Horn Antennas

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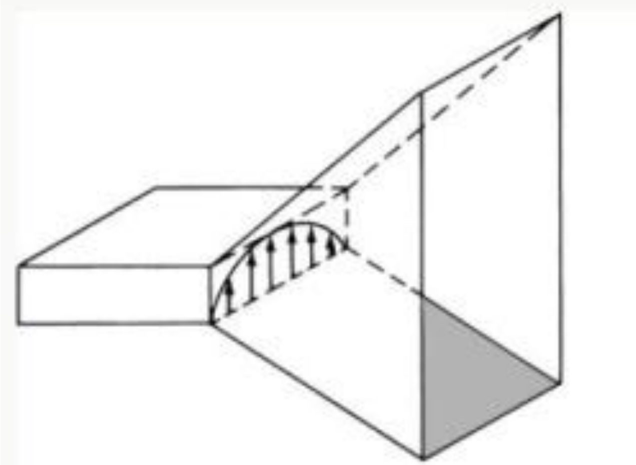
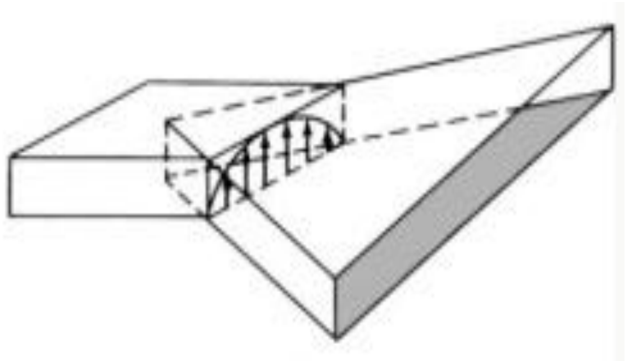
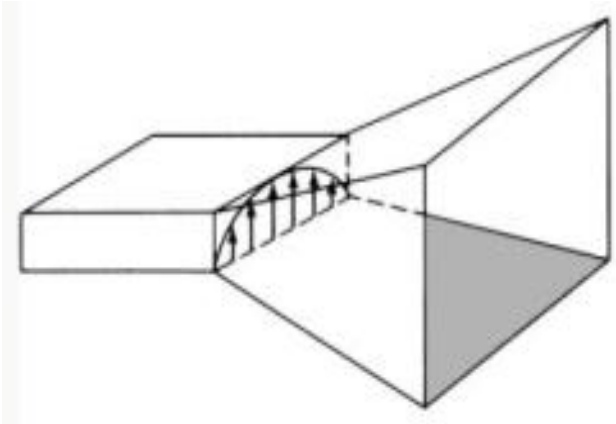


E-Plane Sectoral Horn

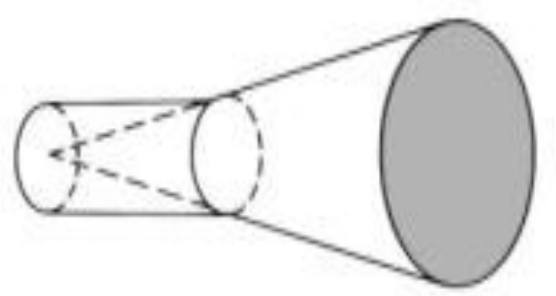


H-Plane Sectoral Horn

TE_{10} mode in Rectangular Waveguide

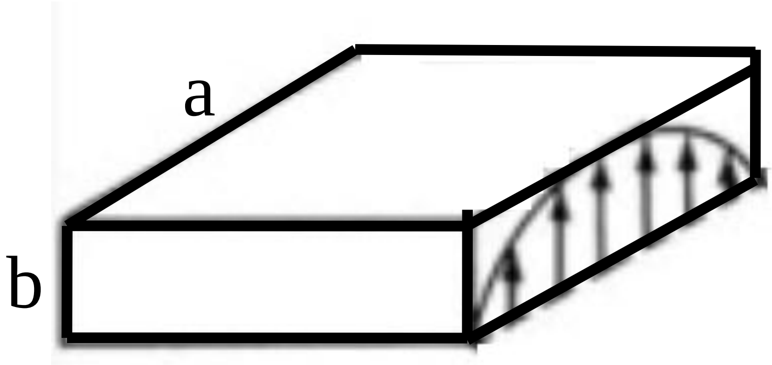


Pyramidal Horn



Conical Horn

Rectangular Waveguide



TE$_{10}$ mode in Rectangular Waveguide

For Fundamental TE$_{10}$ mode: E-Field varies sinusoidally along 'a' and is uniform along 'b'

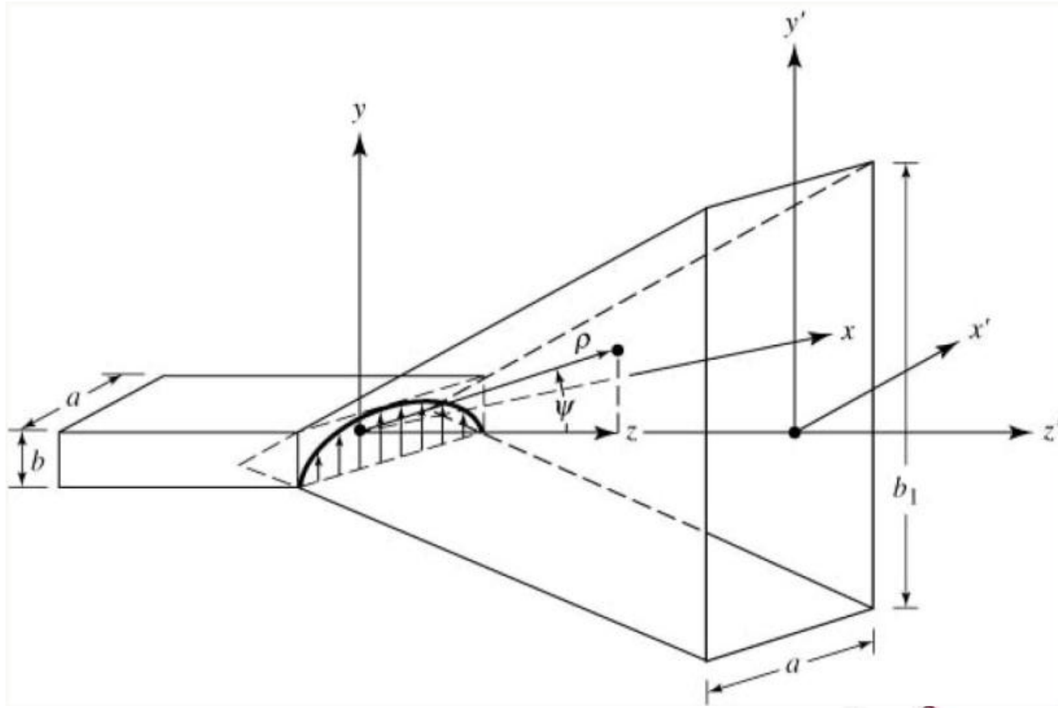
X-Band Waveguide WR90 (8.4 to 12.4 GHz):

a = 0.9" and b = 0.4"

Cut-off Wavelength = 2a = 2 x 0.9 x 2.54 = 4.572 cm

Cut-off Frequency = 3 x 10^{10} / 4.572 = 6.56 GHz

E-Plane Sectoral Horn Antenna

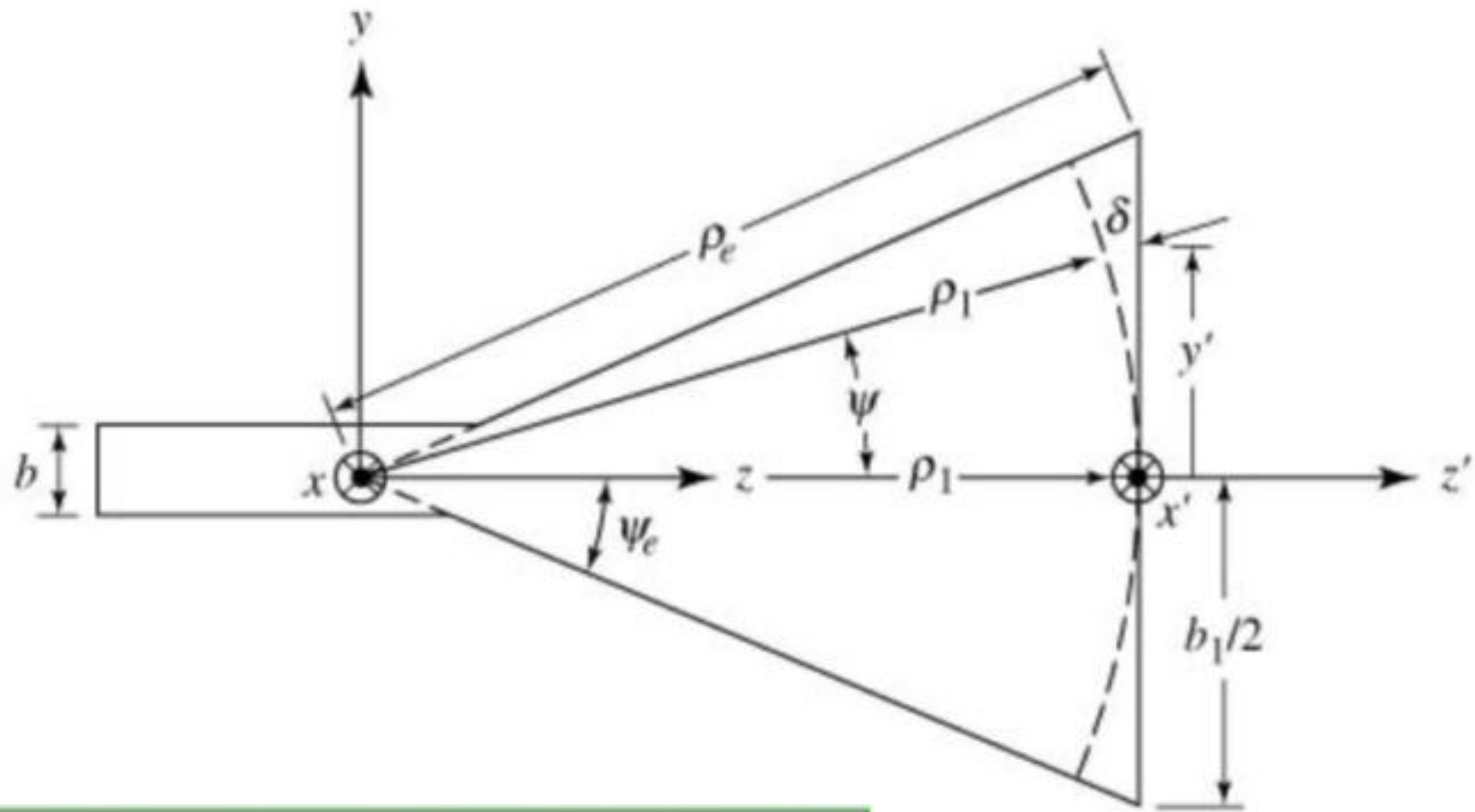


$$E_y'(x',y') = E_1 \cos\left(\frac{\pi}{a}x'\right) e^{-j\frac{k}{2}\frac{y'^2}{\rho_1}}$$

Amplitude Distribution

Phase Distribution

E-Plane Sectoral Horn: Side View

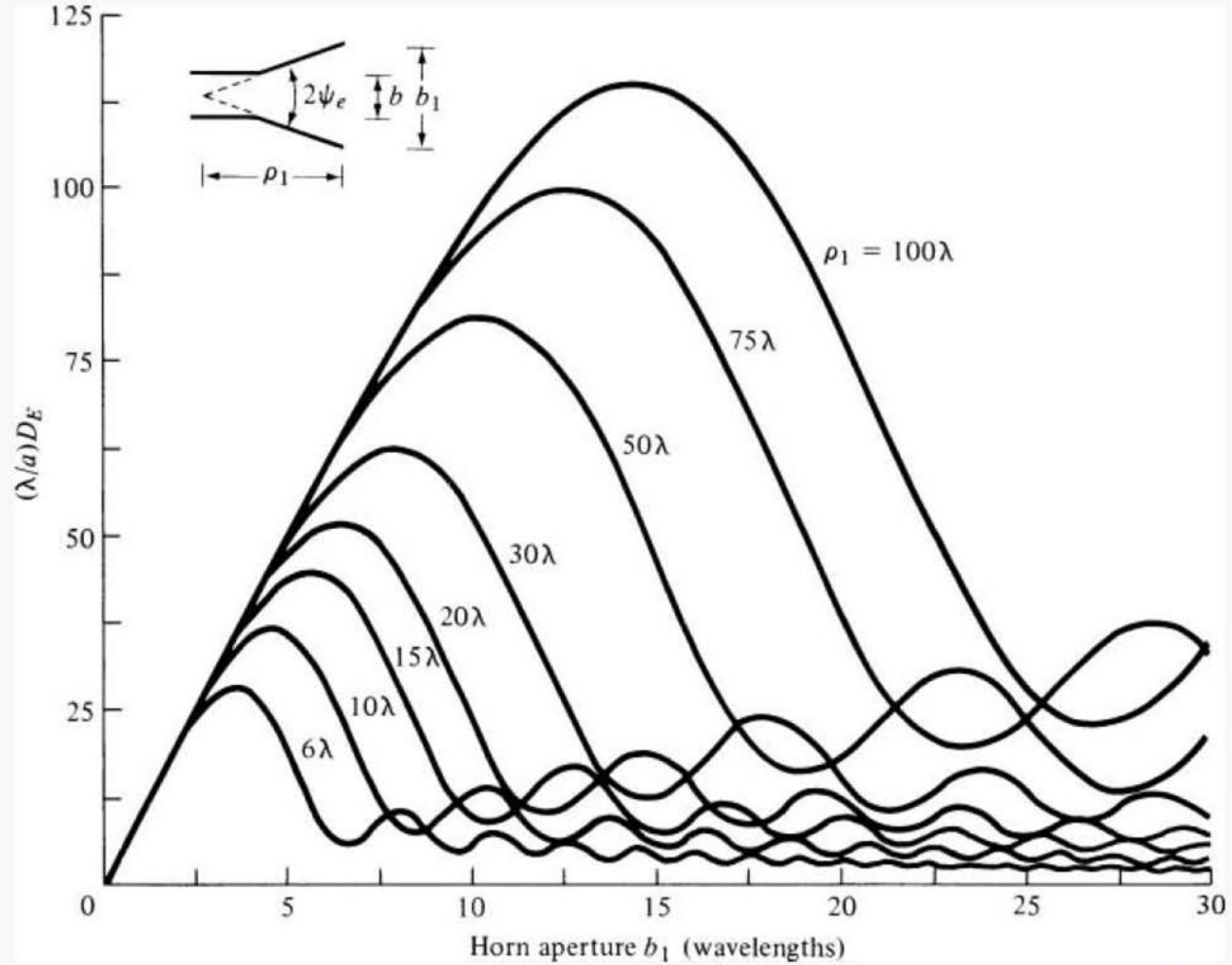


$$\delta(y') = -\rho_1 + \rho_1\left[1 + \left(\frac{y'}{\rho_1}\right)^2\right]^{1/2}$$

$$\Rightarrow$$

$$\delta(y') \approx \frac{1}{2}\left(\frac{y'^2}{\rho_1}\right)$$

E-Plane Sectoral Horn: Directivity Curve



Max. Directivity:

$$b_1 \simeq \sqrt{2\lambda\rho_1}$$

ρ_1	6	10	20	100
b_1	3.46	4.47	6.32	14.14

E-Plane Sectoral Horn: Max. Phase Error

Maximum Directivity occurs when

$$b_1 \simeq \sqrt{2\lambda\rho_1}$$

Maximum Phase error occurs when y' = b_1 / 2

$$\boxed{\delta(y') \approx \frac{1}{2}\left(\frac{y'^2}{\rho_1}\right)}$$

$\delta_{max} = 2\pi s$, **where** $s = \dfrac{b_1^{\,2}}{8\lambda\rho_1}$

which gives 's' approximately equal to:

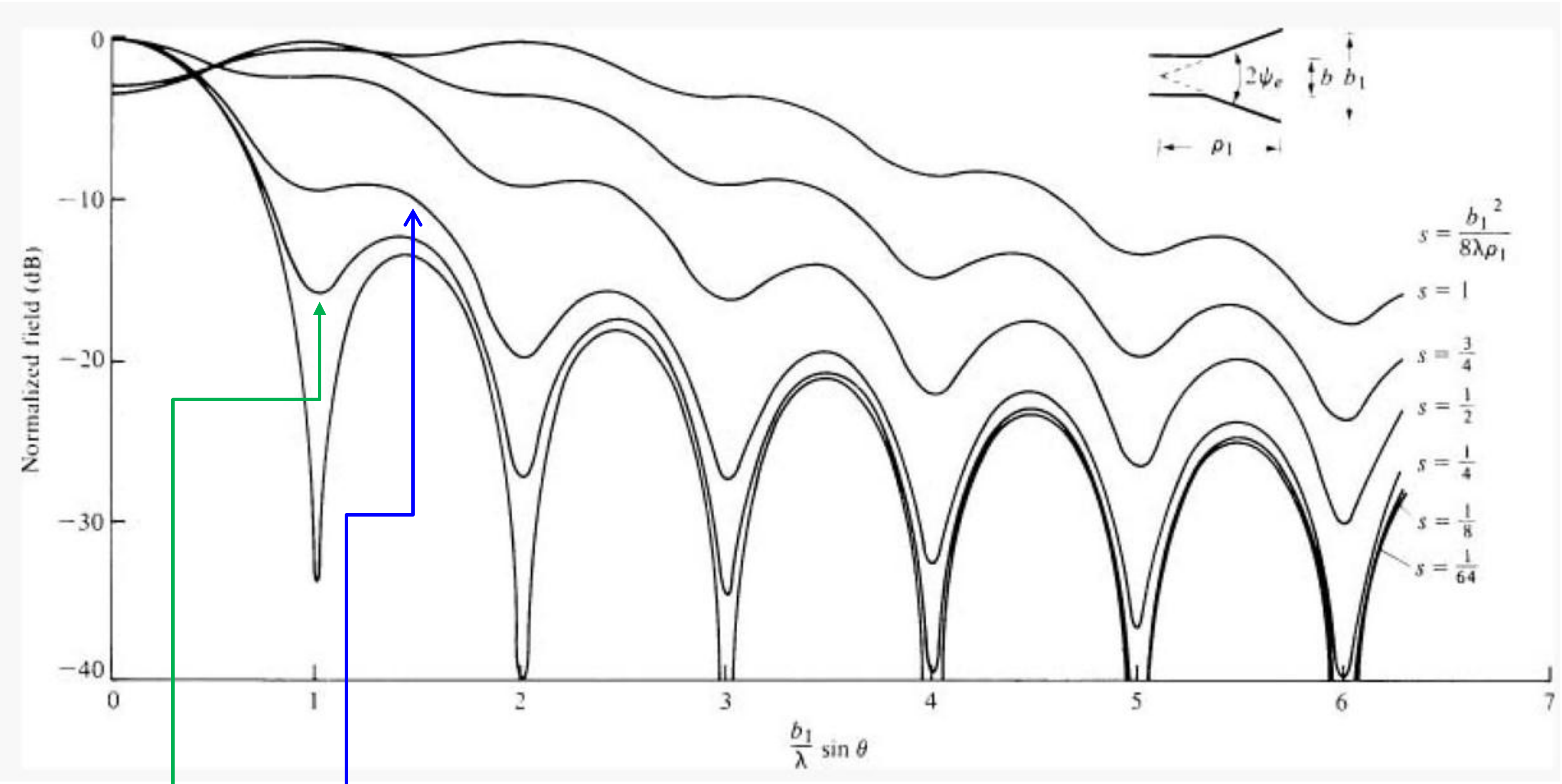
$$s_{op} = \frac{b_1^{\,2}}{8\lambda\rho_1}\bigg|_{b_1=\sqrt{2\lambda\rho_1}} = \frac{1}{4}$$

$\Rightarrow \delta_{max} = 90°$

Phase Error too high:

Not Recommended

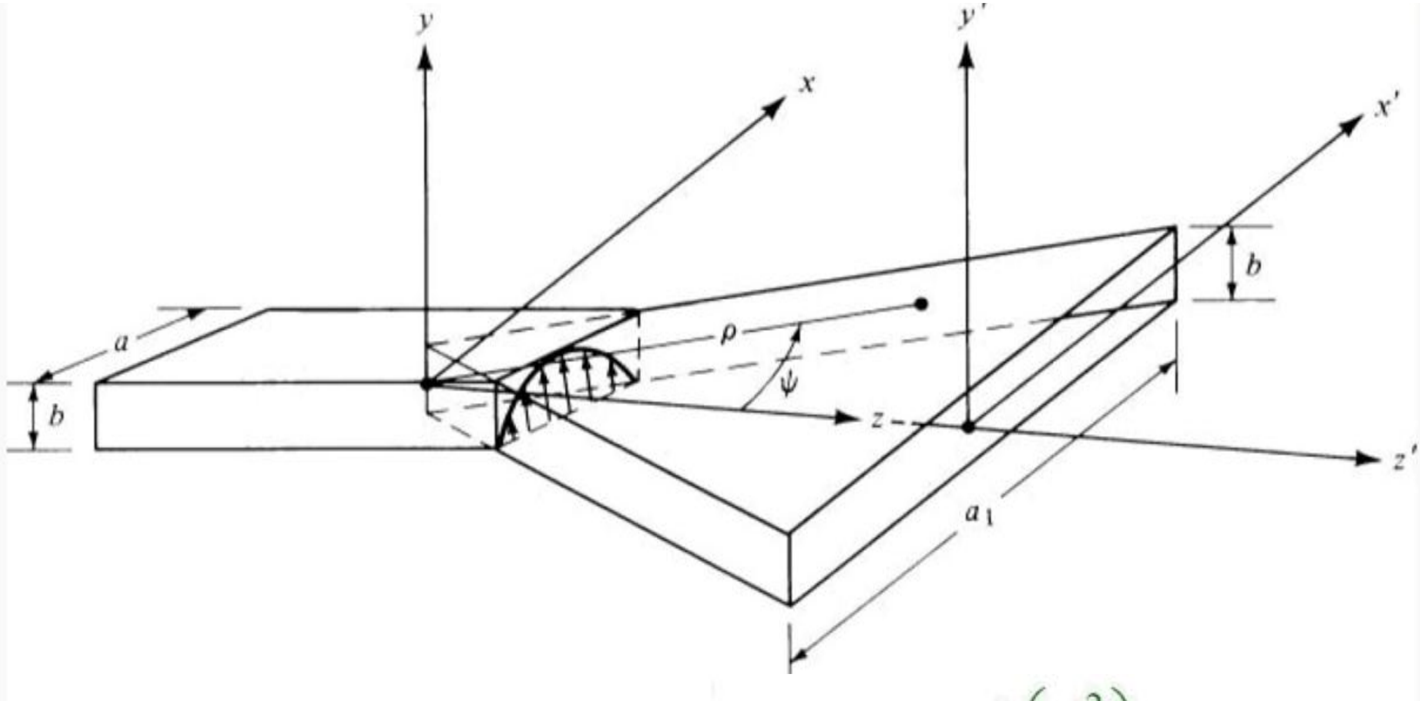
E-Plane Sectoral: Universal Pattern



E-Field for s = 1/4 (δ_{max} = 90°)

E-Field for s = 1/8 (δ_{max} = 45°) - Recommended

H-Plane Sectoral Horn Antenna

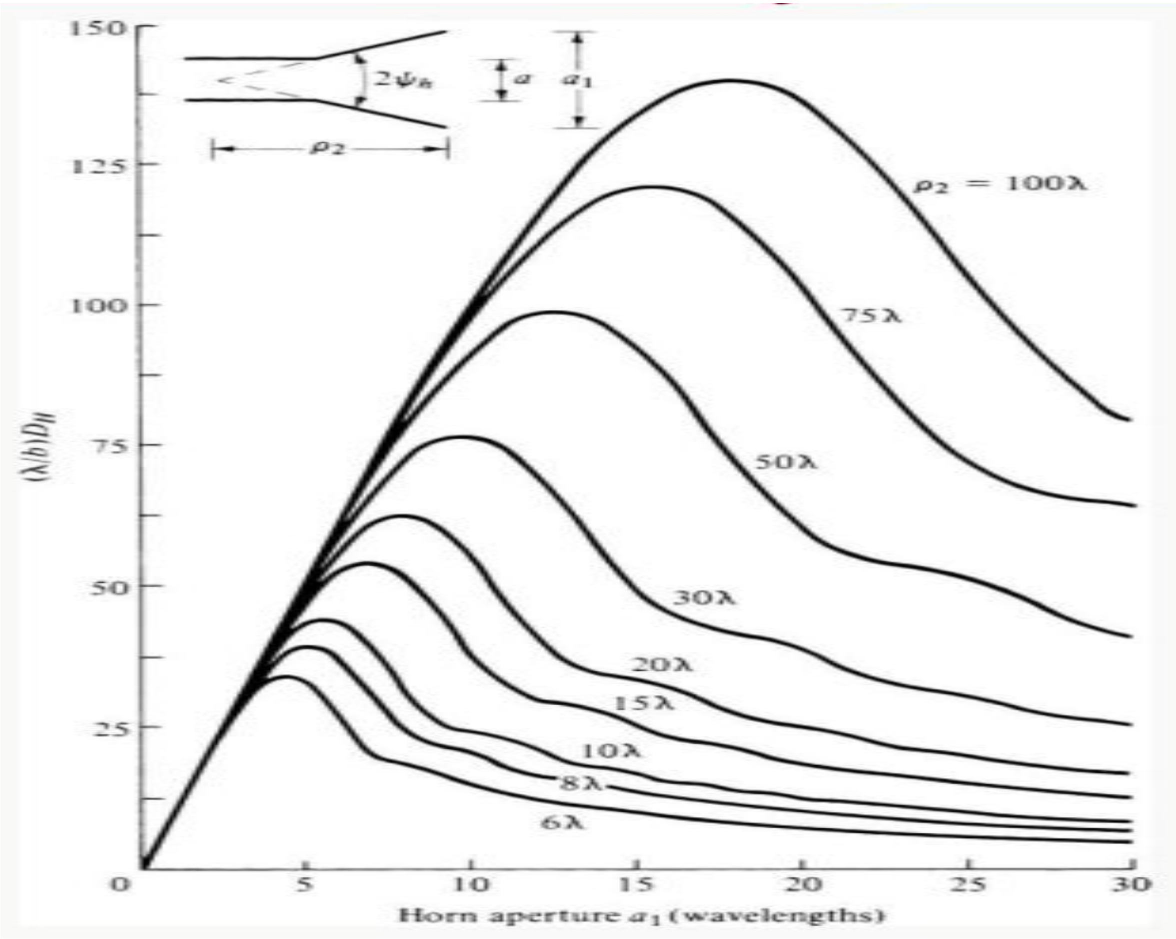


$$E_y' = E_2 \cos\left(\frac{\pi}{a_1} x'\right) e^{-j\frac{k}{2}\left(\frac{x'^2}{\rho_2}\right)}$$

Maximum Phase error at x' = a_1 / 2

$$\delta_{max} = 2\pi t, \text{ where } t = \frac{a_1^2}{8\lambda\rho_2}$$

H-Plane Sectoral Horn: Directivity Curve



Max. Directivity:

$$a_1 \simeq \sqrt{3\lambda\rho_2}$$

ρ_2	6	10	20	100
a_1	4.24	5.48	7.75	17.32

H-Plane Sectoral Horn: Max. Phase Error

Maximum Directivity occurs when

$$a_1 \simeq \sqrt{3\lambda\rho_2}$$

Maximum Phase error occurs when x' = a_1 / 2

$$\delta_{max} = 2\pi t, \text{ where } \quad t = \frac{a_1^2}{8\lambda\rho_2}$$

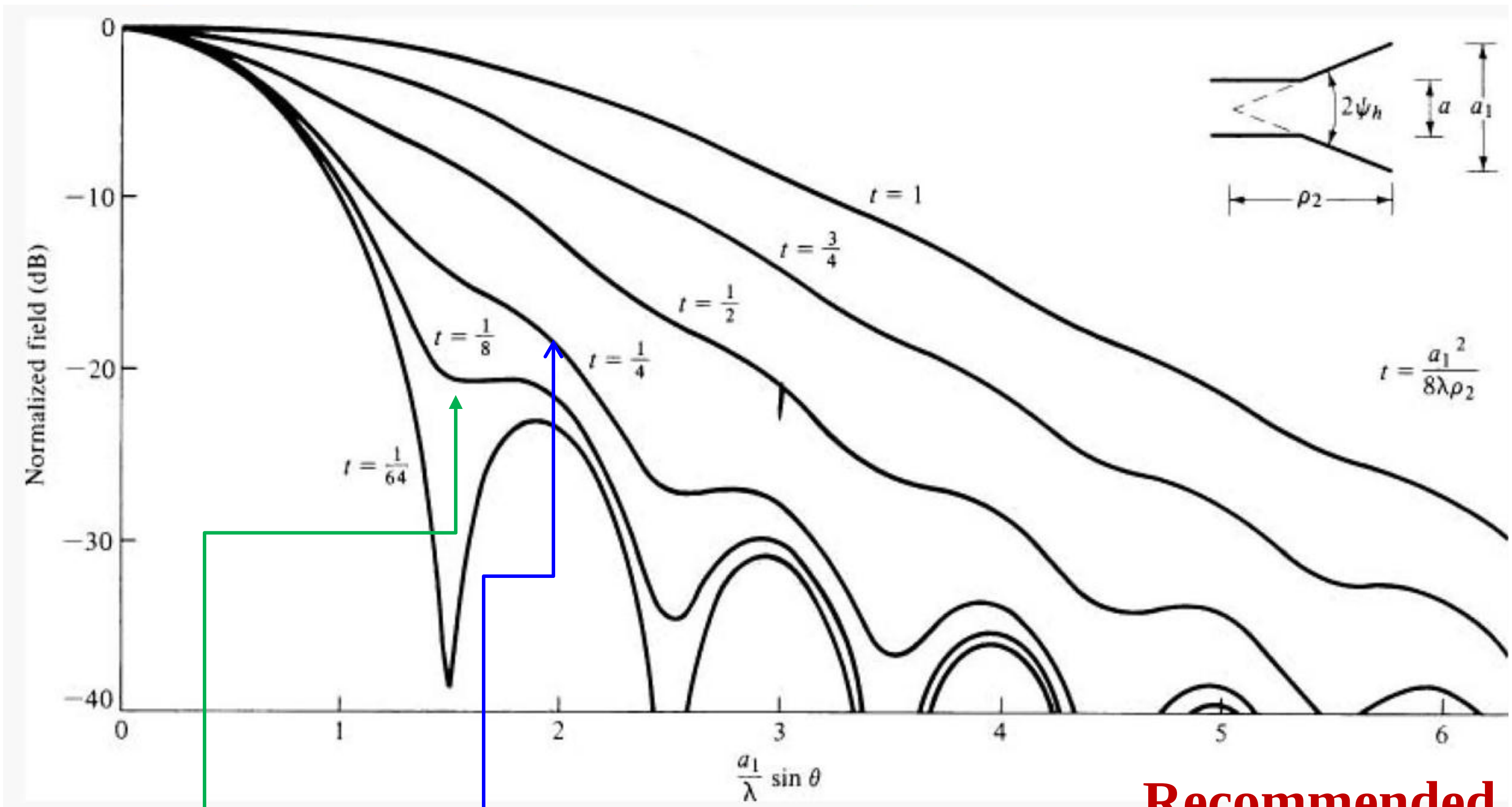
which gives 't' approximately equal to:

$$t_{op} = \left.\frac{a_1^2}{8\lambda\rho_2}\right|_{a_1=\sqrt{3\lambda\rho_2}} = \frac{3}{8} \quad \Rightarrow \delta_{max} = 135°$$

Phase Error too high:

Not Recommended

H-Plane Sectoral: Universal Pattern

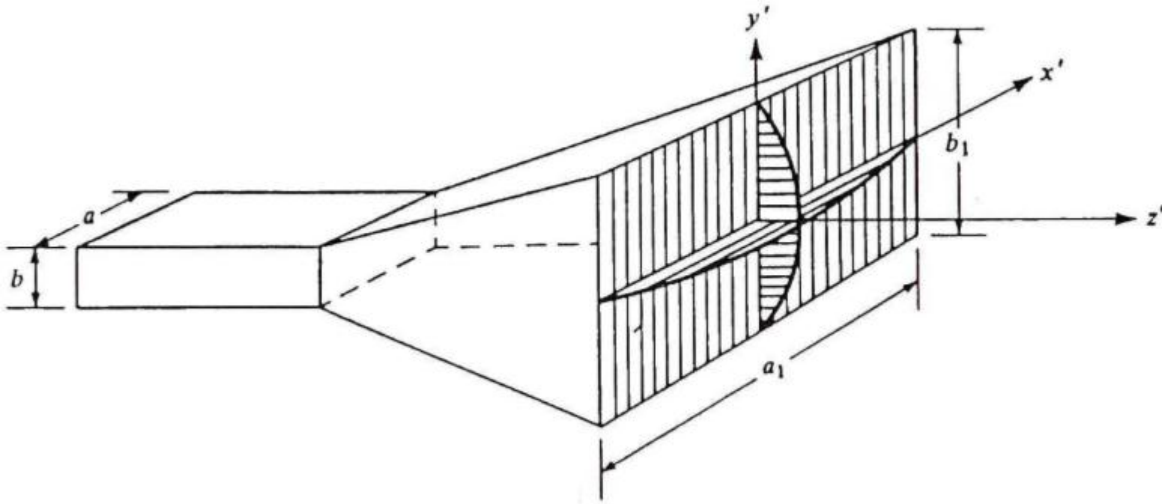


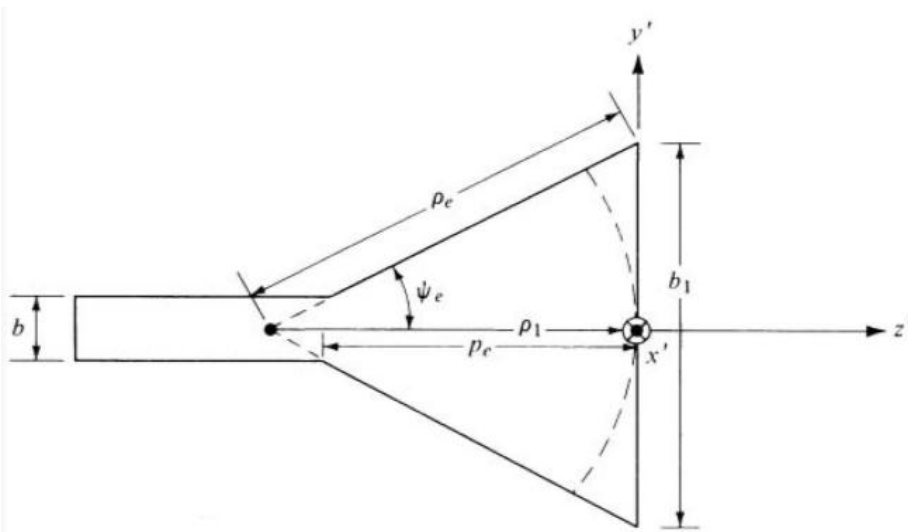
E-Field for t = 1/4 (δ_{max} = 90°)

E-Field for t = 1/8 (δ_{max} = 45°)

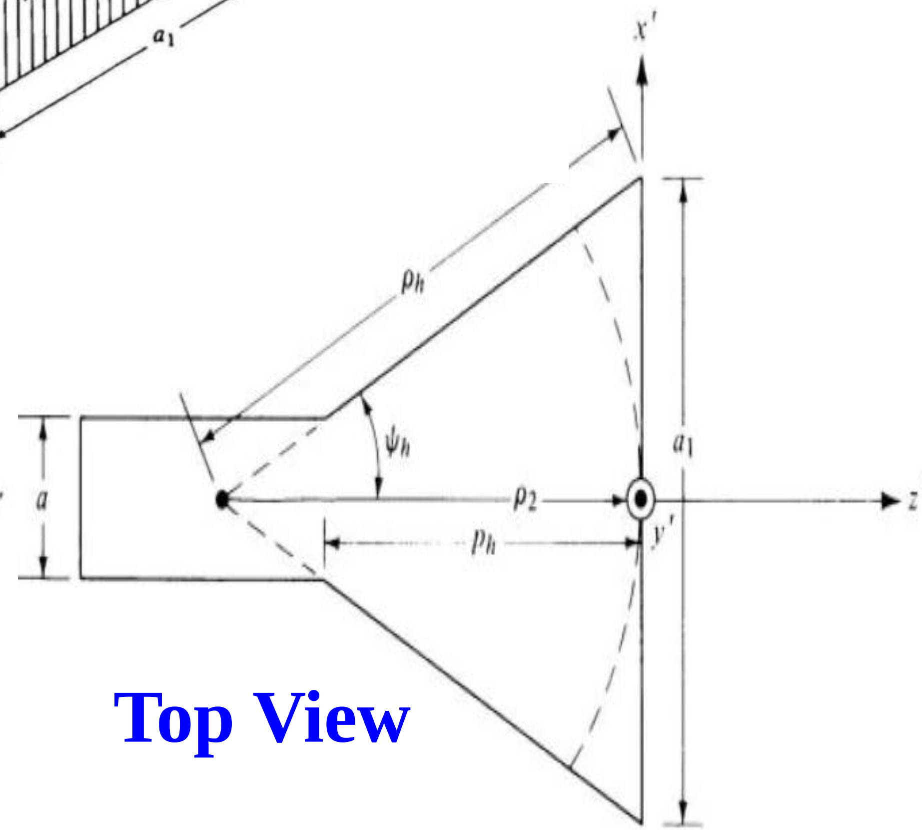
Recommended max. phase error between 45° and 90°

Pyramidal Horn Antenna





Side View



Top View

Pyramidal Horn Antenna

$$E'_y(x', y') = E_0 \cos\left(\frac{\pi}{a_1} x'\right) e^{-j\left[k\left(\frac{x'^2}{2\rho_2} + \frac{y'^2}{2\rho_1}\right)\right]}$$

Condition for Physical Realization:

$$p_e = (b_1 - b)\left[\left(\frac{\rho_e}{b_1}\right)^2 - \frac{1}{4}\right]^{1/2}$$

$$p_h = (a_1 - a)\left[\left(\frac{\rho_h}{a_1}\right)^2 - \frac{1}{4}\right]^{1/2}$$

$$\boxed{p_e = p_h}$$

Pyramidal Horn: Design Procedure

Alternatively

Directivity of Pyramidal Horn Antenna can be obtained using Directivity curves for E-and H-Planes Sectoral Horn antenna

$$D_p = \frac{\pi\lambda^2}{32ab} D_E D_H$$

$$G_0 \simeq \frac{1}{2}\left(\frac{4\pi}{\lambda^2} a_1 b_1\right)$$

$$a_1 \simeq \sqrt{3\lambda\rho_2} \approx \sqrt{3\lambda\rho_h} \qquad \rho_2 \simeq \rho_h$$

$$b_1 \simeq \sqrt{2\lambda\rho_1} \approx \sqrt{2\lambda\rho_e} \qquad \rho_1 \simeq \rho_e$$

$$p_e = (b_1 - b)\sqrt{\left(\frac{p_e}{b_1}\right)^2 - \frac{1}{4}}$$

$$p_h = (a_1 - a)\sqrt{\left(\frac{p_h}{a_1}\right)^2 - \frac{1}{4}}$$

Pyramidal Horn Design Steps

$$\boxed{\left(\sqrt{2\chi}-\frac{b}{\lambda}\right)^2(2\chi-1)=\left[\frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi}}\frac{1}{\sqrt{\chi}}-\frac{a}{\lambda}\right]^2\left[\frac{G_0^{\ 2}}{6\pi^3}\frac{1}{\chi}-1\right]}$$

$$\rho_e=\chi\lambda \Rightarrow \chi=\frac{\rho_e}{\lambda}$$

$$\rho_h=\frac{G_0^{\ 2}}{8\pi^3}\left(\frac{1}{\chi}\right)\lambda$$

1. $\chi \simeq \chi_1 = x(trial) = \dfrac{G_0}{2\pi\sqrt{2\pi}}$

2. $\rho_e=\chi\lambda,\ \rho_h=\dfrac{G_o^{\ 2}}{8\pi^3}\dfrac{1}{\chi}\lambda$

3. $a_1=\sqrt{3\lambda\rho_2}\simeq\sqrt{3\lambda\rho_h}=\dfrac{G_0}{2\pi}\sqrt{\dfrac{3}{2\pi\chi}}\lambda$

$$b_1=\sqrt{2\lambda\rho_1}\simeq\sqrt{2\lambda\rho_e}=\sqrt{2\chi\lambda}$$

4. $p_e,\ p_h$

Pyramidal Horn Design: Example

Given: X-Band (8.2-12.4 GHz), $f = 11$ GHz Horn; Gain=22.6 dB

$a = 0.9$ in (2.286 cm), $b = 0.4$ in (1.016 cm)

Find: Dimensions Of Pyramidal Horn

Solution

$$G_0(dB) = 22.6 = 10\log_{10} G_0 \Rightarrow G_0 = 10^{2.26} = 181.97$$

$$At\ f = 11\ \text{GHz} \Rightarrow \lambda = \frac{30 \text{ x } 10^9}{11 \text{ x } 10^9} = 2.7273\ cm$$

$$b = \frac{1.016}{2.7273}\lambda = 0.3725\lambda;\ \ a = \frac{2.286}{2.7273}\lambda = 0.8382\lambda$$

Pyramidal Horn Design: Example (Contd.)

1. Initial value of χ

$$\chi_1 = \frac{G_0}{2\pi\sqrt{2\pi}} = \frac{181.97}{2\pi\sqrt{2\pi}} = 11.5539$$

which does not satisfy(12-56), or

$$\left(\sqrt{2\chi} - \frac{b}{\chi}\right)^2 (2\chi - 1) = \left(\frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi}}\frac{1}{\sqrt{\chi}} - \frac{a}{\lambda}\right)^2 \left(\frac{G_0{}^2}{6\pi^3}\frac{1}{\chi} - 1\right)$$

After few tries, a more accurate value is

$$\chi = 11.1157$$

2. $\rho_e = \chi\lambda = 11.1157\lambda = 30.316\ cm = 11.935\ in.$

$$\rho_h = \frac{G_0{}^2}{8\pi^3}\left(\frac{1}{\chi}\right)\lambda = 12.0094\lambda = 32.753\ cm = 12.895\ in.$$

Pyramidal Horn Design: Example (Contd.)

3. $$a_1 = \sqrt{3\lambda\rho_2} \approx \sqrt{3\lambda\rho_h} = \frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi\chi}}\lambda = 6.002\lambda$$

$$= 16.370\ cm = 6.445\ in.$$

$$b_1 = \sqrt{2\lambda\rho_1} \approx \sqrt{2\lambda\rho_e} = \sqrt{2\chi}\lambda = 4.715\lambda$$

$$= 12.859\ cm = 5.063\ in.$$

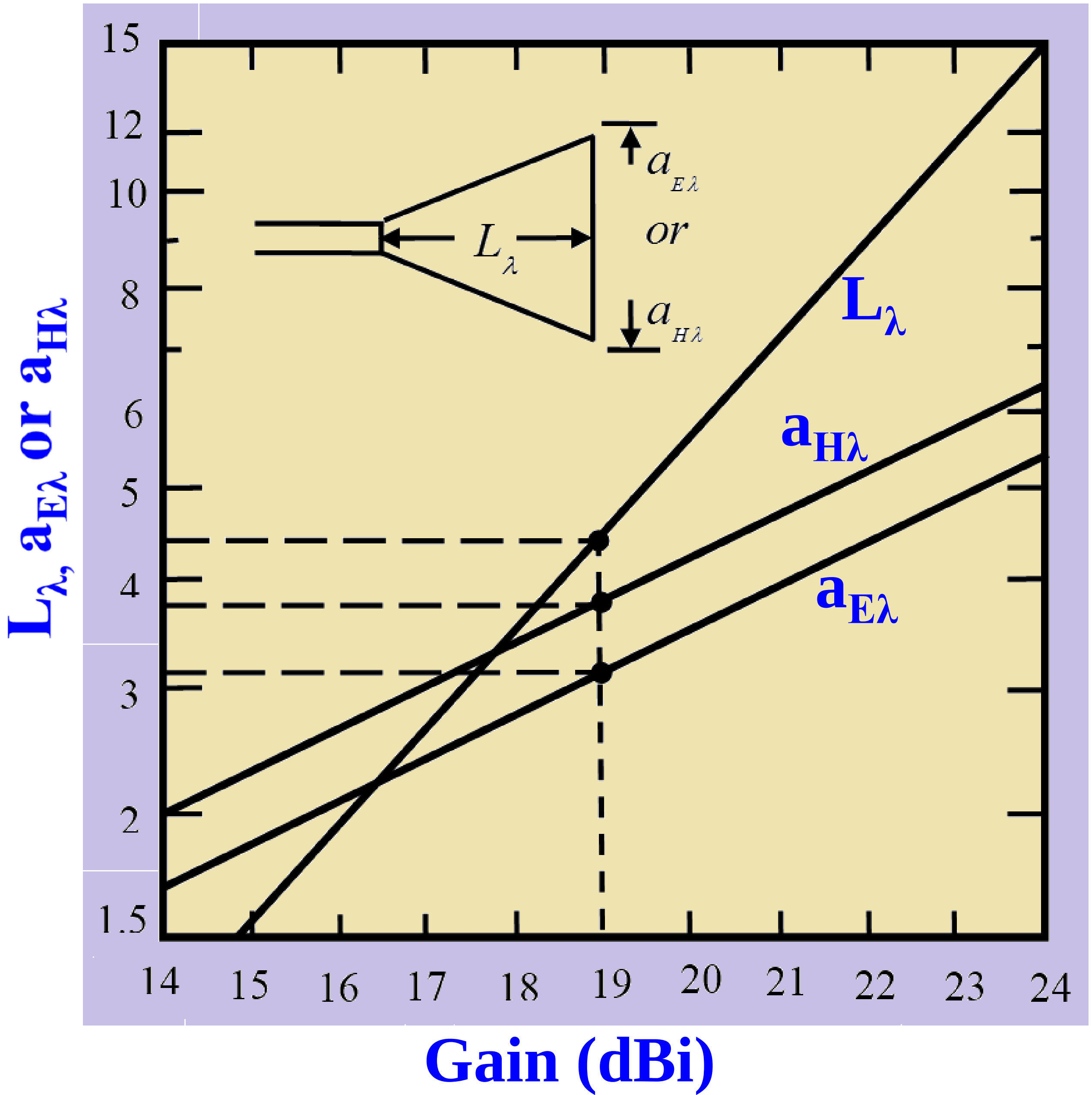
4. $$p_e = (b_1 - b)\left[\left(\frac{p_e}{b_1}\right)^2 - \frac{1}{4}\right]^{1/2} = 10.005\lambda$$

$$= 27.286\ cm = 10.743\ in.$$

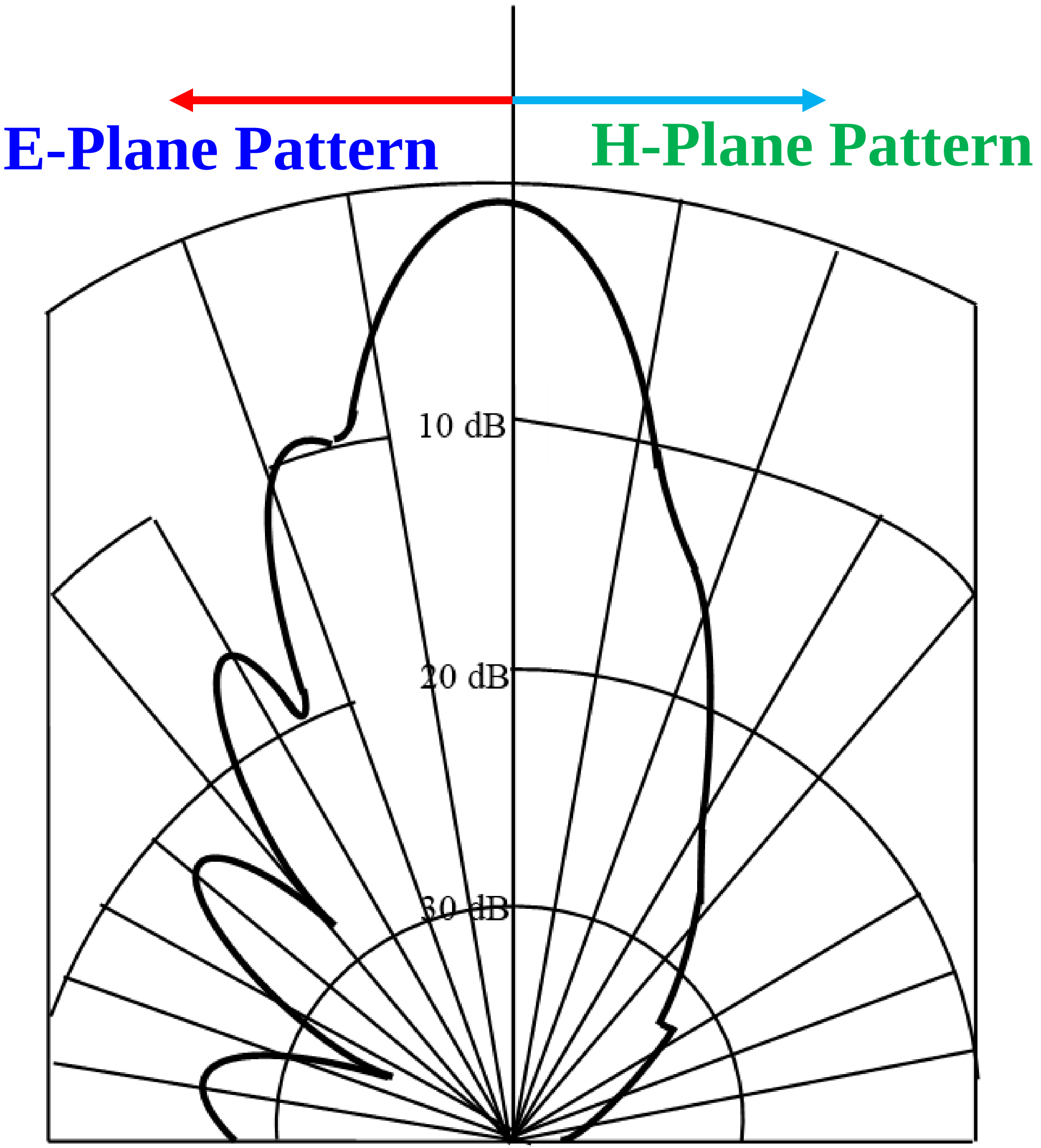
$$p_h = (a_1 - a)\left[\left(\frac{p_h}{a_1}\right)^2 - \frac{1}{4}\right]^{1/2} = 10.005\lambda$$

$$= 27.286\ cm = 10.743\ in.$$

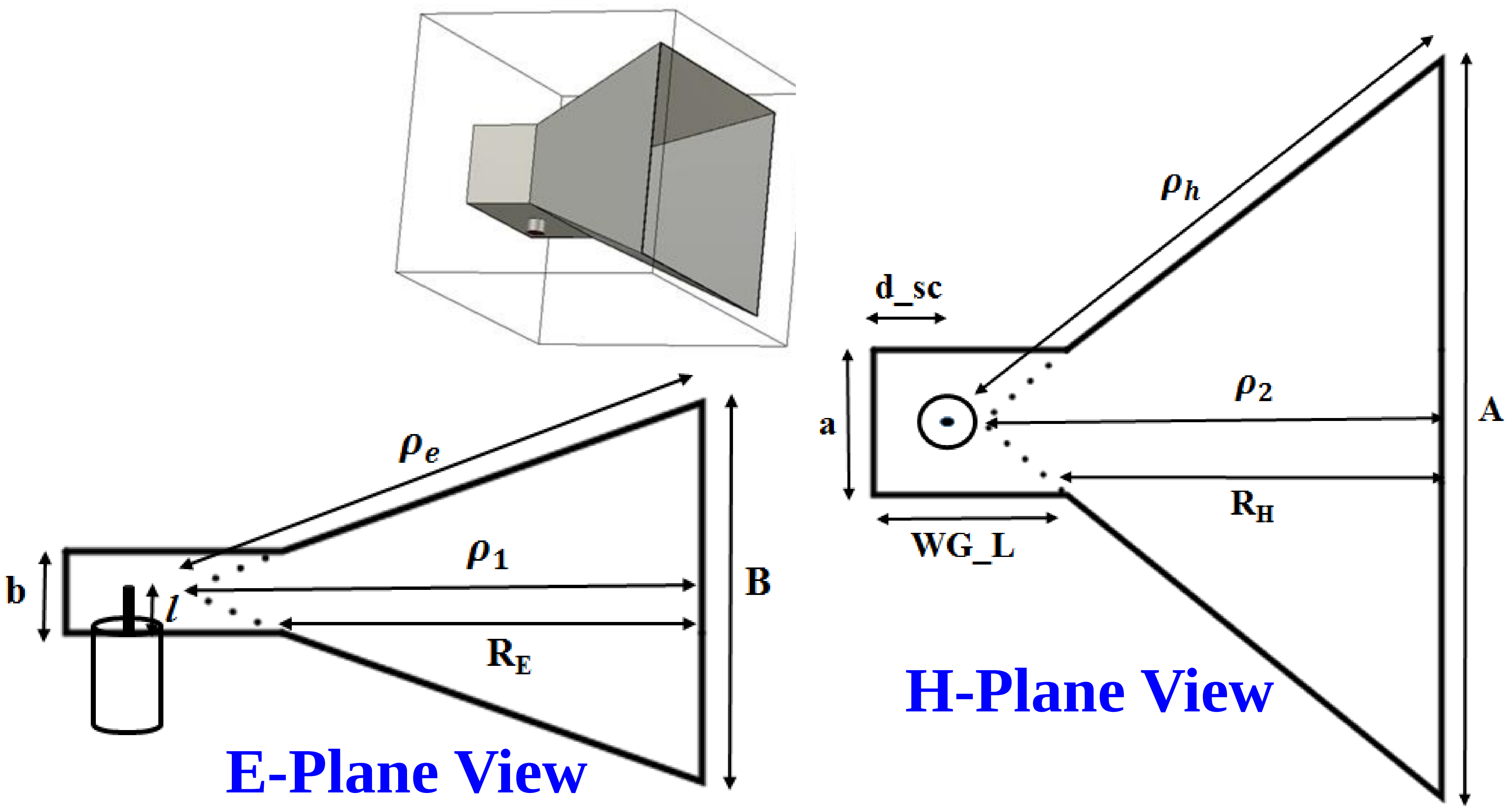
Optimum Dimensions vs. Directivity



Radiation Pattern of Pyramidal Horn Antenna



Coaxial Feed Pyramidal Horn Antenna

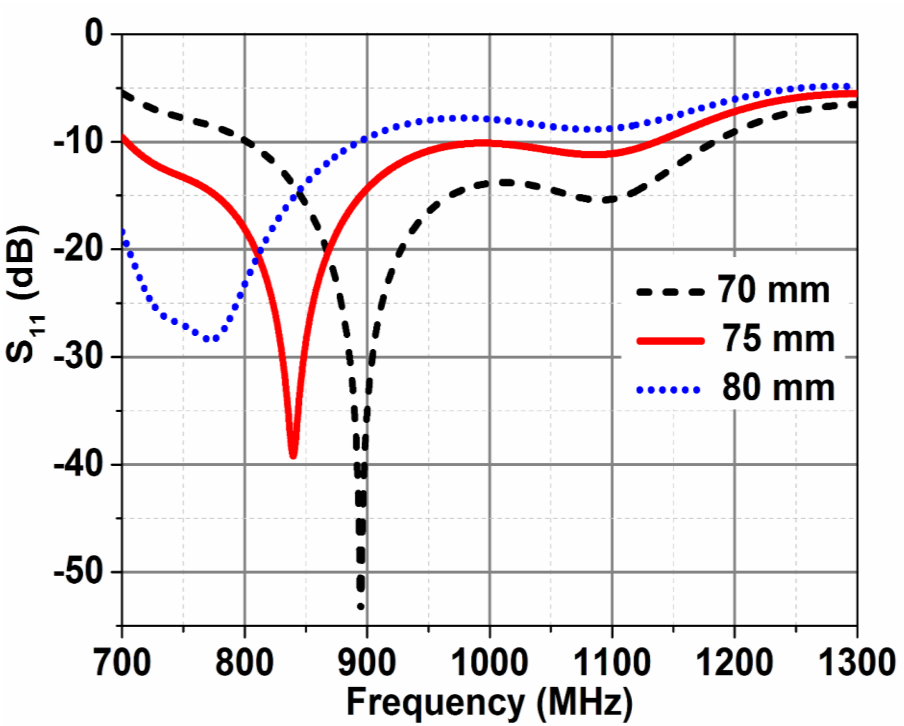


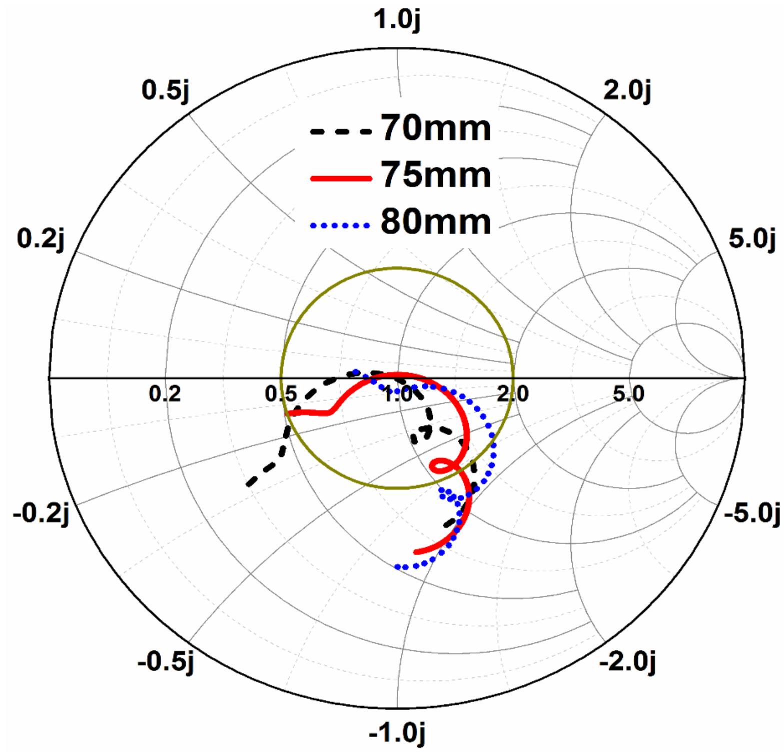
Reference: Hemant Kumar and Girish Kumar, "**Design and Parametric Analysis of Pyramidal Horn Antenna with High Efficiency**", Proceedings of International Symposium on Microwave and Optical Technology (ISMOT) 2015, pp. 134-137.

Coaxial Feed Pyramidal Horn Antenna Designed at 900 MHz

Parameter	**Value (mm)**	**Description**
A	450	Aperture Width
B	320	Aperture Height
a	240	Waveguide Width
b	120	Waveguide Height
WG_L	110	Waveguide Length
$R_E = R_H$	250	Horn Length
l	75	Probe Length
r	3.5	Probe Radius
d_sc	67.5	Distance of feed from short

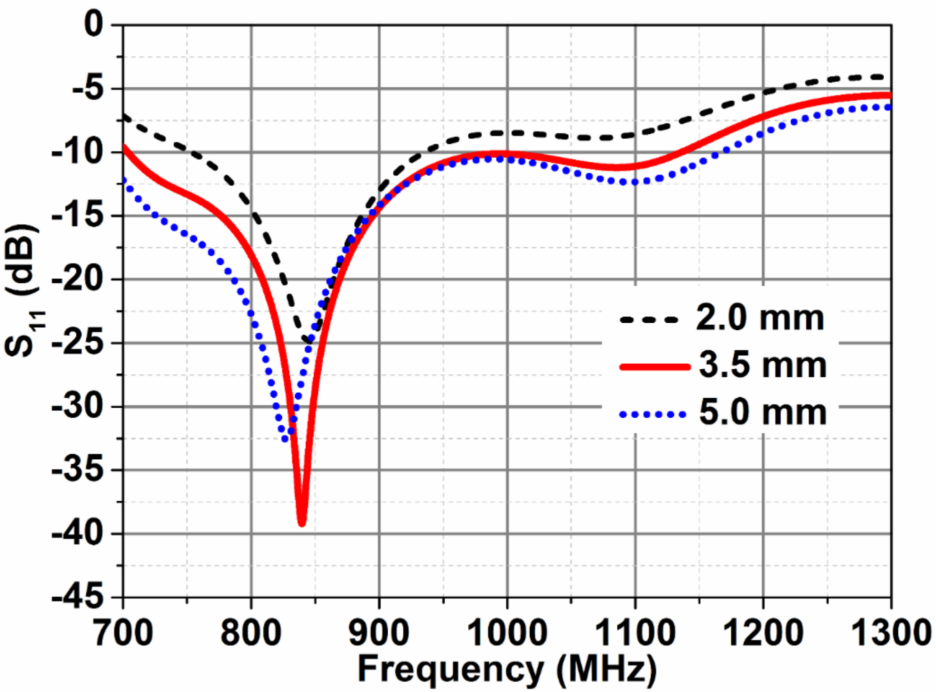
Effect of Probe Feed Length

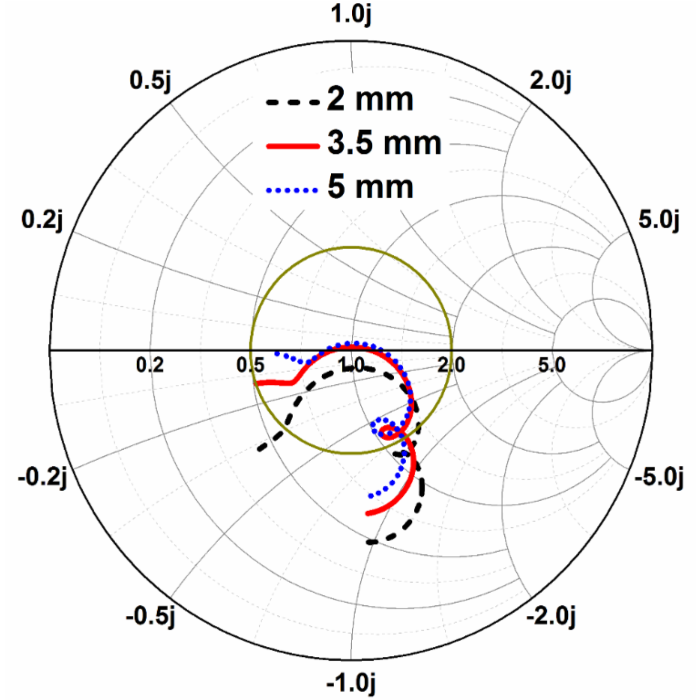




As the probe length increases from 70 to 80 mm, the resonance frequency decreases from 895 to 790 MHz and the input impedance curve rotates clockwise.

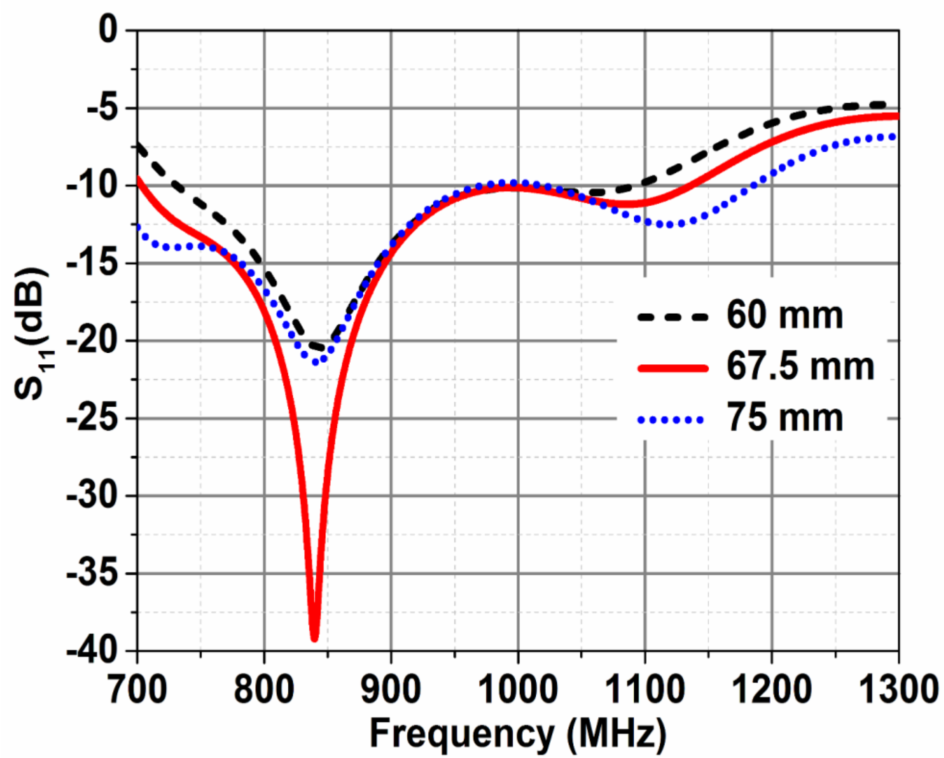
Effect of Probe Feed Radius

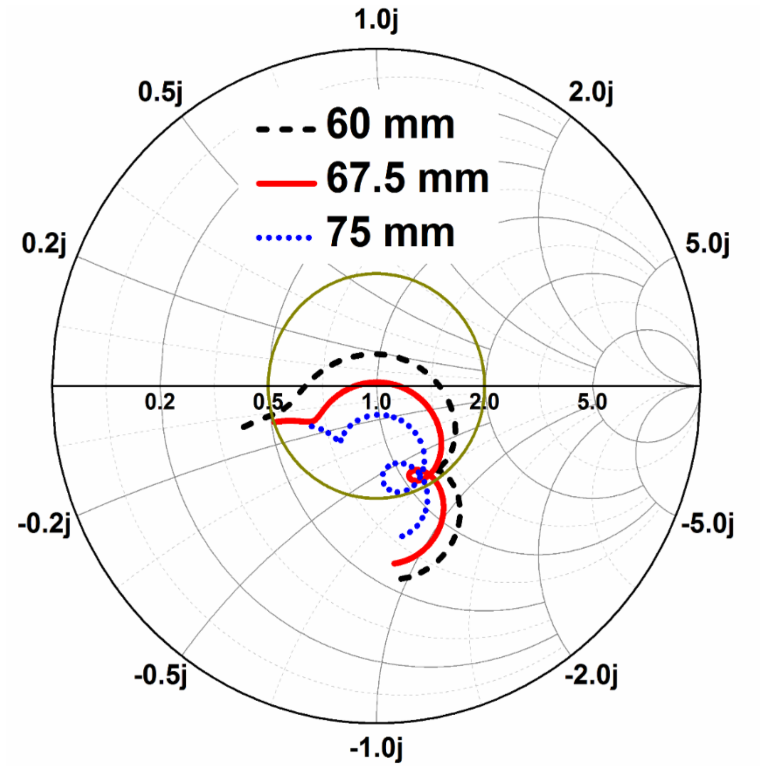




As the probe radius increases from 2 to 5mm, the resonance frequency decreases slightly due to increase in the fringing fields and bandwidth increases.

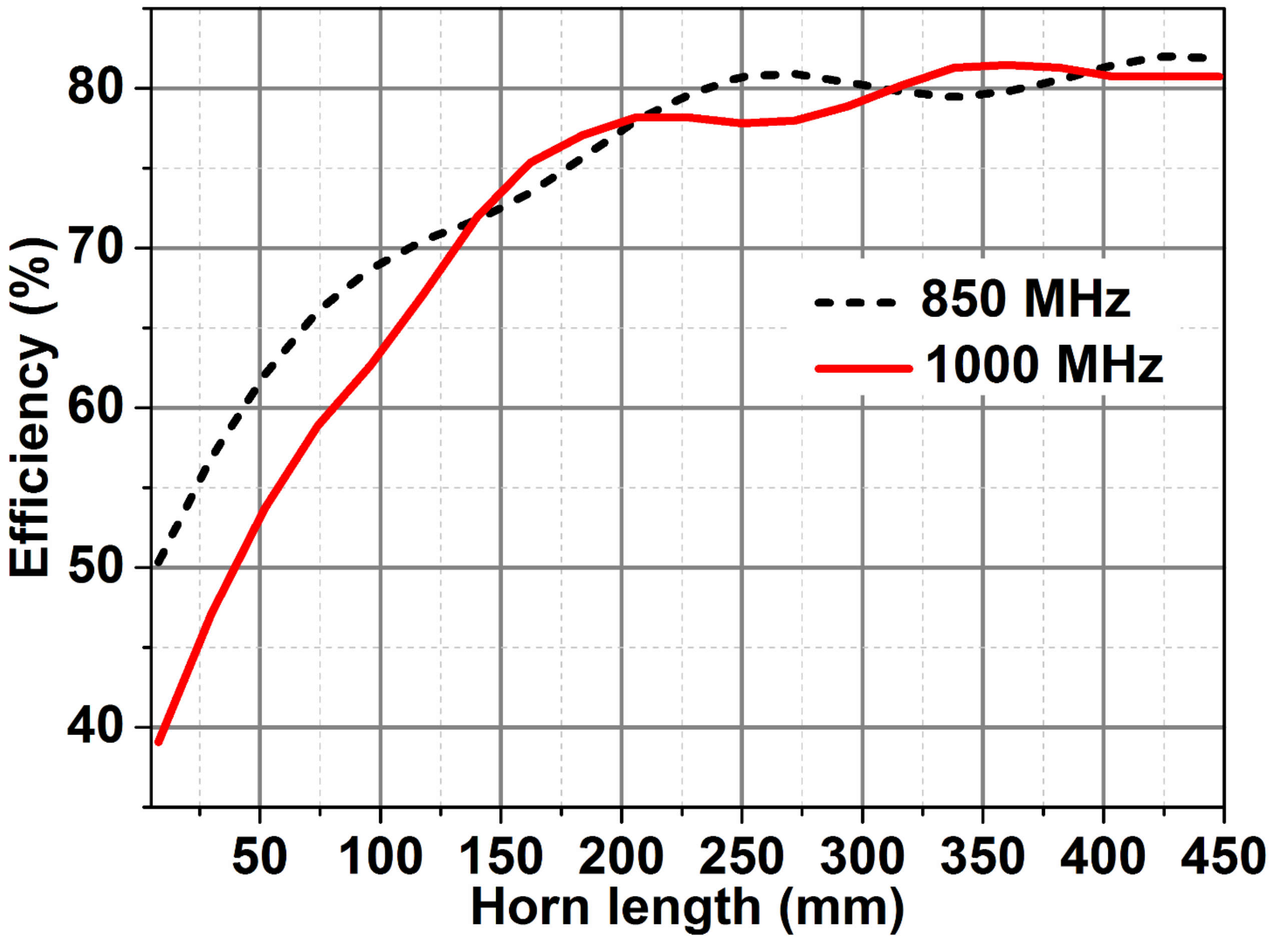
Effect of Probe Feed Location





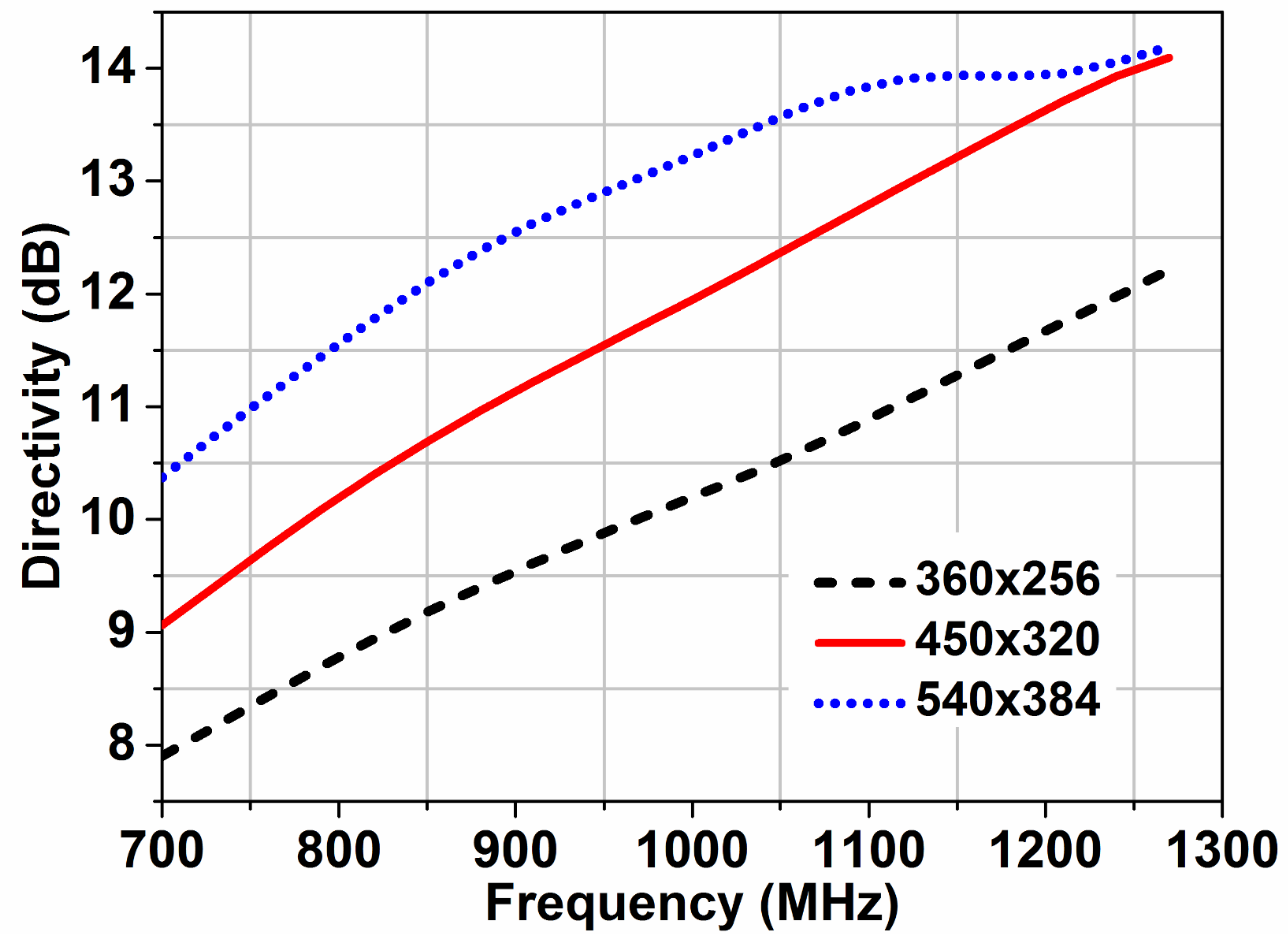
As the probe feed location is moved towards shorting wall (i.e., decreased from 75 to 60 mm), the input impedance becomes inductive so the curve shifts upward.

Effect of Horn Length on Efficiency



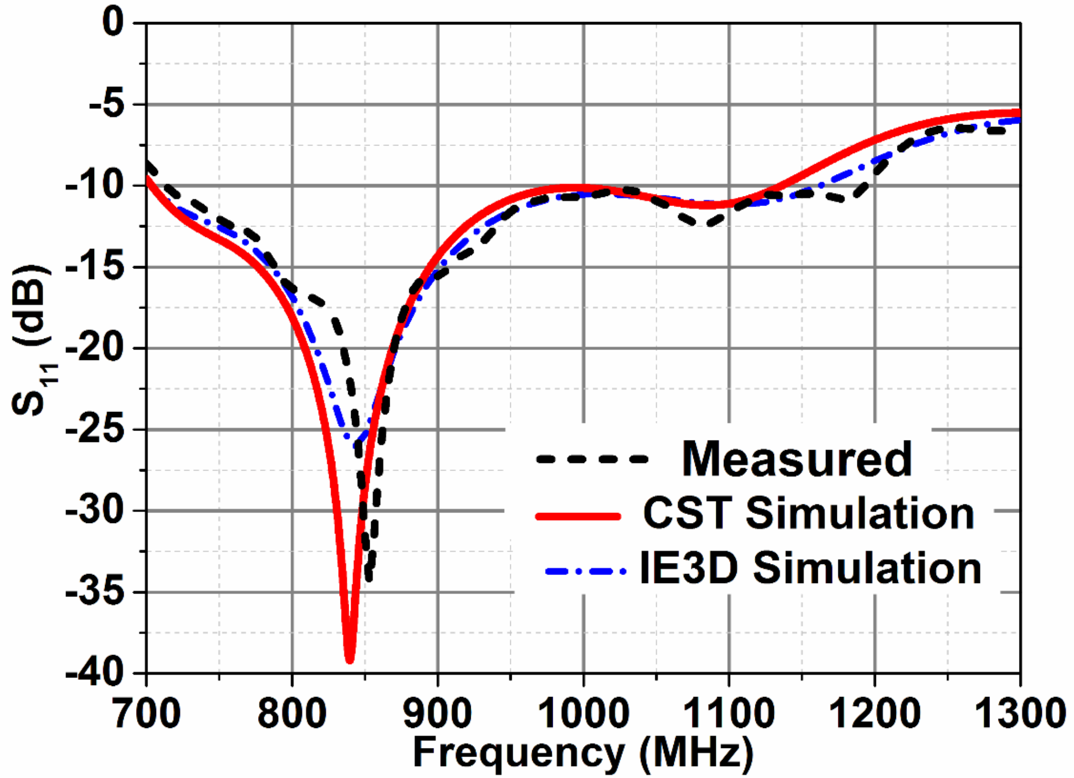
For Horn Length $R_E = R_H > 150$ mm, efficiency $\geq 72\%$
and for $R_E = R_H > 250$ mm, efficiency $\approx 80\%$

Effect of Horn Aperture on Directivity



As aperture area increases, directivity increases. But for larger aperture as frequency increases, phase error increases, which decreases the gain of the horn antenna.

Simulated and Measured S_{11} of Coaxial Feed Pyramidal Horn Antenna



Bandwidth for S11 < -10dB :

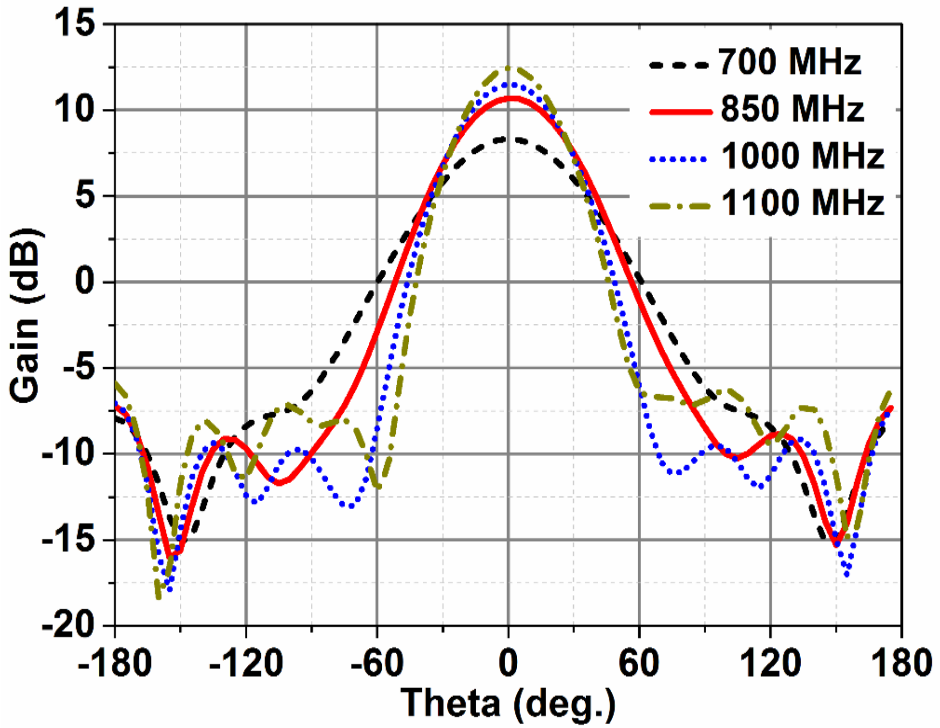
CST Simulation : 47%

IE3D Simulation : 49.5%

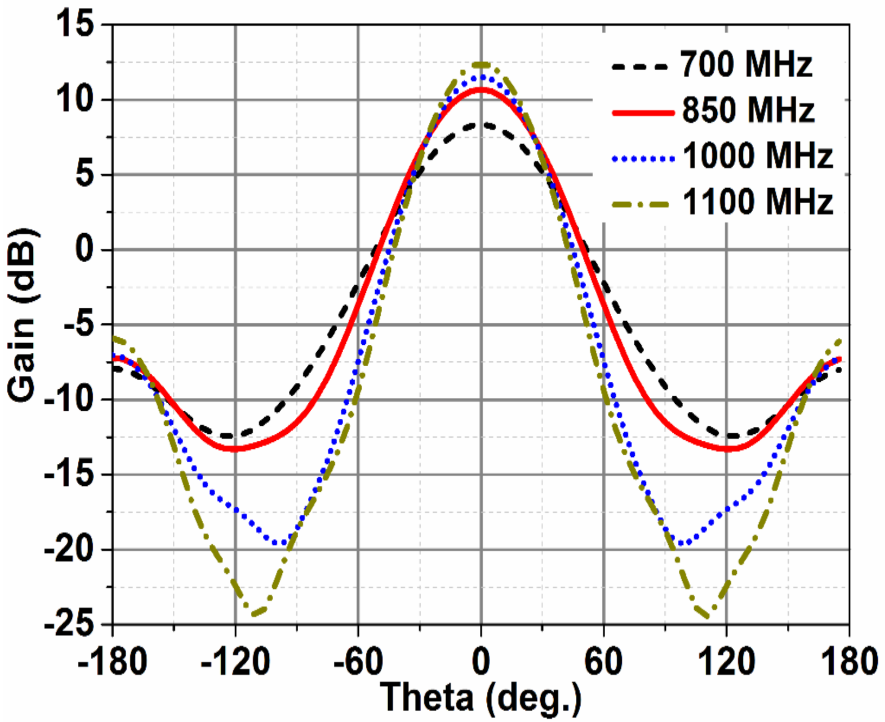
Measured Results : 52%

Simulated Radiation Pattern of Coaxial Feed Pyramidal Horn Antenna

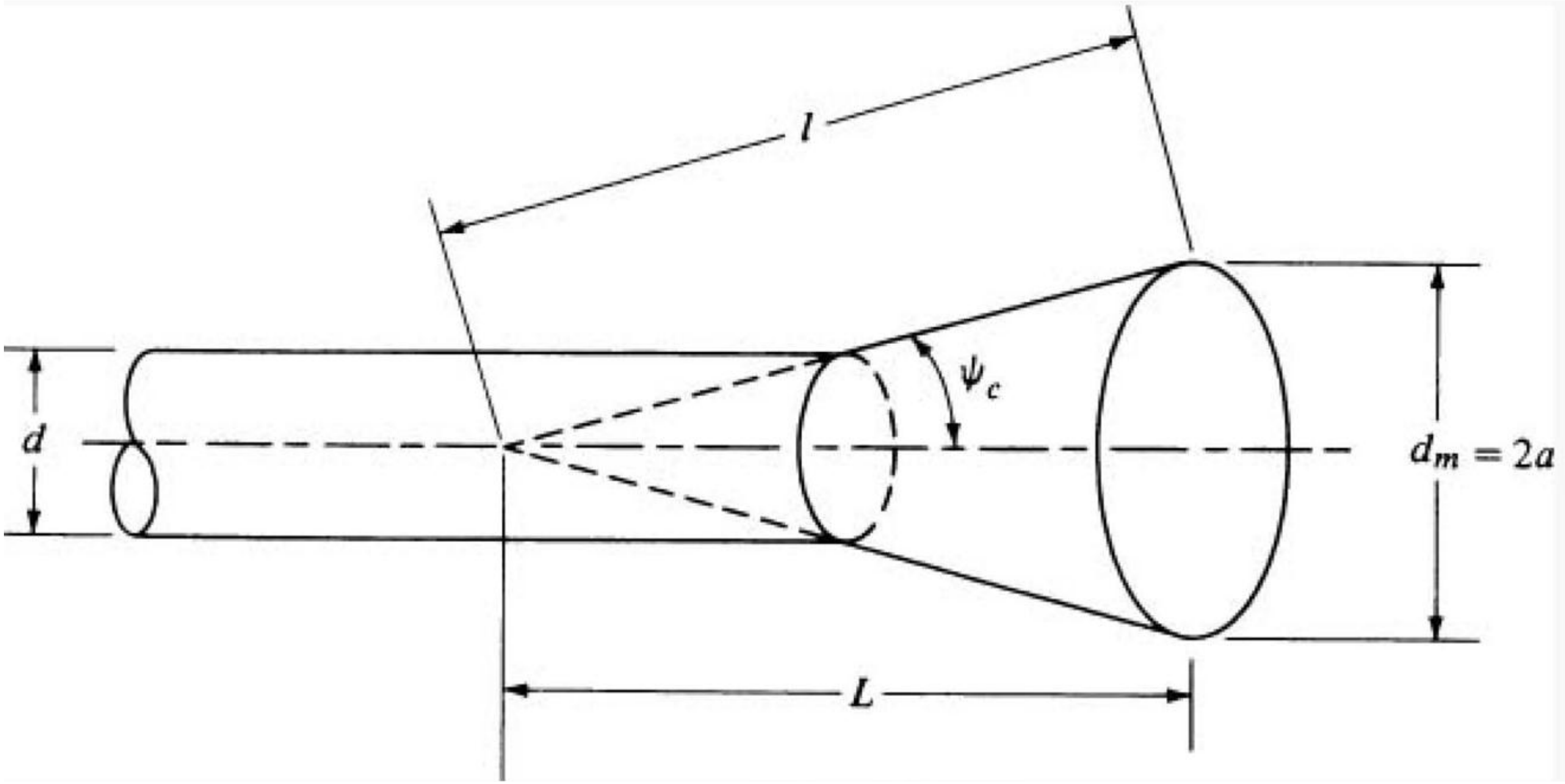
Simulated E-Plane Radiation Pattern



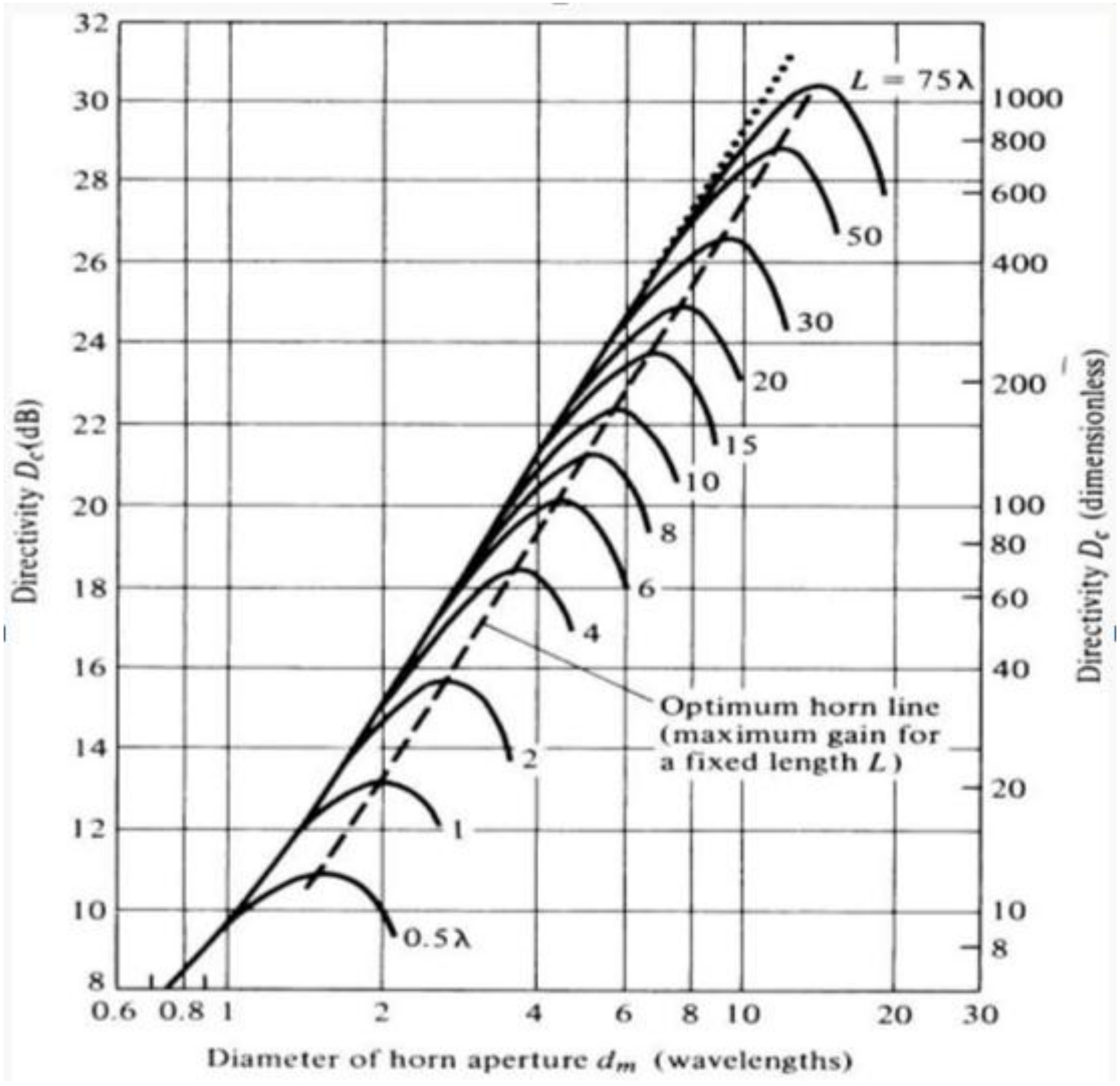
Simulated H-Plane Radiation Pattern



Conical Horn Antenna



Conical Horn: Directivity Curve



Conical Horn Antenna: Directivity

$$s = \frac{d_m^2}{8\lambda l} = \text{maximum phase deviation (in } \lambda)$$

The gain of conical horn is optimum when:

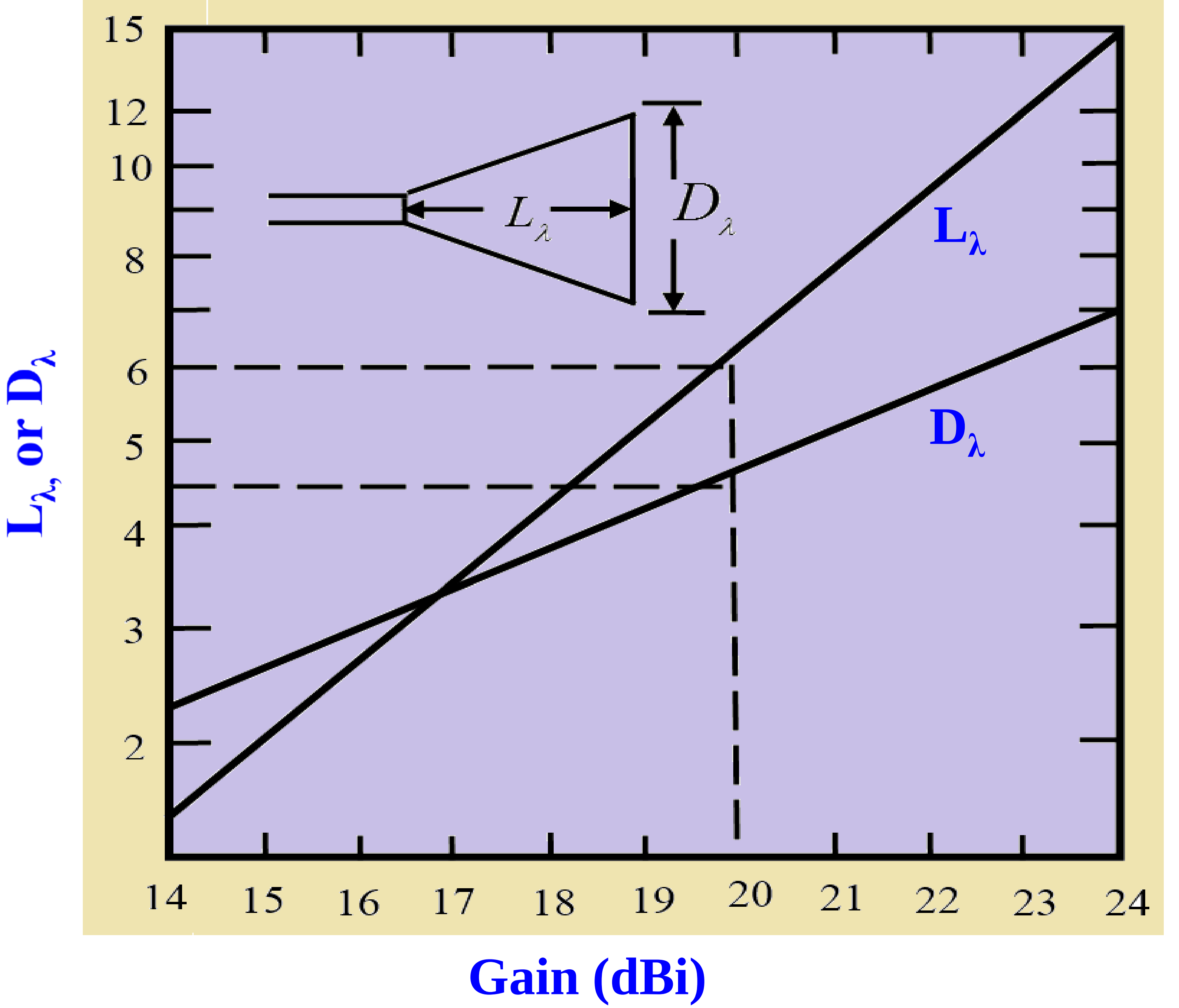
$$d_m \simeq \sqrt{3\lambda l}$$

Thus

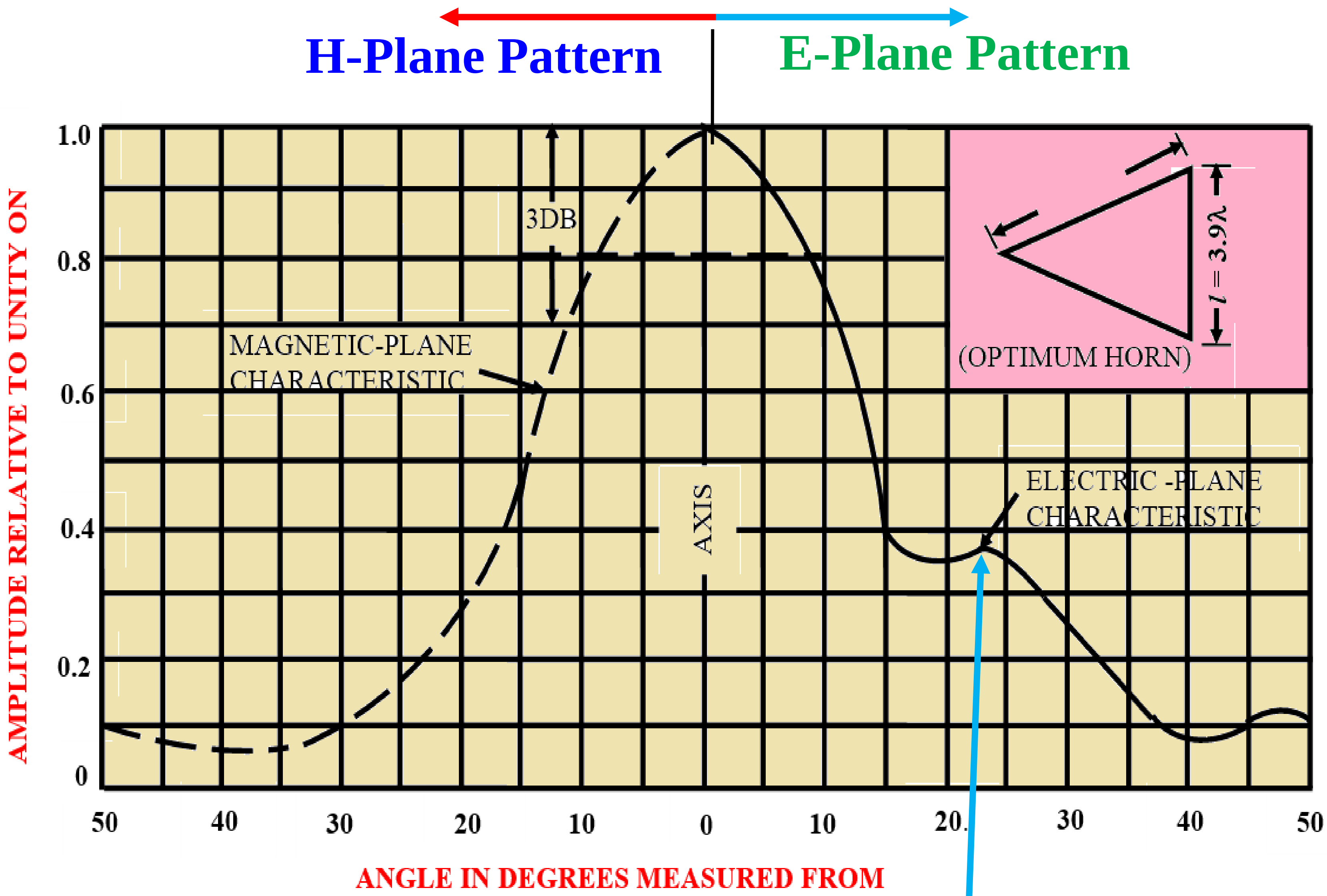
$$s\Big|_{\substack{\text{optimum}\\ \text{gain}}} = \frac{d_m^{\ 2}}{8l\lambda}\Big|_{d_m=\sqrt{3\lambda l}} = \frac{3\lambda l}{8\lambda l} = \frac{3}{8} \Rightarrow \delta_{max} = 135°$$

Phase Error too high:
Not Recommended

Conical Horn Optimum Dimensions vs. Directivity

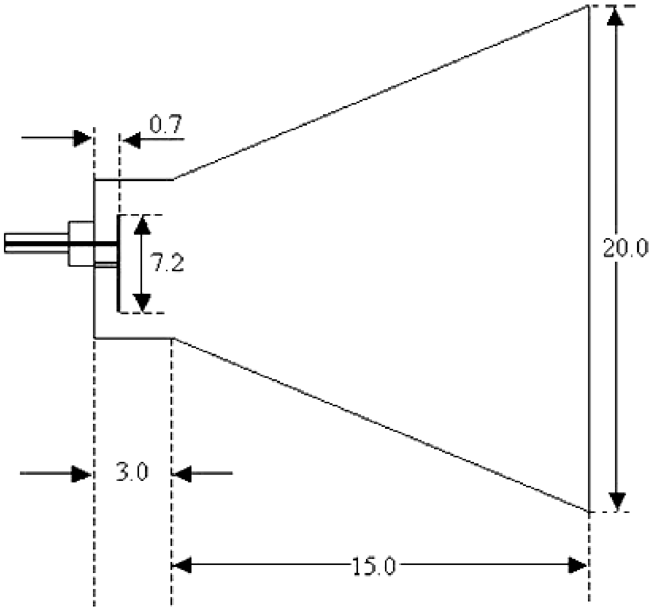


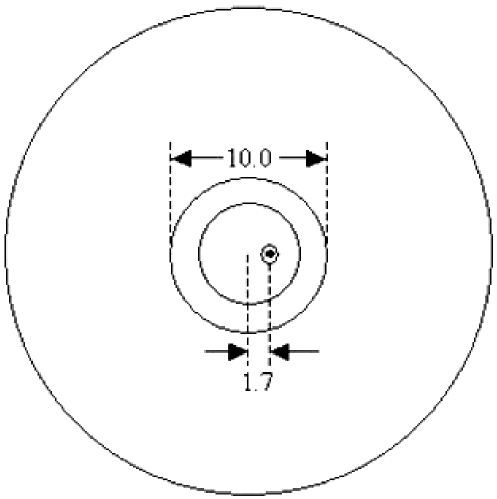
Measured Pattern of Conical Horn

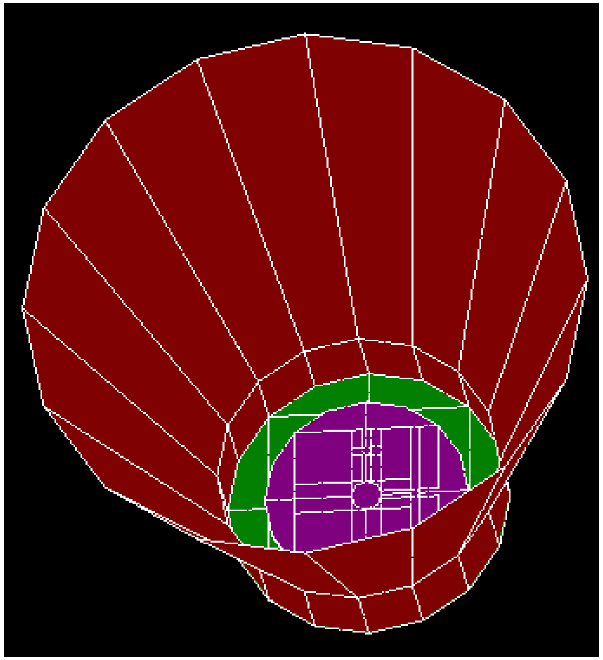


20 Log 0.37 = -8.6 dB. Higher SLL due to large phase error.

MSA Integrated with Conical Horn

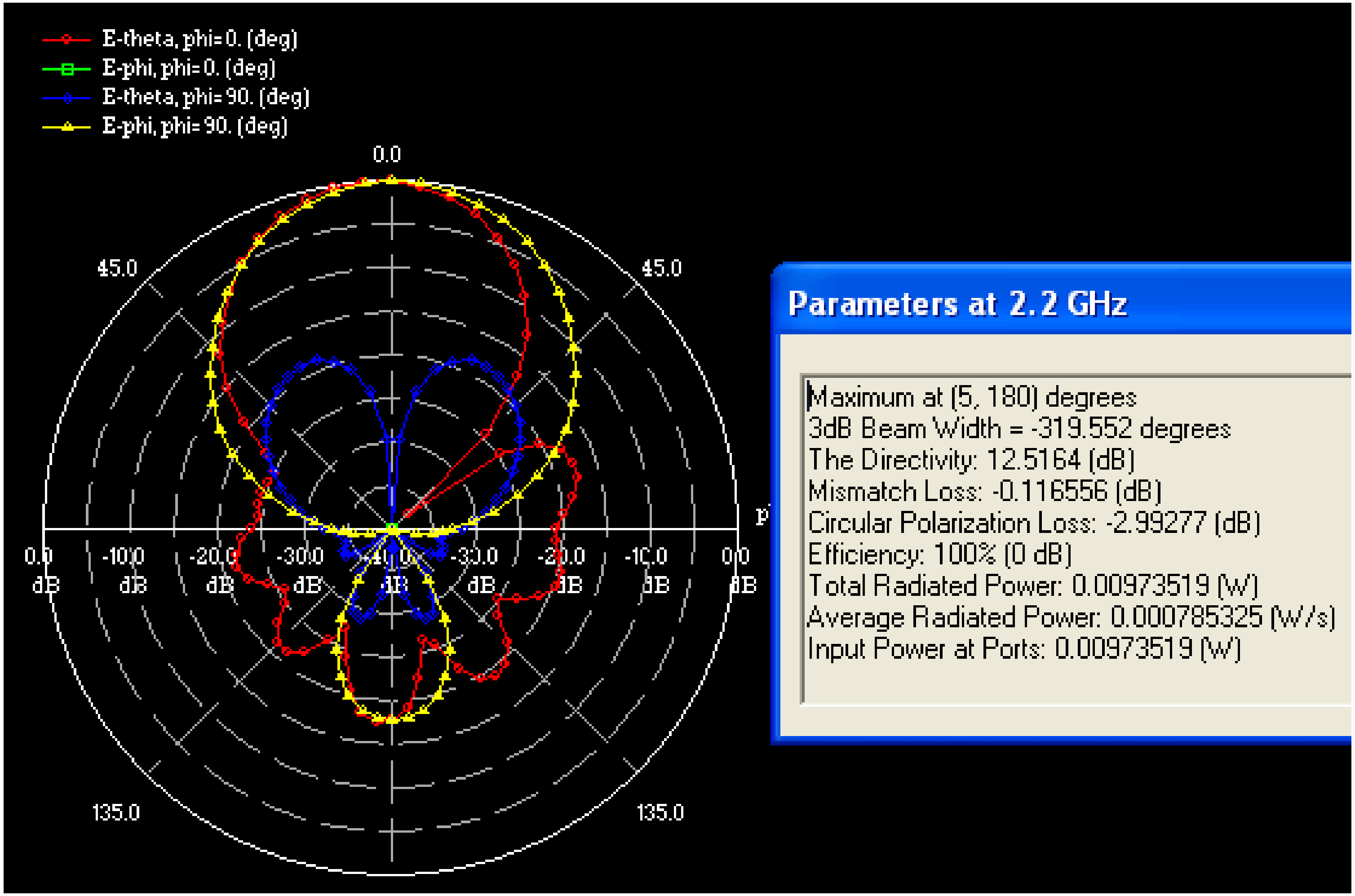






Suspended CMSA integrated inside a Conical Horn Antenna. Simulation using IE3D software.

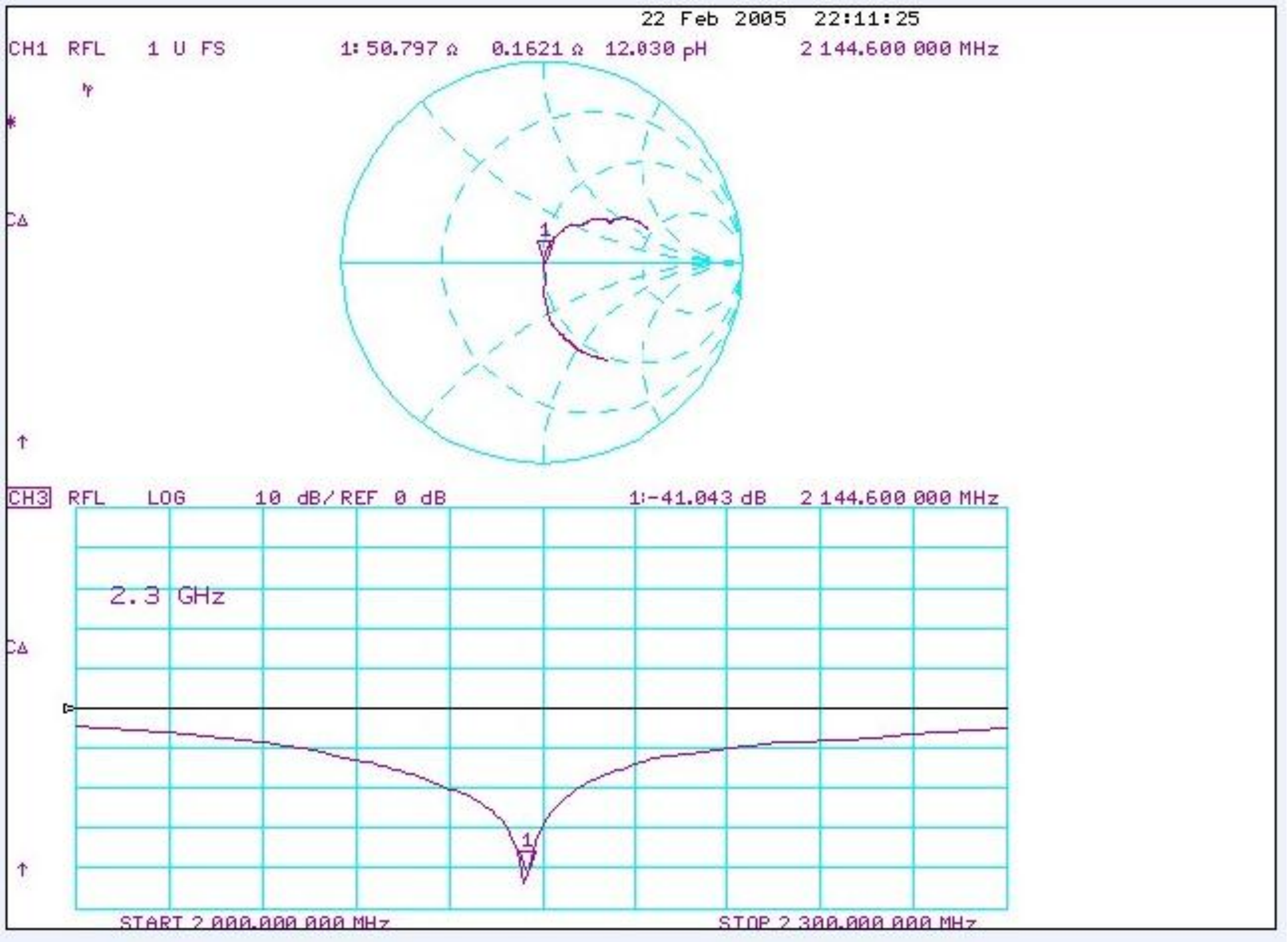
Radiation Pattern of Integrated Conical Horn



Gain of Suspended CMSA = 9 dB

Gain of Integrated Conical Horn Antenna = 12.5 dB

Measured Results of Integrated Conical Horn



Measured BW for |S11| ≤ -10 dB is from 2070 to 2210 MHz