1. It is required to design a voltage amplifier to be driven from a signal source having a 10mV peak amplitude and a source resistance of 10kΩ to supply a peak output of 3V across a 1kΩ load.

(a) What is the required voltage gain from the source to the load?

(a) Required voltage gain $= \frac{v_O}{v_S} = \frac{3\text{ V}}{0.01\text{ V}} = 300\text{ V/V}$

(b) If the peak current available from the source is 0.1µA, what is the smallest input resistance allowed? For the design with this value R_i, find the overall current gain and power gain.

(b) The smallest R_i allowed is obtained from $0.1\ \mu A = \frac{10\text{ mV}}{R_S + R_i} \Rightarrow R_S + R_i = 100\text{ k}\Omega$

Thus $R_i = 90\text{ k}\Omega$. For $R_i = 90\text{ k}\Omega$, $i_i = 0.1\ \mu\text{A}$ peak, and

Overall current gain $= \frac{v_O / R_L}{i_i} = \frac{3\text{ mA}}{0.1\ \mu A} = 3 \times 10^4\text{ A/A}$

$$\text{Overall power gain} = \frac{v_{orms}^2 / R_L}{v_{s(rms)} \times i_{i(rms)}}$$

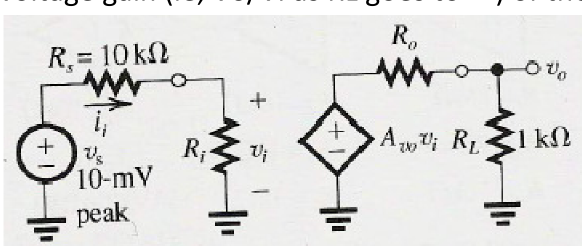
$$= \frac{\left(\frac{3}{\sqrt{2}}\right)^2 / 1000}{\left(\frac{10 \times 10^{-3}}{\sqrt{2}}\right) \times \left(\frac{0.1 \times 10^{-6}}{\sqrt{2}}\right)}$$

$$= 9 \times 10^6\text{ W/W}$$

(c) If the amplifier power supply limits the peak value of the output open-circuit voltage to 5V, what is the largest output resistance allowed?

The voltage across Ro will be 5-3V = 2V. The current through RL and thus also Ro is 3V/1k=3mA so Ro=2/3mA=667Ω

(d) For the design with R_i as in (b) and R_o as in (c), what is the required value of open-circuit voltage gain (ie, Vo/Vi as RL goes to ∞) of the amplifier.



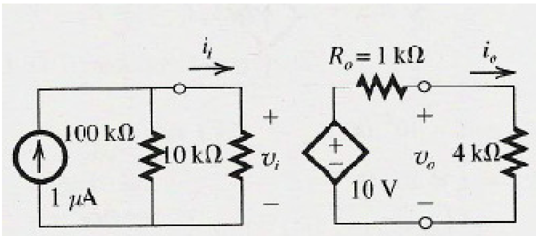
[Use Ri=90k Ω and Ro=667 Ω]

$$300\text{ V/V} = \frac{90}{90 + 10} \times A_{v_o} \times \frac{1}{1 + 0.667}$$

$$\Rightarrow A_{v_o} = 555.7\text{ V/V}$$

2. An amplifier with an input resistance of 10kΩ, when driven by a current source of 1µA and a source resistance of 100kΩ, has a short-circuit output current of 10mA and an open-circuit output voltage of 10V. The device is driving a 4kΩ load. Give the values of the voltage gain, current gain, and power gain expressed as ratios and in decibels?

$$R_O = \frac{\text{Open-circuit output voltage}}{\text{Short-circuit output current}} = \frac{10\text{ V}}{10\text{ mA}} = 1\text{ k}\Omega \qquad v_O = 10 \times \frac{4}{1+4} = 8\text{ V}$$



$$A_v = \frac{v_O}{v_i} = \frac{8}{1 \times 10^{-3} \times (100 \| 10) \times 10^3} = 888\text{ V/V or }58.9\text{ dB}$$

$$A_i = \frac{i_o}{i_i} = \frac{v_O / R_L}{10^{-3} \times \dfrac{100}{100+10}} = \frac{8/(4\times 10^3)}{10^{-3} \times \dfrac{100}{110}} = 2200\text{ A/A or }66.8\text{ dB}$$

$$A_i = \frac{v_O^2 / R_L}{i_i^2 R_i} = \frac{8^2/(4 \times 10^3)}{\left(10^{-3} \times \dfrac{100}{100+10}\right)^2 10 \times 10^3} = 19.36 \times 10^5\text{ W/W or }62.9\text{ dB}$$

$$\text{Overall current gain} \equiv \frac{i_o}{1\ \mu A} = \frac{v_O / R_L}{1\ \mu A} = \frac{8/(4 \times 10^3)}{10^{-3}} = 2000\text{ A/A or }66\text{ dB}$$

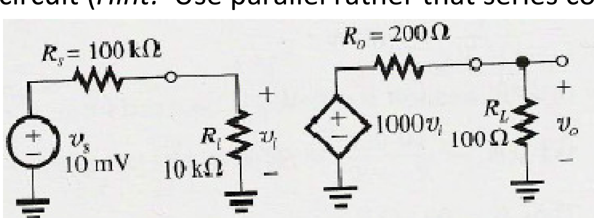
3. A voltage amplifier with an input resistance of 10kΩ, and output resistance of 200Ω, and a gain of 1000 V/V is connected to an input source with a 100kΩ resistance. It also has an open-circuit voltage of 10mV and a 100Ω load. For this situation:

(a) What output voltage results?

(b) What is the voltage gain from source to load?

(c) What is the voltage gain from the amplifier input to the load?

(d) If the output voltage across the load is twice that needed and there are signs of internal amplifier overload, suggest the location and value of a single resistor that would produce the desired output. Choose an arrangement that would cause minimum disruption to an operating circuit (*Hint:* Use parallel rather that series connections.)



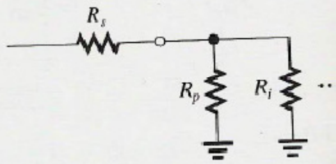
(a)

$$v_O = 10\text{ mV} \times \frac{10}{10+100} \times 1000 \times \frac{100}{100+200} = 303\text{ mV}$$

(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

$$\frac{(R_P \parallel R_i)}{(R_P \parallel R_i) + R_S} = \frac{1}{2}\frac{R_i}{R_i + R_S}$$

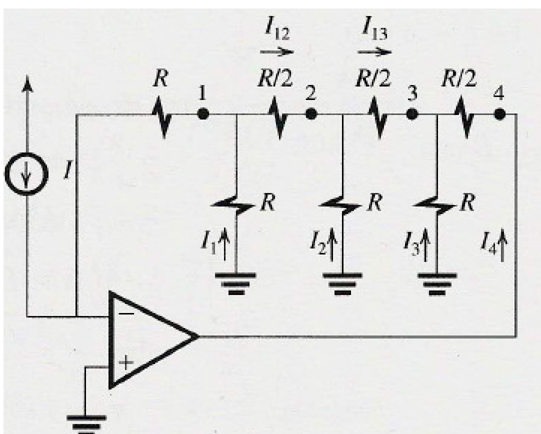
$$\Rightarrow 1 + \frac{R_S}{R_P \parallel R_i} = 22 \Rightarrow R_P \parallel R_i = \frac{R_S}{21} =$$

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

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

4. For the circuit below:

(a) Find the resistances looking into node 1, R_1; node 2, R_2; node 3, R_3; and node 4, R_4.
(b) Find the currents I_1, I_2, I_3, and I_4 in terms of the input current I.
(c) Find the voltage at nodes 1,2,3, and 4, that is V_1, V_2, V_3, and V_4 in terms of IR.



a) $R_1 = R$

$$R_2 = (R \parallel R) + \frac{R}{2} = \frac{R}{2} + \frac{R}{2} = R$$

$$R_3 = (R_2 \parallel R) + \frac{R}{2} = (R \parallel R) + \frac{R}{2} = R$$

$$R_4 = (R_3 \parallel R) + \frac{R}{2} = (R \parallel R) + \frac{R}{2} = R$$

b) $v = RI = RI_1 \Rightarrow I_1 = I$

$$I_{12} = I + I = 2I \Rightarrow v_1 + 2I \times \frac{R}{2} = RI_2$$

$$RI + RI = RI_2 \Rightarrow I_2 = 2I$$

$$I_{13} = I_2 + I_{12} = 4I \Rightarrow v_2 + 4I \times \frac{R}{2} = RI_3$$

$$R \times 2I + 4I \times \frac{R}{2} = RI_3 \Rightarrow I_3 = 4I,$$

$$I_4 = -(4I + 4I)\ I_4 = 8I$$

c) $v_1 = I_1 R = -IR$

$v_2 = -I_2 R = -2IR$

$v_3 = -I_3 R = -4IR$

$$v_4 = -I_3 R + I_4 \frac{R}{2} = -4IR - 8I\frac{R}{2} = -8IR$$

5. A particular enhancement MOSFET for which V_t=0.5V and $k_n'(W/L)$=0.1mA/V^2 is to be operated in the saturation region. If i_D is to be 12.5μA, find the required V_{GS} and the minimum required V_{DS}, Repeat for i_D=50μA.

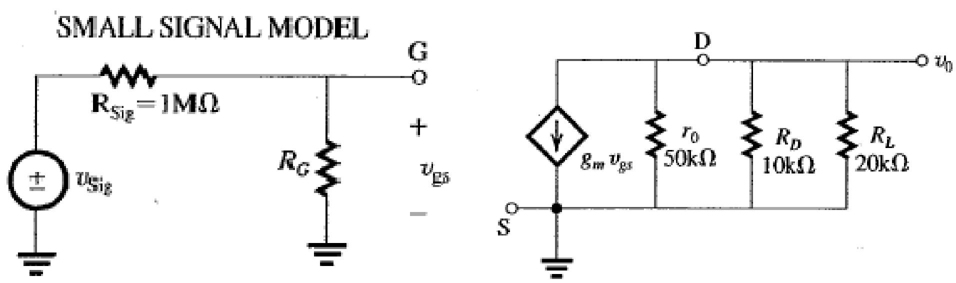
$V_{tn} = 0.5$ V $\quad k_n' \frac{W}{L} = 0.1$ mA/V^2 $\quad$ Saturation mode $v_{DS} \geq (v_{GS} - V_{tn})$ $\quad$ for $i_D = 12.5\ \mu$A $v_{GS} = 1.0$ V and $v_{DS} \geq 0.5$ V

for $i_D = 50\ \mu$A

$v_{GS} = 1.5$ V, and $v_{DS} \geq 1.0$ V

6. Calculate the overall voltage gain of a CS amplifier fed with a 1MΩ source and connected to a 20kΩ load. The MOSFET has g_m=2mA/V and r_o=50kΩ, and a drain resistance R_D=10kΩ is utilized.

$$G_v = -\left(\frac{R_G}{R_G + R_{sig}}\right) g_m (r_O \| R_D \| R_L)$$

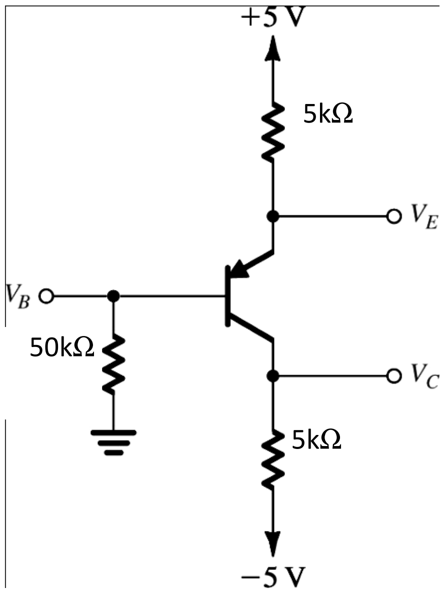


$$= -\frac{R_G}{R_G + 1\ \text{M}\Omega}(2\ \text{mA/V})(50\ \text{k}\Omega \| 10\ \text{k}\Omega \| 20\ \text{k}\Omega)$$

$$= -\frac{R_G}{R_G + 1\ \text{M}\Omega}(2\ \text{mA/V})(5.88\ \text{k}\Omega) \qquad = -\frac{R_G}{R_G + 1\ \text{M}\Omega} 11.76\ \text{V/V}$$

If RG>>1Mohm, then Rsig can be neglected, and GV=-11.76 otherwise the gain if smaller.

7. A single measurement indicates the emitter voltage of the transistor in the circuit below to be 1.2V. Under the assumption that $|V_{BE}|$=0.7V, what are V_B, I_B, I_E, I_C, V_C, β and α?



$$I_E = \frac{5 - 1.2}{5} = 0.76 \text{ mA}$$

$$V_B = 1.2 - 0.7 = 0.5 \text{ V}$$

$$I_B = \frac{0.5 - 0}{50 \text{ k}} = 0.01 \text{ mA}$$

$$I_c = I_E - I_B = 0.75 \text{ mA}$$

$$V_C = -5 + 0.75 \times 5 = -1.25 \text{ V}$$

$$\beta = \frac{I_C}{I_B} = \frac{0.75}{0.01} = 75$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{75}{76} = 0.987$$

8. Two identical CE amplifiers are connected in cascade. The first stage is fed with a source *Vsig* having a resistance *Rsig*=10kΩ. A load resistance R_L=10kΩ is connected to the collector of the second stage. Each BJT is biased at I_C=0.25mA and has β=100 and a very large V_A. Each stage utilizes a collector resistance R_C=10kΩ.

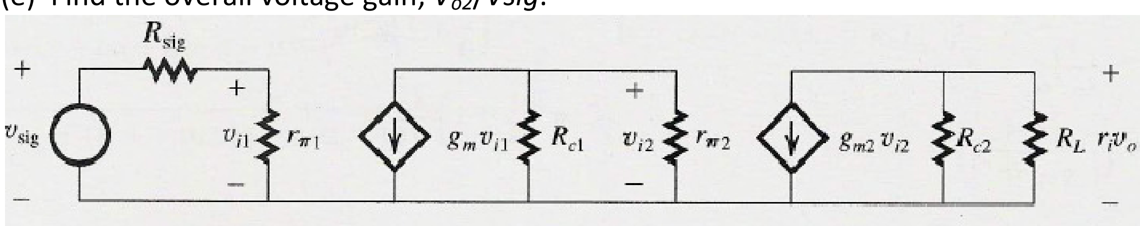
(a) Sketch the equivalent circuit of the two-stage amplifier.

(b) Calculate the voltage transmission from the signal source to the input of the first stage.

(c) Calculate the voltage gain of the first stage, A_{V1}.

(d) Calculate the voltage gain of the second stage, A_{V2}.

(e) Find the overall voltage gain, $V_{o2}/Vsig$.



b) Voltage tranfer from sig to first stage input

$$v_{i1}/v_{sig} = \frac{r_{\pi 1}}{r_{\pi 1} + R_{sig}}$$

Given $I_c = 0.25$ mA; $\beta = 100$; $V_A \to \infty$;
$R_c = 10$ kΩ; $R_{sig} = 10$ kΩ

$$g_m = \frac{I_C}{V_T}, \quad r_\pi = \frac{\beta}{g_m} = \frac{\beta}{I_C} V_T$$

$$r_\pi = \frac{100}{0.25 \times 10^{-3}}(0.015) = 10 \text{ k}\Omega$$

$$v_{i1}/v_{sig} = \frac{10 \text{ k}\Omega}{10 \text{ k}\Omega + 10 \text{ k}\Omega} = 1/2$$

c) $A_{V1} = v_{i2}/v_{i1} = -g_m(R_{c1} \| r_{\pi 2})$

Since $r_\pi = r_{\pi 1} = r_{\pi 2}$ & $R_c = R_{c1} = R_{c2} = 10$ kΩ

$$A_{V1} = -\frac{I_C}{V_T}(10 \text{ k}\Omega \| 10 \text{ k}\Omega)$$

$$= -\frac{0.25 \times 10^{-3}}{0.025}(5 \text{ k}\Omega) = -50$$

d) $A_{V2} = v_O/v_{i2} = -g_m \times (R_{c2} \| R_L)$

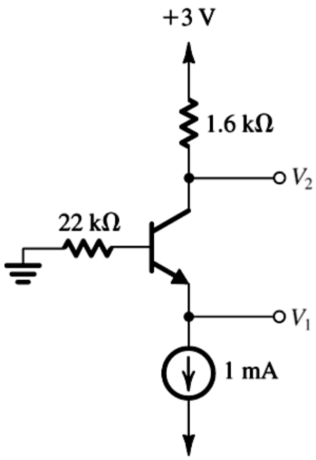
$$= -\frac{I_C}{V_T}(R_{c2} \| R_L) = \frac{0.25 \times 10^{-3}}{0.025}(5 \text{ k}\Omega)$$

$$= -50$$

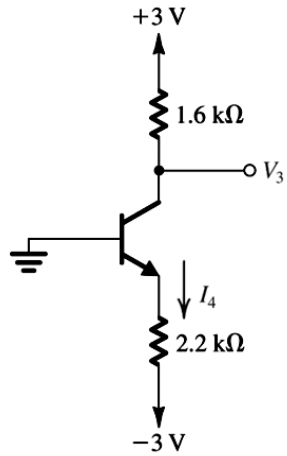
e) $G_V = v_O/v_{sig} = \frac{v_{i1}}{v_{sig}} \times \frac{v_{i2}}{v_{i3}} \times \frac{v_O}{v_{i2}}$

$$= (0.5)(-50)(-50) = G_V = -1250$$

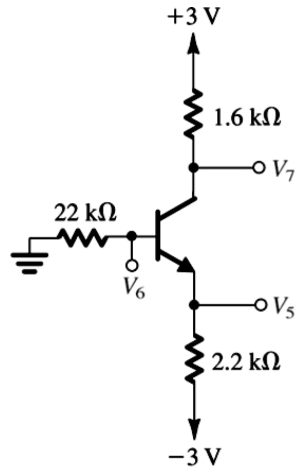
9. For the circuits below, find values for the labeled node voltages and branch currents. Assume β to be very high.



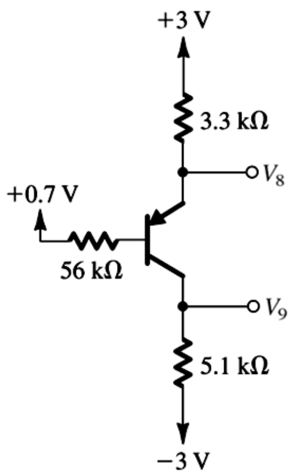
(a)



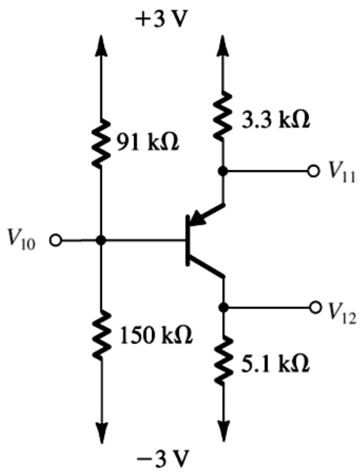
(b)



(c)



(d)



(e)

(a)

$I_C = I_E = 1$ mA

$V_C = 3 - 1.6 \times 1 = 1.4$ V

$I_B \approx 0$ $\beta >> 1$

$V_B = 0$

$V_E = V_B - 0.7 = -0.7$ V

(b)

$V_E = -0.7$ V

$$I_E = \frac{-0.7 + 3}{2.2 \text{ k}} = 1.05 \text{ mA}$$

$V_C = 3 - 1.6 \times 1.05 = +1.32$ V

(c)

$$I_E = \frac{3 - 0.7}{2.2 \text{ k}} = 1.05 \text{ mA}$$

since $I_B = 0$. $+V_B = 0$

$V_E = 0 - 0.7 = -0.7$

$V_C = 3 - 1.6 \times 1.05 = +1.32$ V

Note: essentially identical to (b) since $I_B = 0$

(d)

$$I_E = \frac{3 - 0.7 - 0.7}{3.3} = 0.48 \text{ mA}$$

$V_E = 0.7 + 0.7 = 1.4$ V

$V_C = -3 + 0.48 \times 5.1 = -0.55$ V

$V_B = 0.7$ V

since $I_B = 0$

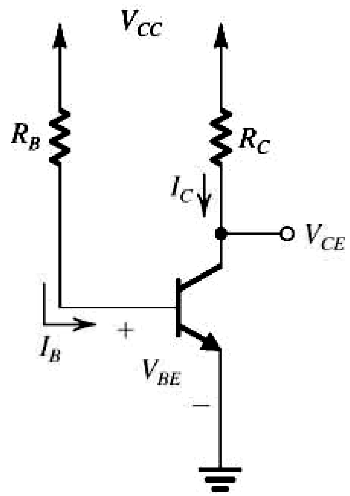
$$V_B = -3 + \frac{150 \times 6}{150 + 91} = \text{[illegible]}$$

$V_E = V_B + 0.7$ V = [illegible]

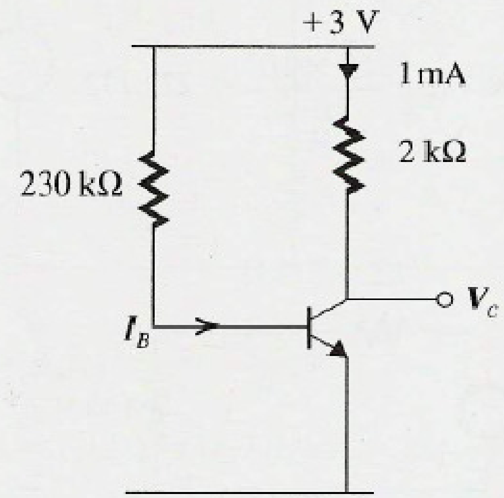
$$I_E = \frac{3 - 1.43}{3.3} = 0.48 \text{ mA}$$

$V_C = -3 + 0.48 \times 5.1 =$ [illegible]

10. It is required to bias the transistor in the circuit to the right at I_C=1mA. The transistor is specified to be nominally 100, but it can fall in the range of 50 to 150. For V_{CC}=+3V and R_C=2kΩ, find the required value of R_B to achieve I_C=1mA for the "nominal" transistor. What is the expected range for I_C and V_{CE}? Comment on the efficacy of this bias design.



(b)



For $\beta = 100$

$$I_B = \frac{I_C}{\beta} = 0.01\text{mA}$$

$$R_B = \frac{V_{CC} - 0.7}{I_B} = 230\text{ k}\Omega$$

$$V_C = V_{CC} - I_C R_C$$

$$V_C = 3 - 1 \times 2 = 1\text{V}$$

For $\beta = 50$

$$I_C = I_B \times 50 = 0.5\text{mA}$$

$$V_C = 3 - 0.5 \times 2 = +2\text{V}$$

For $\beta = 150$

$$I_C = I_B \times 150 = 1.5\text{mA}$$

$$V_C = 3 - 1.5 \times 2 = 0 < 0.3$$

$\therefore$ saturation

Circuit too sensitive to β