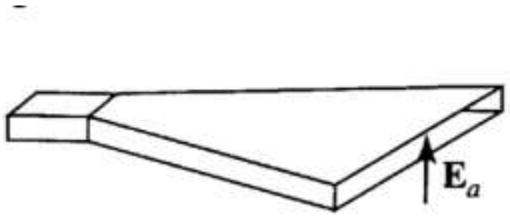
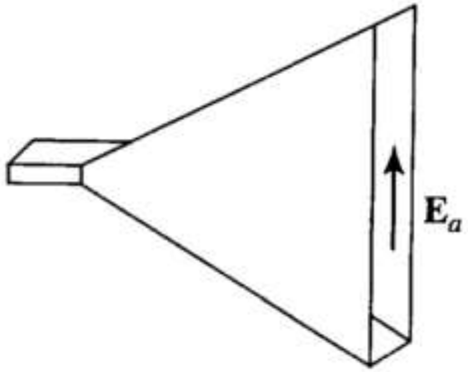
HORN Antenna Design

- The rectangular horns are ideally suited for rectangular waveguide feeds. The horn acts as a gradual transition from a waveguide mode to a free-space mode of the EM wave. When the feed is a cylindrical waveguide, the antenna is usually a conical horn.
- Horn antennas are popular in the microwave bands (above 1 GHz). Horns provide high gain, low VSWR (with waveguide feeds), relatively wide bandwidth, and they are not difficult to make.

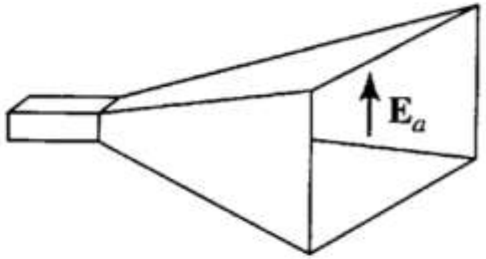
3 Types..



(*a*) *H*-plane sectoral horn.

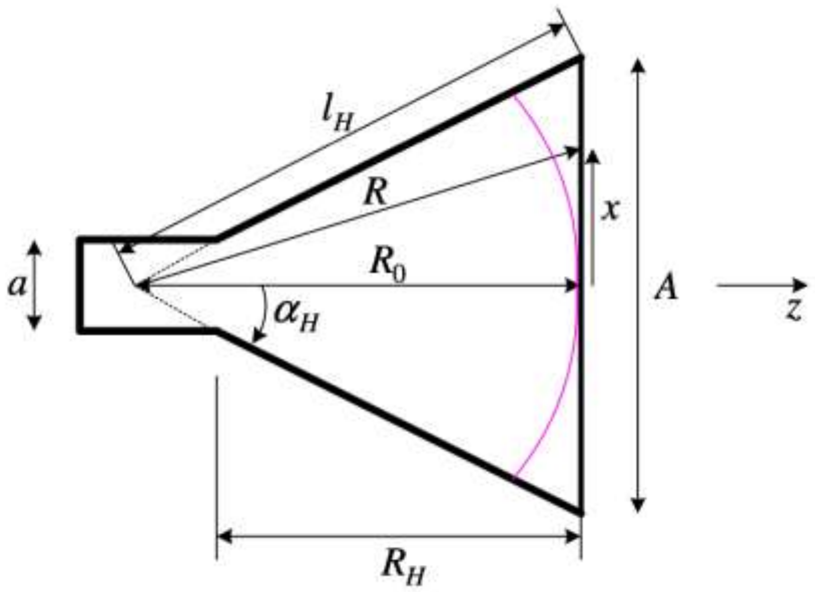


(*b*) *E*-plane sectoral horn.



(*c*) Pyramidal horn.

H-plane (x-z)



H-PLANE (*X*-*Z*) CUT OF AN *H*-PLANE SECTORAL HORN

$$l_H^2 = R_0^2 + \left(\frac{A}{2}\right)^2,$$

$$\alpha_H = \arctan\left(\frac{A}{2R_0}\right),$$

$$R_H = (A-a)\sqrt{\left(\frac{l_H}{A}\right) - \frac{1}{4}}.$$

The amplitude pattern of the *H*-plane sectoral horn is obtained as

$$\bar{E}(\theta,\varphi) = \left(\frac{1+\cos\theta}{2}\right)\cdot\left[\frac{\sin(0.5\beta b\cdot\sin\theta\cdot\sin\varphi)}{(0.5\beta b\cdot\sin\theta\cdot\sin\varphi)}\right]\cdot I(\theta,\varphi).$$

$$D_H = \frac{b}{\lambda}\frac{32}{\pi}\left(\frac{A}{\lambda}\right)\varepsilon_{ph}^{H} = \frac{4\pi}{\lambda^2}\varepsilon_t\varepsilon_{ph}^{H}(Ab)$$

where

$$\varepsilon_t = \frac{8}{\pi^2};$$

$$\varepsilon_{ph}^{H} = \frac{\pi^2}{64t}\left\{\left[C(p_1) - C(p_2)\right]^2 + \left[S(p_1) - S(p_2)\right]^2\right\};$$

$$p_1 = 2\sqrt{t}\left[1 + \frac{1}{8t}\right], \quad p_2 = 2\sqrt{t}\left[-1 + \frac{1}{8t}\right];$$

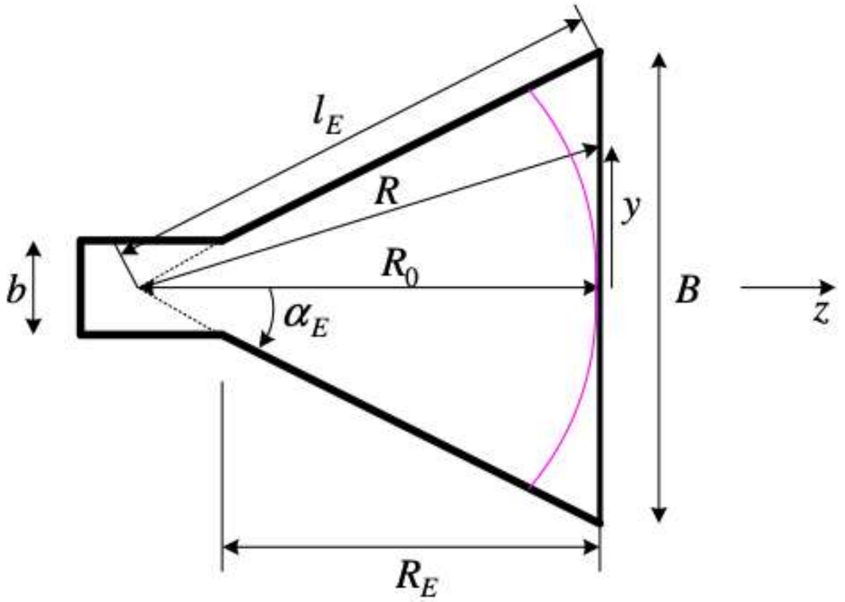
$$t = \frac{1}{8}\left(\frac{A}{\lambda}\right)^2 \frac{1}{R_0/\lambda}.$$

Epsilon ph is the phase aperture efficiency factor.
Epsilon t is the taper factor

From the family of directivity curves it is clear that for a given axial length R_0 and at a given wavelength, there is an optimal aperture width A corresponding to the maximum directivity.

E-plane (y-z)

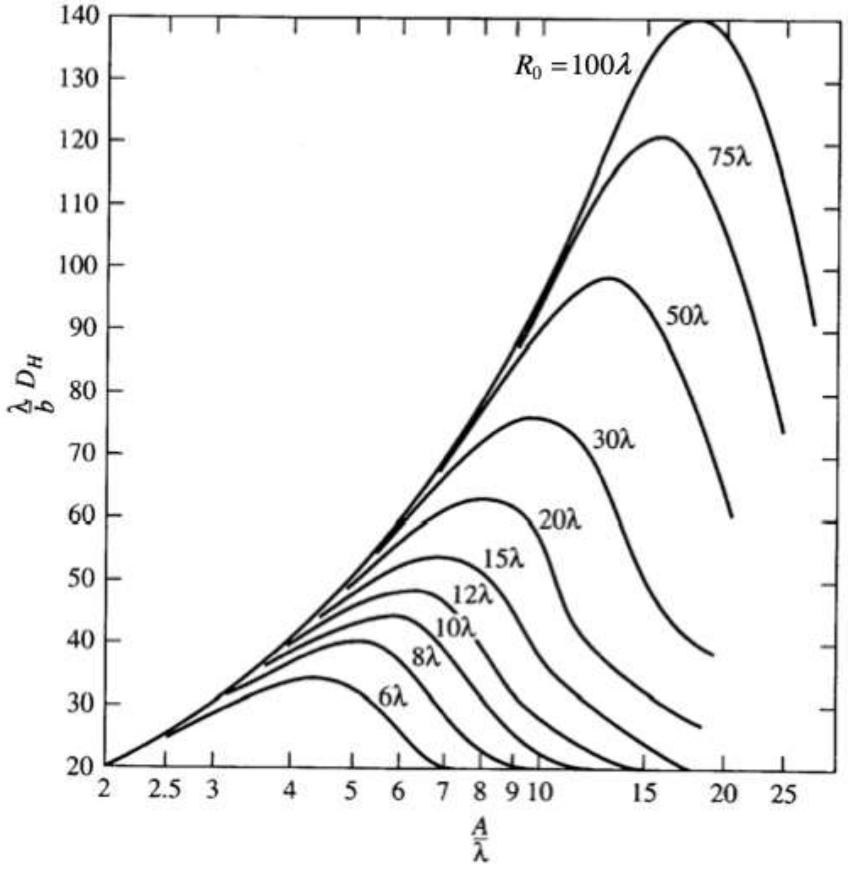
1.2 The *E*-plane sectoral horn



E-plane (*y*-*z*) cut of an *E*-plane sectoral horn

$$D_E = \frac{a}{\lambda}\frac{32}{\pi}\frac{B}{\lambda}\varepsilon_{ph}^{E} = \frac{4\pi}{\lambda^2}\varepsilon_t\varepsilon_{ph}^{E}aB\,,$$

$$\varepsilon_t = \frac{8}{\pi^2},\ \varepsilon_{ph}^{E} = \frac{C^2(q)+S^2(q)}{q^2},\quad q = \frac{B}{\sqrt{2\lambda R_0}}.$$



[Stutzman&Thiele, *Antenna Theory and Design*]

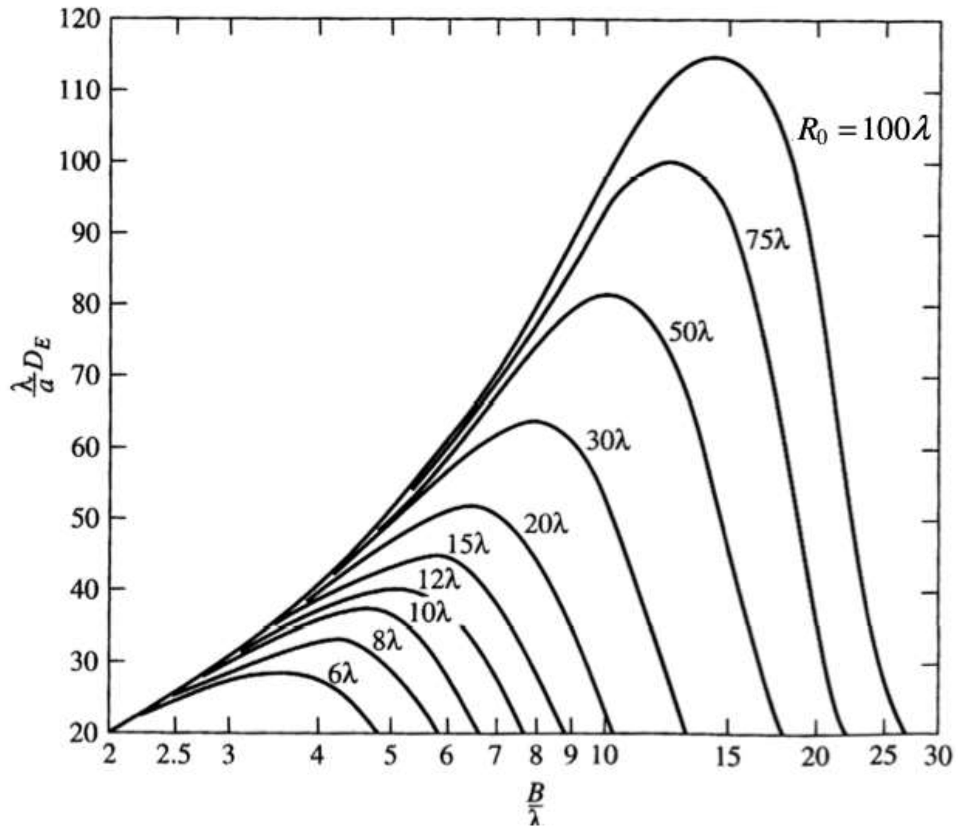
It can be shown that the optimal directivity is obtained if the relation between A and R_0 is

$$A = \sqrt{3\lambda R_0}\,, \tag{18.24}$$

or

$$\frac{A}{\lambda} = \sqrt{3\frac{R_0}{\lambda}}\,. \tag{18.25}$$

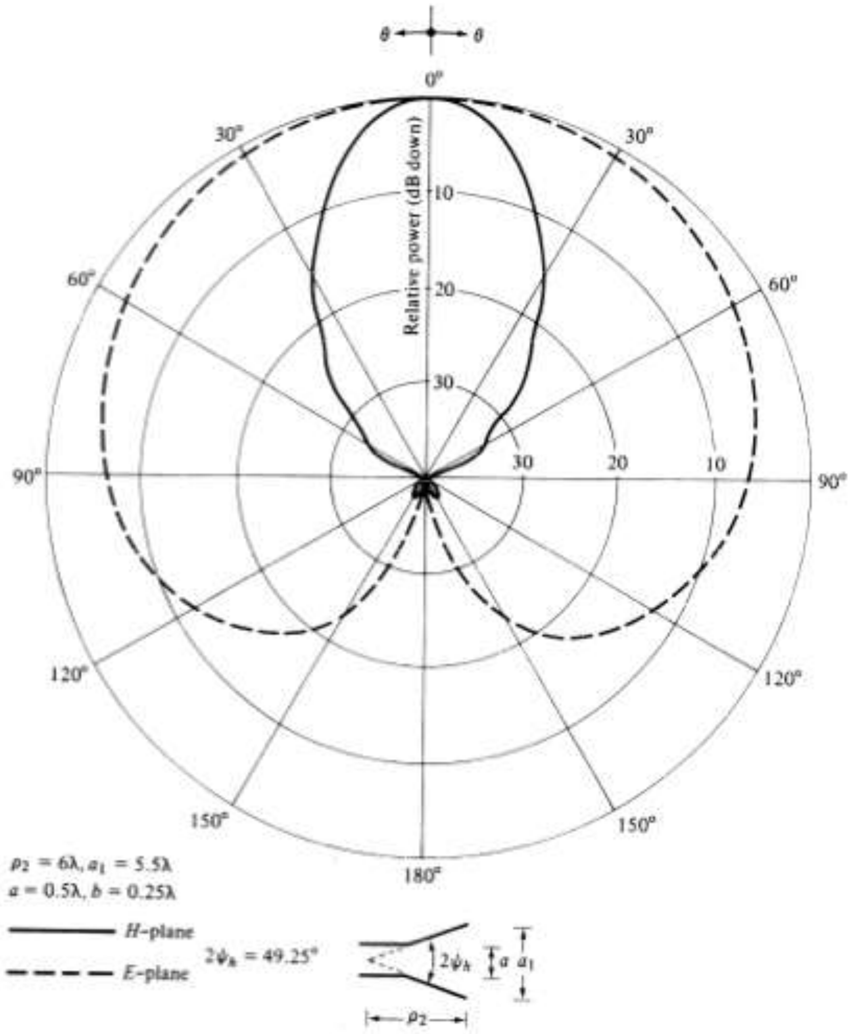
A family of universal directivity curves $\lambda D_E / a$ vs. B/λ with R_0 being a parameter is given below.



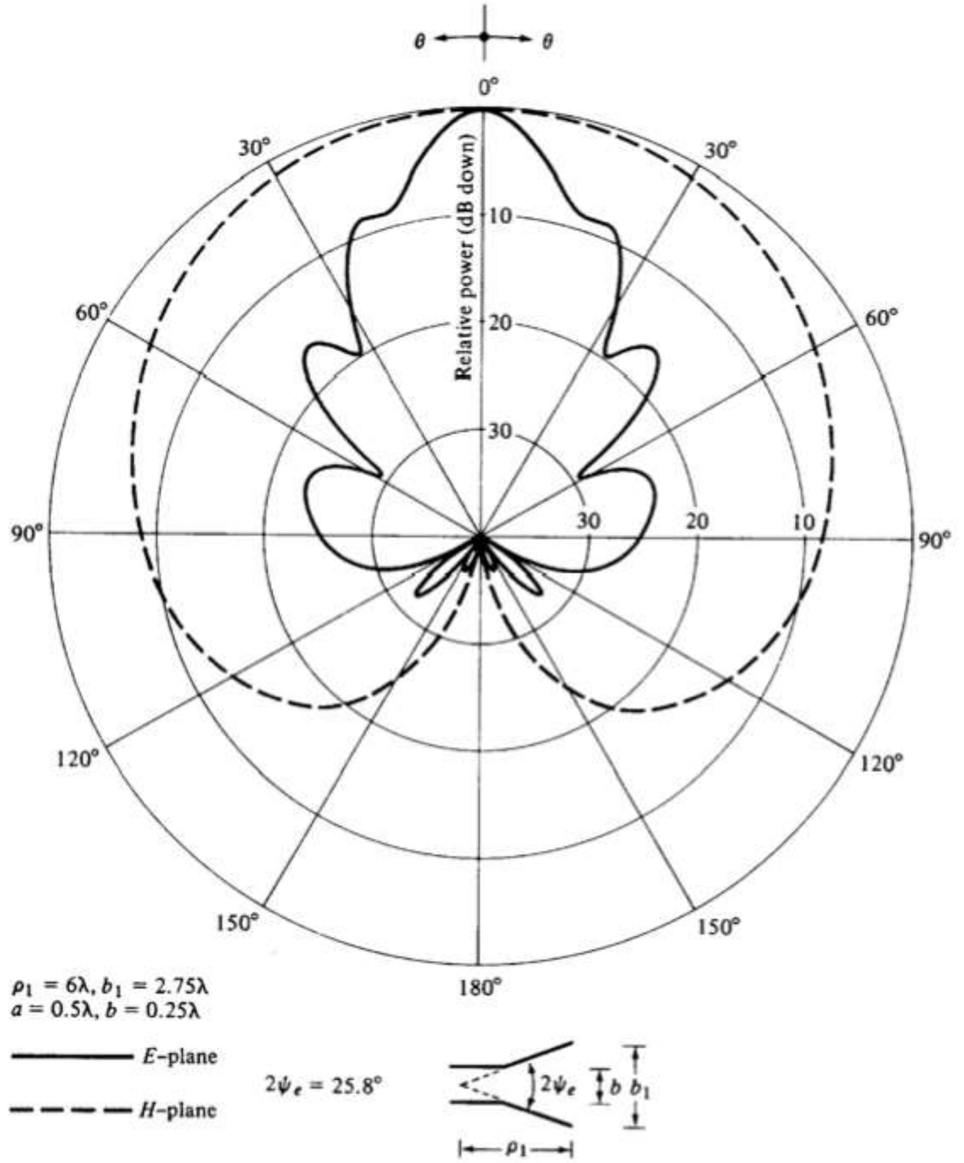
The optimal relation between the flared height B and the horn apex length R_0 that produces the maximum possible directivity is

$$B = \sqrt{2\lambda R_0}\,. \tag{18.37}$$

E- AND *H*-PLANE PATTERN OF *H*-PLANE SECTORAL HORN



E- AND *H*-PLANE PATTERN OF *E*-PLANE SECTORAL HORN

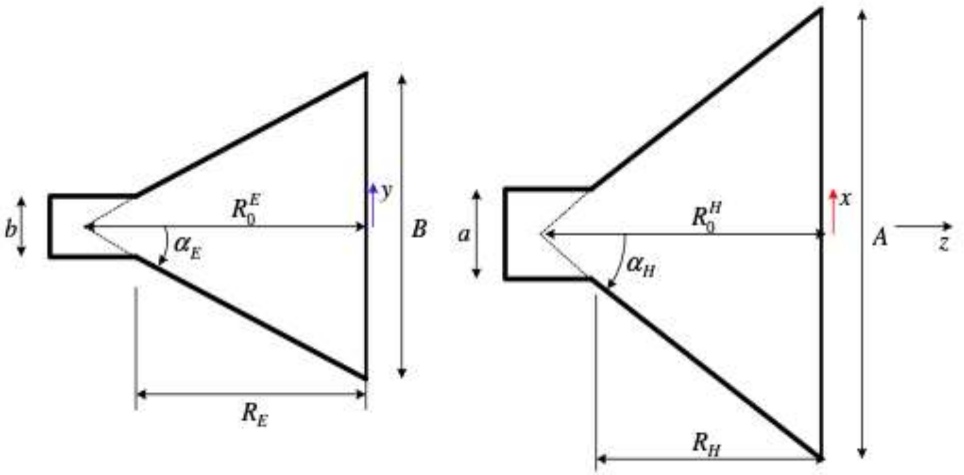


Pyramidal horn antenna

- The pyramidal horn is a popular antenna in the microwave frequency ranges (from ≈1 GHz to 30 GHz). The feeding waveguide is flared in both directions, the *E*-plane and the *H*-plane.
- All results are combinations of the E-plane and *H*-plane sectoral horn analyses.
- The directivity of the pyramidal horn can be found by introducing the phase efficiency factors of both planes and the taper efficiency factor of the *H*-plane.
- The gain of a horn is usually very close to its directivity because the radiation efficiency is very good (low losses). The directivity, as calculated, is very close to measurements.

- The optimal directivity of an *E*-plane horn is achieved at q=1
- ε_{ph} E = 0.8.
- The optimal directivity of an *H*-plane horn is achieved at t = 3/8, ε_{ph} H = 0.79
- ε_{ph} P = 0.632 * ε_t = 0.51
- Therefore, the best achievable directivity for a rectangular waveguide horn is about half that of a uniform rectangular aperture.
- We reiterate that the best accuracy is achieved if ε H and ε E are calculated numerically without using the second-order phase approximation.
- For a horn antenna to be realizable, the following must be true :

$RE = RH = RP$.



It can be shown that

$$\frac{R_0^H}{R_H} = \frac{A/2}{A/2 - a/2} = \frac{A}{A-a}, \tag{18.43}$$

$$\frac{R_0^E}{R_E} = \frac{B/2}{B/2 - b/2} = \frac{B}{B-b}. \tag{18.44}$$

The optimum-gain condition in the E-plane (18.37) is substituted in (18.44) to produce

$$B^2 - bB - 2\lambda R_E = 0. \tag{18.45}$$

There is only one physically meaningful solution to (18.45):

$$B = \frac{1}{2}\left(b + \sqrt{b^2 + 8\lambda R_E}\right). \tag{18.46}$$

Similarly, the maximum-gain condition for the H-plane of (18.24) together with (18.43) yields

$$R_H = \frac{A-a}{A}\left(\frac{A^2}{3\lambda}\right) = A\frac{(A-a)}{3\lambda}. \tag{18.47}$$

$$D_P = \frac{4\pi}{\lambda^2}\varepsilon_t \varepsilon_{ph}^E \varepsilon_{ph}^H AB,$$

where

$$\varepsilon_t = \frac{8}{\pi^2};$$

$$\varepsilon_{ph}^H = \frac{\pi^2}{64t}\left\{\left[C(p_1) - C(p_2)\right]^2 + \left[S(p_1) - S(p_2)\right]^2\right\};$$

$$p_1 = 2\sqrt{t}\left[1 + \frac{1}{8t}\right],\quad p_2 = 2\sqrt{t}\left[-1 + \frac{1}{8t}\right],\ t = \frac{1}{8}\left(\frac{A}{\lambda}\right)^2 \frac{1}{R_0^H/\lambda};$$

$$\varepsilon_{ph}^E = \frac{C^2(q) + S^2(q)}{q^2},\quad q = \frac{B}{\sqrt{2\lambda R_0^E}}.$$

Substituting in the expression for the horn's gain,

$$G = \frac{4\pi}{\lambda^2}\varepsilon_{ap} AB,$$

gives the relation between A, the gain G, and the aperture efficiency ε_{ap}

$$G = \frac{4\pi}{\lambda^2}\varepsilon_{ap} A \frac{1}{2}\left(b + \sqrt{b^2 + \frac{8A(a-a)}{3}}\right),$$

$$\Rightarrow A^4 - aA^3 + \frac{3bG\lambda^2}{8\pi\varepsilon_{ap}}A - \frac{3G^2\lambda^4}{32\pi^2\varepsilon_{ap}^2} = 0.$$

- The optimum gain value of $\varepsilon_{ap} = 0.51$ is usually used, which makes the equation a fourth-order polynomial equation in A. Its roots can be found analytically and numerically.
- In a numerical solution, the first guess is usually set at $A(0) = 0.45\lambda(G)^{-0.5}$. Once A is found, B, $R_E = R_H$ can be computed.
- Horn antennas operate well over a bandwidth of 50%. However, gain performance is optimal only at a given frequency.

Design Parameters

- **S11 (Return Loss):** Reflection coefficient at the antenna's input port. Indicates how much power is reflected from the antenna instead of being radiated, a lower value (e.g., -10 dB or less) signifies better impedance matching between the antenna and the transmission line. **Ideal Value:** S11 < -10 dB over the operating frequency range (less than 10% of power is reflected).
- The radiation pattern corresponds to the energy distribution of the radiated power by the antenna. The antenna converts received signal/electrical power into an electromagnetic wave. The AZ pattern is a radiated wave of power density/gain/directivity along the azimuthal plane at fixed elevation.
- Taper angle: Basically the cone angle. A wider taper angle typically produces a broader radiation pattern, while a narrower one produces a more focused beam. **Gain and Directivity-**Narrow taper angles generally increase antenna gain and directivity by focusing the energy into a smaller area. A smoother taper angle ensures better impedance matching, reducing reflected power.
- Aperture loss – Results from spillover of radiated power, unmatched radiation pattern, poor feed design, edge diffraction.

- It shows how the antenna radiates energy horizontally around its axis, indicating whether the coverage is uniform or directional. A parabolic dish antenna will show a **highly directional main lobe** with minimal side lobes in the AZ plane, while an omnidirectional antenna will have a circular pattern.
- **Beamwidth:** The **3-dB beamwidth** (angular width of the main lobe at half its maximum power) can be determined. This indicates the area of strong signal coverage in the azimuth plane.
- **Directionality:** The shape of the pattern helps identify the directionality. Directional antennas (e.g., parabolic dishes) will have a single, narrow lobe.
- **Interference Analysis:**The pattern helps identify **side lobes** or **back lobes**, which can lead to unwanted radiation or interference.
- The 11dB gain is the maximum value to which the antenna gain can fall within the taper angle.