# UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2006/2007

October/November 2006

## EEE 532 – MICROWAVE CIRCUIT DESIGN

Duration: 2 hours

Please check that this examination paper consists of FOUR pages of printed material and ELEVEN pages Appendices before you begin the examination.

This paper contains SIX questions. TWO questions in Section A, TWO questions in Section B and TWO questions in Section C.

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

Use three answer booklets which is provided where the answer for questions in Section A, B and C are in difference answer booklets.

Answer to any question must start on a new page.

Distribution of marks for each question is given accordingly.

All questions must be answered in English.

**Section A: Answer ONE (1) question**

1. (a) Design a matching section using a single L-network to match a load of $Z_L$= 50 – j50 ohm to a 100 ohm line using lumped components at frequency 1GHz. Give all possible solutions.

(10%)

(b) Design a three section binomial transformer to match 100 ohm load to a 50 ohm line.

(15%)

2. Design a 25dB 3 sections coupled line coupler with a maximally flat coupling response. Assume $Z_o$ =50 Ω, and find $Z_{oe}$, $Z_{oo}$ for each section. Using a substrate of $\varepsilon_r$=10 and thickness of 1mm with center frequency of 3GHz, calculate all the parameters of the stripline using the graph in Appendix I. The voltage at port 3 in terms of port 1 is

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

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

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

(25%)

**Section B: Answer <u>ONE</u> (1) question**

3. (a) A certain two-port network is measured and the following scattering matrix is obtained:

$$[S]=\begin{bmatrix} 0.1\angle 0 & 0.8\angle 90^0 \\ 0.8\angle 90^0 & 0.2\angle 0 \end{bmatrix}$$

From this data, determine whether the network is reciprocal or lossless. If a short-circuit is placed on port 2, what will be the resulting return loss at port 1?

(11%)

(b) Find the S parameter for the series and shunt load shown in Figure 1. Show that $S_{12} = 1 - S_{11}$ for the series case, and $S_{12} = 1 + S_{11}$ for the shunt case. Assume characteristics impedance $Z_o$. [Hint: Refer to Table 1 in Appendix]

(14%)

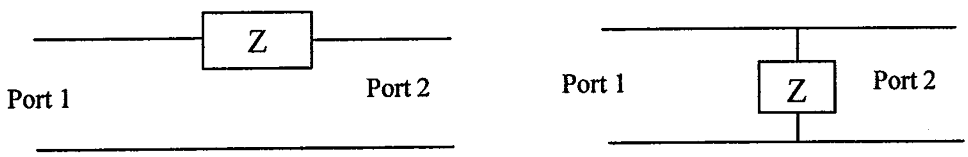


Figure 1

4. Design a low-pass composite filter with cutoff frequency of 2GHz and impedance of 75Ω. Place the infinite attenuation pole at 2.05GHz, and sketch the frequency response from 0 to 4GHz.

(25%)

**Section C: Answer ONE (1) question**

5. Design a Low Noise Amplifier operating at 4 GHz, the biasing of the LNA should be at $V_{DS}$ = 2 V and $I_{DS}$ = 5 mA. The required noise figure must be 1.2 dB. Select $\Gamma_{in}$ for input matching at a point of $C_{in}$. Use single stub matching technique and the length of the microstrip should be in millimeter. The parameters of the transistor can be found in Appendix V.

(25%)

6. (a) Explain the operation of the negative resistance oscillator with the aid of the diagram.

(10%)

(b) Explain what a resonator is and name three type of resonators that are typically used in the oscillator design.

(5%)

(c) Briefly describe the feedback type oscillator topology and explain what are the important criterions in the design of the feedback oscillator.

(5%)

(d) Explain what is phase noise in an oscillator. (5%)

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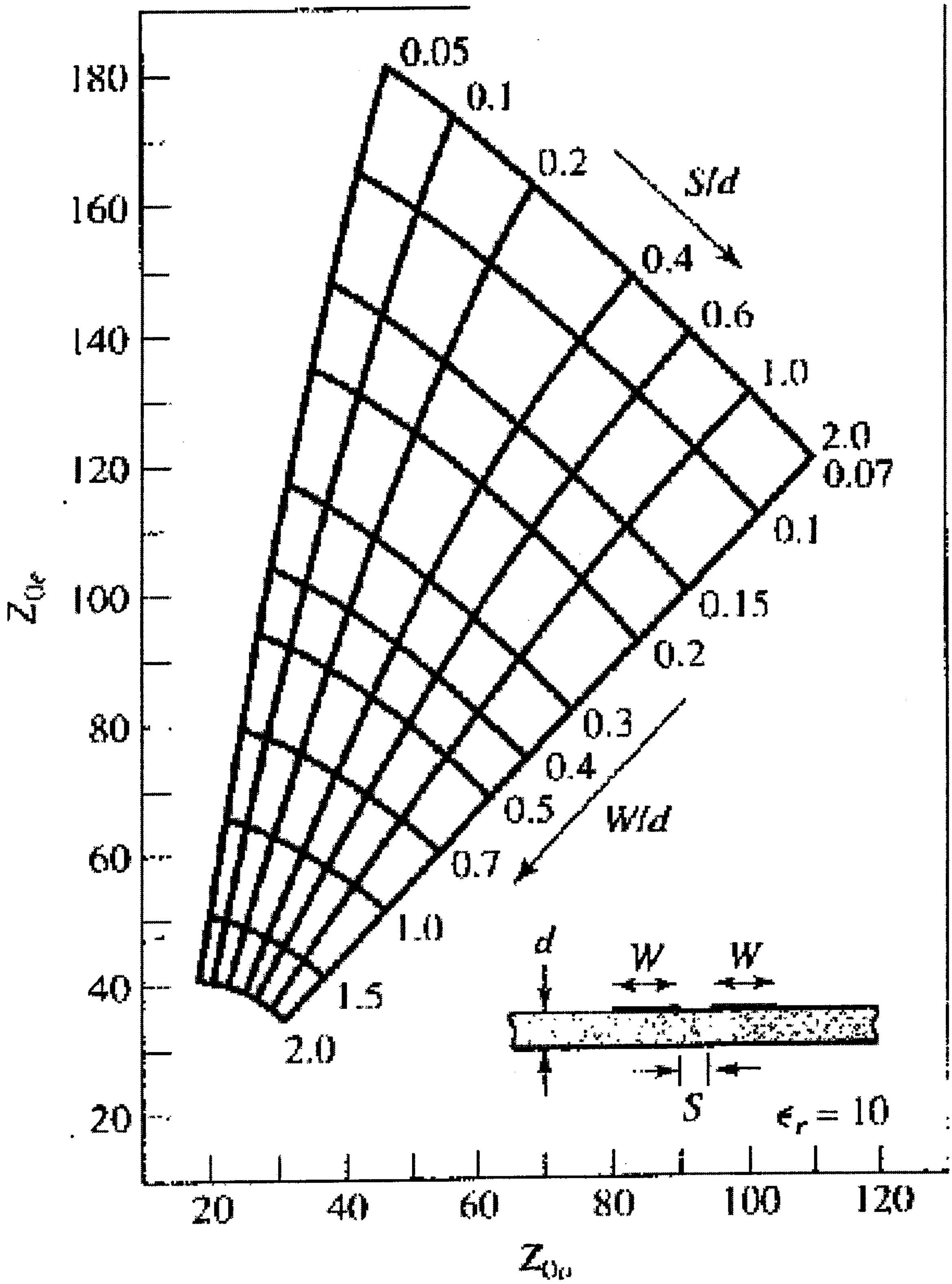

180
160
140
120
100
80
60
40
20
$Z_{0e}$
20
40
60
80
100
120
$Z_{0o}$
0.05
0.1
0.2
0.4
0.6
1.0
2.0
S/d
0.07
0.1
0.15
0.2
0.3
0.4
0.5
0.7
1.0
1.5
2.0
W/d
d
W
W
S
$\epsilon_r = 10$

## 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

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

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

### Butterworth lowpass filter

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

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

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

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

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

### Bandpass filter

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

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

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

## Bilateral

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

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

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

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

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

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

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

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

## Low Noise Amplifier

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

Radius: $$R_i = \frac{1}{1 + N_i}\sqrt{N_i^2 + N_i(1 - |\Gamma_{opt}|^2)}$$

$$Ni = \frac{\left[(Fr - F\min)|1 + \Gamma_{opt}|^2\right]}{4\dfrac{R_n}{Z_o}}$$

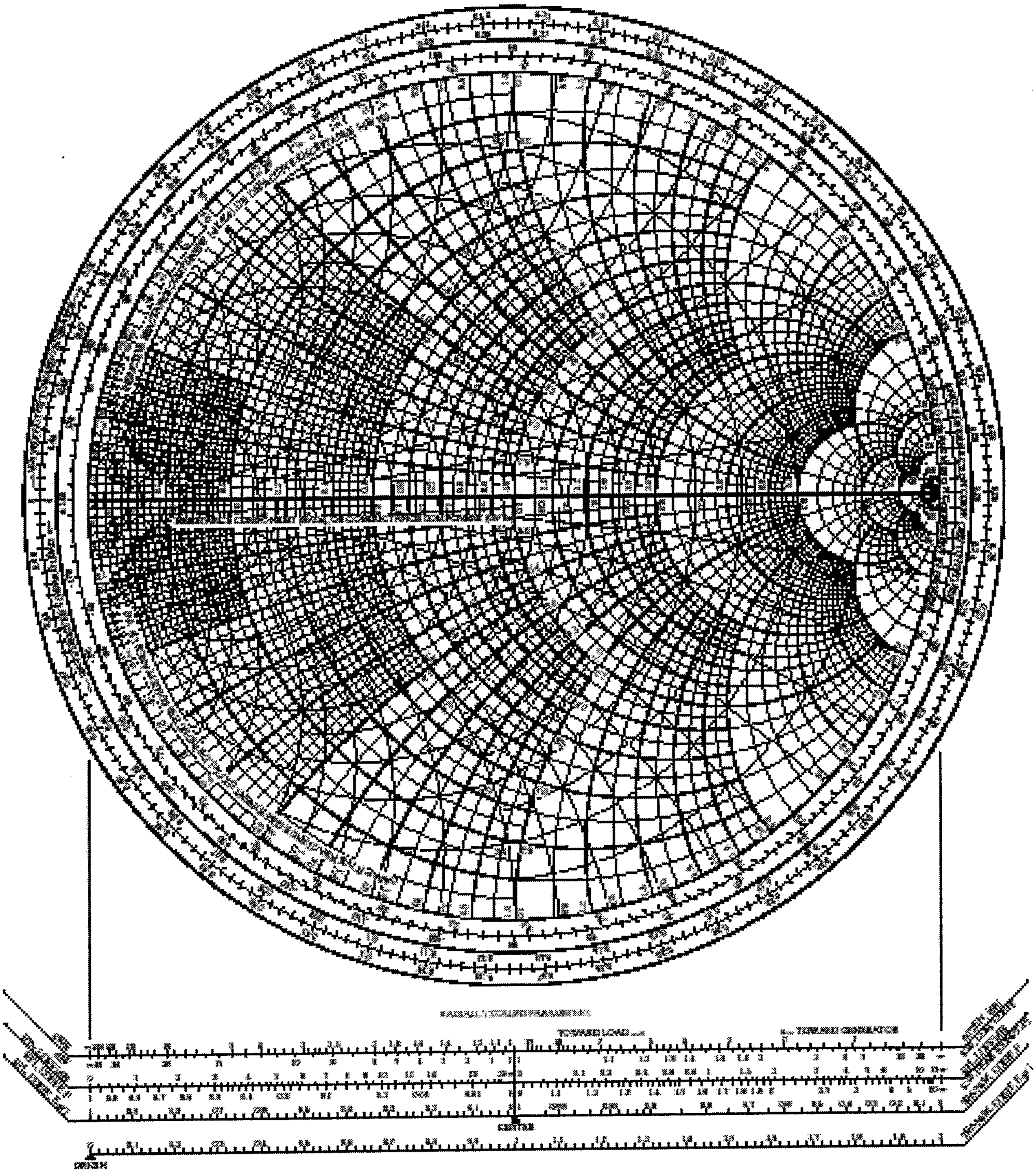
$$\Gamma_L = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_{in}}{1 - S_{11}\Gamma_{in}}\right)^*$$

# APPENDIX III

**[EEE 532]**

| NAME | TITLE | DWG. NO. |
|---|---|---|
| | | DATE |
| SMITH CHART FORM ZY-01-N | Microwave Circuit Design - EE[illegible] - Fall 2000 | |

NORMALIZED IMPEDANCE AND ADMITTANCE COORDINATES



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## ABSOLUTE MAXIMUM RATINGS[1] ($T_A = 25°C$)

| SYMBOLS | PARAMETERS | UNITS | RATINGS |
|---|---|---|---|
| $V_{DS}$ | Drain to Source Voltage | V | 4 |
| $V_{GDO}$ | Gate to Drain Voltage | V | -3 |
| $V_{GSO}$ | Gate to Source Voltage | V | -3 |
| $I_{DS}$ | Drain Current | mA | $I_{DSS}$ |
| $T_{CH}$ | Channel Temperature | °C | 125 |
| $T_{STG}$ | Storage Temperature | °C | -65 to +125 |
| $P_T$ | Total Power Dissipation | mW | 150 |

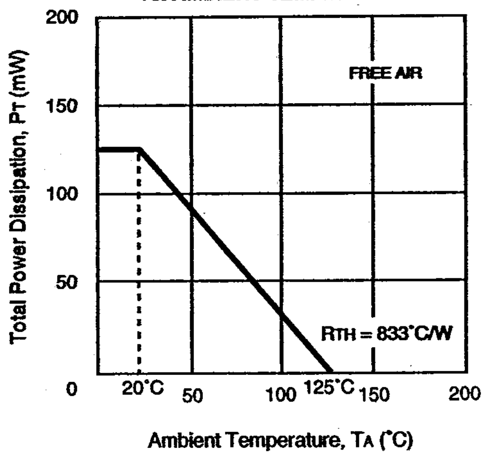
Note:
1. Operation in excess of any one of these parameters may result in permanent damage.

## TYPICAL NOISE PARAMETERS ($T_A = 25°C$)

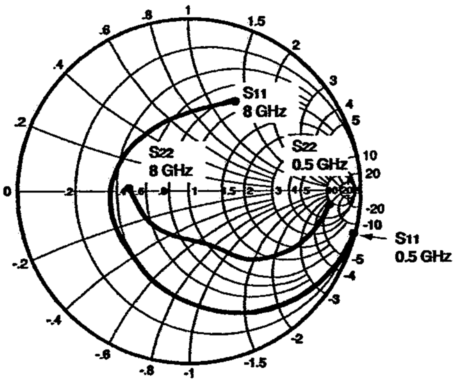
| FREQ. (MHz) | $NF_{OPT}$ (dB) | $G_A$ (dB) | $\Gamma_{OPT}$ MAG | $\Gamma_{OPT}$ ANG | Rn/50 |
|---|---|---|---|---|---|
| $V_{DS} = 2$ V, $I_{DS} = 10$ mA | | | | | |
| 900 | .56 | 20.5 | .76 | 30 | .45 |
| 2000 | .63 | 16.3 | .61 | 41 | .28 |
| 2500 | .68 | 14.1 | .49 | 51 | .18 |
| 3000 | .70 | 13.6 | .39 | 49 | .16 |
| 3500 | .76 | 12.3 | .28 | 71 | .12 |
| 4000 | .82 | 11.6 | .20 | 80 | .10 |
| $V_{DS} = 2$ V, $I_{DS} = 30$ mA | | | | | |
| 2000 | .60 | 17.0 | .56 | 39 | .23 |
| 2500 | .70 | 15.3 | .43 | 46 | .15 |
| 3000 | .76 | 14.2 | .32 | 50 | .26 |
| $V_{DS} = 3$ V, $I_{DS} = 20$ mA | | | | | |
| 900 | .56 | 20.2 | .74 | 26 | 1.54 |
| 2000 | .62 | 16.8 | .62 | 42 | .43 |
| 2500 | .66 | 14.9 | .56 | 50 | .31 |
| 3000 | .70 | 14.0 | .45 | 65 | .24 |
| 3500 | .80 | 13.2 | .36 | 76 | .14 |
| 4000 | .84 | 12.8 | .29 | 85 | .10 |
| 4500 | .90 | 11.0 | .20 | 98 | .08 |

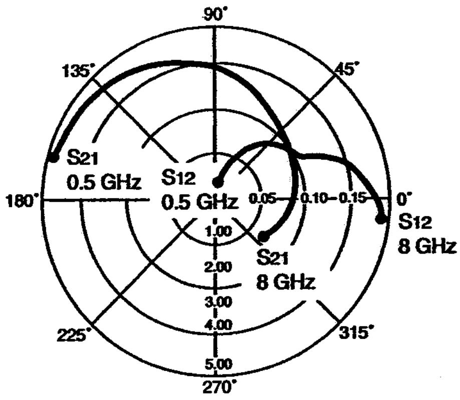
## TYPICAL PERFORMANCE CURVES ($T_A = 25°C$)

**TOTAL POWER DISSIPATION vs. AMBIENT TEMPERATURE**



## TYPICAL SCATTERING PARAMETERS ($T_A = 25°C$)




**$V_{DS}$ = 2 V, $I_{DS}$ = 5 mA**

| FREQUENCY | S11 | | S21 | | S12 | | S22 | | K | MAG[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| (GHz) | MAG | ANG | MAG | ANG | MAG | ANG | MAG | ANG | | (dB) |
| 0.50 | 0.984 | -15.1 | 4.945 | 165.0 | 0.020 | 80.6 | 0.807 | -7.2 | 0.135 | 23.931 |
| 0.60 | 0.979 | -18.0 | 4.908 | 162.3 | 0.023 | 78.9 | 0.803 | -8.6 | 0.152 | 23.292 |
| 0.70 | 0.973 | -21.0 | 4.899 | 159.4 | 0.027 | 77.0 | 0.798 | -10.0 | 0.174 | 22.587 |
| 0.80 | 0.965 | -23.9 | 4.871 | 156.7 | 0.031 | 75.3 | 0.793 | -11.5 | 0.195 | 21.963 |
| 0.90 | 0.958 | -26.8 | 4.843 | 153.9 | 0.034 | 73.7 | 0.788 | -12.9 | 0.213 | 21.536 |
| 1.00 | 0.949 | -29.8 | 4.825 | 151.1 | 0.038 | 72.1 | 0.781 | -14.4 | 0.231 | 21.037 |
| 1.20 | 0.930 | -35.7 | 4.783 | 145.6 | 0.045 | 68.7 | 0.767 | -17.3 | 0.270 | 20.265 |
| 1.40 | 0.906 | -41.5 | 4.723 | 140.2 | 0.052 | 65.4 | 0.751 | -20.2 | 0.314 | 19.582 |
| 1.60 | 0.881 | -47.5 | 4.660 | 134.7 | 0.058 | 62.2 | 0.734 | -23.1 | 0.354 | 19.050 |
| 1.80 | 0.853 | -53.6 | 4.605 | 129.3 | 0.064 | 59.1 | 0.715 | -26.0 | 0.395 | 18.570 |
| 2.00 | 0.821 | -59.8 | 4.531 | 123.8 | 0.070 | 56.0 | 0.696 | -28.9 | 0.438 | 18.111 |
| 2.50 | 0.737 | -76.3 | 4.332 | 110.5 | 0.082 | 48.2 | 0.648 | -36.0 | 0.542 | 17.229 |
| 3.00 | 0.648 | -94.2 | 4.092 | 97.6 | 0.092 | 41.4 | 0.600 | -42.4 | 0.643 | 16.481 |
| 3.50 | 0.569 | -113.6 | 3.805 | 85.3 | 0.098 | 35.3 | 0.556 | -47.7 | 0.748 | 15.891 |
| 4.00 | 0.512 | -133.0 | 3.516 | 73.9 | 0.102 | 30.5 | 0.518 | -51.8 | 0.845 | 15.374 |
| 4.50 | 0.482 | -150.9 | 3.248 | 63.8 | 0.105 | 27.2 | 0.480 | -54.9 | 0.932 | 14.904 |
| 5.00 | 0.472 | -165.2 | 3.025 | 54.7 | 0.108 | 25.3 | 0.444 | -57.8 | 1.004 | 14.074 |
| 5.50 | 0.468 | -175.7 | 2.846 | 46.4 | 0.112 | 24.5 | 0.405 | -61.0 | 1.068 | 12.459 |
| 6.00 | 0.464 | 176.0 | 2.714 | 38.4 | 0.118 | 23.7 | 0.367 | -65.4 | 1.107 | 11.622 |
| 6.50 | 0.456 | 167.9 | 2.601 | 30.5 | 0.126 | 22.4 | 0.331 | -71.6 | 1.130 | 10.955 |
| 7.00 | 0.441 | 158.2 | 2.505 | 22.1 | 0.134 | 20.2 | 0.302 | -80.8 | 1.149 | 10.372 |
| 7.50 | 0.422 | 144.3 | 2.417 | 13.3 | 0.142 | 18.0 | 0.283 | -92.2 | 1.161 | 9.874 |
| 8.00 | 0.411 | 127.5 | 2.321 | 4.0 | 0.151 | 15.0 | 0.281 | -105.9 | 1.152 | 9.503 |

**Note:**

1. Gain Calculations:

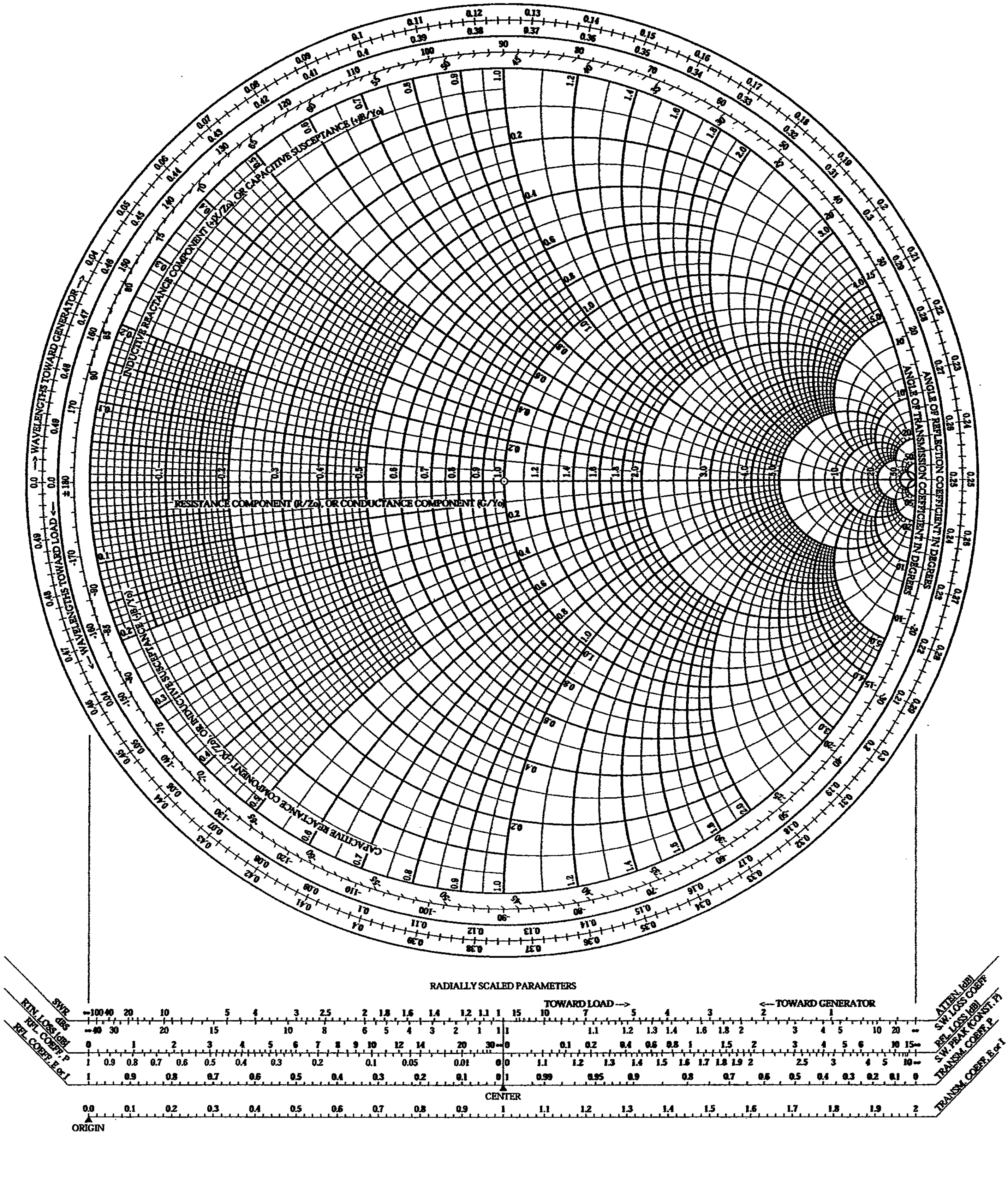
$MAG = \frac{|S_{21}|}{|S_{12}|}\left(K \pm \sqrt{K^2 - 1}\right)$. When $K \leq 1$, MAG is undefined and MSG values are used. $MSG = \frac{|S_{21}|}{|S_{12}|}$, $K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2\,|S_{12} S_{21}|}$, $\Delta = S_{11} S_{22} - S_{21} S_{12}$

MAG = Maximum Available Gain
MSG = Maximum Stable Gain

**APPENDIX V**

# The Complete Smith Chart

Black Magic Design



# The Complete Smith Chart

Black Magic Design

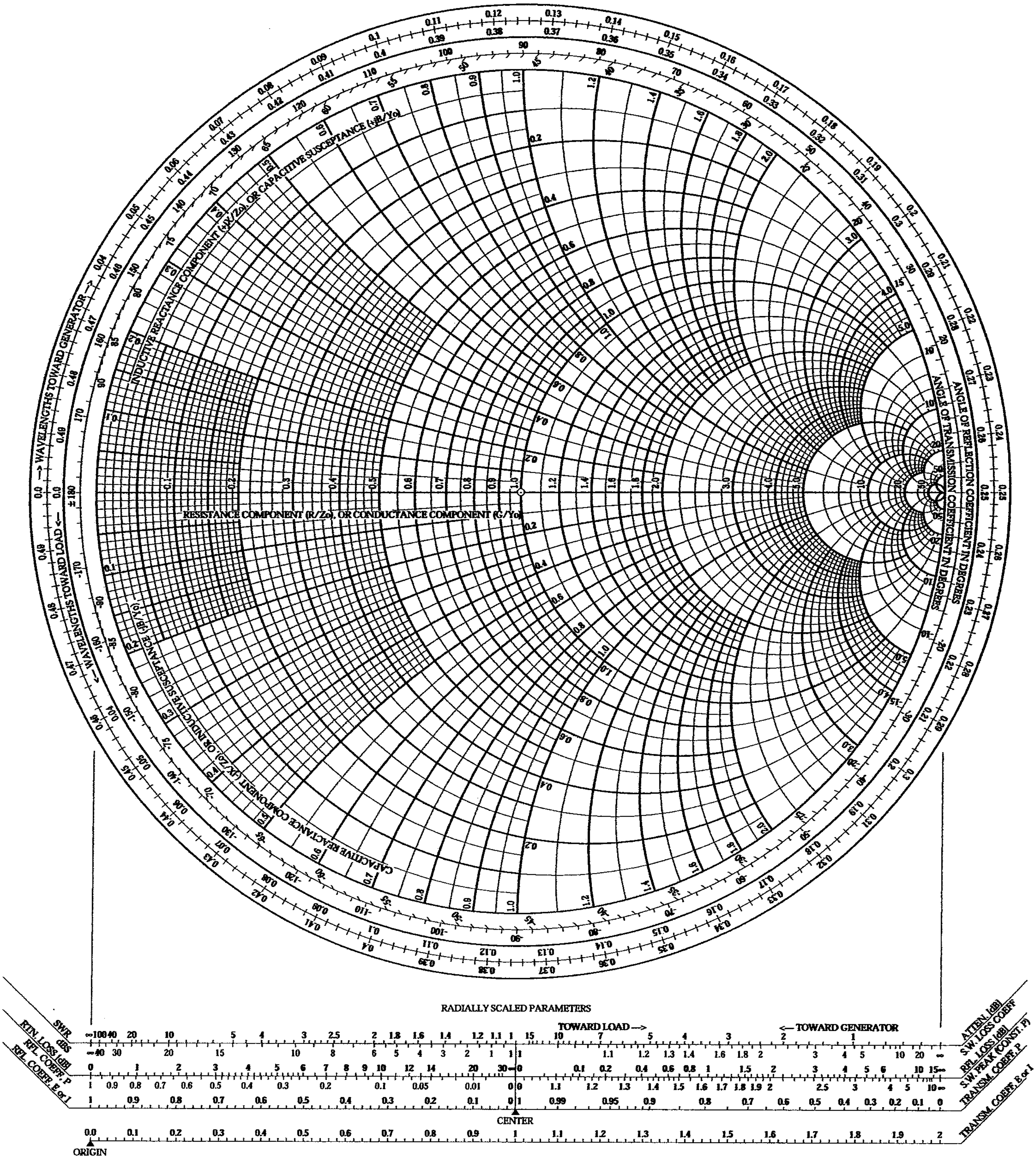


Table 1 Conversions between two-port network parameters

| | $S$ | $Z$ | $Y$ | $ABCD$ |
|---|---|---|---|---|
| $S_{11}$ | $S_{11}$ | $\frac{(Z_{11}-Z_0)(Z_{22}+Z_0)-Z_{12}Z_{21}}{\Delta Z}$ | $\frac{(Y_0-Y_{11})(Y_0+Y_{22})+Y_{12}Y_{21}}{\Delta Y}$ | $\frac{A+B/Z_0-CZ_0-D}{A+B/Z_0+CZ_0-D}$ |
| $S_{12}$ | $S_{12}$ | $\frac{2Z_{12}Z_0}{\Delta Z}$ | $\frac{-2Y_{12}Y_0}{\Delta Y}$ | $\frac{2(AD-BC)}{A+B/Z_0+CZ_0-D}$ |
| $S_{21}$ | $S_{21}$ | $\frac{2Z_{21}Z_0}{\Delta Z}$ | $\frac{-2Y_{21}Y_0}{\Delta Y}$ | $\frac{2}{A+B/Z_0+CZ_0-D}$ |
| $S_{22}$ | $S_{22}$ | $\frac{(Z_{11}+Z_0)(Z_{22}-Z_0)-Z_{12}Z_{21}}{\Delta Z}$ | $\frac{(Y_0+Y_{11})(Y_0-Y_{22})+Y_{12}Y_{21}}{\Delta Y}$ | $\frac{-A+B/Z_0-CZ_0-D}{A+B/Z_0+CZ_0-D}$ |
| $Z_{11}$ | $Z_0\frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{(1-S_{11})(1-S_{22})-S_{12}S_{21}}$ | $Z_{11}$ | $\frac{Y_{22}}{\|Y\|}$ | $\frac{A}{C}$ |
| $Z_{12}$ | $Z_0\frac{2S_{12}}{(1-S_{11})(1-S_{22})-S_{12}S_{21}}$ | $Z_{12}$ | $\frac{-Y_{12}}{\|Y\|}$ | $\frac{AD-BC}{C}$ |
| $Z_{21}$ | $Z_0\frac{2S_{21}}{(1-S_{11})(1-S_{22})-S_{12}S_{21}}$ | $Z_{21}$ | $\frac{-Y_{21}}{\|Y\|}$ | $\frac{1}{C}$ |
| $Z_{22}$ | $Z_0\frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{(1-S_{11})(1-S_{22})-S_{12}S_{21}}$ | $Z_{22}$ | $\frac{Y_{11}}{\|Y\|}$ | $\frac{D}{C}$ |
| $Y_{11}$ | $Y_0\frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$ | $\frac{Z_{22}}{\|Z\|}$ | $Y_{11}$ | $\frac{D}{B}$ |
| $Y_{12}$ | $Y_0\frac{-2S_{12}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$ | $\frac{-Z_{12}}{\|Z\|}$ | $Y_{12}$ | $\frac{BC-AD}{B}$ |
| $Y_{21}$ | $Y_0\frac{-2S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$ | $\frac{-Z_{21}}{\|Z\|}$ | $Y_{21}$ | $\frac{-1}{B}$ |
| $Y_{22}$ | $Y_0\frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$ | $\frac{Z_{11}}{\|Z\|}$ | $Y_{22}$ | $\frac{A}{B}$ |
| $A$ | $\frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}}$ | $\frac{Z_{11}}{Z_{21}}$ | $\frac{-Y_{22}}{Y_{21}}$ | $A$ |
| $B$ | $Z_0\frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}}$ | $\frac{\|Z\|}{Z_{21}}$ | $\frac{-1}{Y_{21}}$ | $B$ |
| $C$ | $\frac{1}{Z_0}\frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}}$ | $\frac{1}{Z_{21}}$ | $\frac{-\|Y\|}{Y_{21}}$ | $C$ |
| $D$ | $\frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}}$ | $\frac{Z_{22}}{Z_{21}}$ | $\frac{-Y_{11}}{Y_{21}}$ | $D$ |

$|Z| = Z_{11}Z_{22} - Z_{12}Z_{21}$; $|Y| = Y_{11}Y_{22} - Y_{12}Y_{21}$; $\Delta Y = (Y_{11}+Y_0)(Y_{22}+Y_0) - Y_{12}Y_{21}$; $\Delta Z = (Z_{11}+Z_0)(Z_{22}+Z_0) - Z_{12}Z_{21}$; $Y_0 = 1/Z_0$

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