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UNIVERSITY OF UTAH

ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

MICROWAVE ENGINEERING I

ECE 5320/6322

MIDTERM EXAMINATION NO. 2

November 7, 2008

1. (25 points)

Pts

9 a. Write the ABCD parameters of the following circuit:

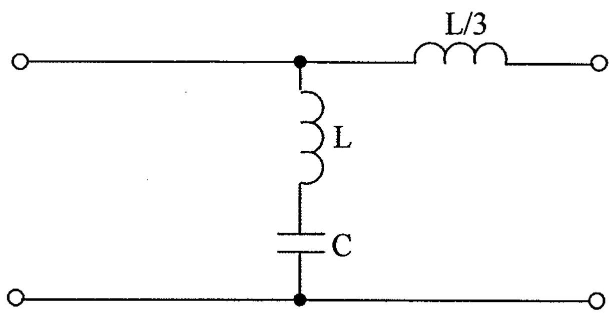


Fig. 1

8 b. Show that AD – BC = 1 for this circuit.

8 c. If L = 3 nH, calculate the value of C to get a shunt arm resonant frequency of 3 GHz.

1. a. From the ABCD parameters for the first two elements in Table 4.1 p. 185 of the Text

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{1}{j(\omega L - \frac{1}{\omega C})} & 1 \end{bmatrix} \begin{bmatrix} 1 & j\frac{\omega L}{3} \\ 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & \frac{j\omega L}{3} \\ \frac{1}{j(\omega L - \frac{1}{\omega C})} & \frac{\cancel{j}\frac{\omega L}{3}}{\cancel{j}(\omega L - \frac{1}{\omega C})} + 1 \end{bmatrix}$$

b.

$$AD - BC = \left[1 + \cancel{\frac{\frac{\omega L}{3}}{(\omega L - \frac{1}{\omega C})}}\right] - \cancel{\frac{\cancel{j}\frac{\omega L}{3}}{\cancel{j}(\omega L - \frac{1}{\omega C})}} = 1$$

c. For the shunt branch, the resonant frequency is given by the equation

$$\omega_r L - \frac{1}{\omega_r C} = 0 \longrightarrow \omega_r = \sqrt{\frac{1}{LC}}$$

$$f_r = 3\,GHz = \sqrt{\frac{1}{LC}} \cdot \frac{1}{2\pi}$$

$$\frac{1}{LC} = (2\pi \times 3 \times 10^9)^2$$

$$C = \frac{1}{\cancel{L}(3 \times \cancel{10^{-9}})(2\pi)^2 \times 9 \times \cancel{10^{18}}\,10^{9}} = \boxed{0.938\,pF}$$

2. (25 points)

The layout of a single section coupled **microstripline** directional coupler using alumina ($\varepsilon_r = 10$) as the substrate is as shown in Fig. 2. Assuming that the thickness d of the substrate is 1/16":

Pts

12 a. Calculate the length ℓ, width W, and spacing S in **millimeters** for a $Z_o = 60\Omega$ coupler with a coupling factor of -13.0 dB for a center frequency of 3 GHz ($\theta = 90^\circ$ for the coupled section).

13 b. Calculate the angles θ and the corresponding upper and lower frequencies for which the coupling factor is -14.0 dB.

Hint: From Eq. 7.88a

$$\frac{V_3}{V_1} = jc\sin\theta e^{-j\theta}$$

Coupling factor C = 20 log c = - 13 dB

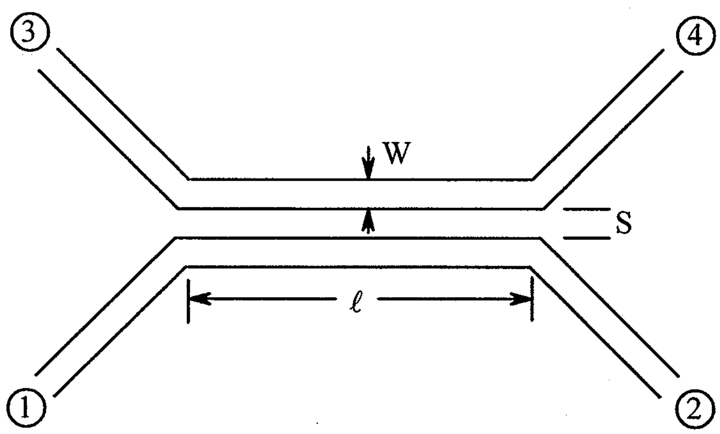


Fig. 2.

2. a. $C = -13\,dB = 20 \log c \longrightarrow c = 10^{-13/20} = 0.2239$

From Eqs. 7.87 a, b

$$Z_{oe} = Z_0 \sqrt{\frac{1+c}{1-c}} = 75.39\ \Omega$$

$$Z_{oo} = Z_0 \sqrt{\frac{1-c}{1+c}} = 47.75\ \Omega$$

From Fig. 7.32 (for the microstrip coupler with $\epsilon_r = 10$)

$$\frac{S}{d} \simeq 0.6 \ ; \ \frac{W}{d} \simeq 0.6$$

It is given that $d = 1/16'' = 1.5875$ mm

$S = 0.953$ mm ; $W = 0.953$

$\lambda_0 = 10$ cm $= 100$ mm

For $\theta = 90°$ $\quad l = \lambda_g/4 = \dfrac{100}{4\sqrt{\epsilon_{eff}}}$ mm

Possibility 1

Since ϵ_{eff} is not prescribed, we can assume $\epsilon_{eff} = \epsilon_r = 10$

in this case $\quad l = \dfrac{\lambda_g}{4} = \dfrac{25}{\sqrt{10}} = 7.9$ mm

Possibility 2

A more accurate procedure is to calculate ϵ_{eff} from Eq. 3.195 on p.144 for the effective dielectric constant of a microstripline for $W/d \simeq 0.6$ obtained above

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{12\frac{d}{W} + 1}} \quad (3.195)$$

From this Eq. we get $\epsilon_{eff} = 6.48$

Therefore $\quad l = \dfrac{\lambda_g}{4} = \dfrac{100}{4\sqrt{6.48}} = 9.82$ mm (This is more accurate !)

b. For a coupling factor $C = -14$ dB, we get $c' = 10^{-14/20} = 0.1995$

$$c' = c \sin\theta = 0.1995$$

$$\sin\theta = \frac{0.1995}{0.2239} = 0.8911$$

$$\theta_1 = 63° \ ; \ \theta_2 = 180 - 63 = 117° \longleftarrow \frac{\omega l}{v_p}$$

$$f_{lower} = \frac{63}{90} \times 3 = 2.1\ GHz \ ; \ f_{higher} = \frac{117°}{90°} = 3.9\ GHz$$

3. (25 points)

Pts

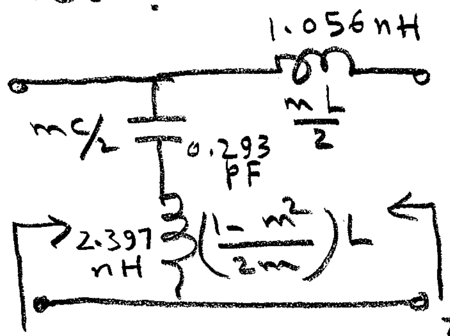
15 a. Design a bisected or half π-section m-derived low-pass filter with the following specifications:

$$R_o = 60\Omega$$
$$f_c = 5 \text{ GHz}$$
$$f_\infty = 6 \text{ GHz}$$

Calculate the values of shunt elements (L, C) and series inductance to use for this half-section filter.

10 b Calculate and mark the image impedances Z_T and Z_π for your half section m-derived filter for a signal frequency of 4 GHz.

3\. a. From the bottom part of Table 8.2 p.387 of the Text, the **bisected** (half-section) π-section low pass filter circuit is as shown below:



$Z_{i\pi} = 55.56\,\Omega$ $\qquad Z_{iT} = 36\,\Omega$

From Eqs. (8.37) and (8.38) [see also the eqs. on p. 8-4 of my Notes]

$$L = \frac{2R_0}{\omega_c} = \frac{R_0}{\pi f_c} = \frac{60}{\pi \times 5\times 10^9} = 3.82\text{ nH}$$

$$C = \frac{2}{\omega_c R_0} = \frac{1}{\pi f_c R_0} = \frac{1}{\pi \times 5\times 10^9 \times 60} = 1.061\text{ pF}$$

From Eq. 8.44 of the Text

$$f_\infty = \frac{f_c}{\sqrt{1-m^2}} \Rightarrow 1-m^2 = \left(\frac{f_c}{f_\infty}\right)^2 = \left(\frac{5}{6}\right)^2 = 0.694$$

$$m = \sqrt{1-\left(\frac{f_c}{f_\infty}\right)^2} = 0.553$$

For the shunt branch of the above bisected π-section cct.

$$\frac{mC}{2} = 0.293\text{ pF} \quad ; \quad \left(\frac{1-m^2}{2m}\right)L = 2.397\text{ nH}$$

For the series branch

$$\frac{mL}{2} = 1.056\text{ nH}$$

b. From Eq. (8.35) of the Text

$$Z_{Tm} = Z_{Tk} = R_0\sqrt{1-\frac{\omega^2}{\omega_c^2}} = 60\sqrt{1-\left(\frac{4}{5}\right)^2} = 36\,\Omega$$

From Eq. 8.46 of the Text

$$Z_{i\pi} = \frac{1-(1-m^2)\left(\frac{\omega}{\omega_c}\right)^2}{\sqrt{1-\left(\frac{\omega}{\omega_c}\right)^2}} R_0 = \frac{1-\left(f^2/f_\infty^2\right)}{\sqrt{1-\left(f^2/f_c^2\right)}} R_0$$

$$= \frac{1-\left(4/6\right)^2}{\sqrt{1-\left(4/5\right)^2}} \cdot 60 = 55.56\,\Omega$$

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Score:

Problem 1	________	of a possible 25 points	
Problem 2	________	of a possible 25 points	
Problem 3	________	of a possible 25 points	
Total	________	of a possible 75 points	