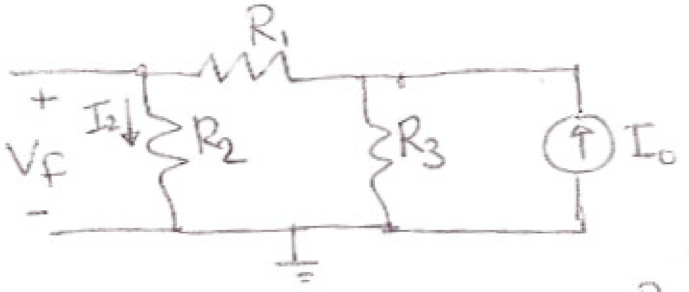
HW #7 Sol'n

1. series-series topology

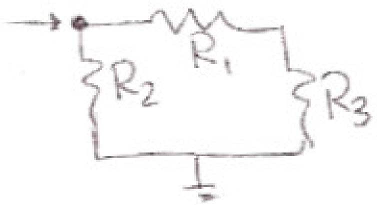
a.



$$\beta = \frac{V_f}{I_o} \Rightarrow V_f = I_2 \cdot R_2 = \frac{R_3 R_2 I_o}{R_1 + R_2 + R_3}$$

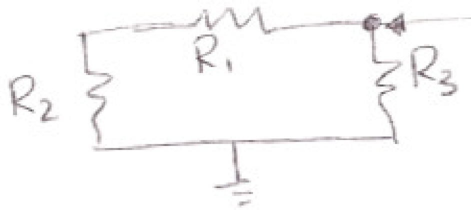
$$\therefore \beta = \boxed{\frac{R_3 R_2}{R_1 + R_2 + R_3}}$$

b. $R_{11} \Rightarrow$



$R_{11} = \boxed{R_2 \parallel (R_1 + R_3)}$

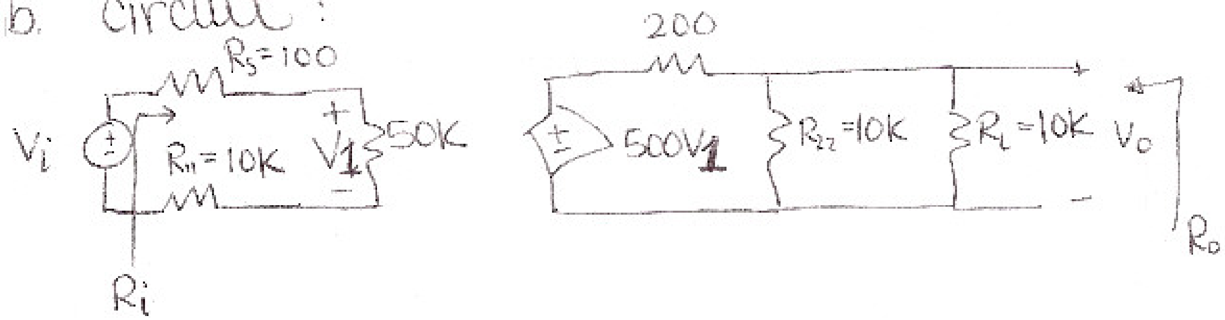
c. R_{22}



$R_{22} = \boxed{R_3 \parallel (R_1 + R_2)}$

2. a. Series-Shunt topology (just from voltage amp.)

b. circuit:



$$A \Rightarrow \frac{500 \cdot V_1 \, (R_{22} \| R_L)}{(R_{22} \| R_L + 200)} = \frac{500(5K)V_1}{5.2K} = V_o$$

$$V_1 = \frac{V_i \cdot 50K}{R_s + 50K + 10K} = \frac{50K \; V_i}{60.1K}$$

$$\frac{V_o}{V_i} = A = \frac{500(5K)50K}{(5.2K)(60.1K)} \cong \boxed{400 \, V/V}$$

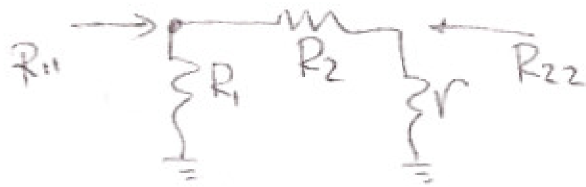
c. $$A_f = \frac{A}{1 + A\beta} = \frac{400}{1 + (400)(.1)} \cong \boxed{9.8 \, V/V}$$

d. $$R_i = R_s + 50K + R_{11} = 60.1K\,\Omega$$

$$R_{if} = R_i(1 + A\beta) = 2.464 \times 10^6 \Omega$$

$$R_{in} = R_{if} - R_s \cong \boxed{2.5M\,\Omega}$$

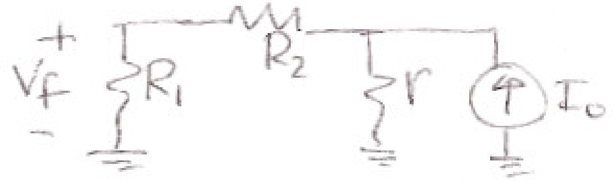
3. Feedback network:



$R_{11} = R_1 \| (R_2 + r) = 200 \| (5K + 200) \cong 193$

$R_{22} = r \| (R_1 + R_2) = 200 \| (5K + 200) \approx 193$

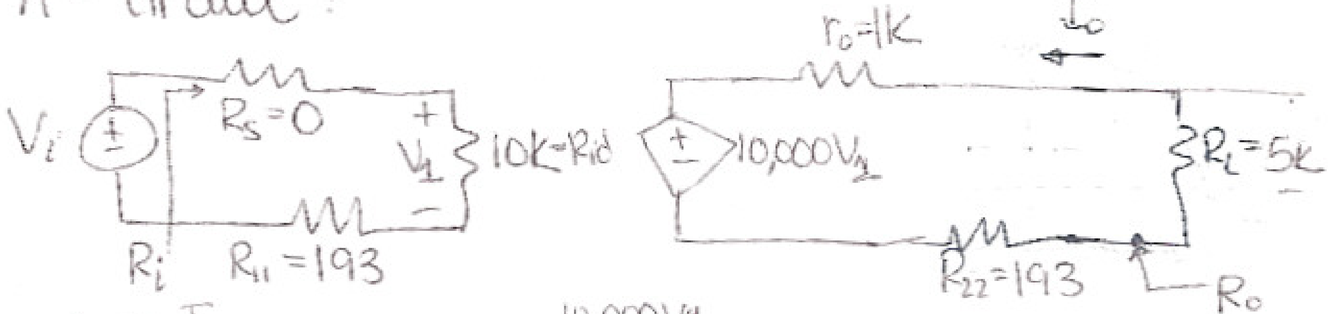
$\beta \Rightarrow$



$\beta = \dfrac{r \cdot R_1}{r + R_1 + R_2}$

$\therefore \beta = \dfrac{(200)(200)}{5k + 400} = 74 \times 10^{-3}$

A - circuit:



$A = \dfrac{I_o}{V_i}$: $I_o = -\dfrac{10{,}000 V_1}{1k + 5k + 193}$

$V_1 = \dfrac{V_i \cdot 10K}{10K + 193}$

$\Rightarrow A = \dfrac{-10{,}000(10K)}{(6{,}193)(10{,}193)}$

$A \doteq -1.6$

$\therefore A_f = \dfrac{A}{1 + A\beta} \cong \boxed{-1.8}$

$R_i = 10{,}193$

$R_{if} = 10{,}193(1 + A\beta) \cong 8{,}986 \Omega$

$R_{in} = R_{if} - R_s = \boxed{8{,}986 \Omega}$

$R_o = R_L + r_o + R_{22} = 6{,}193$

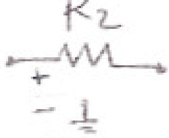
$R_{of} = R_o(1 + A\beta) \cong 5{,}460 \Omega$

$R_{out} = R_{of} - R_L \cong \boxed{5{,}460 \Omega}$

4. a. series-shunt
b. shunt - series
c. shunt - shunt

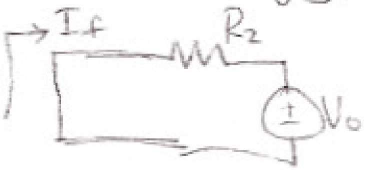
5. Shunt-shunt topology:

Feedback topology $\Rightarrow$



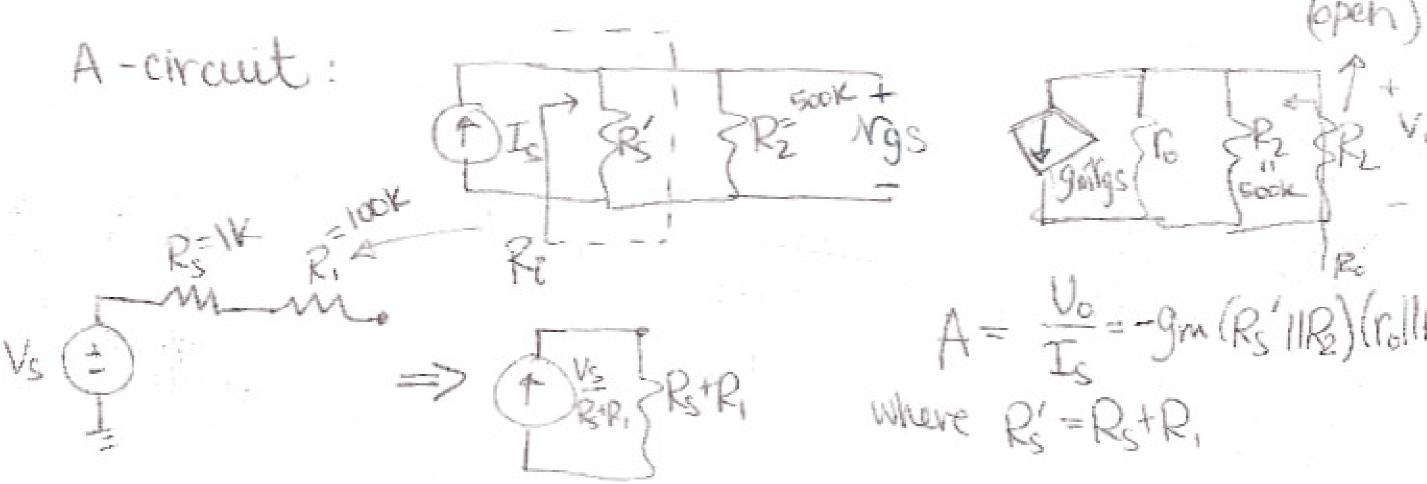
$R_{11} = R_{22} = R_2$

$\frac{I_f}{V_o} \equiv \beta \Rightarrow$



$\therefore I_f = \frac{-V_o}{R_2} \Rightarrow \beta = -\frac{1}{R_2}$

A-circuit:



$A = \frac{V_o}{I_s} = -g_m (R_s' \| R_2)(r_o \| R_2)$

where $R_s' = R_s + R_1$

$g_m = \frac{2I_D}{V_{ov}} = \frac{2(2m)}{1.5-1} = 8m\ A/V$; $r_o = \frac{V_A}{I} = \frac{50}{2m} = 25k\Omega$

$\therefore A = -8m(101k \| 500k)(25k \| 500k) \cong -16.1M\ V/V$

$A_f = \frac{A}{1+A\beta} = \frac{-16.1M}{[1 + (-16.1M)(-\frac{1}{500k})]} \cong -485k\ V/V$

$\frac{V_o}{V_s} = \frac{V_{of}}{I_s(R_s+R_1)} = \frac{-485k}{(101k)} \cong \boxed{-4.8\ V/V}$

$R_o = R_2 \| r_o \cong 24k\Omega \Rightarrow R_{of} = \frac{R_o}{\underbrace{(1+A\beta)}_{33.2}} = \boxed{723\Omega} = R_{out}$

$R_i = (R_s + R_1) \| R_2 = 84k$

$R_{if} = 84k/(1+A\beta) \cong 2{,}531\Omega \Rightarrow R_{in} = R_{if} - R_s \cong \boxed{1531\Omega}$

6. $|A\beta| = 1$

$$A = \frac{A_o}{1+j(f/10)}$$

unity-gain buffer $\Rightarrow \beta = 1$

$$\therefore |A\beta| = \frac{10^5(1)}{\sqrt{1+\frac{f^2}{100}}} = 1$$

$$\therefore \boxed{f \approx 1MHz}$$

$$\phi = -\tan^{-1}\left(\frac{1M}{10}\right) \approx -90°$$

$\therefore$ phase margin $= \boxed{90°}$

7. $$A(f) = \frac{A_o}{(1+\frac{jf}{100K})(1+j\,f/10)}, \quad \beta = 1$$

$$|A\beta| = \frac{10^5 \cdot (1)}{\sqrt{1+\frac{f^2}{(100K)^2}} \cdot \sqrt{1+\frac{f^2}{10^2}}} = 1 \Rightarrow f \approx \boxed{308\ KHz}$$

$$\phi = -\left[\tan^{-1}\left(\frac{f}{100K}\right) + \tan^{-1}\left(\frac{f}{10}\right)\right] = -162°$$

$\therefore$ phase margin $= 180 - 162° \cong \boxed{18°}$

For phase margin $\geq 45°$

$$\tan^{-1}(f_1/100K) \leq 45° \Rightarrow f_1 \leq 100K$$

$$|A\beta| = \frac{10^5 \cdot \beta}{\sqrt{2} \cdot \sqrt{1+1{,}000}} = 1 \quad \therefore \boxed{\beta \cong 447\mu}$$

8. For $60°$ phase margin: (use eq. 8.79)

$$\tan^{-1}\left(\frac{f_1}{10^5}\right) + \tan^{-1}\left(\frac{f_1}{10^6}\right) + \tan^{-1}\left(\frac{f_1}{10^7}\right) = 120°$$

from graph $\Rightarrow f_1 \approx 8\times10^5$ Hz

check $\rightarrow$ $\tan^{-1}\left(\frac{8\times10^5}{10^5}\right) + \tan^{-1}\left(\frac{8\times10^5}{10^6}\right) + \tan^{-1}\left(\frac{8\times10^5}{10^7}\right) \cong$

$83 + 39 + 5 = 127$ (close) $\rightarrow$ $\underline{f_1 = 7\times10^5 \text{ Hz}}$ gives $\phi \cong 120.9$

$$|A(f_1)| = \frac{10^5}{\underbrace{\sqrt{1+\left(\frac{7\times10^5}{10^5}\right)^2}}_{\approx 7}\underbrace{\sqrt{1+\left(\frac{7\times10^5}{10^6}\right)^2}}_{\approx 1.2}\underbrace{\sqrt{1+\left(\frac{7\times10^5}{10^7}\right)^2}}_{\approx 1}} \cong 11,905$$

$|A\beta| = 1$

$\therefore \beta \cong 84\mu$

$$A_f = \frac{10^5}{1+(10^5\cdot 84\mu)} = \boxed{10,638\ V/V}$$

For $90°$ pm: from graph $\Rightarrow$ $\underline{f_2 \approx 3\times10^5 \text{ Hz}}$

$$\tan^{-1}\left(\frac{3\times10^5}{10^5}\right) + \tan^{-1}\left(\frac{3\times10^5}{10^6}\right) + \tan^{-1}\left(\frac{3\times10^5}{10^7}\right) \cong 89.9° \text{ (ok)}$$

$$|A(f_2)| = \frac{10^5}{\sqrt{1+\left(\frac{3\times10^5}{10^5}\right)^2}\sqrt{1+\left(\frac{3\times10^5}{10^6}\right)^2}\sqrt{1+\left(\frac{3\times10^5}{10^7}\right)^2}} \cong 30.3\times10^3\ V/V$$

$|A\beta| = 1 \Rightarrow \beta \cong 33\mu$

$$A_f = \frac{10^5}{1+(10^5\cdot 33\mu)} = \boxed{23,300\ V/V}$$

Chapter 14 — Exercises

14.1

$$I = \frac{|-V_{CC} + V_{CEsat}|}{R_L}$$

$$= \frac{|-15+0.2|}{1} = 14.8 \text{ mA}$$

$$R = \frac{V_{CC} - V_D}{I}$$

$$= \frac{15-0.7}{14.8} = \underline{0.97 \text{ k}\Omega}$$

Output voltage swing = $\underline{-14.8 \text{ V to } +14.8 \text{ V}}$

Min. emitter current = $\underline{0 \text{ mA}}$

Max. emitter current = $2I$

$$= 2 \times 14.8 = \underline{29.6 \text{ mA}}$$

14.2 At $v_O = -10$ V, the load current is -10 mA and the emitter current of Q_1 is $14.8 - 10 = 4.8$ mA. Thus

$$v_{BE1} = 0.6 + 0.025 \ln\left(\frac{4.8}{1}\right)$$

$$= 0.64 \text{ V}$$

Thus, $v_I = -10 + 0.64 = \underline{-9.36 \text{ V}}$

At $v_O = 0$ V, $i_L = 0$ and $i_{E1} = 14.8$ mA

Thus, $v_{BE1} = 0.6 + 0.025 \ln \frac{14.8}{1}$

$$= 0.67 \text{ V}$$

$$v_I = \underline{+0.67 \text{ V}}$$

At $v_O = +10$ V, $i_L = 10$ mA and $i_{E1} = 24.8$ mA

Thus, $v_{BE1} = 0.6 + 0.025 \ln(24.8)$

$$= 0.68 \text{ V}$$

$$v_I = \underline{10.68 \text{ V}}$$

To calculate the incremental voltage gain we use

$$\frac{v_o}{v_i} = \frac{R_L}{R_L + r_{e1}}$$

At $v_O = -10$ V, $i_{E1} = 4.8$ mA and $r_{e1} = \frac{25}{4.8} = 5.2\ \Omega$

Thus, $\frac{v_o}{v_i} = \frac{1}{1+0.0052} = \underline{0.995 \text{ V/V}}$

Similarly, at $v_O = 0$ V, $r_{e1} = \frac{25}{14.8} = 1.7\ \Omega$

and, $\frac{v_o}{v_i} = \frac{1}{1+0.0017} = \underline{0.998 \text{ V/V}}$

At $v_O = +10$ V, $i_{E1} = 24.8$ mA and $r_{e1} = 1\ \Omega$

Thus, $\frac{v_o}{v_i} = \frac{1}{1+0.001} = \underline{0.999 \text{ V/V}}$

14.3 For $v_O = 0$ V,

$$P_{D1} = V_{CC} I = 10 \times 0.1 = \underline{1 \text{ W}}$$

$$P_{D2} = V_{CC} I = 10 \times 0.1 = \underline{1 \text{ W}}$$

For a 10-V amplitude output sinusoid, the waveform shown in Fig. 9.4 apply and the average power dissipation in Q_1 is seen to be $\frac{1}{2} V_{CC} I = \frac{1}{2} \times 10 \times 0.1 = \underline{0.5 \text{ W}}$. Transistor Q_2 carries a constant current I and has an average v_{CE} of 15 V, thus the average power dissipated in Q_2 remains unchanged at $\underline{1 \text{ W}}$. The load power is

$$P_L = \frac{(\hat{V}_o/\sqrt{2})^2}{R_L} = \frac{1}{2}\,\frac{100}{100} = \underline{0.5 \text{ W}}$$

14.4 $P_L = \frac{(8/\sqrt{2})^2}{100} = \underline{0.32 \text{ W}}$

$$P_+ = 10 \times 0.1 = 1 \text{ W}$$

$$P_- = 10 \times 0.1 = 1 \text{ W}$$

$$P_{supplies} = \underline{2 \text{ W}}$$

$$\eta = \frac{P_L}{P_S} \times 100$$

$$= \frac{0.32}{2} \times 100 = \underline{16\ \%}$$

14.5 (a) $P_L = \frac{1}{2}\frac{\hat{V}_o^2}{R_L}$

$$= \frac{1}{2}\,\frac{(4.5)^2}{4} = \underline{2.53 \text{ W}}$$

(b) $P_+ = P_- = V_{CC} \times \frac{1}{\pi}\frac{\hat{V}_o}{R_L}$

$$= 6 \times \frac{1}{\pi} \times \frac{4.5}{4} = \underline{2.15 \text{ W}}$$

(c) $\eta = \frac{P_L}{P_S} = \frac{2.53}{2 \times 2.15} \times 100$

$$= \underline{59\ \%}$$

(d) Peak input currents $= \frac{1}{\beta+1}\,\frac{\hat{V}_o}{R_L}$

$$= \frac{1}{51} \times \frac{4.5}{4}$$

$$= \underline{22.1 \text{ mA}}$$

(e) Using Eq. (9.22)

$$P_{DNmax} = P_{DPmax} = \frac{V_{CC}^2}{\pi^2 R_L}$$

$$= \frac{6^2}{\pi^2 \times 4} = \underline{0.91 \text{ W}}$$