ANTENNAS , WAVE PROPAGATION &TV ENGG

Topics to be covered

- Directivity
- Gain

Directivity

- **Definition1:**

The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

$$D = U_{given\ direc} / U_{av}$$

Definition2:

The avg U is obtained by power radiated by 4π,(rad int of isotropic antenna)

The ratio of its radiation intensity (U) in a given direction over that of an isotropic source.

$$\mathbf{D = U/U_0}$$

Antenna Directivity

Total power radiated $P_{rad} = \int_0^{2\pi} \int_0^{\pi} U(\theta, \varphi) \sin \vartheta d\vartheta d\varphi$

Average radiation intensity $U_{avg} = \frac{P_{rad}}{4\pi}$

$$D = \frac{U}{U_{avg}} = \frac{U}{P_{rad}/4\pi}$$

- ***NOTE:*** ***D* Has no units**

Antenna Directivity

- **Definition3:**

If the direction is not specified then we calculate directivity in the direction of maxima

The ratio of radiation intensity in max. direction to the radiation intensity of isotropic source. (D_0)

$$D_{max} = D_0 = U_{max}/U_0 = 4\pi\, U_{max}/P_{rad}$$

D=directivity

Do=

U=radiation intensity

Umax=

Uo=

Prad=

P

Properties of D

- D=1 for isotropic source
- D>1 for non isotropic

  (max. directivity is greater than 1, Umax>Uo)
- D= $4\pi / \Omega_A$

smaller the beam area……….

Antenna Radiation Efficiency

Conduction and dielectric losses of an antenna (I^2R losses) = e_{cd} efficiency.

Let $\mathbf{R_{cd}}$ represent the actual losses due to conduction and dielectric heating. Then the efficiency is given as

$$K / e_{cd} = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{cd} + R_{rad}}$$

Practically losses are there, so $R_{cd} + R_{rad} > R_{cd}$

Practical antenna: K<1
Ideal antenna: K=1

Overall Antenna Efficiency

The overall antenna efficiency is a coefficient that accounts for all the different losses present in an antenna system.

$$e = e_p \overbrace{e_r e_c e_d}^{e_t} = e_p \cdot e_r e_{cd}$$

$$e_p = polarization \quad mismatches$$

$$e_r = reflection \quad efficiency\,(impedance\,mismatch)$$

$$e_c = conduction \quad losses$$

$$e_d = dielectric \quad losses$$

$$e_{cd} = conductor \,\&\, dielectric \quad losses$$

If antenna is perfectly matched, er=0
e_t = e cd.

Reflection Efficiency

The reflection efficiency through a reflection coefficient (Γ) at the input (or feed) to the antenna.

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

$$\Gamma = \frac{R_{input} - R_{generator}}{R_{input} + R_{generator}}$$

$$R_{input} = antenna \quad input \quad impedance(\Omega)$$

$$R_{output} = generator \quad output \quad impedance(\Omega)$$

Antenna Gain

- Directivity= $D = \frac{4\pi U}{P_{rad}/}$
- Gain= $D = \frac{4\pi U}{P_{in}/}$
- We know K=Prad/Pin
- G= $\frac{K\,4\pi U}{P_{rad}/}$
- So

G=KD

Gain

- It can be measured by **comparing radiation intensity of the antenna under test (AUT) with a reference antenna.**
- Ref antenna =dipole, horn (whose gain can be calculated)

- G= U(AUT)/U(ref)

If ref antenna is isotropic

G=U(AUT)/Pin/4π

G= 4π U (AUT)/Pin

Antenna Gain

- The directivity and gain are measures of the ability of an antenna to concentrate power in a particular direction.
- Directivity – power radiated by antenna (P_0)
- Gain – power delivered to antenna (P_T)

$$G = KD$$

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

- K: radiation efficiency (50% - 75%)
- G has no units
  - Usually relates to the peak directivity of the main radiation lobe
  - Often expressed in dB
  - Known as “Absolute Gain” or “Isotropic Gain”

Antennas – Gain

Gain

The power gain, G, of an antenna is very much like its directive gain, but also takes into account efficiency

$$G(\theta,\phi) = eD(\theta,\phi)$$

The maximum power gain

$$G_{\max} = eD_{\max}$$

The maximum power gain is often expressed in dB.

$$G_{\max}(dB) = 10\log_{10}(G_{\max})$$

Example

D8.3: Suppose an antenna has D = 4, R_{rad} = 40 Ω and R_{diss} = 10 Ω. Find antenna efficiency and maximum power gain. (Ans: e = 0.80, G_{max} = 3.2).

Antenna efficiency

$$e = \frac{R_{rad}}{R_{rad} + R_{diss}} = \frac{40}{10+40} = 0.8 \text{ (or) } 80\%$$

Maximum power gain

$$G_{\max} = eD_{\max} = (4)(0.8) = 3.2$$

Maximum power gain in dB

$$G_{\max}(dB) = 10\log_{10}(G_{\max}) = 10\log_{10}(3.2) = 5.05$$

PFD vs. Antenna Gain

$$S(\vartheta,\varphi) = \frac{\Phi(\vartheta,\varphi)\Delta\vartheta\Delta\varphi}{(r\Delta\vartheta)(r\Delta\varphi)} = \frac{\Phi(\vartheta,\varphi)}{r^2}$$

$$= G(\vartheta,\varphi)\frac{P_0}{4\pi r^2}$$

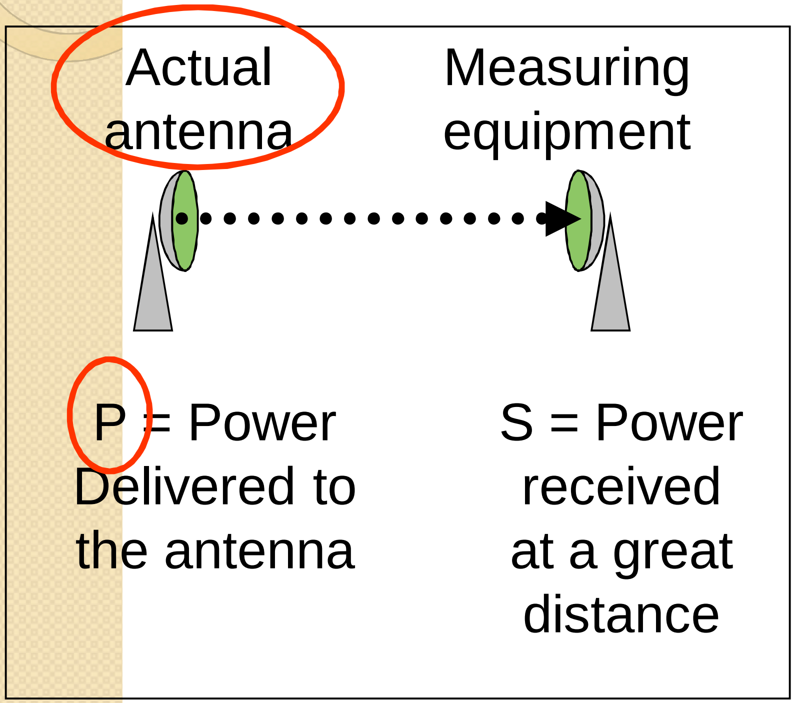
$$= G(\vartheta,\varphi)S_0$$

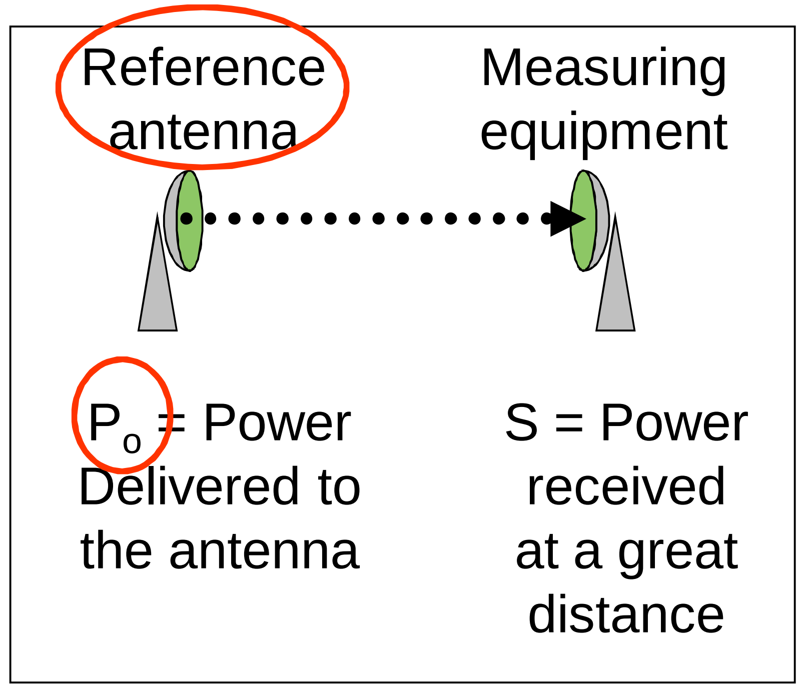
S_0 = PFD produced by a loss-less isotropic radiator

Other Definitions of Gain

- For practical purposes, the antenna gain is defined as the ratio (usually in dB), of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or the same power flux-density at the same distance.
- When not specified otherwise, the gain refers to the direction of maximum radiation.
- The gain may be considered for a specified polarization. [RR 154]

Antenna Gain





Antenna Gain (in the specific direction) = P / P_o

Reference Antennas

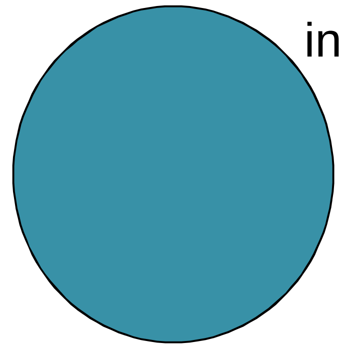
- Isotropic radiator
  - isolated in space (G_i, absolute gain, or isotropic gain)
- Half-wave dipole
  - isolated in space, whose equatorial plane of symmetry contains the given direction (G_d)
- Short vertical antenna
  - (much shorter than $\lambda/4$), close to, and normal to a perfectly conducting plane which contains the given direction (G_v)

Reference Antennas (1)

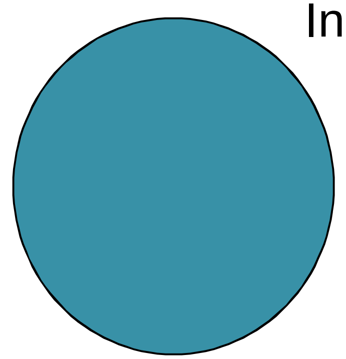
Isotropic antenna

- Sends (receives) energy equally in (from) all directions
- Gain = 1 (= 0 dB)
- When supplied by P, produces at distance r power flux density = $P/(4\pi r^2)$
- Theoretical concept, cannot be physically realized

Radiation pattern
in vertical plane



Radiation pattern
In horizontal plane

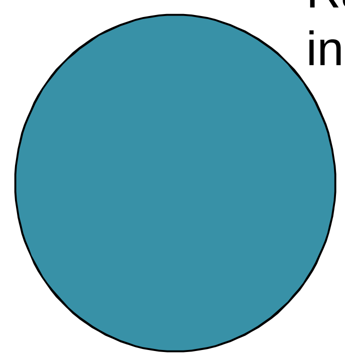


Reference Antennas (2)

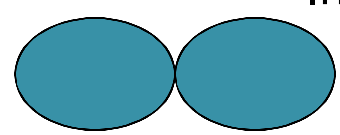
Half-Wave Dipole

- Linear antenna, realizable
- Gain = 1.64 (= 2,15 dB) in the direction of maximum radiation
- Figure-eight-shaped radiation pattern in the dipole plane, omnidirectional (circular) in the orthogonal plan

Radiation pattern
in vertical plane



Radiation pattern
In horizontal plane



Effective aperture and aperture efficiency

Receiving antenna extracts power from incident wave

$$P_{rec} = S_{in} \cdot A_e$$

Aperture and beam area are linked:

$$A_e = \frac{\lambda^2}{\Omega_A}$$

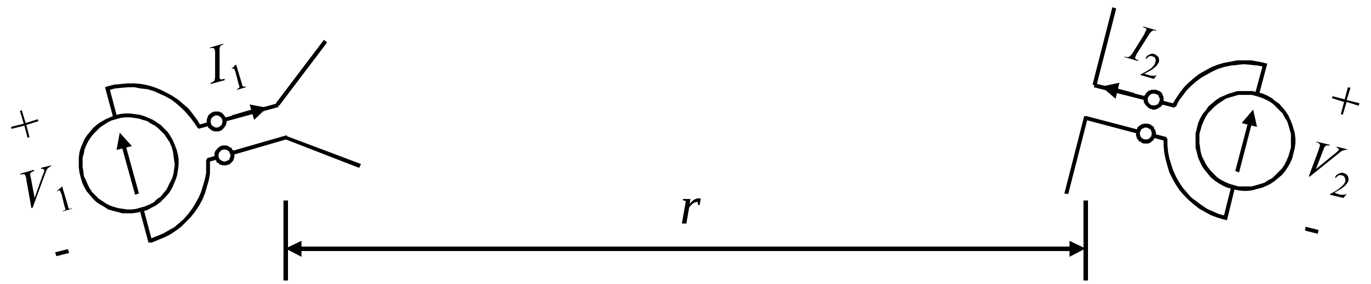
For some antennas, there is a clear physical aperture and an aperture efficiency can be defined

$$\varepsilon_{ap} = \frac{A_e}{A_p}$$

Reciprocity

- Transmission and reception antennas can be used interchangeably
- Medium must be linear, passive and isotropic
- Caveat: Antennas are usually optimised for reception or transmission not both !

Receiving Antennas and Reciprocity



For a linear two-port

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$
$$V_2 = Z_{21}I_1 + Z_{22}I_2$$

Reciprocity

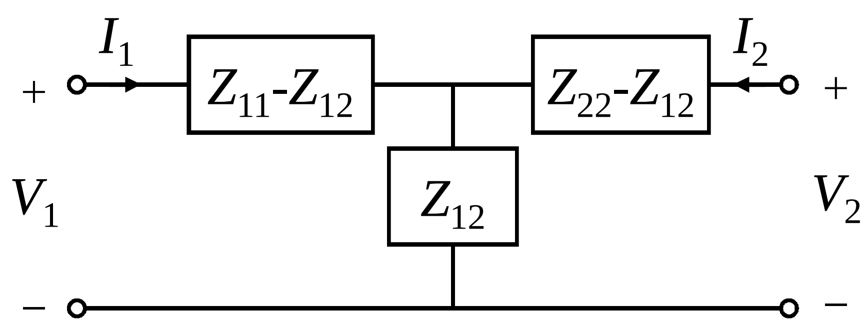
$$Z_{12} = Z_{21}$$

If $I_2 = 0$, $V_2 = Z_{12}I_1 \sim 1/r$

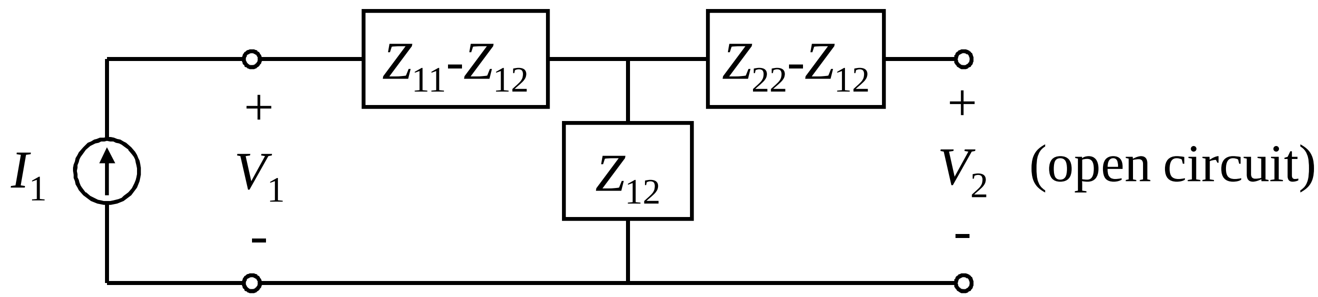
For r large,

$$|Z_{12}| << |Z_{11}|, |Z_{22}|$$

Equivalent Circuit



Circuit Relation for Radiation into Free Space



$V_1 = Z_{11} I_1$ $\qquad$ $V_2 = V_{OC} = Z_{12} I_1$

Transmitted power

$$P_T = (1/2)\mathrm{Re}\left(V_1 I_1^*\right) = (1/2)\mathrm{Re}\left(Z_{11}|I_1|^2\right) = (1/2)R_{r1}|I_1|^2$$

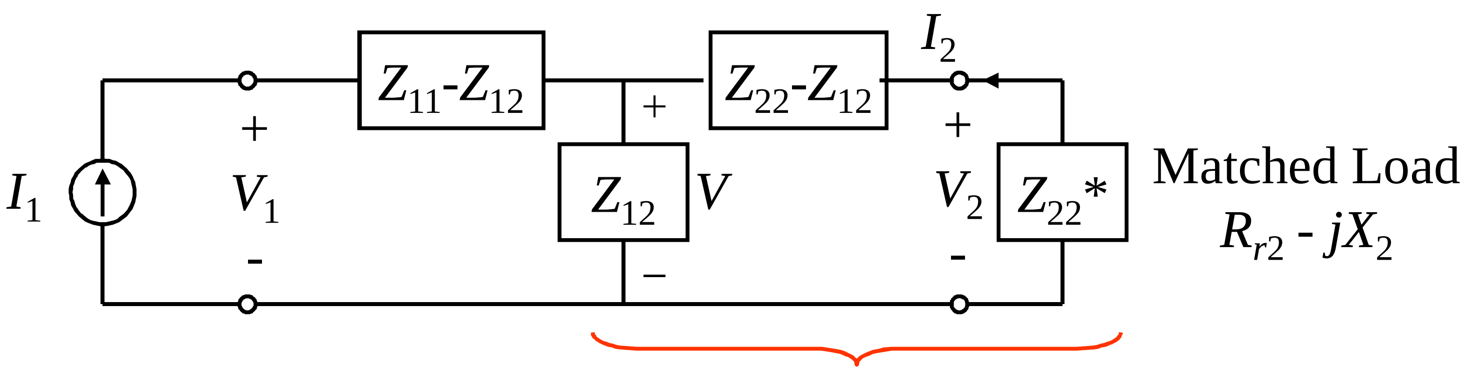
where R_{r1} = radiation resistance of antenna 1

Therefore : $Z_{11} = R_{r1} + jX_1$

Similarily : $Z_{22} = R_{r2} + jX_2$

where R_{r2} = radiation resistance of antenna 2

Received Power and Path Loss Ratio



Current I_1 divides between branches $I_2 = -I_1 \dfrac{Z_{12}}{Z_{12}+\left(Z_{22}-Z_{12}+Z_{22}^*\right)} = -I_1 \dfrac{Z_{12}}{2R_{r2}}$

Received Power for Matched Load $P_R = \dfrac{1}{2}\left|I_2\right|^2 R_{r2} = \dfrac{1}{2}\left|\dfrac{I_1 Z_{12}}{2R_{r2}}\right|^2 = \left|I_1\right|^2 \dfrac{\left|Z_{12}\right|^2}{8R_{r2}}$

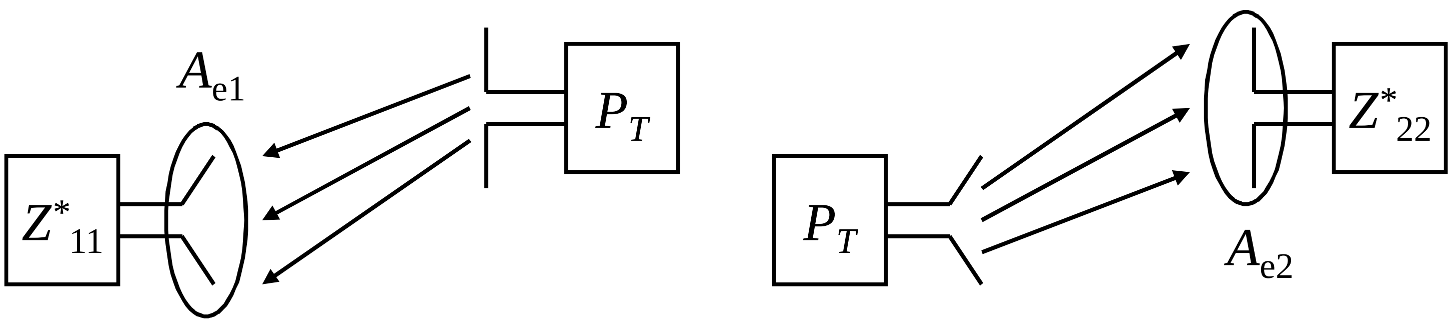
Path Gain $PG \equiv \dfrac{P_R}{P_T} = \dfrac{\left|I_1\right|^2\left|Z_{12}\right|^2 / 8R_{r2}}{\left|I_1\right|^2 R_{r1} / 2} = \dfrac{\left|Z_{12}\right|^2}{4R_{r1}R_{r2}}$

Final expression for PG is the same if antenna 2 radiates and antenna 1 receives.

Effective Area of Receiving Antenna

Effective Area = A_e

$$P_R = \underline{P} \cdot \underline{g}_r A_e = P_T \frac{g(\theta,\phi)}{4\pi r^2} A_e$$



$$PG = \frac{P_R}{P_T} = \frac{g_2 A_{e1}}{4\pi r^2}$$ and by reciprocity $$PG = \frac{P_R}{P_T} = \frac{g_1 A_{e2}}{4\pi r^2}$$

Therefore $g_2 A_{e1} = g_1 A_{e2}$ or $\frac{A_{e1}}{g_1} = \frac{A_{e2}}{g_2} =$ same for all antennas