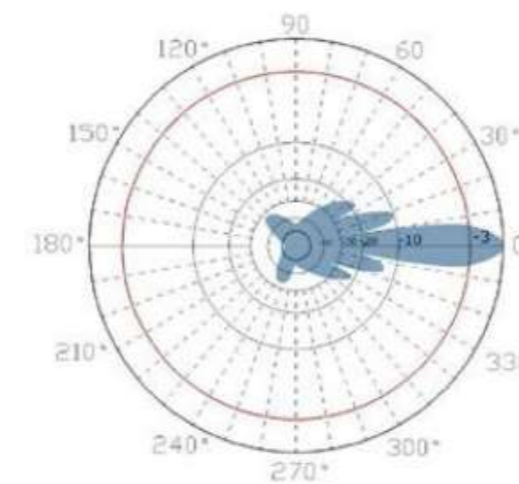


Radiation pattern

three examples from the real life



Horizontal

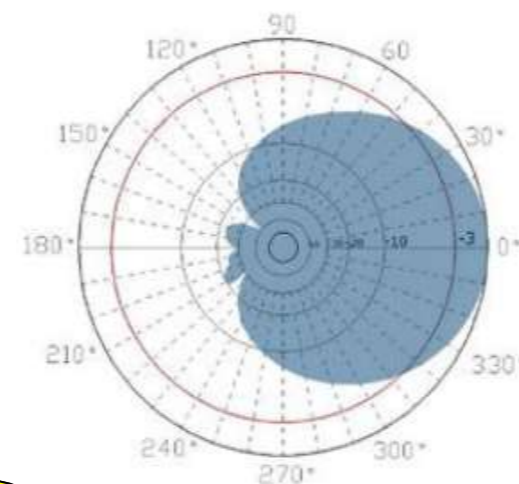


Vertical

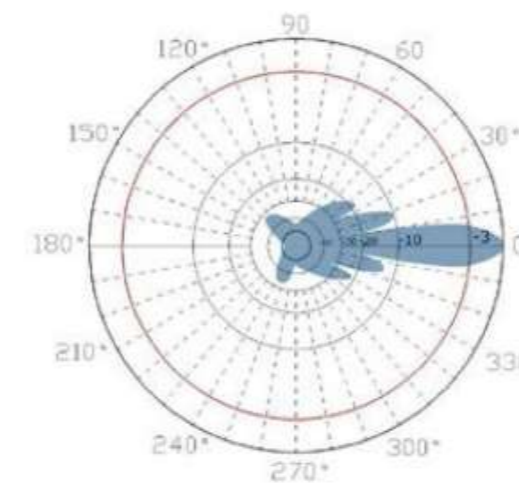
ZDADJ800-13-90 Patterns

Radiation pattern

three examples from the real life



Horizontal



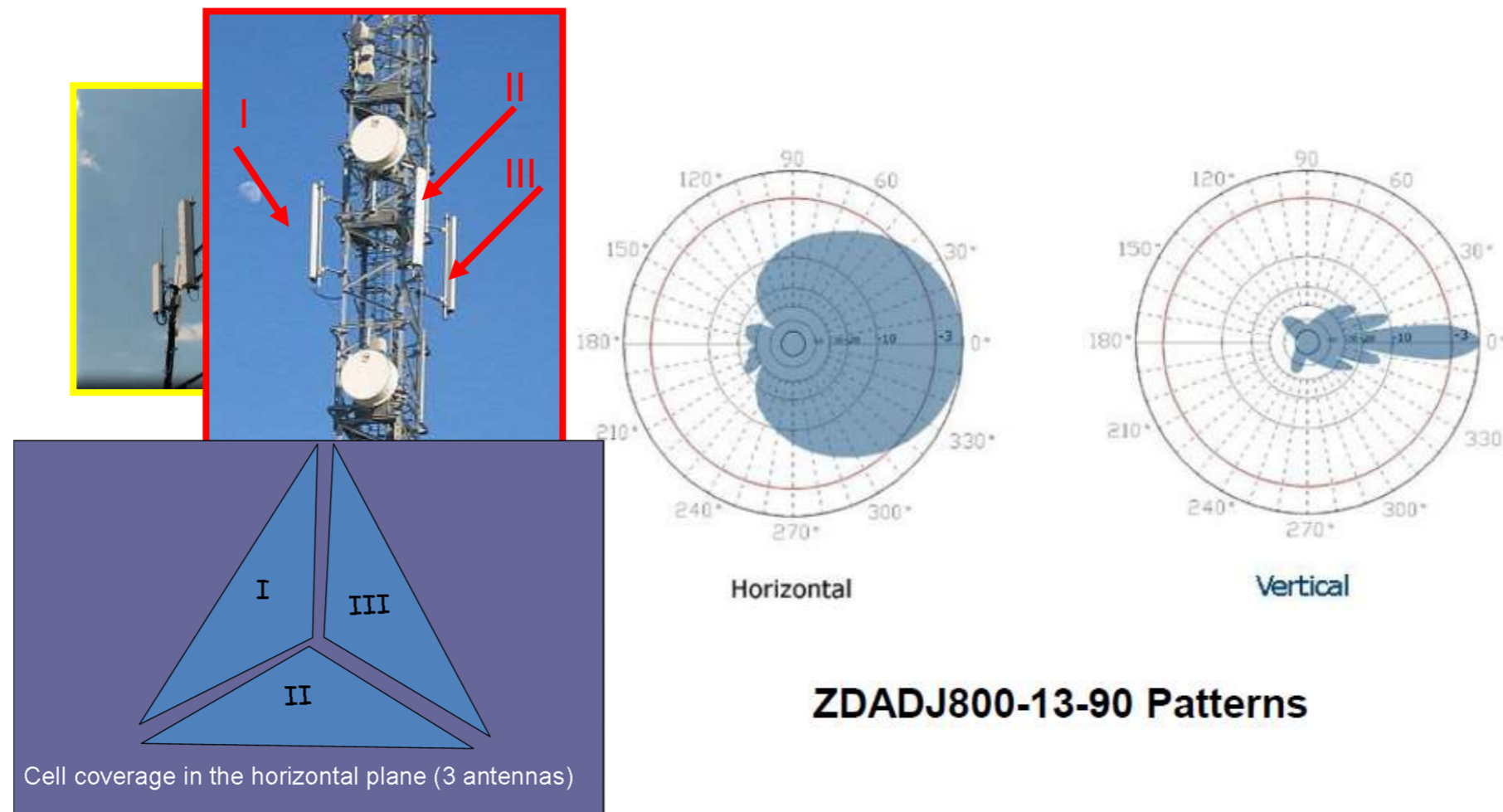
Vertical

....they should be isotropic in the horizontal plane!!

ZDADJ800-13-90 Patterns

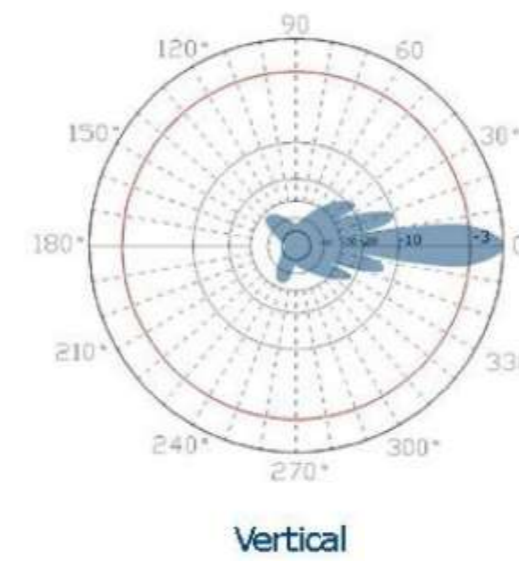
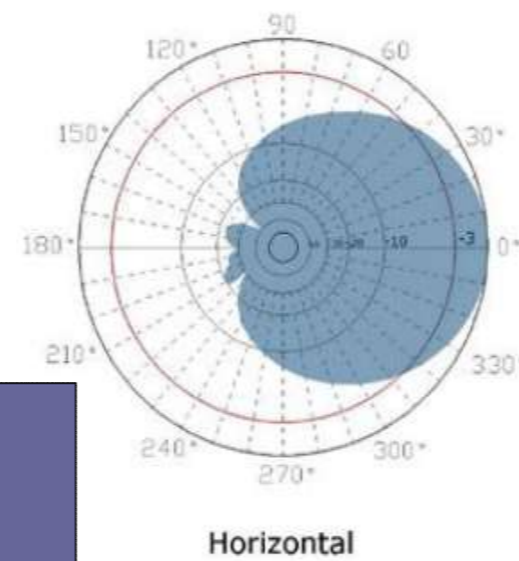
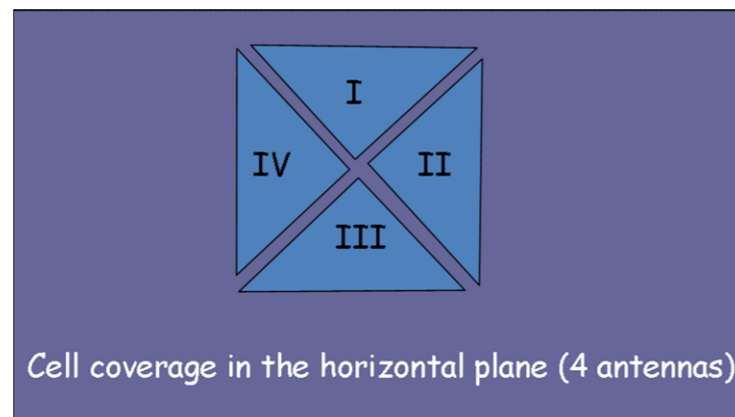
Radiation pattern

three examples from the real life



Radiation pattern

three examples from the real life



ZDADJ800-13-90 Patterns

Parameters of the Tx Antenna

- Effective length
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Beamwidth

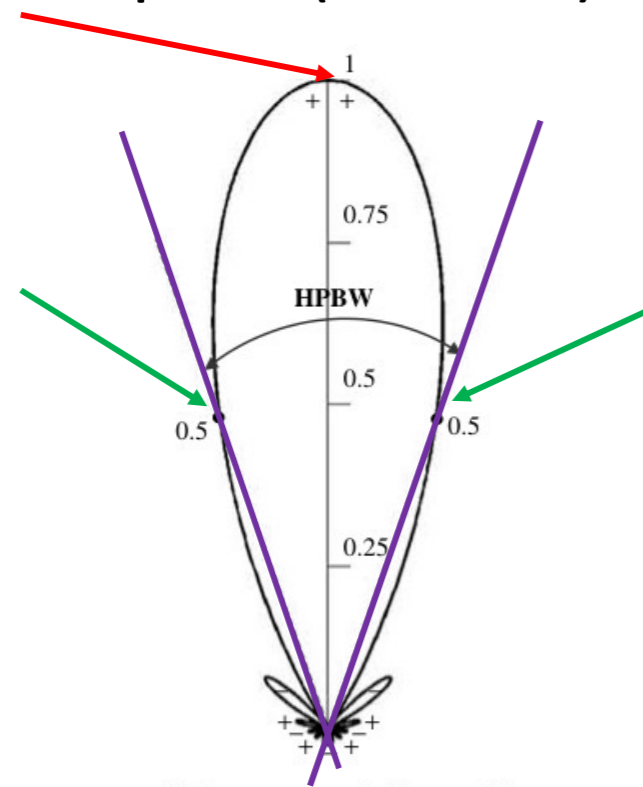
- Associated with the pattern of an antenna is a parameter designated as *beamwidth*.
- The *beamwidth* of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum.

A number of different definitions for the beamwidth exist

- One of the most widely used is the *Half-Power Beamwidth (HPBW)*, or 3-dB beamwidth.
- Another one is the angular separation between the two nulls, and it is referred to as the *First-Null Beamwidth (FNBW)*.

Beamwidth

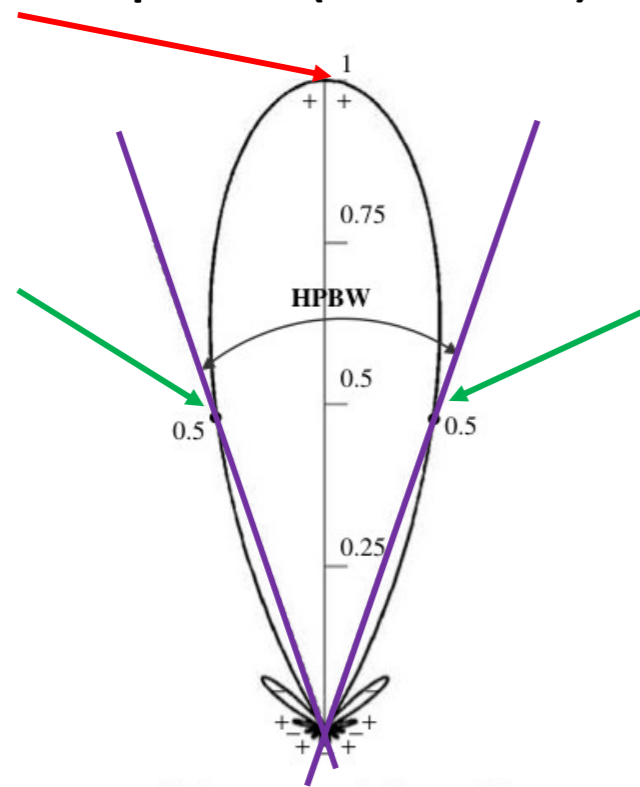
Two-dimensional normalized *power* pattern (*linear scale*)



(b) Power pattern (in linear scale)

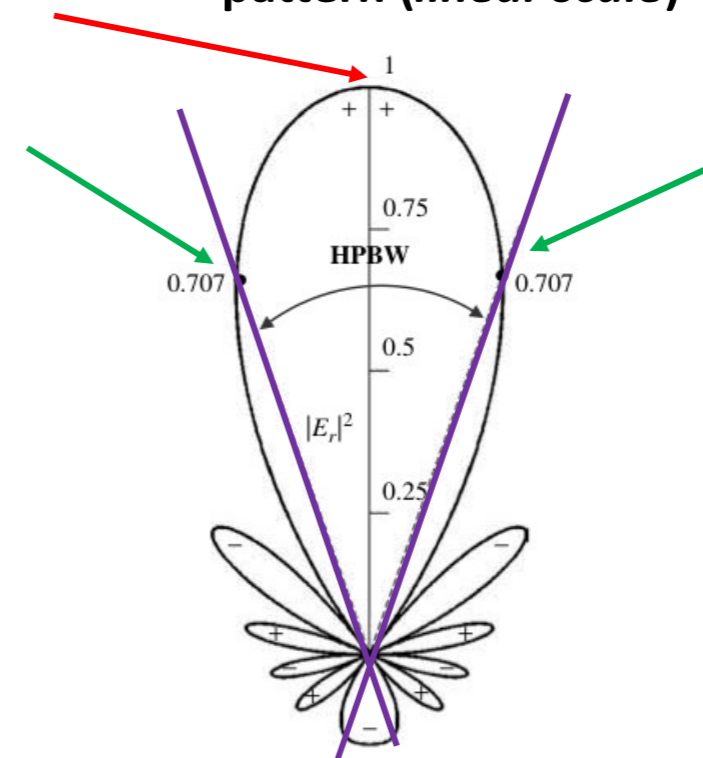
Beamwidth

Two-dimensional normalized *power* pattern (linear scale)



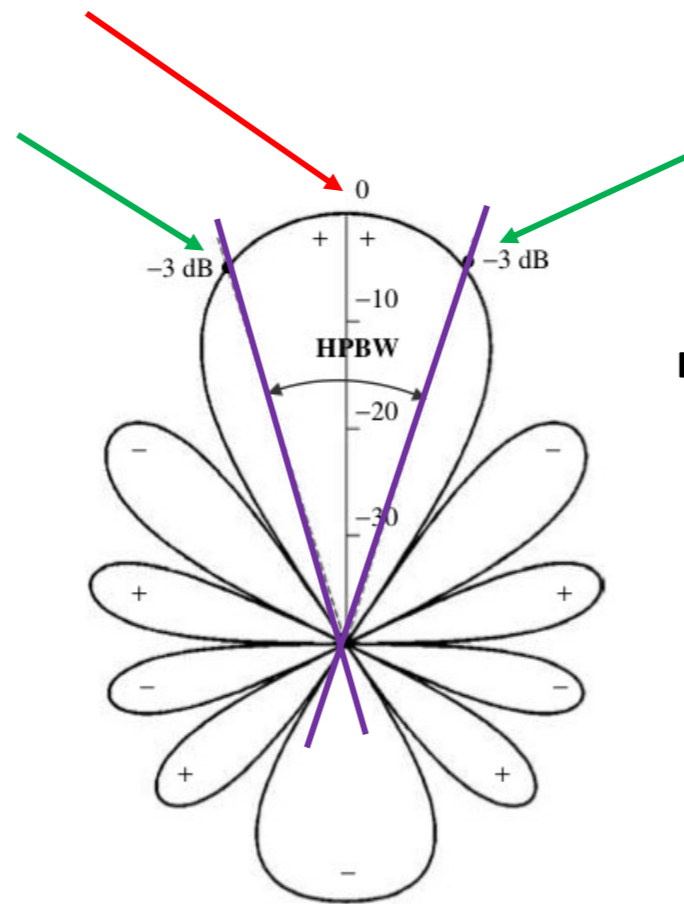
(b) Power pattern (in linear scale)

Two-dimensional normalized *field* pattern (linear scale)



(a) Field pattern (in linear scale)

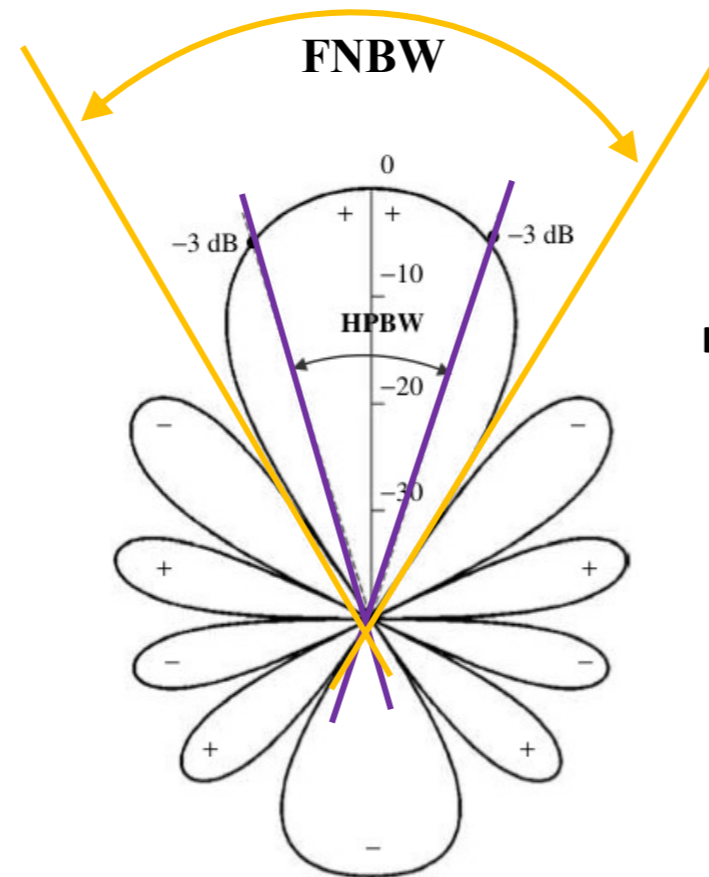
Beamwidth



Two-dimensional
normalized *power* pattern
(in dB)

(c) Power pattern (in dB)

Beamwidth



Two-dimensional
normalized *power* pattern
(in dB)

(c) Power pattern (in dB)

Radiation pattern

three examples from the real life



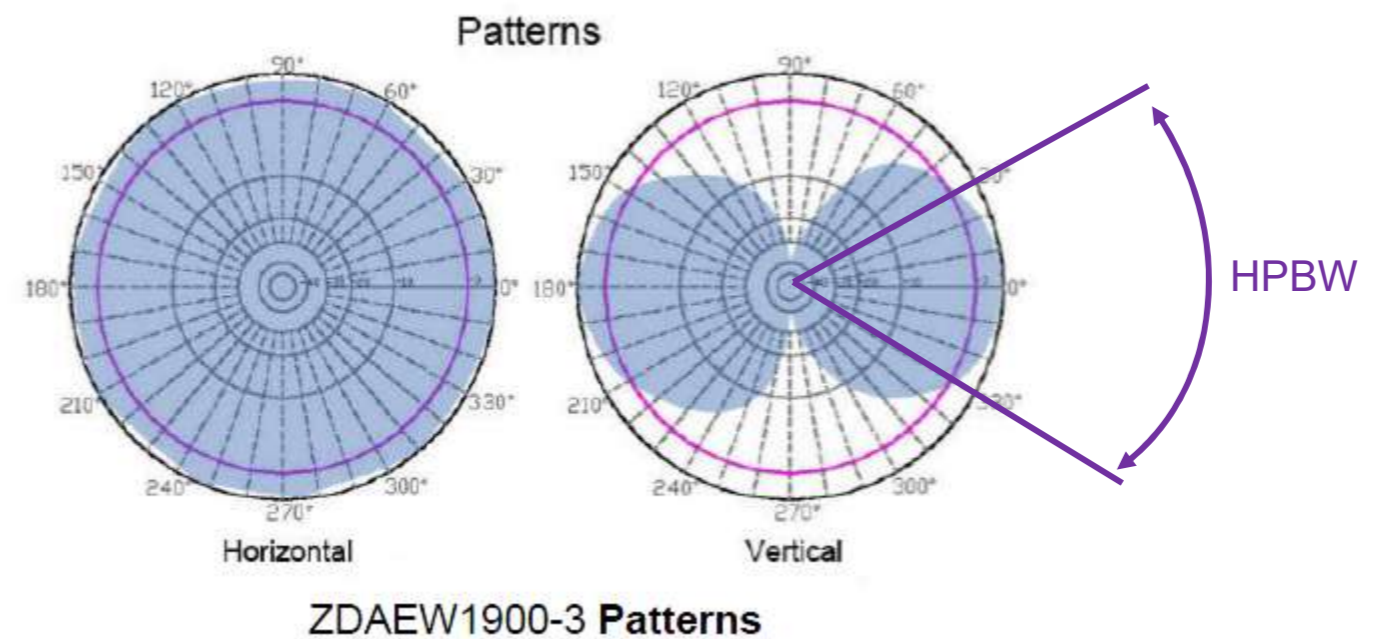
Radiation pattern

three examples from the real life



HPBW (vertical) = 60°

HPBW (horizontal) = 360°



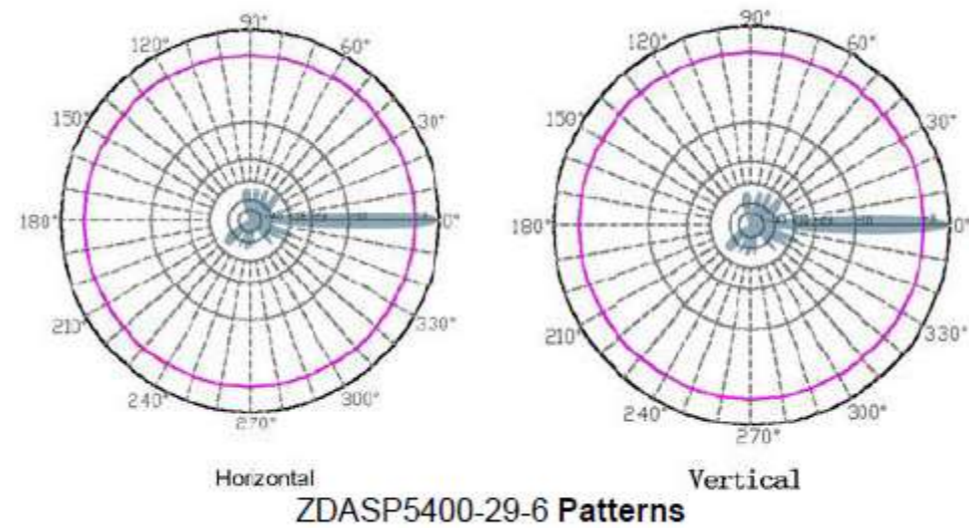
Radiation pattern

three examples from the real life



HPBW (vertical) = 6°

HPBW (horizontal) = 6°



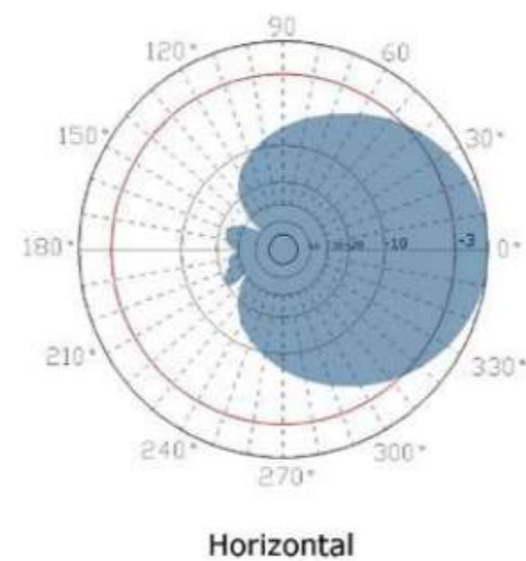
Radiation pattern

three examples from the real life

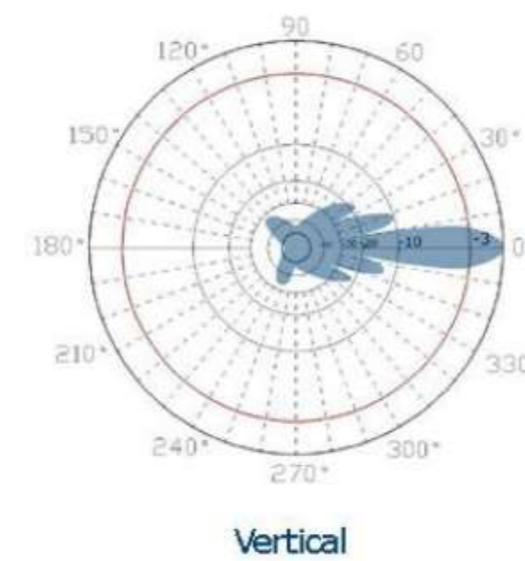


HPBW (vertical) = 14°

HPBW (horizontal) = 90°



Horizontal



Vertical

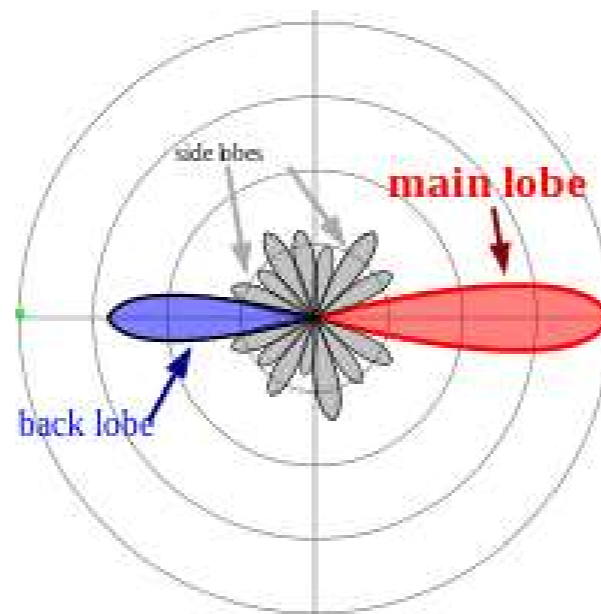
ZDADJ800-13-90 Patterns

Parameters of the Tx Antenna

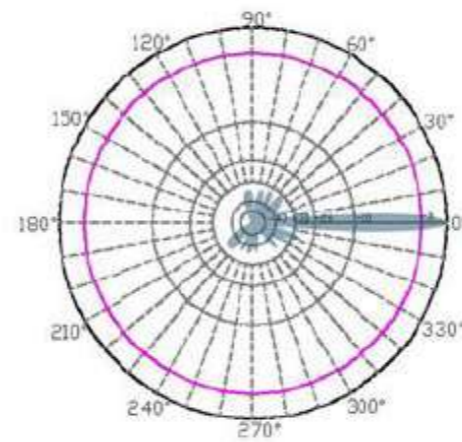
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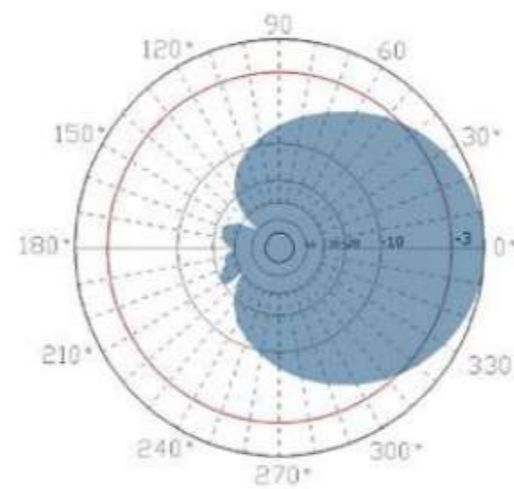
Directivity



Directivity

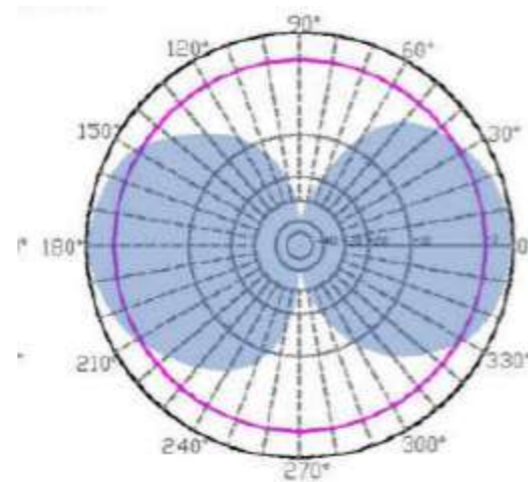


HPBW = 6°

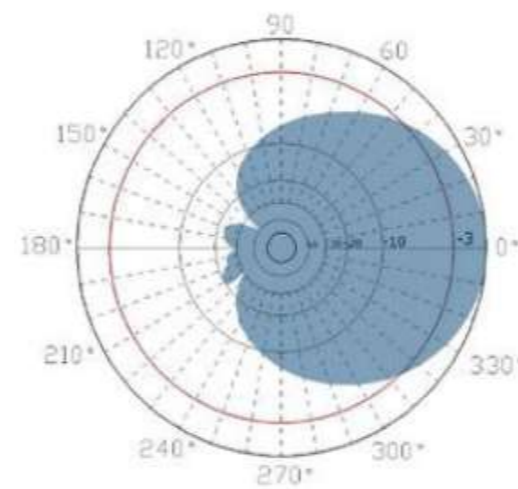


HPBW = 90°

Directivity



HPBW = 60°



HPBW = 90°

Directivity

The directivity of an antenna is :

$$D(\vartheta, \varphi) = \lim_{r \rightarrow \infty} \frac{\frac{1}{2\zeta} |\mathbf{E}(r, \vartheta, \varphi)|^2}{\frac{1}{4\pi r^2} P_{rad}}$$

Directivity

$$r \gg D$$

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

$$r \gg \lambda$$

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

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

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

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

The directivity of an antenna is :

$$D(\vartheta, \varphi) = \lim_{r \rightarrow \infty} \frac{\frac{1}{2\zeta} |\mathbf{E}(r, \vartheta, \varphi)|^2}{\frac{1}{4\pi r^2} P_{rad}}$$

The directivity of an isotropic source is equal to 1 (that is, 0 dB)

$$r \rightarrow \infty$$

$$P_{rad} = P_1 = \oiint_A dA \frac{1}{2\zeta} |\vec{\mathbf{E}}|^2$$

$$\oiint_A dA \vec{\mathbf{S}} \cdot \hat{\mathbf{n}} = P_1 + jP_2$$