Antenna Fundamentals

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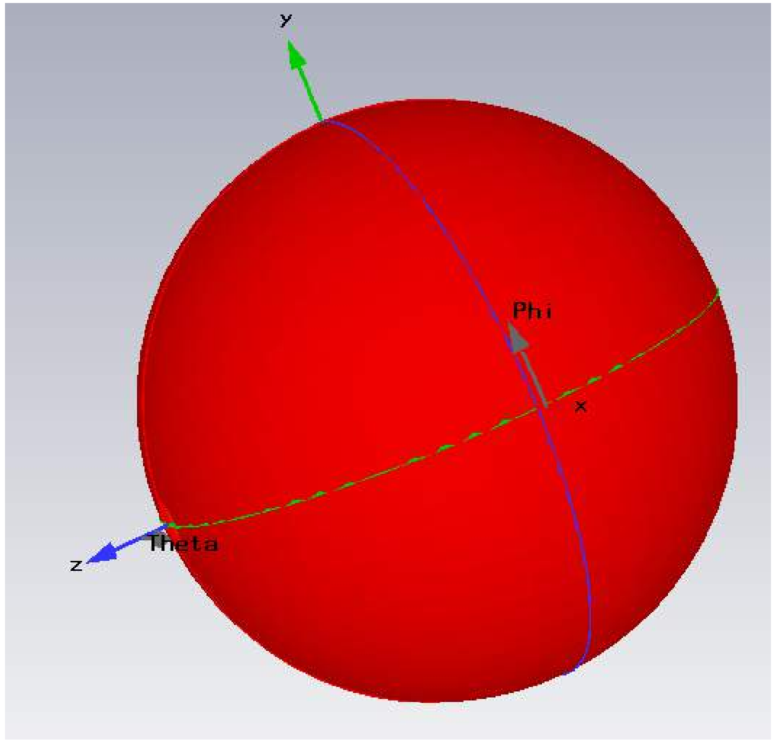
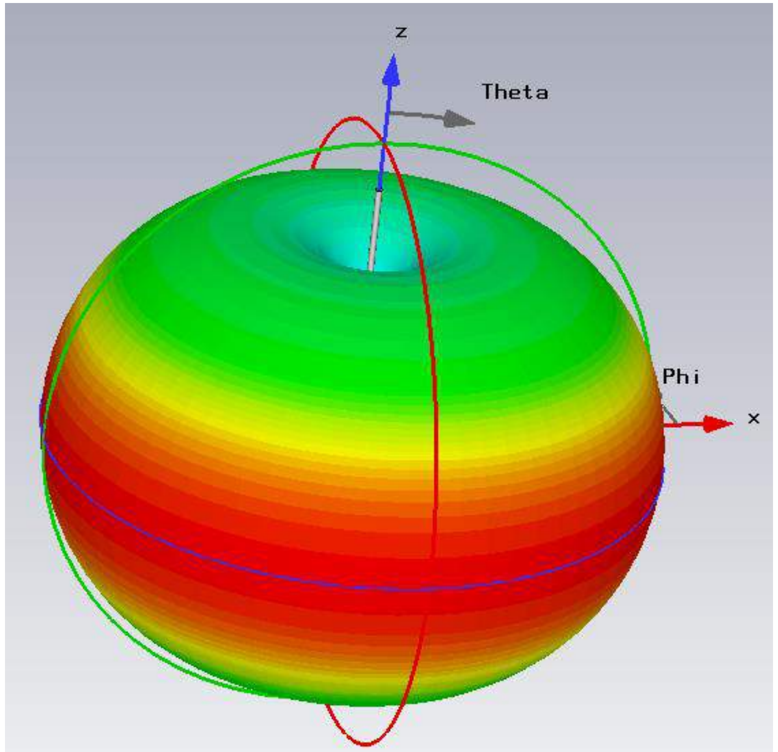
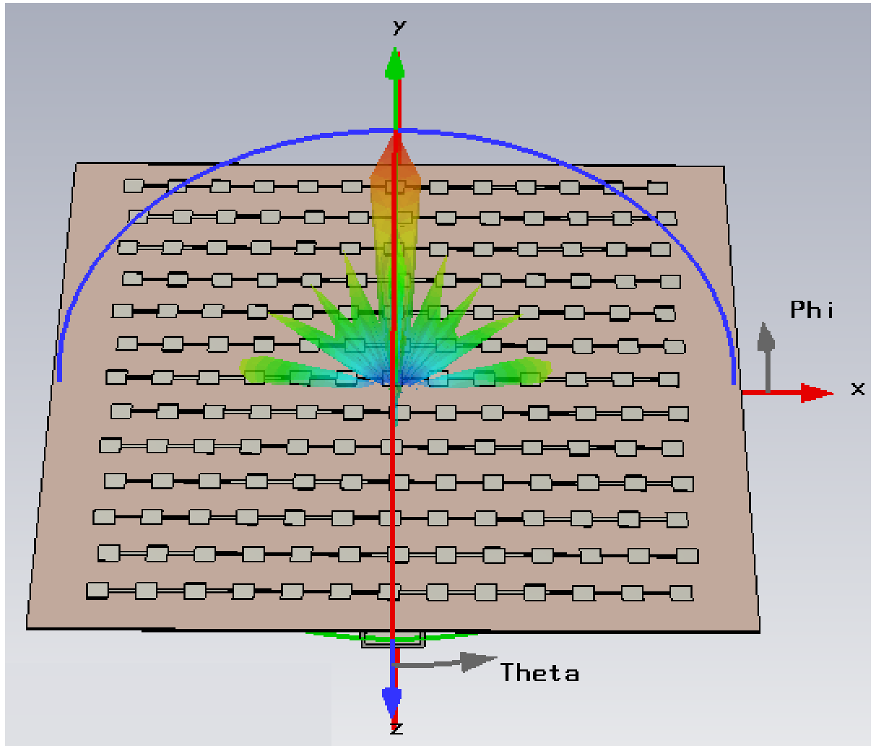
3-D Radiation Pattern of Antenna



Isotropic Radiation Pattern
D = 1 = 0dB

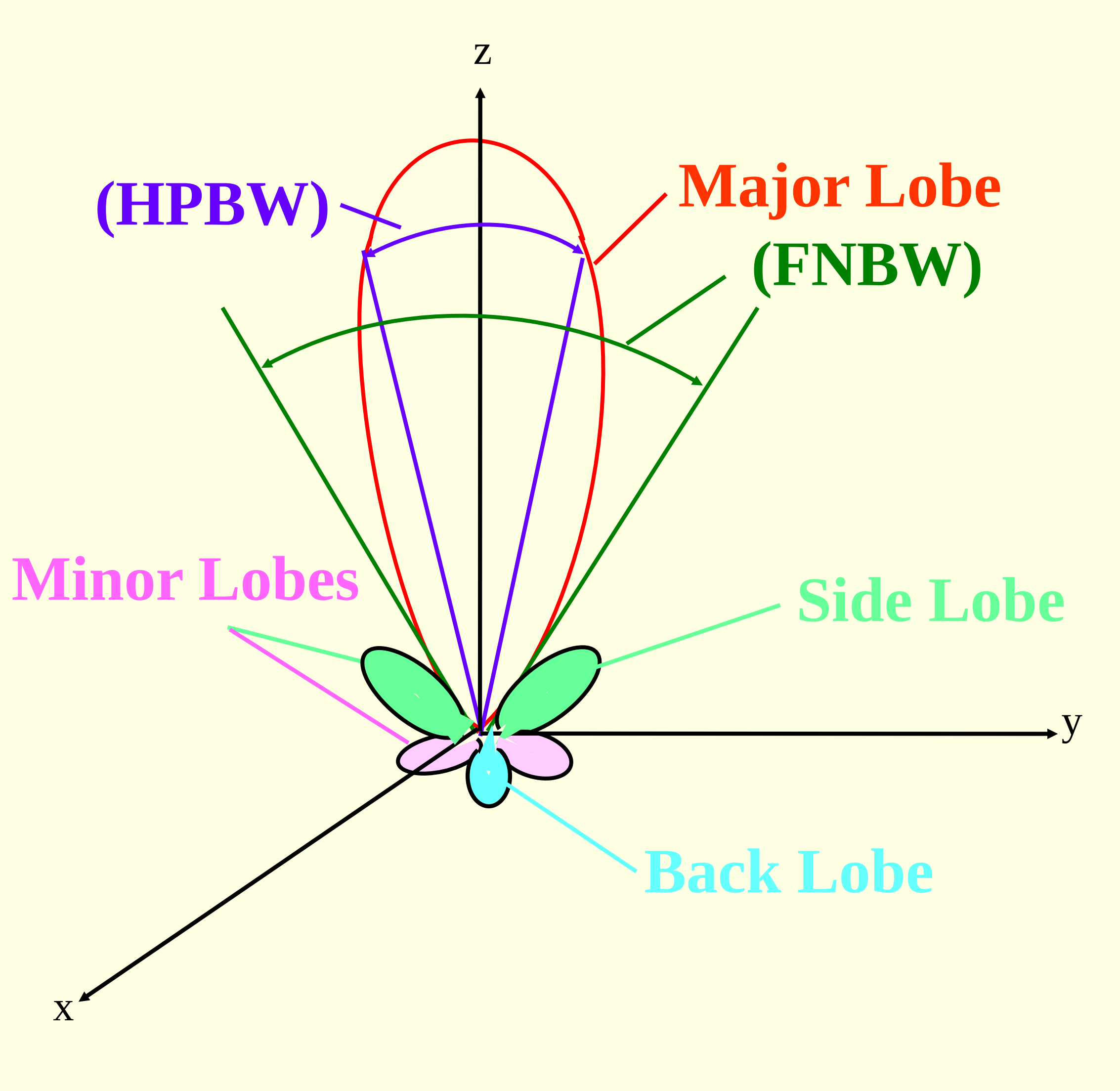


Omni-Directional Radiation Pattern of λ/2 Dipole Antenna
D = 1.64 = 2.1dB



Directional Radiation Pattern of Microstrip Antenna Array
D = 500 = 27dB

2-D Radiation Pattern of Antenna



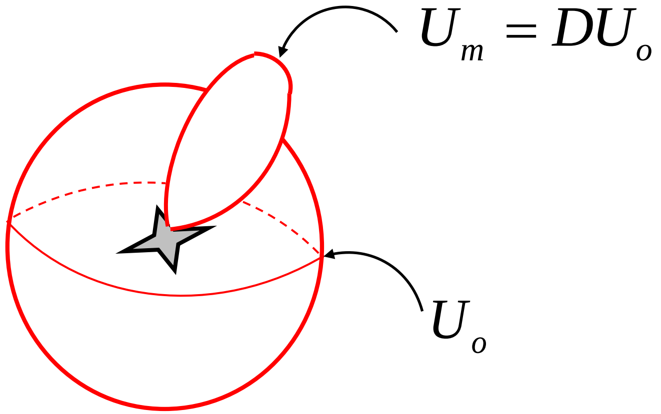
Beamwidth between first nulls (FNBW) ~ 2.25 x HPBW (Half Power Beamwidth)

Side Lobe Level (SLL) ≤ 20 dB for satellite and high power applications

Front to Back Ratio (F/B) ≥ 20 dB

Directivity of Antenna

Directivity of an antenna is the ratio of radiation density in the direction of maximum radiation to the radiation density averaged over all the directions.



$$D = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} = \frac{U_{max}}{U_0}$$

$$D = \frac{U_{max}}{\frac{P_{rad}}{4\pi}} = \frac{4\pi\, U_{max}}{P_{rad}} = \frac{4\pi\, U_{max}}{U_{max}\, \Omega_A} = \frac{4\pi}{\Omega_A}$$

[where, Ω_A is beam solid angle]

$$\Omega_A = \frac{1}{F(\theta,\phi)|_{max}} \int_0^{2\pi} \int_0^{\pi} F(\theta,\phi) \sin\theta\, d\theta\, d\phi$$

where, $F(\theta,\phi) \simeq \left[|E_\theta^o(\theta,\phi)|^2 + |E_\phi^o(\theta,\phi)|^2\right]$

$$D \simeq \frac{4\pi}{\theta_E \theta_H}$$

[where, θ_E, θ_H are in radian]

Example: For Infinitesimal Dipole

$$\theta_E = \pi/2,\ \theta_H = 2\pi \quad \rightarrow D = \frac{4\pi}{\theta_E \theta_H} = \frac{4\pi}{\frac{\pi}{2} x 2\pi} \simeq 1.3 \neq 1.5$$

Directivity and Gain of Antenna

Directivity of Large Antenna

$$D = \frac{32400}{\theta_E \theta_H}$$

where, θ_E, θ_H are in degree

$$D = \frac{4\pi A_{eff}}{\lambda^2}$$

Directivity is proportional to the Effective Aperture Area of Antenna

Directivity of Small Antenna

$$D = \frac{41253}{\theta_E \theta_H}$$

$$\text{Gain} = \eta D$$

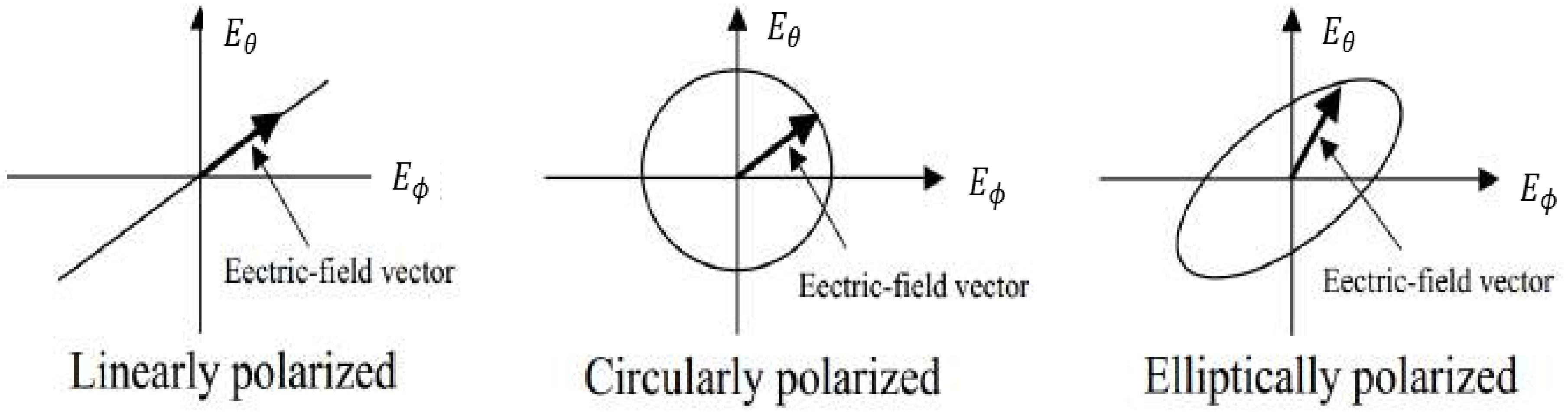
where η is Efficiency of Antenna

Practice Problem: Find the gain in dB of a parabolic reflector antenna at 15 GHz having diameter of 1m. Assume efficiency is 0.6. What will be its gain at 36 GHz?

Hint: Aperture Area of parabolic reflector antenna = πr^2

Polarization of Antenna

Orientation of radiated electric field vector in the main beam of the antenna



$$E = a_\theta E_\theta \cos\omega t + a_\phi E_\phi \cos(\omega t + \alpha)$$

$Case\ 1:\ \alpha = 0\ or\ \pi$ — Wave is Linearly Polarized

$Case\ 2:\ \alpha = \pm\pi/2\ and\ E_\theta = E_\phi$ — Wave is Circularly Polarized

$Case\ 3:\ \alpha = \pm\pi/2\ and\ E_\theta \neq E_\phi$ — Wave is Elliptically Polarized

Axial Ratio of Antenna

$$\text{Axial Ratio(AR)} = \frac{\text{Major Axis of Polarization}}{\text{Minor Axis of Polarization}}$$

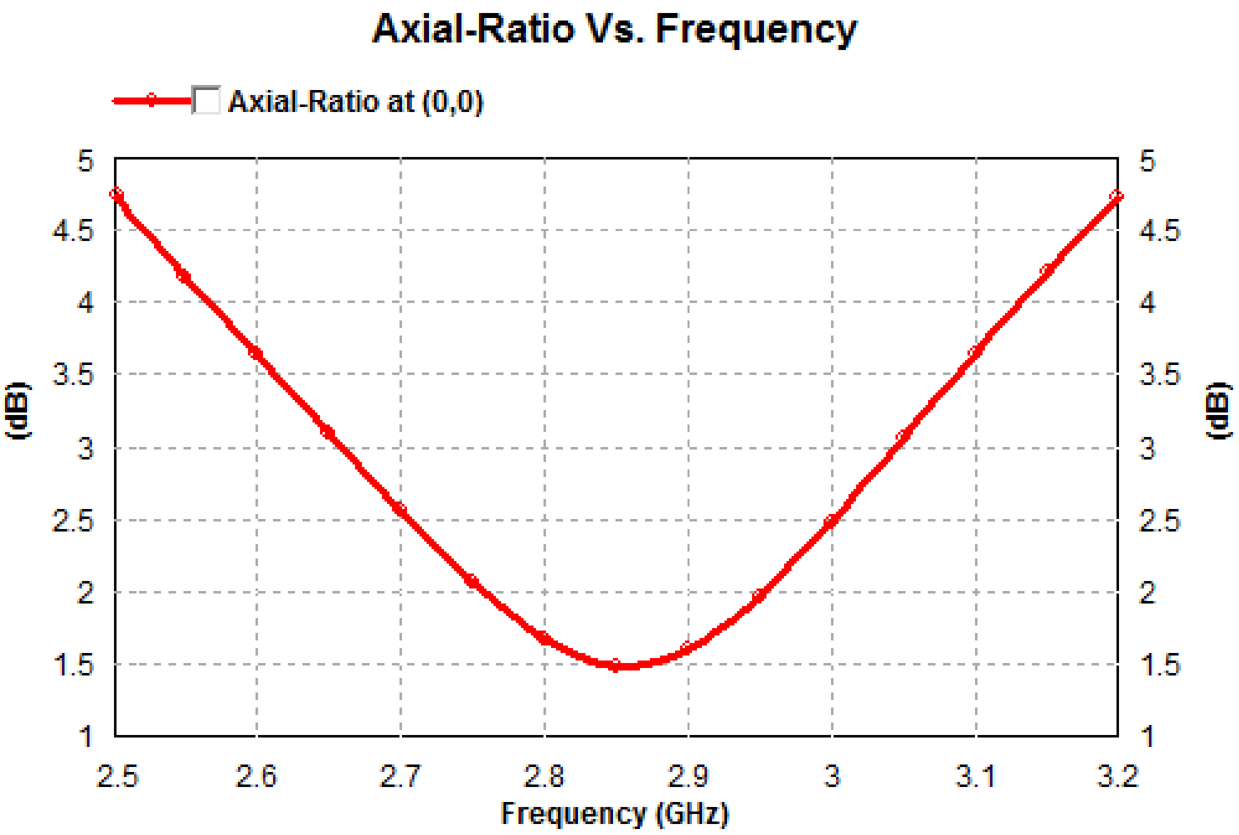
$AR = 1$, circular polarization

$1<AR<\infty$, elliptical polarization

$AR = \infty$, linear polarization

Axial Ratio Bandwidth:

Frequency range over which $AR \leq 3$ dB



Axial Ratio Plot of Circularly Polarized MSA

Bandwidth for $AR \leq 3$dB = 380MHz (13%)

Input Impedance and VSWR of Antenna

Input Impedance

$$Z_A = R_A + jX_A$$

R_A represents power loss from the antenna and X_A gives the power stored in the near field of the antenna

$$R_A = R_r + R_L$$

$$e_r = \frac{R_r}{R_A} = \frac{R_r}{R_r + R_L}$$

→ Radiation Efficiency

Reflection Coefficient and VSWR

$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0}$$

$$\text{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Practice Problem:

Calculate Reflection Coefficient and VSWR for impedance Z_A = 10, 30, 50,100Ω

Input Impedance Plot on Smith Chart

Example: If antenna impedance Z_A= (20+j30)Ω, calculate Γ and VSWR.

$$Z_A = 20\Omega + j30\Omega,\ Z_0 = 50\Omega$$

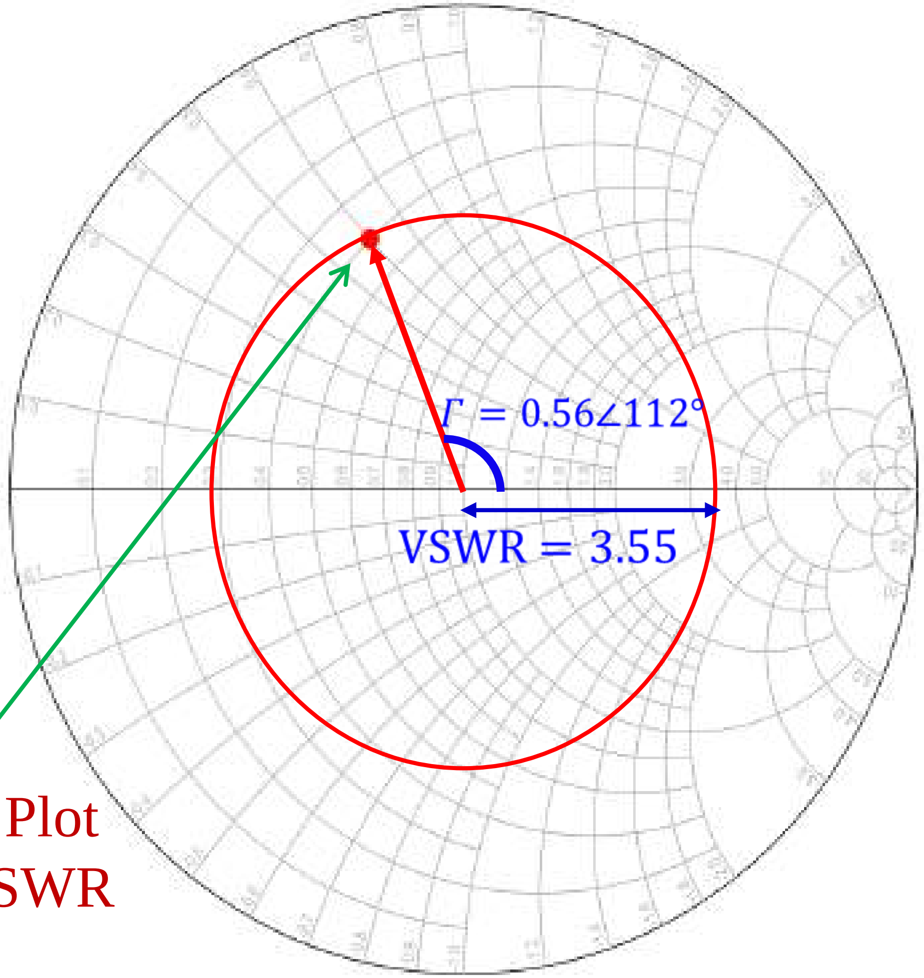
$$Z_{A_{norm}} = \frac{Z_A}{Z_0} = \frac{20 + j30}{50} = 0.4 + j0.6$$

$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0}$$

$$\Gamma = \frac{20 + j30 - 50}{20 + j30 + 50} \simeq -0.2 + 0.52\text{j} = 0.56\angle 112°$$

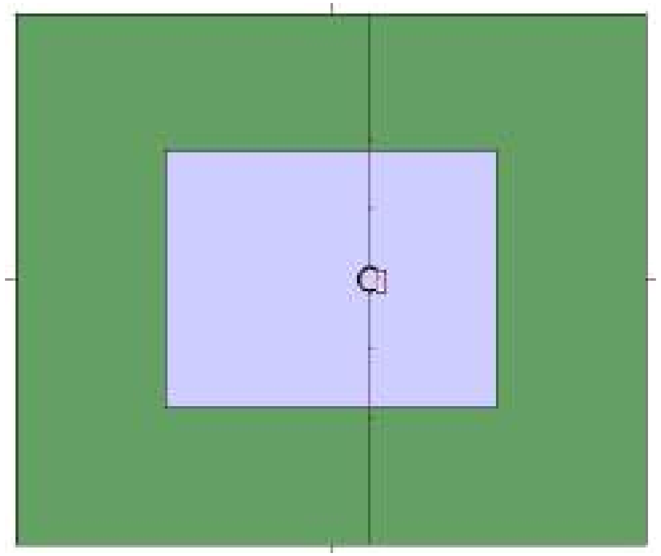
$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$\text{VSWR} = \frac{1+0.56}{1-0.56} \simeq 3.55$$

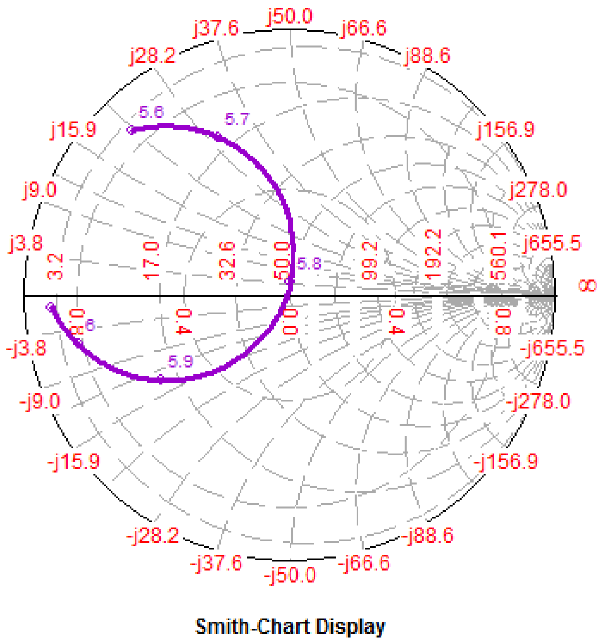


Normalized Input Impedance Plot on Smith Chart gives Γ and VSWR

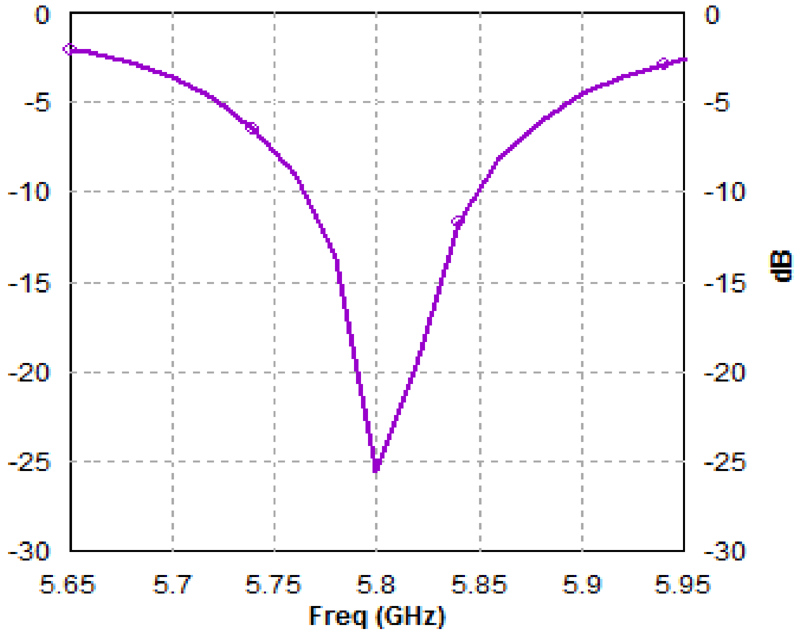
Microstrip Antenna at 5.8 GHz



MSA Design at 5.8GHz for RT Duroid 5880 Substrate height = 0.8mm

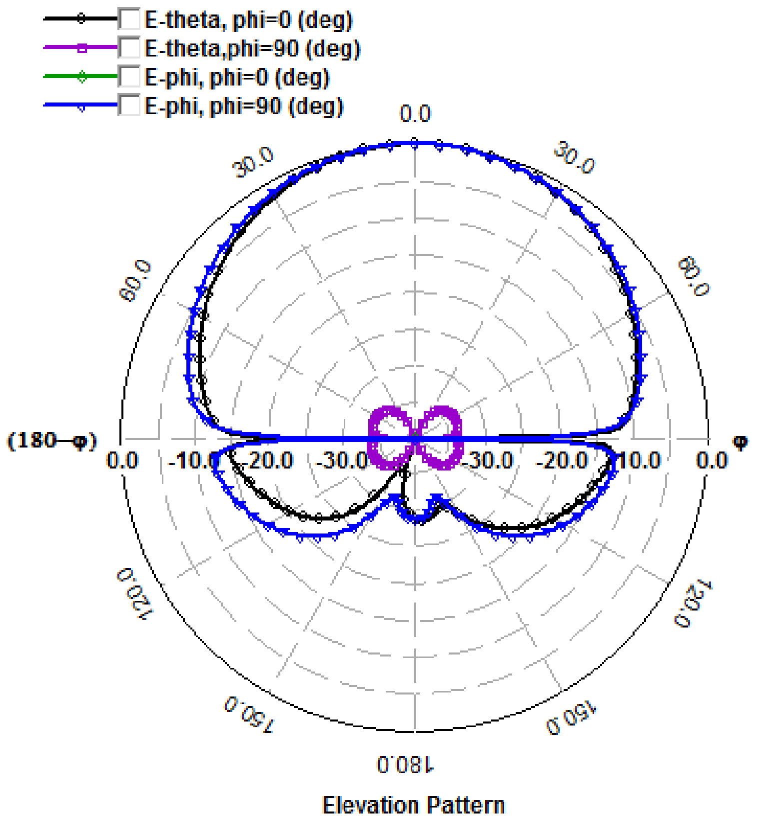


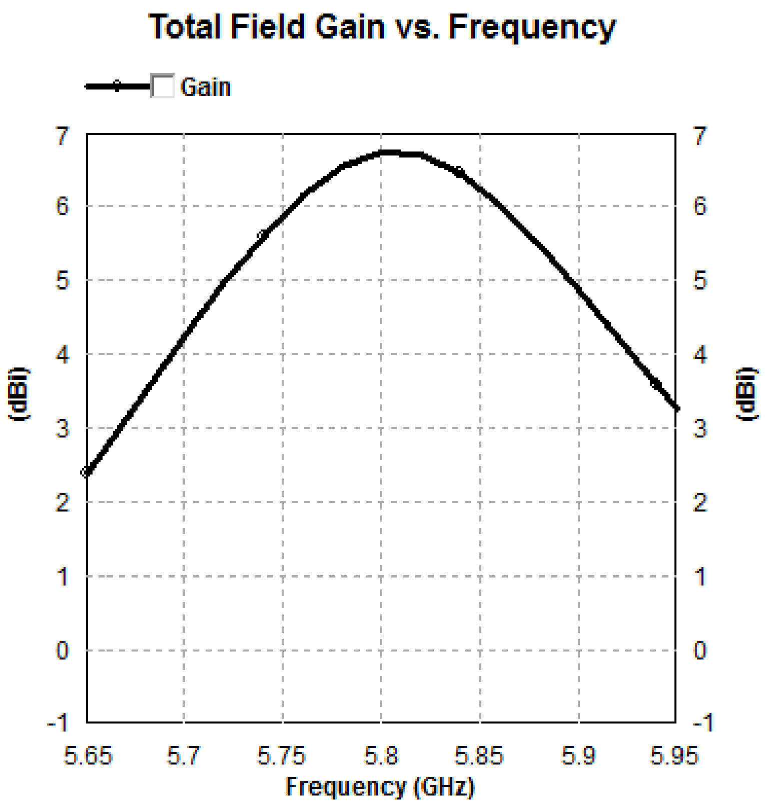
Input Impedance Plot on Smith Chart normalized with 50 ohm

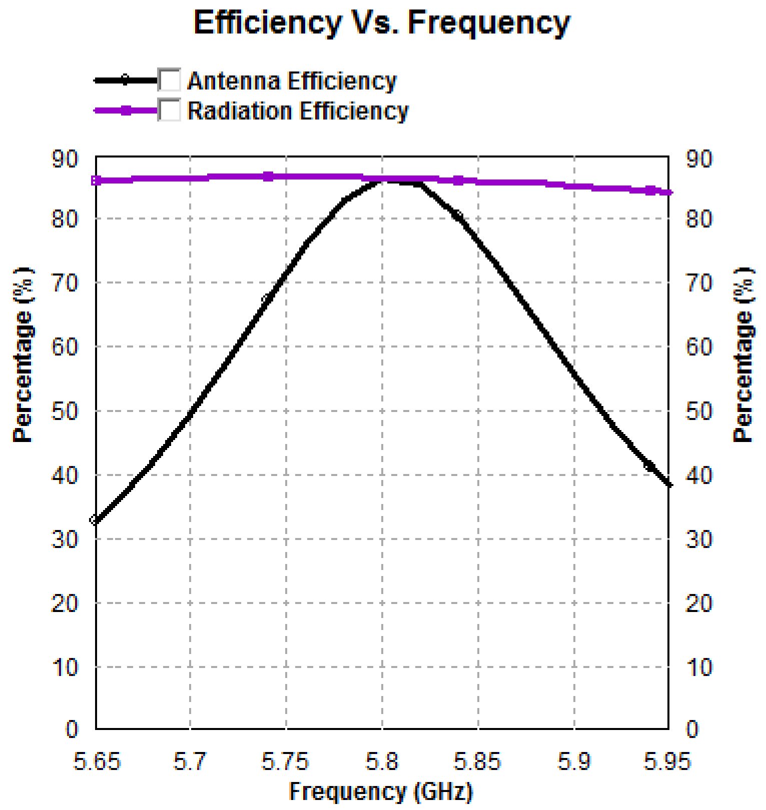


Return Loss Plot BW for |Γ| ≤ -10 dB is 85MHz (1.5%)

Microstrip Antenna Radiation Pattern and Gain





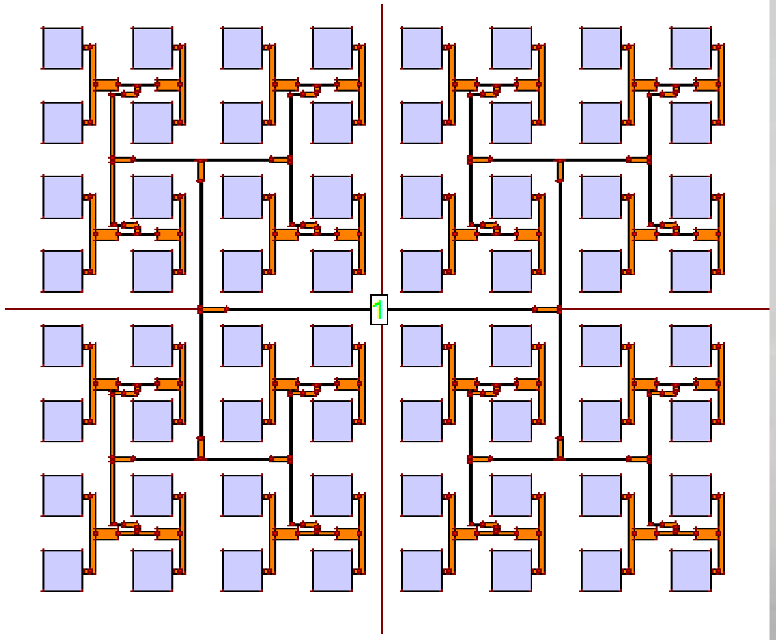


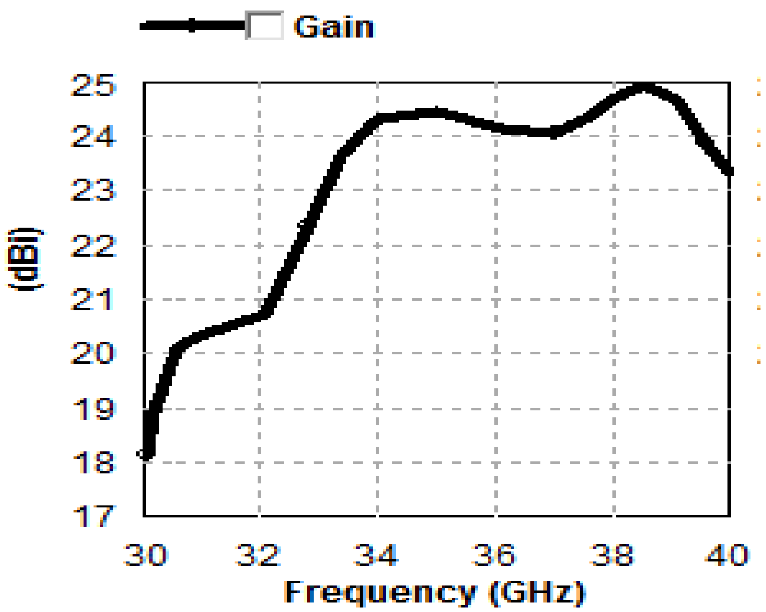
Radiation Pattern
HPBW (H-plane) = 88°
HPBW (E-plane) = 80°

Antenna Gain Plot
BW for 1dB Gain Variation = 126MHz

Antenna Efficiency Plot

Microstrip Antenna Array – Millimeter Wave



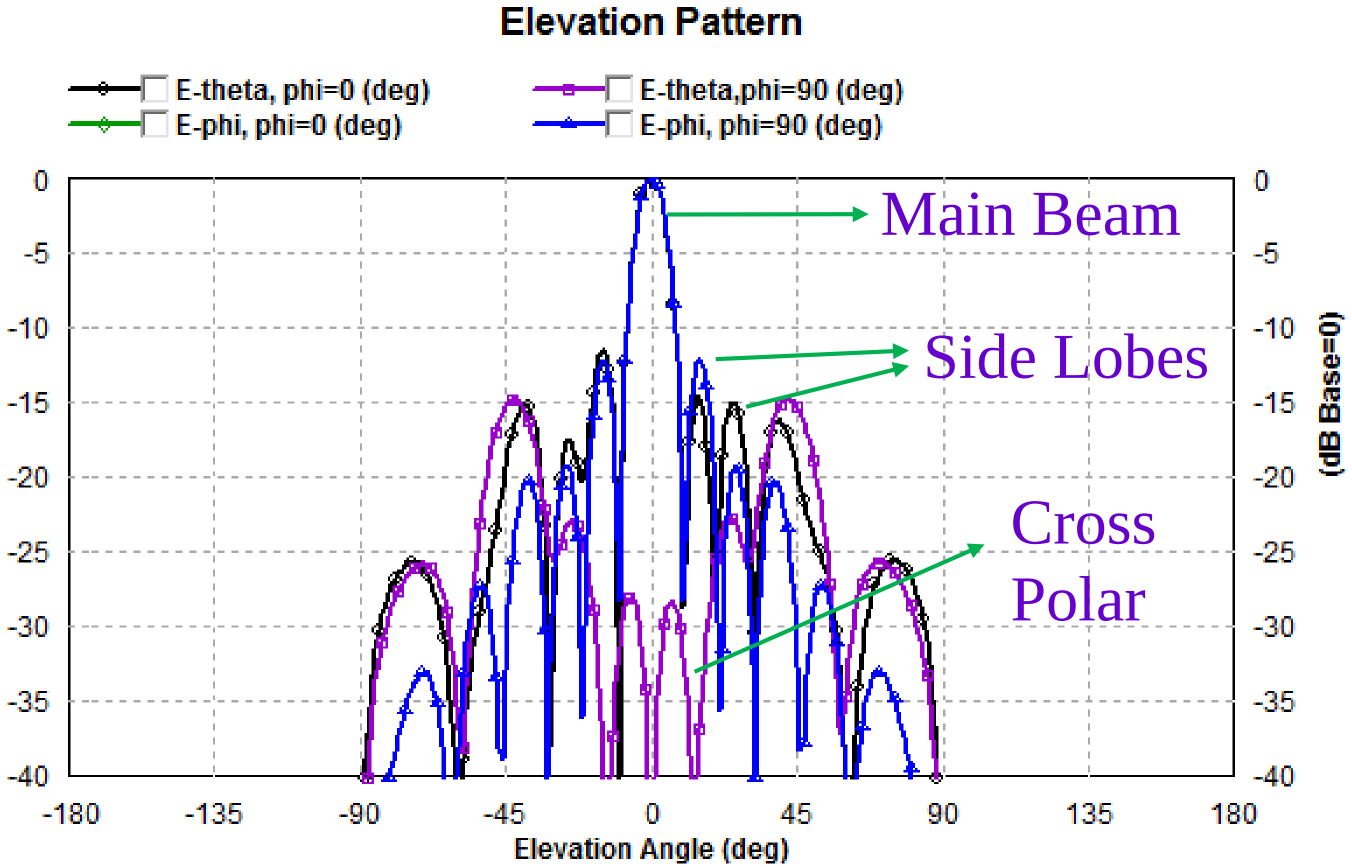


8x8 EMCP MSA Array at Millimeter Wave

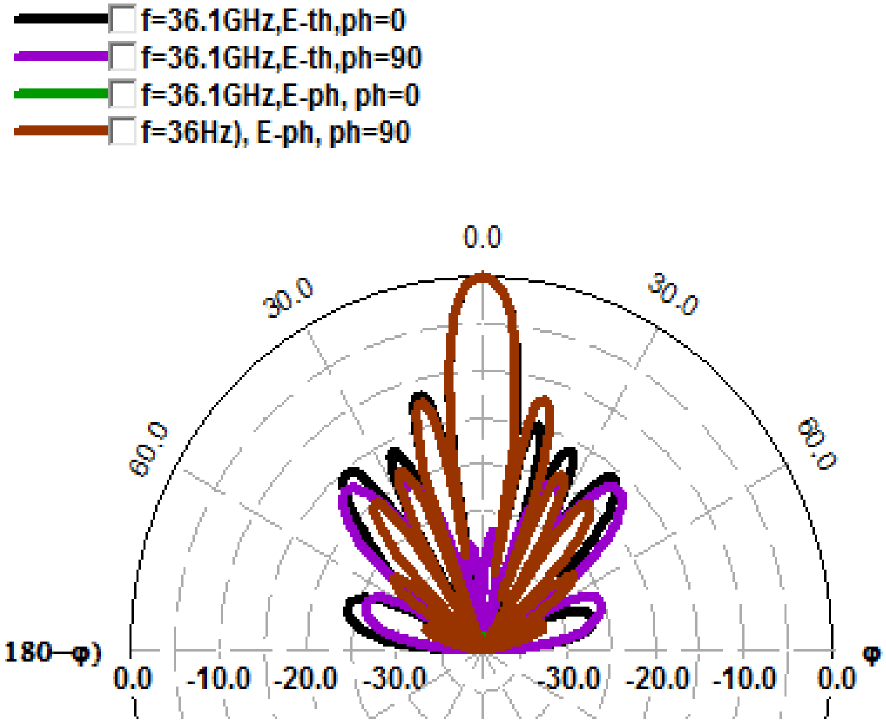
Gain Plot

Gain = 250 = 24 dB

Radiation Pattern of 8x8 MSA Array



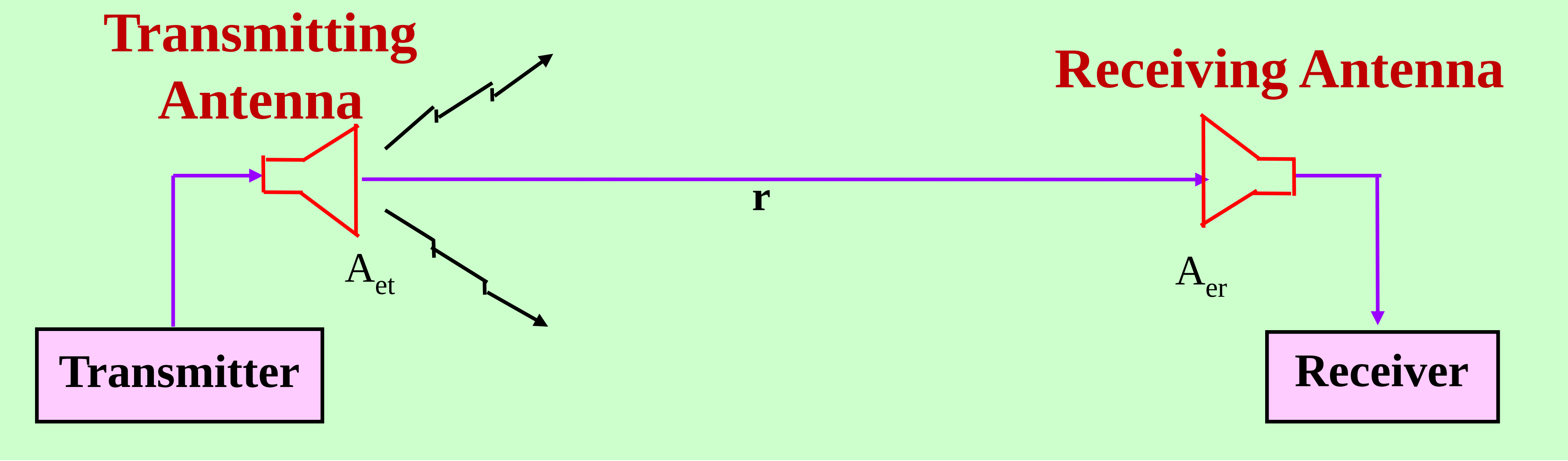
Cartesian Plot



Polar Plot

HPBW= 8.8°, FNBW=20° $\frac{FNBW}{HPBW} \simeq 2.27$ $D = \frac{32400}{8.8° x 8.8°} \simeq 413 = 26.1\text{dB}$ whereas, the simulated directivity is 25.8dB

Link Budget



$$P_d = \frac{P_t G_t}{4\pi r^2} \quad \left({}^{Watt}/_{m^2} \right)$$ → Power Density

$$P_r = P_d A_{er} \quad (Watt)$$

$$G = \frac{4\pi A_e}{\lambda^2}$$

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi r} \right)^2 \quad (Watt)$$ Friis Transmission Equation

Power Density

Example: A GSM1800 cell tower antenna is transmitting 20W of power in the frequency range of 1840 to 1845MHz. The gain of the antenna is 17dB. Find the power density at a distance of (a) 50m and (b) 300m in the direction of maximum radiation.

Power Density: $P_d = \frac{P_t G_t}{4\pi r^2} \quad \left({}^{\text{Watt}}/_{\text{m}^2} \right)$ $\qquad G_t = 17dB = 50$

(a) r = 50m: $P_d = \frac{20 \text{ x } 50}{4\pi \text{ x } 50^2} = 31.8\text{m W/m}^2$

(b) r = 300m: $P_d = \frac{20 \text{ x } 50}{4\pi \text{ x } 300^2} = 0.88\text{m W/m}^2$