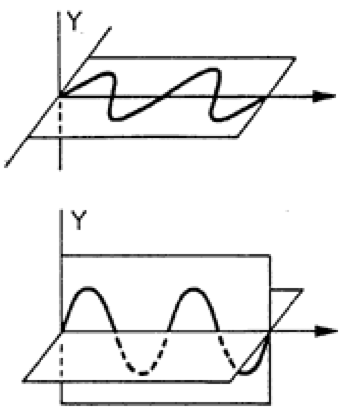
Polarization

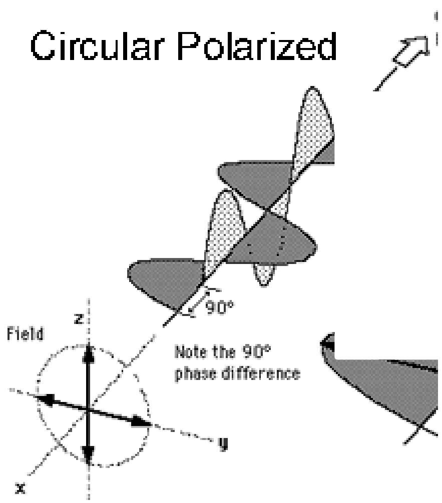
Polarization of antenna is defined by polarized wave it generates (at far field)

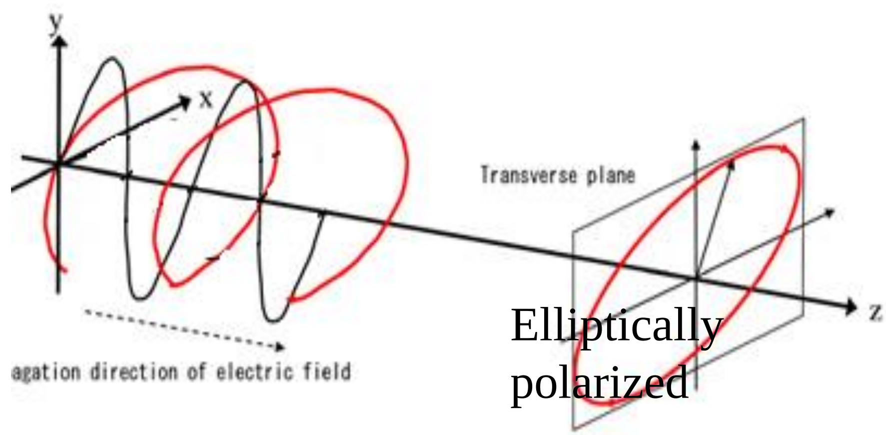
Polarization - The time varying direction and magnitude of electric field vector. It is a curved traced by the end point of arrow representing instantaneous electric field.

- If the trace is a line, then that wave or antenna is *linearly* polarized. Either vertical or horizontal.
- *Circular and elliptical* traces are most generalized forms.



Linear Polarized



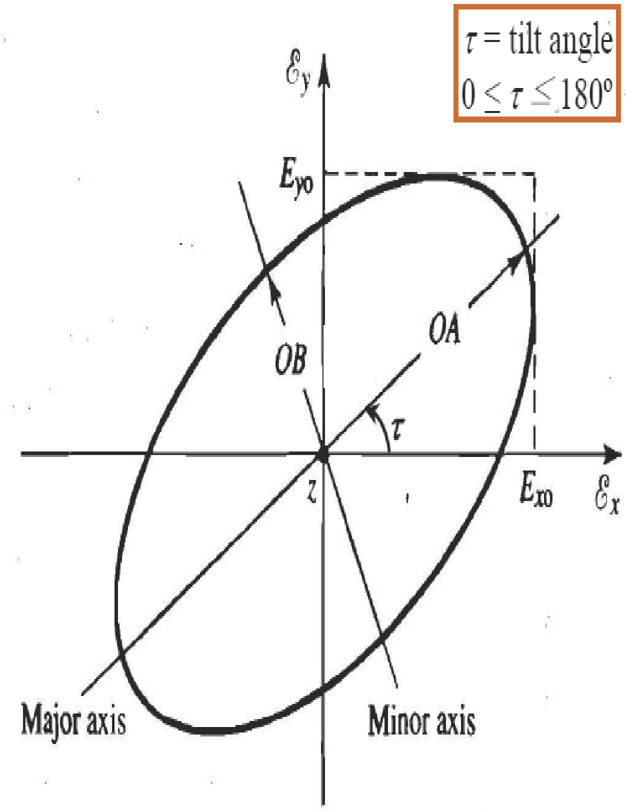


Axial Ratio

The polarization state of an EM wave can also be indicated by another two parameters: Axial Ratio (AR) and the tilt angle (τ). AR is a common measure for antenna polarization. It definition is:

$$\boxed{AR = \frac{OA}{OB}, \quad 1 \le AR \le \infty, \quad \text{or} \quad 0\,\text{dB} \le AR \le \infty\,\text{dB}}$$

where OA and OB are the major and minor axes of the polarization ellipse, respectively. The tilt angle τ is the angle subtended by the major axis of the polarization ellipse and the horizontal axis.



For example:

$$\begin{array}{lll} AR = 1, & \Rightarrow & \text{circular polarization} \\ 1 < AR < \infty, & \Rightarrow & \text{elliptical polarization} \\ AR = \infty, & \Rightarrow & \text{linear polarization} \end{array}$$

AR can be measured experimentally!

Very often, we use the **AR bandwidth** and the **AR beamwidth** to characterize the polarization of an antenna. The AR bandwidth is the frequency bandwidth in which the AR of an antenna changes less than 3 dB from its minimum value. The AR beamwidth is the angle span over which the AR of an antenna changes less than 3 dB from its mimumum value.

Linear, Circular and Elliptic Polarization

- The instantaneous electric field of a plane wave, traveling in the negative z direction, can be written as

$$\mathscr{E}(z;t) = \hat{\boldsymbol{a}}_x \mathscr{E}_x(z;t) + \hat{\boldsymbol{a}}_y \mathscr{E}_y(z;t).$$

- By considering the complex counterpart of these instantaneous components, we can write

$$\mathscr{E}_x(z;t) = E_{xo}\cos(\omega t + kz + \phi_x),$$
$$\mathscr{E}_y(z;t) = E_{yo}\cos(\omega t + kz + \phi_y).$$

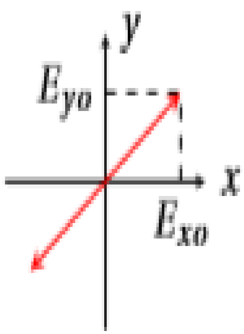
where E_{xo} and E_{yo} are the maximum magnitudes of the x- and y-components.

- By defining $\Delta\phi = \phi_y - \phi_x$, we can state these as

$$\mathscr{E}_x(z;t) = E_{xo}\cos(\omega t + kz),$$
$$\mathscr{E}_y(z;t) = E_{yo}\cos(\omega t + kz + \Delta\phi).$$

Linear polarization

$$\Delta\phi = n\pi, \quad n = 1, 2, \ldots$$



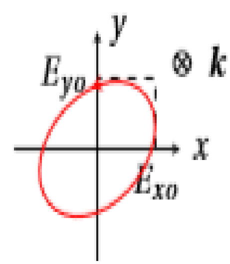
Elliptic Polarization

$$|\mathscr{E}_{\S}| \neq |\mathscr{E}_y| \Rightarrow \boldsymbol{E}_{xo} \neq \boldsymbol{E}_{yo}.$$

$$\Delta\phi = \pm\left(2n + \frac{1}{2}\right)\pi, \quad n = 0, 1, 2, \ldots.$$

OR

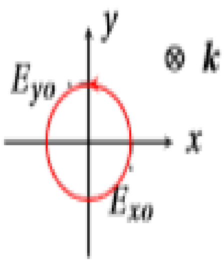
$$\Delta\phi \neq \pm n\frac{\pi}{2} \quad n = 0, 1, 2, \ldots.$$



Circular Polarization

$$|\mathscr{E}_{\S}| = |\mathscr{E}_y| \Rightarrow \boldsymbol{E}_{xo} = \boldsymbol{E}_{yo}.$$

$$\Delta\phi = \begin{cases} +\left(2n + \frac{1}{2}\right)\pi, & n = 0, 1, 2, \ldots \quad \text{CW,} \\ -\left(2n + \frac{1}{2}\right)\pi, & n = 0, 1, 2, \ldots \quad \text{CCW.} \end{cases}$$



Cross Polarization

Ratio of (orthogonal X-pol field strength)/(desired co-pol field) expressed in dB (power)

e.g. For a vertical polarized antenna, the X-polarization is horizontal.
For a RHCP, the x-pol is LHCP.

Ideally, X-pol is = 0 (- infinity dB).
In reality, x-pol is usually between -15 to -40 dB.
due to non-ideal alignment, depolarization of wave in media (such as Faraday Rotation).

X-pol is more commonly used in linear polarization.

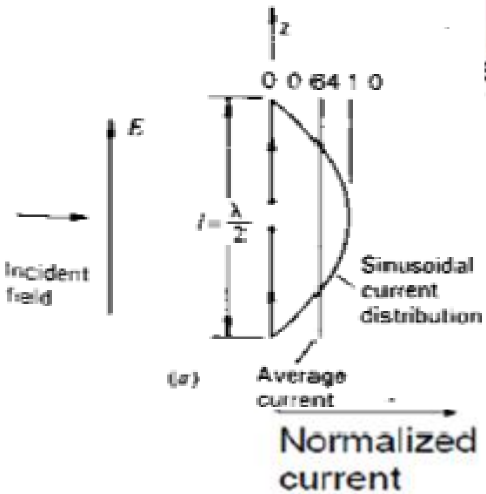
Effective height

Effective height is current average (I_{av}) value of maximum current (I_o) times the physical height (h_p) .

$$h_e = 0.64\, h_p$$

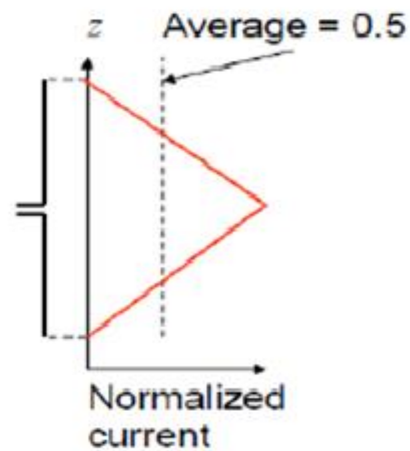
$$\boxed{h_e = \frac{I_{av}}{I_o} h_p (m)}$$

e = 0.64



Length, $l=\lambda/2$

Effective height = $0.64\, l$

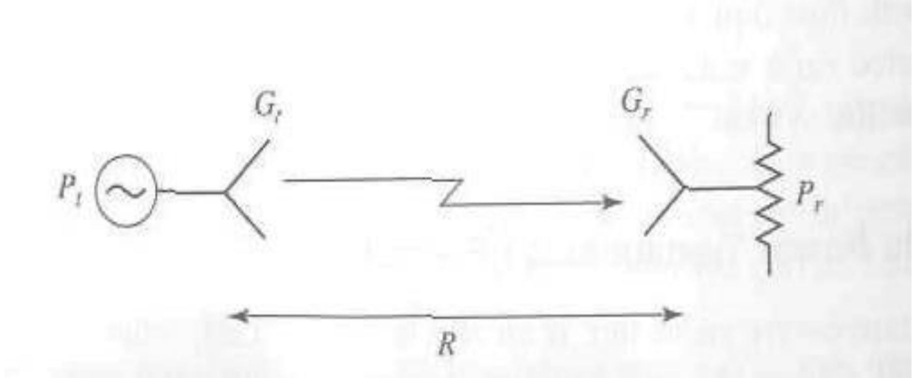


Length, $l=\lambda/10$

Effective height = $0.5\, l$

Effective height provides an indication as to how much of the antenna height is involved in radiating (or receiving). Application in designing small antennas.

Friss Transmission Equation



Power density radiated by the transmitter $W_i = \dfrac{P_t G_t}{4\pi R^2}$ --------(1)

Power received by the receiver antenna with aperture area Ae $P_r = W_i A_e$ --------(2)

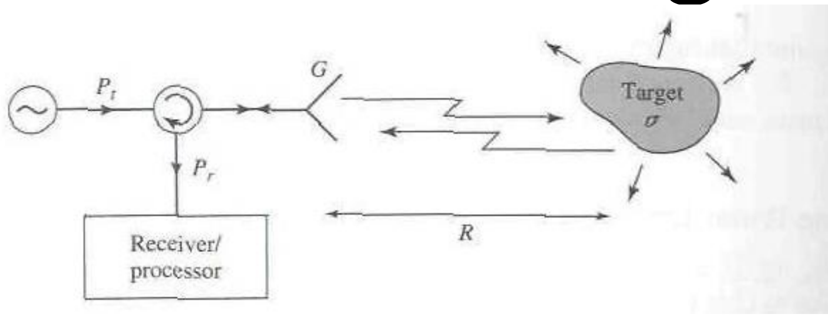
Where

Effective area $A_e = \dfrac{G\lambda^2}{4\pi}$ --------(3)

Received power $P_r = \dfrac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$ --------(1) & (3)

Refer: Microwave Engg Pozar

Radar Range Equation



Power density incident on target $$W_i = \frac{P_t G}{4\pi R^2}$$

Radar cross section $$\sigma = \frac{P_s}{W_i}$$

Power density Reflected by target $$W_t = W_i \times \sigma$$

Power density incident at receive antenna $$W_t = W_i \times \frac{\sigma}{4\pi R^2} = \frac{P_t G}{4\pi R^2} \times \frac{\sigma}{4\pi R^2}$$

Power density at receiver antenna $$P_r = \frac{P_t G}{4\pi R^2} \times \frac{\sigma}{4\pi R^2} \times A_e = \frac{P_t G_t G_R \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Antenna Vector Effective Length and Equivalent Areas

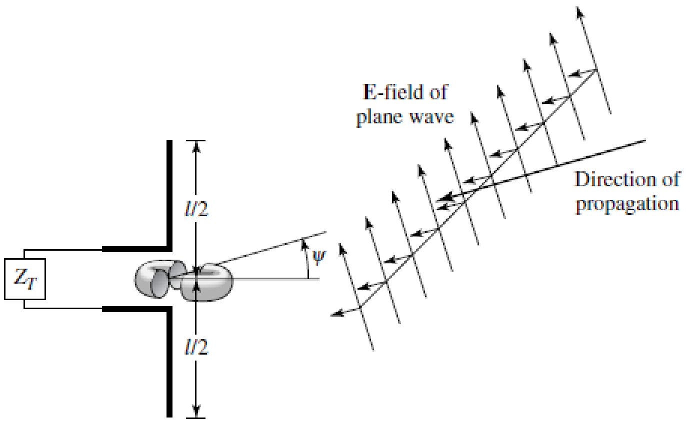
- An antenna in the receiving mode, iis used to capture electromagnetic waves and to extract power from them.

- In this concept, we can define equivalent length which is used to determine the open circuit voltage induced on the antenna terminals when the wave impinges on it.

Vector Effective Length

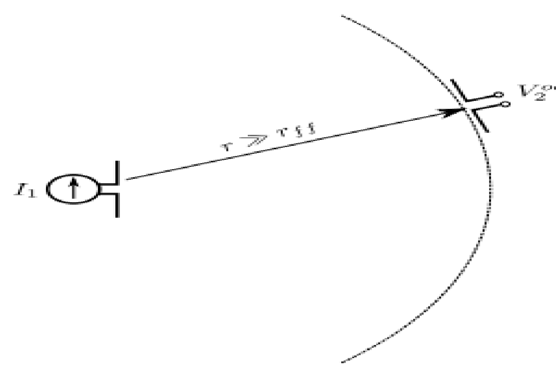
- **Definition:**

The ratio of the magnitude of the open-circuit voltage developed at the terminals of the antenna to the magnitude of the electric-field strength in the direction of the antenna polarization.



(a) Dipole antenna in receiving mode

- The vector effective length for an antenna is usually a complex vector quantity represented by



$$\boldsymbol{\ell}_e(\theta, \phi) = \hat{\mathbf{a}}_\theta l_\theta(\theta, \phi) + \hat{\mathbf{a}}_\phi l_\phi(\theta, \phi) \quad (2$$

In transmitting mode, the field radiated by antenna is

$$\mathbf{E}_a = \hat{\mathbf{a}}_\theta E_\theta + \hat{\mathbf{a}}_\phi E_\phi = -j\eta \frac{kI_{in}}{4\pi r} \boldsymbol{\ell}_e e^{-jkr} \qquad (2\text{-}92)$$

In the receiving mode

$$V_{oc} = \mathbf{E}^i \cdot \boldsymbol{\ell}_e \qquad (2\text{-}93)$$

V_{oc} = open-circuit voltage at antenna terminals
$\mathbf{E}^i$ = incident electric field
$\boldsymbol{\ell}_e$ = vector effective length

→ V_{oc} can be thought of as the voltage induced in a linear antenna of length l_e when l_e and $\boldsymbol{E}^i$ are linearly polarized.

- The antenna vector effective length is used to determine the polarization efficiency of the antenna.

Example 2.14

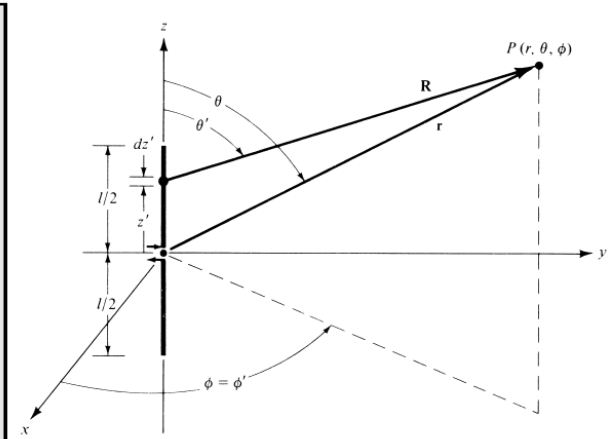
The far-zone field radiated by a small dipole of length $l < \lambda/10$ and with a triangular current distribution, as shown in Figure 4.4, is derived in Section 4.3 of Chapter 4 and it is given by (4-36a), or

$$\mathbf{E}_a = \hat{\mathbf{a}}_\theta j\eta \frac{kI_{in}le^{-jkr}}{8\pi r}\sin\theta$$

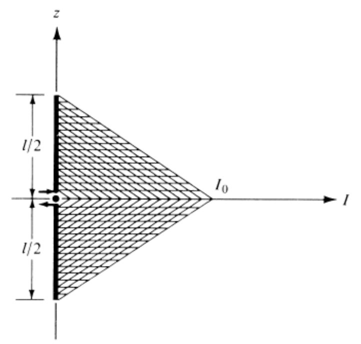
Determine the vector effective length of the antenna.

Solution: According to (2-92), the vector effective length is

$$\boldsymbol{\ell}_e = -\hat{\mathbf{a}}_\theta \frac{l}{2}\sin\theta$$



(a) Dipole and geometry



(b) Current distribution

Figure 4.4 Geometrical arrangement of dipole and current distribution.

- This indicates, as it should, that the effective length is a function of the direction angle θ, and its maximum occurs when $\theta = 90^\circ$.

- The effective length of the dipole to produce the same output open-circuit voltage is only half (50%) of its physical length if it were replaced by a thin conductor having a uniform current distribution.

Polarization Loss Factor and Efficiency

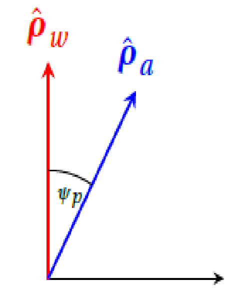
- Polarization mismatch occurs when transmitting and receiving antennas are of different polarization.
- E field of incoming wave is $\boldsymbol{E}_i = \hat{\boldsymbol{\rho}}_w E_i,$

where $\hat{\boldsymbol{\rho}}_w$ is the unit vector of the wave. The polarization of the electric field of the receiving antenna can be expressed as

$$\boldsymbol{E}_a = \hat{\boldsymbol{\rho}}_a E_a,$$

where $\hat{\boldsymbol{\rho}}_a$ is its unit vector.

- The polarization loss can be taken into account by introducing a *polarization loss factor* (PLF). It is defined, based on the polarization of the antenna in its transmitting mode, as



$$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 = |\cos\psi_p|^2.$$

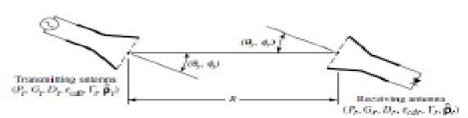
where ψ_p is the angle between the two unit vectors.

- The PLF is dimensionless and corresponds to the polarization efficiency e_p.

If reflection and polarization losses are also included, then the maximum effective area of is represented by

$$\begin{aligned} A_{em} &= e_0 \left(\frac{\lambda^2}{4\pi}\right) D_0 |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 \\ &= e_{cd}(1 - |\Gamma|^2) \left(\frac{\lambda^2}{4\pi}\right) D_0 |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2 \end{aligned} \qquad (2\text{-}112)$$

Friis Transmission Equation



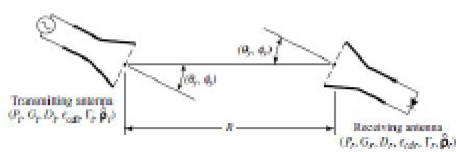
$$\boxed{\frac{P_r}{P_t} = e_{cdt} e_{cdr} (1 - |\Gamma_t|^2)(1 - |\Gamma_r|^2) \left(\frac{\lambda}{4\pi R}\right)^2 D_t(\theta_t, \phi_t) D_r(\theta_r, \phi_r) |\hat{\boldsymbol{\rho}}_t \cdot \hat{\boldsymbol{\rho}}_r|^2}$$

Effective area and power received when polarization losses are included

If reflection and polarization losses are also included, then the maximum effective area of is represented by

$$\boxed{\begin{aligned} A_{em} &= e_0 \left(\frac{\lambda^2}{4\pi}\right) D_0 |\hat{\rho}_w \cdot \hat{\rho}_a|^2 \\ &= e_{cd}(1 - |\Gamma|^2) \left(\frac{\lambda^2}{4\pi}\right) D_0 |\hat{\rho}_w \cdot \hat{\rho}_a|^2 \end{aligned}} \tag{2-112}$$

Friis Transmission Equation



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

Antenna Temperature

Although power is important parameter in Radar and Communication, antenna temperature is important in the design of passive sensors in radio astronomy and remote sensing

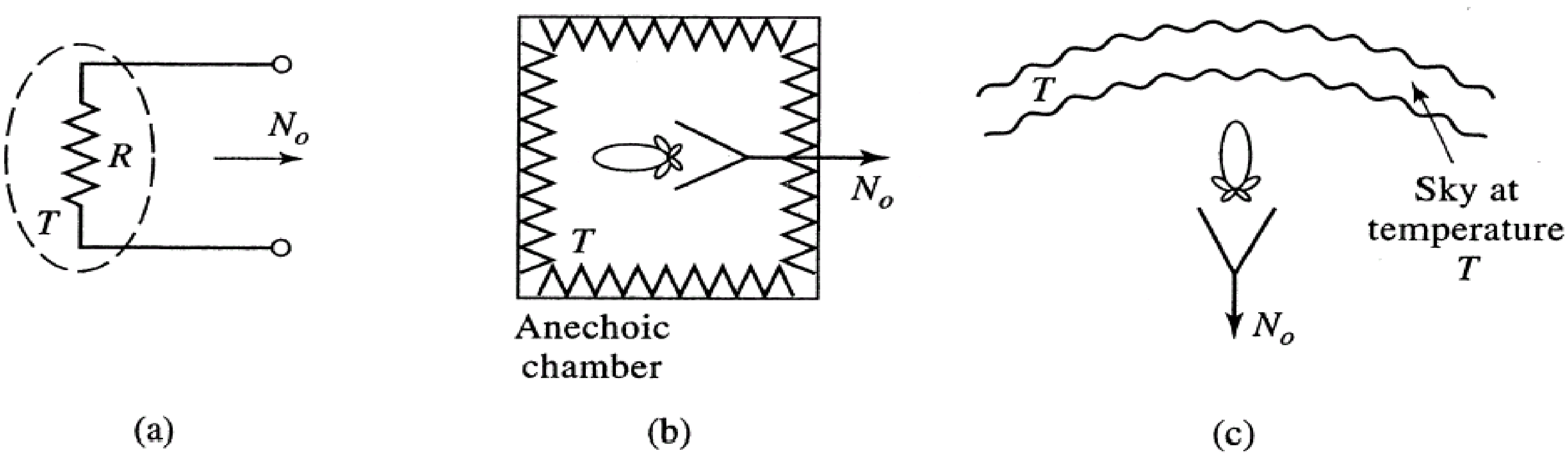


Figure 13.4 (p. 641)

concept of background temperature. (*a*) A resistor at temperature *T*. (*b*) An antenna in an anechoic chamber at temperature *T*. (*c*) An antenna viewing a uniform sky background at temperature *T*.

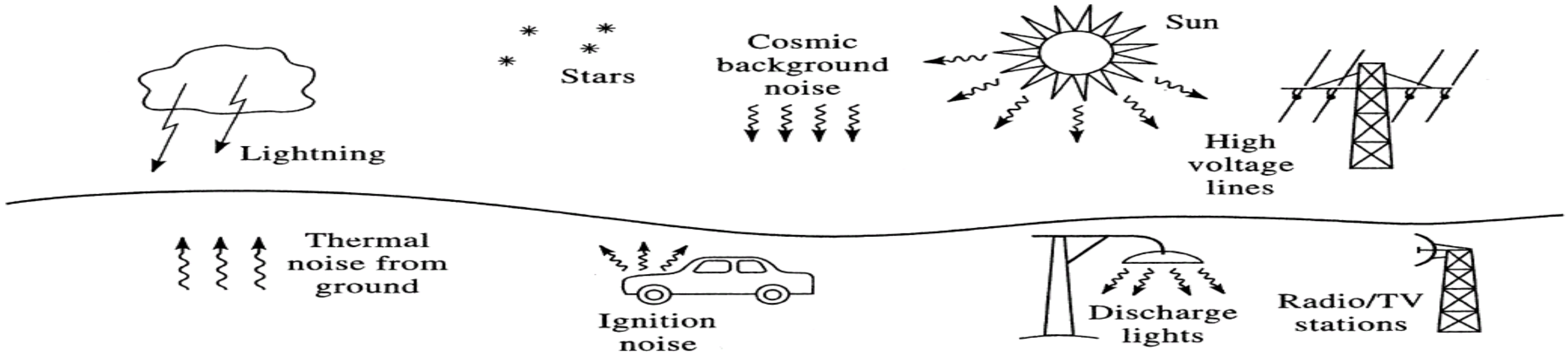


Figure 13.5 (p. 642)

Natural and manmade sources of background noise.

$$T_A = \frac{\int_0^{2\pi} \int_0^{\pi} T_B(\theta, \phi) G(\theta, \phi) \sin\theta \, d\theta \, d\phi}{\int_0^{2\pi} \int_0^{\pi} G(\theta, \phi) \sin\theta \, d\theta \, d\phi} \qquad (2\text{-}144)$$

where

T_A = antenna temperature (effective noise temperature of the antenna radiation resistance; K)

$G(\theta, \phi)$ = gain (power) pattern of the antenna