Main remarks

In the Far-Field

- The **E** and **H** field component **are perpendicular** to each other and **transverse to the** radial **direction of propagation**
- The **E** and **H** field component are in **time phase**
- The E and H field component are both varying **inversely with the distance** to the dipole
- The **spherical wave** can be locally considered as a **plane wave**

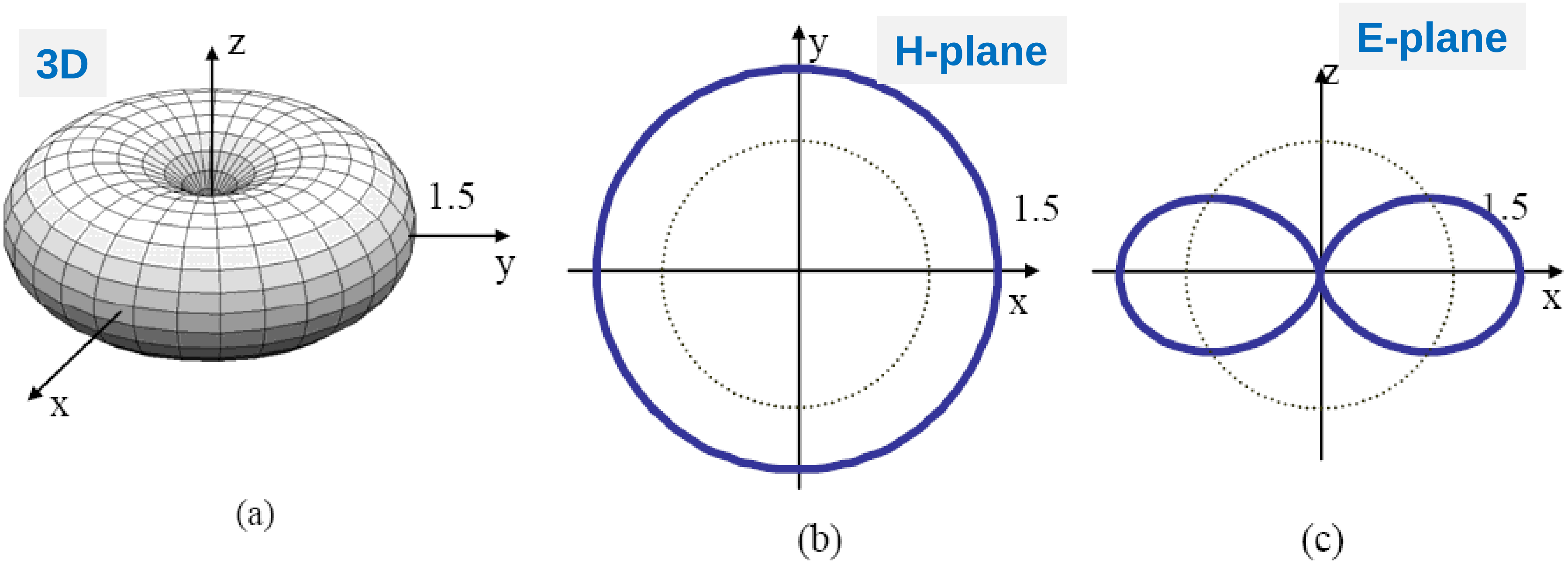
with $$\vec{H} = \frac{\hat{r} \times \vec{E}}{\eta}$$ in practice we can assume $$\frac{E_\theta}{H_\phi} \approx \eta$$

We can compute the Poynting vector for the field (**infinitesimal dipole**)

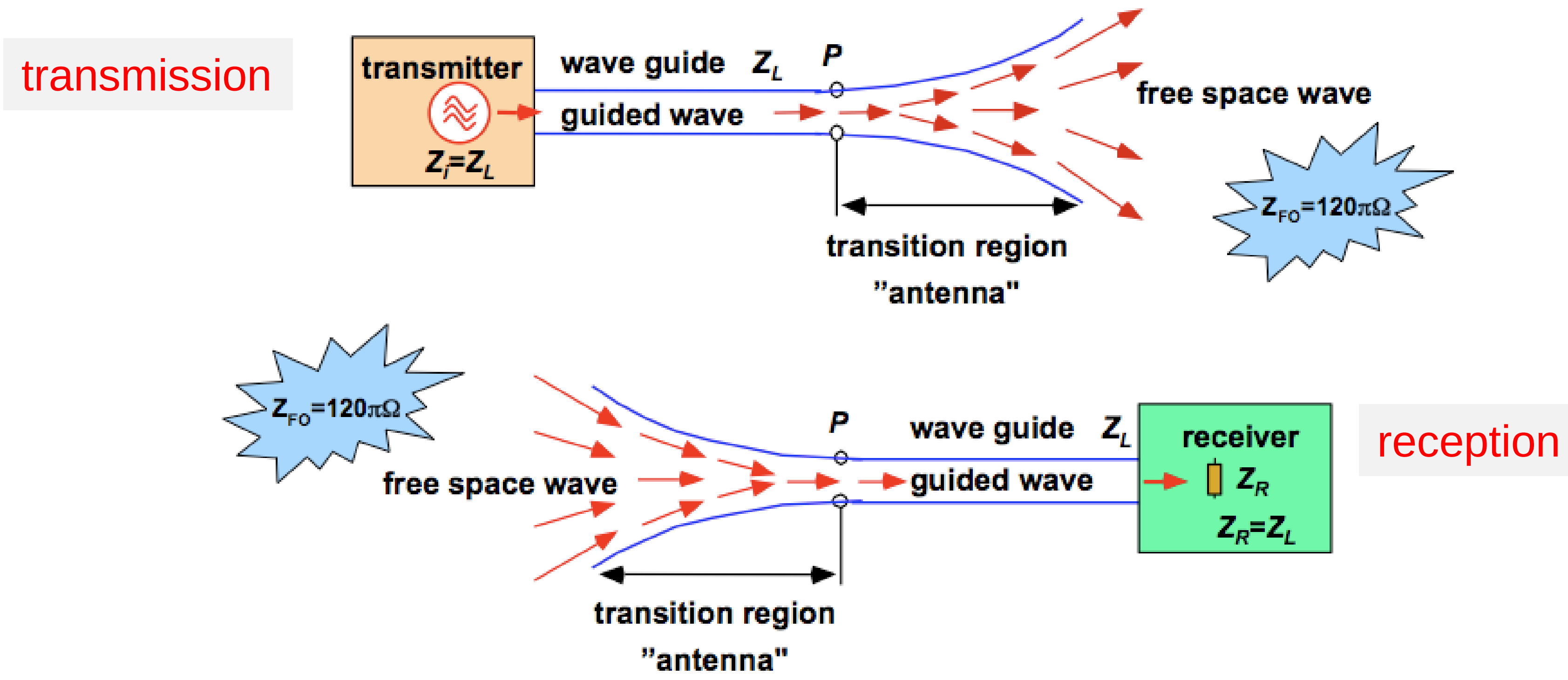
$$\vec{W}_{av} = \frac{1}{2} Re(\vec{E} \times \vec{H}^*) = \hat{r}\frac{1}{2\eta}|E_\theta|^2 = \hat{r}\frac{\eta}{2}\left|\frac{kI_o l}{4\pi}\right|^2 \frac{\sin^2\theta}{r^2}$$

We obtain the real power radiated by the dipole

- Infinitesimal Dipole (short dipole)
- How we can represented the radiated power?
  - It’s a function of spatial variables (θ,ϕ)
  - 3D or 2D plots in specific planes
  - No energy is radiated by the dipole along the direction of the dipole axis
  - Maximum radiation occurs in θ=90º (broadside direction)

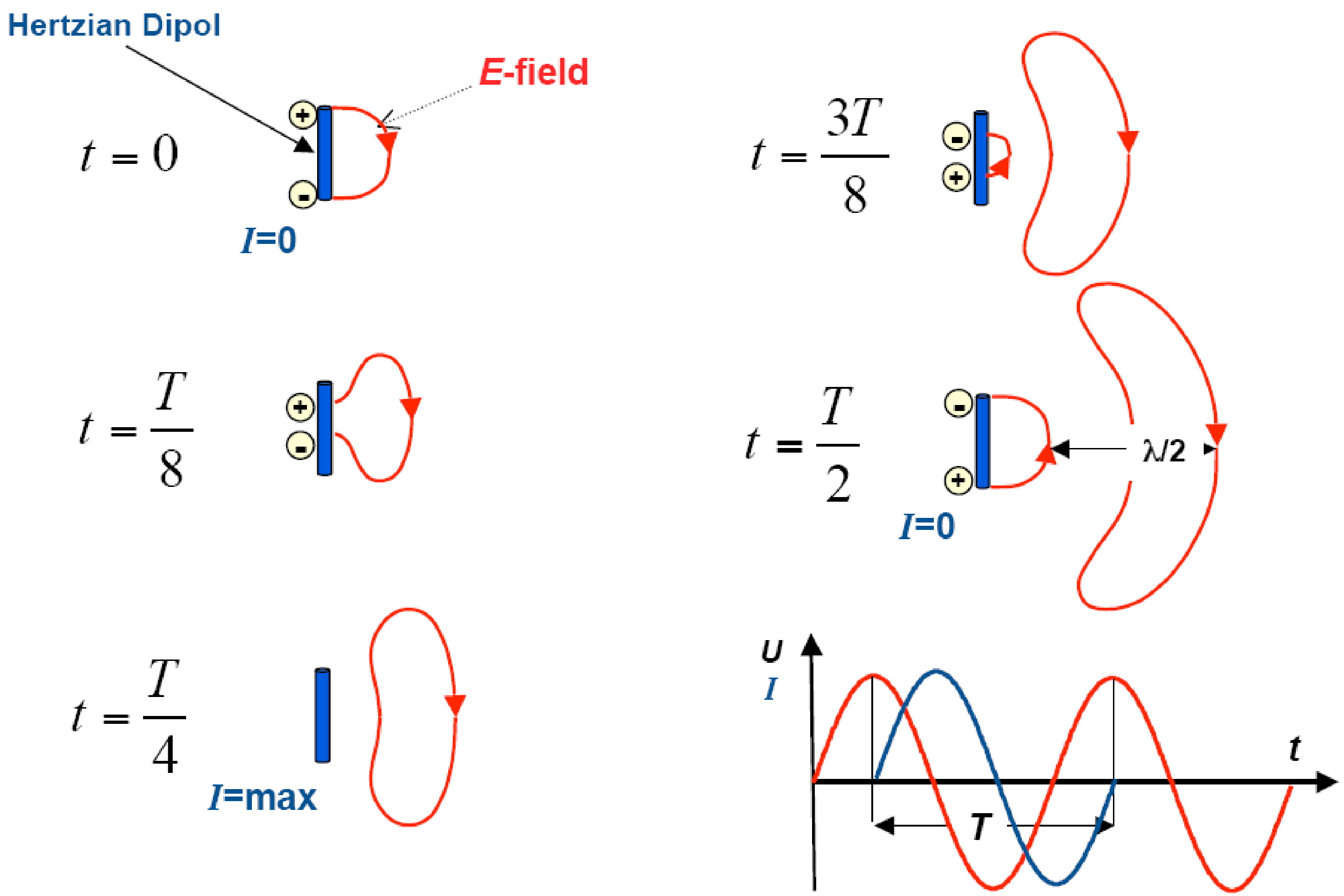


- Antenna performance consist of two aspects: its radiation properties and its impedance:
  - To match the antenna and the line impedances
  - To radiate and receive electromagnetic energy effectively in some directions (depending on the application)

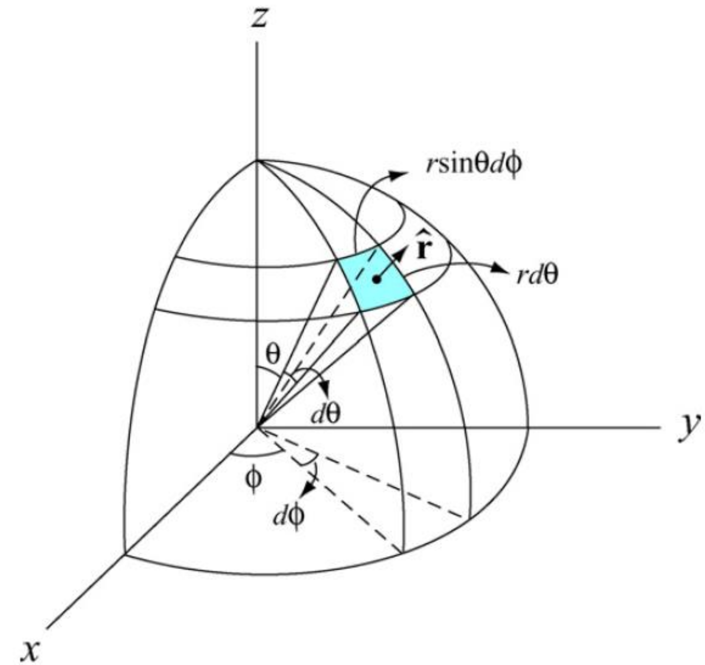


Antenna as a **transducer** between a **guided** electromagnetic wave and a **free-space** wave

Fundamentals of radiation



Radiated field in… far-field approximation



- The antenna radiates an electromagnetic field

$$\vec{E}_{rad} \quad \vec{H}_{rad}$$

The radiation density is described by Poynting's vector…

$$W_{rad} = \frac{1}{2}\left[\vec{E}_{rad} \times \vec{H}^{*}_{rad}\right]$$

Very far from the antenna

$$W_{rad} = \frac{1}{2\eta}\left|\vec{E}_{rad}(r,\theta,\phi)\right|^2$$

Spherical coordinates

$$\vec{E}_{rad}(r,\theta,\phi) = E_\theta(r,\theta,\phi)\hat{\theta} + E_\phi(r,\theta,\phi)\hat{\phi}$$

Radiation intensity

Is the power density radiated per unit solid angle, in a particular direction, by an antenna

$$U = r^2 W_{rad}$$ (W/sr)

Far field approximation

$$\vec{W} = \frac{1}{2} Re(\vec{E} \times \vec{H}^*)$$ (W/m^2)

$$U \approx \frac{r^2}{2\eta}[|E_\theta|^2 + |E_\phi|^2]$$

$$P_{rad} = \oint_\Omega U d\Omega = \int_0^{2\pi} \int_0^{\pi} U(\theta,\phi) \sin\theta d\theta d\phi$$

Total radiated power

Radiation Pattern

- **It is a KEY parameter which gives the spatial distribution of the energy that the antenna radiates**
  - It is a graphical representation of the antenna radiation properties as a function of the angula coordinates.
  - We compute the radiation pattern as the **radiation intensity divided by its maximun value**
  - The radiation pattern is a **normalized function of** variables (θ, ϕ) in a spherical coordinate system.

$$r(\theta, \phi) = \frac{U(\theta, \phi)}{U_{max}}$$

In certain cases it is found convenient to plot the antenna pattern on a decibel scale by expressing $r(\theta, \phi)$ in decibels

$$r(dB) = 10 log_{10} r$$

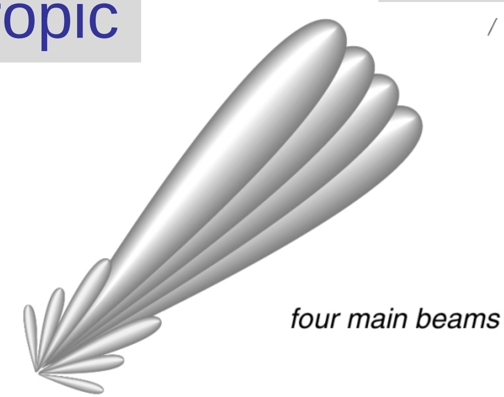
Radiation Pattern

- Some examples of radiation pattern geometries

Isotropic

Omniazimuthal

Directive



multibeam antenna

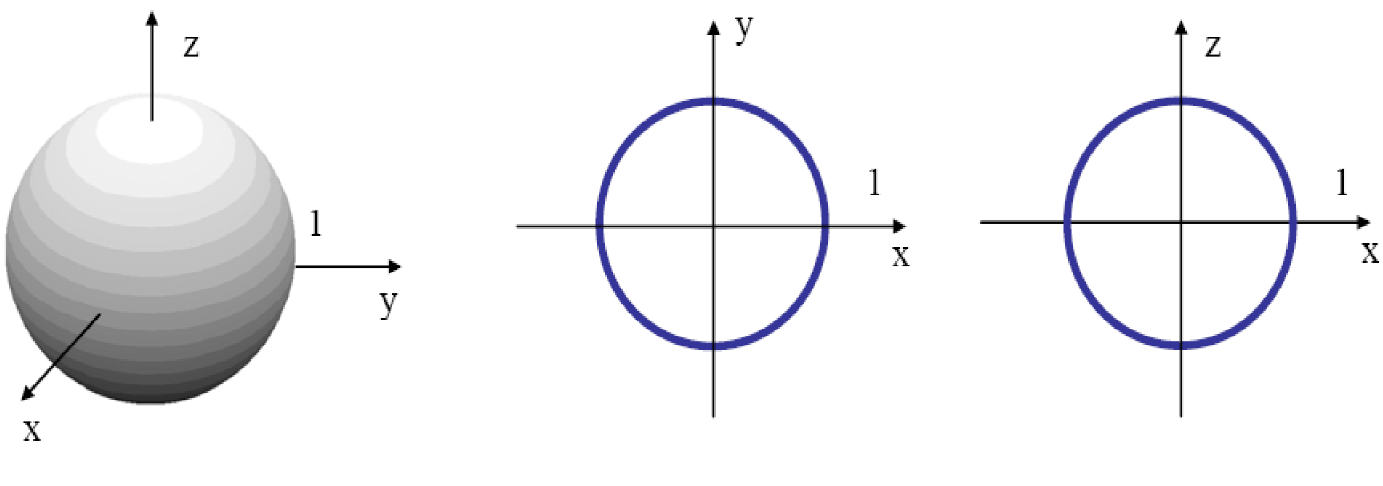
Multibeam pattern

Isotropic Antenna

- **IDEAL antenna** which radiates the same power intensity in all directions
  - It is used as a reference to define antenna parameters
  - To exist would require a point source
  - Radiated power density would be the same in all direction.

$$P_{iso} = \oint_{\Omega} U_o d\Omega = U_o 4\pi \qquad U_o = \frac{P_{rad}}{4\pi} \qquad W_{iso} = \frac{P_{rad}}{4\pi r^2}$$

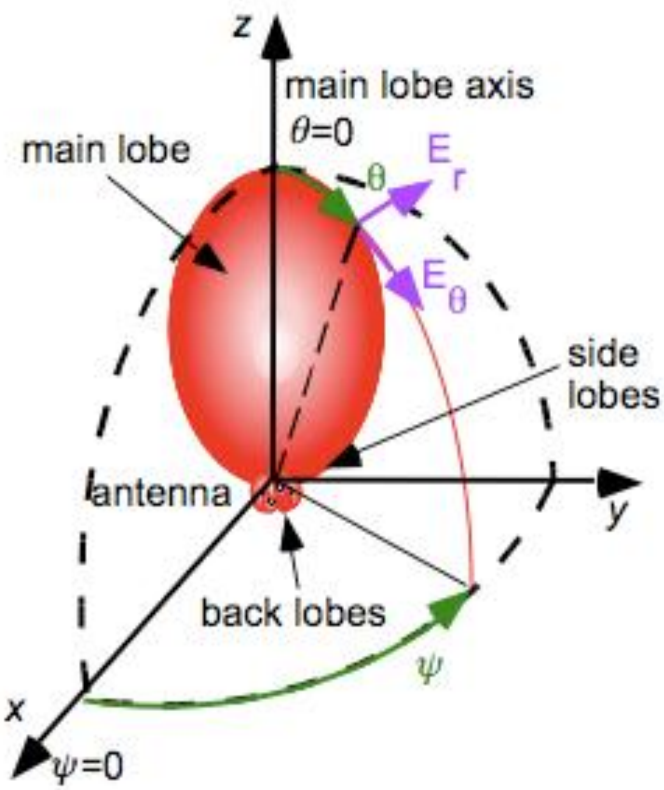
The radiation intensity is constant over all space and also the pattern



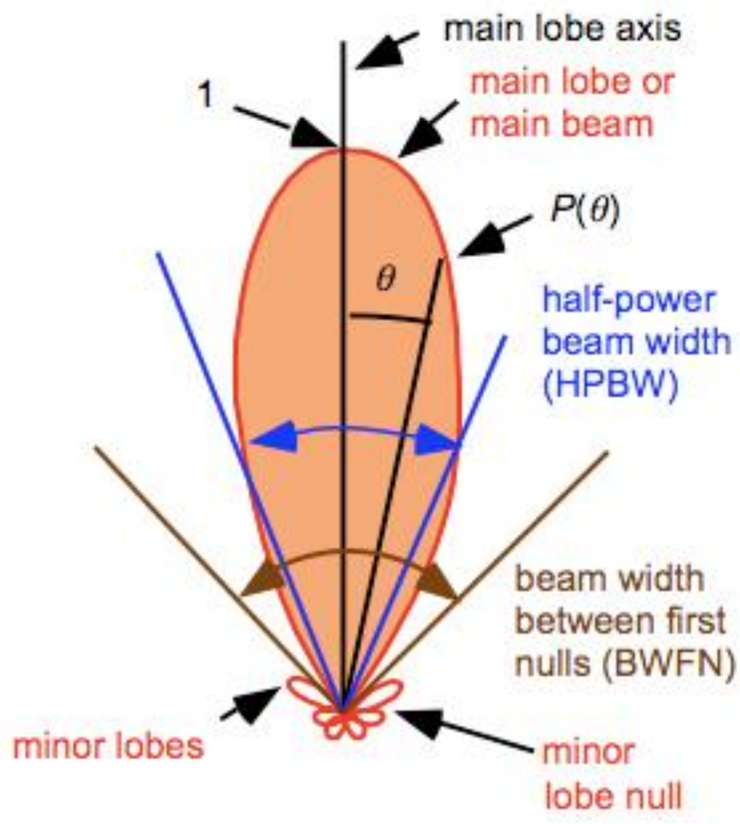
(a) (b) (c)

Representative plots of the radiation pattern

Field pattern



Power pattern



Directivity

Directivity: is defined as the ratio of the radiation intensity in a certain direction to the radiation intensity of a reference antenna

$$D = \frac{U}{U_{ref}}$$

$$D = \frac{U(\theta,\phi)}{U_{iso}(\theta,\phi)} = 4\pi\frac{U(\theta,\phi)}{P_{rad}}$$

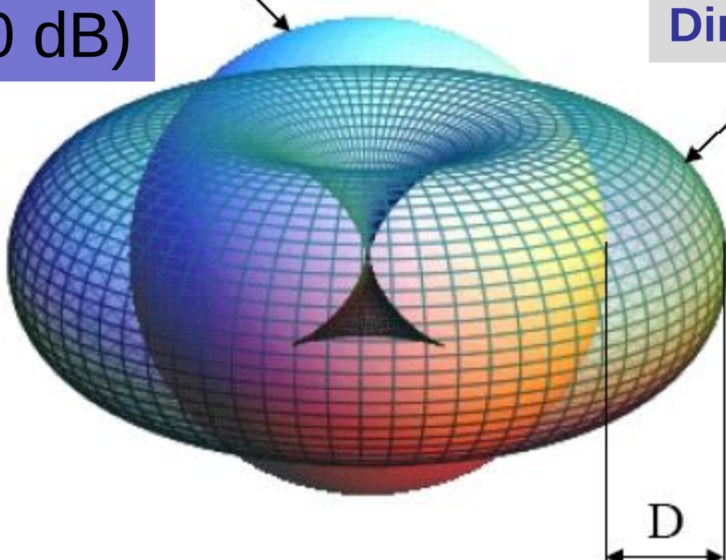
Usually we consider the isotropic radiator as the reference antenna

Isotropic Antenna

D=1 (0 dB)

Directive Antenna

D>1 (0 dB)

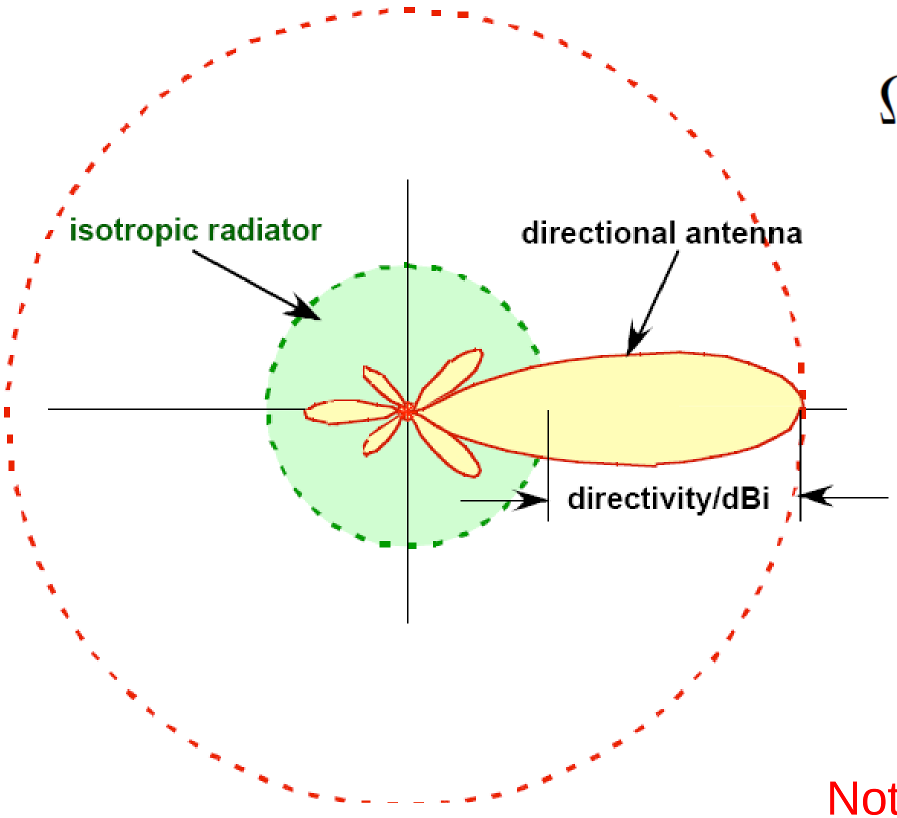


$$D = \frac{U_{max}}{U_o} = 4\pi\frac{U_{max}}{P_{rad}}$$

Maximum value of D

Directivity

- **Antenna beam solid angle** *is defined as the solid angle through which all the power of the antenna will be flow if its radiation intensity is constant (and equal to the maximum value of U) for all angles within* Ω_A



$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} r(\theta, \phi) \sin\theta d\theta d\phi$$

$$D = \frac{4\pi}{\Omega_A}$$

The directiviy is entirely determined by pattern shape

Note: For isotropic antenna we have….D=1

Gain and Efficiency

- The Gain is a parameter that takes into account the efficiency of the antenna as well as its directional capabilities

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

$$G = 4\pi \frac{U}{P_{in}}$$

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

$$G_{max} = e \cdot D_{max}$$

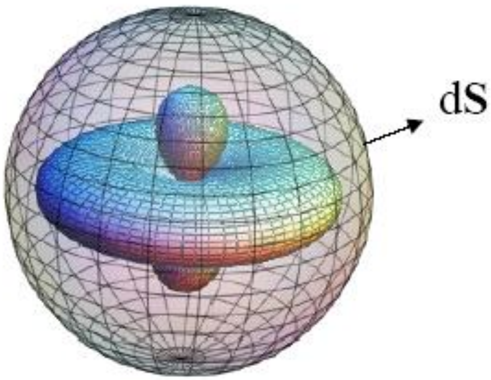
$$e \leq 1$$

The definition for the **Gain** is similar to the **Directiviy**, <u>except</u> that it is referred to the input power **P_{in}**, rather than the radiated power **P_{rad}**

$$G_{max} \leq D_{max}$$

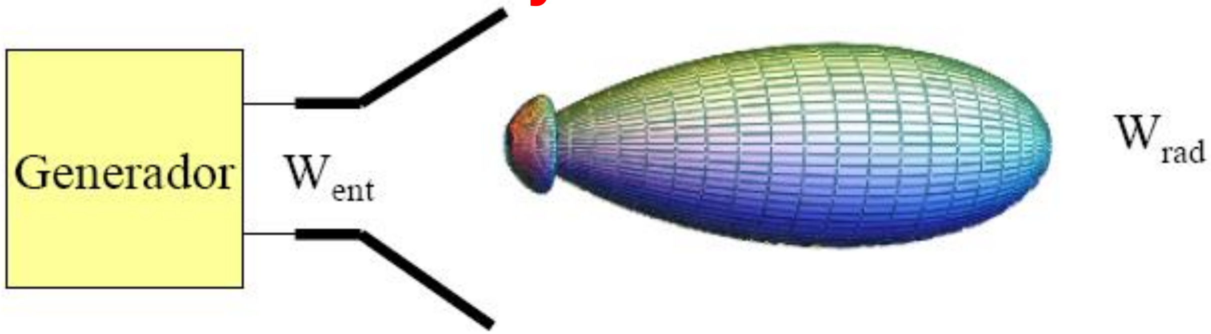
Total efficiency → $$e = e_r \cdot e_c \cdot e_d$$

Reflection efficiency (→ e_r) Conducting efficiency (→ e_c) Dielectric efficiency (→ e_d)



Gain

- The Gain of the antenna is the maximum value of the G(θ,ϕ) function ⇒ **Usually we need to measure it!**



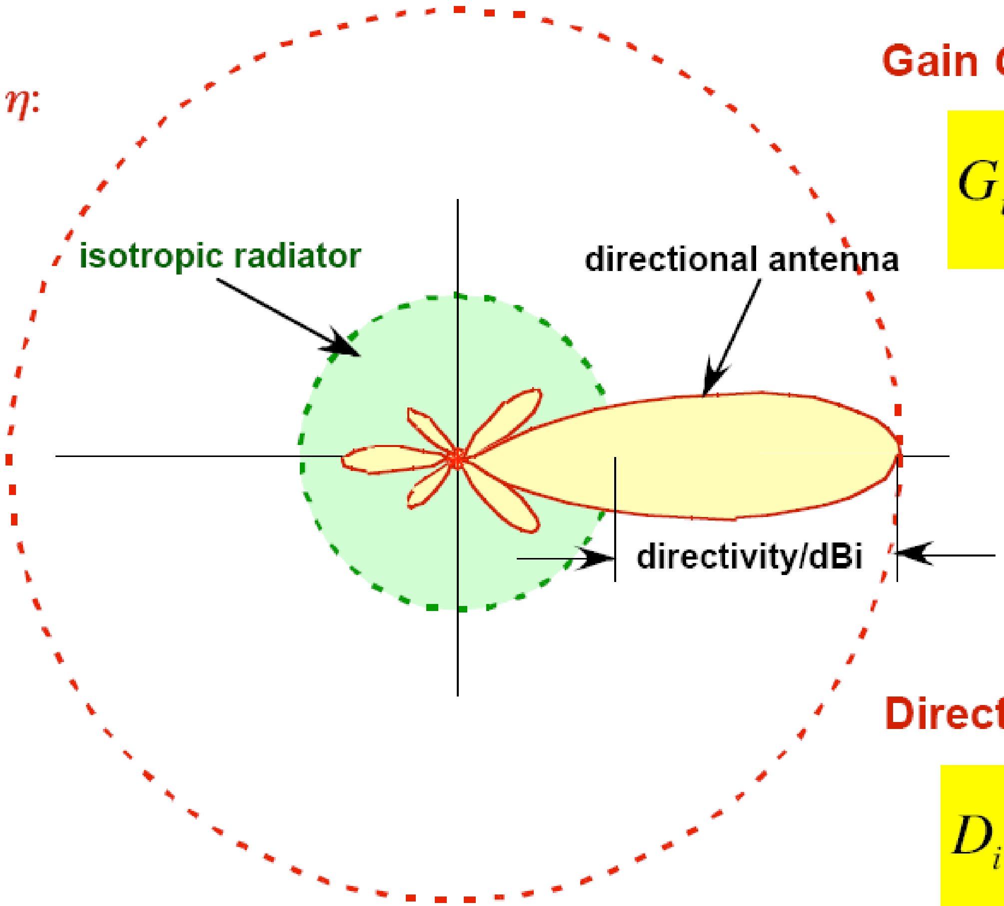
$$G(\theta,\phi) = \frac{P_{rad}(\theta,\phi)}{\dfrac{W_{ent}}{4\pi r^2}} \qquad D(\theta,\phi) = \frac{P_{rad}(\theta,\phi)}{\dfrac{W_{rad}}{4\pi r^2}}$$

The antenna is a passive device

Gain and efficiency

Ant. Efficiency η:

$$\eta = \frac{G}{D}$$



Gain G:

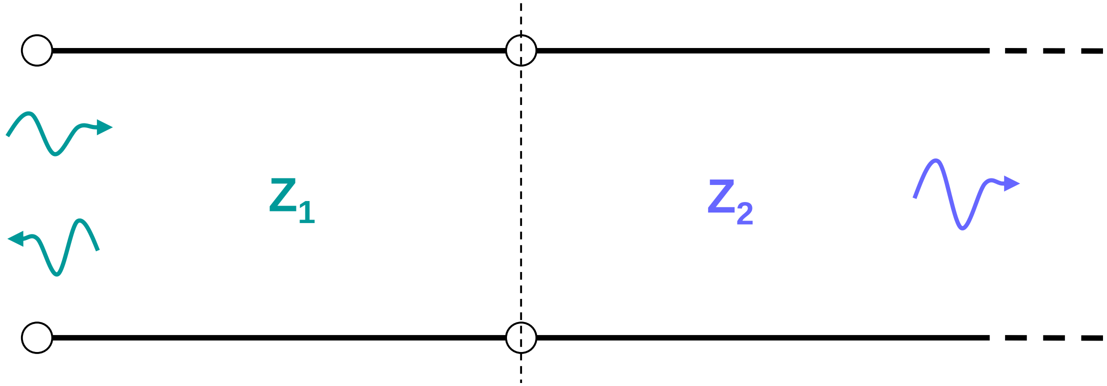
$$G_i = \frac{dP_T / d\Omega}{P_{in} / 4\pi}$$

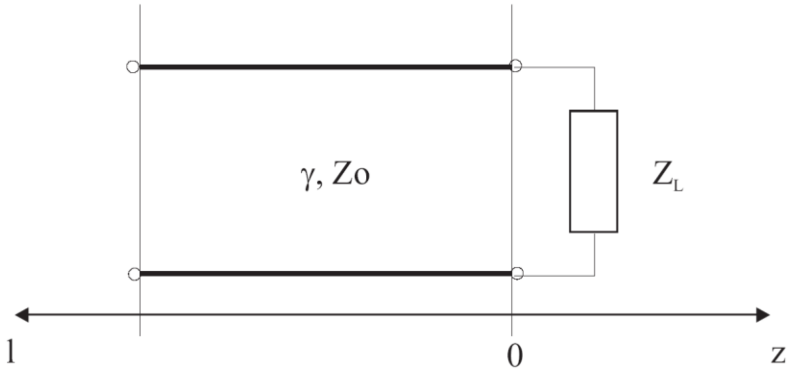
Directivity D:

$$D_i = \frac{dP_T / d\Omega}{P_T / 4\pi}$$

P_T = transmitted power; P_{in} = antenna input power

Transmission lines





$$V(z)=V_o^+\left[e^{j\beta l}+\Gamma\cdot e^{-j\beta l}\right]$$

$$I(z)=\frac{V_o^+}{Z_o}\left[e^{j\beta l}-\Gamma\cdot e^{-j\beta l}\right]$$

$$\Gamma=\frac{V_o^-}{V_o^+}=\frac{Z_L-Z_o}{Z_L+Z_o}$$

Return losses:

$$RL=-20\cdot\log(|\Gamma|)$$ dB

$$P_{av}=\frac{1}{2}\frac{|V_o^+|^2}{Z_o}\left(1-|\Gamma|^2\right)$$

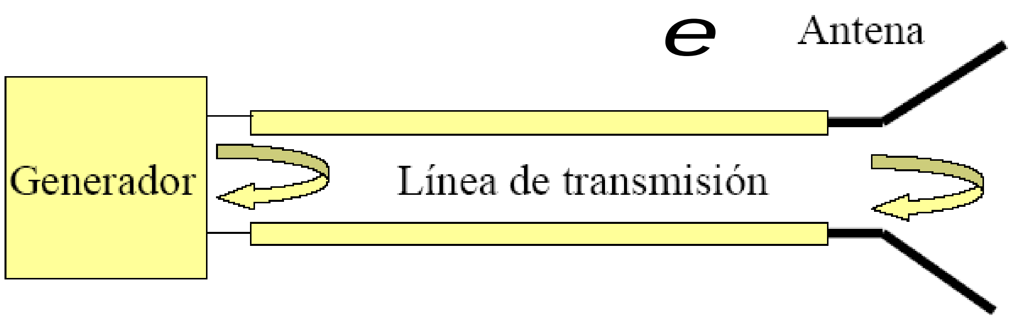
$$ROE=SWR=\frac{V_{\max}}{V_{\min}}=\frac{1+|\Gamma|}{1-|\Gamma|}$$

Input Impedance / Bandwidth

- The input impedance of an antenna is generally a function of frequency. Thus the antenna will be matched to the transmission line only within a bandwidth

$$\Gamma = \frac{Z_{ant} - Z_{ltx}}{Z_{ant} + Z_{ltx}}$$

Γ is the voltage reflection coefficient



The **bandwidth** can be considered to be the **range of frecuencies**, where the antenna characteristics (**input impedance**, pattern, polarization, gain, etc) are within an acceptable value

For exemple, the reflection efficiency determines the impedance bandwidth for the antenna

$$e_r = (1 - |\Gamma|^2)$$

….the range of frecuencies where the reflection coefficient is below a certain value

SWR

- Normally when we have an antenna we characterize the **Voltage Standing Wave Ratio**

$$0 \leq \Gamma \leq 1$$

$$SWR = \frac{1+\Gamma}{1-\Gamma}$$

$$1 \leq SWR \leq \infty$$

- We need to achieve a very low SWR if we want to design an efficient antenna (in terms of reflection…)