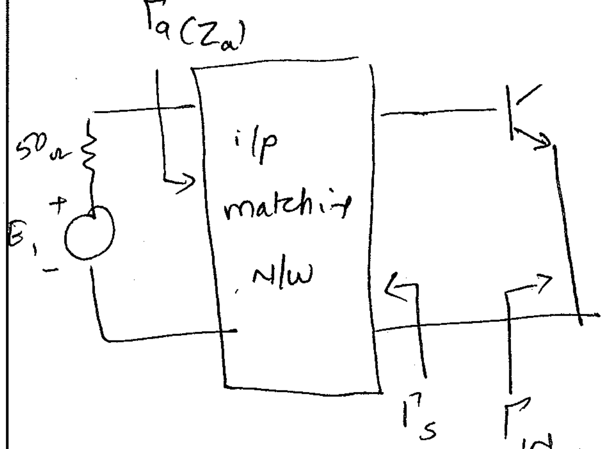
Constant VSWR circle

→ The data sheet for an amplifier usually includes the maximum allowable values of its i/p & o/p VSWR.

→ I/p VSWR ⊙ can be drawn on Γ_s plane & o/p VSWR ⊙ can be drawn on Γ_L plane.

For amplifier shown in the figure.



$$(VSWR)_{IN} = \frac{1+|\Gamma_a|}{1-|\Gamma_a|} \quad -(1)$$

$$|\Gamma_a| = \left| \frac{\Gamma_{IN} - \Gamma_s^*}{1 - \Gamma_{IN}\Gamma_s} \right| \quad -(2)$$

Constant values of $|\Gamma_a|$ are obtained by values of Γ_s that lie on a ⊙

For designing for a given $(VSWR)_{IN}$:-

① Calculate

$$C_{v_i} = \frac{\Gamma_{IN}^* (1-|\Gamma_a|^2)}{1-|\Gamma_a \Gamma_{IN}|^2} \quad -(3)$$

$$r_{v_i} = \frac{|\Gamma_a| (1-|\Gamma_{IN}|^2)}{1-|\Gamma_a \Gamma_{IN}|^2} \quad -(4)$$

In an unconditionally stable case, and in many potentially unstable case, Γ_s can be selected to Γ_{IN}^* for $(VSWR)_{IN} = 1$

Since Γ_L and Γ_{IN} as well as Γ_S and Γ_{OUT} are related by bilinear transformation it follows that circles in Γ_L plane map into $\odot$ in the Γ_{IN} plane and circles in Γ_S plane map into circles in the Γ_{OUT} plane.

These transformations are useful to map values of Γ_L on a constant G_P circle into a circle in the Γ_S plane, where $\Gamma_S = \Gamma_{IN}^*$ and values of Γ_S on a constant G_A $\odot$ into a $\odot$ in the Γ_L plane where $\Gamma_L = \Gamma_{OUT}^*$

The $\odot$ given by

$$C_i = \frac{(1 - S_{22} C_{oo})(S_{11} - \Delta C_{oo})^* - r_{oo}^2 \Delta^* S_{22}}{|1 - S_{22} C_{oo}|^2 - r_{oo}^2 |S_{22}|^2}$$

& radius

$$r_i = \frac{r_{oo} |S_{12} S_{21}|}{\left| |1 - S_{22} C_{oo}|^2 - r_{oo}^2 |S_{22}|^2 \right|}$$

$C_{oo} \to C_P$ or C_A

$r_{oo} \to r_P$ or r_A

$\cancel{C_0 = r_{OUT}^*}$ maps the values of Γ_L into a $\odot$ in $\Gamma_S = \Gamma_{IN}^*$ plane.

$\cancel{r_0 = r_{OUT}}$

$\parallel^{ly}$ a $\odot$ in the Γ_S plane given by

$$|\Gamma_S - C_{ii}| = r_{ii}$$

maps into a $\odot$ in the $\Gamma_L = \Gamma_{OUT}^*$ plane given by

$$C_o = \frac{(1 - S_{11} C_{ii})(S_{22} - \Delta C_{ii})^* - r_{ii}^2 \Delta^* S_{11}}{|1 - S_{11} C_{ii}|^2 - r_{ii}^2 |S_{11}|^2}$$

$$r_o = \frac{r_{ii} |S_{12} S_{21}|}{\left| |1 - S_{11} C_{ii}|^2 - r_{ii}^2 |S_{11}|^2 \right|}$$

& $|\Gamma_a| = 0$ From (3) and (4) we obtain

$$C_{v_i}\Big|_{|\Gamma_a|=0} = \Gamma_{IN}^* \quad \& \quad r_{v_i}\Big|_{|\Gamma_a|=0} = 0$$

In other words, the value of $\Gamma_S = \Gamma_{IN}^*$ produces $|\Gamma_a| = 0$ & consequently $(VSWR)_{IN} = 1$

III^{ly}

$$(VSWR)_{OUT} = \frac{1+|\Gamma_b|}{1-|\Gamma_b|} \qquad -(5)$$

$$|\Gamma_b| = \left| \frac{\Gamma_{OUT} - \Gamma_L^*}{1 - \Gamma_{OUT}\Gamma_L} \right| \qquad -(6)$$

The o/p ~~stab~~ VSWR ⊙ can be drawn with

$$C_{v_o} = \frac{\Gamma_{OUT}^* (1-|\Gamma_b|^2)}{1-|\Gamma_b \Gamma_{OUT}|^2} \qquad -(7)$$

$$r_{v_o} = \frac{|\Gamma_b|(1-|\Gamma_{OUT}|^2)}{1-|\Gamma_b \Gamma_{OUT}|^2} \qquad -(8)$$

egr $S_{11} = 0.6\angle 36^\circ$ $S_{12} = 0.14\angle -85^\circ$ $S_{21} = 2.3\angle -80^\circ$ $S_{22} = 0.15\angle 45^\circ$

1) Determine $G_{A,max}$ and draw a constant G_A circle that is 1dB less than $G_{A,max}$

Soln

(1) $K = 1.17$

$|\Delta| = 0.368$ $\Delta = 0.368\angle 27.91^\circ$

Transistor is unconditionally stable. We can use simultaneous conjugate match with-

$$\Gamma_{MS} = \frac{B_1 - \sqrt{B_1^2 - 4|C_1|^2}}{2C_1}$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \qquad C_1 = S_{11} - \Delta S_{22}^*$$

$$\Gamma_{ML} = \frac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \qquad C_2 = S_{22} - \Delta S_{11}^*$$

$$\Gamma_{MS} = 0.714\angle -40.45^\circ \qquad \Gamma_{ML} = 0.387\angle -129.36^\circ$$

resulting in $(VSWR)_{IN} = (VSWR)_{OUT} = 1$

$$G_{A,max} = \frac{|S_{21}|}{|S_{12}|}\left(K - \sqrt{K^2 - 1}\right)$$

$$= 9.24 \quad \text{or } 9.66\,\text{dB}$$

Constant G_A ⊙ with 1dB less than $G_{A,max}$ is the ⊙ for $G_A = 8.66$ dB. The center & radius of this ⊙ can be obtained as

$$C_a = \frac{g_a C_1^*}{1 + g_a(|S_{11}|^2 - |\Delta|^2)}$$

$$r_a = \frac{\left[1 - 2K|S_{12}S_{21}|g_a + |S_{12}S_{21}|^2 g_a^2\right]^{1/2}}{|1 + g_a(|S_{11}|^2 - |\Delta|^2)|}$$

$$g_a = \frac{G_A}{|S_{21}|^2} = \frac{7.3451}{(2.3)^2} = 1.3886$$

$C_a = 0.602 \angle -40.45^\circ$

$r_a = 0.3$

b) Select values of Γ_s on $G_A = G_{A,max} - 1\ dB$ ⊙. For each value of Γ_s determine values of Γ_L that lie on constant $(VSWR)_{OUT} = 1.5$ circle. Draw constant VSWR out ⊙.

eg: $S_{11} = 0.55\angle{-120^\circ}$ $\quad S_{12} = 0.14\angle{30^\circ}$

$S_{21} = 3.5\angle{60^\circ}$ $\quad S_{22} = 0.2\angle{-50^\circ}$

Analyze the trade-offs between operating power gain, stability & VSWRs

Soln

(1) Calculate $$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} = 0.947$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} = 0.521\angle{-102.01^\circ}$$

$K<1 \rightarrow$ transistor is potentially unstable.

(2) Draw i/p & o/p stability ⊙

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

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

$C_S = 16.47\angle{130.7^\circ}$ $\quad C_L = 1.22\angle{-59.25^\circ}$

$r_S = 15.52$ $\quad r_L = 2.12$

The maximum stable gain is

$$G_{MSG} = \frac{|S_{21}|}{|S_{12}|} = \frac{3.5}{0.14} = 25 \quad (13.98\,dB)$$

Choose $G_p = 12\,dB$

③ Calculate C_p & r_p

$$C_p = \frac{g_p C_2^*}{1 + g_p(|S_{22}|^2 - |\Delta|^2)} = 0.519 \angle 120.75^\circ$$

$$r_p = \frac{[1 - 2K|S_{12}S_{21}|g_p + |S_{12}S_{21}|^2 g_p^2]^{1/2}}{|1 + g_p(|S_{22}|^2 - |\Delta|^2)|} = 0.639$$

④ Values of Γ_L on 12 dB gain are chosen

⑤ Mapping $G_p = 12\,dB$ constant gain ⊙ into $\Gamma_S = \Gamma_{IN}^*$ plane.

⑥ Calculate C_i & r_i with $C_{oo} = C_p = 0.519 \angle 120.75^\circ$ &

$r_{oo} = r_p = 0.639$

$C_i = 0.8 \angle 130.7^\circ$ $r_i = 0.338$

⑦ Using

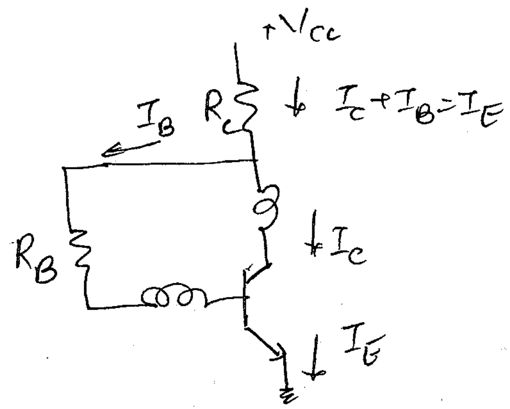
$$\Gamma_{IN} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$$ for a & b we get a' & b'

DC Bias Circuit for Transistors

The purpose of a good dc bias design is to select the proper quiescent point and hold the quiescent point constant over variations in transistor parameters and temperature. A resistor bias N/w can be used with good results over moderate temperature changes. For large temperature changes an active bias N/w is preferred for large temperature changes.

At low frequencies a bypassed emitter resistor is an important contributor to the quiscent point stability. At microwave frequencies, the bypass capacitor, which is in ||el to the emitter resistor can produce oscillations by making the i/p port unstable at some frequencies. Resistance in an amplifier circuit can degrade the noise figure.

A resistive feedback N/w with voltage feedback is shown in the figure below.



If V_{BE} is the base emitter voltage.

$$V_{BE}+I_BR_B+I_ER_C=V_{cc}$$

$$I_B=I_E-I_C=(1-\alpha)\,I_E$$

$$=\frac{I_E}{1+\beta}$$

$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_B/(1+\beta)}$$

$$I_B R_B + I_E R_C = V_{CC} - V_{BE}$$

$$\frac{I_E}{1+\beta} R_B + I_E R_C = V_{CC} - V_{BE}$$

$$I_E = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{(1+\beta)}}$$

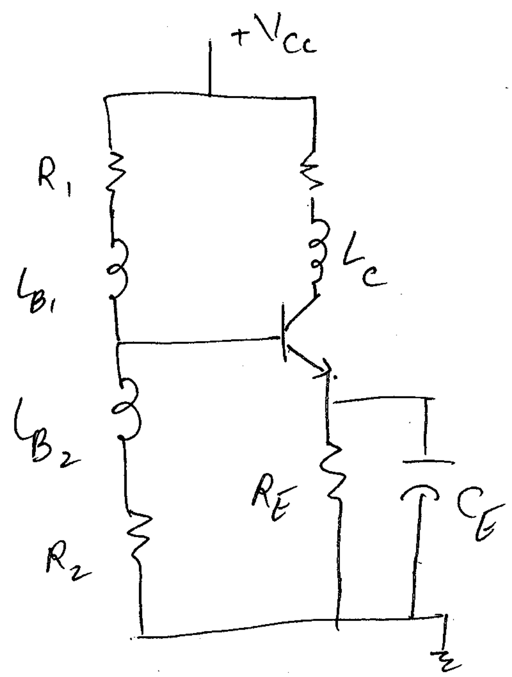
For I_E to be less sensitive to changes in V_{BE} and β, the following condition must be satisfied

$$V_{CC} >> V_{BE}$$

$$R_C >> \frac{R_B}{1+\beta}$$

Advisable to use high V_{CC} and R_C. We can also use small R_B but it will limit V_{CE} and therefore the swing in output.

An alternative biasing N/w that uses a bypassed resistor at the emitter as shown in the figure



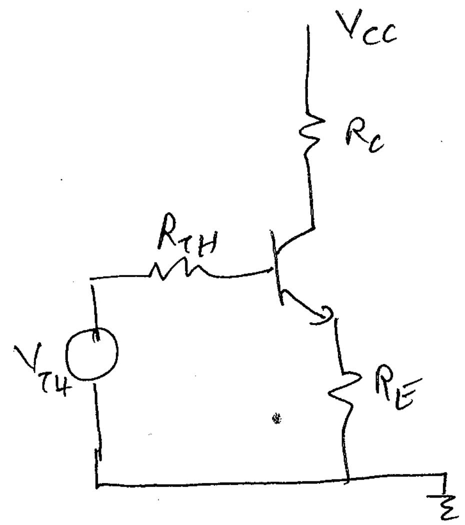
L_C, L_{B_1} and L_{B_2} are used to block RF. C_E is used to bypass RF

Thevenin equivalent of this circuit for the dc condition.

$$V_{TH} = \frac{R_2}{R_1+R_2} V_{CC}$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

From the equivalent ckt we have



$$V_{TH} = R_{TH} I_B + V_{BE} + R_E I_E$$

$$= \left(\frac{R_{TH}}{1+\beta} + R_E\right) I_E + V_{BE}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/(1+\beta)}$$

Following condition must be met for stable I_E

$$V_{TH} >> V_{BE} \quad \&$$

$$R_E >> \frac{R_{TH}}{1+\beta}$$

V_{CC}, V_{TH} cannot be increased arbitrarily because it reduces V_{CB} and hence V_{CE}. Smaller V_{CE} means limited output swing.

→ Large R_E will reduce V_{CE} as well.

→ Smaller R_{TH} will mean low input impedance of the circuit.

V_{TH} is selected no more than 15 to 20% of V_{CC}

3.9.2

a) $V_{CC} = 15V \quad I_C \approx I_E$

$$V_{CC} = V_{CE} + I_C(R_C + R_E)$$

$$R_C + R_E = \frac{15-8}{2\times10^{-3}} = 3.5k\Omega$$

Assuming voltage across R_E is 10% to 20% of V_{CC}

$$R_E = \frac{10\% V_{CC}}{I_C} = 750\Omega$$

$$R_C = 2500 - 750 = 2.75k\Omega.$$

$$V_{TH} = \frac{V_{CC} R_2}{R_1 + R_2} \qquad R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_1 = R_{TH} \frac{V_{CC}}{V_{TH}} \qquad R_2 = \frac{R_{TH}}{1 - \frac{V_{TH}}{V_{CC}}}$$

for good beta (β) stabilility

R_{TH} is selected. such that

$$\beta R_E = 10 R_{TH}$$

$$R_{TH} = \frac{\beta R_E}{10} = \frac{100(750)}{10} = 7.5k\Omega$$

$$V_{TH} = I_B R_{TH} + 0.7 + I_E R_E = 2.35V$$

$$R_1 = 47.9k\Omega$$