UNIVERSITI SAINS MALAYSIA

Semester I Examination
Academic Session 2007/2008

October/November 2007

EEE 532 – MICROWAVE CIRCUIT DESIGN

Time : 2 hours

INSTRUCTION TO CANDIDATE:

Please ensure that this examination paper contains **THIRTEEN (13)** printed pages including Appendices (9 pages) and **SIX (6)** questions before answering.

This question paper has three sections, **Section A, Section B** and **Section C**.

Answer **ONE (1)** questions in **Section A, Section B** and **Section C**.
ONE (1) question from any **Section**. Answer **FOUR (4)** questions.

Use three answer booklets which is provided where the answer for questions in **Section A, B and C** are in difference answer booklets.
Distribution of marks for each question is given accordingly.

All questions must be answered in English.

Section A: Answer <u>ONE</u> (1) question.

1. (a) Derive the [Z] matrix for the following two port network in Figure 1.

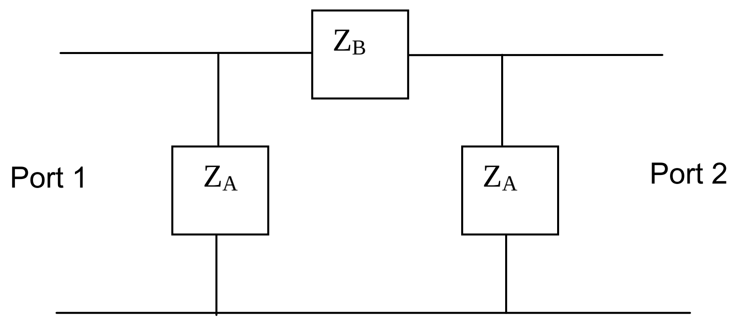

Figure 1.

(15%)

(b) Consider a lossless two-port network.

(i) If the network is reciprocal, show that $|S_{21}|^2 = 1 - |S_{11}|^2$.

(ii) If the network is nonreciprocal, show that it is impossible to have unidirectional transmission where $S_{12} = 0$ and $S_{21} \neq 0$.

(10%)

2. Design a Butterworth lowpass filter with a cutoff frequency of 1 GHz at 3dB and attenuation level greater than 20 dB at 2.5 GHz. The filter is design on the printed circuit board with a dielectric constant, ε_r =2.5 and impedance Z_0 =50 Ω .

(25%)

Section B: Answer ONE (1) question.

3. (a) Design a matching sections using a quarter-wave transformer to match a load of Z_L= 100 + j50 ohm to a 50 ohm line at frequency of 1 GHz.

(10 marks)

(b) If the same load is to be matched with 50 ohm line using a three-sections maximally flat quarter – wave transformer, calculate all the characteristic impedance of the three sections.

(15 marks)

4. Design a 15dB broadband 3 sections maximally flat coupled line coupler using a substrate of ε_r=4.5 and thickness of 1.5 mm with center frequency of 2 GHz. The input of all ports are to be 50 ohm . Given that the voltage expression at port 3 in terms of port 1 is

$$V_3 = 2jV_1 \sin\theta \, e^{-jN\theta}\left[C_1\cos(N-1)\theta + C_2\cos(N-3)\theta + ...\tfrac{1}{2}C_M\right]$$

where N=number of section , M=(N+1)/2 , $C_o = \left|\frac{V_3}{V_1}\right|_{\theta=\pi/2}$

Assume that the coupler is symmetrical such that $C_1 = C_N$, $C_2 = C_{N-1}$ etc

Using the following formula

$$Z_{oe} = Z_o\sqrt{\frac{1+C}{1-C}}$$

$$Z_{oo} = Z_o\sqrt{\frac{1-C}{1+C}}$$

$$\frac{1}{2}\left(Z_{oe} - Z_{oo}\right) = JZ_o$$

and the graph in Appendix 2 calculate the microstripline dimension , *s* and *w* of the above coupler.

(25 marks)

Section C: Answer ONE (1) question.

5. Referring to the ATF 36077 datasheet as in Appendix 3, using the S parameter at 7 GHz. The source impedance is $Z_S = 40\Omega$ and the load impedance is $Z_L = 60\Omega$. Calculate:

   (i) Power Gain. (5 Marks)

   (ii) Available Gain. (5 Marks)

   (iii) Transducer power gain. (5 Marks)

   (iv) Determine the transistor stability. (10 Marks)

6. (a) Referring to Figure 2, explain the operation of the circuit. (10 Marks)

   (b) Using the S parameter as in Question 5, design a Low Noise Amplifier operating at 4 GHz having a noise figure of 4 dB. Use single stub matching for the input and quarter wave transformer matching at the output. Use C_i as your Γ_S. Microwave laminate is Ultralam 2000 having a dielectric constant of 2.45, a thickness of 0.5 mm and copper thickness of 35 µm. (15 Marks)

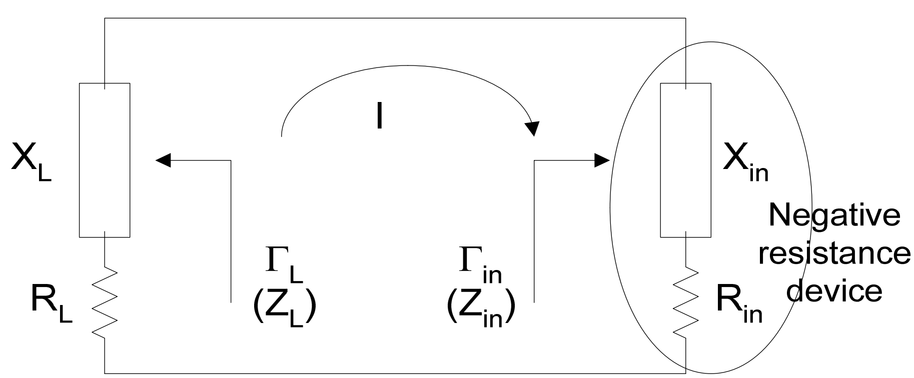

Figure 2

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LNA DESIGN

$$C_i = \frac{\Gamma_{opt}}{(1+N_i)}$$

$$R_i = \frac{1}{(1+N_i)}\sqrt{N_i^{\,2} + N_i\left(1-\left|\Gamma_{opt}\right|^2\right)}$$

$$N_i = \frac{\left[(F_r - F_{\min})\left|1+\Gamma_{opt}\right|^2\right]}{4r_n}$$

$$\Gamma_L = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_{in}}{1-S_{11}\Gamma_{in}}\right)^*$$

Important Formulas:

Network parameters

S=parameter

$$S_{11} = \left.\frac{V_{r1}}{V_{i1}}\right|_{V_{r2}=0} \qquad S_{12} = \left.\frac{V_{t2}}{V_{i2}}\right|_{V_{r2}=0} \qquad S_{21} = \left.\frac{V_{t1}}{V_{i1}}\right|_{V_{r1}=0} \qquad S_{22} = \left.\frac{V_{rt2}}{V_{i2}}\right|_{V_{r1}=0}$$

ABCD parameter

$$A = \left.\frac{V_1}{V_2}\right|_{I_2=0} \qquad B = \left.\frac{V_1}{-I_2}\right|_{V_2=0} \qquad C = \left.\frac{I_1}{V_2}\right|_{I_2=0} \qquad D = \left.\frac{I_1}{-I_2}\right|_{V_2=0}$$

Conversion

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \frac{1}{Z_oA + B + Z_o^2C + Z_oD} \begin{bmatrix} Z_oA + B - Z_o^2C - Z_oD & 2Z_o(AD - BC) \\ 2Z_o & -Z_oA + B - Z_o^2C + Z_oD \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{2S_{21}} \begin{bmatrix} (1+S_{11})(1-S_{22}) + S_{12}S_{21} & Z_o((1+S_{11})(1+S_{22}) - S_{12}S_{21}) \\ \frac{1}{Z_o}((1-S_{11})(1-S_{22}) - S_{12}S_{21}) & (1-S_{11})(1+S_{22}) + S_{12}S_{21} \end{bmatrix}$$

<u>Butterworth lowpass filter</u>

$g_k = 2\sin(2k-1)\frac{\pi}{2n}$ where k=1,………., n

$g_0 = g_{n+1} = 1$

$$n = \frac{\log_{10}\left(10^{A/10} - 1\right)}{2\log_{10}(\omega/\omega_c)}$$

$$C_k = \frac{g_k}{Z_o\omega_c}$$

$$L_k = \frac{Z_o g_k}{\omega_c}$$

<u>Bandpass filter</u>

$$J_{01} = \left(\frac{\pi\,\Omega}{2g_0g_1}\right)^{\frac{1}{2}}$$

$J_{k,k+1} = \left(\frac{\pi\,\Omega}{2}\right)\frac{1}{\sqrt{g_k \cdot g_{k-1}}}$ where k=1,………., n

$$J_{n,n+1} = \left(\frac{\pi\,\Omega}{2.g_n \cdot g_{n+1}}\right)$$

<u>Amplifier design</u>

Unilateral

$$\Gamma_S = \left(\frac{Z_S - Z_O}{Z_S + Z_O} \right) \qquad \Gamma_L = \left(\frac{Z_L - Z_O}{Z_L + Z_O} \right)$$

$$\Gamma_{in} = \left(S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L} \right) \qquad \Gamma_{out} = \left(S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S} \right)$$

Stability:

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |D|^2}{2|S_{12} S_{21}|}$$

$$D = S_{11} S_{22} - S_{12} S_{21}$$

Power gain:

$$G = \left(\frac{|S_{21}|^2 (1 - |\Gamma_L|^2)}{(1 - |\Gamma_{in}|^2) |1 - S_{22} \Gamma_L|^2} \right)$$

Available Power gain:

$$G_A = \left(\frac{|S_{21}|^2 (1 - |\Gamma_S|^2)}{|1 - S_{11} \Gamma_S|^2 (1 - |\Gamma_{out}|^2)} \right)$$

Transducer Power Gain:

$$G_T = \frac{|S_{21}|^2 (1 - |\Gamma_S|^2)(1 - |\Gamma_L|^2)}{|1 - \Gamma_S \Gamma_{in}|^2 |1 - S_{22} \Gamma_L|^2}$$

Bilateral

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|}{2|S_{12}S_{21}|}$$

$$\Gamma_s = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \qquad B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \qquad C_1 = S_{11} - \Delta S_{22}^*$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \qquad B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \qquad C_2 = S_{22} - \Delta S_{11}^*$$

$$\Gamma_{in} = \Gamma_S^* = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \qquad \Gamma_{out} = \Gamma_L^* = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

$$C_L = \frac{\left(S_{22} - \Delta S_{11}^*\right)^*}{|S_{22}|^2 - |\Delta|^2} \qquad R_L = \left|\frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2}\right|$$

$$C_S = \frac{\left(S_{11} - \Delta S_{22}^*\right)^*}{|S_{11}|^2 - |\Delta|^2} \qquad R_S = \left|\frac{S_{12}S_{21}}{|S_{11}|^2 - |\Delta|^2}\right|$$

$$G_{T\,\max} = \frac{1}{1 - |\Gamma_s|^2}|S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

Microstrip:

$$Z_O = \frac{377}{\sqrt{\varepsilon_r}\left(\frac{w}{h} + 2\right)}$$

Trigonometric Function

$$\sin\alpha\sin\beta = \frac{1}{2}\cos(\alpha-\beta) - \frac{1}{2}\cos(\alpha+\beta)$$

$$\cos\alpha\cos\beta = \frac{1}{2}\cos(\alpha-\beta) + \frac{1}{2}\cos(\alpha+\beta)$$

$$\sin\alpha\cos\beta = \frac{1}{2}\sin(\alpha+\beta) + \frac{1}{2}\sin(\alpha-\beta)$$

$$\cos\alpha\sin\beta = \frac{1}{2}\sin(\alpha+\beta) - \frac{1}{2}\sin(\alpha-\beta)$$

$$\sin 2\alpha = 2\sin\alpha\cos\alpha = \frac{2\tan\alpha}{1+\tan^2\alpha}$$

$$\cos 2\alpha = \cos^2\alpha - \sin^2\alpha = 2\cos^2\alpha - 1 = 1 - 2\sin^2\alpha$$

$$\sin 3\alpha = 3\sin\alpha - 4\sin^3\alpha$$

$$\cos 3\alpha = 4\cos^3\alpha - 3\cos\alpha$$

$$\sin 4\alpha = 4\sin\alpha\cos\alpha - 8\sin^3\alpha\cos\alpha$$

$$\cos 4\alpha = 8\cos^4\alpha - 8\cos^2\alpha = 1$$

$$\sin 5\alpha = 5\sin\alpha - 20\sin^3\alpha + 16\sin^5\alpha$$

$$\cos 5\alpha = 16\cos^5\alpha - 20\cos^3\alpha + 5\cos\alpha$$

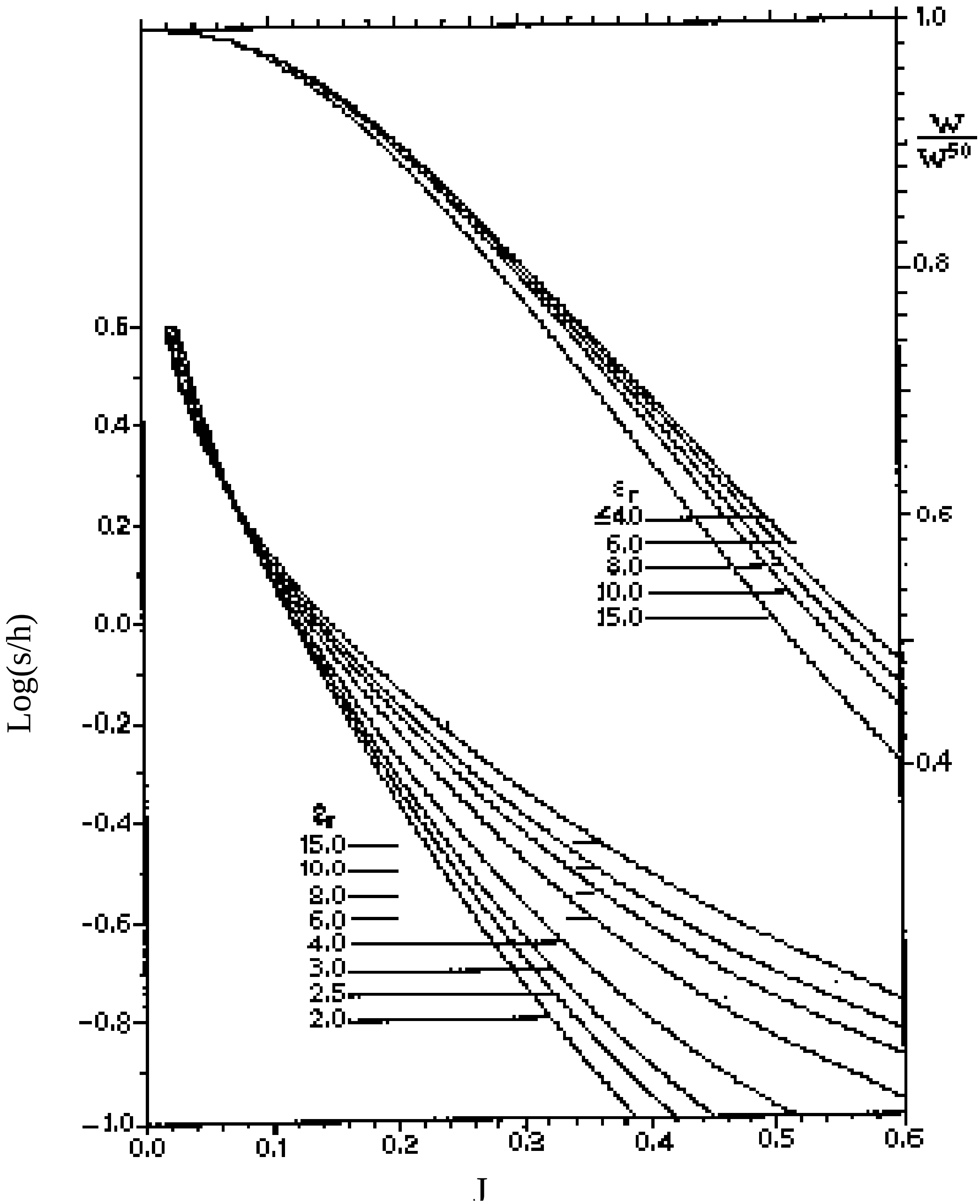
Multisection transformer

Binomial matching transformer

$$\Gamma_n = AC_n^N = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} \cong \frac{1}{2}\ln\frac{Z_{n+1}}{Z_n}$$

$$A = 2^{-N}\,\frac{Z_L - Z_o}{Z_L + Z_o} \cong 2^{-N}\,\ln\frac{Z_L}{Z_o}$$

$$C_n^N = \frac{N!}{(N-n)!\,n!}$$


1.0
W/W50
0.8
0.6
0.4
εr
≤4.0
6.0
8.0
10.0
15.0
0.5
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Log(s/h)
εr
15.0
10.0
8.0
6.0
4.0
3.0
2.5
2.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
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