Horn Antenna :-

Horn antennas are flared open waveguides, which produce an ideal wavefront with larger aperture and provide greater directivity.

A Horn antenna can operate satisfactorily at frequencies up to 1 GHz.

Advantage :

1. High gain
2. Low VSWR
3. Wide Bandwidth
4. Low weight and easy to construct them.

Application :

1. used as a feed for a reflector antenna.
2. It is the ideal choice for rover station.

Horn antenna may be considered as a transformer from the impedance of a Txn. line to the impedance of free space (377Ω).

Various configurations of Horn antenna :

Horn antennas are broadly classified as,

1. Rectangular
2. Circular

The vertical and Horizontal planes are referred as E-plane and H-plane.

E-plane contains electric field and the H-plane contains magnetic field

When the corresponding planes are flared then the resultant antenna is called as E-plane or H-plane sectoral horn antenna.

When both the planes are flared then it is referred as pyramidal Horn antenna.

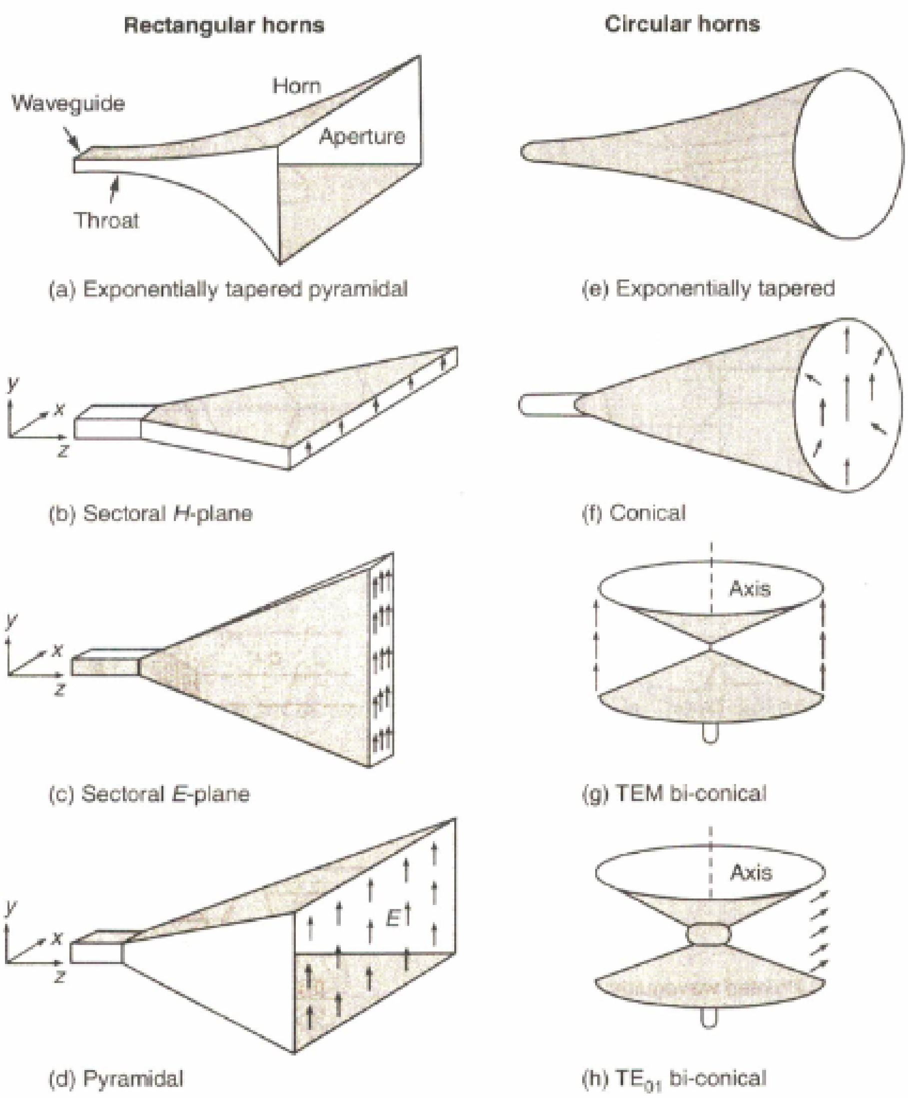


FIG. 11.1 Various types of horn antennas.

The arrows in the figure indicate the field directions and the length represents the magnitude of the field intensity.

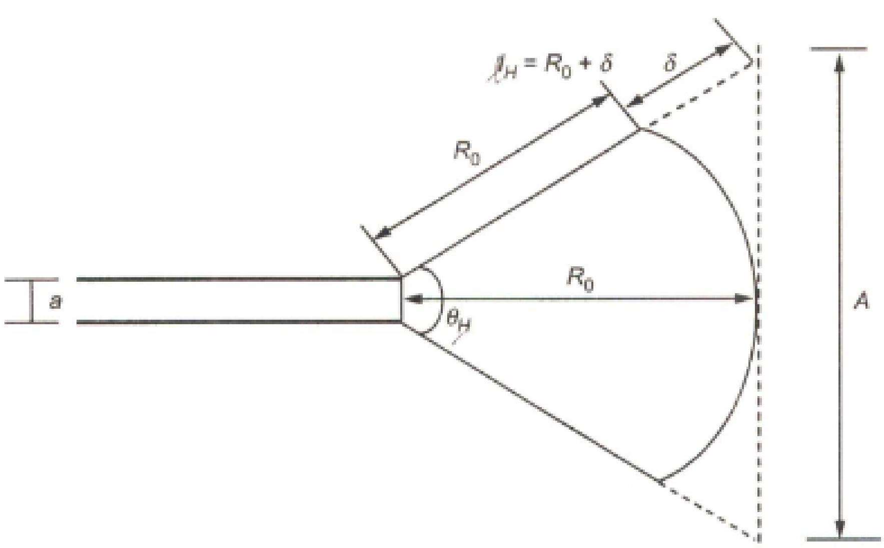
The conical horn antenna is similar to pyramidal horn antenna.

TEM Bi-conical antenna is excited in TEM mode by a vertical radiator and TE_{01} Bi-conical antenna is excited in TE_{01} mode by a small horizontal loop antenna.

Both TEM Bi-conical and TE_{01} Bi-conical horn antennas are non-directional in the horizontal plane.

Horn antenna Parameters :-

The cross-sectional view of a rectangular horn antenna is shown in fig below.



consider the triangle AOB

$$\cos\frac{\theta}{2} = \frac{\text{adj. side}}{\text{hyp}} = \frac{R_0}{R_0+\delta} = \frac{R_0}{l_H} \rightarrow (1)$$

$$\sin\frac{\theta}{2} = \frac{\text{opp. side}}{\text{hyp}} = \frac{A/2}{R_0+\delta} = \frac{A}{2(R_0+\delta)} = \frac{A}{2l_H} \rightarrow (2)$$

$$\tan\frac{\theta}{2} = \frac{A/2}{R_0} = \frac{A}{2R_0} \rightarrow (3)$$

where 'δ' is the Path difference (in m) between the rays travelling along the side and along the axis of the horn.

usually the value of 'δ' lies in between 0.1λ and 0.4λ.

However, in the E-plane of the horn $\delta \leq 0.25\lambda$ and in the H-plane of the horn δ is 0.4λ.

A → Aperture of Horn

θ → Flare angle

$$\theta = 2\tan^{-1}\left(\frac{A}{2R_0}\right) = 2\cos^{-1}\left(\frac{R_0}{l_H}\right) \rightarrow (4)$$

From Right angle triangle, AOB

$$R_0+\delta = \sqrt{R_0^2+(A/2)^2}$$

$$(R_0+\delta)^2 = R_0^2+(A/2)^2$$

$$R_0^2 + \delta^2 + 2R_0\delta = R_0^2 + \frac{A^2}{4}$$

$$\cancel{R_0^2} + 2R_0\delta = \cancel{R_0^2} + \frac{A^2}{4} \qquad \because \delta \ll R_0$$

$$2R_0\delta = \frac{A^2}{4}$$

$$R_0 = \frac{A^2}{8\delta} \rightarrow (5)$$

Equations (4) and (5) are the design equations of Horn antenna.

Again from $\cos\frac{\theta}{2} = \frac{R_0}{R_0+\delta} = \frac{R_0}{l_H}$

$$R_0 + \delta = \frac{R_0}{\cos(\theta/2)}$$

$$\delta = \frac{R_0}{\cos(\theta/2)} - R_0 \rightarrow (6)$$

Optimum Horn :

Generally to obtain uniform aperture distribution, it is observed that the horn should be very long with small flare angle. But for practical convenience, the horn should be as short as possible. Between these 2 extreme conditions, it is possible to design a horn which has a minimum beamwidth and for a given length it is free of side lobes. such a horn is called optimum horn or optimum flare horn.

The dimension for optimum horn is

$$\delta_0 = \frac{R_0}{\cos\left(\frac{\theta}{2}\right)} - R_0 \rightarrow (7)$$

$$R_0 = \frac{\delta_0 \cos\left(\frac{\theta}{2}\right)}{1-\cos\left(\frac{\theta}{2}\right)} \rightarrow (8)$$

Directivity :

The directivity of horn antenna is expressed as

$$D = \frac{4\pi A_e}{\lambda} = \frac{4\pi \varepsilon_h A_p}{\lambda} \rightarrow (9)$$

A_e - Effective Aperture

A_p - Physical Aperture

ε_h - Aperture Efficiency

λ - operating wavelength

Generally $A_p \simeq 1.0\lambda$ and $\varepsilon_h = 60\%$.

$$\therefore D = \frac{7.5 A_p}{\lambda} = 10 \log\left(\frac{7.5 A_p}{\lambda}\right) \text{dBi} \rightarrow (10)$$

FNBW :

The first null beam width for different types of horn apertures are,

Rectangular aperture $= 115/R_{o\lambda}$

circular aperture $= 140/D_{\lambda}$

optimum E-plane rectangular horn $= 115/a_{E\lambda}$

optimum H-plane rectangular horn $= 172/a_{H\lambda}$

HPBW :

The half power Beam width for different types of horn apertures are given as

Rectangular aperture $= 51/R_{o\lambda}$

circular aperture $= 58/D_{\lambda}$

optimum E-plane rectangular horn $= 56/a_{E\lambda}$

optimum H-plane rectangular horn $= 67/a_{H\lambda}$

The dimensions of a rectangular Pyramidal horn for optimum gain are given as,

$$A = \sqrt{3\lambda_o a_H} \quad \text{and} \quad B = \sqrt{3\lambda_o a_E}$$

The effective area is close to 50% of its aperture area and its gain is given as,

$$\text{Gain (dB)} = 8.1 + 10 \log \left(AB/\lambda_o^2 \right)$$

H - plane sectoral Horn antenna :

If the horn serves to flare only in H-plane dimension then it is called as H-plane sectoral horn antenna.

The Geometrical configuration and cross sectional view of the H-plane horn antenna is shown below.

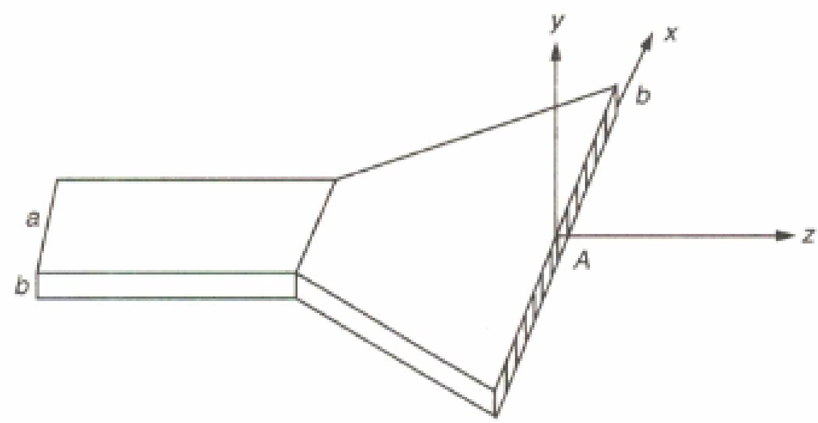
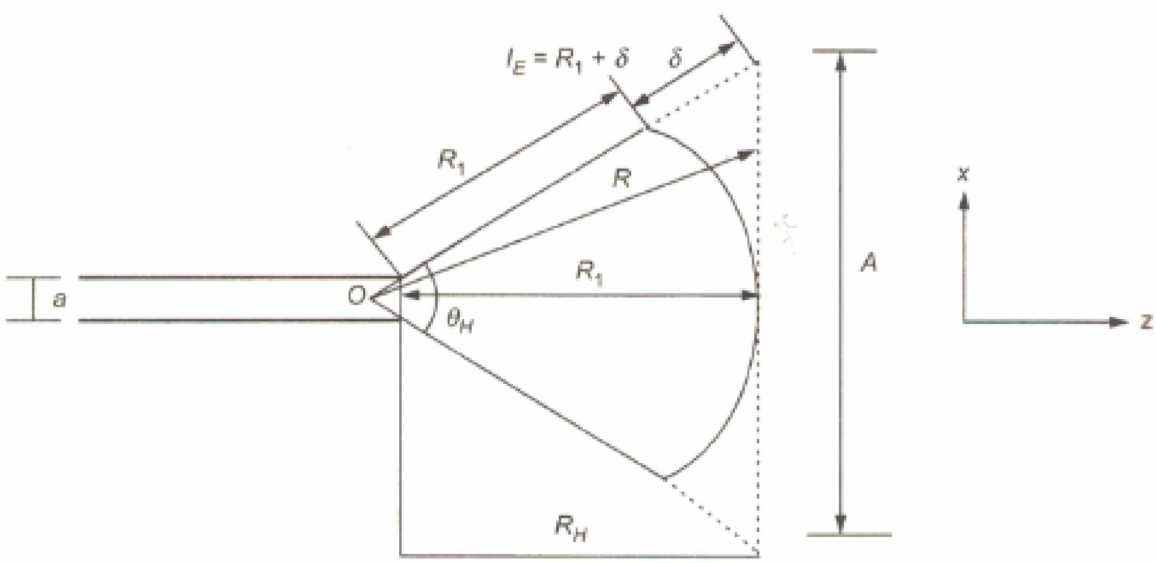


FIG. 11.4(a) Geometry of H-plane sectoral horn antenna.



Cross-section of H-plane sectoral horn antenna.

From cross section, l_E, R, R_1 and R_H as well as θ_H are geometrical parameters and they are related as,

$$R_H = (A - a)\left[\left(\frac{l_E}{A}\right)^2 - \frac{1}{4}\right]^{1/2} \rightarrow (1)$$

and $R = \sqrt{R_1^2 + x^2}$

$$= R_1 \sqrt{1 + \left(\frac{x}{R_1}\right)^2}$$

$$R = R_1 \left[1 + \left(\frac{x}{R_1}\right)^2\right]^{1/2} \rightarrow (2)$$

By Binomial series, $(1+x)^n = 1 + \frac{n}{1!} \cdot x + \frac{n(n-1)}{2!} x^2 + \cdots$

$$\therefore R = R_1 \left[1 + \frac{1}{2}\left(\frac{x}{R_1}\right)^2 + \left(\frac{-1}{8}\right)\left(\frac{x}{R_1}\right)^4 + \cdots\right]$$

since $x << R_1$,

$$R = R_1 \left[1 + \frac{1}{2}\left(\frac{x}{R_1}\right)^2\right]$$

$$R \simeq R_1 + \frac{1}{2}\left(\frac{x^2}{R_1}\right)$$

$$R - R_1 \simeq \frac{1}{2}\left(\frac{x^2}{R_1}\right) \longrightarrow (3)$$

∴ Aperture phase variation in x direction can be given as,

$$e^{-jk(R-R_1)} = e^{-j\left(\frac{k}{2R_1}\right)x^2} \rightarrow (4)$$

Hence the aperture electric field distribution inside the aperture leads to

$$E_{ay} = E_0 \cos\left(\frac{\pi}{A}x\right) e^{-j\left(\frac{k}{2R_1}\right)x^2} \rightarrow (5)$$

and zero elsewhere.

The aperture distribution phase error as a function of position 'x' is given by

$$\delta_1 = \frac{k}{2R_1} x^2 \rightarrow (6)$$

Since the maximum value of 'x' is $A/2$, the maximum phase error will be

$$\delta_{1\,max} = \frac{k}{2R_1}\left(\frac{A}{2}\right)^2 = \frac{\pi}{4\lambda}\left(\frac{A^2}{R_1}\right) \rightarrow (7)$$

The complex far-zone radiated electric field in (θ, ϕ) direction is

$$E = jabkE_0 \frac{e^{-jkr}}{4kr}(1+\cos\theta) \cdot \left[\frac{\sin\left(\frac{kb}{2}\right)\sin\theta \cdot \sin\phi}{\frac{kb}{2} \cdot \sin\theta \cdot \sin\phi}\right] \rightarrow (8)$$

where 'r' is the far-field distance and $I(\theta, \phi)$ is a constant of function (θ, ϕ).

In the E-plane $\phi = 90^\circ$, the normalized radiated electric field is given by

$$F_E(\theta) = \left[\frac{1+\cos\theta}{2}\right] \frac{\sin\left[\left(\frac{kb}{2}\right)\sin\theta\right]}{\left[\frac{kb}{2}\sin\theta\right]} \rightarrow (9)$$

In the H-plane, $\phi = 0^\circ$, the normalized radiated field is given by

$$F_H(0) = \left[\frac{1+\cos\theta}{2}\right] f_H(\theta) \rightarrow (10)$$

in which

$$f_H(\theta) = \int_{-A/2}^{A/2} \cos\left(\frac{\pi}{A}x'\right) e^{-jk\sqrt{R_1^2+x'^2}} \cdot e^{jk\sin\theta x'} \cdot dx' \rightarrow (11)$$

where x' is the value of x along $(+A)$ direction.

The H-plane beam width for an optimum H-plane sectoral horn for $A \gg \lambda$ is given by

$$HPBW = 1.36\frac{\lambda}{A} = 78^\circ\frac{\lambda}{A} \rightarrow (12)$$

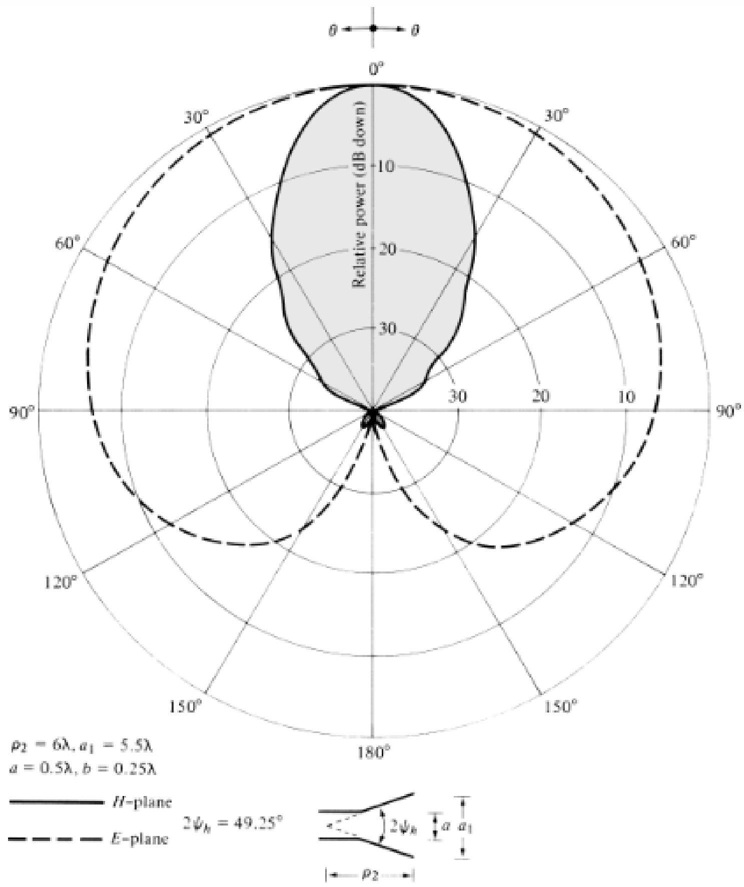
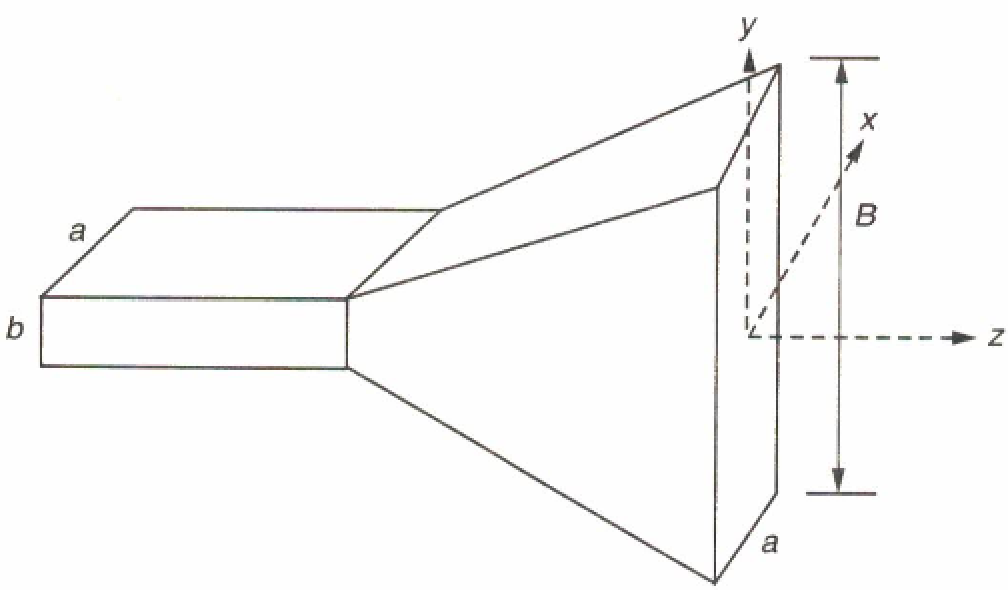
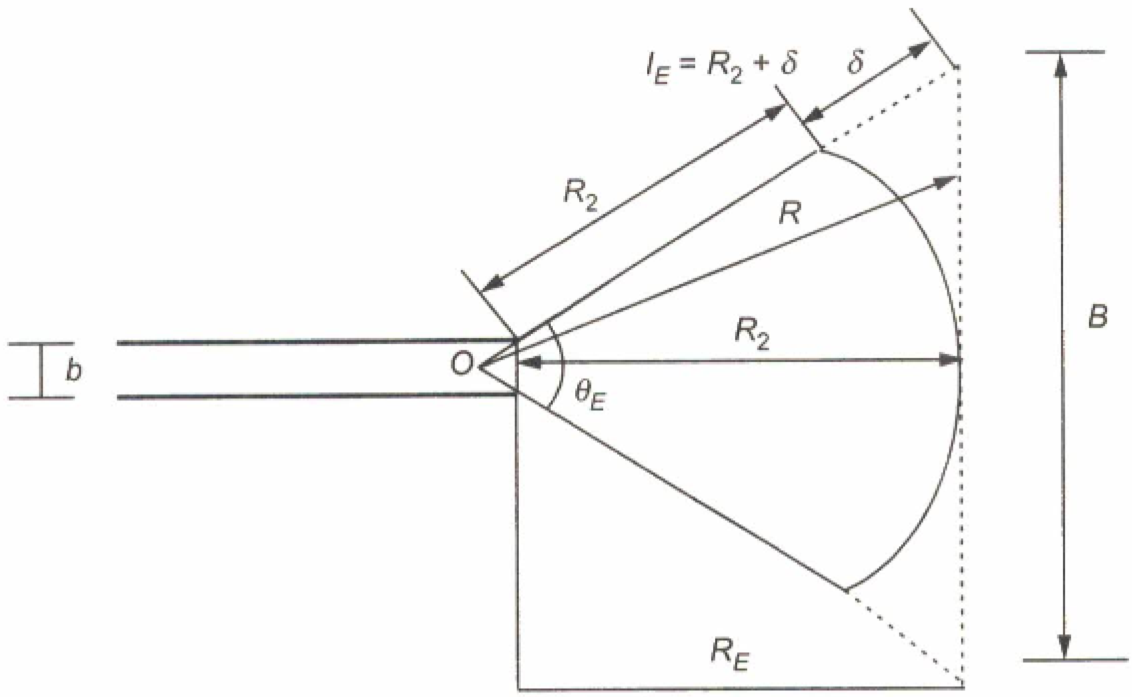


Figure 13.12 *E*- and *H*-plane patterns of *H*-plane sectoral horn.

E-plane sectoral Horn antenna :

E-plane sectoral horn antenna is formed by flaring a rectangular waveguide in the E-plane.





The geometrical parameters are related as follows:

$$R_E = (B-b)\left[\left(\frac{l_E}{B}\right)^2 - \frac{1}{4}\right]^{1/2} \rightarrow (1)$$

$$l_E = \left[R_2^2 + (B/2)^2\right]^{1/2} \rightarrow (2)$$

and $$\theta_E = 2\tan^{-1}\left(B/2R_2\right) \rightarrow (3)$$

with the similar procedure like H-plane sectoral horn antenna, the parameters of the E-plane horn antenna can be expressed as,

$$R - R_2 \simeq \frac{1}{2}\left(\frac{y^2}{R_2}\right) \rightarrow (4)$$

Aperture phase-variation in y-direction can be given by

$$e^{jK(R-R_2)} = e^{-j\left(\frac{K}{2R_2}\right)y^2} \rightarrow (5)$$

and hence the aperture electric field distribution inside the aperture leads to

$$E_{ay} = E_0 \cos\left(\frac{\pi y}{B}\right) e^{-j\left(\frac{K}{2R_2}\right)y^2} \rightarrow (6)$$

and zero elsewhere.

The aperture distribution phase error as a function of position 'y' is therefore given by

$$\delta_2 = \frac{K}{2R_2} y^2 \rightarrow (7)$$

Since the maximum value of 'y' is $(B/2)$, the maximum phase error will be

$$\delta_{2\,max} = \frac{K}{2R_2}\left(\frac{B}{2}\right)^2 = \frac{\pi}{4\lambda}\left(\frac{B^2}{R_2}\right) \rightarrow (8)$$

The complete far-zone radiated electric field in (θ, ϕ) direction is

$$E = jabKE_0 \cdot \frac{e^{-jkr}}{2\pi r} \cdot \left(\frac{1+\cos\theta}{2}\right) \frac{\sin\left[\left(\frac{ka}{2}\right)\sin\theta\right] \cdot \sin\phi}{\frac{ka}{2}\sin\theta \cdot \sin\phi} \rightarrow (9)$$

In the H-plane $\phi = 0^\circ$ and the normalized radiated electric field is therefore given by

$$F_H(\theta) = \left(\frac{1+\cos\theta}{2}\right)\left[\frac{\sin\left(\frac{ka}{2}\right)\sin\theta}{\left(\frac{ka}{2}\right)\sin\theta}\right] \rightarrow (10)$$

similarly, the E-plane pattern follows with $\phi = 90^\circ$ can be expressed as,

$$F_E(\theta) = \left[\frac{1+\cos\theta}{2}\right] f_E(\theta) \rightarrow (11)$$

where, $$f_E(\theta) \propto \int_{-B/2}^{B/2} e^{-j\beta\sqrt{R_2^2+y'^2}} \cdot e^{j\beta\sin\theta\, y'} \cdot dy' \rightarrow (12)$$

The HPBW for an optimum E-plane sectoral horn is expressed as,

$$HPBW = 0.94\frac{\lambda}{B} = 54^\circ\frac{\lambda}{B} \rightarrow (13)$$

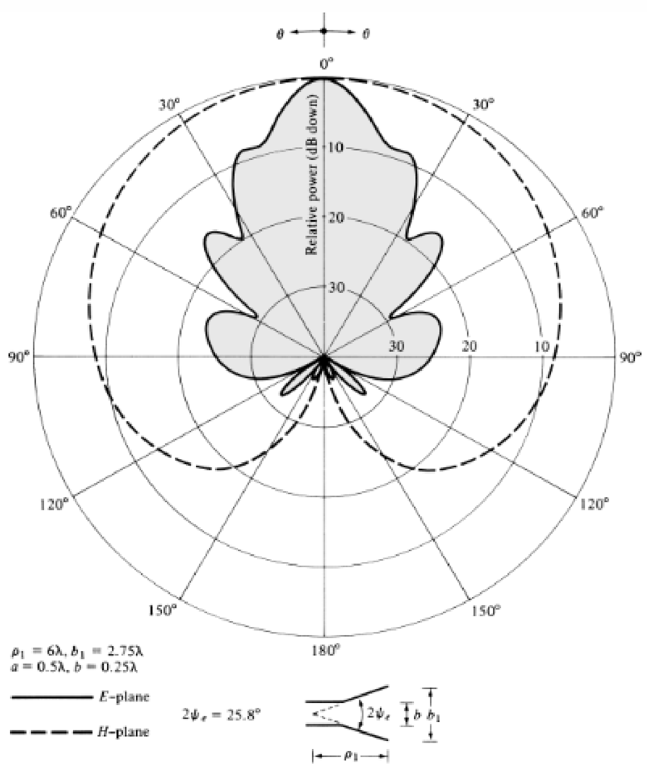


Figure 13.4 E- and H-plane patterns of an E-plane sectoral horn.

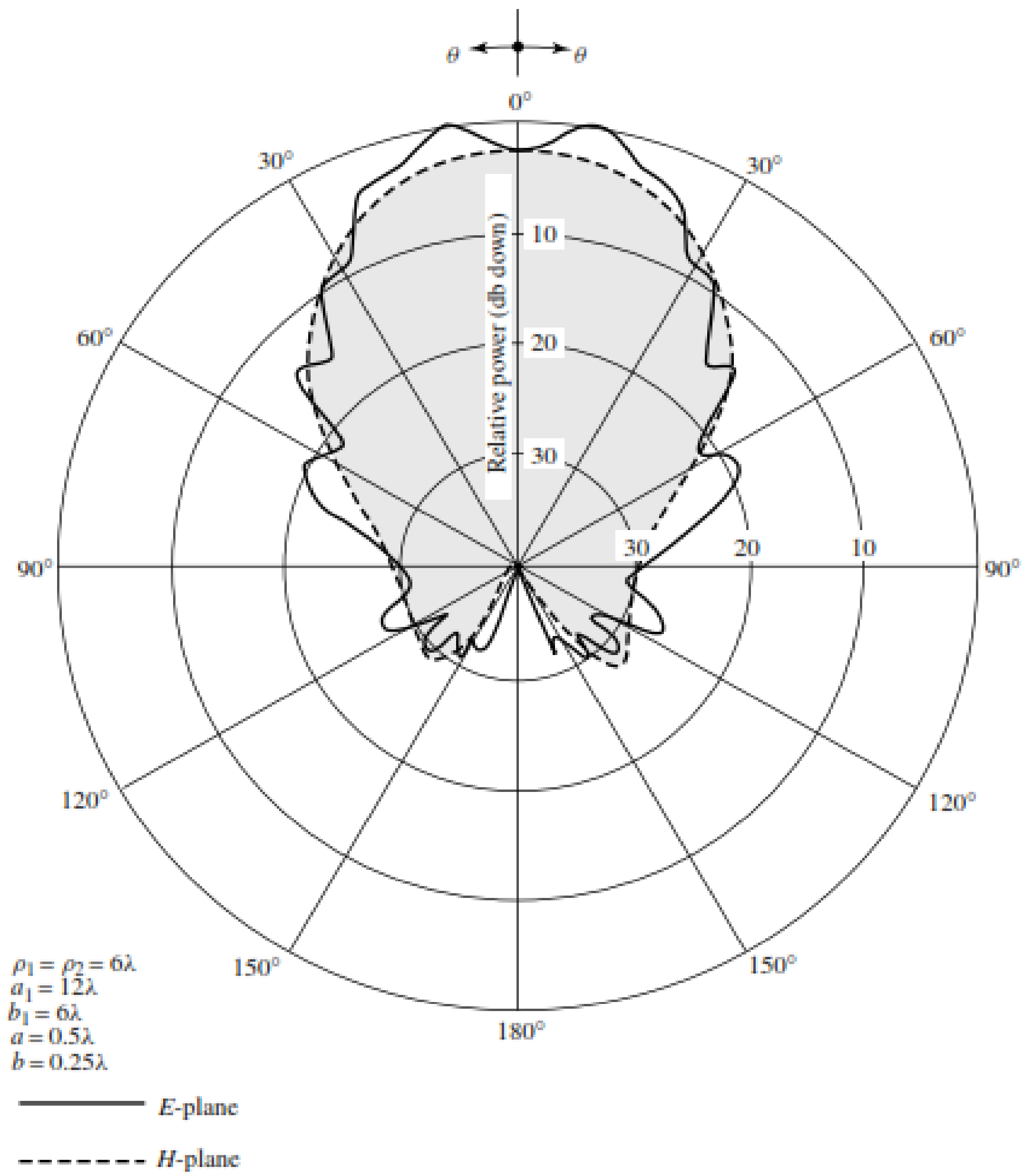


Figure 13.21 *E*- and *H*-plane amplitude patterns of a pyramidal horn with maximum not on axis.