For the rectangular microstrip antenna of part 1), compute and graph the E-plane and H-plane **normalized** directivity patterns (both unitless and in dB) with the positive *x*-axis pointing toward top of page. For the radiation patterns in dB, use a 0 to -40 dB scale. Also, find the actual HPBW in the E- and H-planes. In a table, list the estimated HPBWs, actual HPBWs, and percent differences (%). How do they compare?

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Design a rectangular microstrip antenna to operate at a frequency of 2 GHz on a Montoya Corporation substrate with a relative permittivity of 2.2 and dielectric thickness of 0.064" = 64 mils, 0.5 oz. copper cladding (17 μm), and tan(δ) = 0.003. The antenna is to be matched to a 50 Ω microstrip transmission line on this substrate using an inset feed. Discuss and justify design choices. Accurately sketch a top view of the final design (all dimensions in mm). **EE 583 only**- Include a fully-labeled Smith chart showing the normalized admittances $y_1 = y_2$ and y_{2t} (i.e., y_2 translated across length $L + \Delta L$ of microstrip antenna) and discuss results.

Summary of necessary dimensions & parameters from design-

h = 0.064 in(25.4 mm/in) = **1.6256 mm**, f_r = 2 GHz

Free space wavelength **λ_0 = 149.8962 mm** and wave number **k_0 = 41.9169 rad/m**.

Patch width ⇒ **W = 59.2517 mm**

effective length of patch ⇒ **L_{eff} = 51.4695 mm**

Patch length ⇒ L = 49.7537 mm

Slot conductance ⇒ **G_1 = 1.5735 mS**.

mutual conductance between the slots ⇒ **G_{12} = 0.4651 mS**

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Per (14-43), the total (far-field) electric field for the two radiating slots is-

$$E_\phi^t = j\frac{k_0 h W E_0 e^{-jk_0 r}}{\pi r}\left\{\sin\theta\frac{\sin(X)}{X}\frac{\sin(Z)}{Z}\right\}\cos\left(\frac{k_0 L_{\text{eff}}}{2}\sin\theta\sin\phi\right)$$

where $X(\theta,\phi) = \frac{k_0 h}{2}\sin\theta\sin\phi$ (14-43a) and $Z(\theta) = \frac{k_0 W}{2}\cos\theta$ (14-43b).

Normalize by dividing out lead terms-

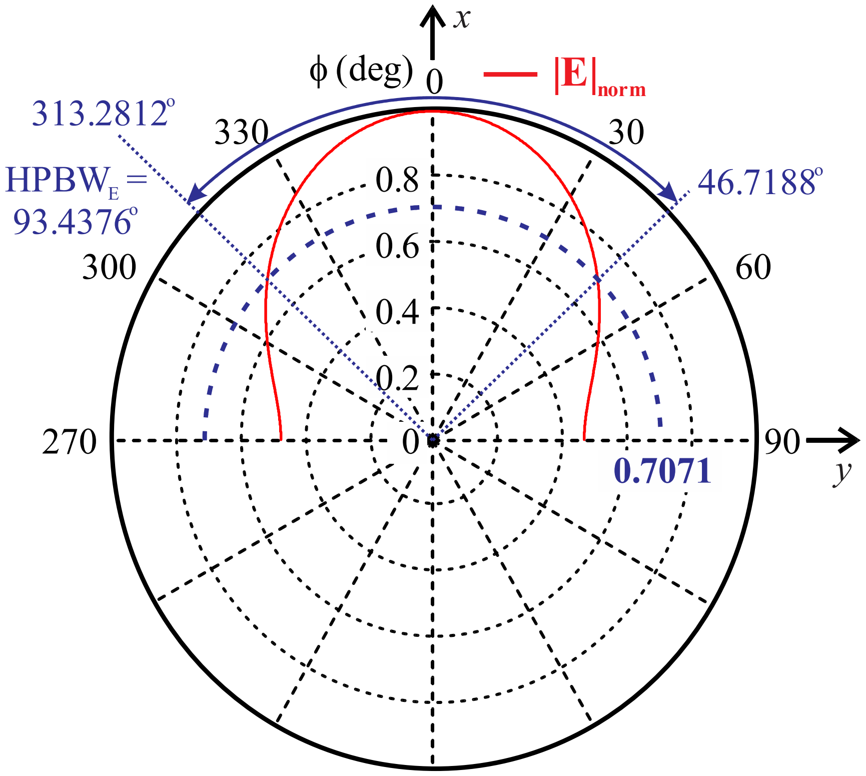
$$E_{\phi,n}^t = E_\phi^t \Big/ \left(j\frac{k_0 h W E_0 e^{-jk_0 r}}{\pi r}\right) = \sin\theta\frac{\sin(X)}{X}\frac{\sin(Z)}{Z}\cos\left(\frac{k_0 L_{\text{eff}}}{2}\sin\theta\sin\phi\right).$$

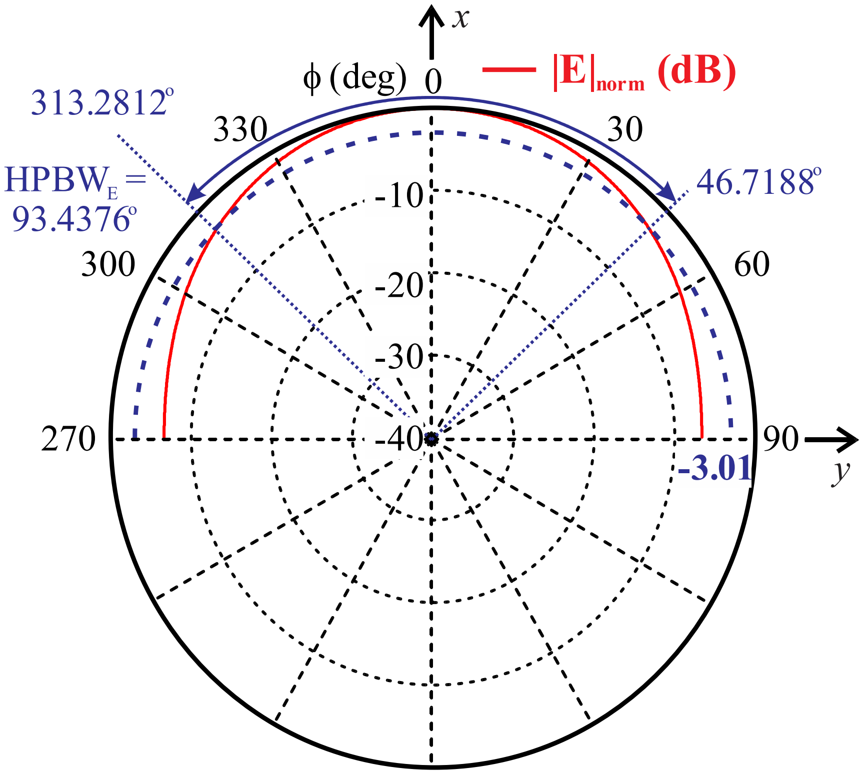
The E-plane is on the *x*-*y* plane where θ = 90° and 0 ≤ ϕ ≤ 90° & 270° ≤ ϕ < 360°. Note, to 'trick' MathCad, let -90° ≤ ϕ ≤ 90°.

The H-plane is on the *x*-*z* plane where ϕ = 0 and 0° ≤ θ ≤ 180°.

MathCad & CorelDraw were used to produce the following plots.

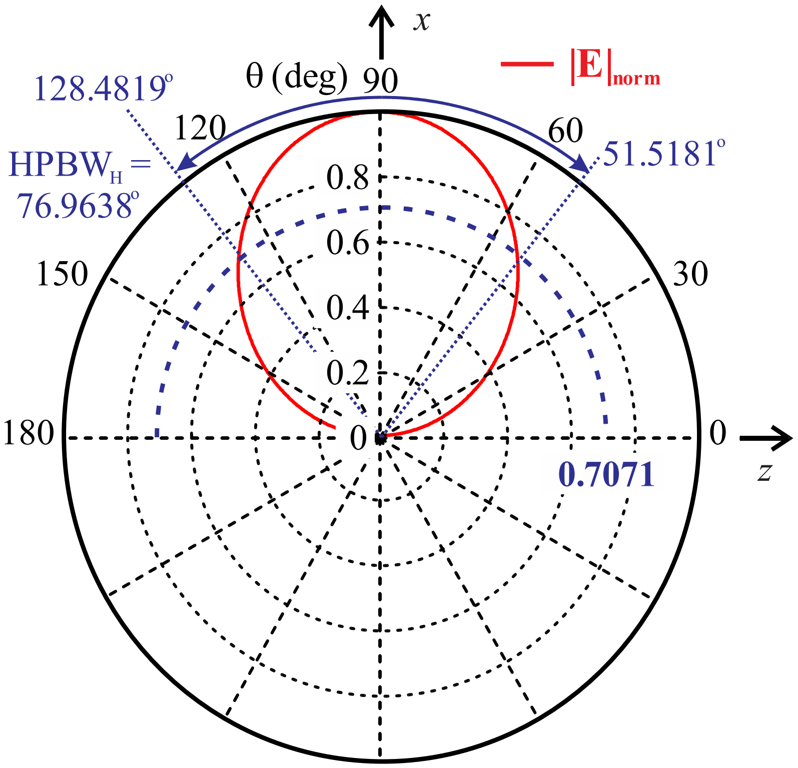
E-Plane Radiation Patterns (x-y plane where $\theta = 90°$ and $0 \le \phi \le 90°$ & $270° \le \phi < 360°$)

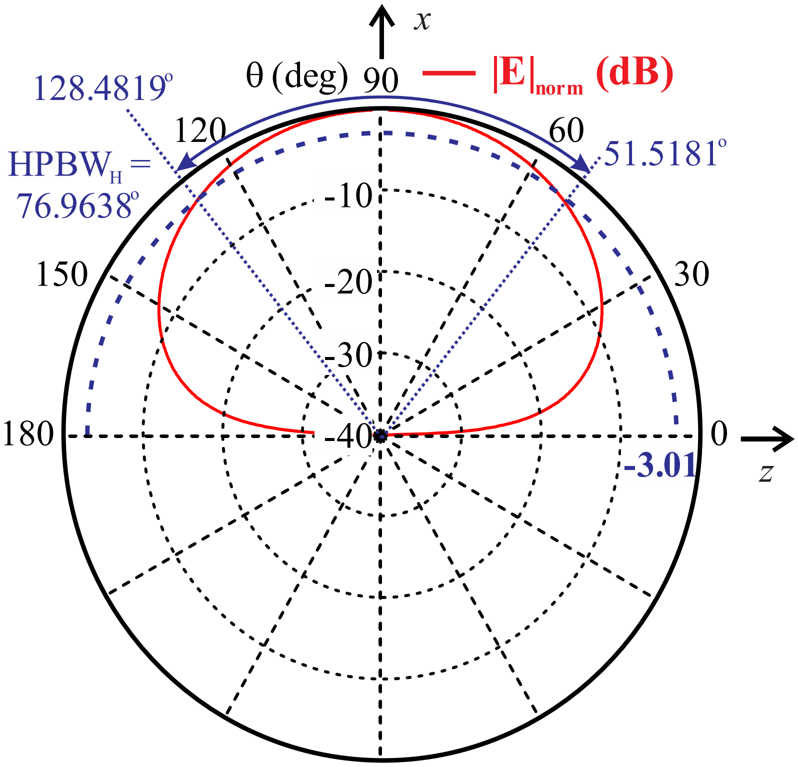




The exact E-Plane half-power beamwidth **$\mathrm{HPBW}_E = 93.4376°$** whereas the estimate from problem 2) was **$\mathrm{HPBW}_{E,est} = 90.3761°$**. Pretty good agreement.

H-Plane Radiation Patterns (x-z plane where $\phi = 0$ and $0° \le \theta \le 180°$)





The exact H-Plane half-power beamwidth is **$\text{HPBW}_H = 76.9638°$** whereas the estimate from problem 2) was **$\text{HPBW}_{H,est} = 56.3626°$**. Not very good agreement.

MathCad excerpt

Estimated HPBWs for this microstrip patch antenna using (14-58) & (14-59)

$$\Theta E := 2\cdot \mathrm{asin}\left[\sqrt{\frac{7.03\cdot \lambda 0^2}{4\cdot \pi^2\cdot\left(3\cdot \mathrm{Leff}^2 + h^2\right)}}\right] \qquad \boxed{\Theta E\cdot\frac{180}{\pi} = 90.376} \quad \text{degrees}$$

$$\Theta H := 2\cdot \mathrm{asin}\left[\sqrt{\frac{1}{(2 + k0\cdot W)}}\right] \qquad \boxed{\Theta H\cdot\frac{180}{\pi} = 56.363} \quad \text{degrees}$$

$$X(\theta,\phi) := \frac{k0\cdot h}{2}\cdot\sin(\theta)\cdot\cos(\phi) \qquad Z(\theta,\phi) := \frac{k0\cdot W}{2}\cdot\cos(\theta)$$

$$E(\theta,\phi) := \sin(\theta)\cdot\frac{\sin(X(\theta,\phi))}{X(\theta,\phi)}\cdot\frac{\sin(Z(\theta,\phi))}{Z(\theta,\phi)}\cdot\cos\left[\frac{k0\cdot \mathrm{Leff}}{2}\cdot(\sin(\theta)\cdot\sin(\phi))\right]$$

$$n := 0..\,720 \qquad \phi_n := (n - 360)\cdot\frac{\pi}{720} \qquad \theta_n := n\cdot\frac{\pi}{720}$$

E-plane radiation pattern (x-y plane where $\theta = \pi/2 = 90$ deg, symmetric around ϕ=0)

$$\mathrm{Epln}_n := E\left(\frac{\pi}{2},\phi_n\right) \qquad \mathrm{Epln\_dB}_n := 20\cdot\log\left(\mathrm{Epln}_n\right)$$

Find E-plane half power |E|=0.707107 points:

$$E\left(\frac{\pi}{2},46.7188\cdot\frac{\pi}{180}\right) = 0.707107 \qquad E\left(\frac{\pi}{2},-46.7188\cdot\frac{\pi}{180}\right) = 0.707107$$

$$\mathrm{HPBWepln} := 2\cdot 46.7188 \qquad \boxed{\mathrm{HPBWepln} = 93.4376} \quad \text{deg}$$

Fair agreement with part 2) estimate of ΘE = 90.3761 degrees.

H-plane radiation pattern (y-z plane where $\phi = 0$ or π, symmetric around θ=90 deg)

$$\mathrm{Ehpln}_n := E\left(\theta_n,0\right) \qquad \mathrm{Ehpln\_dB}_n := \mathrm{if}\left(\mathrm{Ehpln}_n \le 0.01,-40,20\cdot\log\left(\mathrm{Ehpln}_n\right)\right)$$

Find H-plane half power |E|=0.707107 points on either side of 90 deg:

$$E\left(128.4819\cdot\frac{\pi}{180},0\right) = 0.707107 \qquad E\left(51.5181\cdot\frac{\pi}{180},0\right) = 0.707107$$

$$\mathrm{HPBWhpln} := 128.4819 - 51.5181 \qquad \boxed{\mathrm{HPBWhpln} = 76.9638} \quad \text{deg}$$

Not very good agreement with part 2) estimate of ΘH = 56.3626 degrees.

$$\mathrm{Ehalf\_pwr}_n := 0.5\cdot\sqrt{2} \qquad \mathrm{Ehalf\_dB}_n := 20\cdot\log\left(0.5\cdot\sqrt{2}\right)$$