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.

****

Design Procedure (All calculations done using MathCad for full precision.)

1) Specify ε_r and h of substrate, the desired resonant frequency f_r, and the impedance $Z_{c,\text{feed}}$ of the feeding transmission line.

$$\boldsymbol{\varepsilon_r = 2.6,\quad h = 0.5" = 1.27\text{ cm},\quad f_r = 485\text{ MHz},\quad \&\quad Z_{c,\text{feed}} = 50\,\Omega}$$

2) Calculate width of patch using (14-6)

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{2.9979\times10^8}{2(485\times10^9)}\sqrt{\frac{2}{2.6+1}} \quad\Rightarrow\quad \underline{\boldsymbol{W = 23.036\text{ cm}}}$$

3) Calculate effective relative permittivity using (14-1)

$$\varepsilon_{\text{r,eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-0.5} = \frac{2.6+1}{2} + \frac{2.6-1}{2}\left[1+12\frac{1.27}{23.036}\right]^{-0.5} \quad\Rightarrow\quad \underline{\boldsymbol{\varepsilon_{\text{r,eff}} = 2.4206}}$$

4) Calculate fringing length using (14-2)

$$\Delta L = 0.412h\frac{\left(\varepsilon_{\text{r,eff}}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{\text{r,eff}}-0.258\right)\left(\frac{W}{h}+0.8\right)} = 0.412(1.27)\frac{(2.4206+0.3)\left(\frac{23.036}{1.27}+0.264\right)}{(2.4206-0.258)\left(\frac{23.036}{1.27}+0.8\right)}$$

$$\Rightarrow\quad \underline{\boldsymbol{\Delta L = 0.63962\text{ cm}}}$$

5) Calculate the effective length (14-5) and guided wavelength λ.

$$L_{\text{eff}} = \frac{c}{2f_r\sqrt{\varepsilon_{\text{r,eff}}}} = \frac{2.9979\times10^8}{2(485\times10^6)\sqrt{2.4206}} \quad\Rightarrow\quad \underline{\boldsymbol{L_{\text{eff}} = 19.8648\text{ cm}}}$$

and

$$\lambda = 2L_{\text{eff}} = 2(19.8648) \quad\Rightarrow\quad \underline{\boldsymbol{\lambda = 39.7297\text{ cm}}}$$

6) Calculate the patch length L (14-7) and L/λ. Then, calculate and check that $W/L < 2$.

$L = L_{eff} - 2\Delta L = 19.8648 - 2(0.63962) \Rightarrow$ **$L = 18.5856$ cm**

$L/\lambda = 18.5856/39.7297 \Rightarrow$ **$L/\lambda = 0.4678$**

$W/L = 23.036/18.5856 \Rightarrow$ **$W/L = 1.2395$ (should be OK as it is < 2)**

7) Calculate $G_1 \approx G_2$ and $B_1 \approx B_2$.

$$G_{1,est} = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right] \quad \text{for } \frac{h}{\lambda_0} < \frac{1}{10} \quad (14-8a)$$

$$B_{1,est} = \frac{W}{120\lambda_0}\left[1 - 0.636\ln(k_0 h)\right] \quad \text{for } \frac{h}{\lambda_0} < \frac{1}{10} \quad (14-8b)$$

where

$\lambda_0 = c/f_r = 2.9979\times10^8/485\times10^6 \Rightarrow \lambda_0 = 61.8129$ cm,

$h/\lambda_0 = 1.27/61.8129 \Rightarrow h/\lambda_0 = 0.02055$,

and $k_0 = 2\pi/\lambda_0 = 2\pi/0.61813 \Rightarrow k_0 = 10.16485$ rad/m,

$$G_{1,est} = \frac{23.036}{120(61.8129)}\left[1 - \frac{1}{24}\left(10.165 * 1.27 * 10^{-2}\right)^2\right] \Rightarrow \underline{G_{1,est} = 3.1035 \text{ mS}}$$

$$B_{1,est} = \frac{23.036}{120(61.8129)}\left[1 - 0.636\ln\left(10.165 * 1.27 * 10^{-2}\right)\right] \Rightarrow \underline{B_{1,est} = 7.1493 \text{ mS}}$$

numerically integrate (notes & 14-12a)-

$$G_1 = \frac{1}{\pi\eta_0}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\, d\theta$$

$$= \frac{1}{\pi(376.73)}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\frac{10.165(0.23036)}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta\, d\theta \Rightarrow \mathbf{G_1 = 1.4136 \text{ mS}}$$

$$\text{(notes)}\ B_1 = \left(\frac{G_1}{G_{1,est}}\right)B_{1,est} = \left(\frac{1.4136}{3.1035}\right)7.1493 \Rightarrow \mathbf{B_1 = 3.2565 \text{ mS}}.$$

Therefore, $Y_1 = Y_2 = G_1 + j\,B_1 \Rightarrow$ **$Y_1 = Y_2 = 1.4136 + j\,3.2565$ mS**

8) Calculate the TL characteristic impedance $Z_{c,\text{ant}}$ (14-19a) and admittance $Y_{c,\text{ant}}$ for the rectangular microstrip antenna.

$$Z_{c,\text{ant}} = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{\text{r,eff}}}} \ln\left[\dfrac{8h}{W} + \dfrac{W}{4h}\right] & \dfrac{W}{h} \le 1 \\ \dfrac{\eta_0}{\sqrt{\varepsilon_{\text{r,eff}}}\left[\dfrac{W}{h} + 1.393 + 0.667\ln\left(\dfrac{W}{h} + 1.444\right)\right]} & \dfrac{W}{h} > 1 \end{cases}$$

here $W/h = 23.036/1.27 = 18.1388$ and

$$Z_{c,\text{ant}} = \frac{376.7303}{\sqrt{2.4206}\left[18.1388 + 1.393 + 0.667\ln(18.1388 + 1.444)\right]} \Rightarrow \underline{\mathbf{Z_{c,ant} = 11.2541\ \Omega}}$$

and

$$Y_{c,\text{ant}} = \frac{1}{Z_{c,\text{ant}}} = \frac{1}{2.295} \Rightarrow \underline{\mathbf{Y_{c,ant} = 0.08886\ S}}$$

9) (**EE 583 only**) Use Smith chart to check if $\tilde{Y}_2 = \tilde{G}_2 + j\tilde{B}_2 \approx G_1 - jB_1 = Y_1^*$.

On Smith chart (next page), plot $y_2 = Y_2/Y_{c,\text{ant}} = (1.4136 + j\,3.2565)10^{-3}(11.2541)$

$\Rightarrow \underline{y_2 \approx 0.0159 + j0.0366 \text{ S/S}}$.

Move $(L+\Delta L)/\lambda = (18.5856+0.63962) / 39.7297 = 0.4839$ WAVELENGTHS TOWARD GENERATOR on arc of constant $|\Gamma|$.

On Smith chart, read off $\Rightarrow \underline{y_{2t} = 0.0159 - j0.063 \text{ S/S}}$.

We only loosely meet the condition $y_{2t} \approx y_1^*$ (real part good, imaginary poor) -

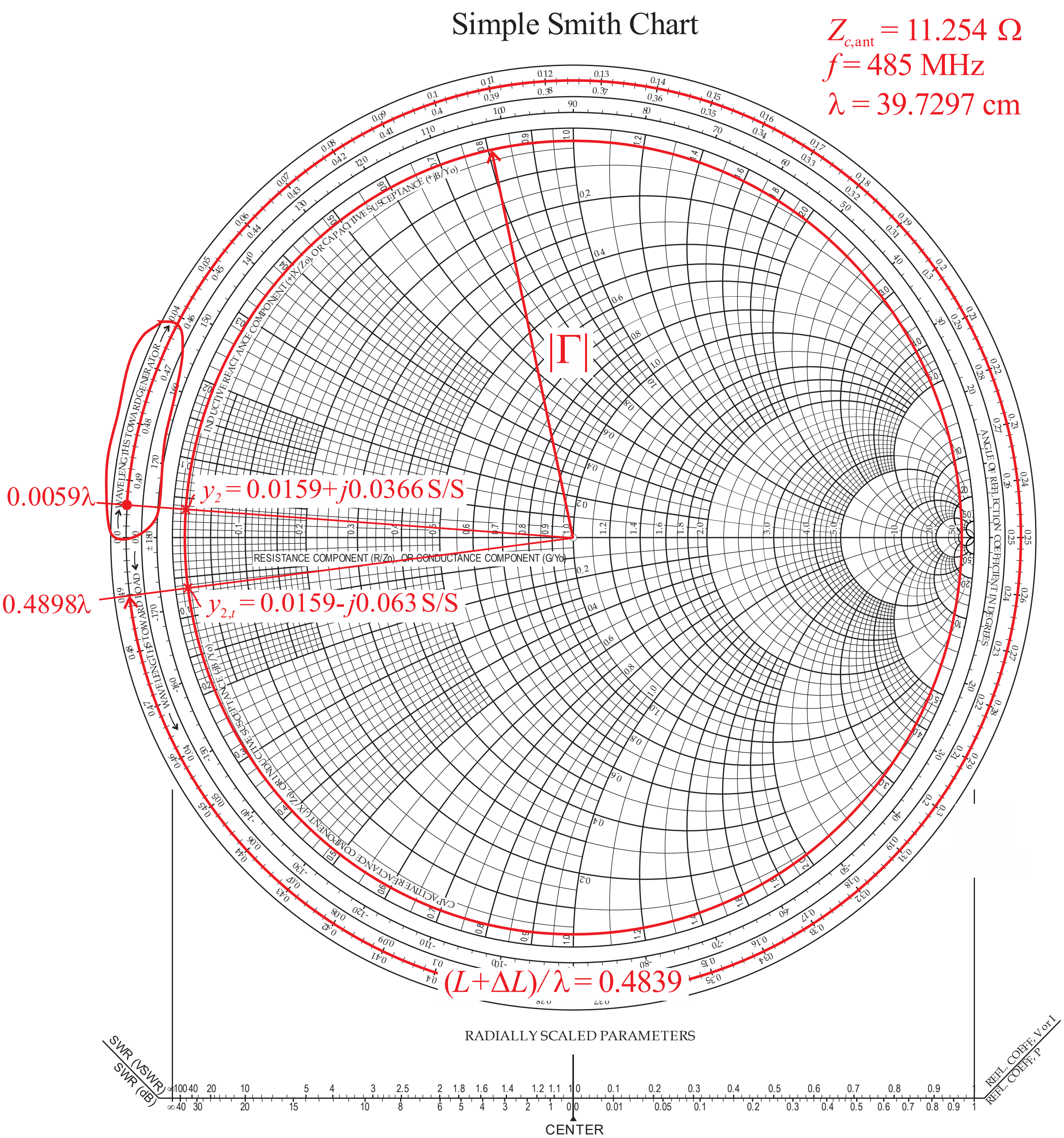
$\underline{y_{2t} = 0.0159 - j0.063 \text{ S/S} \sim y_1^* = 0.0159 - j0.0366 \text{ S/S}}$

10) Numerically calculate the mutual conductance G_{12} (14-18a) between the slots

$$G_{12} = \frac{1}{\pi\eta_0}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\dfrac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0\left(k_0 L\sin\theta\right)\sin^3\theta\, d\theta$$

$$= \frac{1}{\pi(376.73)}\int_{\theta=0}^{\pi}\left[\frac{\sin\left(\dfrac{10.165(0.23036)}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0\left(10.165(0.185856)\sin\theta\right)\sin^3\theta\, d\theta$$

$\Rightarrow \underline{\mathbf{G_{12} = 0.5627\ mS}}$



11) Calculate R_{in}, use plus (+) sign in (14-17) equation.

$$Z_{\text{in}} = R_{\text{in}} = \frac{1}{2\left(G_1 + G_{12}\right)} = \frac{1}{2\left(1.4136 + 0.5627\right)10^{-3}} \quad \Rightarrow \quad \underline{\mathbf{Z_{in} = R_{in} = 252.9959\,\Omega}}$$

12) Since an inset microstrip feed is required (i.e., $R_{\text{in}} \neq Z_{c,\text{feed}}$), calculate length y_0 of the inset needed to match the rectangular patch to the feeding transmission line. When $G_1/Y_{c,\text{feed}} << 1$ and $B_1/Y_{c,\text{feed}} << 1$, a good starting point is

$$y_0 \approx \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_{c,\text{feed}}}{R_{\text{in}}}}\right) \quad \text{(14-20a).}$$

Here, $G_1/Y_{c,\text{feed}} = G_1 Z_{c,\text{feed}} = 0.001414(75) = 0.106 << 1$ (OK),

but $B_1/Y_{c,\text{feed}} = B_1 Z_{c,\text{feed}} = 0.003256(75) = 0.244 << 1$ (so-so).

So, we will estimate $y_{0,\text{est}} \approx \dfrac{18.5856}{\pi}\cos^{-1}\left(\sqrt{\dfrac{75}{252.996}}\right)$ $\Rightarrow$ **$y_{0,\text{est}} = 5.887$ cm**

Check this estimate using (14-20a)-

$$R_{\text{in}}(y_0) \simeq \frac{1}{2(G_1+G_{12})}\left[\cos^2\left(\frac{\pi y_0}{L}\right) + \frac{G_1^2+B_1^2}{Y_{c,\text{feed}}^2}\sin^2\left(\frac{\pi y_0}{L}\right) - \frac{B_1}{Y_{c,\text{feed}}}\sin\left(\frac{2\pi y_0}{L}\right)\right]$$

$$\simeq 252.996\left[\cos^2\left(\frac{\pi y_0}{0.1859}\right) + \frac{0.00141^2+0.00326^2}{0.01333^2}\sin^2\left(\frac{\pi y_0}{0.1859}\right) - \frac{0.00326}{0.01333}\sin\left(\frac{2\pi y_0}{0.1859}\right)\right]$$

$\Rightarrow$ **$R_{\text{in}}(y_{0,\text{est}} = 5.887\text{ cm}) = 31.18\ \Omega$**

Noting $R_{\text{in}}(y_{0,\text{est}})$ is too low, iteratively adjust inset length y_0 using above equation-

$\Rightarrow R_{\text{in}}$(**$y_0 = 4.6131$ cm**) $= 75\ \Omega = Z_{c,\text{feed}}$.

13) Determine the width W_0 of the feeding microstrip transmission line.

Method 2: Iteratively guess the width W_0 of the feeding transmission line using-

$$\varepsilon_{\text{r,eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W_0}\right]^{-0.5} \quad \text{(14-1)}$$

and (14-19b)

$$Z_{c,\text{feed}} = \frac{\eta_0}{\sqrt{\varepsilon_{\text{r,eff}}}\left[\dfrac{W_0}{h} + 1.393 + 0.667\ln\left(\dfrac{W_0}{h}+1.444\right)\right]} \qquad \frac{W_0}{h} > 1.$$

to get $Z_{c,\text{feed}} = 75\ \Omega$ & $\varepsilon_{\text{r,eff}} = 2.059$, when $W_0 = 1.40827\,h$ $\Rightarrow$ **$W_0 = 1.7885$ cm ~ 1.79 cm**.

14) Select the notch width n in the range $0.2W_0 < n < 0.5W_0$ (notes).

Arbitrarily select $n \approx 0.28W_0$ rounded off to two decimal places $\Rightarrow$ **$n = 0.5$ cm**.

Accurately sketch top view of final design (all dimensions in cm).