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. What is the HPBW in the E- and H-planes? How do these HPBWs compare with estimates from part 2)?

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Design a rectangular microstrip antenna to operate at the center frequency of UHF TV channel 16 on a polystyrene substrate- assume h = 0.5”, 2 oz. copper cladding (68 μm), loss tangent tan(δ) = 0.00013, and a relative dielectric constant $\varepsilon_r = 2.6$. The antenna is to be matched to a 75 Ω microstrip transmission line on this substrate. Discuss and justify design choices. Accurately sketch top view of final design (all dimensions in cm). **EE 583 only**- Include a fully-labeled Smith chart showing $y_1 = y_2$ and y_{2t} (i.e., y_2 translated across length $L + \Delta L$ of microstrip antenna) and discuss results.

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Summary of necessary dimensions & parameters from design-

h = 0.5” = 1.27 cm, f_r = 485 MHz

Free space wavelength **λ_0 = 61.813 cm** and wave number **k_0 = 10.165 rad/m**.

Patch width ⇒ **W = 23.036 cm**

effective length of patch ⇒ **L_{eff} = 19.865 cm**

Patch length ⇒ L = 18.586 cm

Slot conductance ⇒ **G_1 = 1.4136 mS**.

mutual conductance between the slots ⇒ **G_{12} = 0.5627 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 the lead terms-

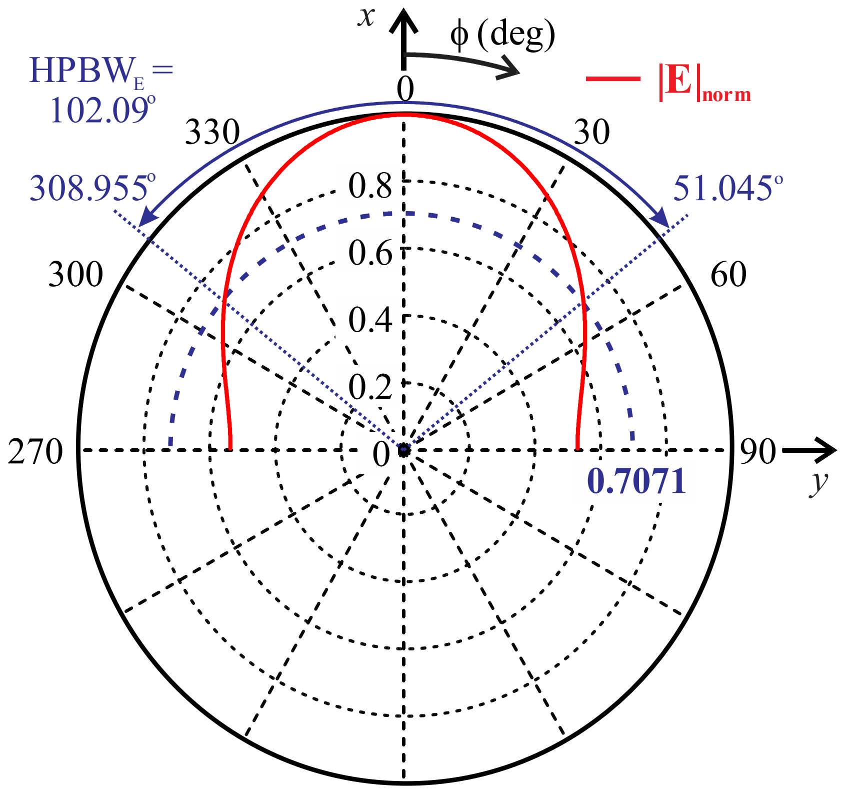
$$E_{\phi,n}^t = E_\phi^t \Big/ \left(j\frac{k_0 h W E_0 e^{-jk_0 r}}{\pi r}\right) = \sin\theta\,\frac{\sin(X)}{X}\,\frac{\sin(Z)}{Z}\cos\left(\frac{k_0 L_{\text{eff}}}{2}\sin\theta\sin\phi\right).$$

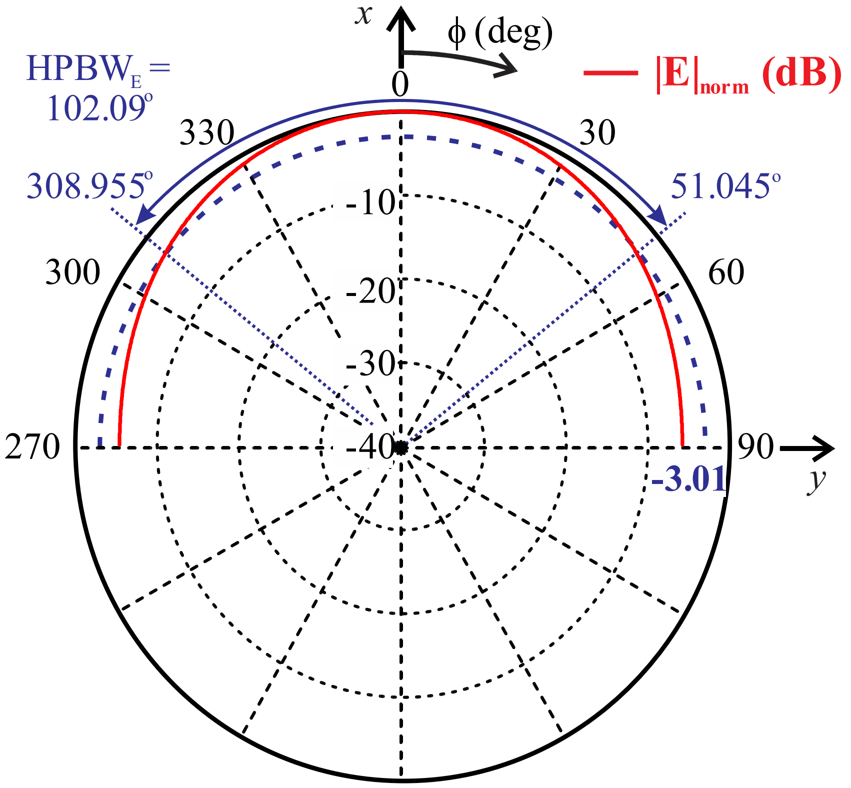
The E-plane is on the *x*-*y* plane where θ = 90° and 0 ≤ ϕ ≤ 90° & 270° ≤ ϕ < 360°. Note, to ‘trick’ MathCad, let -90° ≤ ϕ ≤ 90°.

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

MathCad & CorelDraw (rotate & add labels) were used to produce the following plots.

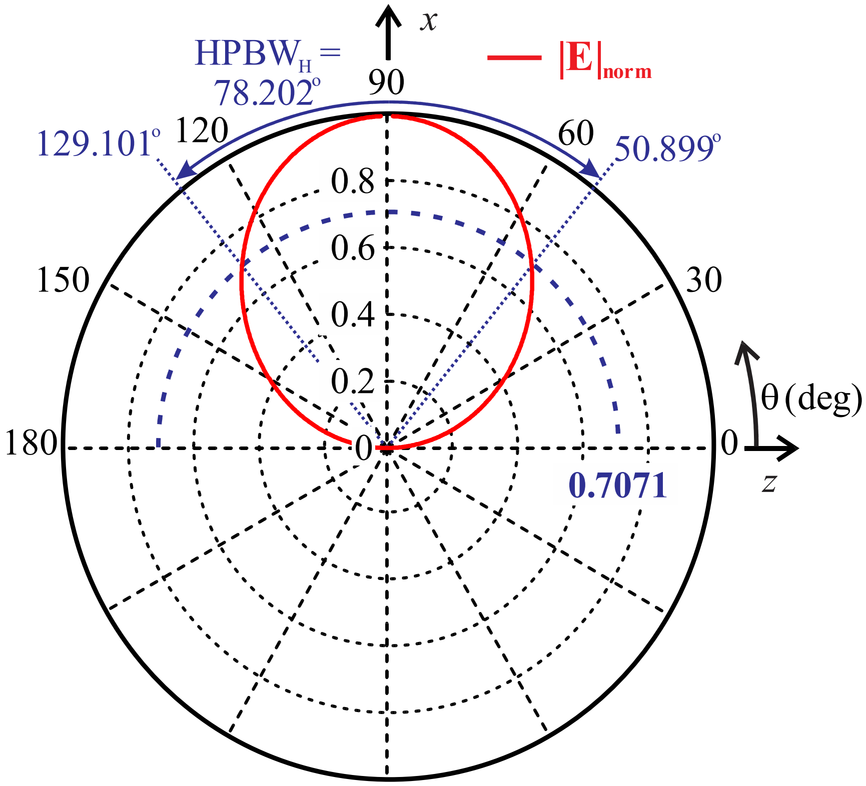
E-Plane Radiation Patterns (x-y plane where $\theta = 90°$ and $0 \le \phi \le 90°$ & $270° \le \phi < 360°$)

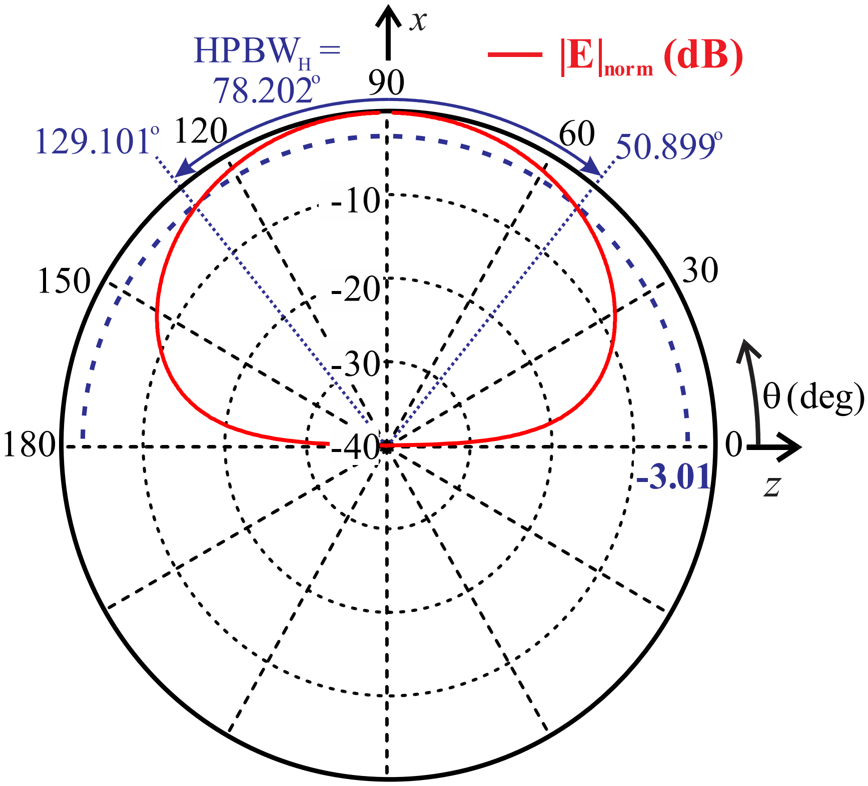




The exact E-Plane half-power beamwidth **$\text{HPBW}_E = 102.09°$** whereas the estimate from problem 2) was **$\text{HPBW}_{E,est} = 98.505°$**. Pretty good agreement, w/in 3.585° or ~3.5%).

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





The exact H-Plane half-power beamwidth is **$HPBW_H = 78.202°$** whereas the estimate from problem 2) was **$HPBW_{H,est} = 57.361°$**. Mediocre agreement (w/in 20.84° or ~26.7%).

MathCad excerpt

Estimated HPBWs for this microstrip patch antenna

$$\Theta E := 2\cdot \mathrm{asin}\left[\sqrt{\frac{7.03\cdot \lambda 0^2}{4\cdot \pi^2\cdot\left(3\cdot \mathrm{Leff}^2 + h^2\right)}}\right] \qquad \boxed{\Theta E\cdot\frac{180}{\pi} = 98.505} \quad \text{degrees}$$

$$\Theta H := 2\cdot \mathrm{asin}\left[\sqrt{\frac{1}{(2 + k0\cdot W)}}\right] \qquad \boxed{\Theta H\cdot\frac{180}{\pi} = 57.361} \quad \text{degrees}$$

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

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

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

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

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

Find E-plane half power |E|=0.70711 points:

$$E\left(\frac{\pi}{2},51.045\cdot\frac{\pi}{180}\right) = 0.70711 \qquad E\left(\frac{\pi}{2},-51.045\cdot\frac{\pi}{180}\right) = 0.70711$$

$$\mathrm{HPBWepln} := 2\cdot 51.045 \qquad \boxed{\mathrm{HPBWepln} = 102.09} \quad \text{deg}$$

Decent agreement with part 2) estimate of ΘE = 98.505 deg, within 3.6 degrees.

H-plane radiation pattern (y-z plane where $\phi = 0$ or π, symmetric around $\theta = 90$ 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|=0.70711 points:

$$E\left(129.101\cdot\frac{\pi}{180},0\right) = 0.70711 \qquad E\left(50.899\cdot\frac{\pi}{180},0\right) = 0.70711$$

$$\mathrm{HPBWhpln} := 129.101 - 50.899 \qquad \boxed{\mathrm{HPBWhpln} = 78.202} \quad \text{deg}$$

Mediocre agreement with part 2) estimate of ΘH = 57.361 deg, off 20.84 degrees.