ECC 203 : Electromagnetics and Radiating Systems

Antenna Parameters 3

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Contents

- Antenna Parameters
  - Input Impedance
  - Antenna Radiation Efficiency
  - Antenna Equivalent Areas
  - Friis Transmission Equation & RADAR Range Equation

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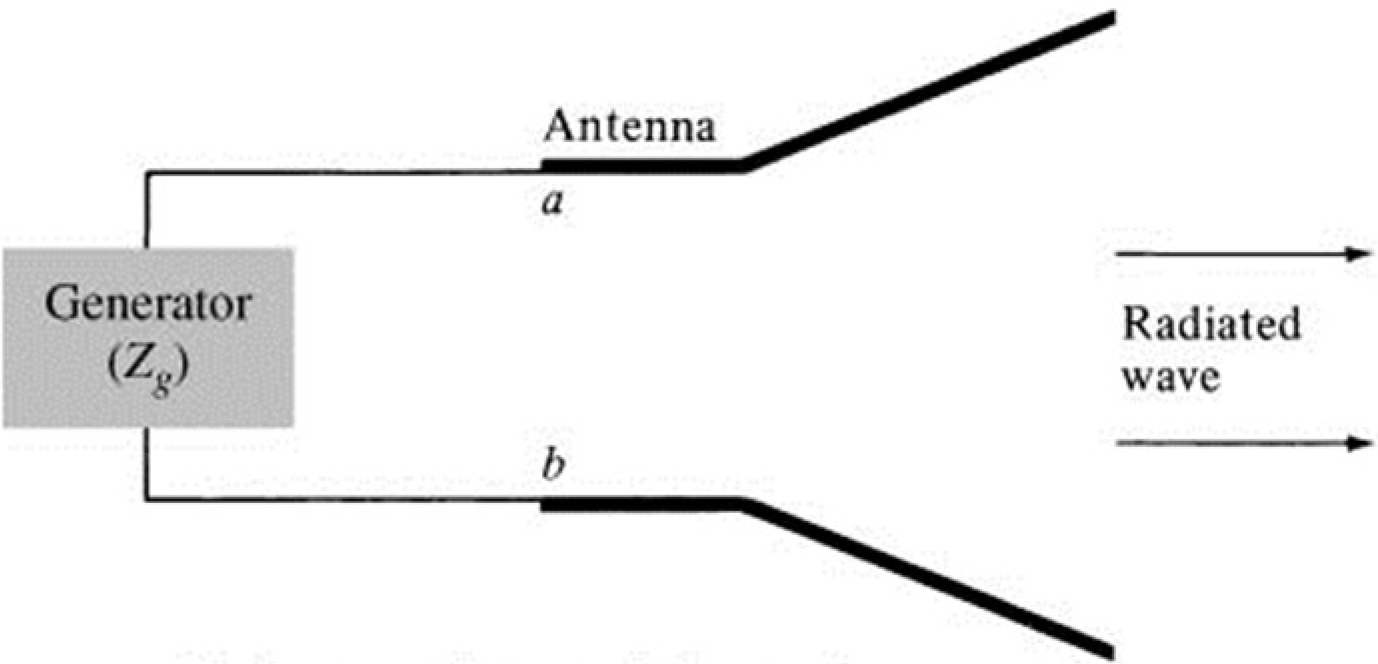
Input Impedance

- *Input impedance is defined as the impedance presented by an antenna at its terminals.*



(a) Antenna in transmitting mode

Thevenin Equivalent: Transmitting

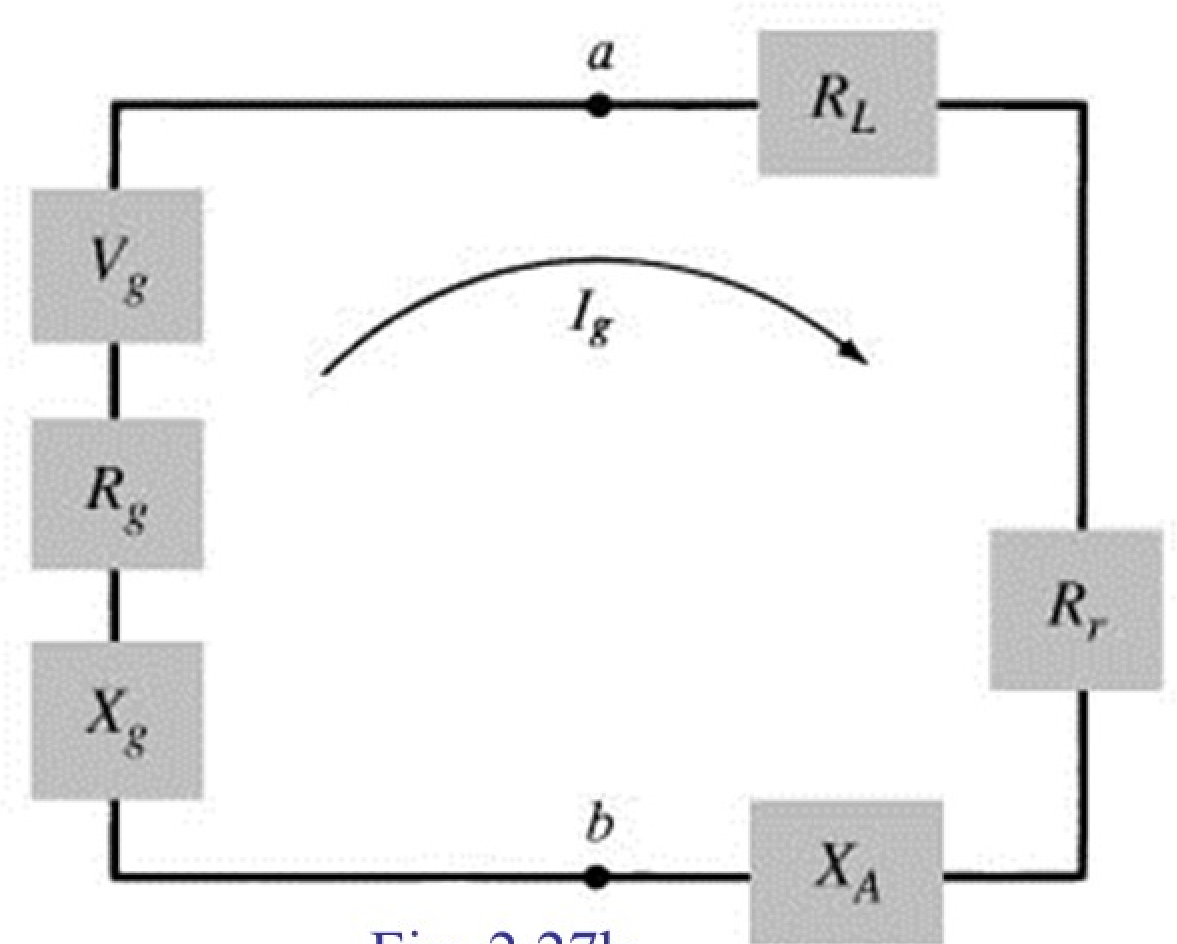


Fig. 2.27b

Norton Equivalent

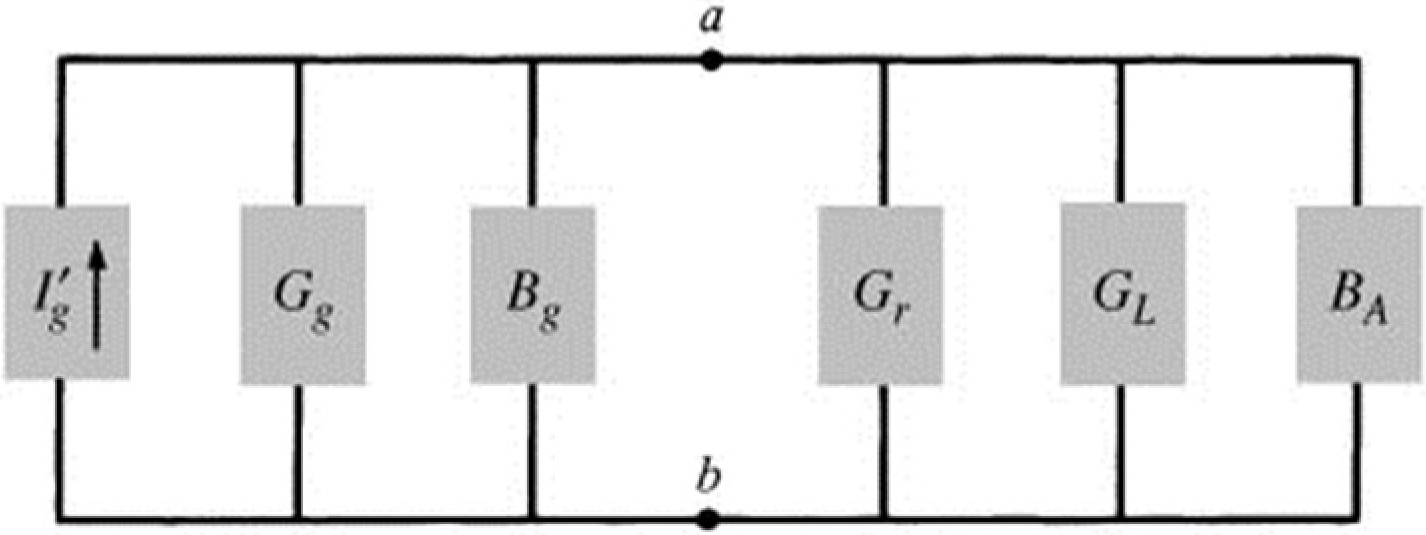


Fig. 2.27c

Power Radiated (R_r) by Antenna

$$P_r = \frac{1}{2}|I_g|^2 R_r \qquad (2\text{-}76)$$

Power Dissipated (R_L) by Antenna

$$P_L = \frac{1}{2}|I_g|^2 R_L \qquad (2\text{-}77)$$

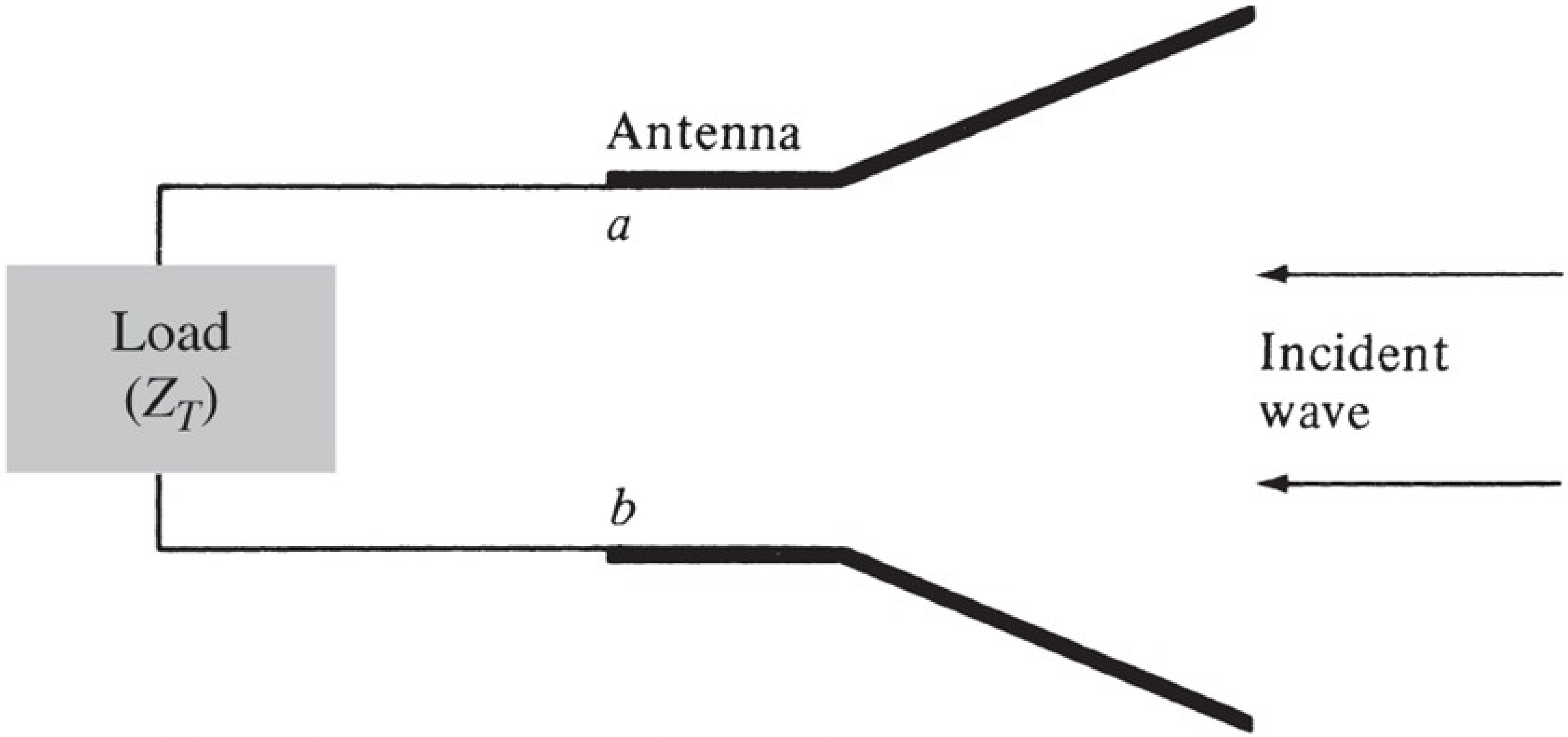
Power Dissipated by (R_g) Generator

$$P_g = \frac{1}{2}|I_g|^2 R_g \qquad (2\text{-}78)$$

Maximum Power Delivered to Antenna (for Radiation and Dissipation) when

$$\left.\begin{aligned} R_A &= R_r + R_L = R_g \qquad (2\text{-}79) \\ X_A &= -X_g \qquad (2\text{-}80) \end{aligned}\right\} \text{Conjugate Matching}$$

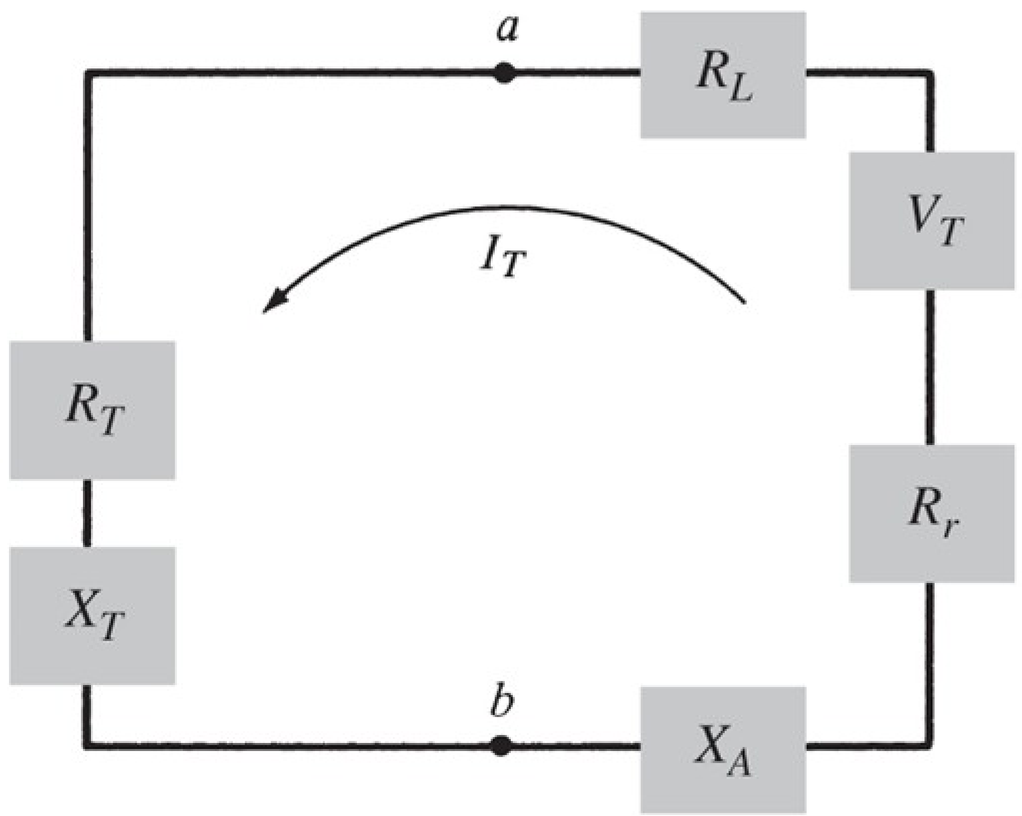
Antenna In Receiving Mode



(a) Antenna in receiving mode

Fig. 2.28a

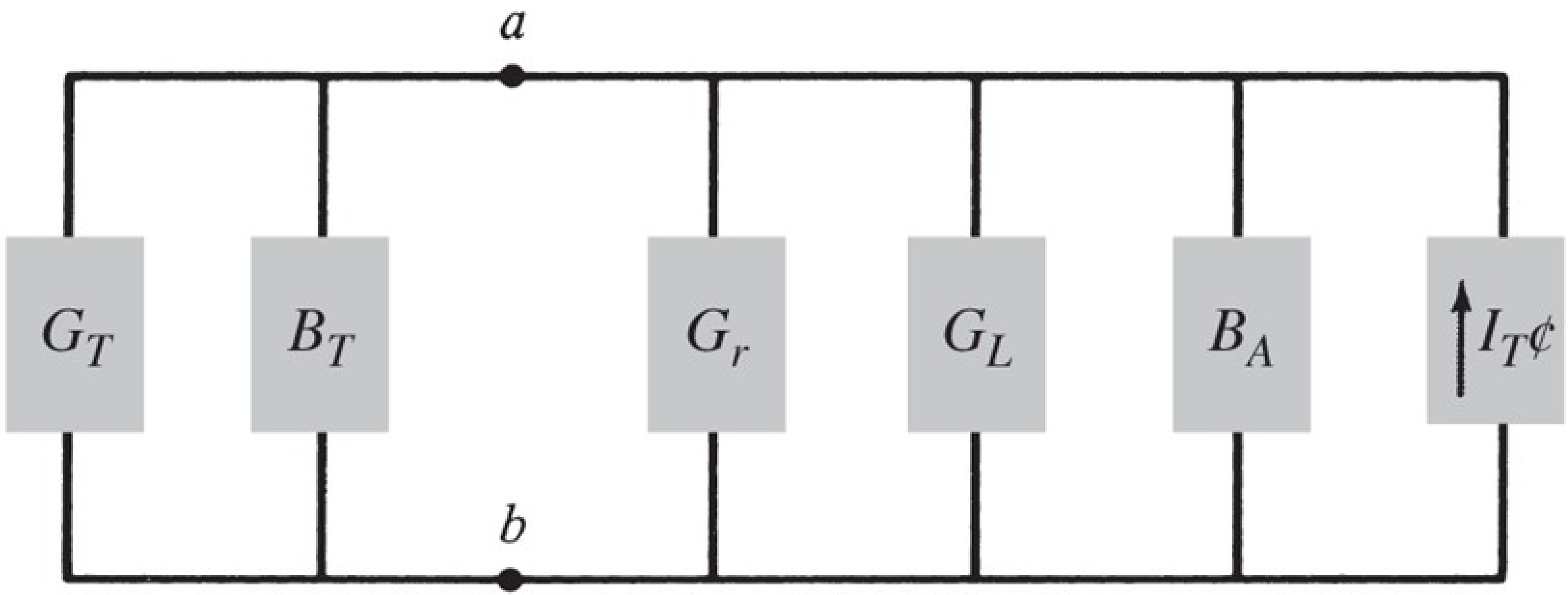
Thevenin Equivalent
(Receiving Mode)



(b) Thevenin equivalent

Fig. 2.28b

Norton Equivalent
(Receiving Mode)



(c) Norton equivalent

Fig. 2.28c

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$$e_o = e_r e_c e_d = e_r e_{cd} = \underbrace{\left(1-|\Gamma|^2\right)}_{e_r} e_{cd}$$

where

$$e_{cd} = \text{Radiation Efficiency}$$

$$e_{cd} = \frac{\text{Power Radiated by Antenna } (P_r)}{\text{Power Delivered to Antenna } (P_r + P_L)}$$

$$\boxed{e_{cd} = \frac{\frac{1}{2}|I_g|^2 R_r}{\frac{1}{2}|I_g|^2 R_r + \frac{1}{2}|I_g|^2 R_L} = \frac{R_r}{R_r + R_L}} \quad \text{(2-90)}$$

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Aperture Antenna in Receiving Mode

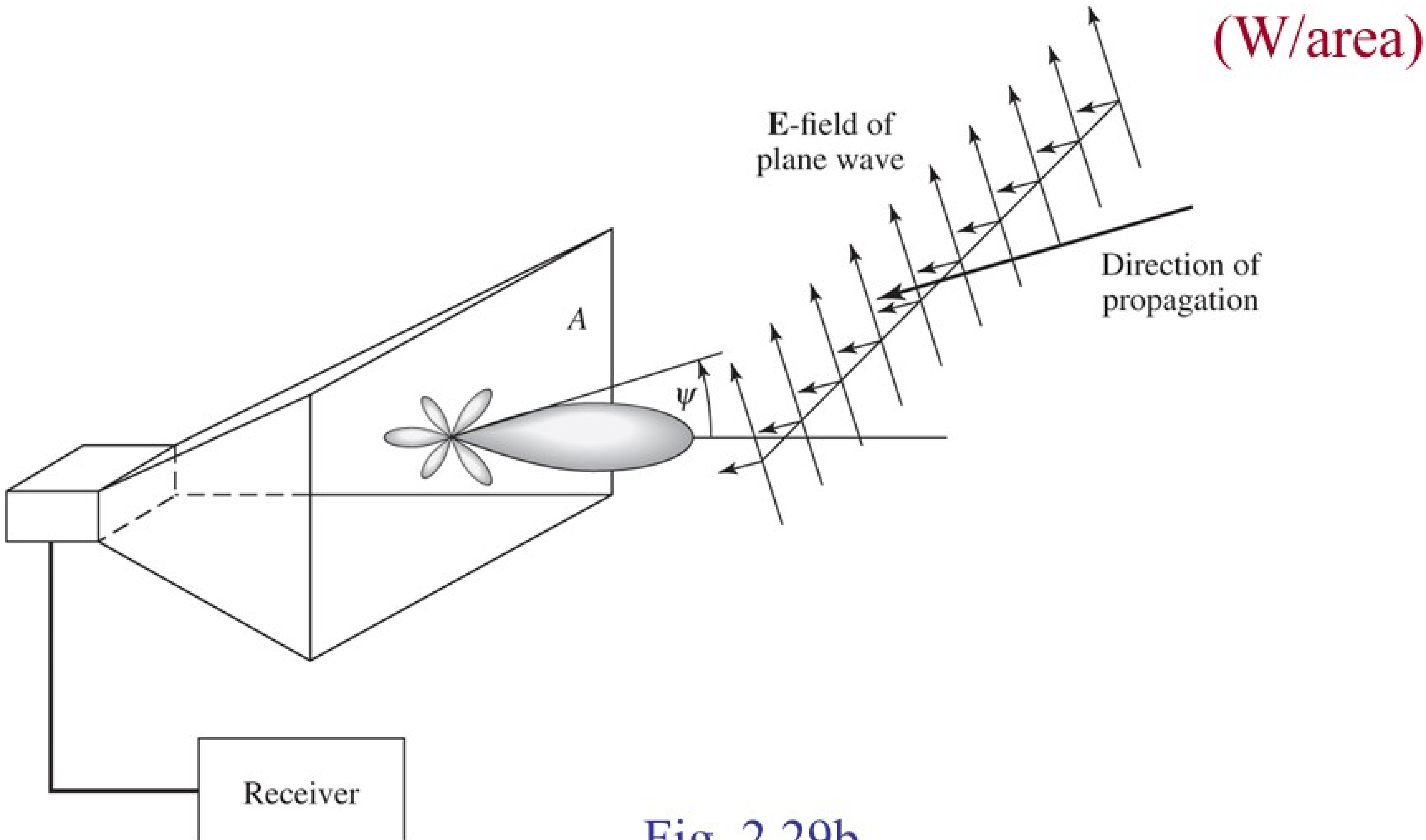

Fig. 2.29b

Effective Area (Aperture) A_e

$$P_T = W_i A_e$$

$$A_e = \frac{P_T}{W_i} \qquad (2\text{-}94)$$

A_e = effective area (aperture) (m^2)

P_T = power delivered to load (W)

W_i = power density of incident wave (W/m^2)

Assuming No Losses

$$\boxed{A_{em} = \frac{\lambda^2}{4\pi} D_o}$$

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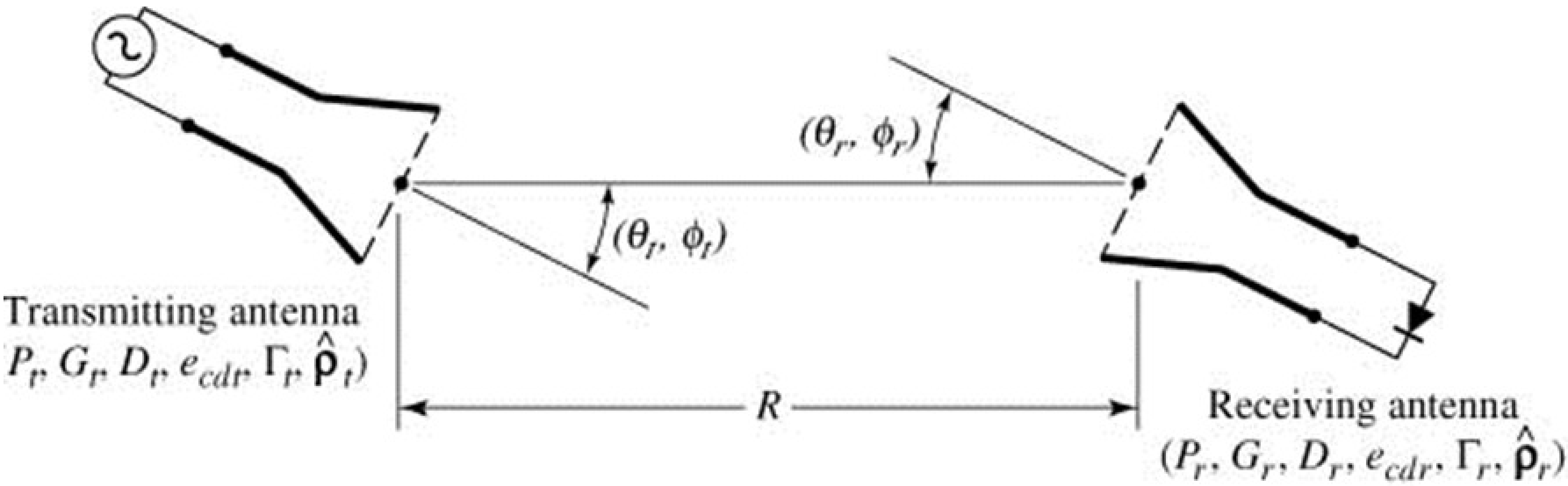
(θ_r, ϕ_r)
(θ_t, ϕ_t)
Transmitting antenna
$(P_t, G_t, D_t, e_{cdt}, \Gamma_t, \hat{\rho}_t)$
R
Receiving antenna
$(P_r, G_r, D_r, e_{cdr}, \Gamma_r, \hat{\rho}_r)$

Fig. 2.31

Assuming No Losses:

$$\boxed{\frac{P_r}{P_t} = D_{ot} D_{or} \left(\frac{\lambda}{4\pi R} \right)^2}$$

More General: Includes Losses:

$$\boxed{\frac{P_r}{P_t} = G_{ot} G_{or} \underbrace{\left(\frac{\lambda}{4\pi R} \right)^2}_{\text{Free space loss factor}} \left| \hat{\rho}_t \cdot \hat{\rho}_r \right|^2 \qquad (2\text{-}118)}$$

$$\frac{P_r}{P_t} = e_t e_r \frac{\lambda^2 D_t(\theta_t, \phi_t) D_r(\theta_r, \phi_r)}{(4\pi R)^2} \qquad \text{(2-117)}$$

$$\frac{P_r}{P_t} = e_{cdt} e_{cdr} \left(1 - |\Gamma_t|^2\right)\left(1 - |\Gamma_r|^2\right)\left(\frac{\lambda}{4\pi R}\right)^2 D_t D_r$$

$$\frac{P_r}{P_t} = e_{cdt} e_{cdr} \left(1 - |\Gamma_t|^2\right)\left(1 - |\Gamma_r|^2\right)\left(\frac{\lambda}{4\pi R}\right)^2 D_t D_r \left|\hat{\rho}_t \cdot \hat{\rho}_r\right|^2$$

$$\boxed{\frac{P_r}{P_t} = \left(1 - |\Gamma_t|^2\right)\left(1 - |\Gamma_r|^2\right)\left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r \left|\hat{\rho}_t \cdot \hat{\rho}_r\right|^2}$$

(2-117)

Example 2.16

Two lossless X-band (8.2-12.4 GHz) horn antennas are separated by a distance of 100λ. The reflection coefficients at the terminalsof the transmitting and receiving antennas are 0.1 and 0.2, respectively. The maximum directivities of the transmitting and receiving antennas (over isotropic) are 16 and 20 dB, respectively. Assuming that the input power in the lossless transmission line is 2W, and the antennas are aligned for maximum radiation and arepolarization matched, find the power delivered to the load connected to the receiver. (2-126)

Solution

For this problem

$e_{cdt} = e_{cdr} = 1$ because the antennas are lossless

$|\hat{\rho}_t \cdot \hat{\rho}_r| = 1$ because the antennas are polarization-matched

$$\left.\begin{aligned} D_t &= D_{0t} \\ D_r &= D_{0r} \end{aligned}\right\}$$ because the antennas are aligned for maximum radiation between them

$D_{0t} = 16 \text{ dB} \Rightarrow 39.81$ (dimensionless)

$D_{0r} = 20 \text{ dB} \Rightarrow 100$ (dimensionless)

Using (2-118), we can write that

$$P_t = [1-(0.1)^2][1-(0.2)^2]\left\{[(\lambda/(4\pi \cdot 100\lambda)]\right\}^2 (39.81)(100)(2)$$

$$P_t = 4.777 \text{ mW}$$

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Bistatic Radar Cross Section (RCS)

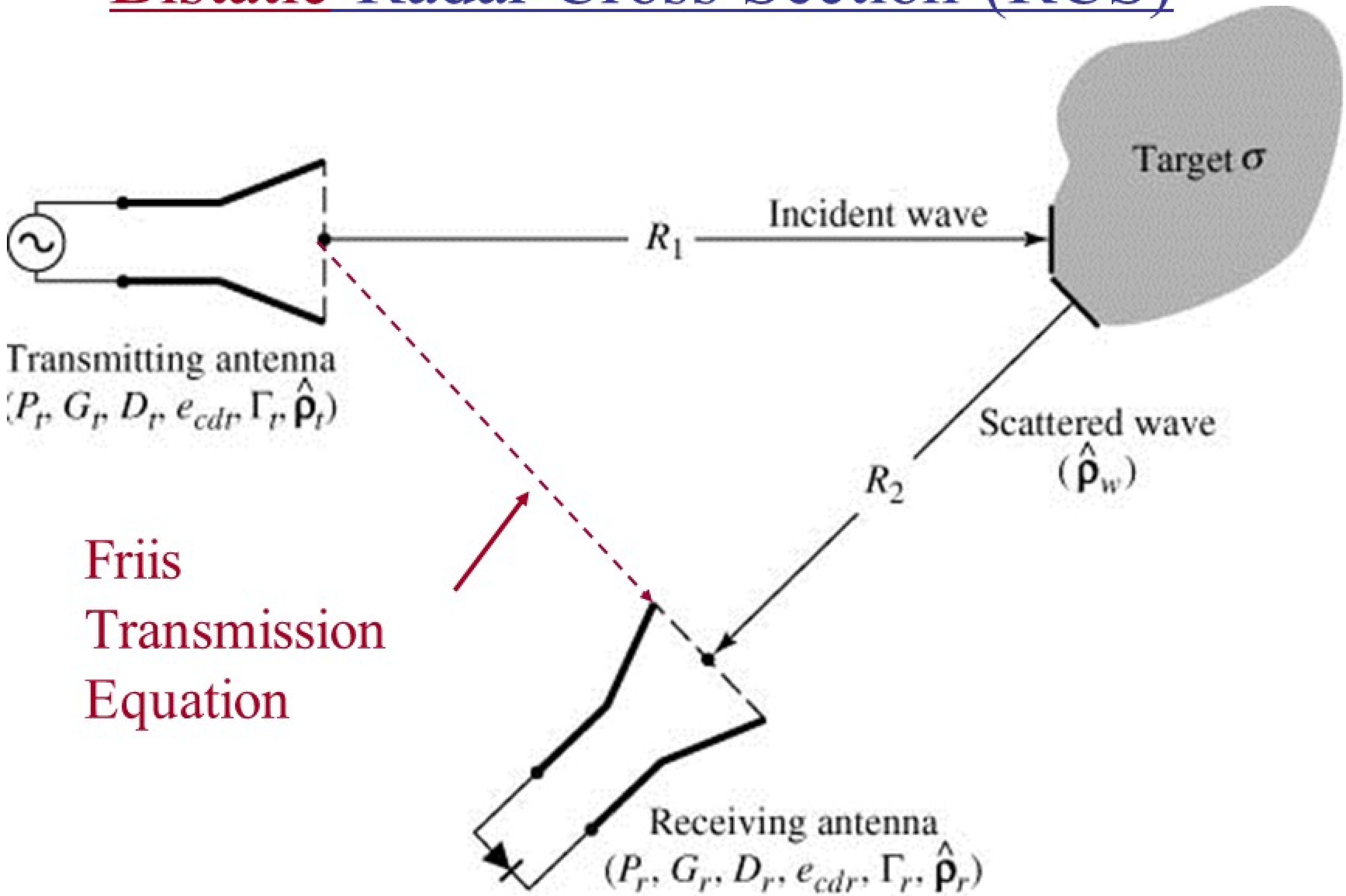

Fig. 2.32

Radar Cross Section (RCS) σ

(using Power Densities)

$$\sigma = \lim_{R \to \infty} \left[4\pi R^2 \frac{W_s}{W_i} \right]$$

(2-120a)

$$W_s = \left(\frac{\sigma W_i}{4\pi R^2} \right)$$

RCS is a Function of:

1. Shape of target (geometry)
2. Material properties of target
3. Polarization of incident wave
4. Angle of incidence of incident wave
5. Observation angle of incident wave

$$\frac{P_r}{P_t} = e_{cdt} e_{cdr} \sigma \frac{D_t(\theta_t, \phi_t) D_r(\theta_r, \phi_r)}{4\pi} \left(\frac{\lambda}{4\pi R_1 R_2} \right)^2$$

$$\frac{P_r}{P_t} = e_{cdt} e_{cdr} \left(1 - |\Gamma_t|^2\right)\left(1 - |\Gamma_r|^2\right)$$

$$\cdot \sigma \frac{D_t(\theta_t, \phi_t) D_r(\theta_r, \phi_r)}{4\pi} \left(\frac{\lambda}{4\pi R_1 R_2} \right)^2 \left| \hat{\rho}_t \cdot \hat{\rho}_r \right|^2$$

$$\boxed{\frac{P_r}{P_t} = \sigma \frac{G_{ot} G_{or}}{4\pi} \left(\frac{\lambda}{4\pi R_1 R_2} \right)^2 \left| \hat{\rho}_t \cdot \hat{\rho}_r \right|^2} \qquad (2\text{-}125)$$

For polarization-matched antennas aligned for maximum directional radiation reception, (2-125) reduces to

$$\boxed{\frac{P_r}{P_t} = \sigma \frac{G_{ot} G_{or}}{4\pi} \left(\frac{\lambda}{4\pi R_1 R_2} \right)^2 \left| \hat{\rho}_t \cdot \hat{\rho}_r \right|^2} \qquad (2\text{-}126)$$

Equation (2-124), (2-125) or (2-126) is known as the *Radar Range Equation*. It relates the power P_r (delivered to the receiver load) to the input power P_t (transmittedby the antenna), after it has been scattered by a target with a radar cross section (echo area) of σ.

Thank You

Questions?