SOLUTIONS MANUAL

MICROWAVE TRANSISTOR AMPLIFIERS

Analysis and Design

SECOND EDITION

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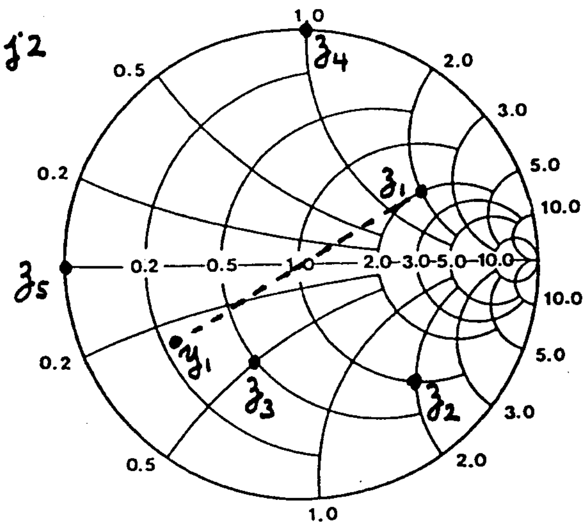
2.1) (a) LET $z_1 = \frac{Z}{50} = \frac{100+j100}{50} = 2+j2$

(z_1 IS SHOWN IN THE SMITH CHART)

(b) $y_1 = \frac{1}{z_1} = 0.25 - j0.25$

(y_1 IS SHOWN IN THE SMITH CHART)



(c) IN THE ZY SMITH CHART THE LOCATION OF z_1 IS THE SAME AS IN (a). THE VALUE OF y_1 IS READ FROM THE GREEN CIRCLES.

(d) $z_2 = \frac{50-j100}{50} = 1-j2$

$y_2 = \frac{1}{z_2} = 0.2+j0.4$

$z_3 = \frac{25-j25}{50} = 0.5-j0.5$ $\qquad z_4 = j\frac{50}{50} = j1$ $\qquad z_5 = j0$

$y_3 = \frac{1}{z_3} = 1+j$ $\qquad y_4 = \frac{1}{z_4} = -j1$ $\qquad y_5 = \infty$

(z_2, z_3, z_4, AND z_5 ARE SHOWN IN THE SMITH CHART)

2.2) (a) $z = -r + jx \quad , \quad \Gamma = \frac{z-1}{z+1} = \frac{-(r+1)+jx}{(1-r)+jx} \qquad (1)$

$$|\Gamma| = \frac{\sqrt{(r+1)^2+x^2}}{\sqrt{(1-r)^2+x^2}} = \left[\frac{r^2+2r+1+x^2}{r^2-2r+1+x^2}\right]^{1/2} \qquad (2)$$

IN (1) THE NUMERATOR IS GREATER THAN THE DENOMINATOR, SINCE $2r > -2r$. HENCE, $|\Gamma| > 1$

(b) FROM (1): $\frac{1}{\Gamma^*} = \frac{(1-r)-jx}{-(r+1)-jx} = \frac{(r-1)+jx}{(r+1)+jx} \qquad (3)$

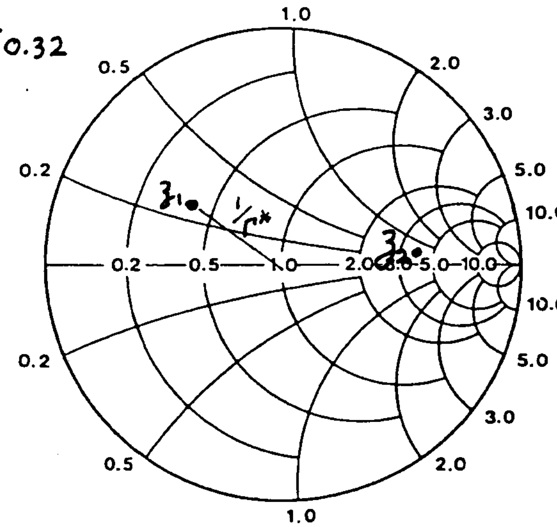
EQ. (3) IS IDENTICAL TO THE TRANSFORMATION IN (2.2.2) WHERE $z = r+jx$ WITH $r \geq 0$. HENCE, NEGATIVE RESISTANCES CAN BE HANDLED IN THE SMITH CHART BY PLOTTING $\frac{1}{\Gamma^*}$ AND INTERPRETING THE RESISTANCE CIRCLES AS BEING NEGATIVE, AND THE REACTANCE CIRCLES AS MARKED.

(c) $z_1 = \frac{Z_1}{50} = \frac{-20+j16}{50} = -0.4+j0.32$

FROM THE SMITH CHART WE READ:

$$\frac{1}{\Gamma^*} = 0.47 \angle 139°$$

HENCE $\Gamma = 2.1 \angle 139°$



FOR:

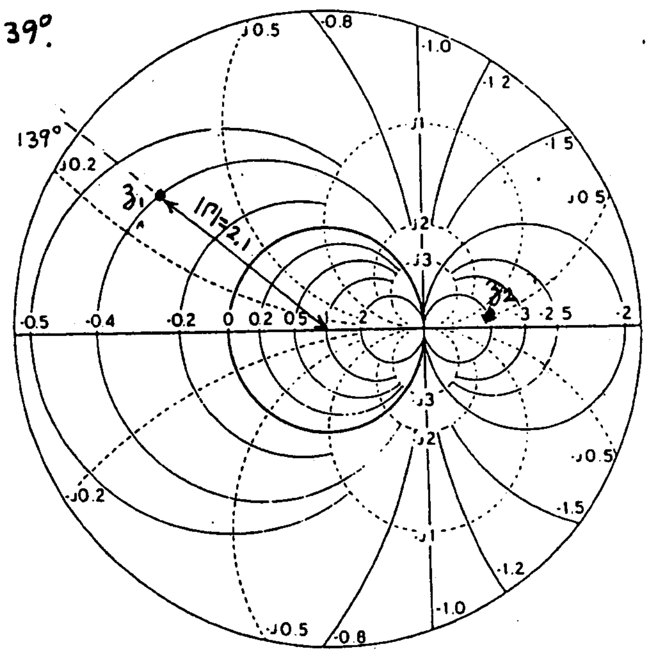
$$z_2 = \frac{-200+j25}{50} = -4+j0.5$$

$$\frac{1}{\Gamma^*} = 0.61 \angle 3.75°$$

HENCE $\Gamma = 1.6 \angle 3.75°$

(d) SEE THE COMPRESSED SMITH CHART. FOR $z_1 = -0.4+j0.32$ WE READ: $|\Gamma| = 2.1$, $\angle\Gamma = 139°$. HENCE $\Gamma = 2.1 \angle 139°$.

SIMILARLY, FOR z_2 WE OBTAIN $\Gamma = 1.6 \angle 3.75°$



(e) $|\Gamma| \approx 3.2$

2.3) $$Z(d) = Z_0 \frac{Z_L + jZ_0 \tan\beta d}{Z_0 + jZ_L \tan\beta d}$$

$$Z\left(d+\frac{n\lambda}{2}\right) = Z_0 \frac{Z_L + jZ_0 \tan\left(\beta d + \frac{n\beta\lambda}{2}\right)}{Z_0 + jZ_L \tan\left(\beta d + \frac{n\beta\lambda}{2}\right)} \quad ; \; n\beta\frac{\lambda}{2} = n\frac{2\pi}{\lambda}\frac{\lambda}{2} = n\pi$$

$$\tan(\beta d + n\pi) = \tan\beta d$$

HENCE,

$$Z\left(d+\frac{n\lambda}{2}\right) = Z(d)$$

2.4) FROM (2.2.6) AND (2.2.7): LET $\Gamma_0 = |\Gamma_0| e^{j\phi_\ell}$, THEN

$$\Gamma = \Gamma_0 e^{-j2\beta d} = |\Gamma_0| e^{j(\phi_\ell - 2\beta d)} = |\Gamma| e^{j\phi}; \quad |\Gamma| = |\Gamma_0|$$

$$\phi = \phi_\ell - 2\beta d$$

$$Z(d) = Z_0 \left[\frac{1 + |\Gamma| e^{j\phi}}{1 - |\Gamma| e^{j\phi}} \right]$$

$$= Z_0 \left[\frac{1 + |\Gamma|\cos\phi + j|\Gamma|\sin\phi}{1 - |\Gamma|\cos\phi - j|\Gamma|\sin\phi} \right] \qquad (1)$$

$$= Z_0 \left[\frac{1 - |\Gamma|^2\cos^2\phi - |\Gamma|^2\sin^2\phi + j2|\Gamma|\sin\phi}{(1 - |\Gamma|\cos\phi)^2 + (|\Gamma|\sin\phi)^2} \right]$$

OR

$$Z(d) = Z_0 \left[\frac{1 - |\Gamma|^2 + j2|\Gamma|\sin\phi}{1 - 2|\Gamma|\cos\phi + |\Gamma|^2} \right] = R(d) + jX(d)$$

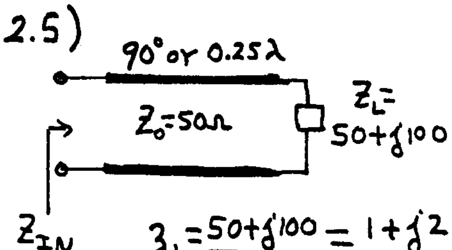
HENCE: $R(d) = Z_0 \dfrac{1 - |\Gamma|^2}{1 - 2|\Gamma|\cos\phi + |\Gamma|^2}$, $X(d) = Z_0 \dfrac{2|\Gamma|\sin\phi}{1 - 2|\Gamma|\cos\phi + |\Gamma|^2}$

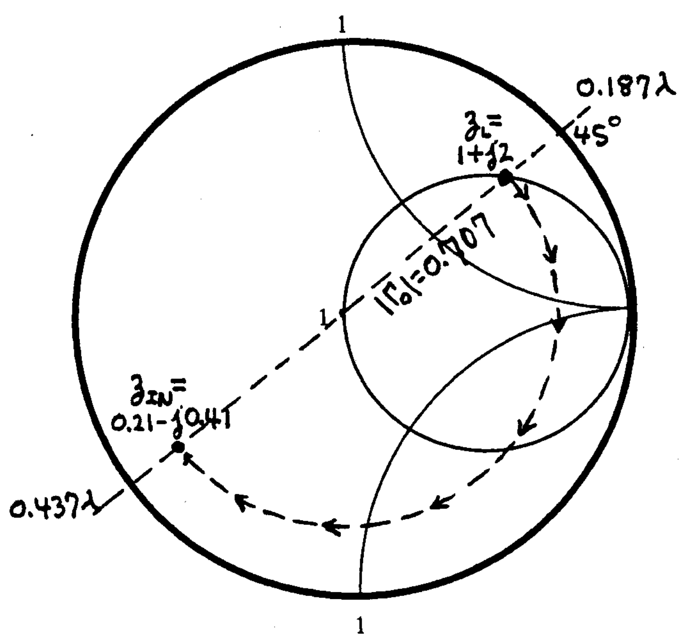
ALSO, FROM (1)

$$|Z(d)| = Z_0 \left[\frac{(1 + |\Gamma|\cos\phi)^2 + (|\Gamma|\sin\phi)^2}{(1 - |\Gamma|\cos\phi)^2 + (|\Gamma|\sin\phi)^2} \right]^{1/2} = Z_0 \left[\frac{1 + 2|\Gamma|\cos\phi + |\Gamma|^2}{1 - 2|\Gamma|\cos\phi + |\Gamma|^2} \right]^{1/2}$$

$$\theta_d = \tan^{-1} \frac{X(d)}{R(d)} = \tan^{-1} \left[\frac{2|\Gamma|\sin\phi}{1 - |\Gamma|^2} \right]$$

2.5)





$$z_L = \frac{50 + j100}{50} = 1 + j2$$

LOCATE z_L IN THE SMITH CHART. AT z_L READ 0.187λ. DRAW A CONSTANT $|\Gamma|$ CIRCLE. z_{IN} IS AT 0.25λ FROM z_L (OR $0.187\lambda + 0.25\lambda = 0.437\lambda$).

HENCE: $z_{IN} = 0.21 - j0.41$

$Z_{IN} = 50 z_{IN} = 10.5 - j20.5\,\Omega$

$\Gamma_0 = 0.707 \angle 45°$

$$VSWR = \frac{1 + 0.707}{1 - 0.707} = 5.83$$

2.6) (a) $|V(d)|_{max} = |A_1|(1+|\Gamma_0|)$ AND $|I(d)|_{min} = \dfrac{|A_1|}{Z_0}(1-|\Gamma_0|)$

HENCE: $$R(d)_{max} = \frac{|V(d)|_{max}}{|I(d)|_{min}} = Z_0\,\frac{1+|\Gamma_0|}{1-|\Gamma_0|}$$

$$r(d)_{max} = \frac{R(d)_{max}}{Z_0} = \frac{1+|\Gamma_0|}{1-|\Gamma_0|} = \text{VSWR}$$

(b) $|V(d)|_{min} = |A_1|(1-|\Gamma_0|)$ AND $|I(d)|_{max} = \dfrac{|A_1|}{Z_0}(1+|\Gamma_0|)$

HENCE: $$R(d)_{min} = \frac{|V(d)|_{min}}{|I(d)|_{max}} = Z_0\,\frac{1-|\Gamma_0|}{1+|\Gamma_0|}$$

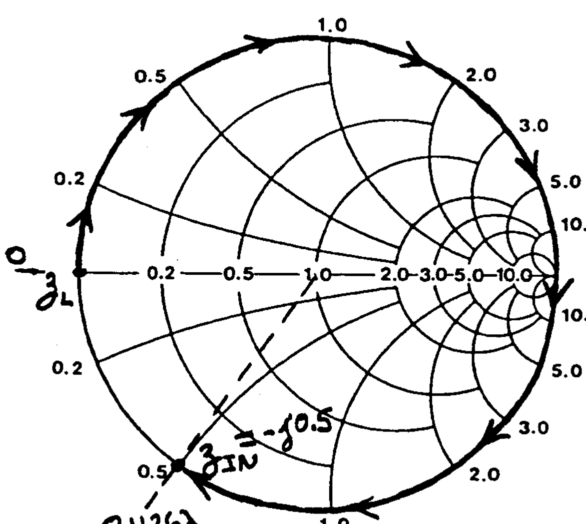
$$r(d)_{min} = \frac{R(d)_{min}}{Z_0} = \frac{1-|\Gamma_0|}{1+|\Gamma_0|} = \frac{1}{\text{VSWR}}$$

2.7) (a) $z_{IN} = -j\dfrac{25}{50} = -j0.5$

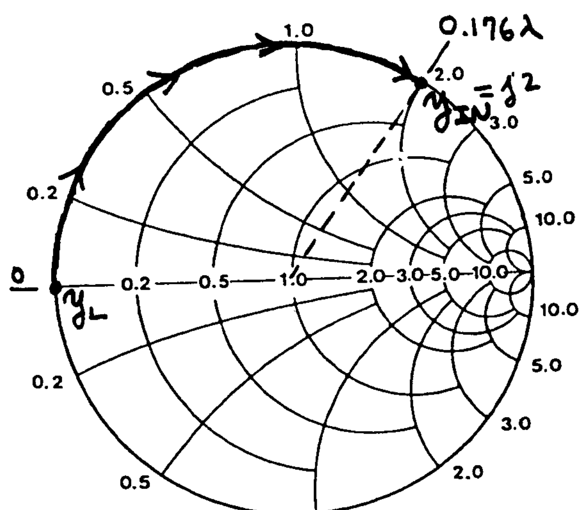
FROM THE Z SMITH CHART : $\ell = 0.426\lambda$

(b) $y_{IN} = j2$

FROM THE Y SMITH CHART: $\ell = 0.176\lambda$

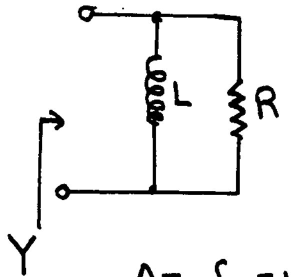


Z CHART



Y CHART

2.8) THE FREQUENCY RESPONSE FOLLOWS A CONSTANT CONDUCTANCE CIRCLE WITH $g=1$. THE EQUIVALENT CIRCUIT IS (SEE FIG. 2.3.2b)



$$Y = \frac{1}{R} - \frac{j}{\omega L}$$

$$y = \frac{Y}{Y_o} = YZ_o = \frac{Z_o}{R} - j\frac{Z_o}{\omega L}$$

$$g = 1 = \frac{Z_o}{R} \Rightarrow R = 50\,\Omega$$

AT $f_b = 1\,\text{GHz}$: $-j\frac{50}{\omega_b L} = -j0.5$, $L = \frac{50}{0.5(2\pi 10^9)} = 15.9\,\text{nH}$

OBSERVE THAT AT $f_a = 500\,\text{MHz}$: $y = -j\frac{Z_o}{\omega_a L} = \frac{-j50}{2\pi\, 500\, 10^6\, 15.9\, 10^{-9}} = j1$

2.9) (a) $r = 0.4$, $R = 50r = 50(0.4) = 20\,\Omega$

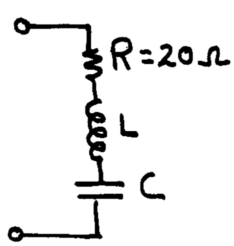
AT f_a, THE REACTANCE IS $-j0.6$; AND AT f_b IS $-j0.32$.

$$Z = 20 - \frac{j}{\omega C} \qquad \therefore \frac{1}{\omega_a C} = 0.6(50) = 30 \qquad (C = 50\,\text{pF})$$

OR $f_a = \frac{1}{2\pi(30)\,50\,10^{-12}} = 106.1\,\text{MHz}$

AND $\frac{1}{\omega_b C} = 0.32(50) = 16 \Rightarrow f_b = \frac{1}{2\pi(16)\,50\,10^{-12}} = 198.9\,\text{MHz}$

(b) THE EQUIVALENT CIRCUIT IS A SERIES R, L, C CIRCUIT.



AT $f_a = 500\,\text{MHz}$, $Z = 20 + j10$

$$\therefore 20 + j10 = R + j\left(\omega_a L - \frac{1}{\omega_a C}\right) \qquad (1)$$

AT $f_b = 1\,\text{GHz}$, $Z = 20 + j30$

$$\therefore 20 + j30 = R + j\left(\omega_b L - \frac{1}{\omega_b C}\right) \qquad (2)$$

FROM (1) AND (2) IT FOLLOWS THAT $R = 20\,\Omega$ AND

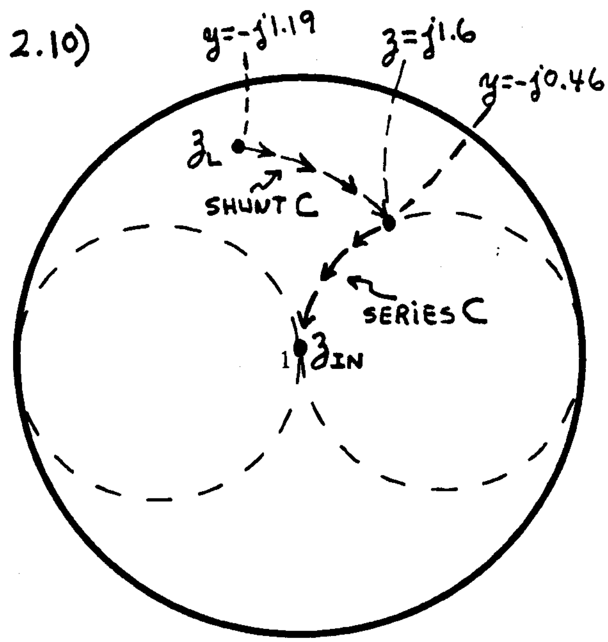
$$10 = 2\pi\left(f_a L - \frac{1}{f_a C}\right) \quad \text{AND} \quad 30 = 2\pi\left(f_b L - \frac{1}{f_b C}\right)$$

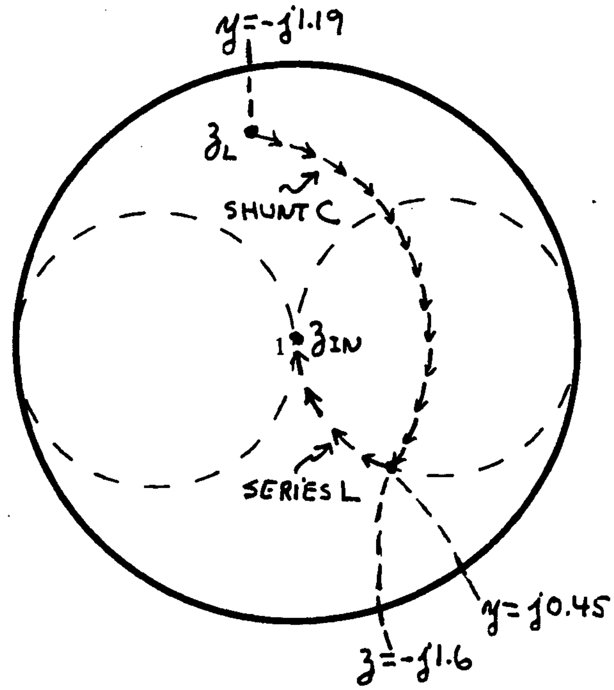
THE SIMULTANEOUS SOLUTION OF THESE EQUATIONS IS:

$L = 5.31\,\text{nH}$

$C = 47.64\,\text{pF}$

2.10)



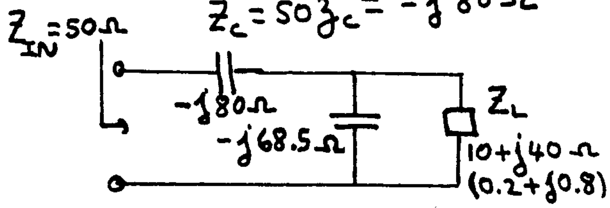


SHUNT C: $y_c = -j0.46 - (-j1.19) = j0.73$

$Z_c = \dfrac{50}{y_c} = -j68.5\,\Omega$

SERIES C: $z_c = 0 - j1.6 = -j1.6$

$Z_c = 50 z_c = -j80\,\Omega$

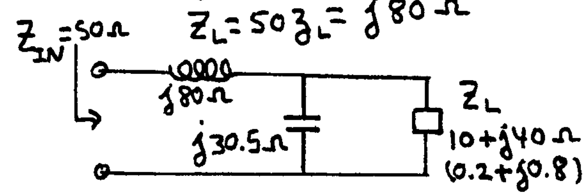


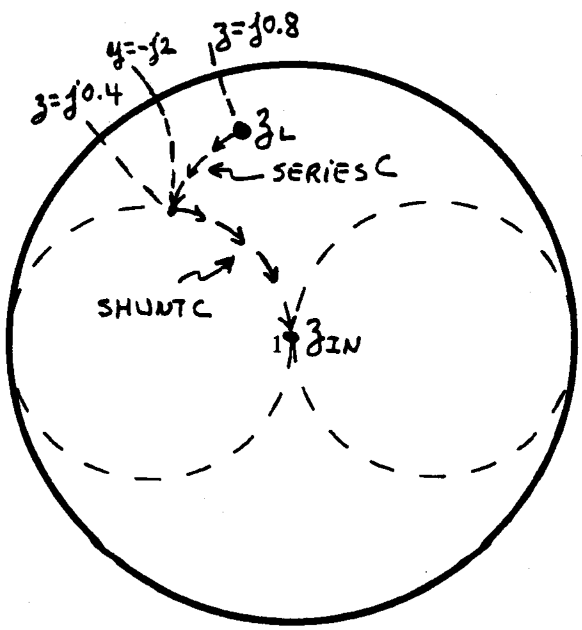
SHUNT C: $y_c = j0.45 - (-j1.19) = j1.64$

$Z_c = \dfrac{50}{j1.64} = -j30.5\,\Omega$

SERIES L: $z_L = 0 - (-j1.6) = j1.6$

$Z_L = 50 z_L = j80\,\Omega$



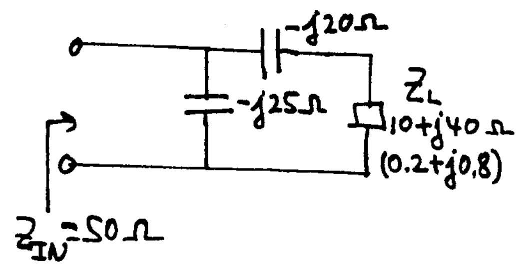


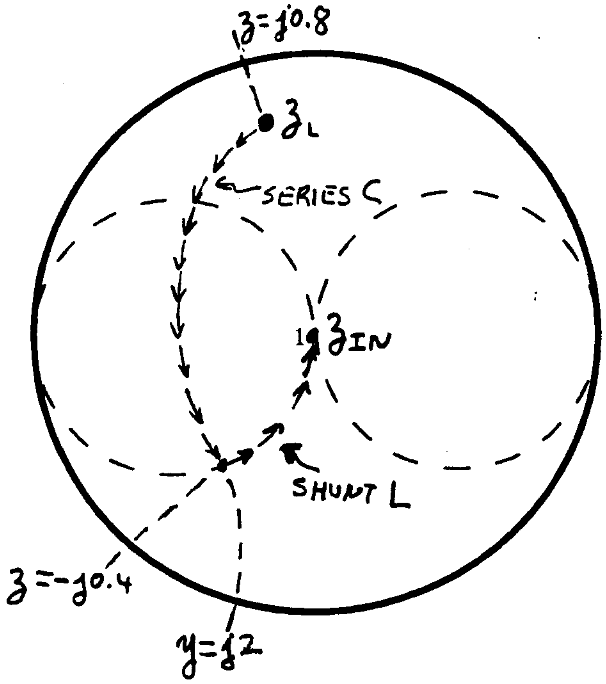
SERIES C: $z_c = j0.4 - j0.8 = -j0.4$

$Z_c = 50 z_c = -j20\,\Omega$

SHUNT C: $y_c = 0 - (-j2) = j2$

$Z_c = \dfrac{50}{j2} = -j25\,\Omega$



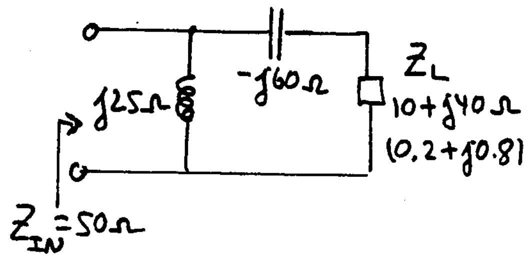


SERIES C: $z_C = -j0.4 - j0.8 = -j1.2$

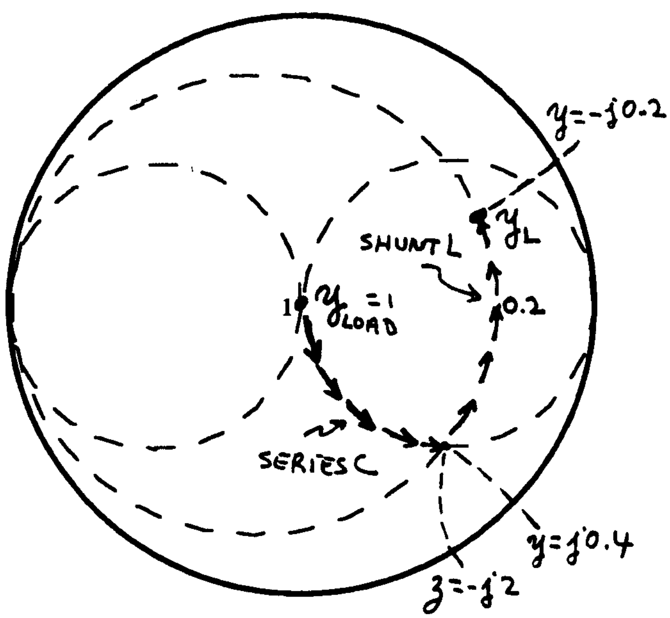
$Z_C = 50 z_C = -j60\,\Omega$

SHUNT L: $y_L = 0 - j2 = -j2$

$Z_L = \frac{50}{y_L} = j25\,\Omega$



2.11) $y_L = \frac{Y_L}{Y_0} = Z_0 Y_L = 50(4-j4)10^{-3} = 0.2 - j0.2$



SERIES C: $z_C = -j2 - j0 = -j2$

$Z_C = 50 z_C = -j100\,\Omega$

SHUNT L: $y_L = -j0.2 - j0.4 = -j0.6$

$Z_L = \frac{50}{y_L} = j83.3\,\Omega$

AT $f = 700$ MHz:

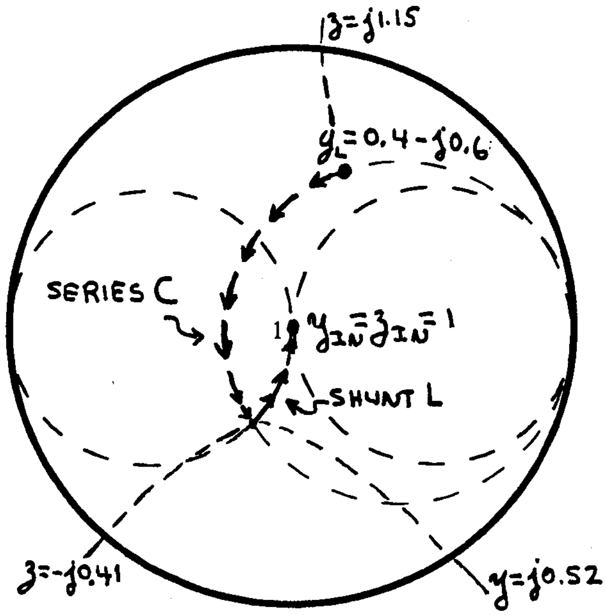
$Z_L = j\omega L = j83.3$

$L = \frac{83.3}{2\pi\, 700\,10^6} = 18.9$ nH

$Z_C = \frac{-j}{\omega C} = -j100$

$C = \frac{1}{100(2\pi\, 700\,10^6)} = 2.27$ pF

2.12) ONLY CIRCUIT (b) CAN MATCH $Y_L = 8 - j12$ mS TO $Z_{IN} = 50\Omega$.



SERIES C: $z_c = -j0.41 - j1.15 = -j1.56$

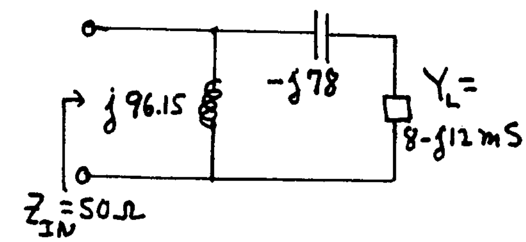
$Z_c = 50 z_c = -j78\,\Omega$

$C = \frac{1}{\omega(78)} = \frac{1}{2\pi 10^9 (78)} = 2.04$ pF

SHUNT L: $y_L = 0 - j0.52 = -j0.52$

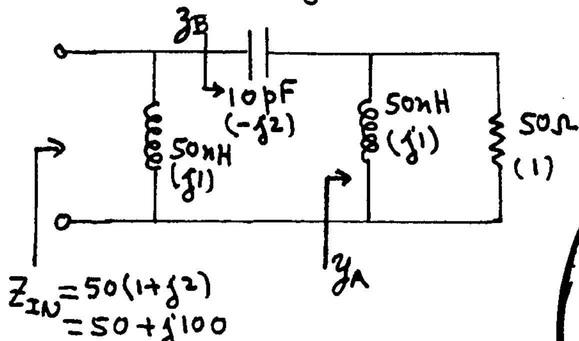
$Z_L = \frac{50}{y_L} = j96.15\,\Omega$

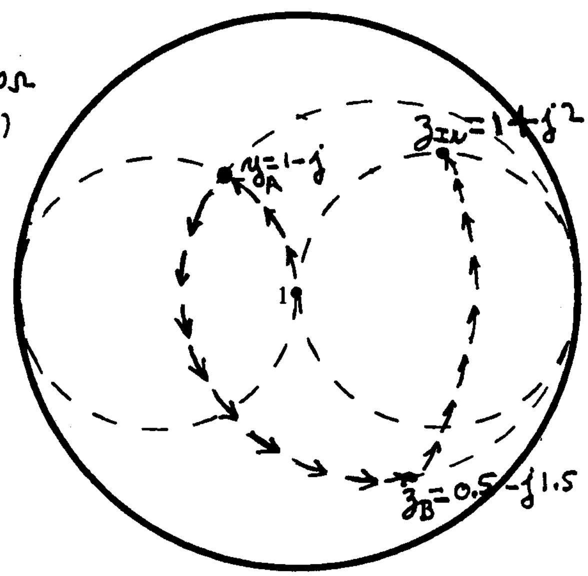
$L = \frac{96.15}{\omega} = \frac{96.15}{2\pi 10^9} = 15.3$ nH



2.13) $Z_L = j\omega L = j10^9\, 50\, 10^{-9} = j50$ OR $z_L = j\frac{50}{50} = j1$

$Z_c = \frac{1}{j\omega C} = \frac{1}{j10^9\, 10\, 10^{-12}} = -j100$ OR $z_c = -j\frac{100}{50} = -j2$





$z_{IN} = 1 + j2$

$Z_{IN} = 50 z_{IN} = 50 + j100\,\Omega$

2.14) LET $Z_0 = 100\,\Omega$.

THEN $z_L = \frac{Z_L}{100} = 1 - j$

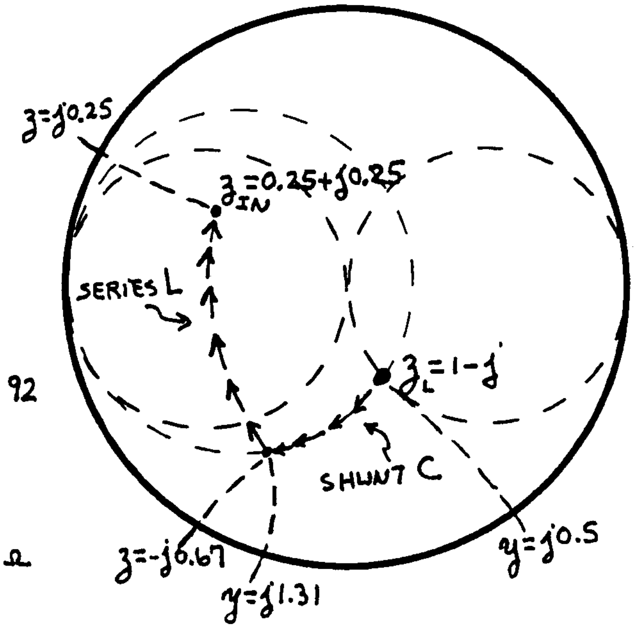
AND $z_{IN} = \frac{Z_{IN}}{100} = 0.25 + j0.25$

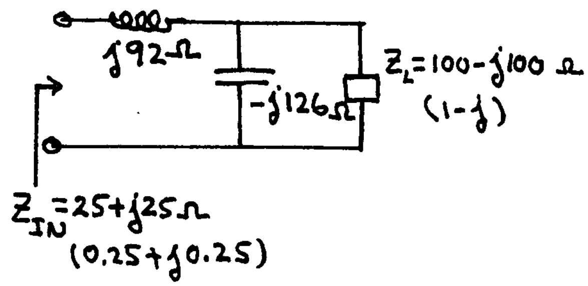
SHUNT C: $y_C = j1.31 - j0.5 = \cancel{j1.26}$ .81

$Z_C = \frac{100}{y_C} = -j126\,\Omega$

SERIES L: $z_L = j0.25 - (-j0.67) = j0.92$

$Z_L = 100 z_L = j92\,\Omega$





2.15) (a) $z_L = \frac{50}{50} = 1$

$z_{IN} = \frac{20 + j20}{50} = 0.4 + j0.4$

DRAW THE Q=5 CIRCLES (SEE FIG.2.4.16)

THE MOTION FROM A TO B -- SERIES L_1:

AT B: $z_B = 1 + j3$

$z_{L_1} = j3$ or $Z_{L_1} = j3(50) = j150\,\Omega$

THE MOTION FROM B TO C -- SHUNT C:

AT B: $y_B = 0.1 - j0.3$

AT C: $y_C = 0.1 + j0.5$

$y_C = j0.5 - (-j0.3) = j0.8$

$Z_C = \frac{50}{j0.8} = -j62.5\,\Omega$

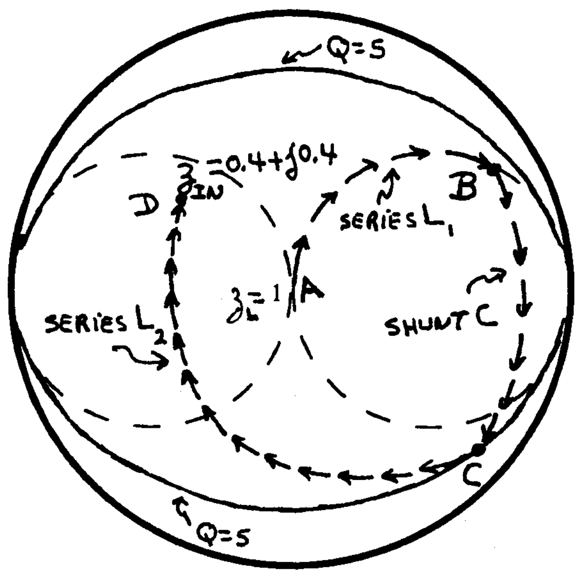
THE MOTION FROM C TO D -- SERIES L_2:

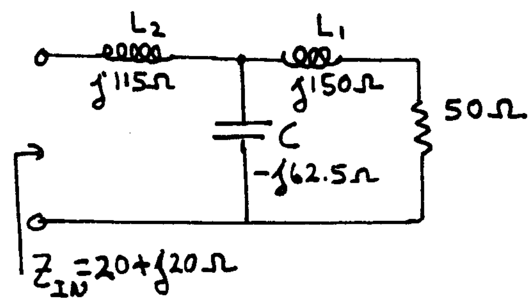
AT C: $z_C = 0.4 - j1.9$

AT D: $z_D = 0.4 + j0.4$

$z_{L_2} = j0.4 - (-j1.9) = j2.3$

$Z_{L_2} = 50(j2.3) = j115\,\Omega$



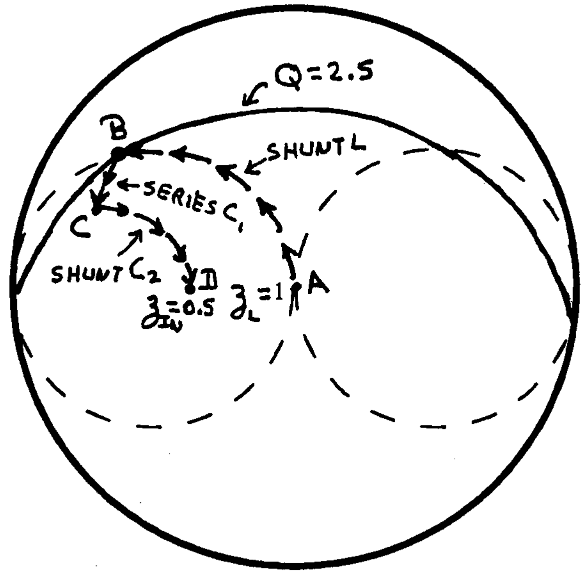


(b) $z_L = 1$ AND $z_{IN} = 0.5$

AT B: $y_B = 1 - j2.6$, $z_B = 0.13 + j0.335$

AT C: $y_C = 2 - j3.4$, $z_C = 0.13 + j0.215$

AT D: $y_D = 2$, $z_D = z_{IN} = 0.5$



SHUNT L: $y_L = -j2.6$

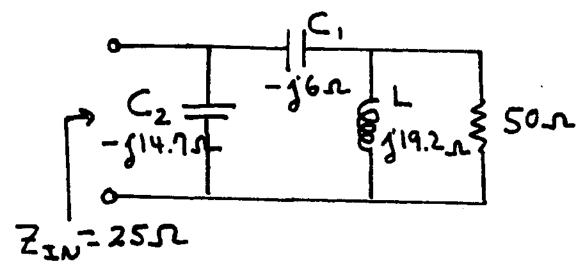
$$Z_L = \frac{50}{-j2.6} = j19.2\ \Omega$$

SERIES C_1: $z_{C_1} = j0.215 - j0.335 = -j0.12$

$$Z_{C_1} = 50(-j0.12) = -j6\ \Omega$$

SHUNT C_2: $y_{C_2} = 0 - (-j3.4) = j3.4$

$$Z_{C_2} = \frac{50}{j3.4} = -j14.7\ \Omega$$



2.16) (a) FROM FIG. 2.5.2 WITH $Z_0 = 50\ \Omega$ AND $\epsilon_r = 2.23$ WE OBTAIN:

$$\frac{W}{h} \approx 3.1 \quad \text{OR} \quad W = 3.1(0.7874) = 2.44\ \text{mm}$$

FROM FIG. 2.5.3 WITH $W/h = 3.1$ AND $\epsilon_r = 2.23$ WE OBTAIN:

$$\frac{\lambda}{\lambda_{TEM}} = 1.08 \quad \text{OR} \quad \lambda = 1.08\lambda_{TEM} = 1.08\frac{\lambda_0}{\sqrt{2.23}} = 0.723\lambda_0$$

SINCE $\lambda = \dfrac{\lambda_0}{\sqrt{\epsilon_{ff}}}$, THEN $\dfrac{1}{\sqrt{\epsilon_{ff}}} = 0.723$ OR $\epsilon_{ff} = 1.91$

(b) FROM (2.5.11): $$\frac{W}{h} = \frac{2}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{2.23-1}{2(2.23)}\left[\ln(B-1) + 0.39 - \frac{0.61}{2.23}\right]\right\} \quad (1)$$

WHERE $$B = \frac{377\pi}{2(50)\sqrt{2.23}} = 7.931 \quad (2)$$

SUBSTITUTE (2) INTO (1) TO OBTAIN: $\dfrac{W}{h} = 3.073$

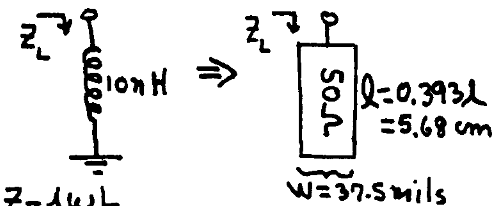
FROM (2.5.8): $$\lambda = \frac{\lambda_0}{\sqrt{2.23}}\left[\frac{2.23}{1 + 0.63(2.23-1)(3.073)^{0.1255}}\right]^{1/2} = 0.724\lambda_0$$

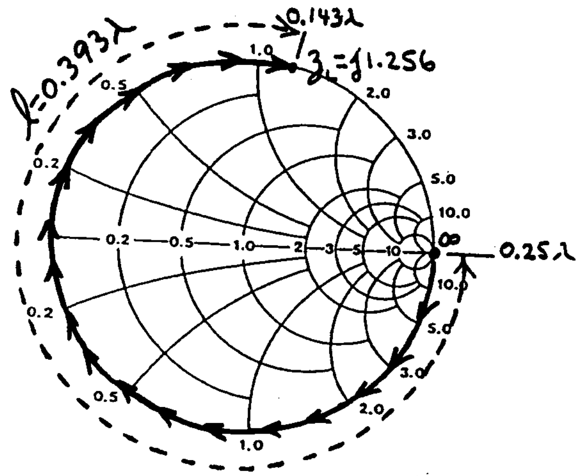
$$\frac{1}{\sqrt{\epsilon_{ff}}} = 0.724 \quad \text{OR} \quad \epsilon_{ff} = 1.91$$

2.17) APPROXIMATE VALUES CAN BE OBTAINED FROM FIGS. 2.5.2 AND 2.5.3.
EXACT VALUES ARE GIVEN IN FIG. 2.5.4.

$$\therefore \frac{W}{h} = 1.5 \quad \text{OR} \quad W = 1.5(25) = 37.5 \text{ mils}$$

FROM FIG. 2.5.3: $\dfrac{\lambda}{\lambda_{TEM}} = 1.18$ OR $\lambda = 1.18\,\lambda_{TEM} = 1.18\,\dfrac{3\,10^{10}}{\sqrt{6}\;10^{9}} = 14.45$ cm





$$Z_L = j\omega L$$
$$= j2\pi 10^{9}(10\,10^{-9}) = j62.8\,\Omega$$
$$z_L = \frac{Z_L}{50} = \frac{j62.8}{50} = j1.256$$

HENCE: $\ell = 0.393\lambda$

OR

$\ell = 0.393(14.45) = 5.68$ cm

OR $\ell = 5.68\left(\dfrac{1000}{2.54}\right) = 2,236.2$ mils

2.18) AT $f = 1$ GHz, $\lambda_0 = 30$ cm. MICROSTRIP: $\epsilon_r = 2.23$, $h = 0.7874$ mm

LINE WITH $Z_0 = 29.9\,\Omega$ AND $\ell = \frac{\lambda}{4}$: $\quad B = \dfrac{377\pi}{2(29.9)\sqrt{2.23}} = 13.26$

$$\frac{W}{h} = \frac{2}{\pi}\left\{13.26 - 1 - \ln\left(2(13.26) - 1\right) + \frac{2.23-1}{2(2.23)}\left[\ln(13.26-1) + 0.39 - \frac{0.61}{2.23}\right]\right\} = 6.203$$

$$\therefore W = 6.203h = 6.203(0.7874) = 4.884 \text{ mm}$$

$$\lambda = \frac{\lambda_0}{\sqrt{2.23}}\left[\frac{2.23}{1 + 0.63(2.23-1)(6.203)^{0.1255}}\right]^{1/2} = 0.712\lambda_0$$

NOTE: SINCE $\lambda = \dfrac{\lambda_0}{\sqrt{\epsilon_{ff}}}$ THEN $\dfrac{1}{\sqrt{\epsilon_{ff}}} = 0.712$ OR $\epsilon_{ff} = 1.974$

$$\ell = \frac{\lambda}{4} = 0.25(0.712\lambda_0) = 0.25(0.712)(30) = 5.34 \text{ cm}$$

SIMILARLY, WE OBTAINED:

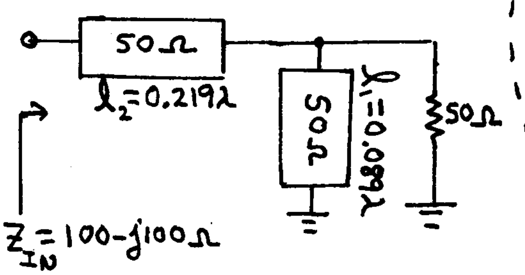
$Z_0 = 52.64\,\Omega$, $\ell = 3\lambda/8$	$Z_0 = 95.2\,\Omega$, $\ell = \frac{3\lambda}{8}$	$Z_0 = 79\,\Omega$, $\ell = \lambda/4$
$\frac{W}{h} = 2.89$ OR $W = 2.27$ mm	$\frac{W}{h} = 0.99$, $W = 0.779$ mm	$\frac{W}{h} = 1.44$, $W = 1.134$ mm
$\lambda = 0.726\lambda_0$, $\epsilon_{ff} = 1.89$	$\lambda = 0.747\lambda_0$, $\epsilon_{ff} = 1.79$	$\lambda = 0.74\lambda_0$, $\epsilon_{ff} = 1.825$
$\ell = \frac{3\lambda}{8} = \frac{3}{8}(0.726)(30) = 8.167$ cm	$\ell = \frac{3\lambda}{8} = 8.4$ cm	$\ell = \frac{\lambda}{4} = 5.55$ cm

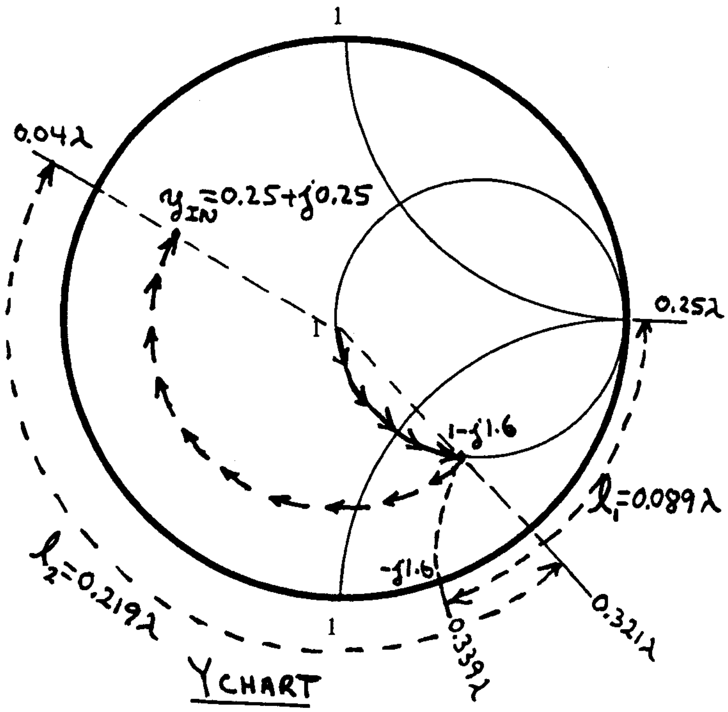
2.19) (a) $z_{IN} = \frac{Z_{IN}}{50} = 2 - j2$

$y_{IN} = \frac{1}{z_{IN}} = 0.25 + j0.25$

$l_1 = 0.339\lambda - 0.25\lambda = 0.089\lambda$

$l_2 = 0.042\lambda + (0.5\lambda - 0.321\lambda) = 0.219\lambda$

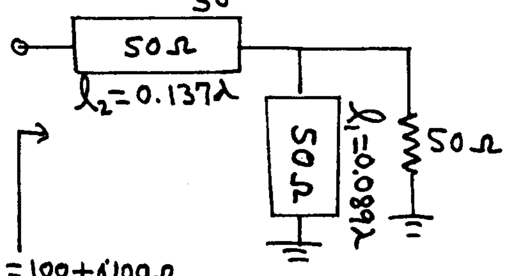




(b) If l_1 is an open-circuited stub, then

$l_1 = 0.25\lambda + 0.089\lambda = 0.339\lambda$

(c) For $z_{IN} = \frac{Z_{IN}}{50} = 2 + j2$, one answer is:



If l_1 is an open-circuited stub, then

$l_1 = 0.25\lambda + 0.089\lambda = 0.339\lambda$

2.20) (a) $z_L = \frac{15 + j25}{50} = 0.3 + j0.5$

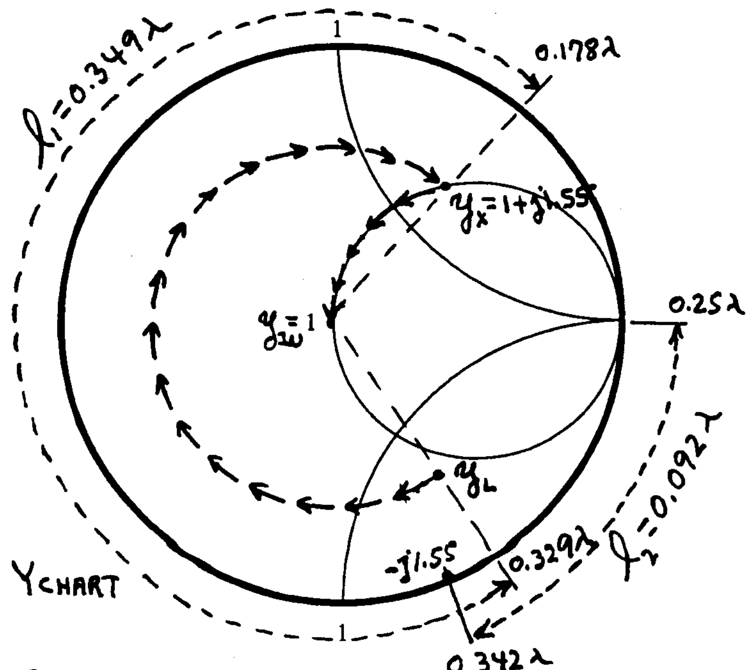
$y_L = \frac{1}{z_L} = 0.882 - j1.47$

Rotate, along a constant $|\Gamma|$ circle, from y_L until the unit conductance circle is reached at y_x.

$y_x = 1 + j1.55$

$l_1 = 0.178\lambda + (0.5\lambda - 0.329\lambda)$

$= 0.349\lambda$



$y_{IN} = y_{s.c} + y_x$

$1 = y_{s.c} + (1 + j1.55)$

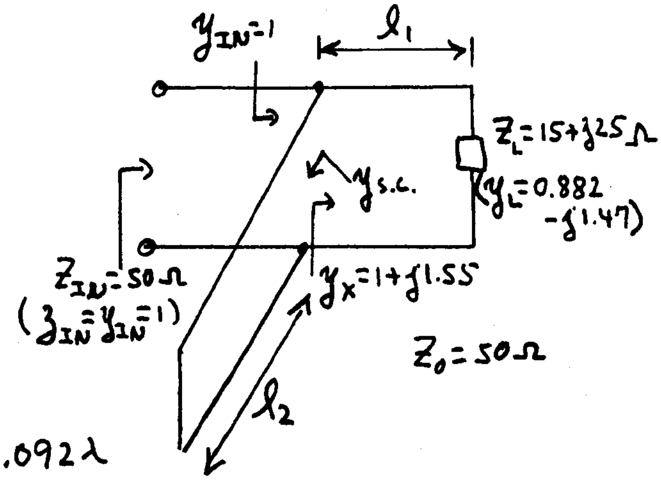
HENCE, $y_{s.c} = -j1.55$

The LENGTH l_2 OF THE SHORT CIRCUITED STUB MUST HAVE

$y_{sc} = -j1.55$

FROM THE Y SMITH CHART:

$l_2 = 0.342\lambda - 0.25\lambda = 0.092\lambda$



(b) IF THE CHARACTERISTIC IMPEDANCE OF THE STUB IS $Z_0' = 100\,\Omega$.

$$Z_{s.c.} = \frac{50}{y_{s.c}} = \frac{50}{-j1.55} = j32.26\,\Omega$$

THEN: $j32.26 = jZ_0' \tan\beta d = j100 \tan\beta d \Rightarrow \beta d = 0.312$

$$d \equiv l_2 = \frac{0.312}{2\pi/\lambda} = 0.05\lambda$$

ANOTHER WAY: NORMALIZE $Z_{s.c}$ WITH Z_0', $z_{s.c} = j\frac{32.26}{100} = j0.323$

THEN: $y_{s.c} = \frac{1}{z_{s.c}} = -j3.09$. LOCATE $y_{s.c} = -j3.09$ IN THE Y SMITH CHART, AND READ $l_2 = 0.302\lambda - 0.25\lambda = 0.052\lambda$

2.21) (a) $Y_{IN} = G_{IN} + jB_{IN} = 50 + j40$ mS, $R_{IN} = \frac{1}{G_{IN}} = \frac{1}{50\,10^{-3}} = 20\,\Omega$

$$Z_{01} = \sqrt{Z_L R_{IN}} = \sqrt{50(20)} = 31.62\,\Omega$$

IN A SHORT-CIRCUITED $\frac{3\lambda}{8}$ STUB: $Y_{sc} = jY_{02}$. HENCE, $jY_{02} = jB_{IN} = j40$ mS

OR $Y_{02} = 40$ mS, $Z_{02} = \frac{1}{Y_{02}} = 25\,\Omega$

(b) $Y_{IN} = G_{IN} - jB_{IN} = 50 - j40$ mS, $R_{IN} = \frac{1}{G_{IN}} = 20\,\Omega$.

THEN, $Z_{01} = \sqrt{50(20)} = 31.62\,\Omega$. IN A SHORT-CIRCUITED $\frac{\lambda}{8}$ STUB:

$Y_{sc} = -jY_{02}$. HENCE, $Y_{02} = 40$ mS OR $Z_{02} = \frac{1}{40\,10^{-3}} = 25\,\Omega$.

(c) $Y_{IN} = G_{IN} + jB_{IN} = 10 + j20$ mS, $R_{IN} = \frac{1}{G_{IN}} = \frac{1}{10\,10^{-3}} = 100\,\Omega$

THEN, $Z_{01} = \sqrt{50(100)} = 70.7\,\Omega$. IN AN OPEN-CIRCUITED $\frac{\lambda}{8}$ STUB:

$Y_{o.c} = jY_{02}$. HENCE, $Y_{02} = 20$ mS OR $Z_{02} = \frac{1}{20\,10^{-3}} = 50\,\Omega$.

(d) $Y_{IN} = 10 - j20$ mS. HENCE: $Z_{01} = \sqrt{50(100)} = 70.7\,\Omega$.

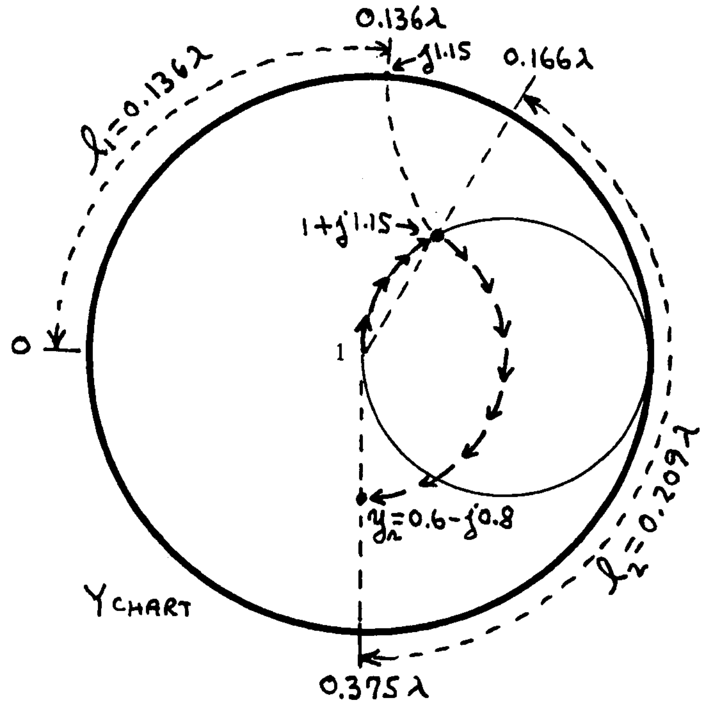
IN AN OPEN-CIRCUITED $\frac{3\lambda}{8}$ STUB: $Y_{oc} = -jY_{02}$. HENCE, $Z_{02} = \frac{1}{Y_{02}} = \frac{1}{20\,10^{-3}} = 50\,\Omega$.

2.22)(a) $\Gamma_\ell = 0.5\angle 90^\circ$, $z_\ell = 0.6 + j0.8$

$\therefore\ y_\ell = \frac{1}{z_\ell} = 0.6 - j0.8$

FROM THE SMITH CHART:

$\ell_1 = 0.136\lambda$, $\ell_2 = 0.375\lambda - 0.166\lambda$
$= 0.209\lambda$



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IN FIG. P.22(b):

$Y_\ell = \frac{0.6 - j0.8}{50} = 12 - j16$ mS

$\therefore\ Z_{01} = \sqrt{50\left(\frac{1}{12\,10^{-3}}\right)} = 64.5\ \Omega$

USING A $\frac{3\lambda}{8}$ OPEN-CIRCUITED STUB:

$-jY_{02} = -j16$ mS, OR $Y_{02} = 16$ mS

$Z_{02} = \frac{1}{16\,10^{-3}} = 62.5\ \Omega$

(b) BALANCED FORM OF THE STUBS.

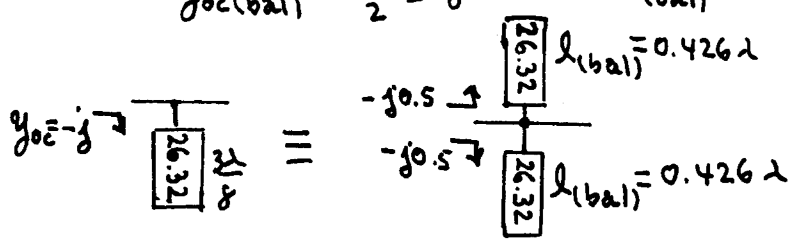
FOR FIG. P.22(a): $y_{bal} = j\frac{1.15}{2} = j0.575 \Rightarrow \ell_{1(bal)} = 0.083\lambda$

FOR FIG. P.22(b): $Z_{02(bal)} = 2(62.5) = 125\ \Omega$

2.23) THE $\frac{3\lambda}{8}$ STUB WITH $Z_0 = 26.32\ \Omega$ HAS AN ADMITTANCE OF $-j0.038$S.

IN A $Z_0 = 26.32\ \Omega$ SYSTEM: $y_{oc} = (26.32)(-j0.038) = -j1$

THEN: $y_{oc(bal)} = \frac{-j1}{2} = -j0.5 \Rightarrow \ell_{(bal)} = 0.426\lambda$



THE $\frac{3\lambda}{8}$ STUB WITH $Z_0 = 47.6\ \Omega$ HAS AN ADMITTANCE OF $-j0.021$ S.

$y_{oc} = 47.6(-j0.021) = -j1$

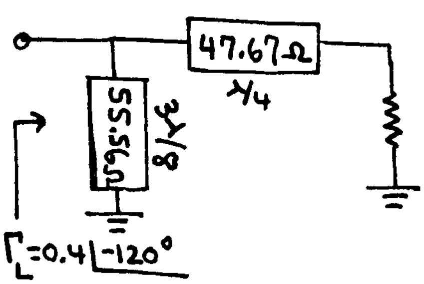
THEN: $y_{oc(bal)} = -j\frac{1}{2} = -j0.5 \Rightarrow \ell_{(bal)} = 0.426\lambda$

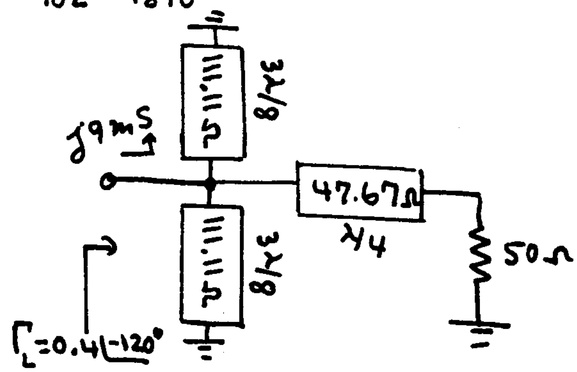
2.24) (a) $\Gamma_L = 0.4\angle{-120^\circ}$, $z_L = 0.538 - j0.444$, $y_L = \frac{1}{z_L} = 1.105 + j0.912$

$Y_L = \frac{y_L}{50} = 22 + j18\ mS$

HENCE: $Z_{01} = \sqrt{50\left(\frac{1}{22\,10^{-3}}\right)} = 47.67\,\Omega$ AND

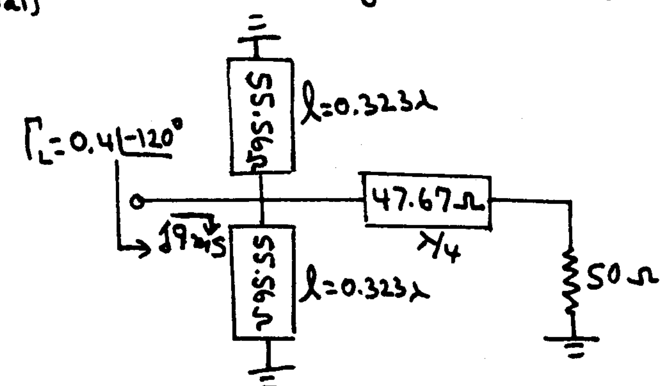
$jY_{02} = j18\,mS$ OR $Z_{02} = \frac{1}{Y_{02}} = \frac{1}{18\,10^{-3}} = 55.56\,\Omega$





BALANCE FORM (USE $2Z_{02} = 111.11\,\Omega$)

(b) EACH SIDE OF THE BALANCE STUBS HAS AN ADMITTANCE OF $j9\,mS$. IF ITS CHARACTERISTIC IMPEDANCE IS $Z_0 = \frac{111.11}{2} = 55.56\,\Omega$, THEN $y_{(b2l)} = j9\,10^{-3}(55.56) = j0.5$. HENCE: $l = 0.323\lambda$.



2.25) $\Gamma_s = 0.8\angle 160^\circ$, $y_s = \frac{1}{z_s} = 2.64 - j4$

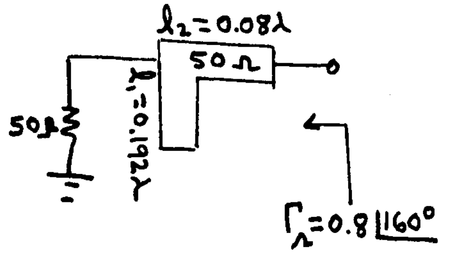
$\Gamma_L = 0.7\angle 20^\circ$, $y_L = \frac{1}{z_L} = 0.182 - j0.171$

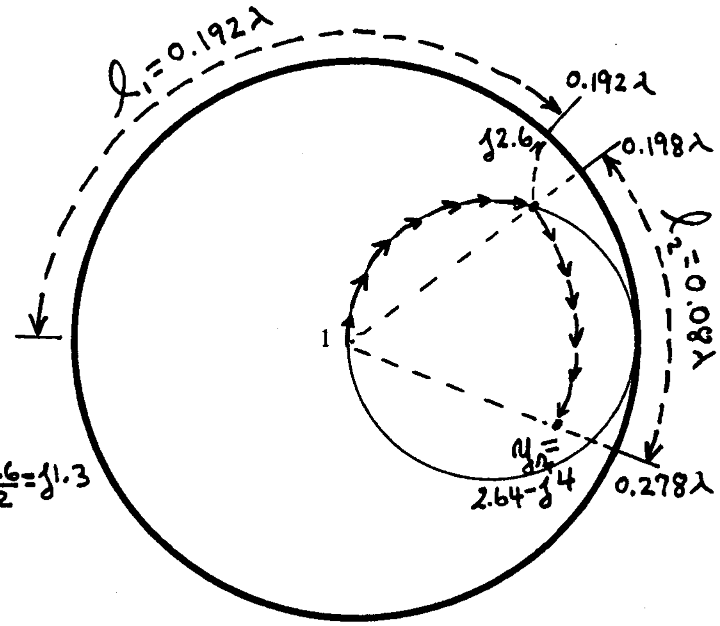
THE DESIGN OF THE MATCHING CIRCUITS IS SHOWN IN THE Y SMITH CHARTS.

MATCHING TO Γ_s:

OPEN STUB LENGTH: $\ell_1 = 0.192\lambda$

SERIES TRANS. LINE: $\ell_2 = 0.08\lambda$





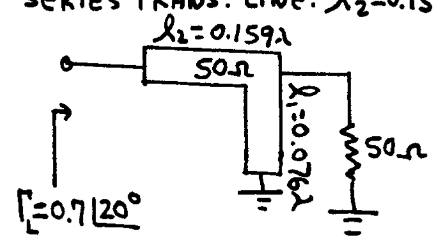
BALANCED SHUNT STUBS: $y_{(bal)} = j\frac{2.6}{2} = j1.3$

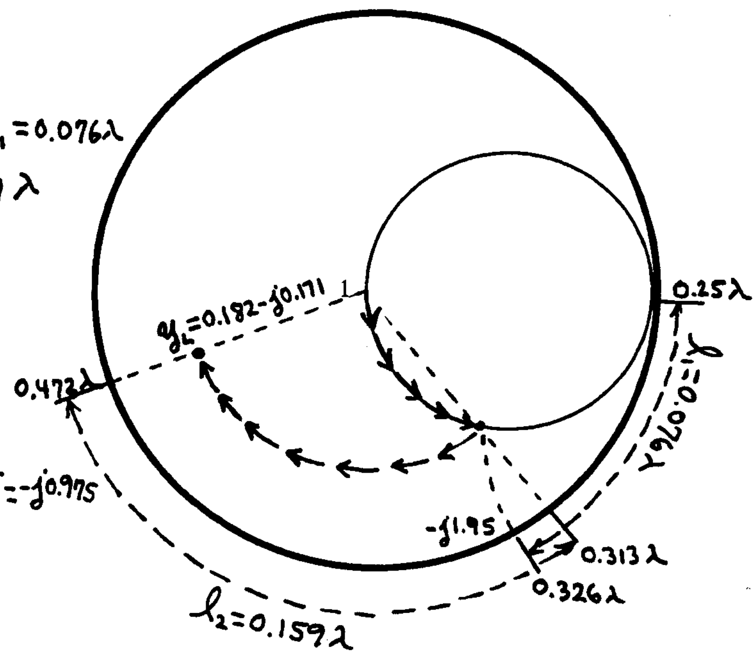
LENGTH OF EACH SIDE: $\ell_1' = 0.146\lambda$

MATCHING TO Γ_L:

SHORT-CIRCUITED STUB LENGTH: $\ell_1 = 0.076\lambda$

SERIES TRANS. LINE: $\ell_2 = 0.159\lambda$

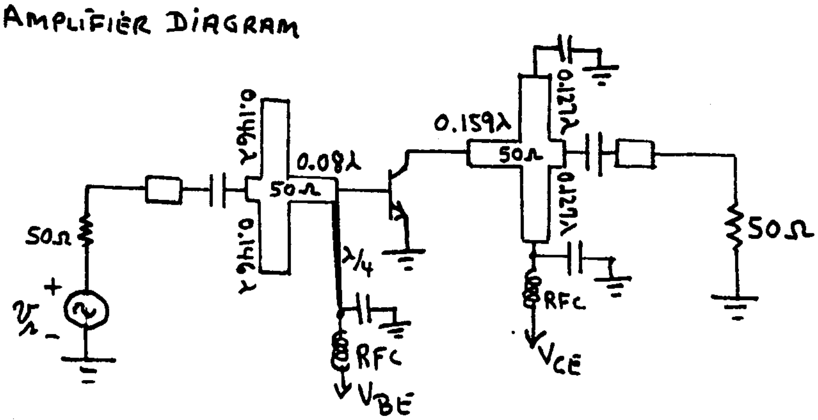




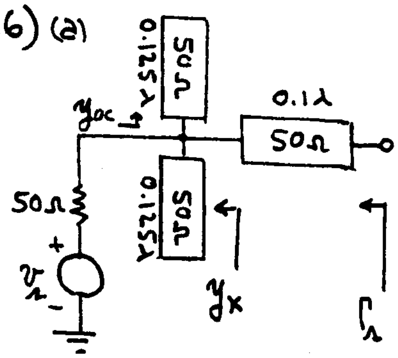
BALANCED SHUNT STUBS: $y_{(bal)} = -j\frac{1.95}{2} = -j0.975$

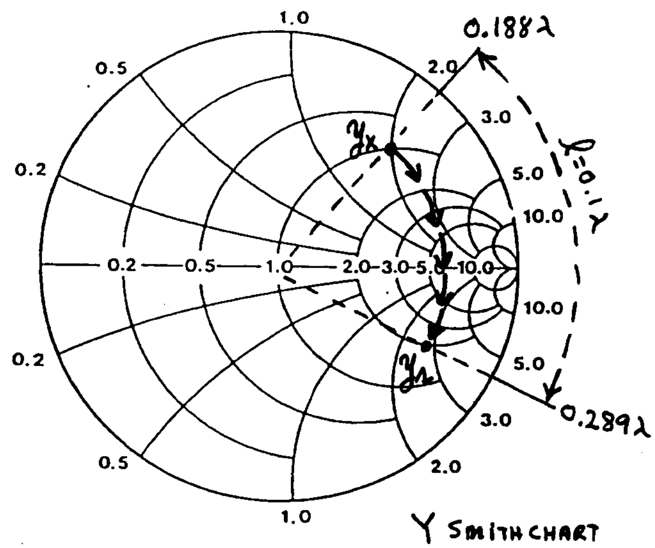
LENGTH OF EACH SIDE: $\ell_1' = 0.127\lambda$

AMPLIFIER DIAGRAM



2.26) (a)





Y SMITH CHART

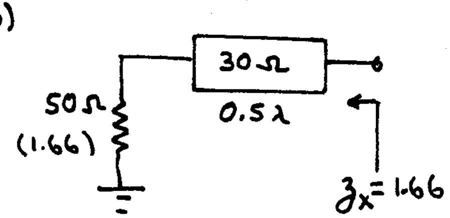
THE ADMITTANCE OF THE 0.125λ STUB IS: $y_{oc} = j$

HENCE: $y_x = 1 + j + j = 1 + 2j$

LOCATE y_x IN THE Y CHART, AND ROTATE 0.1λ TO FIND y_s. HENCE

$$y_s = 2 - j2.7 \quad \text{AND} \quad \Gamma_s = 0.71 \angle 152^\circ$$

(b)



NORMALIZING WITH $Z_0 = 30\Omega$

$z = \frac{50}{30} = 1.66$

HENCE, THE IMPEDANCE z_x AT 0.5λ FROM THE LOAD END IS:

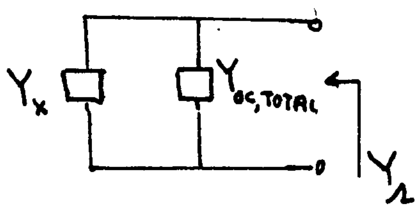
$$z_x = 1.66 \text{ OR } Z_x = 30(1.66) = 50\Omega$$

AND $Y_x = \frac{1}{Z_x} = 20 \text{ mS}$

THE 75Ω, 0.46λ BALANCE STUB HAS: $y_{oc} = -j0.26$ OR

$$y_{oc,TOTAL} = 2(-j0.26) = -j0.52$$

$$Y_{oc,TOTAL} = -j\frac{0.52}{75} = -j7 \text{ mS}$$



$$Y_s = Y_x + Y_{oc,TOTAL}$$

$$Y_s = 20 - j7 \text{ mS}$$

IN A 50-Ω SYSTEM: $y_s = 50 Y_s = 1 - j0.35$

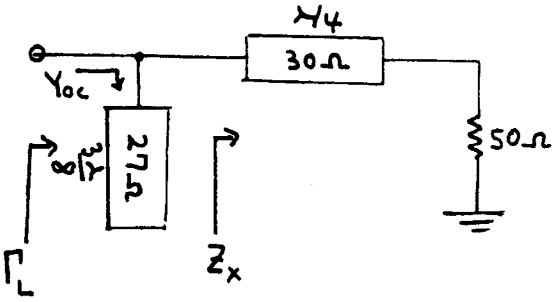
$$z_s = \frac{1}{y_s} = 0.891 + j0.312$$

AND $\Gamma_s = 0.172 \angle 99.9^\circ$

2.27) (a) $\lambda = \dfrac{3\,10^{10}}{6\,10^{9}} = 5\text{ cm}$, $\ell_1 = 1.25\text{cm} = 1.25\dfrac{\lambda}{5} = \dfrac{\lambda}{4}$

$\ell_2 = 1.87\text{ cm} = 1.87\dfrac{\lambda}{5} = 0.375\lambda = \dfrac{3\lambda}{8}$

FOR THE $\frac{\lambda}{4}$ LINE:



$$Z_x = \frac{Z_0^2}{Z_L} = \frac{30^2}{50} = 18\,\Omega$$

$$Y_x = \frac{1}{Z_x} = 56\text{ mS}$$

FOR THE $\frac{3\lambda}{8}$ STUB:

$y_{oc} = -j$, $Y_{oc} = \frac{1}{27}(-j) = -j\,37\text{ mS}$

HENCE: $Y_L = Y_x + Y_{oc} = 56 - j37\text{ mS}$

IN A 50 Ω SYSTEM: $y_L = 50\,Y_L = 2.8 - j1.85$ AND $\Gamma_L = 0.61\angle 160.2^\circ$

(b) FOR BALANCE STUBS USE $Z_0 = 2(27) = 54\,\Omega$ WITH LENGTHS OF $\frac{3\lambda}{8}$.

2.28) $\Gamma_{IN} = 0.5\angle 100^\circ$, $z_{IN} = 0.527 + j0.692$

THE 50 Ω, 0.15λ TRANSFORMS z_{IN} TO THE IMPEDANCE $z_x = 2.94 - j0.74$,

OR $y_x = \frac{1}{z_x} = 0.32 + j0.08$

THE ADMITTANCE OF THE $\frac{\lambda}{8}$ STUB IS: $y_{oc} = j$. HENCE, FOR THE TWO STUBS: $y_{oc,TOTAL} = j + j = 2j$

THEN, $y_A = y_x + y_{oc,TOTAL} = 0.32 + j0.08 + j2$
$= 0.32 + j2.08$

$$Z_A = 50\,z_A = \frac{50}{y_A} = (0.072 - j0.47)50 = 3.6 - j23.5\,\Omega$$

2.29)

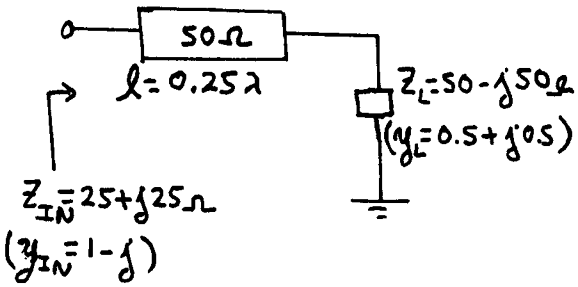
$z_L = \frac{Z_L}{50} = 1 - j$, $z_{IN} = \frac{Z_{IN}}{50} = 0.5 + j0.5$

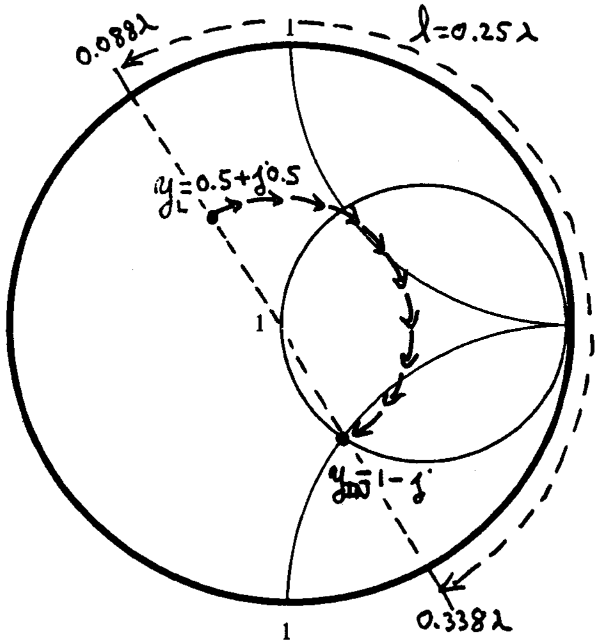
$y_L = \frac{1}{z_L} = 0.5 + j0.5$, $y_{IN} = \frac{1}{z_{IN}} = 1 - j$

y_L AND y_{IN} ARE ON THE SAME CONSTANT $|\Gamma|$ CIRCLE. HENCE, A SERIES TRANSMISSION LINE OF LENGTH:

$\ell = 0.338\lambda - 0.088\lambda = 0.25\lambda$

WILL CHANGE y_L TO y_{IN}.





2.30) $z_L = \frac{50+j50}{50} = 1+j$

THE 50Ω, 0.125λ CHANGES $z_L = 1+j$ to $z_x = 2-j$ (OR $y_x = 0.4+j0.2$)

THE 50Ω, 0.125λ STUB HAS: $y_{oc} = j$

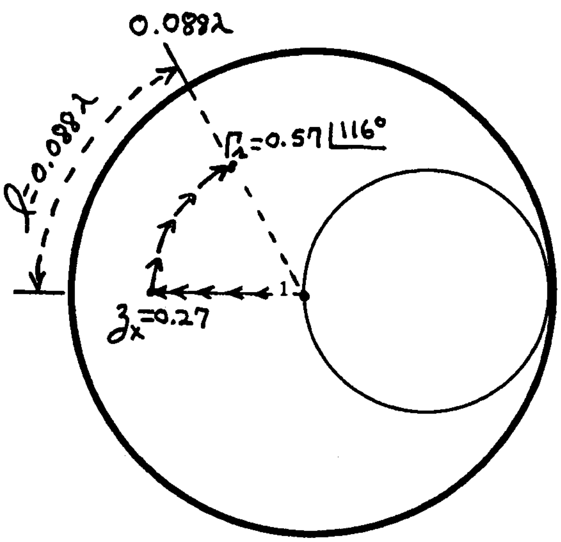
HENCE: $y_L = y_x + y_{oc} = 0.4 + j0.2 + j = 0.4 + j1.2$ AND $\Gamma_L = 0.728\,\underline{|-104°}$

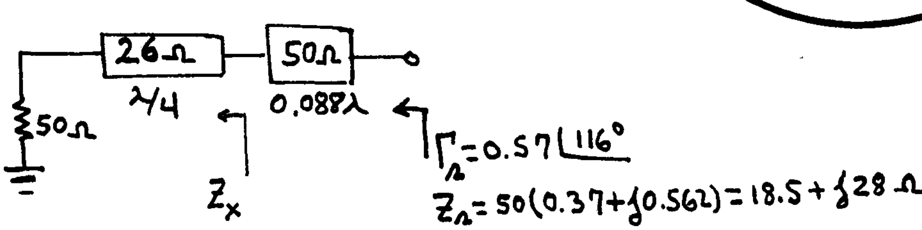
2.31) LOCATE $\Gamma_\Omega = 0.57\,\underline{|116°}$ IN THE SMITH CHART AND READ:

$z_x = 0.27$ OR $Z_x = 50 z_x = 13.5\,\Omega$

THE TRANSFORMATION OF 50Ω to $Z_x = 13.5\,\Omega$ CAN BE DONE WITH A $\frac{\lambda}{4}$ LINE WITH: $Z_o = \sqrt{50(13.5)} = 26\,\Omega$

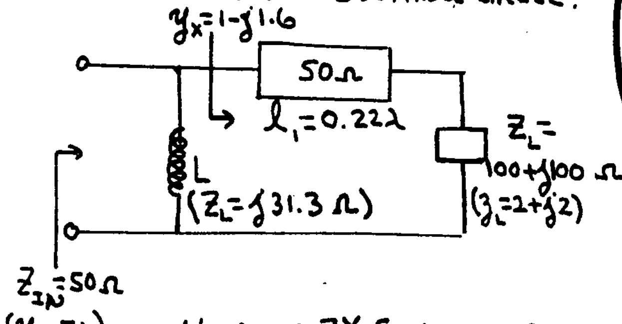
THEN, A SERIES TRANS. LINE OF LENGTH: $\ell = 0.088\lambda$ TRANSFORMS $Z_x = 13.5\,\Omega$ TO $Z_\Omega = 18.5 + j28\,\Omega$ OR $\Gamma_\Omega = 0.57\,\underline{|116°}$

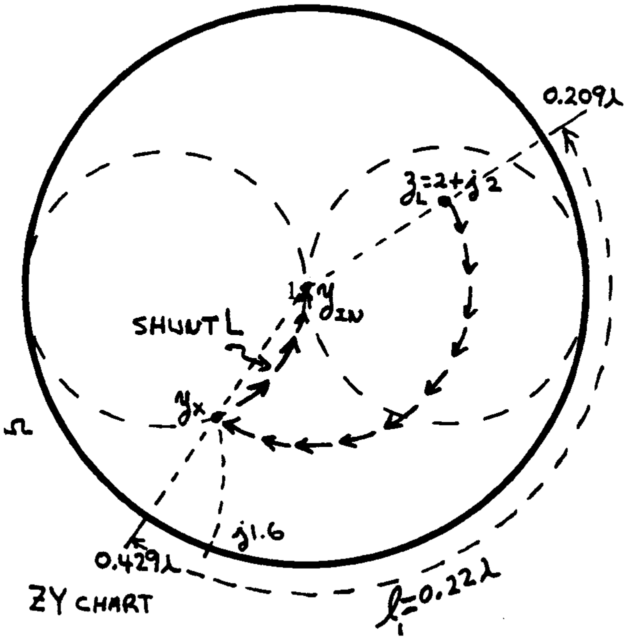




2.32) (a) $z_L = \dfrac{100 + j100}{50} = 2 + j2$

THE TRANSMISSION LINE PRODUCES A MOTION ALONG A CONSTANT $|\Gamma|$ CIRCLE, AND THE INDUCTOR L PRODUCES A MOTION ALONG A CONSTANT CONDUCTANCE CIRCLE.





ZY CHART

USING A ZY SMITH CHART:

$l_1 = 0.429\lambda - 0.209\lambda = 0.22\lambda$

AT y_x: $y_x = 1 - j1.6$. THEN, $y_L = 0 - (j1.6) = -j1.6$

OR $Z_L = 50 z_L = \dfrac{50}{-j1.6} = j31.3\ \Omega$

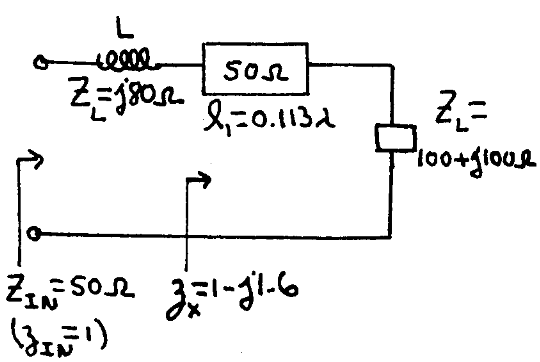
(b) IN THIS CIRCUIT THE INDUCTOR PRODUCES A MOTION ALONG A CONSTANT RESISTANCE CIRCLE.

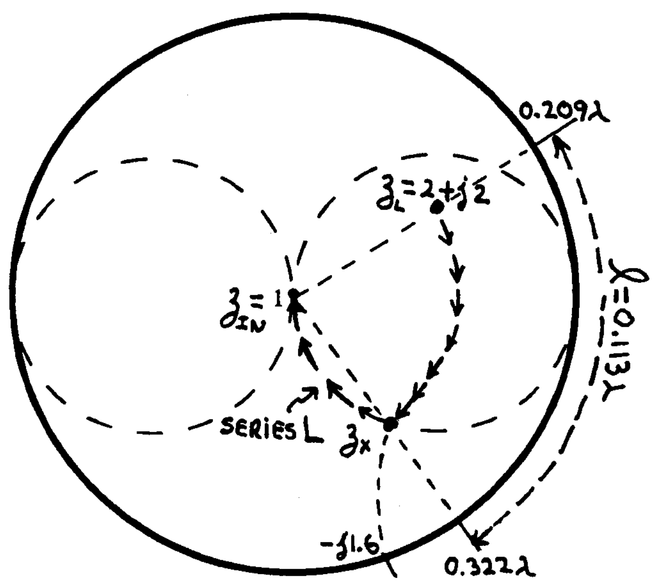
$l_1 = 0.322\lambda - 0.209\lambda = 0.113\lambda$

AT z_x: $z_x = 1 - j1.6$

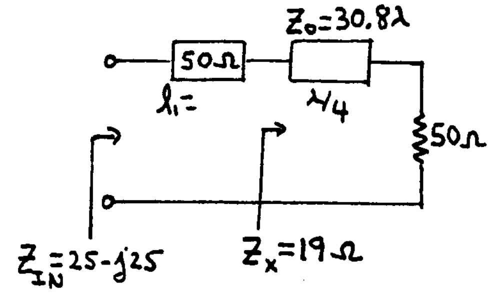
$z_L = 0 - (-j1.6) = j1.6$

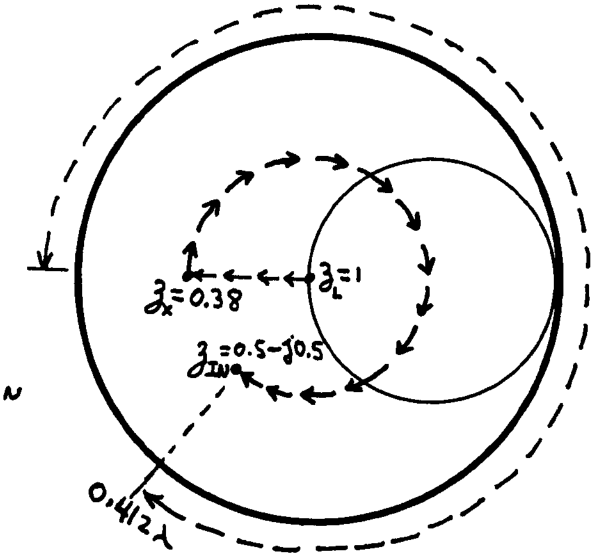
$Z_L = 50 z_L = 50(j1.6) = j80\ \Omega$





2.33) (a) $z_{IN} = \frac{25-j25}{50} = 0.5 - j0.5$





Z_x AND Z_{IN} MUST BE ON THE SAME CONSTANT $|\Gamma|$ CIRCLE. ONE SOLUTION IS SHOWN ON THE SMITH CHART.

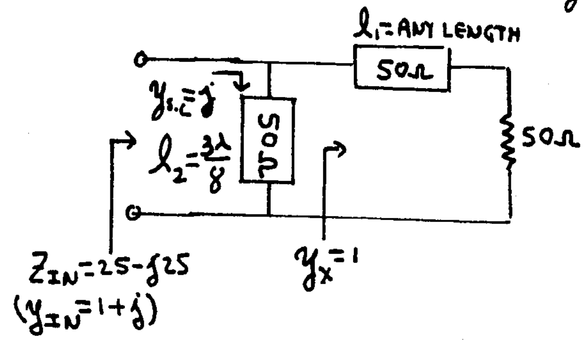
$$Z_x = 50 z_x = 50(0.38) = 19\Omega$$

THEN: $Z_0 = \sqrt{Z_L Z_x} = \sqrt{50(19)} = 30.8\Omega$

AND $l_1 = 0.412\lambda$

(b) $z_{IN} = 0.5 - j0.5$, $y_{IN} = \frac{1}{z_{IN}} = 1 + j$

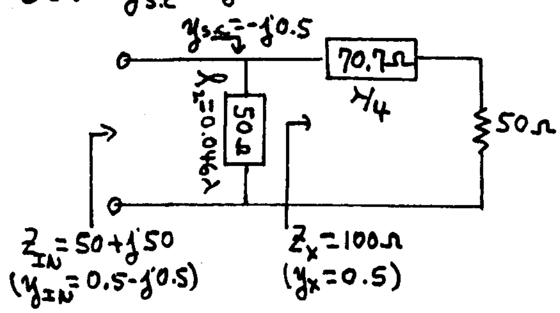
LETTING $Z_0 = 50\Omega$ AND $l_1 =$ ANY LENGTH, THE ADMITTANCE $y_x = 1$. THEN, THE SHUNT STUB MUST PROVIDE: $y_{s.c} = j$. HENCE: $l_2 = \frac{3\lambda}{8}$.



$$y_{IN} = y_x + y_{s.c} = 1 + j$$

(c) $z_{IN} = \frac{50+j50}{50} = 1 + j$, $y_{IN} = 0.5 - j0.5$, $Y_{IN} = 10 - j10$ mS

$\therefore$ $Z_0 = \sqrt{Z_L Z_x} = \sqrt{50\left(\frac{1}{10\,10^{-3}}\right)} = 70.7\Omega$. THE STUB ADMITTANCE MUST BE: $y_{s.c} = -j0.5$. HENCE: $l_2 = 0.426\lambda$



$$y_{IN} = y_x + y_{s.c} = 0.5 - j0.5$$

2.34) STARTING WITH (2.6.13):

$$G_T = \frac{(1-|\Gamma_s|^2)\,|S_{21}|^2\,(1-|\Gamma_L|^2)}{|(1-S_{11}\Gamma_s)(1-S_{22}\Gamma_L)-S_{21}S_{12}\Gamma_s\Gamma_L|^2} \qquad (1)$$

THE DENOMINATOR CAN BE EXPRESSED AS

$$|1-S_{22}\Gamma_L|^2\left|1-S_{11}\Gamma_s-\frac{S_{12}S_{21}\Gamma_s\Gamma_L}{1-S_{22}\Gamma_L}\right|^2 =$$

$$|1-S_{22}\Gamma_L|^2\left|1-\Gamma_s\underbrace{\left(S_{11}-\frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}\right)}_{\Gamma_{IN}}\right|^2 = |1-S_{22}\Gamma_L|^2\,|1-\Gamma_s\Gamma_{IN}|^2$$

HENCE, (1) CAN BE EXPRESSED IN THE FORM

$$G_T = \frac{1-|\Gamma_s|^2}{|1-\Gamma_s\Gamma_{IN}|^2}\,|S_{21}|^2\,\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \qquad (2.6.14)$$

ANOTHER WAY OF WRITING THE DENOMINATOR IS:

$$|1-S_{11}\Gamma_s|^2\left|1-S_{22}\Gamma_L-\frac{S_{12}S_{21}\Gamma_s\Gamma_L}{1-S_{11}\Gamma_s}\right|^2 =$$

$$|1-S_{11}\Gamma_s|^2\left|1-\Gamma_L\underbrace{\left(S_{22}-\frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s}\right)}_{\Gamma_{OUT}}\right|^2 = |1-S_{11}\Gamma_s|^2\,|1-\Gamma_L\Gamma_{OUT}|^2$$

HENCE, (1) CAN ALSO BE EXPRESSED AS:

$$G_T = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}\,|S_{21}|^2\,\frac{1-|\Gamma_L|^2}{|1-\Gamma_L\Gamma_{OUT}|^2} \qquad (2.6.15)$$

2.35) $\dfrac{b_1}{b_s} = \dfrac{S_{11}(1-\Gamma_L S_{22})+S_{21}\Gamma_L S_{12}}{D}$, $\dfrac{b_2}{b_s} = \dfrac{S_{21}}{D}$

$\dfrac{a_1}{b_s} = \dfrac{1-S_{22}\Gamma_L}{D}$, $\dfrac{a_2}{b_s} = \dfrac{S_{21}\Gamma_L}{D}$,

$$D = 1-(S_{11}\Gamma_s+S_{22}\Gamma_L+S_{21}\Gamma_L S_{12}\Gamma_s)+S_{11}\Gamma_s S_{22}\Gamma_L$$

HENCE: $$A_v = \frac{\frac{a_2}{b_s}+\frac{b_2}{b_s}}{\frac{a_1}{b_s}+\frac{b_1}{b_s}} = \frac{S_{21}\Gamma_L+S_{21}}{S_{11}(1-\Gamma_L S_{22})+S_{21}\Gamma_L S_{12}+1-S_{22}\Gamma_L}$$

OR $$A_v = \frac{S_{21}(\Gamma_L+1)}{1-S_{22}\Gamma_L+S_{11}(1-\Gamma_L S_{22})+S_{21}\Gamma_L S_{12}}$$

2.36) (a) FROM (2.8.6), WITH $\Gamma_L = \Gamma_{OUT}^* = 0.682\angle 97^\circ$, WE OBTAIN $|\Gamma_b| = 0$.

THEN, USING (2.8.4), $(VSWR)_{out} = 1$.

(b) WHEN $\Gamma_L = \Gamma_{OUT}^*$ WE HAVE $|\Gamma_b| = 0$ OR $\Gamma_b = 0$. HENCE,

$Z_b = Z_0 = 50\,\Omega$.

(c) $$|\Gamma_b| = \left|\frac{\Gamma_{OUT} - \Gamma_L^*}{1 - \Gamma_{OUT}\Gamma_L}\right| = \left|\frac{0.5\angle -60^\circ - 0.682\angle -97^\circ}{1 - 0.5\angle -60^\circ (0.682\angle 97^\circ}\right| = 0.546$$

$$(VSWR)_{out} = \frac{1 + 0.546}{1 - 0.546} = 3.41$$

2.37) (a) FROM (2.8.3), WITH $\Gamma_s = \Gamma_{IN}^* = 0.545\angle 77.7^\circ$, WE OBTAIN $|\Gamma_a| = 0$.

THEN, USING (2.8.1), $(VSWR)_{in} = 1$.

(b) WHEN $\Gamma_s = \Gamma_{IN}^*$ WE HAVE $|\Gamma_a| = 0$ OR $\Gamma_a = 0$. HENCE,

$Z_a = Z_0 = 50\,\Omega$

(c) $$|\Gamma_a| = \left|\frac{\Gamma_{IN} - \Gamma_s^*}{1 - \Gamma_{IN}\Gamma_s}\right| = \left|\frac{0.4\angle 45^\circ - 0.545\angle -77.7^\circ}{1 - 0.4\angle 45^\circ (0.545\angle 77.7^\circ)}\right| = 0.735$$

$$(VSWR)_{in} = \frac{1 + 0.735}{1 - 0.735} = 6.54$$