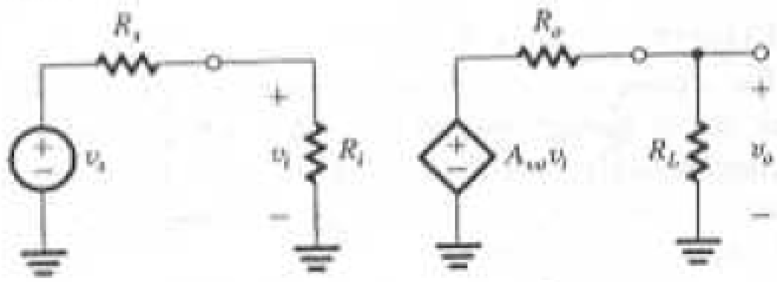
1.45



$$\frac{v_o}{v_s} = \frac{R_i}{R_i + R_s} \times A_{v_o} \times \frac{R_L}{R_L + R_o}$$

(a) $$\frac{v_o}{v_s} = \frac{10R_s}{10R_s + R_s} \times A_{v_o} \times \frac{10R_o}{10R_o + R_o}$$

$$= \frac{10}{11} \times 10 \times \frac{10}{11} = 8.26 \text{ V/V}$$

or, 20 log 8.26 = 18.3 dB

(b) $$\frac{v_o}{v_s} = \frac{R_s}{R_s + R_s} \times A_{v_o} \times \frac{R_o}{R_o + R_o}$$

$$= 0.5 \times 10 \times 0.5 = 2.5 \text{ V/V}$$

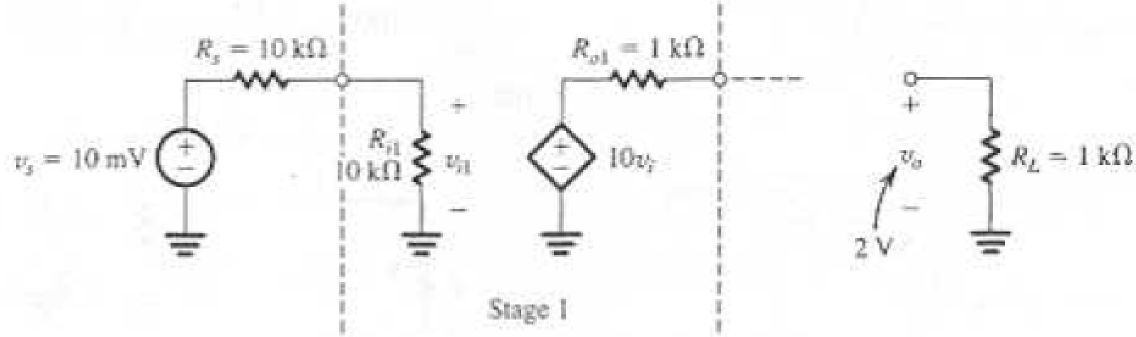
or, 20 log 2.5 = 8 dB

(c) $$\frac{v_o}{v_s} = \frac{R_s/10}{(R_s/10) + R_s} \times A_{v_o} \times \frac{R_o/10}{(R_o/10) + R_o}$$

$$= \frac{1}{11} \times 10 \times \frac{1}{11} = 0.083 \text{ V/V}$$

or 20 log 0.083 = −21.6 dB

1.51



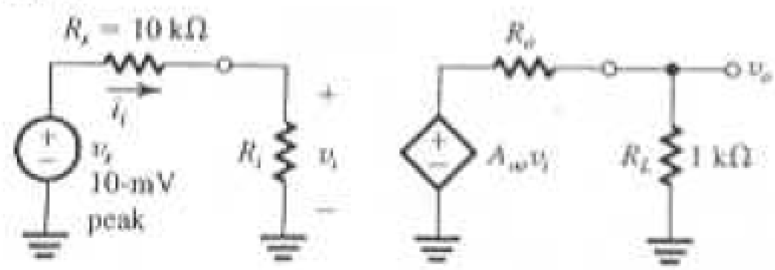
Required overall voltage gain = 2 V / 10 mV = 200 V/V. Each stage is capable of providing a *maximum* voltage gain of 10 (the open-circuit gain value). For n stages in cascade the maximum (unattainable) voltage gain in 10^n. We thus see that we need at least 3 stages. For 3 stages, the overall voltage gain obtained is

$$\frac{v_o}{v_s} = \frac{10}{10+10} \times 10 \times \frac{10}{1+10} \times 10 \times \frac{10}{1+10} \times 10 \times \frac{1}{1+1}$$

$$= 206.6 \text{ V/V}$$

Thus, three stages suffice and provide a gain slightly larger than required. The output voltage actually obtained is 10 mV × 206.6 = 2.07 V.

1.53



(a) Required voltage gain $= \frac{v_o}{v_s}$

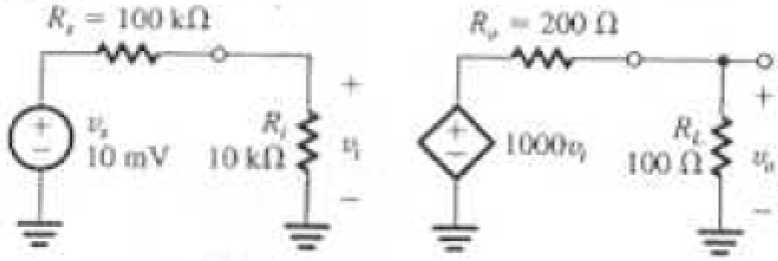
$$= \frac{3 \text{ V}}{0.01 \text{ V}} = 300 \text{ V/V}$$

(c) If $(A_{v_o} v_i)$ has its peak value limited to 5 V, the largest value of R_o is found from

$$5 \times \frac{R_L}{R_L + R_o} = 3 \Rightarrow R_o = \frac{2}{3} R_L = 667\ \Omega$$

(If R_o were greater than this value, the output voltage across R_L would be less than 3 V.)

1.54



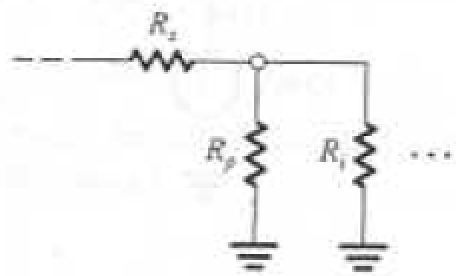
(a) $v_o = 10\text{ mV} \times \frac{10}{10+100} \times 1000 \times \frac{100}{100+200}$

$= 303\text{ mV}$

(b) $\frac{v_o}{v_s} = \frac{303\text{ mV}}{10\text{ mV}} = 30.3\text{ V/V}$

(c) $\frac{v_o}{v_i} = 1000 \times \frac{100}{100+200} = 333.3\text{ V/V}$

(d)



Connect a resistance R_p in parallel with the input and select its value from

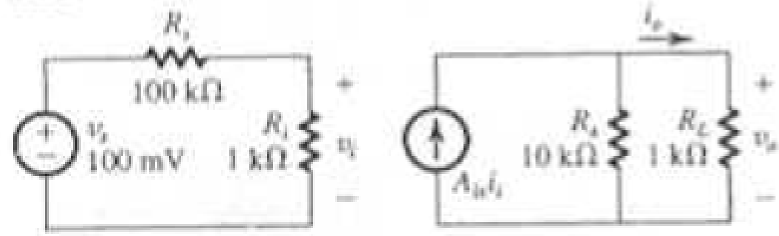
$$\frac{(R_p \parallel R_i)}{(R_p \parallel R_i) + R_s} = \frac{1}{2}\,\frac{R_i}{R_i + R_s}$$

$$\Rightarrow 1 + \frac{R_s}{R_p \parallel R_i} = 22 \Rightarrow R_p \parallel R_i = \frac{R_s}{21} = \frac{100}{21}$$

$$\Rightarrow \frac{1}{R_p} + \frac{1}{R_i} = \frac{21}{100}$$

$$R_p = \frac{1}{0.21 - 0.1} = 9.1\ \text{k}\Omega$$

1.55



(a) Current gain $= \frac{i_o}{i_i}$

$$= A_{is} \frac{R_o}{R_o + R_L}$$

$$= 100\frac{10}{11}$$

$$= 90.9\ \frac{\text{A}}{\text{A}} = 39.2\ \text{dB}$$

(b) Voltage gain $= \frac{v_o}{v_s}$

$$= \frac{i_o}{i_i}\frac{R_s}{R_s + R_i}$$

$$= 90.9 \times \frac{1}{101}$$

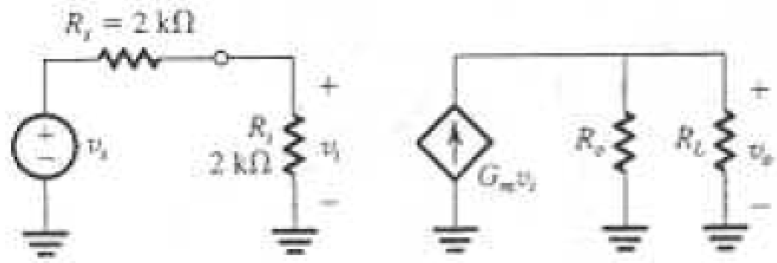
$$= 0.9\ \text{V/V} = -0.9\ \text{dB}$$

(c) Power gain $= A_p = \frac{v_o i_o}{v_i i_i}$

$$= 0.9 \times 90.9$$

$$= 81.8\ \text{W/W} = 19.1\ \text{dB}$$

1.56



$G_m = 40$ mA/V

$R_o = 20$ kΩ

$R_L = 1$ kΩ

$$v_i = v_s \frac{R_i}{R_s + R_i}$$

$$= v_s \frac{2}{2+2} = \frac{v_s}{2}$$

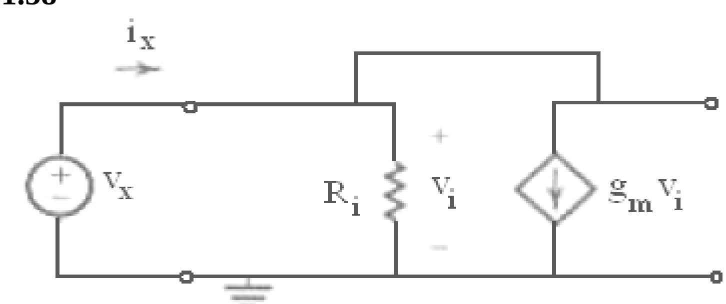
$$v_o = G_m v_i (R_L \parallel R_o)$$

$$= 40 \frac{20 \times 1}{20 + 1} v_i$$

$$= 40 \frac{20}{21} \frac{v_s}{2}$$

Overall voltage gain $\equiv \frac{v_o}{v_s} = 19.05$ V/V

1.58



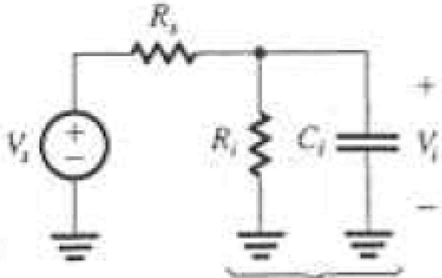
$$v_i = v_x$$

$$i_{Ri} = \frac{v_x}{R_i}$$

$$i_x = i_{Ri} + g_m v_i = v_x / R_i + g_m v_x$$

$$\Rightarrow R_{in} = v_x / i_x = R_i \,\|\, 1/g_m$$

1.67 Using the voltage divider rule,



$$Z_i = R_i \,//\, \frac{1}{sC_i}$$

$$Y_i = \frac{1}{R_i} + sC_i$$

$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s}$$

$$= \frac{1}{1 + R_s Y_i}$$

$$= \frac{1}{1 + R_s\left(\frac{1}{R_i} + sC_i\right)}$$

$$= \frac{1}{1 + \frac{R_s}{R_i} + sC_i R_s} = \frac{1\Big/\left(1 + \frac{R_s}{R_i}\right)}{1 + sC_i \frac{R_s}{1 + \frac{R_s}{R_i}}}$$

$$= \frac{1}{1 + \frac{R_s}{R_i}} \frac{1}{1 + sC_i\left(\frac{R_s R_i}{R_s + R_i}\right)}$$

$$= \frac{R_i}{R_i + R_s} \frac{1}{1 + sC_i(R_i \,//\, R_s)}$$

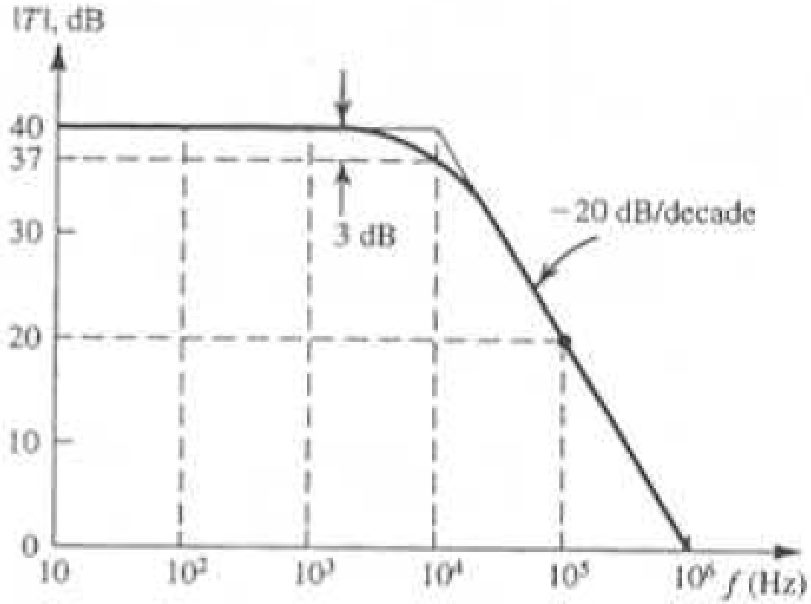
This transfer function is of the STC low-pass type with a dc gain $K = R_i/(R_i + R_s)$ and a 3-dB frequency $\omega_0 = 1/C_i(R_i \,//\, R_s)$.

For $R_s = 20\ k\Omega$, $R_i = 80\ k\Omega$, and $C_i = 5$ pF,

$$\omega_0 = \frac{1}{5 \times 10^{-12} \times \frac{20 \times 80}{20 + 80} \times 10^3} = 1.25 \times 10^7 \text{ rad/s}$$

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1.25 \times 10^7}{2\pi} \simeq 2 \text{ MHz}$$

1.70 The given measured data indicate that this amplifier has a low-pass STC frequency response with a low-frequency gain of 40 dB, and a 3-dB frequency of 10^4 Hz. From our knowledge of the Bode plots for low-pass STC networks (Figure . . .) we can complete the Table entries and sketch the amplifier frequency response.



f (Hz)	|T| (dB)	∠T (degrees)
1000	40	−5.7°
10^4	37	−45°
10^5	20	−84.3°
10^6	0	−90°

1.72 Since the overall transfer function is that of three identical STC LP circuits in cascade (but with no loading effects since the buffer amplifiers have input and zero output resistances) the overall gain will drop by 3 dB below the value at dc at the frequency for which the gain of each STC circuit is 1 dB down. This frequency is found as follows: The transfer function of each STC circuit is

$$T(s) = \frac{1}{1 + \frac{s}{\omega_0}}$$

where

$$\omega_0 = 1/CR$$

Thus,

$$|T(j\omega)| = \frac{1}{\sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^2}}$$

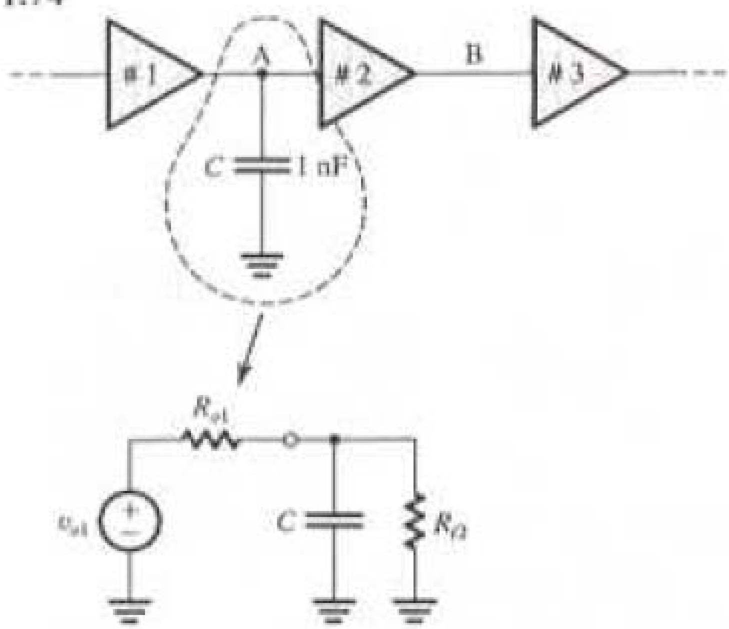
$$20 \log \frac{1}{\sqrt{1 + \left(\frac{\omega_{1\text{-dB}}}{\omega_0}\right)^2}} = -1$$

$$\Rightarrow 1 + \left(\frac{\omega_{1\text{-dB}}}{\omega_0}\right)^2 = 10^{0.1}$$

$$\omega_{1\text{-dB}} = 0.51\,\omega_0$$

$$\omega_{3\text{-dB}} = 0.51/CR$$

1.74



Since when C is connected the 3-dB frequency is reduced by a large factor, the value of C must be much larger than whatever parasitic capacitance originally existed at node A (i.e., between A and ground). Furthermore, it must be that C is now the dominant determinant of the amplifier 3-dB frequency (i.e., it is dominating over whatever may be happening at node B or anywhere else in the amplifier). Thus, we can write

$$150\text{ kHz} = \frac{1}{2\pi C(R_{o1} \,//\, R_{i2})}$$

$$\Rightarrow (R_{o1} \,//\, R_{i2}) = \frac{1}{2\pi \times 150 \times 10^3 \times 1 \times 10^{-9}}$$

$$= 1.06\text{ k}\Omega$$

Now $R_{i2} = 100\text{ k}\Omega$,

Thus $R_{o1} = 1.07\text{ k}\Omega$

Similarly, for node B,

$$15\text{ kHz} = \frac{1}{2\pi C(R_{o2} \,//\, R_{i3})}$$

$$\Rightarrow R_{o2} \,//\, R_{i3} = \frac{1}{2\pi \times 15 \times 10^3 \times 1 \times 10^{-9}}$$
$$= 10.6 \text{ k}\Omega$$

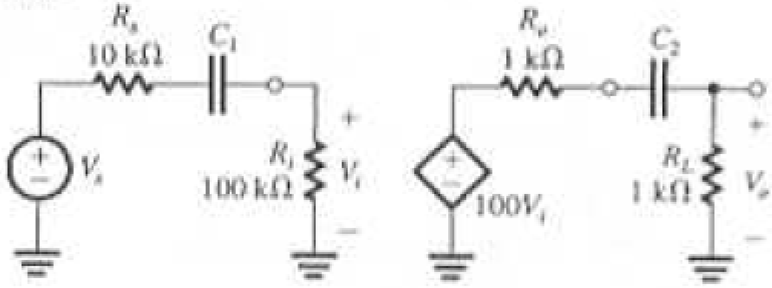
$$R_{o2} = 11.9 \text{ k}\Omega$$

She should connect a capacitor of value C_p to node B where C_p can be found from,

$$10 \text{ kHz} = \frac{1}{2\pi C_p (R_{o2} \,//\, R_{i3})}$$
$$\Rightarrow C_p = \frac{1}{2\pi \times 10 \times 10^3 \times 10.6 \times 10^3}$$
$$= 1.5 \text{ nF}$$

Note that if she chooses to use node A she would need to connect a capacitor 10 time larger!

1.75



For the input circuit, the corner frequency f_{01} is found from

$$f_{01} = \frac{1}{2\pi C_1 (R_s + R_i)}$$

For $f_{01} \le 100$ Hz,

$$\frac{1}{2\pi C_1 (10 + 100) \times 10^3} \le 100$$

$$\Rightarrow C_1 \ge \frac{1}{2\pi \times 110 \times 10^3 \times 10^2} = 4.4 \times 10^{-8}$$

Thus we select $C_1 = 1 \times 10^{-7}$ F $= 0.1\ \mu$F. The actual corner frequency resulting from C_1 will be

$$f_{01} = \frac{1}{2\pi \times 10^{-7} \times 110 \times 10^{3}} = 14.5 \text{ Hz}$$

For $f_{02} \le 100$ Hz,

$$\frac{1}{2\pi C_2(1+1)\times 10^{3}} \le 100$$

$$\Rightarrow C_2 \ge \frac{1}{2\pi \times 2 \times 10^{3} \times 10^{2}} = 0.8 \times 10^{-6}$$

Select $C_2 = 1 \times 10^{-6} = 1\ \mu\text{F}$

This will place the corner frequency at

$$f_{02} = \frac{1}{2\pi \times 10^{-6} \times 2 \times 10^{3}} = 80 \text{ Hz}$$

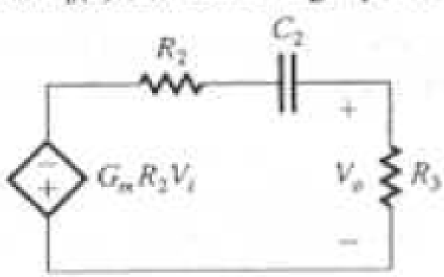
$$T(s) = \frac{R_i}{R_i + R_s} \times \frac{s}{s+\omega_{01}} \times 100 \times \frac{R_L}{R_L + R_o} \times \frac{s}{s+\omega_{02}}$$

1.77

$$T_i(s) = \frac{V_i(s)}{V_s(s)} = \frac{1/sC_1}{1/sC_1 + R_1} = \frac{1}{sC_1R_1 + 1} \quad \text{LP}$$

$$\text{3 dB frequency} = \frac{1}{2\pi C_1 R_1} = \frac{1}{2\pi 10^{-11} 10^{6}} = 15.9 \text{ Hz}$$

For $T_o(s)$, the following equivalent circuit can be used:



$$T_o(s) = -G_m R_2 \frac{R_3}{R_2 + R_3 + 1/sC_2}$$

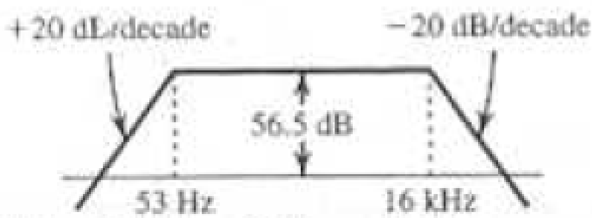
$$= -G_m(R_2 \,//\, R_3)\frac{s}{s + \dfrac{1}{C_2(R_2+R_3)}}$$

$$3 \text{ dB frequency} = \frac{1}{2\pi C_2(R_2 + R_3)}$$

$$= \frac{1}{2\pi 100 \times 10^{-9} \times 30 \times 10^3} = 53 \text{ Hz}$$

$$\therefore T(s) = T_i(s) T_o(s)$$

$$= \frac{1}{1 + \frac{s}{2\pi \times 15.9 \times 10^3}} \times -666.7 \times \frac{s}{s + (2\pi \times 53)}$$



Bandwidth = 16 kHz − 53 Hz ≃ 16 kHz

1.79 Using the voltage-divider rule we obtain

$$\frac{V_o}{V_i} = \frac{Z_2}{Z_1 + Z_2}$$

where

$$Z_1 = R_1 \,/\!/\, \frac{1}{sC_1} \quad \text{and} \quad Z_2 = R_2 \,/\!/\, \frac{1}{sC_2}.$$

It is obviously more convenient to work in terms of admittances. Therefore we express V_o/V_i in the alternate form

$$\frac{V_o}{V_i} = \frac{Y_1}{Y_1 + Y_2}$$

and substitute $Y_1 = (1/R_1) + sC_1$ and $Y_2 = (1/R_2) + sC_2$ to obtain

$$\frac{V_o}{V_i} = \frac{\frac{1}{R_1} + sC_1}{\frac{1}{R_1} + \frac{1}{R_2} + s(C_1 + C_2)}$$

$$\frac{V_o}{V_i} = \frac{C_1}{C_1 + C_2} \frac{s + \dfrac{1}{C_1 R_1}}{s + \dfrac{1}{(C_1 + C_2)}\left(\dfrac{1}{R_1} + \dfrac{1}{R_2}\right)}$$

This transfer function will be independent of frequency (s) if the second factor reduces to unity. This in turn will happen if

$$\frac{1}{C_1 R_1} = \frac{1}{C_1 + C_2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

which can be simplified as follows

$$\frac{C_1 + C_2}{C_2} = R_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \qquad (1)$$

$$1 + \frac{C_2}{C_1} = 1 + \frac{R_1}{R_2}$$

or

$$C_1 R_1 = C_2 R_2$$

When this condition applies, the attenuator is said to be compensated, and its transfer function is given by

$$\frac{V_o}{V_i} = \frac{C_1}{C_1 + C_2}$$

which, using Eq. (1) above can be expressed in the alternate form

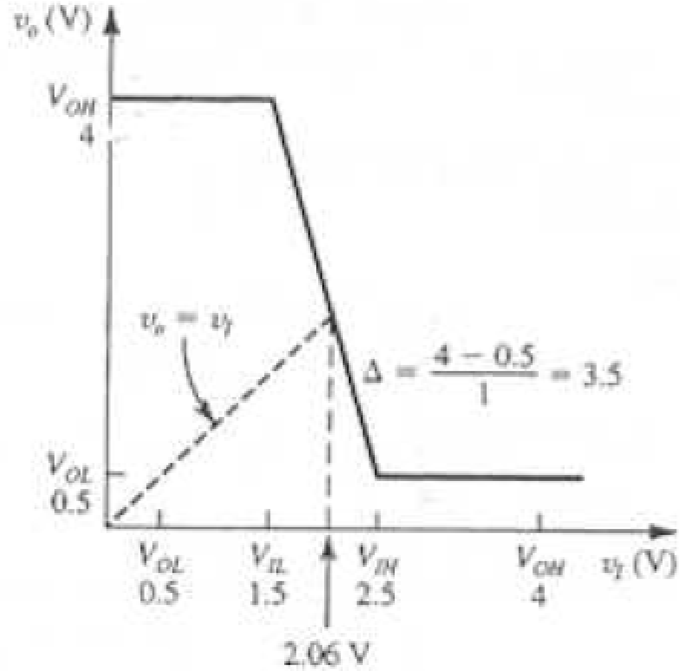
$$\frac{V_o}{V_i} = \frac{1}{1 + \dfrac{R_1}{R_2}} = \frac{R_2}{R_1 + R_2}$$

Thus when the attenuator is compensated ($C_1 R_1 = C_2 R_2$) its transmission can be determined either by its two resistors R_1, R_2 or by its two capacitors. C_1, C_2, and the transmission is *not* a function of frequency.

1.81 $NM_H = V_{OH} - V_{IH} = 3.3 - 1.7 = 1.6\ \text{V}$

$$NM_L = V_{IL} - V_{OL} = 1.3 - 0 = 1.3\ \text{V}$$

1.82



(a) $NM_H = V_{OH} - V_{IH} = 4 - 2.5 = 1.5\ \text{V}$

$NM_L = V_{IL} - V_{OL} = 1.5 - 0.5 = 1\ \text{V}$

(b) In the transition region

$$V_O = 4 - 3.5(V_I - 1.5)$$

$$= 9.25 - 3.5V_I$$

If

$$V_O = V_I \Rightarrow 4.5V_O = 9.25$$

$$V_O = V_I = 2.06\ \text{V}$$

(c) Slope = −3.5 V/V

3.19

$$i_1 = I_S e^{0.7/V_T} = 10^{-3}$$

$$i_2 = I_S e^{0.5/V_T}$$

$$\frac{i_2}{i_1} = \frac{i_2}{10^{-3}} = e^{\frac{0.5-0.7}{0.025}}$$

$$i_2 = \underline{\underline{0.335\ \mu A}}$$

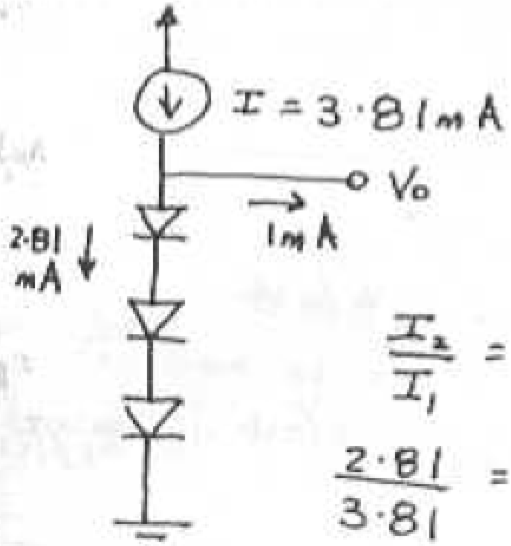
3.23

∴ The voltage across each diode is $V_0/3$

$$I = I_S e^{\frac{V_0/3}{n V_T}} = 10^{-14} e^{\frac{2/3}{0.025}}$$

$$= \underline{\underline{3.81\,mA}}$$

CONT.

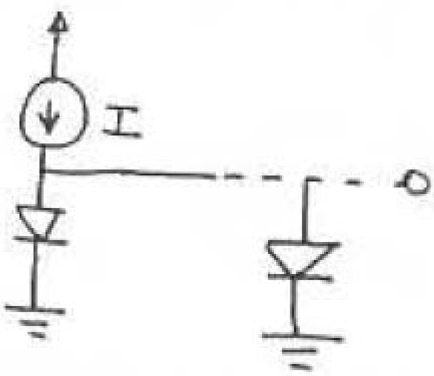


$$\frac{I_2}{I_1} = e^{\frac{(V_2 - V_1)/3}{0.025}}$$

$$\frac{2.81}{3.81} = e^{\frac{(V_2 - 2)/3}{0.025}}$$

$$\Delta V = V_2 - 2 = -\underline{\underline{22.8\,mV}}$$

3.24



With one diode the current through it is

$$I = I_S e^{V_1/nV_T}$$

CONT.

With two diodes in parallel, the current splits between each diode so that the diodes each has half the current

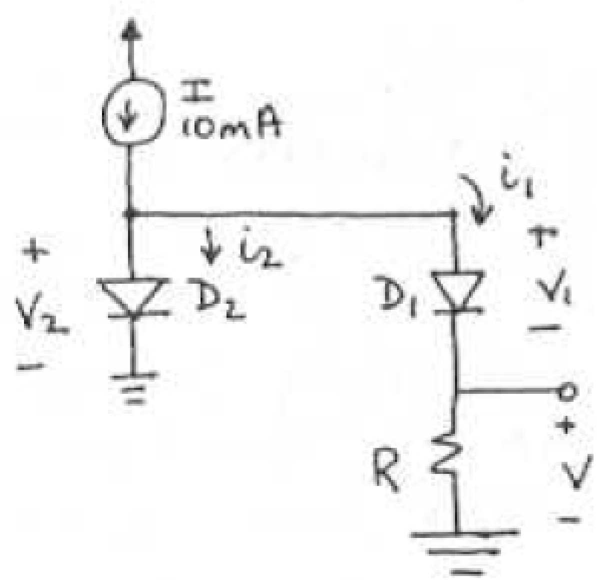
$$\frac{I}{2} = I_s e^{V_2/nV_T}$$

$$\therefore \frac{I/2}{I} = e^{\frac{V_2 - V_1}{nV_T}}$$

The change in voltage is

$$\Delta V = V_2 - V_1 = nV_T \ln\left(\frac{1}{2}\right) = \underline{\underline{-17.3\text{mV}}}$$

3.26



CONT.

Given for each diode

$i = I_S e^{V/nV_T} \Rightarrow 10\times10^{-3} = I_S e^{0.7/n\times0.025}$ ①

$100\times10^{-3} = I_S e^{0.8/n\times0.025}$ ②

②/① $10 = e^{0.1/n(0.025)}$

$n = 1.737$

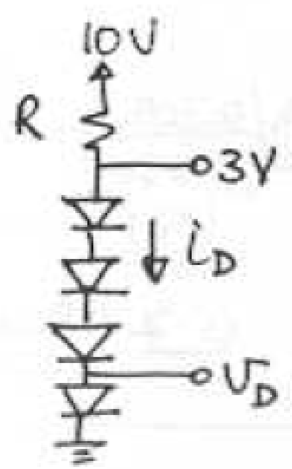
$V = V_2 - V_1 = nV_T \ln(i_2/i_1) = 80\text{mV}$

$1.737(25\times10^{-3}) \ln\left(\frac{0.01 - i_1}{i_1}\right) = 80$

$i_1 = 1.4\ mA$

$R = 80/i_1 = 80/1.4 = \underline{\underline{57.1\Omega}}$

3.36



$V_D = \frac{3}{4} = 0.75V$

$i_D = I_S e^{V_D/nV_T}$

$\frac{i_{D2}}{i_{D1}} = e^{\frac{V_{D2} - V_{D1}}{nV_T}}$

CONT.

$$\therefore\ i_D = i_{D2} = i_{D1}\, e^{\frac{v_{D2}-v_{D1}}{nV_T}}$$

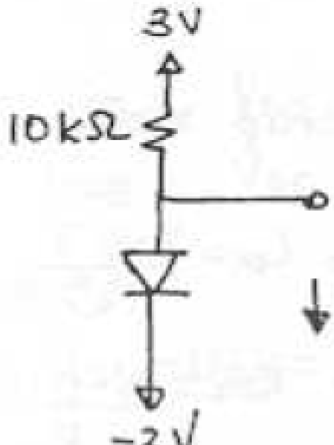
$$= 1 \times e^{\frac{0.75-0.7}{1\times 0.025}}$$

$$= 7.389\ \text{mA}$$

$$\therefore\ R = \frac{10-3}{I_D} = \frac{10-3}{7.389} = \underline{\underline{0.947\,k\Omega}}$$

3.46

(a)

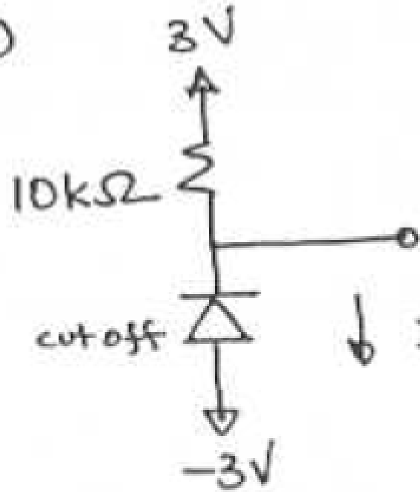


$V = -3 + 0.7 = \underline{\underline{-2.3V}}$

$$I = \frac{3+2.3}{10}$$

$$= \underline{\underline{0.53\ \text{mA}}}$$

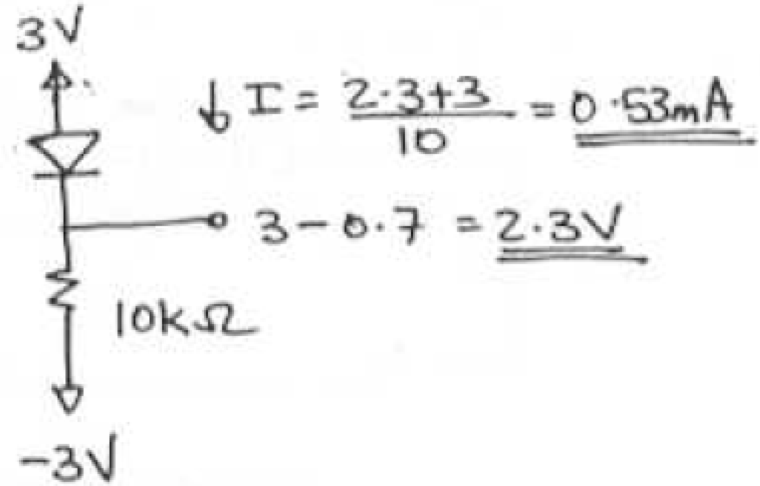
(b)



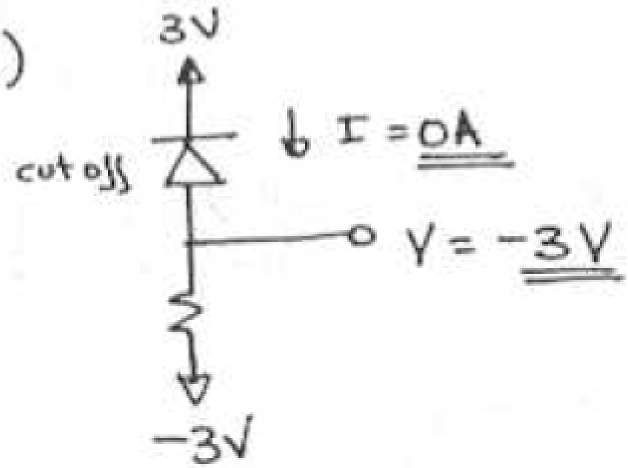
$V = 3 - I(10) = \underline{\underline{3V}}$

$I = \underline{\underline{0A}}$

(c)

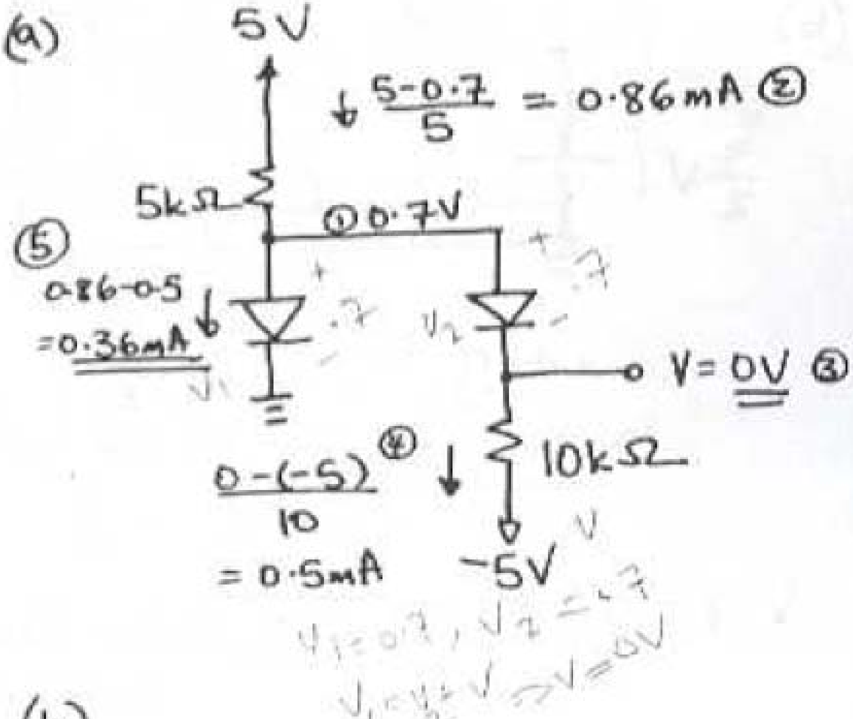


(d)

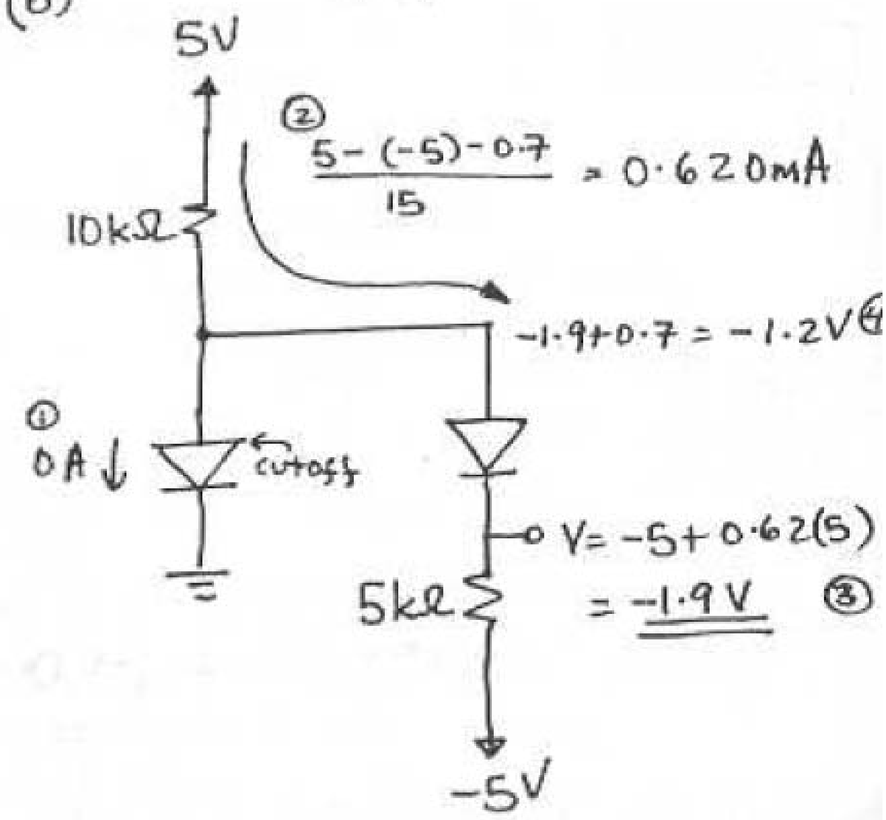


3.48

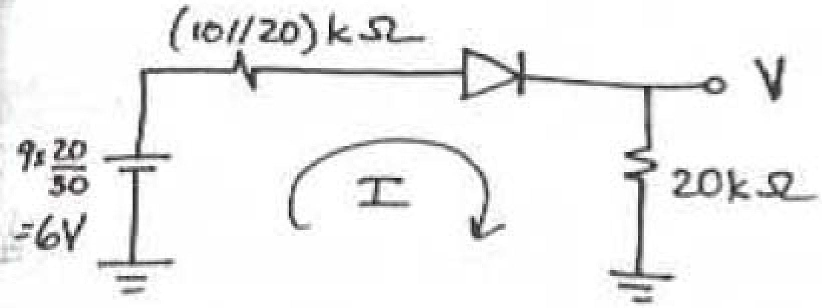
(a)


5V
$\frac{5-0.7}{5} = 0.86mA$ ②
5kΩ
① 0.7V
⑤
$0.86-0.5 = 0.36mA$
V = 0V ③
$\frac{0-(-5)}{10} = 0.5mA$ ④
10kΩ
-5V

(b)


5V
②
$\frac{5-(-5)-0.7}{15} = 0.620mA$
10kΩ
$-1.9+0.7 = -1.2V$ ④
①
0A
cutoff
V = -5 + 0.62(5)
= -1.9 V ③
5kΩ
-5V

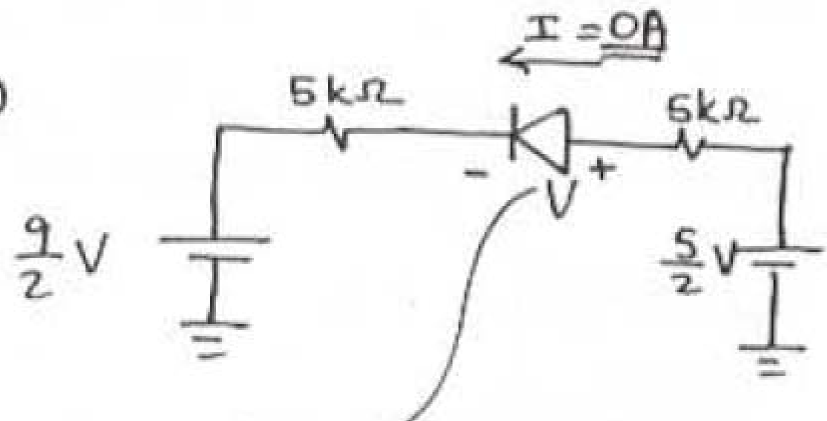
3.49



$$I = \frac{6 - 0.7}{(10 \| 20) + 20} = \underline{\underline{0.199\,mA}}$$

$$V = 20I = \underline{\underline{3.98V}}$$

(b)

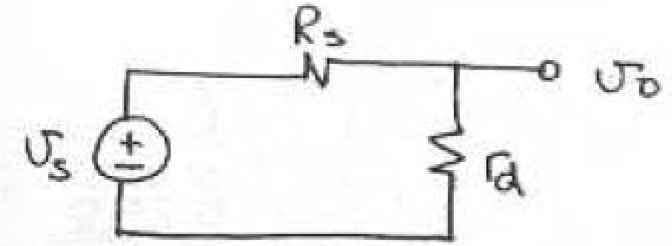


cutoff ∵ $\frac{5}{2} < \frac{9}{2}$

∴ $I = \underline{\underline{0A}}$

$$V = 5/2 - 9/2 = -\underline{\underline{2V}}$$

3.54



SMALL SIGNAL EQUIVALENT CIRCUIT

To find the small-signal response, v_o, open the dc current source I, and short the capacitors C_1 and C_2. Also replace the diode with its small signal resistance:

$$r_d = \frac{nV_T}{I} \qquad n=2$$

Now:

$$v_o = v_s \frac{r_d}{r_d + R_s}$$

$$= v_s \frac{nV_T/I}{\frac{nV_T}{I} + R_s} = v_s \frac{nV_T}{nV_T + IR_s}$$

Q.E.D.

CONT.

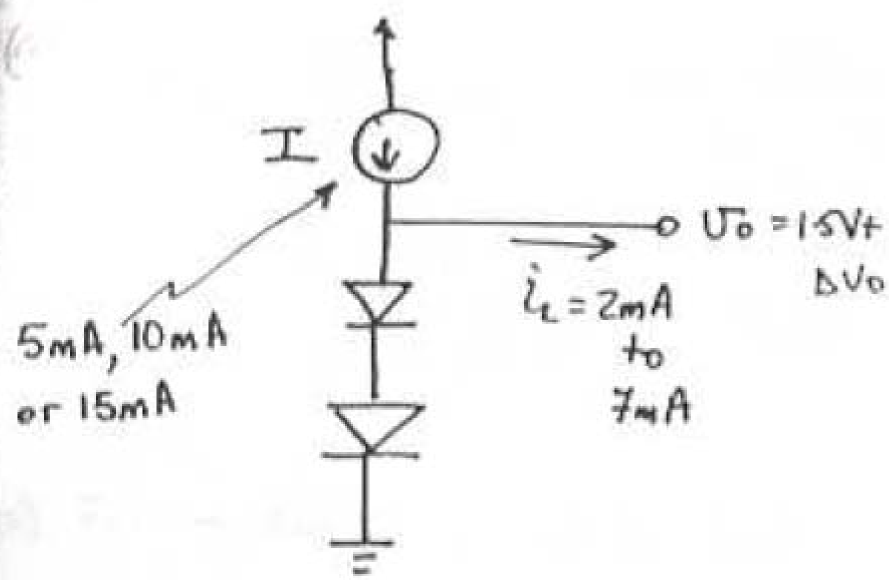
$$v_o = 10\,mV \frac{0.05}{0.05 + 10^3 I}$$

$$= \begin{cases} 0.476\ mV & \sim I = 1mA \\ 3.333\ mV & \sim I = 0.1mA \\ 9.804\ mV & \sim I = 1\mu A \end{cases}$$

For $v_o = \frac{1}{2} v_S = v_S \times \frac{0.05}{0.05 + 10^3 I}$

$I = \underline{\underline{50\,\mu A}}$

3.62



CONT.

For a load current of 2 to 7 mA, I must be greater than 7 mA. Thus the 5 mA source would not do.

We are left to choose between the 10 and 15 mA sources. The 15 mA source provides lower load regulation because the diodes will have more current flowing through them at all times. This is shown below:

Load Regulation if I = 10 mA

use $\frac{i_{D2}}{i_{D1}} = e^{\Delta V / 2 \times n V_T}$ ← 2 diodes

$\therefore e^{\Delta V / 0.05 \times 2} = 3/10 \text{ to } 8/10$

$\Delta V_o = -120\,\text{mV} \text{ to } -22.3\,\text{mV}$

$\therefore$ The peak to peak ripple is

$-120 - (-22.3) \approx -100\,\text{mV}$

$\text{Load Regulation} = \frac{\Delta V_o}{I_L} = \frac{-100}{5}$

$= -20\ \frac{\text{mV}}{\text{mA}}$

Load Regulation for $I = 15mA$.
Here the current through the diodes change from 8 to 13 mA corresponding to

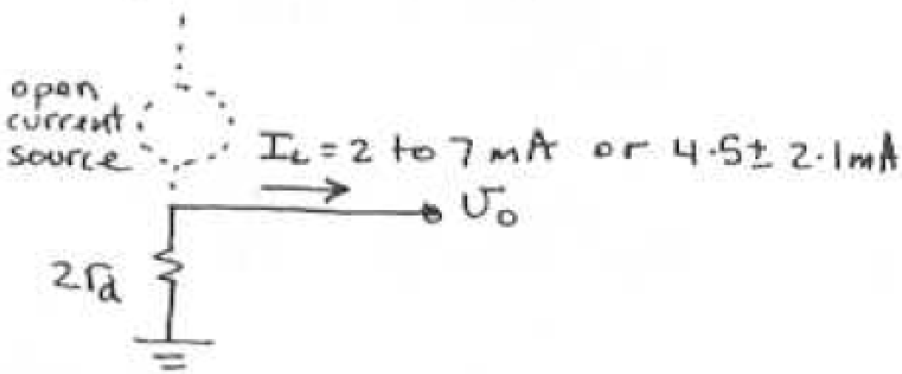
$$\Delta V_o = 0.1 \ln(8/13)$$

$$= -49mV$$

$$\text{Load Regulation} = \frac{-49}{5} \approx -10 \frac{mV}{mA}.$$

The obvious disadvantage of using the 15 mA supply is the requirement of higher current and higher power dissipation.

Alternate solution of Line Regulation using the small signal model



Load Regulation $= \frac{\Delta V_o}{I_L} = -2r_d = \frac{-2nV_T}{I_D}$

Where the bias current $I_D = 10 - 4.5$ for the 10 mA source.

$$\Rightarrow \frac{\Delta V_o}{I_L} = -\frac{2 \times 2 \times 0.025}{10 - 4.5} = -18.2 \frac{mV}{mA}$$

For 15 mA source $I_D = 15 - 4.5$

$$\frac{\Delta V_o}{\Delta I_L} = \frac{-0.1}{15-4.5} = -9.5 \frac{mV}{mA}$$

Sketch of output:-