For the rectangular microstrip antenna of part 1), compute the maximum directivity (unitless and dBi) using both numerical methods discussed in class. Compare the results and discuss any differences. Also, compute the *estimated* half-power beamwidths (HPBW) in the E- and H-planes.

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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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Find directivity (All calculations done using full precision of MathCad)

Both methods assume $k_0 h \ll 1$. Here, $k_0 h$ = 41.9169(0.0016256) = 0.06814 << 1 (OK).

Method 1

Find parameter I_2 (14-55a) by numerical integration-

$$I_2 = \int_{\phi=0}^{\pi}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\cos^2\left(\frac{k_0 L_{eff}}{2}\sin\theta\sin\phi\right)d\theta\, d\phi$$

$$= \int_{\phi=0}^{\pi}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\frac{41.917(0.05925)}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\cos^2\left(\frac{41.917(0.05147)}{2}\sin\theta\sin\phi\right)d\theta\, d\phi$$

⇒ I_2 = 3.682473.

The maximum directivity $D_{\max,1}$ (14-55)from method 1 is

$$D^{\text{tot}}_{\max,1} = \left(\frac{2\pi W}{\lambda_0}\right)^2 \frac{\pi}{I_2} = \left(\frac{2\pi \bullet 0.05925}{0.149896}\right)^2 \frac{\pi}{3.6825} \quad \Rightarrow \quad \underline{\boldsymbol{D_{\max,1} = 5.2625 = 7.2119\ \text{dBi}}}$$

Method 2

Find parameter I_1 (14-53a) by numerical integration-

$$I_1 = \int_{\theta=0}^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\, d\theta = \int_{\theta=0}^{\pi} \left[\frac{\sin\left(\frac{41.917(0.05925)}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\, d\theta$$

$$\Rightarrow \underline{I_1 = 1.862313}.$$

The maximum directivity of a single rectangular slot (14-53) is

$$D_{\max} = D_0 = \left(\frac{2\pi W}{\lambda_0}\right)^2 \frac{1}{I_1} = \left(\frac{2\pi \bullet 0.05925}{0.149896}\right)^2 \frac{1}{1.862313} \quad \Rightarrow \quad \underline{D_0 = 3.31228}.$$

The maximum directivity $D_{\max,2}$ (14-56) from method 2 is

$$D^{\text{tot}}_{\max,2} = D_0\left(\frac{2}{1 + G_{12}/G_1}\right) = 3.3123\left(\frac{2}{1 + 0.46513/1.5735}\right) \Rightarrow \underline{\boldsymbol{D_{\max,2} = 5.1131 = 7.0869\ \text{dBi}}}$$

Methods 1 & 2 agree to within 0.125 dB!

Find estimated half-power beamwidths (HPBW) in E- & H-planes (14-58) & (14-59)

$$\Theta_E \simeq 2\sin^{-1}\sqrt{\frac{7.03\lambda_0^{\,2}}{4\pi^2\left(3L_{\text{eff}}^{\,2} + h^2\right)}} = 2\sin^{-1}\sqrt{\frac{7.03(0.148962)^2}{4\pi^2\left(3(0.0514695)^2 + (0.0016256)^2\right)}}$$

$$\Rightarrow \underline{\textbf{HPBW}_E = \Theta_E = \textbf{90.3761°}}.$$

and

$$\Theta_H \simeq 2\sin^{-1}\sqrt{\frac{1}{2 + k_0 W}} = 2\sin^{-1}\sqrt{\frac{1}{2 + 41.9169(0.059252)}}$$

$$\Rightarrow \underline{\textbf{HPBW}_H = \Theta_H = \textbf{56.3626°}}.$$