Corso di Laurea in Ingegneria Informatica, Biomedica e delle Telecomunicazioni

Corso di Campi Elettromagnetici
a.a. 2017-2018

20 Maggio 2018

Antenna Parameters

Summary of the past lecture

Antenna Parameters

Parameters of the Tx Antenna

Parameters of the Rx Antenna

Summary of the past lecture
Tx Antenna parameters

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

Summary of the past lecture
Tx Antenna parameters

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Summary of the past lecture

Parameters of the Tx Antenna

Effective length

$$r >> D$$

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

$$r >> \lambda$$

Fraunhofer region

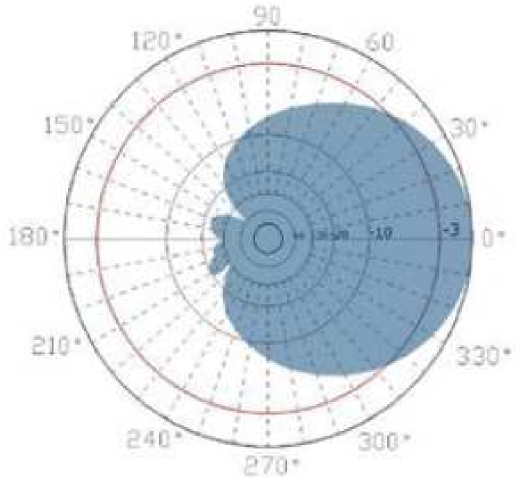
$$\begin{cases} \mathbf{E}(\vec{\mathbf{r}}) = \mathbf{E}(r,\vartheta,\varphi) = \frac{j\zeta I}{2\lambda}\frac{e^{-j\beta r}}{r}\mathbf{l}(\vartheta,\varphi) \\ \zeta\mathbf{H}(\vec{\mathbf{r}}) = \hat{i}_r \times \mathbf{E}(\vec{\mathbf{r}}) \end{cases}$$

$\mathbf{l}(\vartheta,\varphi) = l_\vartheta(\vartheta,\varphi)\hat{i}_\vartheta + l_\varphi(\vartheta,\varphi)\hat{i}_\varphi$ is the **effective length** of the antenna

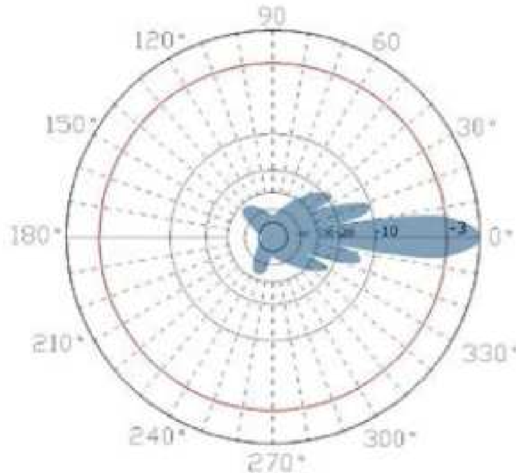
Summary of the past lecture

Radiation pattern

three examples from the real life



Horizontal



Vertical

HPBW (vertical) = 14°

HPBW (horizontal) =90°

ZDADJ800-13-90 Patterns

Tx Antenna parameters

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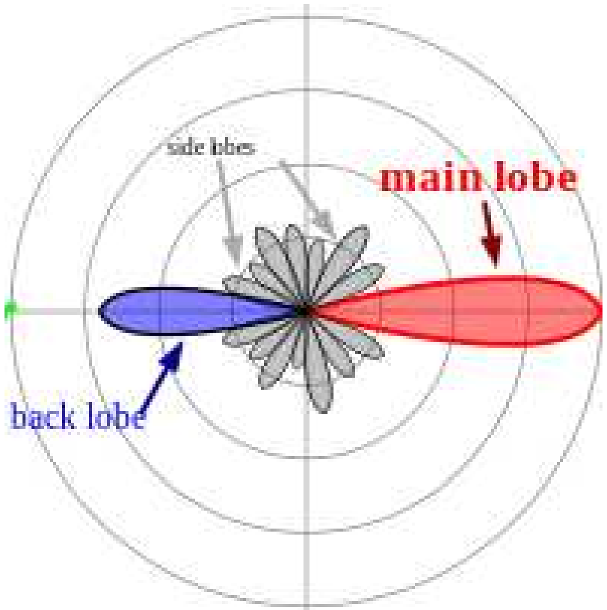
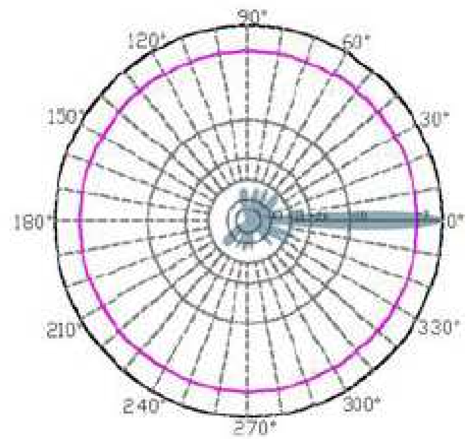
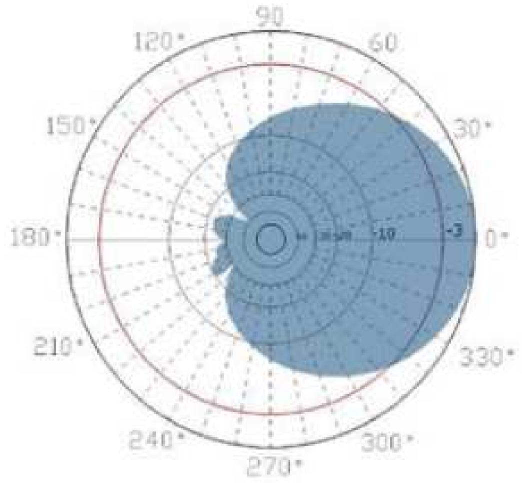
Directivity



Directivity

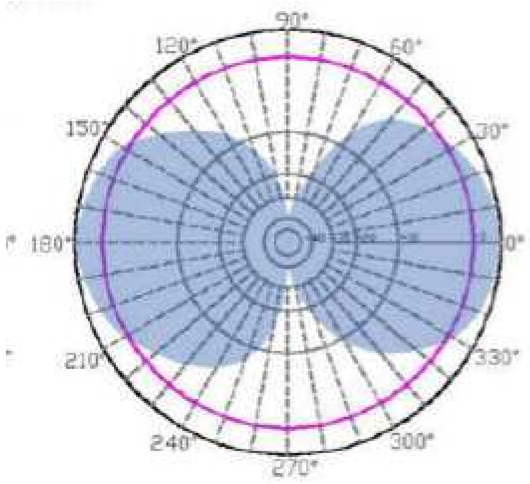


HPBW = 6°

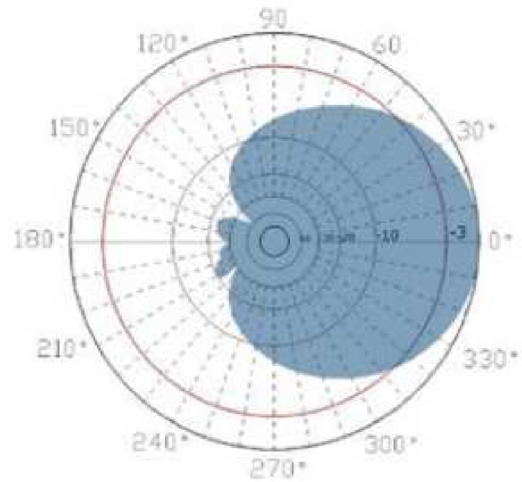


HPBW = 90°

Directivity



HPBW = 60°



HPBW = 90°

Directivity

- The directivity of an antenna is :

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

....memo....

$$P = \frac{1}{2}\oiint_S \left[\mathbf{E}\times\mathbf{H}^*\right]\cdot \hat{i}_r dS = P_1 + jP_2$$

P_1 being the radiated power (hereafter named P_{rad})

$r >> D$

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

$r >> \lambda$

Fraunhofer region

The Poynting vector simplifies as

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

.... and thus, in a spherical reference system centered in the antenna,

$$P = \int_0^{2\pi} d\varphi \int_0^{\pi} d\vartheta \frac{\left|\mathbf{E}\right|^2}{2\zeta} r^2 \sin\vartheta = P_1 = P_{rad}$$

Directivity

- The directivity of an antenna is :

$$D(\vartheta,\varphi)=\lim_{r\to\infty}\frac{\frac{1}{2}\frac{\left|\mathbf{E}(r,\vartheta,\varphi)\right|^2}{\zeta}}{\frac{1}{4\pi r^2}P_{rad}}=\lim_{r\to\infty}\frac{\frac{1}{2}\frac{\left|\mathbf{E}(r,\vartheta,\varphi)\right|^2}{\zeta}}{\frac{1}{4\pi r^2}\int_0^{2\pi}d\varphi\int_0^{\pi}d\vartheta\frac{\left|\mathbf{E}(r,\vartheta,\varphi)\right|^2}{2\zeta}r^2\sin\vartheta}$$

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

….. Memo ….

Elementary electrical dipole

$$P=\frac{1}{2}\oiint_S\left[\mathbf{E}\times\mathbf{H}^*\right]\cdot\hat{i}_r dS=\frac{1}{2}\int_0^{2\pi}d\varphi\int_0^{\pi}d\vartheta r^2\sin\vartheta E_\vartheta H_\varphi^*=\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2\left[1-j\frac{1}{(\beta r)^3}\right]|I|^2$$

far field

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

$$P=P_1+jP_2$$

$$P_1=P_{rad}=\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2|I|^2$$

$$P_2=-\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2\frac{1}{(\beta r)^3}|I|^2$$

$$D(\vartheta,\varphi)=\frac{3}{2}\sin^2\vartheta$$

$$D_{\max}=10\log_{10}1.5=1.76\text{ dB}$$

….. Memo ….

Small loop antenna

$$P = \frac{1}{2}\oiint_S \left[\mathbf{E}\times\mathbf{H}^*\right]\cdot\hat{i}_r dS = -\frac{1}{2}\int_0^{2\pi} d\varphi \int_0^{\pi} d\vartheta r^2 \sin\vartheta E_\varphi H_\vartheta^* = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2\left[1 + j\frac{1}{(\beta r)^3}\right]|I|^2$$

far field

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

$$P = P_1 + jP_2$$

$$P_1 = P_{rad} = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2|I|^2$$

$$P_2 = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2\frac{1}{(\beta r)^3}|I|^2$$

$$D(\vartheta,\varphi) = \frac{3}{2}\sin^2\vartheta$$

$$D_{max} = 10\log_{10}1.5 = 1.76 \text{ dB}$$

Tx Antenna parameters

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

Gain

Directivity

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

Gain

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

P_{rad}: radiated power

P_{in}: input power

Gain

- If one replace P_{rad} with the input real power to the antenna P_{in} one finds the definition of the *Gain*.
- For a lossless antenna, $P_{in}=P_{rad}$ and $G=D$. If losses are present $P_{ing}>P_{rad}$ and $G<D$.
- *Note that both D and G are dimensionless.*

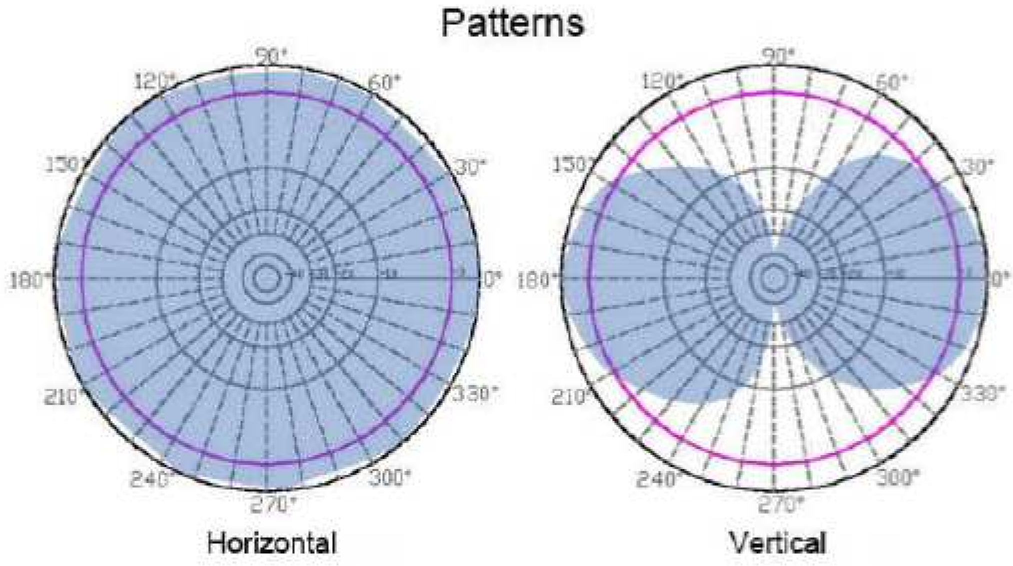
Gain

three examples from the real life

Gain

three examples from the real life

(maximum) Gain = 3 dB

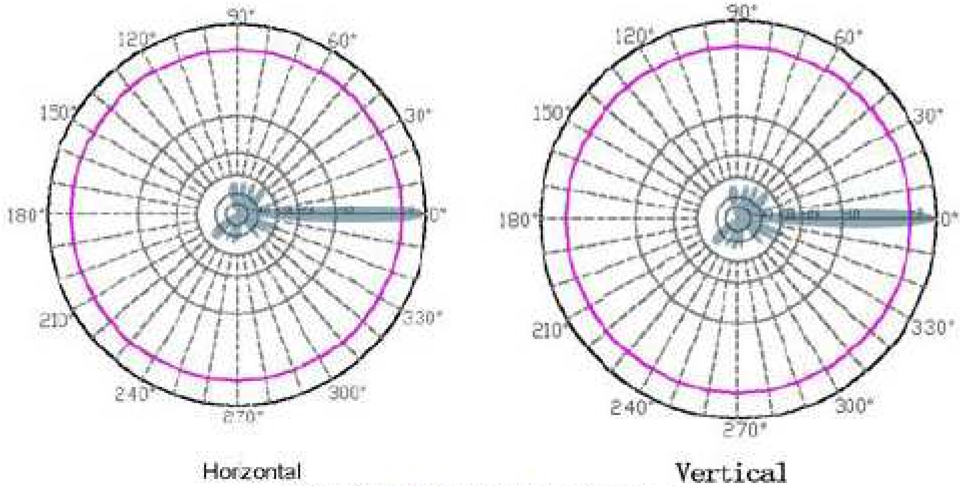


ZDAEW1900-3 **Patterns**

Gain

three examples from the real life

(maximum) Gain = 29 dB

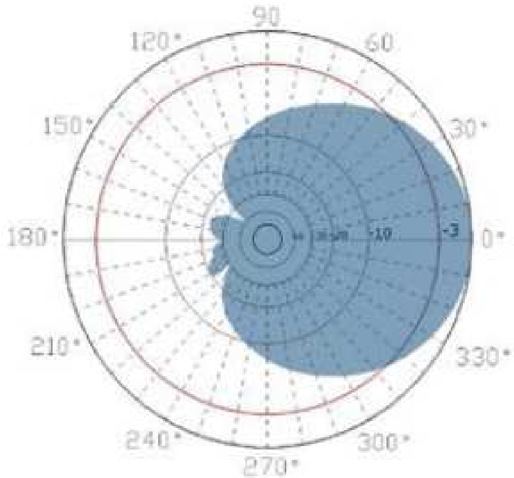


ZDASP5400-29-6 **Patterns**

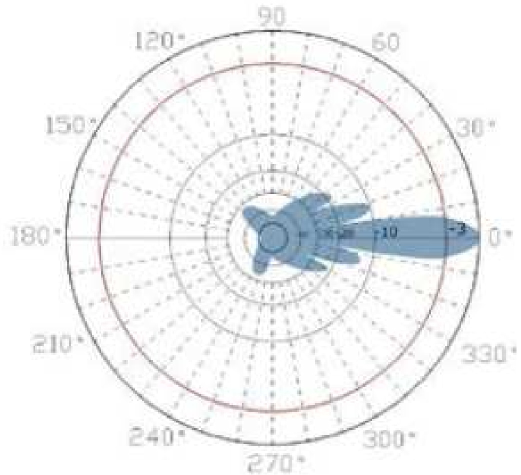
Gain

three examples from the real life

(maximum) Gain = 13 dB



Horizontal



Vertical

ZDADJ800-13-90 Patterns

Tx Antenna parameters

- Effective length
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Radiation resistance

- Associated to the far-field radiated power one can define the radiation Resistance R_{rad}:

$$P_{rad} = \int_0^{2\pi} d\varphi \int_0^{\pi} d\vartheta \frac{|\mathbf{E}|^2}{2\zeta} r^2 \sin\vartheta = \frac{1}{2} R_{rad} |I|^2$$

….. Memo ….

Elementary electrical dipole

$$P=\frac{1}{2}\oiint_S\left[\mathbf{E}\times\mathbf{H}^*\right]\cdot\hat{i}_r dS=\frac{1}{2}\int_0^{2\pi}d\varphi\int_0^{\pi}d\vartheta r^2\sin\vartheta E_\vartheta H_\varphi^*=\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2\left[1-j\frac{1}{(\beta r)^3}\right]|I|^2$$

$$P=P_1+jP_2$$

$$P_1=P_{rad}=\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2|I|^2$$

$$P_2=-\frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2\frac{1}{(\beta r)^3}|I|^2$$

$$R_{rad}=\frac{2\pi}{3}\zeta\left(\frac{\Delta z}{\lambda}\right)^2$$

..... Memo ....

Small loop antenna

$$P = \frac{1}{2}\oiint_S \left[\mathbf{E}\times\mathbf{H}^*\right]\cdot\hat{i}_r dS = -\frac{1}{2}\int_0^{2\pi} d\varphi \int_0^{\pi} d\vartheta r^2 \sin\vartheta E_\varphi H_\vartheta^* = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2\left[1 + j\frac{1}{(\beta r)^3}\right]|I|^2$$

$$P = P_1 + jP_2$$

$$P_1 = P_{rad} = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2 |I|^2$$

$$P_2 = \frac{1}{2}\frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2 \frac{1}{(\beta r)^3}|I|^2$$

$$R_{rad} = \frac{2\pi}{3}\zeta\left(\frac{\beta\Delta S}{\lambda}\right)^2$$

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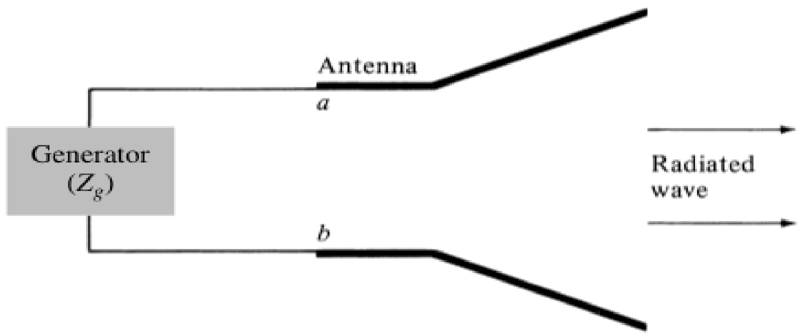
Input impedance

- *Input impedance* is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point."

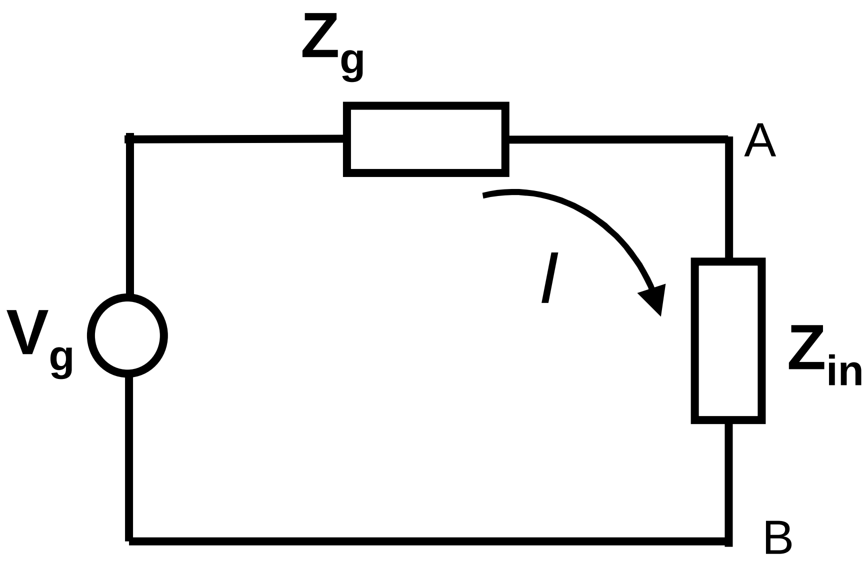
Input impedance

- We are primarily interested in the input impedance at a pair of terminals which are the input terminals of the antenna. In Figure these terminals are denoted as a − b.

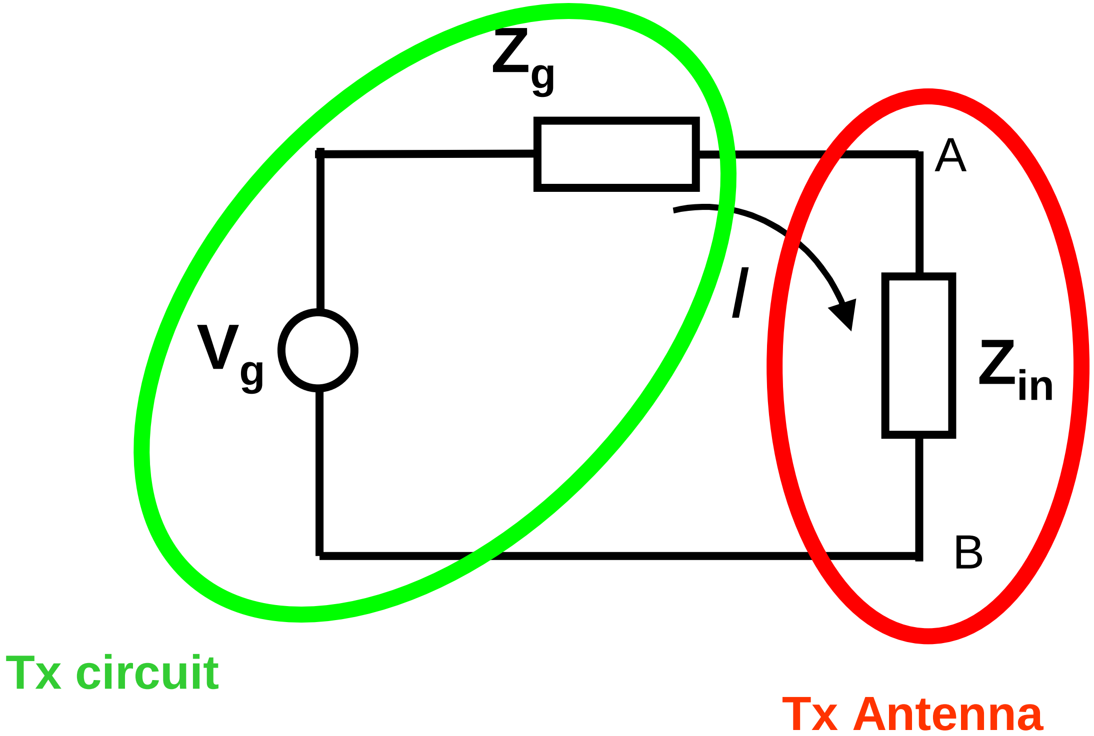


Antenna in transmitting mode

Equivalent circuit of the Tx antenna



Equivalent circuit of the Tx antenna



$$Z_{in} = R_{in} + jX_{in}$$

$$P_{in} = \frac{1}{2} R_{in} |I|^2$$

$$P_{rad} = \frac{1}{2} R_{rad} |I|^2$$

$$P_{rad} \le P_{in}$$

$$\Rightarrow \quad R_{rad} \le R_{in} \quad \Rightarrow \quad R_{in} = R_{rad} + R_{\Omega}$$

Directivity

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

Gain

$$G(\vartheta,\phi) = \lim_{r\to\infty} \frac{\frac{1}{2}\frac{|\mathbf{E}|^2}{\zeta}}{\frac{1}{4\pi r^2}P_{in}}$$

$$P_{rad} = \frac{1}{2}R_{rad}|I|^2$$

$$P_{in} = \frac{1}{2}R_{in}|I|^2 = \frac{1}{2}(R_{rad}+R_{\Omega})|I|^2$$

Radiation Efficiency $$\eta = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{rad}+R_{\Omega}} = \frac{G}{D}$$

Input impedance

- The input impedance of an antenna is generally a function of frequency.
- The input impedance of the antenna depends on many factors including its geometry, its method of excitation, and its proximity to surrounding objects.
- Because of their complex geometries, only a limited number of practical antennas have been investigated analytically. For many others, the input impedance has been determined experimentally.

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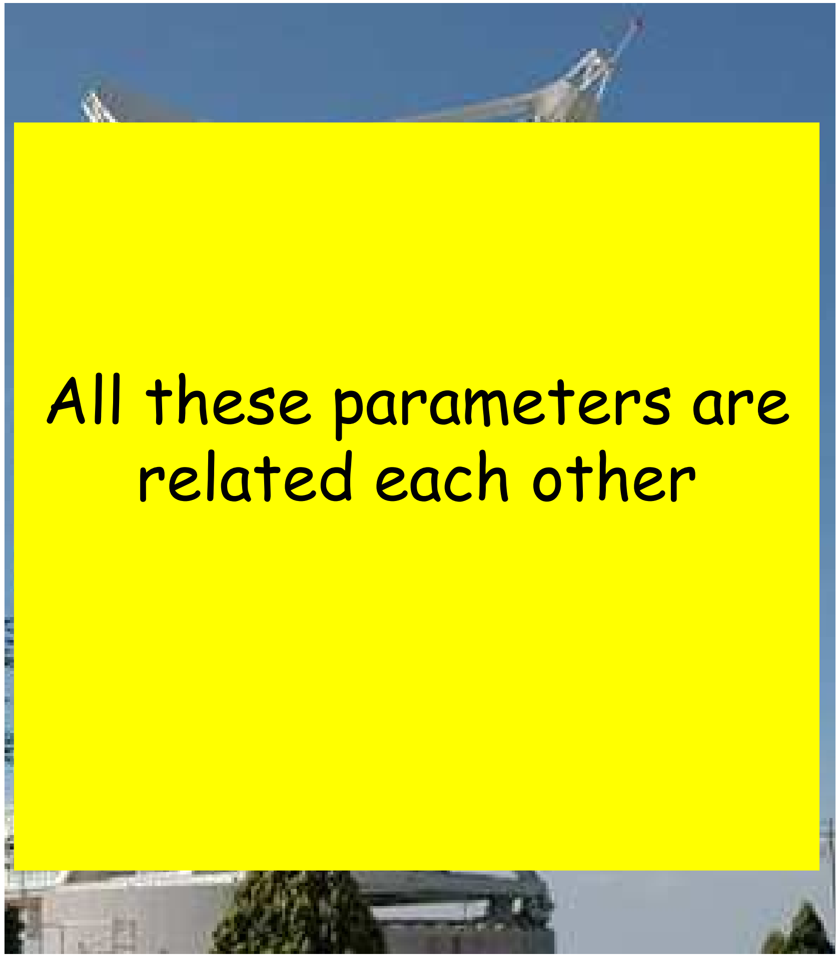

Bandwidth

- The *bandwidth* of an antenna is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.”
- The bandwidth can be considered to be the range of frequencies, where the antenna characteristics are within an acceptable value of those at the center frequency.

Bandwidth

- For *broadband antennas*, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies of acceptable operation. For example, a 10:1 bandwidth indicates that the upper frequency is 10 times greater than the lower.
- For *narrowband antennas*, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth. For example, a 5% bandwidth indicates that the frequency difference of acceptable operation is 5% of the center frequency of the bandwidth.

Bandwidth

Log.-periodic Antenna, Frequency 400-4000 MHz for Amateur radio

UHA 9125 D, Half – Wave Dipole