SOLUTIONS MANUAL

MICROWAVE TRANSISTOR AMPLIFIERS

Analysis and Design

SECOND EDITION

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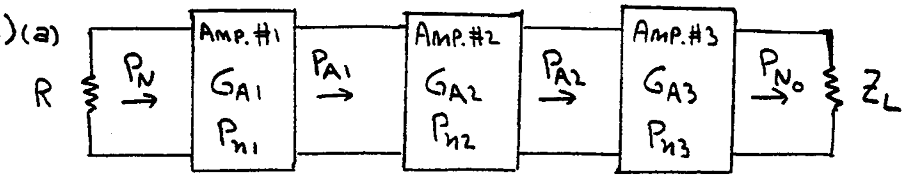
4.1) (a)



$P_N = kTB \qquad P_{A1} = G_{A1}P_N + P_{n1} \qquad P_{A2} = G_{A2}P_{A1} + P_{n2} \qquad P_{N_o} = G_{A3}P_{A2} + P_{n3}$

$$F = \frac{P_{N_o}}{P_N G_{A1} G_{A2} G_{A3}} = \frac{G_{A3}G_{A2}G_{A1}P_N + G_{A3}G_{A2}P_{n1} + G_{A3}P_{n2} + P_{n3}}{P_N G_{A1}G_{A2}G_{A3}}$$

$$= 1 + \frac{P_{n1}}{P_N G_{A1}} + \frac{P_{n2}}{P_N G_{A1}G_{A2}} + \frac{P_{n3}}{P_N G_{A1}G_{A2}G_{A3}} \qquad (1)$$

LET: $F_1 = 1 + \dfrac{P_{n1}}{P_N G_{A1}}$, $F_2 = 1 + \dfrac{P_{n2}}{P_N G_{A2}}$, $F_3 = 1 + \dfrac{P_{n3}}{P_N G_{A3}}$

THEREFORE, (1) CAN BE EXPRESSED IN THE FORM:

$$F = F_1 + \frac{F_2 - 1}{G_{A1}} + \frac{F_3 - 1}{G_{A1}G_{A2}}$$

(b) $F = 10^{0.1} + \dfrac{10^{0.3} - 1}{10^1} = 1.358$ OR $1.33\ dB$

4.2) (a) THE GAIN-CIRCLES ARE THE CONSTANT-GAIN G_A CIRCLES.

FROM FIG. P.2(a): $F_{min} = 3.3\ dB$, $\Gamma_{opt} \approx 0.56\angle{-155^\circ}$.

r_n IS EVALUATED BY READING A VALUE OF F AND ITS ASSOCIATED Γ_s, AND USING (4.3.4). FROM FIG. P.2(a) WE READ:

$F = 4.5\ dB$ AT $\Gamma_s \approx 0.56\angle{-94^\circ}$. THEN

$$10^{0.45} = 10^{0.33} + \frac{4r_n\,|0.56\angle{-94^\circ} - 0.56\angle{-155^\circ}|^2}{(1-(0.56)^2)\,|1 + 0.56\angle{-155^\circ}|^2} \Rightarrow r_n = 0.108$$

FROM FIG. P.2(b): $F_{min} = 1.7\ dB$, $\Gamma_{opt} \approx 0.215\angle{149^\circ}$.

USING: $F = 3\ dB$ AT $\Gamma_s = 0.445\angle{26^\circ}$ WE OBTAIN $r_n = 0.202$

(b) FOR THE $G_A = 10.7\ dB$ CIRCLE IN FIG. 4.3.4:

$g_a = 4.158$, $C_a = 0.574\angle{-154^\circ}$, $r_a = 0.423$

4.3) (a) THE $G_A = 14\ dB$ CIRCLE AND THE $F = 2\ dB$ CIRCLE INTERSECT AT TWO POINTS. THE VALUE OF Γ_s AT THESE THE POINTS ARE:

$\Gamma_s \approx 0.5\angle{160^\circ}$ AND $\Gamma_s \approx 0.25\angle{-150^\circ}$

(b) LET $\Gamma_s = 0.5\angle{160^\circ}$, THEN $\Gamma_{OUT} = 0.657\angle{-73.3^\circ}$

FOR $(VSWR)_{OUT} = 1$: $\Gamma_L = \Gamma_{OUT}^* = 0.657\angle{73.3^\circ}$

THEN, $\Gamma_{IN} = 0.8\angle{165.6^\circ}$, $|\Gamma_a| = 0.678$, $(VSWR)_{in} = 5.2$

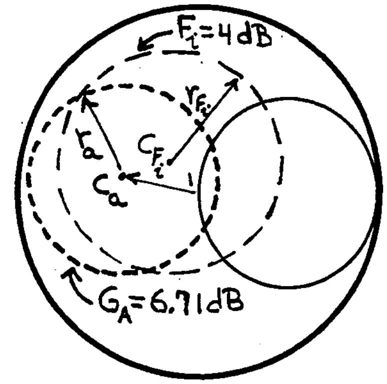
4.4) (a) $K = 2.25$ AND $\Delta = 0.246\angle 112.8^\circ$ $\therefore$ UNCONDITIONALLY STABLE

(b) $G_{A,max} = \dfrac{|S_{21}|}{|S_{12}|}\left(K - \sqrt{K^2-1}\right) = 9.36$ OR $9.71\,dB$

(c) $G_A = 9.71 - 3 = 6.71\,dB$

FOR THE $G_A = 6.71\,dB$ CIRCLE: $g_a = 1.173$,

$C_a = 0.42\angle 174.5^\circ$, $r_a = 0.515$



Γ_s PLANE

(d) FOR THE 3dB NOISE CIRCLE:

$C_{F_i} = 0.405\angle 145^\circ$, $r_{F_i} = 0.388$

FOR THE 4 dB NOISE CIRCLES:

$C_{F_i} = 0.279\angle 145^\circ$, $r_{F_i} = 0.616$

THE $F_i = 4\,dB$ CIRCLE IS DRAWN ON THE SMITH CHART.

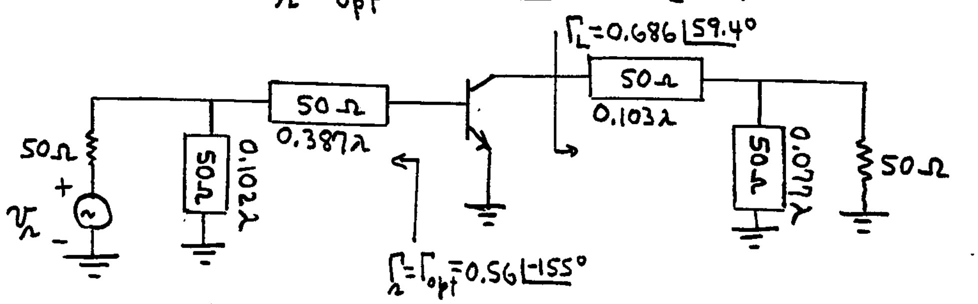
(e) FOR $G_{A,max}$: $\Gamma_s = \Gamma_{Ms} = 0.667\angle 174.5^\circ$, $\Gamma_L = \Gamma_{ML} = 0.587\angle 102.2^\circ$.

$$\therefore\ F = 10^{0.25} + \frac{4\left(\frac{5}{50}\right)\left|0.667\angle 174.5^\circ - 0.5\angle 145^\circ\right|^2}{\left(1-(0.667)^2\right)\left|1+0.5\angle 145^\circ\right|^2} = 1.97 \text{ OR } 2.95\,dB$$

4.5) $F_{min} = 3.3\,dB$, $\Gamma_{opt} = 0.56\angle -155^\circ$, $r_n = 0.108$

$K = 1.1$, $\Delta = 0.273\angle 126.8^\circ$ $\therefore$ UNCONDITIONALLY STABLE

DESIGN WITH $\Gamma_s = \Gamma_{opt} = 0.56\angle -155^\circ$ AND $\Gamma_L = \Gamma_{OUT}^* = 0.686\angle 59.4^\circ$



$G_A = 16.67$ OR $12.2\,dB$

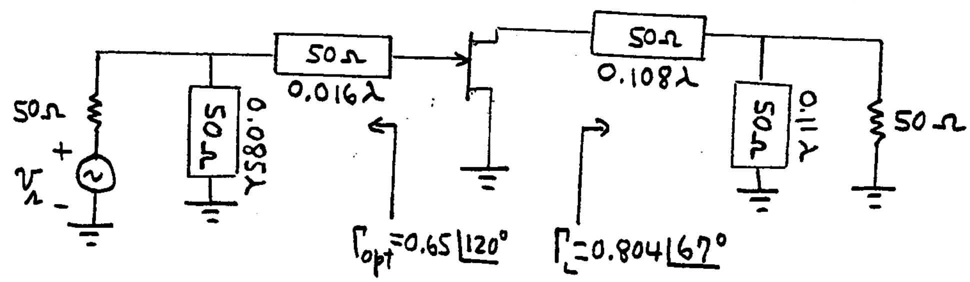
$G_T = G_A = 16.67$ OR $12.2\,dB$

$G_p = 20.62$ OR $13.1\,dB$

ALSO: $\Gamma_{IN} = 0.801\angle 156.2^\circ$, $|\Gamma_a| = 0.438$, $(VSWR)_{in} = 2.6$, $(VSWR)_{out} = 1$.

4.6) $K = 2.18$, $\Delta = 0.555\angle{-178.3^\circ}$ ∴ UNCONDITIONALLY STABLE

DESIGN WITH $\Gamma_s = \Gamma_{opt} = 0.65\angle{120^\circ}$ AND $\Gamma_L = \Gamma_{OUT}^* = 0.804\angle{67^\circ}$



$G_A = G_T = 75.6$ OR 18.8 dB

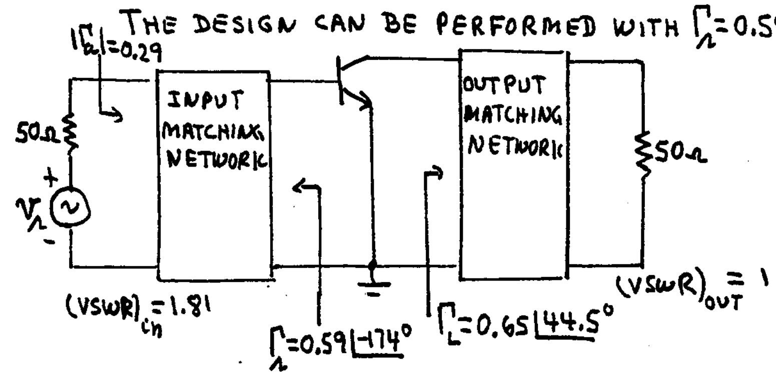
ALSO: $\Gamma_{IN} = 0.806\angle{-119.6^\circ}$, $|\Gamma_a| = 0.327$, $(VSWR)_{in} = 1.97$, $(VSWR)_{OUT} = 1$

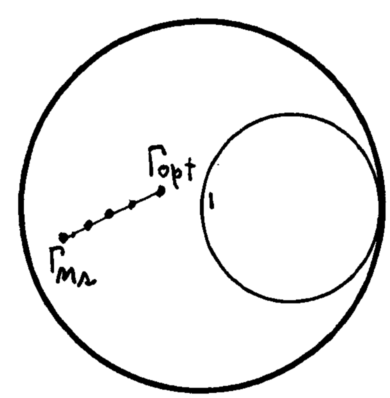
4.7) $K = 1.235$, $\Delta = 0.175\angle{166.2^\circ}$ ∴ UNCONDITIONALLY STABLE

$G_{A,max} = 43.07$ OR 16.3 dB, $\Gamma_{Ms} = 0.787\angle{-170.1^\circ}$, $\Gamma_{ML} = 0.749\angle{44.8^\circ}$

Γ_s	$\Gamma_L = \Gamma_{OUT}^*$	Γ_{IN}	$\lvert\Gamma_a\rvert$	$(VSWR)_{in}$	G_A(dB)	F(dB)
$0.2\angle{155^\circ}$	$0.528\angle{41.7^\circ}$	$0.704\angle{170.8^\circ}$	0.62	4.27	13.75	1.6
$0.32\angle{172^\circ}$	$0.559\angle{42.9^\circ}$	$0.715\angle{170.8^\circ}$	0.535	3.30	14.5	1.66
$0.43\angle{180^\circ}$	$0.592\angle{43.7^\circ}$	$0.726\angle{170.7^\circ}$	0.446	2.61	15.1	1.82
$0.59\angle{-174^\circ}$	$0.650\angle{44.5^\circ}$	$0.747\angle{170.6^\circ}$	0.290	1.81	15.8	2.30
$0.787\angle{-170.1^\circ}$	$0.749\angle{44.8^\circ}$	$0.787\angle{170.1^\circ}$	0	1	16.3	3.76

THE DESIGN CAN BE PERFORMED WITH $\Gamma_s = 0.59\angle{-174^\circ}$ AND $\Gamma_L = 0.65\angle{44.5^\circ}$.





$G_A = 15.8$ dB

$F = 2.3$ dB

4.8) $K = 0.96$, $\Delta = 0.6\angle -73.1°$ $\therefore$ POTENTIALLY UNSTABLE

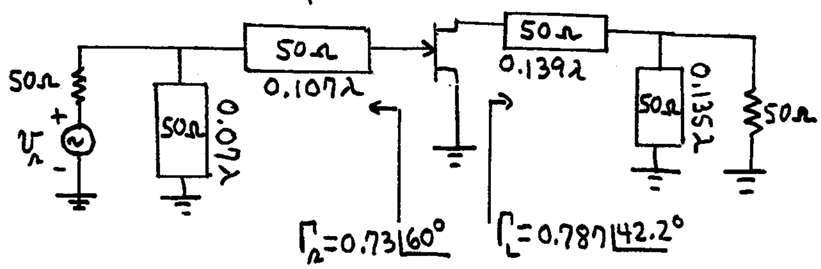
INPUT STABILITY CIRCLE: $C_s = 1.34\angle 62.7°$, $r_s = 0.345$

OUTPUT STABILITY CIRCLE: $C_L = 1.55\angle 47.2°$, $r_L = 0.56$

DESIGN WITH $\Gamma_s = \Gamma_{opt} = 0.73\angle 60°$ AND $\Gamma_L = \Gamma_{OUT}^* = 0.787\angle 42.2°$

BOTH Γ_{opt} AND Γ_L ARE IN THE STABLE REGION (AS EXPECTED).

A DESIGN FOR Γ_{opt} AND Γ_L IS SHOWN BELOW:



$G_A = 14.9$ dB
$F = 1.25$ dB
$(VSWR)_{in} = 2.4$
$(VSWR)_{out} = 1$

4.9) THIS TRANSISTOR IS POTENTIALLY UNSTABLE.

$G_{MSG} = 59.6$ OR 17.8 dB. LET US DESIGN FOR $G_A = 14$ dB.

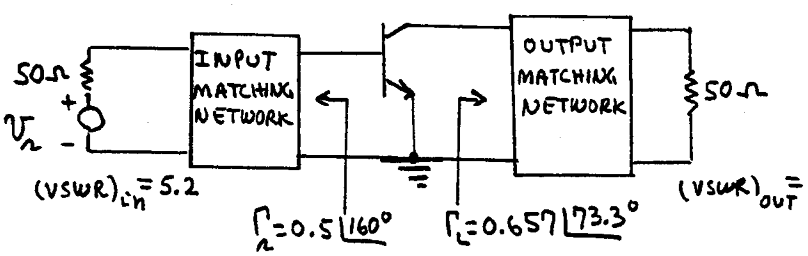
FIG. P4.2(b) SHOWS THAT THE $G_A = 14$ dB CIRCLE AND THE $F = 2$ dB CIRCLE INTERSECT AT TWO POINTS, NAMELY:

$\Gamma_s \approx 0.5\angle 160°$ AND $\Gamma_s \approx 0.25\angle -150°$

Γ_s	G_A(dB)	F(dB)	$\Gamma_L = \Gamma_{OUT}^*$	$(VSWR)_{OUT}$	Γ_{IN}	$\lvert\Gamma_a\rvert$	$(VSWR)_{in}$
$0.5\angle 160°$	13.6	2	$0.657\angle 73.3°$	1	$0.8\angle 165.6°$	0.678	5.2
$0.25\angle -150°$	13.5	1.9	$0.685\angle 65.3°$	1	$0.793\angle 162.4°$	0.683	5.3

SELECT $\Gamma_s = 0.5\angle 160°$ AND $\Gamma_L = 0.657\angle 73.3°$.

$G_T = G_A = 13.6$ dB AND $G_p = 17.2$ dB



4.10) TRANSISTOR #1: $K=0.869$, $\Delta = 0.348\angle -39.2^\circ$ ∴ POTENTIALLY UNSTABLE

$G_{MSG} = 44$ OR $16.4\,dB$.

INPUT STABILITY CIRCLE: $C_s = 16.75\angle -37.3^\circ$, $r_s = 17.61$

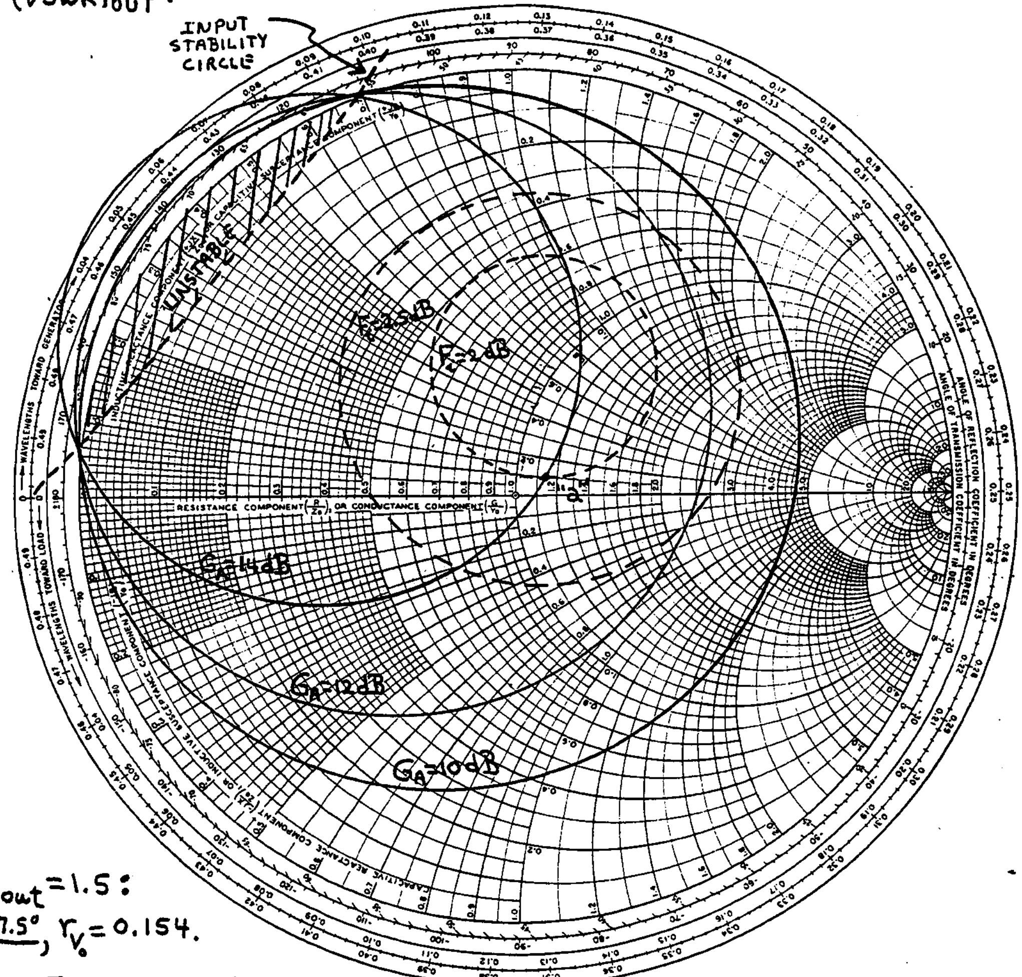
OUTPUT STABILITY CIRCLE: $C_L = 4.06\angle 44.5^\circ$, $r_L = 3.16$

THE $G_A = 14\,dB$, $12\,dB$, AND $10\,dB$ CIRCLES, THE $F_i = 2\,dB$, AND $2.5\,dB$ CIRCLES, AND THE INPUT STABILITY CIRCLE ARE DRAWN IN THE SMITH CHART.

G_A(dB)	C_a	r_a
14	$0.561\angle 142.7^\circ$	0.597
12	$0.35\angle 142.7^\circ$	0.724
10	$0.219\angle 142.7^\circ$	0.821

F_i(dB)	C_{F_i}	r_{F_i}
2	$0.306\angle 77^\circ$	0.258
2.5	$0.254\angle 77^\circ$	0.458

LET US TRY A DESIGN WITH Γ_s AT POINT "a": $\Gamma_s = 0.08\angle 31^\circ$. WITH THIS VALUE OF Γ_s WE FIND: $\Gamma_L = \Gamma_{OUT}^* = 0.485\angle 37.5^\circ$, $\Gamma_{IN} = 0.555\angle -140^\circ$, $|\Gamma_a| = 0.577$, AND $(VSWR)_{in} = 3.7$. THE VALUE OF $(VSWR)_{in}$ CAN BE IMPROVED IF WE DESIGN FOR A HIGHER $(VSWR)_{OUT}$.



FOR $(VSWR)_{out} = 1.5$:

$C_{V_o} = 0.47\angle 37.5^\circ$, $r_{V_o} = 0.154$.

SELECTING $\Gamma_L = 0.32\angle 37.5^\circ$ IT FOLLOWS THAT

$\Gamma_{IN} = 0.449\angle -134.7^\circ$, $|\Gamma_a| = 0.47$, AND $(VSWR)_{in} = 2.78$

TRANSISTOR #2 : THE DESIGN PROCEDURE IS SIMILAR TO THE ONE USED WITH TRANSISTOR #1. ONLY THE CALCULATIONS FOR THE G_A CIRCLES AND FOR THE NOISE CIRCLES ARE GIVEN.

$K = 0.244$, $\Delta = 0.263\angle 56.2^\circ$ ∴ POTENTIALLY UNSTABLE

$G_{MSG} = 22.5$ dB

INPUT STABILITY CIRCLE: $C_s = 2.04\angle 172.2^\circ$, $r_s = 1.55$

OUTPUT STABILITY CIRCLE: $C_L = 1.63\angle 21.9^\circ$, $r_L = 1.07$

THE CALCULATIONS FOR THE $G_A = 18$ dB AND 16 dB CIRCLES, AND FOR THE $F_i = 1.2$ dB AND 1.5 dB CIRCLES ARE:

G_A(dB)	C_a	r_a
18	$0.376\angle 172.2^\circ$	0.796
16	$0.255\angle 172.2^\circ$	0.849

F_i(dB)	C_{F_i}	r_{F_i}
1.2	$0.39\angle 32^\circ$	0.246
1.5	$0.35\angle 32^\circ$	0.378

4.11) $K = 0.774$, $\Delta = 0.46\angle -129.3^\circ$ ∴ POTENTIALLY UNSTABLE.

$G_{MSG} = 14.36$ dB

INPUT STABILITY CIRCLE $\begin{cases} C_s = 2.06\angle 120.3^\circ \\ r_s = 1.19 \end{cases}$ OUTPUT STABILITY CIRCLE $\begin{cases} C_L = 334.6\angle -65.4^\circ \\ r_L = 335.4 \end{cases}$

CONSIDER THE $G_p = 10$ dB AND 12 dB CIRCLES:

G_p(dB)	C_p	r_p
12	$0.58\angle 114.6^\circ$	0.663
10	$0.366\angle 114.6^\circ$	0.754

THE TRANSFORMATIONS OF THE $G_p = 12$ dB AND 10 dB CIRCLES TO THE $\Gamma_s = \Gamma_{IN}^*$ PLANE ARE SHOWN IN THE SMITH CHART. ALSO, THE $F_i = 1.2$ dB AND 1.5 dB CIRCLES ARE SHOWN, AS WELL AS ONE $(VSWR)_{in} = 2$ CIRCLE.

$G_p = 12$ dB CIRCLE IN THE $\Gamma_s = \Gamma_{IN}^*$ PLANE: $C_i = 0.959\angle 120.3^\circ$, $r_i = 0.366$

$G_p = 10$ dB CIRCLE IN THE $\Gamma_s = \Gamma_{IN}^*$ PLANE: $C_i = 0.858\angle 120.3^\circ$, $r_i = 0.372$

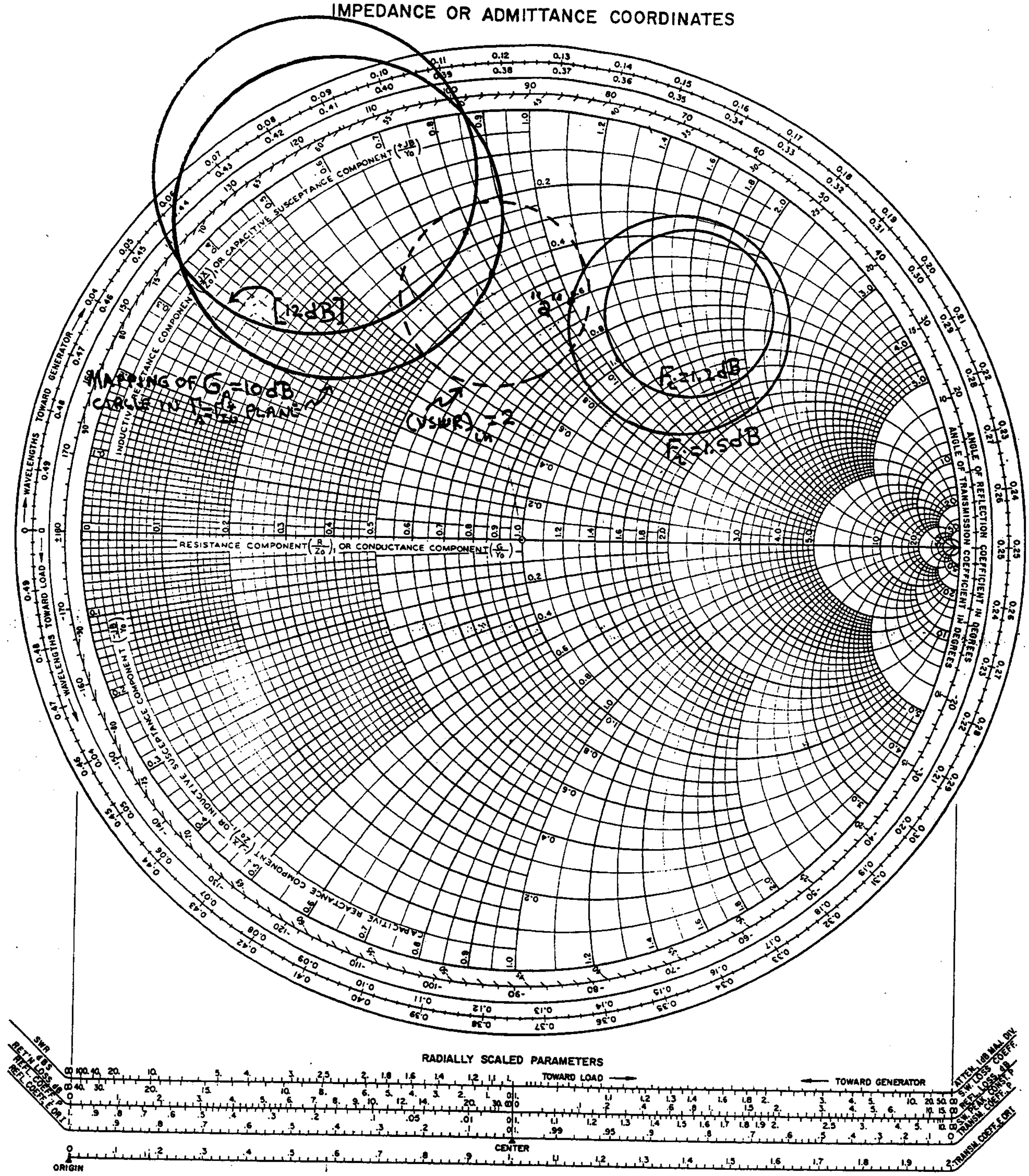
$F_i = 1.2$ dB CIRCLE IN THE Γ_s PLANE: $C_{F_i} = 0.654\angle 55^\circ$, $r_{F_i} = 0.188$

$F_i = 1.5$ dB CIRCLE IN THE Γ_s PLANE: $C_{F_i} = 0.621\angle 55^\circ$, $r_{F_i} = 0.252$

A POINT ON THE $G_p = 10$ dB CIRCLE IS $\Gamma_L = 0.416\angle -57.3^\circ$. THEN, $\Gamma_{IN} = 0.62\angle -97^\circ$. THE VALUE $\Gamma_s = \Gamma_{IN}^*$ RESULTS IN $(VSWR)_{in} = 1$, AND A VERY-HIGH NOISE FIGURE. THE CIRCLE $(VSWR)_{in} = 2$ IS DRAWN (i.e, $C_{V_i} = 0.576\angle 97^\circ$ AND $r_{V_i} = 0.214$). A CONVENIENT VALUE OF Γ_s IS AT POINT "a": $\Gamma_s = 0.56\angle 79^\circ$, AND IT FOLLOWS THAT

Γ_s	Γ_L	G_p(dB)	F_i(dB)	Γ_{OUT}	$\lvert\Gamma_a\rvert$	$(VSWR)_{in}$	$\lvert\Gamma_b\rvert$	$(VSWR)_{out}$
$0.56\angle 79^\circ$	$0.416\angle -57.3^\circ$	10	1.5	$0.35\angle -107^\circ$	0.286	1.8	0.664	4.9

IMPEDANCE OR ADMITTANCE COORDINATES



4.12) $K = 1.04$, $\Delta = 0.83 \angle -47.5°$ ∴ UNCONDITIONALLY STABLE

$G_{p,max} = 5.166$ OR 7.13 dB. CONSIDER THE $G_p = 6$ dB AND 5 dB CIRCLES.

$G_p = 6$ dB CIRCLE IN THE $\Gamma_s = \Gamma_{IN}^*$ PLANE: $C_i = 0.257 \angle -10°$, $r_i = 0.443$

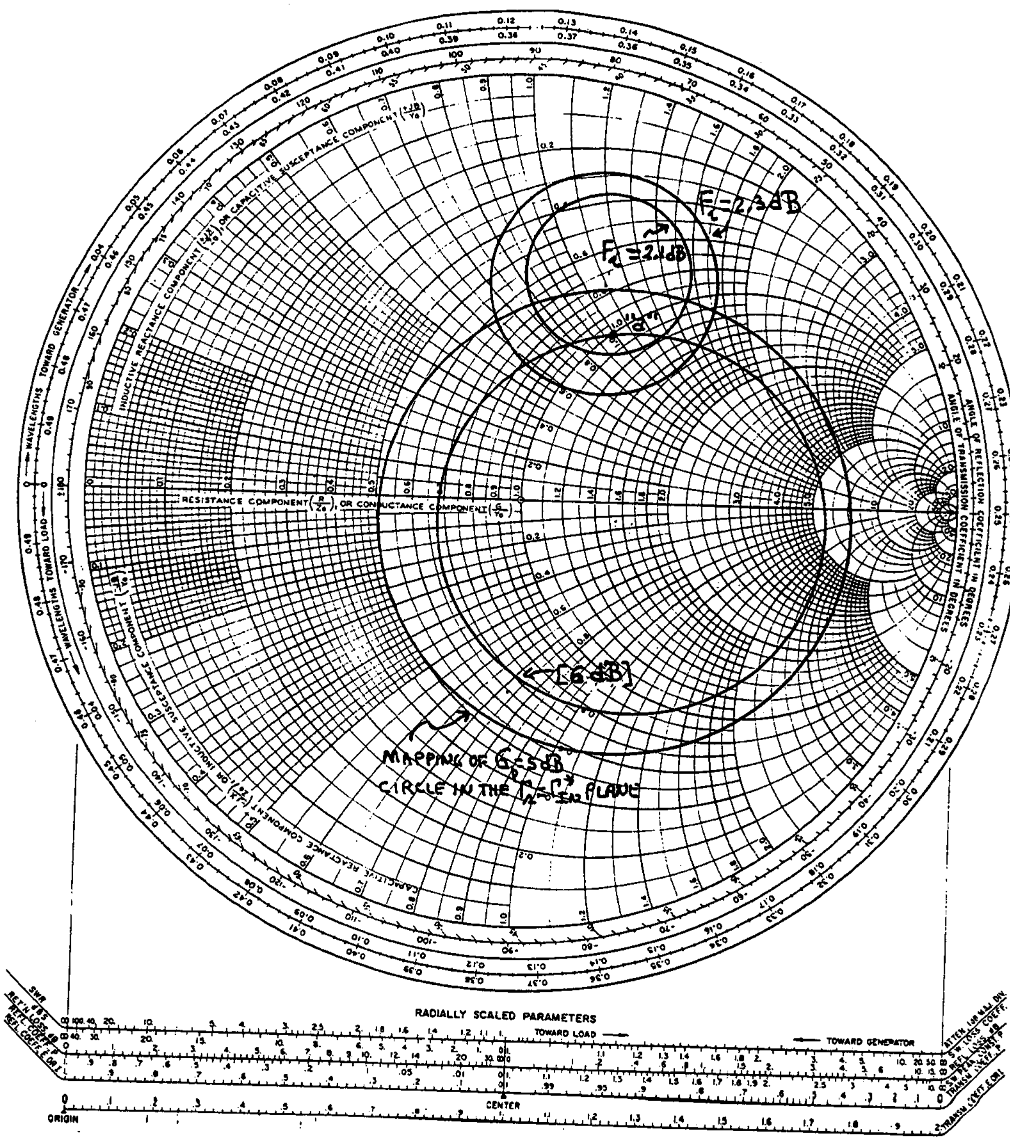
$G_p = 5$ dB CIRCLE IN THE $\Gamma_s = \Gamma_{IN}^*$ PLANE: $C_i = 0.223 \angle -10°$, $r_i = 0.541$

$F_i = 2.1$ dB CIRCLE IN THE Γ_s PLANE: $C_{F_i} = 0.569 \angle 71°$, $r_{F_i} = 0.185$

$F_i = 2.3$ dB CIRCLE IN THE Γ_s PLANE: $C_{F_i} = 0.539 \angle 71°$, $r_{F_i} = 0.262$

THESE CIRCLES ARE DRAWN IN THE SMITH CHART. SELECTING Γ_s AT POINT "a" RESULTS IN $F_i < 2.1$ dB, $G_p = 6$ dB, AND $(VSWR)_{in} = 1$. THAT IS:

Γ_s	Γ_L	Γ_{IN}	Γ_{OUT}	G_p(dB)	F_i(dB)	$(VSWR)_{in}$	$\lvert\Gamma_b\rvert$	$(VSWR)_{OUT}$
$0.44 \angle 63°$	$0.86 \angle 50.5°$	$0.44 \angle -63°$	$0.765 \angle -44.7°$	6	2	1	0.355	2.1



4.13) $G_A(\text{dB}) = 14+14+14-7.5+16+16 = 66.5 \text{ dB}$

THE NOISE FIGURE OF THE LNB IS DETERMINED BY THE NOISE FIGURE OF THE LNA (i.e., THE FIRST 3 AMPLIFIERS).

$$F = F_1 + \frac{F_2-1}{G_{A1}} + \frac{F_3-1}{G_{A1}G_{A2}} = 10^{0.05} + \frac{10^{0.09}-1}{10^{1.4}} + \frac{10^{0.11}-1}{10^{1.4}10^{1.4}} = 1.131 \text{ OR } 0.54 \text{ dB}$$

THE CONTRIBUTION TO F FROM THE MIXER, AMP. 5, AND AMP. 6 IS NEGLIGIBLE.

4.14) THE FOLLOWING CALCULATIONS ARE MADE:

f(MHz)	$\lvert S_{21}\rvert^2$	$G_{s,max}$	$G_{L,max}$	$G_{TU,max}$
150	25 (14dB)	0.45 dB	7.6 dB	22 dB
250	16 (12dB)	0.38 dB	5.8 dB	18.2 dB
400	7.94 (9dB)	0.28 dB	4.6 dB	13.9 dB

OBSERVE THAT $G_{s,max}$ IS VERY SMALL AT THE THREE FREQUENCIES OF INTEREST. HENCE, ONLY THE LOAD MATCHING NETWORK WILL BE USED TO COMPENSATE FOR THE VARIATIONS IN $\lvert S_{21}\rvert^2$. THE INPUT MATCHING NETWORK CAN BE DESIGNED TO PROVIDE A GOOD $(VSWR)_{in}$, OR FOR $G_s = 0$ dB.

FOR $G_{TU} = 12$ dB, DESIGN G_L TO HAVE -2 dB AT 150 MHz, 0 dB AT 250 MHz, AND 3 dB AT 400 MHz.

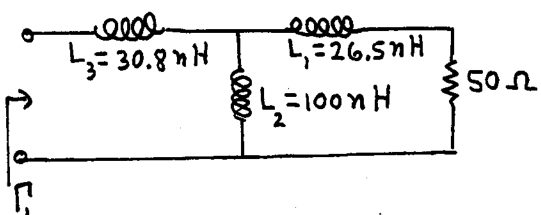
f(MHz)	G_L(dB)	g_L	C_{g_L}	r_{g_L}
150	−2	0.109	$0.378\angle 16^\circ$	0.62
250	0	0.260	$0.494\angle 115^\circ$	0.494
400	3	0.687	$0.7\angle 126^\circ$	0.242

THE GAIN CIRCLES ARE DRAWN IN THE SMITH CHART. AFTER SOME TRIALS AND ERRORS, THE FOLLOWING MATCHING CIRCUIT WAS OBTAINED:

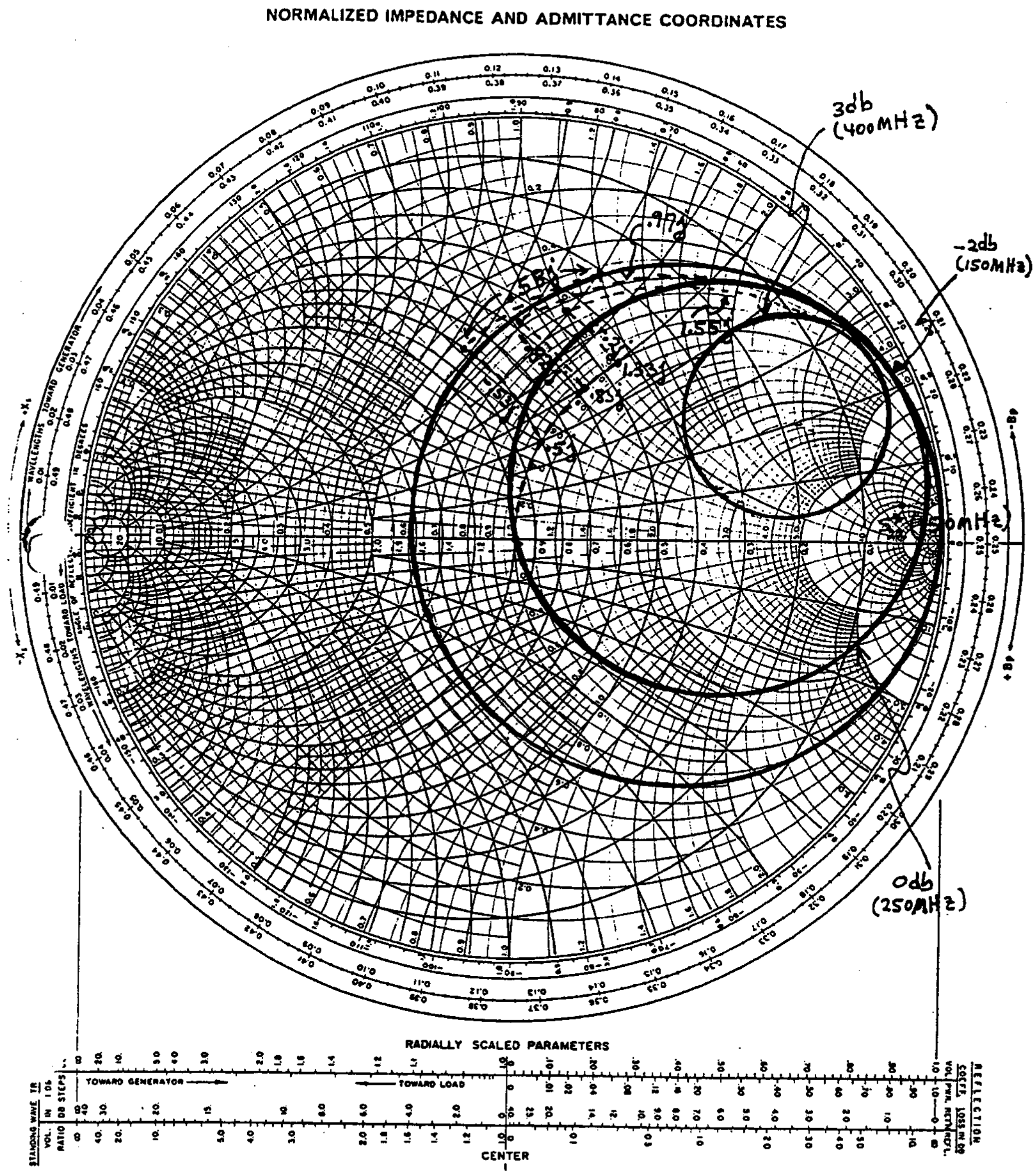
$Z_{L_1} = j\omega L_1$

$Y_{L_2} = -j/\omega L_2$

$Z_{L_3} = j\omega L_3$



f(MHz)	Z_{L1}	$z_{L1} = \frac{Z_{L1}}{50}$	Y_{L2}	y_{L2}	Z_{L2}	z_{L2}
150	j24.97	j0.5	−j10.61mS	−j0.53	j29.03	j0.58
250	j41.62	j0.83	−j6.36mS	−j0.32	j48.4	j0.97
400	j66.6	j1.33	−j3.98mS	−j2	j77.4	j1.55

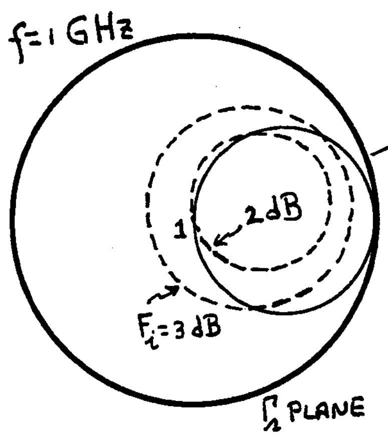


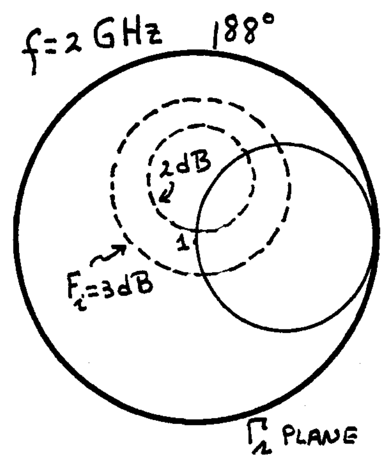
4.15) $G_{TU} = G_s G_o G_L$, $G_{TU}(dB) = G_s(dB) + G_o(dB) + G_L(dB)$

f(GHz)	$G_{s,max}$(dB)	$G_o = \lvert S_{21}\rvert^2$(dB)	$G_{L,max}$(dB)	$G_{TU,max}$(dB)
1	2.3	14.05	4.25	20.6
2	1.86	9.97	3.6	15.43

NOISE CIRCLES CALCULATIONS:

f(GHz)	F_i(dB)	C_{F_i}	r_{F_i}
1	2	$0.395 \angle 23^\circ$	0.378
	3	$0.286 \angle 23^\circ$	0.591
	4	$0.212 \angle 23^\circ$	0.708
2	2	$0.377 \angle 88^\circ$	0.261
	3	$0.304 \angle 88^\circ$	0.477
	4	$0.244 \angle 88^\circ$	0.604



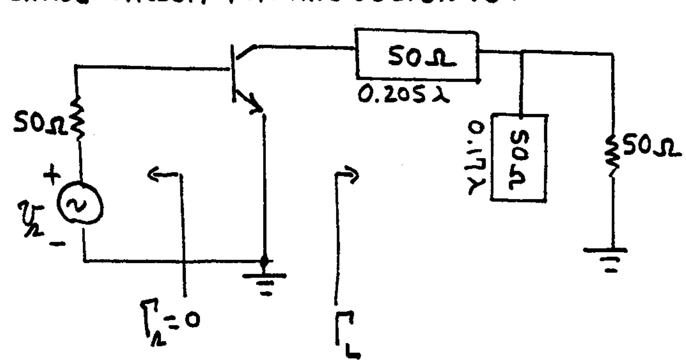


IT IS SEEN THAT THE NOISE FIGURE IS LESS THAN 3 dB AT 1 GHz AND 2 GHz WITH $\Gamma_s = 0$. THE INPUT MATCHING NETWORK IS DESIGNED WITH $\Gamma_s = 0$, AND IT FOLLOWS THAT $G_s = 0$ dB.

A DESIGN FOR $G_{TU} = 10$ dB REQUIRES THAT $G_L = -4$ dB AT 1 GHz, AND $G_L = 0$ dB AT 2GHz. THAT IS,

AT 1GHz: $G_{TU} = 0 + 14.05 - 4 \approx 10$dB ; AT 2GHz: $G_{TU} = 0 + 9.97 + 0 \approx 10$ dB

A MATCHING CIRCUIT FOR THIS DESIGN IS:



4.16) (a) $S_{11a}=S_{11b}=S_{11}$ $\quad S_{21a}=S_{21b}=S_{21}$

$S_{12a}=S_{12b}=S_{12}$ $\quad S_{22a}=S_{22b}=S_{22}$

$$S_{11}=\frac{e^{-j\pi}}{2}(S_{11a}-S_{11b})=0 \quad ,(VSWR)_{in}=1$$

$$S_{22}=\frac{e^{-j\pi}}{2}(S_{22a}-S_{22b})=0 \quad ,(VSWR)_{OUT}=1$$

$$G_T=(0.5)^2|S_{21a}+S_{21b}|^2=(0.5)^2[2(3.4)]^2=11.56 \text{ OR } 10.6\text{ dB}$$

(b) $S_{11b}=0.525\angle 168^\circ,\ S_{12b}=0.084\angle 63^\circ,\ S_{21b}=3.57\angle 73.5^\circ,\ S_{22b}=0.42\angle -42.75^\circ$

$$S_{11}=\frac{e^{-j\pi}}{2}(0.5\angle 160^\circ-0.525\angle 168^\circ)=0.038\angle -125.2^\circ,\ (VSWR)_{in}=\frac{1+0.038}{1-0.038}=1.08$$

$$S_{22}=\frac{e^{-j\pi}}{2}(0.4\angle -45^\circ-0.42\angle -42.75^\circ)=0.013\angle -5^\circ,\ (VSWR)_{out}=\frac{1+0.013}{1-0.013}=1.03$$

$$G_T=(0.5)^2|3.4\angle 70^\circ+3.57\angle 73.5^\circ|^2=12.13 \text{ OR } 10.8\text{ dB}$$

4.17)(a) FOR IDENTICAL AMPLIFIERS: $S_{11}=S_{22}=0$. THEN,

$$K=\frac{1+|\Delta|^2}{2|S_{12}S_{21}|}=\frac{1+|S_{12}S_{21}|^2}{2|S_{12}S_{21}|}=\frac{1+P^2}{2P},\quad P=|S_{12}S_{21}|$$

THE MINIMUM VALUE OF K OCCURS WHEN $P=1$, AND IT IS $K=1$.

(b) $S_{11}=0,\ S_{22}=0$

$$S_{21}=\frac{e^{-j\frac{\pi}{2}}}{2}(S_{21a}+S_{21b})=\frac{e^{-j\frac{\pi}{2}}}{2}2(-10.9+j7.895)=7.895+j10.9$$

$$S_{12}=\frac{e^{-j\frac{\pi}{2}}}{2}(S_{12a}+S_{12b})=\frac{e^{-j\frac{\pi}{2}}}{2}2(0.009+j0.015)=0.015-j0.009$$

$$P=|S_{12}S_{21}|=|0.017(13.46)|=0.235 \quad ,|\Delta|<1 \text{ AND}$$

$$K=\frac{1+(0.235)^2}{2(0.235)}=2.25 \quad \therefore \text{UNCONDITIONALLY STABLE.}$$

4.18)

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix}=\begin{bmatrix} 1/R_2 & -1/R_2 \\ \frac{g_m}{1+g_mR_1}-\frac{1}{R_2} & \frac{1}{R_2}\end{bmatrix}\begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

FROM TABLE 1.8.1: $y'_{11}=y_{11}Z_0=\frac{Z_0}{R_2}$, $y'_{12}=y_{12}Z_0=-\frac{Z_0}{R_2}$,

$y'_{21}=y_{21}Z_0=\frac{g_mZ_0}{1+g_mR_1}-\frac{Z_0}{R_2}$, $y'_{22}=y_{22}Z_0=\frac{Z_0}{R_2}$

$$\Delta_3=(1+y'_{11})(1+y'_{22})-y'_{12}y'_{21}=\left(1+\frac{Z_0}{R_2}\right)^2+\frac{Z_0}{R_2}\left(\frac{g_mZ_0}{1+g_mR_1}-\frac{Z_0}{R_2}\right)$$

OR

$$\Delta_3=1+\frac{2Z_0}{R_2}+\frac{g_mZ_0^2}{R_2(1+g_mR_1)}$$

$$S_{11}=\frac{(1-y'_{11})(1+y'_{22})+y'_{12}y'_{12}}{\Delta_3}=\frac{1}{\Delta_3}\left[\left(1-\frac{Z_0}{R_2}\right)\left(1+\frac{Z_0}{R_2}\right)+\frac{Z_0}{R_2}\left(\frac{Z_0}{R_2}-\frac{g_m Z_0}{1+g_m R_1}\right)\right]$$

$$\therefore \quad S_{11}=\frac{1}{\Delta_3}\left[1-\frac{g_m Z_0^2}{R_2(1+g_m R_1)}\right]$$

$$S_{22}=\frac{(1+y'_{11})(1-y'_{22})+y'_{12}y'_{21}}{\Delta_3}=\frac{1}{\Delta_3}\left[1-\frac{g_m Z_0^2}{R_2(1+g_m R_1)}\right]$$

$$S_{21}=-\frac{2y'_{21}}{\Delta_3}=\frac{-2}{\Delta_3}\left[\frac{g_m Z_0}{1+g_m R_1}-\frac{Z_0}{R_2}\right]=\frac{1}{\Delta_3}\left[\frac{-2g_m Z_0}{1+g_m R_1}+\frac{2Z_0}{R_2}\right]$$

$$S_{12}=-\frac{2y'_{12}}{\Delta_3}=\frac{-2}{\Delta_3}\left(-\frac{Z_0}{R_2}\right)=\frac{2Z_0}{\Delta_3 R_2}$$

4.19) IF S_{11} IS APPROXIMATED BY $0.97\angle 0^\circ$, THE ASSOCIATED $r_{b'e}$ IS 3.28 kΩ.

$$G_T=10=|S_{21}|^2 \Rightarrow S_{21}=-3.16$$

FROM (4.4.10):

$$R_2=Z_0(1-S_{21})=50(1+3.16)=208\ \Omega$$

THE VALUE OF g_m FOR $(VSWR)_{in}\approx 1$ AND $(VSWR)_{out}\approx 1$ FOLLOWS FROM (4.4.9). THAT IS,

$$g_m=\frac{R_2}{Z_0^2}=\frac{208}{50^2}=83\ mS$$

4.20) $G_T=10=|S_{21}|^2 \Rightarrow S_{21}=-3.16$.

FROM (4.4.10): $R_2=Z_0(1-S_{21})=50(1+3.16)=208\ \Omega$

AT THE LOWER FREQUENCIES THE VALUE OF $S_{11}=0.651\angle -74^\circ$ $(6+j14\,mS)$ CORRESPONDS TO AN $r_{b'e}$ OF 166.6 Ω. HENCE, THE CONDITION $r_{b'e}\gg R_2$ IS NOT SATISFIED, AND A SERIES FEEDBACK RESISTOR R_1 IS NEEDED.

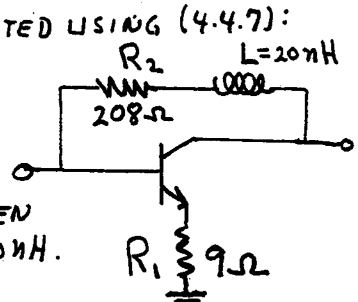
FROM (4.4.10): $g_{m(min)}=\dfrac{1+3.16}{50}=83\ mS$

THE VALUE OF THE TRANSISTOR g_m AT THE LOWER FREQUENCIES (WITH $S_{21}\approx 34\angle 180^\circ$) IS:

$$g_m=-\frac{S_{21}}{2Z_0}=\frac{34}{2(50)}=340\ mS$$

SINCE $g_m>g_{m(min)}$, R_1 IS CALCULATED USING (4.4.7):

$$R_1=\frac{Z_0^2}{R_2}-\frac{1}{g_m}=\frac{50^2}{208}-\frac{1}{0.34}=9\ \Omega$$



AN INDUCTOR IS USUALLY NEEDED IN SERIES WITH R_2 IN ORDER TO REDUCE THE FEEDBACK AT THE HIGHER FREQUENCIES AND TO FLATTEN THE GAIN. TYPICAL VALUES OF L ARE 20nH TO 30nH.

(b) THE FEEDBACK CIRCUIT WAS SIMULATED USING THE HEWLETT-PACKARD MDS PROGRAM. THE RESULTS ARE:

f(MHz)	S_{11}	S_{21}	S_{12}	S_{22}	$G_T = 10\log\lvert S_{21}\rvert^2$
100	$0.057\angle -163^\circ$	$3.27\angle 177.3^\circ$	$0.183\angle -1.86^\circ$	$0.044\angle 113.4^\circ$	10.3 dB
200	$0.062\angle -146.6^\circ$	$3.29\angle 174.5^\circ$	$0.182\angle -3.8^\circ$	$0.083\angle 95.4^\circ$	10.3 dB
400	$0.086\angle -120.3^\circ$	$3.35\angle 168.6^\circ$	$0.177\angle -7.6^\circ$	$0.161\angle 78.4^\circ$	10.5 dB
600	$0.132\angle -105.3^\circ$	$3.45\angle 161.7^\circ$	$0.169\angle -11.4^\circ$	$0.243\angle 66.4^\circ$	10.8 dB
800	$0.196\angle -102.9^\circ$	$3.52\angle 154^\circ$	$0.157\angle -14.4^\circ$	$0.32\angle 54.1^\circ$	10.9 dB
1000	$0.27\angle -104.5^\circ$	$3.56\angle 145.3^\circ$	$0.142\angle -16.8^\circ$	$0.393\angle 42.4^\circ$	11.0 dB
1500	$0.46\angle -117.7^\circ$	$3.38\angle 121.9^\circ$	$0.102\angle -11.6^\circ$	$0.518\angle 13.6$	10.6 dB

4.21) (a)

$$Q_1 = \frac{X_c}{R} = \frac{1}{\omega_0 C R} = \frac{1}{2\pi\, 500\,10^6 (100\,10^{-2})5} = 0.637$$

$$Q_2 = \frac{f_0}{f_2 - f_1} = \frac{500\,10^6}{600\,10^6 - 400\,10^6} = 2.5$$

$$\Gamma_x = e^{-\pi(Q_2/Q_1)} = e^{-\pi(2.5/0.637)} = 4.4\ 10^{-6}$$

(b)

$$Q_1 = \frac{R}{X_c} = \omega_0 R C = 2\pi\,(9\,10^9)\,50\,(10^{-12}) = 2.83$$

$$Q_2 = \frac{f_0}{f_2 - f_1} = \frac{9\,10^9}{12\,10^9 - 6\,10^9} = 1.5$$

$$\Gamma_x = e^{-\pi(Q_2/Q_1)} = e^{-\pi(1.5/2.83)} = 0.19$$

4.22)

$$\int_0^\infty \frac{1}{\omega^2}\ln\left|\frac{1}{\Gamma}\right| d\omega \le \pi RC \Rightarrow \ln\left|\frac{1}{\Gamma_x}\right| \int_{\omega_a}^{\omega_b} \frac{d\omega}{\omega^2} = \pi RC$$

OR $\ln|\Gamma_x|\left(\frac{1}{\omega_b} - \frac{1}{\omega_a}\right) = \pi RC \Rightarrow \ln|\Gamma_x| = \frac{\omega_a\omega_b\pi RC}{\omega_a - \omega_b} = \frac{-\pi\omega_0^2 RC}{\omega_b - \omega_a}$

OR $\ln|\Gamma_x| = -\pi\frac{Q_2}{Q_1}$ WHERE $\omega_0 = \sqrt{\omega_a\omega_b}$, $Q_2 = \frac{\omega_0}{\omega_b - \omega_a}$, $Q_1 = \frac{1}{\omega_0 RC}$

$\therefore |\Gamma_x| = e^{-\pi Q_2/Q_1}$, ω_0 IS THE GEOMETRIC MEAN OF ω_a AND ω_b.

FOR: $\int_0^\infty \frac{1}{\omega^2} \ln\left|\frac{1}{\Gamma}\right| d\omega \le \frac{\pi L}{R} \Rightarrow \ln|\Gamma_x| \left(\frac{1}{\omega_b} - \frac{1}{\omega_a}\right) = \frac{\pi L}{R}$

OR $\ln|\Gamma_x| = \frac{-\pi \omega_o^2 L}{(\omega_b-\omega_a)R} = -\pi \frac{Q_2}{Q_1} \Rightarrow |\Gamma_x| = e^{-\pi Q_2/Q_1}$

WHERE $\omega_o = \sqrt{\omega_a \omega_b}$, $Q_2 = \frac{\omega_o}{\omega_b - \omega_a}$, $Q_1 = \frac{R}{\omega_o L}$

FOR: $\int_0^\infty \ln\left|\frac{1}{\Gamma}\right| d\omega \le \frac{\pi R}{L} \Rightarrow \ln|\Gamma_x| = \frac{-\pi R}{(\omega_b-\omega_a)} = -\pi\frac{Q_2}{Q_1} \Rightarrow |\Gamma_x| = e^{-\pi Q_2/Q_1}$

WHERE $Q_2 = \frac{\omega_o}{\omega_b-\omega_a}$, $Q_1 = \frac{\omega_o L}{R}$

4.23) (a) $\Gamma_{IN} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} = \frac{S_{11}-\Delta\Gamma_L}{1-S_{22}\Gamma_L}$

$$\frac{\partial \Gamma_{IN}}{\partial \Gamma_L} = \frac{(1-S_{22}\Gamma_L)S_{12}S_{21} + S_{12}S_{21}\Gamma_L S_{22}}{(1-S_{22}\Gamma_L)^2}$$

$$\delta_{IN} = \left|\frac{d\Gamma_{IN}/\Gamma_{IN}}{d\Gamma_L/\Gamma_L}\right| = \left|\frac{\Gamma_L(1-S_{22}\Gamma_L)\left[(1-S_{22}\Gamma_L)S_{12}S_{21} + S_{12}S_{21}S_{22}\Gamma_L\right]}{(S_{11}-\Delta\Gamma_L)\;(1-S_{22}\Gamma_L)^2}\right|$$

$$\delta_{IN} = \left|\frac{\Gamma_L(1-S_{22}\Gamma_L)S_{12}S_{21} + S_{12}S_{21}S_{22}\Gamma_L^2}{(S_{11}-\Delta\Gamma_L)(1-S_{22}\Gamma_L)}\right| = \frac{|S_{21}||S_{12}||\Gamma_L|}{|1-S_{22}\Gamma_L||S_{11}-\Delta\Gamma_L|}$$

(b) $|1-S_{22}\Gamma_L||S_{11}-\Delta\Gamma_L| = |S_{21}S_{12}|\delta_{IN}^{-1}|\Gamma_L|$

$|S_{11} - \Delta\Gamma_L - S_{11}S_{22}\Gamma_L + S_{22}\Delta\Gamma_L^2 - S_{21}S_{12}\delta_{IN}^{-1}\Gamma_L| = 0$

$\left|\Gamma_L^2 - \Gamma_L\left(\frac{\Delta + S_{11}S_{22} + S_{12}S_{21}\delta_{IN}^{-1}}{S_{22}\Delta}\right) + \frac{S_{11}}{S_{22}\Delta}\right| = 0$

$\therefore\ |\Gamma_L| = \left|\alpha \pm \left|\alpha^2 - \frac{S_{11}}{S_{22}\Delta}\right|^{1/2}\right|$ WHERE $\alpha = \frac{\Delta + S_{11}S_{22} + S_{12}S_{21}\delta_{IN}^{-1}}{2S_{22}\Delta}$

(c) $\Gamma_{OUT} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s} = \frac{S_{22}-\Delta\Gamma_s}{1-S_{11}\Gamma_s}$

$$\frac{\partial\Gamma_{OUT}}{\partial\Gamma_s} = \frac{(1-S_{11}\Gamma_s)S_{12}S_{21} + S_{12}S_{21}\Gamma_s S_{11}}{(1-S_{11}\Gamma_s)^2}$$

$$\delta_{OUT} = \left|\frac{\partial\Gamma_{OUT}/\Gamma_{OUT}}{\partial\Gamma_s/\Gamma_s}\right| = \left|\frac{\Gamma_s(1-S_{11}\Gamma_s)\left[(1-S_{11}\Gamma_s)S_{12}S_{21} + S_{12}S_{21}S_{11}\Gamma_s\right]}{(S_{22}-\Delta\Gamma_s)\;(1-S_{11}\Gamma_s)^2}\right|$$

$$\delta_{OUT} = \left|\frac{\Gamma_s(1-S_{11}\Gamma_s)S_{12}S_{21} + S_{12}S_{21}S_{11}\Gamma_s^2}{(S_{22}-\Delta\Gamma_s)(1-S_{11}\Gamma_s)}\right| = \frac{|S_{21}||S_{12}||\Gamma_s|}{|1-S_{11}\Gamma_s||S_{11}-\Delta\Gamma_s|}$$

4.24) (a) $\Gamma_s = S_{11}^* = 0.75\angle 100^\circ$ AND $\Gamma_L = S_{22}^* = 0.7\angle 50^\circ$

(b) $Y_s = \frac{1}{Z_s} = 7 - j23$ mS , $Y_L = \frac{1}{Z_L} = 4 - j9$ mS

$$(BW)_{IN}^i = \frac{2f_0 G_{s,m}}{|B_{s,m}|} = \frac{2(8\,10^9)\,0.007}{0.023} = 4.87 \text{ GHz}$$

$$(BW)_{OUT}^i = \frac{2f_0 G_{L,m}}{|B_{L,m}|} = \frac{2(8\,10^9)(0.004)}{0.009} = 7.11 \text{ GHz}$$

(c) $(BW)_{IN} = 20\%\,(BW)_{IN}^i = 974$ MHz

$Y_{IN} = 7 + j23$ mS

THE REQUIRED VALUE OF C'_{IN} (FROM (4.6.5)) IS:

$$C'_{IN} = \frac{B_{IN,m}}{\omega_0}\left[\frac{(BW)_{IN}^i}{(BW)_{IN}} - 1\right] = \frac{23\,10^{-3}}{2\pi(8\,10^9)}\left[\frac{4.87}{0.974} - 1\right] = 1.83 \text{ pF}$$

(d) $Y'_{IN} = Y_{IN} + j\omega C'_{IN} = (7 + j23)10^{-3} + j2\pi(8\,10^9)(1.83\,10^{-12}) = 7 + j115$ mS

$\Gamma'_{IN} = 0.98\angle -160.4^\circ$, $\therefore \Gamma_s = \Gamma'^*_{IN} = 0.98\angle 160.4^\circ$, $\Gamma_L = S_{22}^* = 0.7\angle 50^\circ$

$$G_{TU,max} = \frac{1}{1-(0.98)^2}(2.5)^2\frac{1}{1-(0.7)^2} = 309.4 \text{ OR } 24.9 \text{ dB}$$

4.25) $\Gamma_{Ms} = 0.476\angle 166^\circ \Rightarrow Y_{Ms} = 51 - j15$ mS

$\Gamma_{ML} = 0.846\angle 72^\circ \Rightarrow Y_{ML} = 3 - j14$ mS

$$(BW)_{IN}^i = \frac{2(4\,10^9)\,0.051}{0.015} = 27.2 \text{ GHz}, \quad (BW)_{OUT}^i = \frac{2(4\,10^9)\,0.003}{0.014} = 1.714 \text{ GHz}$$

THE VALUE OF L'_{OUT} REQUIRED FOR $BW \approx (BW)_{OUT} = 400$ MHz IS

$$L'_{OUT} = \frac{1}{\omega_0 |B_{OUT,m}|\left[\frac{(BW)_{OUT}^i}{(BW)_{OUT}} - 1\right]} = \frac{1}{2\pi(4\,10^9)0.014\left[\frac{1.714\,10^9}{0.4\,10^9} - 1\right]} = 0.865 \text{ nH}$$

4.26) FROM (4.7.4): $P_{i,mds} = -174 + 10\log 800\,10^6 + 5 + 3 = -76.97$ dBm

FROM (4.7.5): $P_{o,mds} = P_{i,mds} + G_A = -76.97 + 30 = -46.97$ dBm.
(WITH $G_A = G_T$)

$$DR = P_{1dB} - P_{o,mds} = 28 - (-46.97) = 74.97 \text{ dB}$$

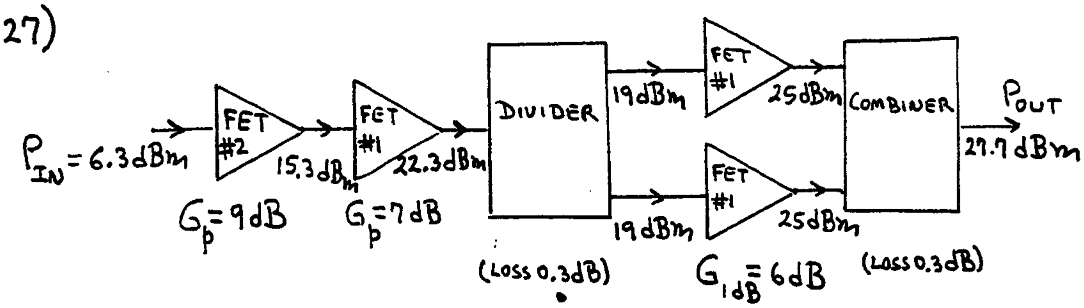
$$P_{IP} = P_{1dB} + 10 = 28 + 10 = 38 \text{ dBm}$$

$$DR_f = \tfrac{2}{3}(P_{IP} - P_{o,mds}) = \tfrac{2}{3}(38 - (-46.97)) = 69.3 \text{ dB}$$

FOR NO THIRD-ORDER IM:

$$P_{OUT} = P_{o,mds} + DR_f = -46.97 + 69.3 = 22.3 \text{ dBm}$$

4.27)



4.28) $K = 1.61$, $\Delta = 0.313\angle 18.8^\circ$ $\therefore$ UNCONDITIONALLY STABLE

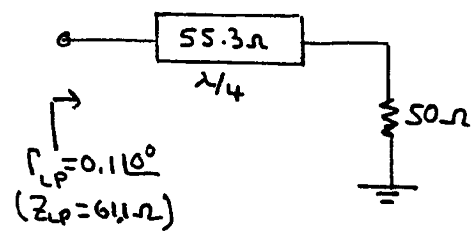
$\Gamma_L = \Gamma_{LP} = 0.1\angle 0^\circ$ AND $\Gamma_s = \Gamma_{sP} = \Gamma_{IN}^* = 0.324\angle 146.6^\circ$

OUTPUT MATCHING CIRCUIT:

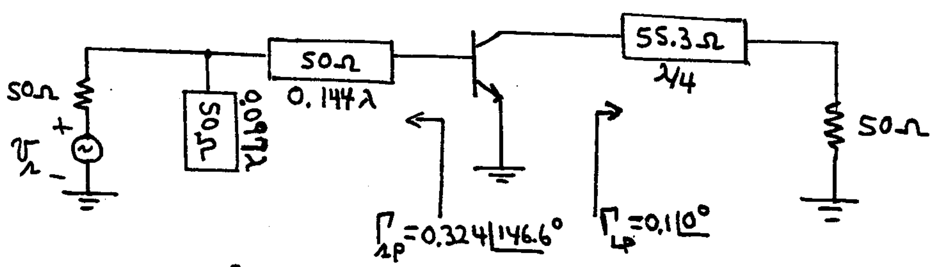
$Z_{LP} = 61.1\,\Omega$

USING A $\lambda/4$ TRANSFORMER

$Z_0 = \sqrt{61.1(50)} = 55.3\,\Omega$



INPUT MATCHING CIRCUIT: USE A SHUNT STUB (OPEN CIRCUIT) OF LENGTH 0.097λ FOLLOWED BY A SERIES TRANS. LINE OF LENGTH 0.144λ.



4.29) $$P_{IN} = \frac{E^2_{s,rms}}{4(50)} = \frac{(79.5\,10^{-3})^2}{200} = 3.16\,10^{-5}\,W \text{ OR } -15\,dBm$$

$$P_{OUT} = P_{IN} + 13 + 13 + 10 + 9 = -15 + 45 = 30\,dBm$$

OR $P_{OUT} = 1\,W$

4.30) THE BLOCK DIAGRAM IS IDENTICAL TO THE ONE IN FIG. 4.7.18, EXCEPT THAT $Z_s = 1.19 + j1.35\,\Omega$ AND $Z_L = 8.1 - j4.1\,\Omega$

4.31) YES.