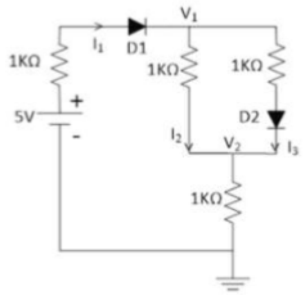
1

1. Find the current I1(in mA). Assume D1 and D2 to be silicon diodes with forward voltages of 0.7 V.

1 / 1 pt

Auto-graded



1.58 ✓

2. Find the current I2 (in mA) in the circuit in question 1.

1 / 1 pt

Auto-graded

1.14 ✓

3. Find the current I3 (in mA) in the circuit in question 1.

1 / 1 pt

Auto-graded

0.44 ✓

4. Find the voltage V1 (in Volts) in the circuit in question 1.

1.5 / 1.5 pts

Auto-graded

2.72 ✓

5. Find the voltage V2 (in Volts) in the circuit in question 1.

1.5 / 1.5 pts

Auto-graded

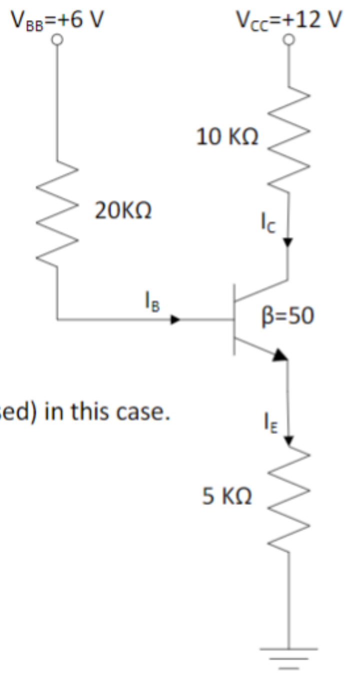
1.58 ✓

2

Question:

Consider the circuit shown where the transistor has β=50.

Give the bias point of the transistor, i.e. (V_{CE}, I_B, I_C) and the voltages V_E, V_B and V_C



Answer Key: **V_{CE}= 0.1 V** **I_B= 0.058 mA** **I_C = 0.774 mA**
V_E = 4.16 V **V_B = 4.86 V** **V_C = 4.26 V**

Note that the transistor is in saturation ($I_C<\beta I_B$, B-C junction forward biased) in this case.

Solution (This transistor is in saturation which should be verified!)

$5.3 = 20\, I_B + 5(I_B+I_C)$ **$25I_B + 5I_C = 5.3$**

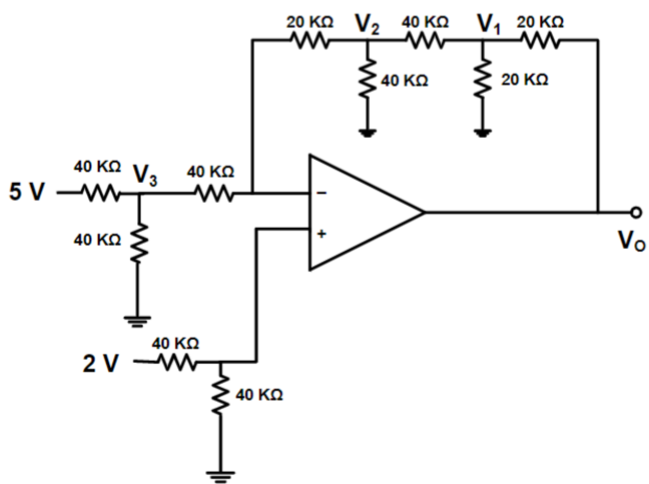
$V_E=5(I_B + I_C)$
$V_C=0.1 + V_E = 0.1 +5(I_B +I_C)$ and also $V_C = 12- 10I_C$ as well

Therefore, **$5I_B + 15I_C = 11.9$**
Solving, I_B= 0.058 mA I_C= 0.774 mA I_E= 0.832 mA
So $V_E =I_E R_E = 4.16$ V $V_B=V_E+0.7 = 4.86$ V $V_C=0.1+V_E = 4.26$ V
Notice $I_C<\beta I_B$ and B-C junction is forward-biased at 0.6 V, as required for the transistor to be in saturation

If we had assumed the transistor to be in the active region, then we would get I_B=0.0193 mA I_C= 0.9636 mA I_E=0.9829 mA V_E=4.9145 V V_B=5.6145 V V_C= 2.364 V which is clearly impossible as then B-C junction becomes forward biased.

3

Q1. Calculate the voltages V_0, V_1, V_2 and V_3 in the circuit given below **[1.75 × 4]**



4

1. For the circuit shown in Fig. 1, find the voltages V1 and V2 and the currents I1, I2 and I3. Assume the diodes **to be ideal with a forward voltage drop of 0.7 V**. **[1 X 5]**

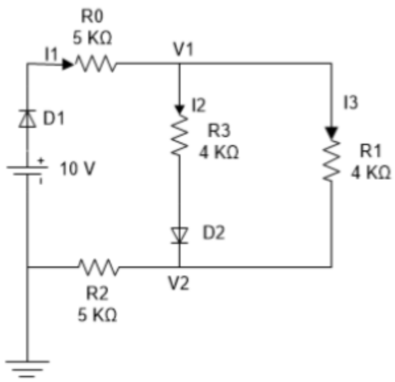


Fig. 1

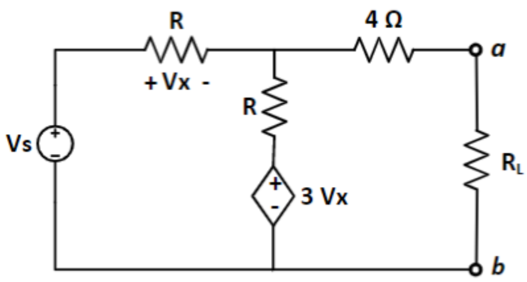


Fig. 2

Solution: (i) V1 = 5.570 V **(ii) V2 = 3.730 V** **(iii) I1 = 0.746 mA**

(iv) I2 = 0.285 mA **(v) I3 = 0.460 mA**

5

1. Consider the circuit shown in Fig. 1 with an NPN silicon transistor. For this, find (a) the Bias Point (Q-Point) in terms of (i) V_{CE}, (ii) I_C and (iii) I_B, and (b) The value of r_e to be used in the small-signal model. (Assume V_T=26 mV). **[1+1+1+2]**

Solution: (a)(i) V_{CE} = 1.76 V **(ii) I_C = 0.72 mA** **(iii) I_B = 0.036 mA**

(b) r_e = 0.034 KΩ

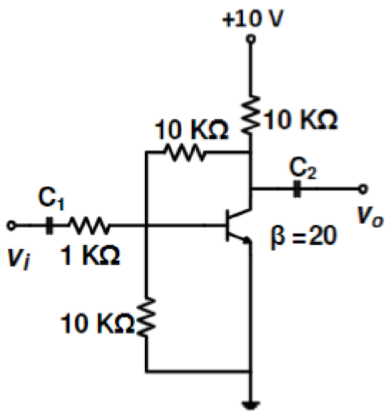


Fig. 1

6

2. Consider the transistor amplifier shown in Fig. 2 with an NPN transistor which has **β=99** and $r_e = 0.02\ K\Omega$. Neglect r_o . For this, find (a) Voltage Gain A_V , (b) Input Impedance R_i and (c) Output Impedance R_O.

[2+2+1]

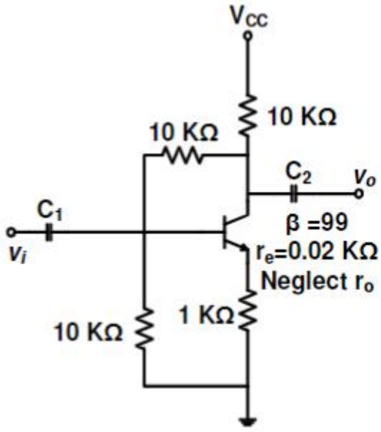


Fig. 2

Solution: (a) A_V **= - 4.353** **(b)** R_i **= 1.550 KΩ** **(c)** R_o **= 4.998 KΩ**

7

3. For the circuit shown in Fig. 3, using ideal opamps, calculate **(a)** $A_{VL} = \frac{V_L}{V_i}$ and **(b)** $A_{VO} = \frac{V_O}{V_i}$.

[2.5+2.5]

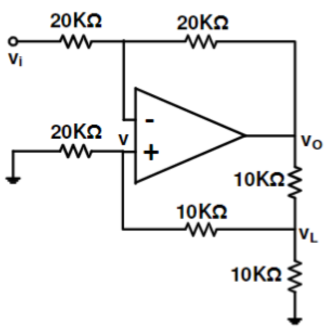


Fig. 3

Solution: (a) A_{VL} **= - 1** **(b)** A_{VO} **= - 2.333**

8

1(a) For circuit shown in Fig 1(a), find the voltage V and the current I. Assume that the diodes are ideal with cut-in voltage of 0.7 V. [3]

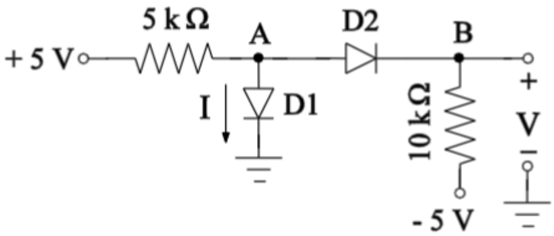


Fig 1(a)

1(b) For circuit shown in Fig 1(b), the transistor Q has $\beta = 200$. Find R_E and R_B for $V_{CE} = 4\ V$ and $I_C = 2\ mA$. (Assume $V_{BE} = 0.7\ V$) [2]

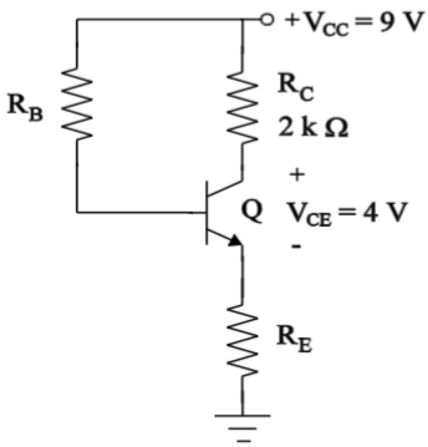


Fig1(b)

9

2. The circuit shown in Figure 2 operates in linear mode and the op-amp is assumed ideal.
   a. Find the expression for output voltage v_o in terms of $i_{s1}, i_{s2}, R_1, R_2, R_3$ and R_4. [3]
   b. If $i_{s1} = 10\ \mu A$, $i_{s2} = 0\ \mu A$, $R_1 = R_3 = 10\ k\Omega$ and $R_2 = R_4$, find the value of R_2 that yield $v_o = -1$ V. [2]

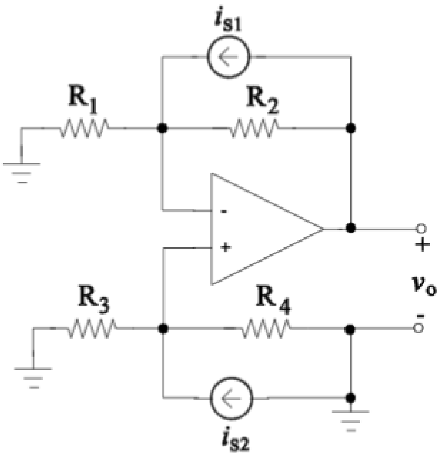


Figure 2

2a. Let v_n and v_p denote the voltages at inverting and non-inverting terminals of op-amp. Now applying KCL at the node formed between R_1-R_2, we have

$$\frac{v_n}{R_1} - i_{s1} + \frac{v_n - v_o}{R_2} = 0 \quad \Rightarrow \quad v_n = \frac{\left(i_{s1} + \frac{v_o}{R_2}\right)}{\frac{1}{R_1} + \frac{1}{R_2}}$$

On applying the KCL at the node formed between R_3-R_4, we have

$$\frac{v_p}{R_3} - i_{s2} + \frac{v_p}{R_4} = 0 \quad \Rightarrow \quad v_p = i_{s2}(R_3 \parallel R_4)$$

In linear mode of operation, $v_n = v_p$ so

$$\frac{\left(i_{s1} + \frac{v_o}{R_2}\right)}{\frac{1}{R_1} + \frac{1}{R_2}} = i_{s2}(R_3 \parallel R_4)$$

On simplification we have

$$v_o = -i_{s1}R_2 + i_{s2}(R_3 \parallel R_4)\left(1 + \frac{R_2}{R_1}\right)$$ [3]

2b. For $i_{s2} = 0\ \mu A$, from the relation derived in part (a) we get $v_o = -i_{s1}R_2$

$$\therefore\ R_2 = -\frac{v_o}{i_{s1}} = -\frac{-1\,V}{10\ \mu A} = 100\ k\Omega$$

[2]

Alternatively:

For $i_{s2} = 0\ \mu A$, we have , $v_n = v_p = 0\,V$.

This means that the current i_{s1} flows only through R_2 and therefore $v_o = -i_{s1}R_2$

10

1.Your lab partner has made the circuit shown in the **Figure for Problem 1** to be used as an AC amplifier.

(a) Using a DC Voltmeter, you measure the DC voltages at point A, C and E (with respect to ground) to be **V_A=3.45 V, V_C=9.39 V and V_E=2.63 V**.

4947 20.9

Using these measurements, calculate the r_e and β of the transistor. [1+1]

(*Hint: Solution can be done in a number of different ways. Round-off and measurement errors may cause some numerical differences in the results obtained by the different approaches. This will be acceptable.*)

(b) Using r_e=50Ω and β=20,

(i) Draw the small signal equivalent circuit of the amplifier [2]

-1.1

(ii) Calculate the voltage gain $A_V = \frac{v_o}{v_i}$ of the amplifier [2]

(iii) Calculate the Input impedance of the amplifier. 21.74 [1]

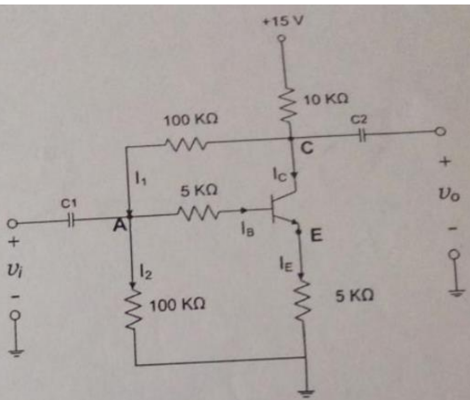


Figure for Problem 1

11

4. (a) In the circuit shown in **Figure for Problem 4(a)**, assume ideal diodes (i.e. forward voltage drop of 0 V) and assume that the input waveform v_I is the sine wave $10\sin(2\pi \times 10^3 t)$. [4]

(i) Sketch the corresponding output waveform v_O and label it neatly.

(ii) What are the positive and negative peak values of this output waveform and what is its frequency?

$V_I < 0$ D1 on, D2 off

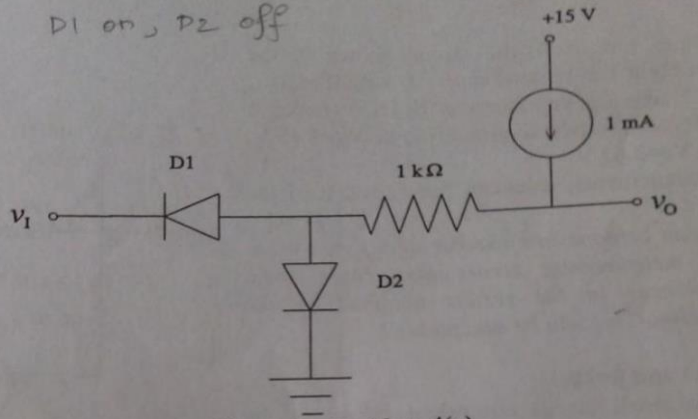


Figure for Problem 4(a)

(b) For the circuit shown in the **Figure for Problem 4(b)**, determine the range of V_I that will result in the load voltage V_L being maintained at 10 V. [4]

10 < < 30.545

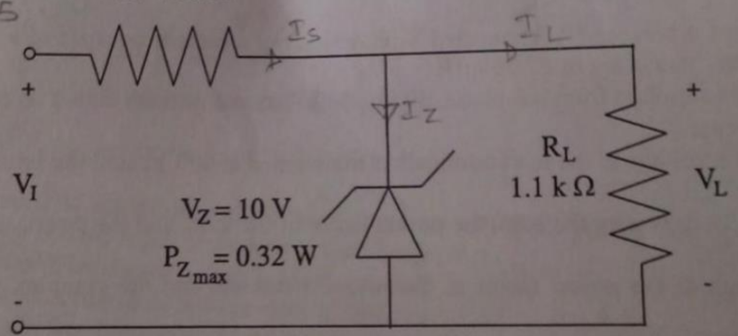


Figure for Problem 4(b)

12

1. (a) Find the bias point of the transistor in the circuit shown in Figure 1. [4]

(b) Draw the small signal equivalent circuit of the amplifier and use that to find the AC voltage gain $A_V = \frac{v_o}{v_i}$ [2+2]

(c) Use the small signal equivalent circuit, to find the input impedance Z_i of this amplifier. [2]

Note: Ignore r_o for (b) and (c).

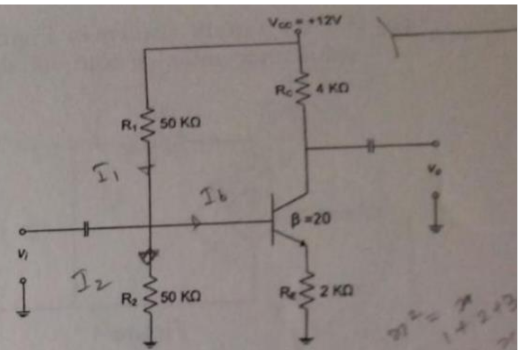


Figure 1

13

Problem: Determine the voltage V_D that must be applied across a diode having reverse saturation current I_s = 0.01 μA at 25°C, to establish a diode current I_D = 10 mA.

If the temperature of the diode now changes to 30°C, by what percentage should the diode voltage V_D be changed to maintain I_D at 10 mA? (Assume ideality factor n =2)

Solution:

$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)$ **with** $V_T = \dfrac{kT}{q}$

$k = (1.38\times10^{-23})$ J/K (**Boltzmann's constant**), $q = 1.6\times10^{-19}$ C (**Electronic Charge**)

At 25°C, $T = 273+25 = 298$ **K and** $V_T = 25.70$ **mV**

$$\frac{I_D}{I_s} = \frac{10\times10^{-3}}{0.01\times10^{-6}} = 10^6$$

Therefore, $V_D = nV_T \ln\left(\dfrac{I_D}{I_S}+1\right)$ **= 0.71 V**

For Temperature = 30°C

We know, $I_{S2} = I_{S1}\times 2^{\left(\frac{T_2-T_1}{10}\right)}$

Here, $T_1 = 298$K and $T_2 = 273+30 = 303$ K for $I_{S1} = I_S\big|_{T=298K}$ and $I_{S2} = I_S\big|_{T=303K}$

At 30°C (303 K),

$I_{s2} = \left(0.01\times10^{-6}\right)\times\sqrt{2} = 1.414\times10^{-8}\ A = I_S\big|_{T=303K}$ and $V_T = 26.134$ mV

Using the new values for I_S **and** V_T**,**

the required V_D **for** I_D **= 10** mA **is -**V_D **= 0.704V**

Therefore, **Percentage decrease in** V_D **required is** $\dfrac{0.710-0.704}{0.710}\times100 = 0.85$**%.**

Problem-1: In the circuit shown below, calculate the voltages V1 and V2 and the currents I1, I2 and I3. Assume the forward voltage drop across the diodes to be 0.7 volts.

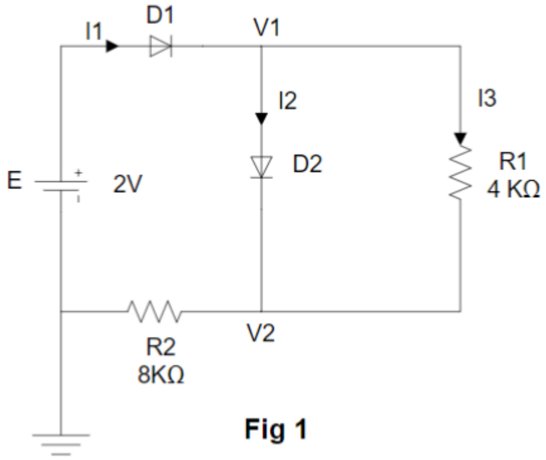


Fig 1

Solution-1:

V1 = 2-0.7 = 1.3 V as D1 will always be **ON.**

If D2 is also ON, then V2 will be 1.3 - 0.7 = 0.6 V and I_{R2} = I1 will be 0.6/8 = 0.075 mA and I3 = I_{R1} = 0.7/4 = 0.175 mA.

This is clearly impossible as I3 cannot be more than I_{R2} or I1.
Therefore, D2 cannot be ON, i.e. D2 must be OFF.

If D2 is OFF,
then **I1 = I3 = I_{R2} = 1.3/12 = 0.1083 mA** and **I2 = 0.**

Then **V2 = 8x0.1083 = 0.867V.**

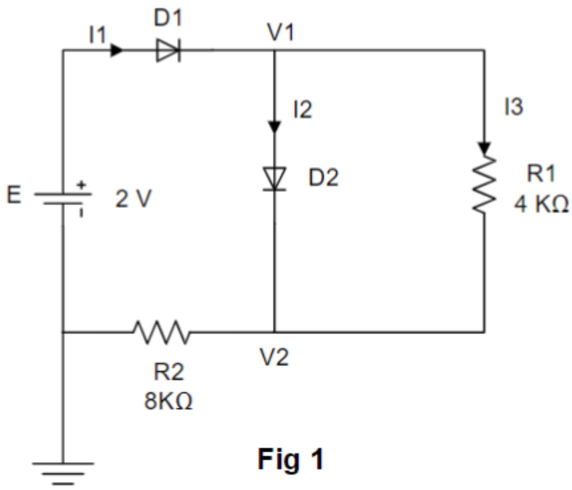


Fig 1

Problem-2: (a) For the circuit shown below, what is the maximum value of the source voltage V_S for which the voltage across the load resistance R_L can be maintained at 5.6V?

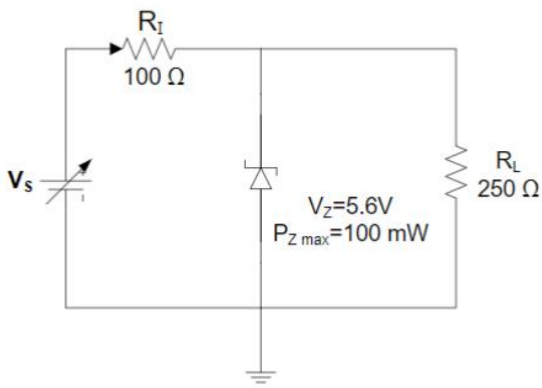


Fig 2

b) If the Zener diode is such that a minimum current of 1 mA is required for the Zener action to take place, what is the minimum source voltage V_S that can be used?

Solution-2:

(a) Since $P_Z = V_Z I_Z$ where I_Z is the current through the zener diode,
we have **$I_{Z,\,MAX}$ = 100/5.6 = 17.86 mA**
Since I_{RL}= 5.6/0.250 = 22.4 mA, we have
$I_{RI\ MAX} = I_{Z\ MAX} + I_{RL}$ = 17.86 + 22.4 = 40.26 mA

Therefore, **$V_{S\ MAX} = I_{RI\ MAX}R_I + V_Z$ = 40.26*0.1 + 5.6 = 9.63 V.**

(b) When the Zener diode is drawing minimum current,
we have **$I_{RI\ MIN} = 1 + I_{RL}$ = 23.4 mA**
Therefore,
$V_{S\ MIN} = I_{RI\ MIN}R_I + V_Z$ = 23.4*0.1+5.6 = 7.94 V.

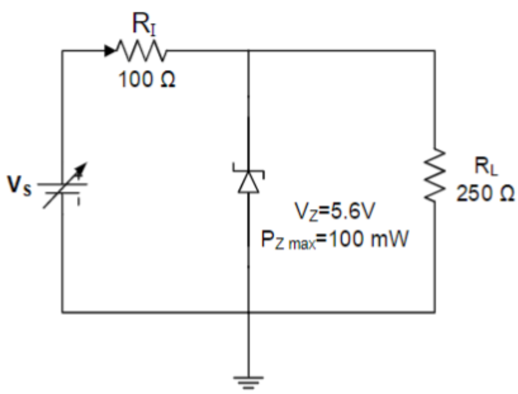


Fig 2

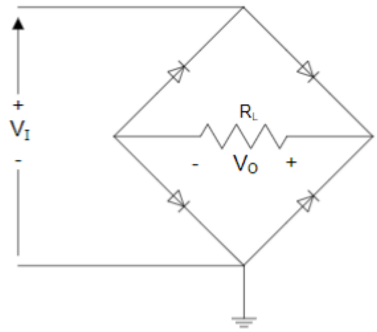
16

Problem:

The bridge rectifier shown in the figure uses ideal diodes with a diode drop of **0.7 V.**

a) If the voltage $\mathbf{V_I}$ is sinusoidal with **25 V (RMS)** and the load resistance $\mathbf{R_L}$ is **100 Ω**, what is the DC load current?

b) What would be the required **PIV** of the diodes in the circuit?



Solution:

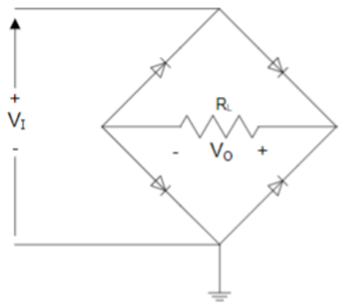
(a) Corresponding to RMS voltage of $V_{rms} = 25\,V$, the peak voltage will be $V_m = \sqrt{2}V_s = 35.36\,V$.

Taking into account the forward voltage drops across two diodes, we get –

$$V_{dc} = \frac{2}{\pi}(V_m - 2\times 0.7) = \frac{2}{\pi}(33.96) = 21.62\,V$$

Therefore,

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{21.62}{100} = 0.2162\,A$$



(b) Each diode should have a PIV rating higher than **(V_m-0.7) = 34.66.**

Problem-1:

For the circuit shown in **Fig. 1**, what will be the state of the two diodes, **D1** and **D2**? What will be the voltages **V_A, V_B** and the currents **I_{D1}** and **I_{D2}**? Assume that a diode has a forward bias voltage of **0.7 V** when it is conducting (i.e. **when it is ON**). (*Hint: There are four possibilities for the diode states of which only one will actually happen. Find this out and use it to find the required voltages and currents.*)

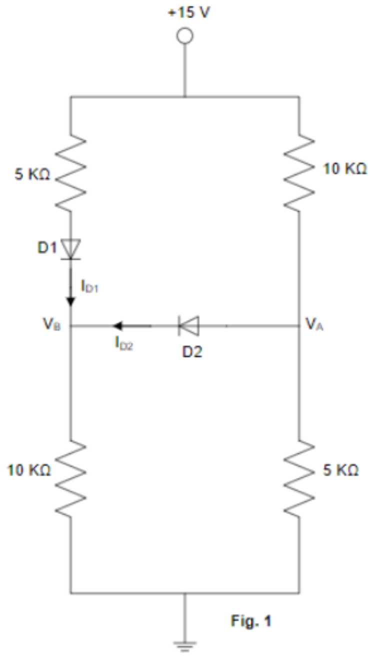


Fig. 1

Solution-1:

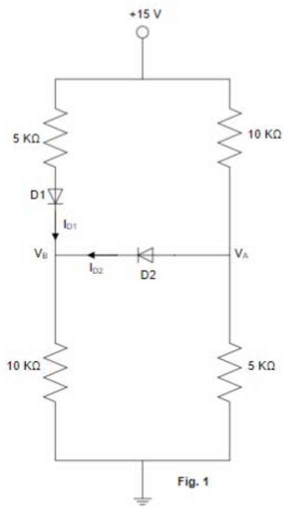


Fig. 1

Consider each of the four possibilities of the diodes being ON or OFF (ON if it is forward biased and OFF if its reverse biased).

D2 and D1 both OFF

This obviously cannot happen as +15 V is being applied

D2 is ON and D1 is OFF

If this is the case, then $I_{D1} = 0$, $V_B = V_A - 0.7$, $I_{D2} = (V_A-0.7)/10$

$$\frac{15-V_A}{10} = \frac{V_A}{5} + \frac{V_A - 0.7}{10}$$

Therefore, V_A= 3.925 V and V_B = 3.225 V. But if V_B = 3.225 V then D1 will be ON (forward biased) and the current I_{D1} through it will be (15-0.7-3.225)/5 = 2.215 mA. This is clearly inconsistent with our assumption that D1 is OFF. Therefore, this also cannot happen!

D2 and D1 are both ON

$V_B = V_A-0.7$ and

$$\frac{15-V_A}{10} = I_{D2} + \frac{V_A}{5} \qquad (a)$$

$$\frac{15-0.7-(V_A-0.7)}{5} + I_{D2} = \frac{V_A-0.7}{10} \qquad (b)$$

Solving (a) and (b), we get I_{D2}= - 0.786 mA. This is clearly inconsistent with our initial assumption that D2 is ON. (The current I_{D2} has to be positive if D2 is ON.) Therefore, this also cannot happen!

D2 is OFF and D1 is ON

V_A = $15\left(\frac{5}{5+10}\right)$ **= 5 V and V_B =** $\left(\frac{15-0.7}{15}\right)10$ **= 9.533 V**

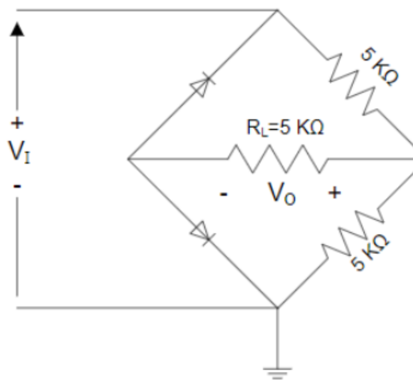
Note that this is consistent with our assumption that D2 is OFF and D1 is ON so this will be the state of the two diodes.

I_{D2} = 0 as D2 is OFF

I_{D1} = 0.9533 mA.

Problem-2:

Assume that ideal diodes with a diode voltage drop of **0.7 V** are used in the circuit given below. Derive the $\mathbf{V_O}$ vs. $\mathbf{V_I}$ characteristic of this circuit and draw it.

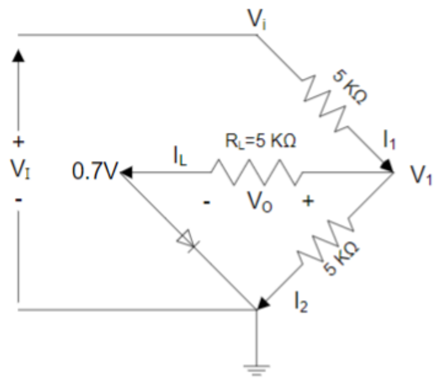


Solution-2:

We need to consider the following cases

(i) **For $|V_I| \leq 0.7$ V,** the current through the load resistance will be zero as the source voltage is not enough to forward bias the diode. Therefore, $\mathbf{V_O = 0}$ **V.**

(ii) For V_I which is high enough and positive (we figure out later how high!), the circuit will effectively be as shown below



$$\frac{V_I - V_1}{5} = \frac{V_1 - 0.7}{5} + \frac{V_1}{5} \quad \Rightarrow \quad V_I = 3V_1 - 0.7 \quad \Rightarrow \quad V_1 = \frac{1}{3}(V_I + 0.7)$$

$$I_L = \frac{V_1 - 0.7}{5}\,mA = \frac{V_I - 1.4}{15}\,mA \quad \Rightarrow \quad V_O = 5I_L = \frac{1}{3}(V_I - 1.4)\,V$$

Looking at the above, $I_L \geq 0$ will be needed for the diode to conduct in the above circuit. So the above expression for V_O will only be valid if $\mathbf{V_I \geq 1.4}$ **V**.

A similar approach can be taken when V_I is large and negative and combining the two we get that for

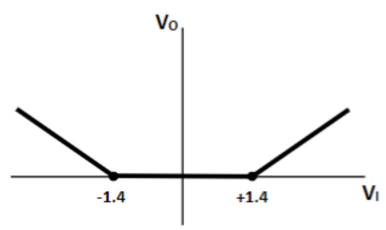
$|V_I| \geq 1.4$ V, $V_O = (|V_I - 1.4|)/3$ V

(iii) For **$0.7 < V_I < 1.4$ V**, the diode still cannot be forward biased. Since we are assuming an ideal diode which does not conduct any current unless the forward bias voltage reaches 0.7 V, the current through it will remain zero. Therefore, I_L will also be zero and we will have $\mathbf{V_O = 0}$.

Summarizing the above,

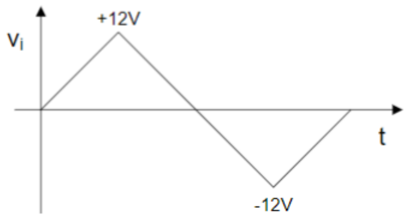
$|V_I| \leq 1.4$ V **$V_O = 0$ V**

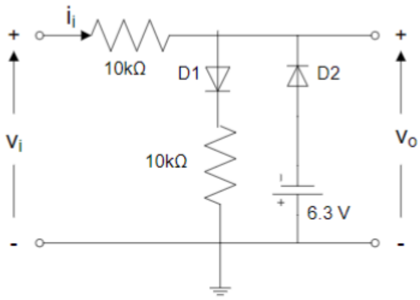
$|V_I| \geq 1.4$ V **$V_O = (|V_I - 1.4|)/3$ V**



Problem-1:

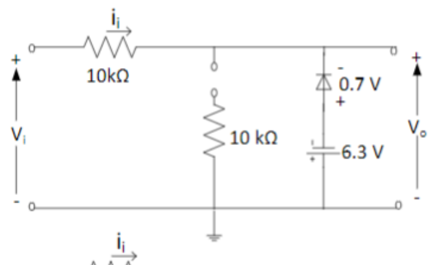
For the circuit shown, sketch the waveform for the output voltage V_o when the voltage waveform V_i is applied. Assume ideal diodes with a forward voltage of 0.7 V.



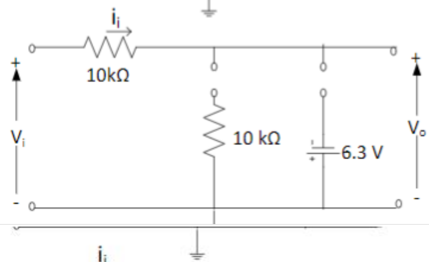


Solution

a) D2 conducts during the portion of the input waveform, when V_i <-7V (i.e. -(0.7V+6.3V)). For this, the output V_o will be held at -7V.



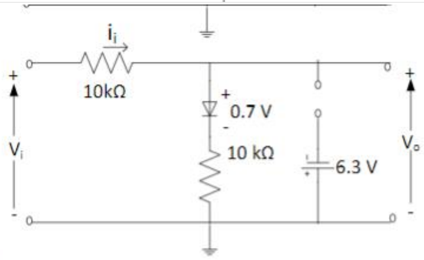
b) For $0.7\text{V} \geq V_i \geq -7\text{V}$, both D1 and D2 are OFF and $V_O = V_i$

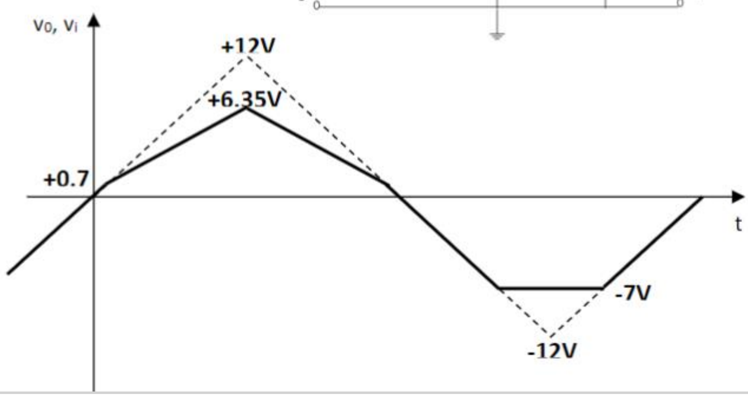


c) For $V_i \geq 0.7$V, D1 conducts but D2 is OFF and we have

$$V_O = 0.7 + \frac{V_i - 0.7}{20} \times 10 = 0.5V_i + 0.35$$

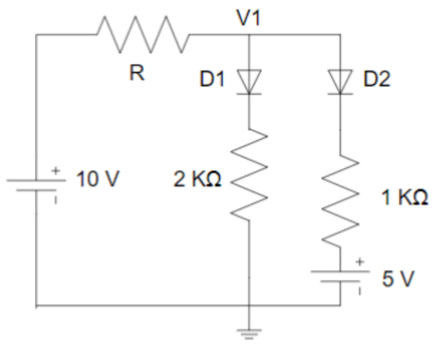
(For V_i=+12V, V_o=6.35V)





Problem-2:

For the circuit shown, find the range of resistance values for R to have both D1 and D2 forward biased (ON or conducting). Assume the diodes to be ideal with a forward bias voltage of 0.7 V.



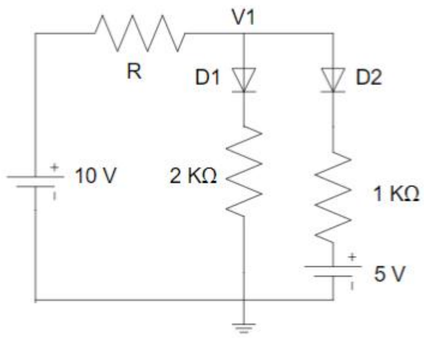
Solution:

For D1 and D2 both to be ON, V1>5.7 V would be required.

When D1 and D2 are both ON, we will have,

$$\frac{10\text{-V1}}{R}=\frac{\text{V1-0.7}}{2}+\frac{\text{V1-5.7}}{1}$$

$$\text{V1}=\frac{6.05+\frac{10}{R}}{1.5+\frac{1}{R}}$$



Since, we require V1>5.7 V, we get

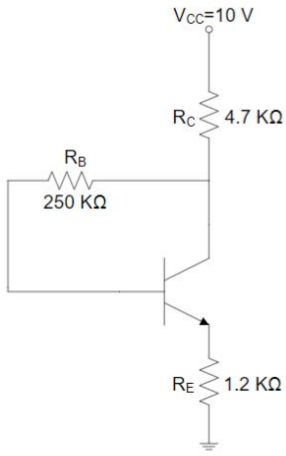
$$\frac{6.05+\frac{10}{R}}{1.5+\frac{1}{R}}>5.7$$ or **R< 1.72 KΩ**

Problem-1:

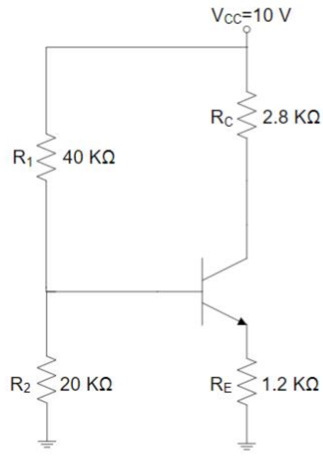
(a) In the two circuits shown, the transistors have β=100. Assume V_{BE}=0.7 V when the B-E junction is forward biased and V_{CE}=0.1 V if the transistor is in saturation

Find the Q-point for the transistors in (i) and (ii), i.e. V_{CE}, I_C and I_B

(b) Justify the observation that the type of biasing circuit shown in (i) cannot put the transistor in the saturation or cut-off mode!



(i)



(ii)

Solution

i) Assuming the transistor to be in the active region –

$$V_{CC} = R_C(I_C + I_B) + I_B R_B + 0.7 + I_E R_E$$

$$I_B = \frac{10-0.7}{R_C(\beta+1) + R_B + (\beta+1)R_E}$$

$$= \frac{9.3}{101*4.7 + 250 + 101*1.2} = 0.011\,\text{mA}$$

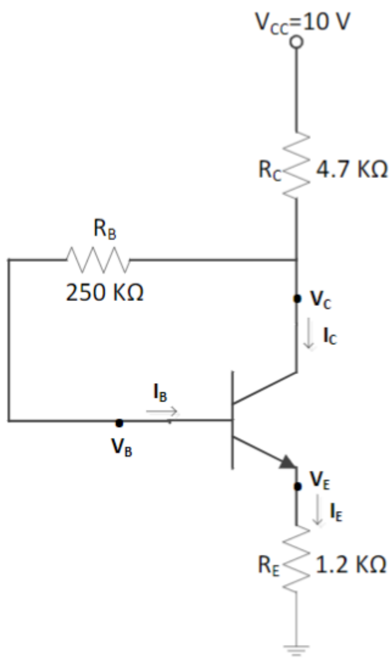
$$I_C = 1.1\,\text{mA}$$

$$V_C = 10 - 4.7*(1.1+0.011) = 4.78\,\text{V}$$

$$V_E = 1.2*101*(0.011) = 1.33\,\text{V}$$

Therefore $V_{CE} = V_C - V_E = 3.45\,\text{V}$

Note that V_B=2.03 V implying that the C-B junction is reverse biased as it should be for the transistor to operate in the active region.



ii) Assuming the transistor to be in the active region –

Thevenin's Equivalent of the Base Voltage supply gives

$$V_{BB} = \frac{10}{3}\text{ V} \qquad R_B = R_1 \| R_2 = 13.333\ K\Omega$$

$$V_{BB} = I_B R_B + 0.7 + I_E R_E$$

$$I_B = \frac{3.333 - 0.7}{13.333 + (101)1.2} = 0.0196\text{ mA}$$

$$I_C = 1.96\text{ mA}$$

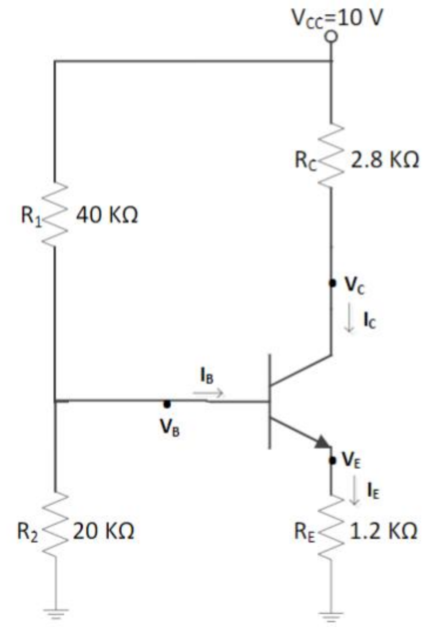
$$V_C = 10 - 2.8 * 1.96 = 4.51\text{ V}$$

$$V_E = 1.2 * (101) * 0.0196 = 2.38\ V$$

$$V_B = V_E + 0.7 = 3.08 V$$

Therefore $V_{CE} = V_C - V_E = 2.13\text{ V}$

Note that B-C junction will be reverse biased so transistor is indeed in the active region



Solution

With V_{CC} as given, the B-E junction cannot be reverse biased so it would not be possible to put the transistor in cut-off. For the transistor to be in saturation, the B-C junction must also be forward-biased (at 0.6 V), but that is also clearly impossible.

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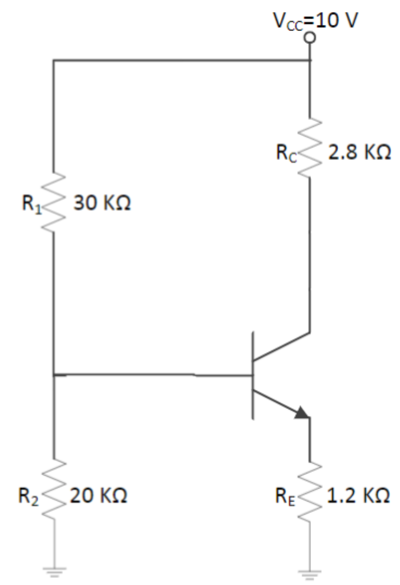
Problem-2:

2. In the circuit (ii) of Problem-1, R_1 is changed to be 30 KΩ while everything else remains the same (as shown in the Figure). What will be the state of the transistor in this case?



Solution:

In this case, V_{BB}= 4 V and R_B= 12 KΩ.

If transistor is assumed to be in the active region, then –

$$I_B = \frac{4-0.7}{12+101*1.2} = 0.0248 \text{ mA}$$

I_C=2.48 mA; I_E=2.5048 mA

and V_E = 3.0058 V; V_B = 3.7058 V; V_C = 3.056 V

But this would make B-C forward biased which is clearly impossible. Therefore, **transistor cannot be in the active region.**

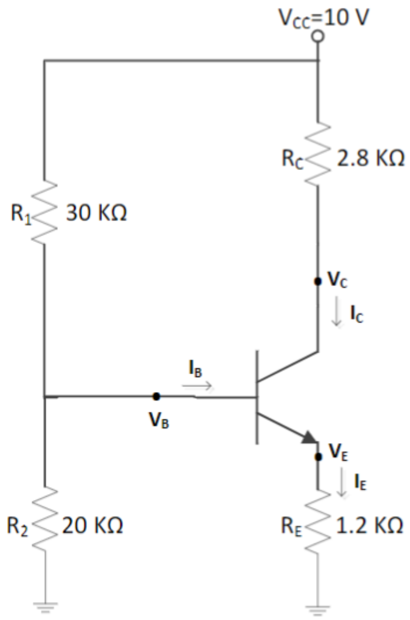
If transistor is assumed to be in the saturation region, then

$$4-0.7 = 12I_B + 1.2(I_B + I_C) \qquad 13.2I_B + 1.2I_C = 3.3$$
$$10-0.1 = 2.8I_C + 1.2(I_B + I_C) \qquad 1.2I_B + 4I_C = 9.9$$

Solving, we get

I_B = 0.0257 mA; I_C = 2.4673 mA; I_E = 2.493 mA;

Note that $I_C<\beta I_B$, therefore **the transistor is indeed in Saturation.**



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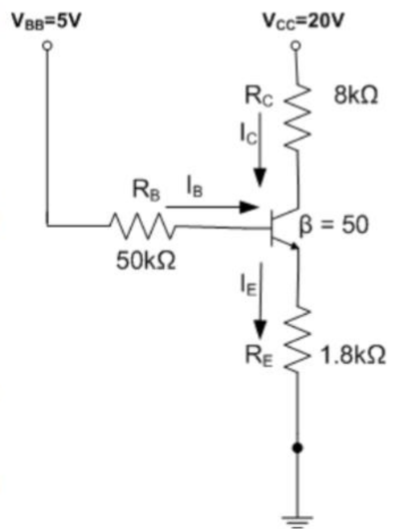
Problem: This circuit was one of the first circuits considered in class for biasing a transistor where we had assumed the transistor to be in the active region and verified that to be the correct assumption.
We found the Q-Point of the transistor to be V_{CE}=5.05 V, I_C=1.52 mA, I_B=0.0303 mA

Let us play Devil's Advocate now and assume the transistor to be in the saturation region. Show that that would not be a logically consistent assumption to make.

Try this on your own (Not to be submitted, Solution not provided) – Show how this can be used as a voltage amplifier by coupling a capacitor to the base and another to the collector. Find its AC Voltage Gain A_V. (Remember to find r_e first!)
You can further modify the circuit by adding a capacitor in parallel with R_E. Will that change the bias point? How will the gain be modified now?



Solution: Assuming the transistor to be in saturation, we get –

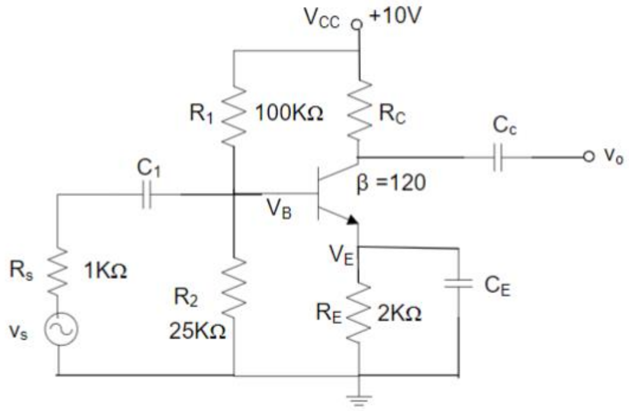
$$50I_B + 1.8(I_B + I_C) = 5 - 0.7 = 4.3 \qquad 51.8I_B + 1.8I_C = 4.3$$
$$8I_C + 1.8(I_B + I_C) = 19.9 \qquad 1.8I_B + 9.8I_C = 19.9$$

Solving we get I_B=0.0125 mA and I_C=2.0283 mA

Since β is given to be 50, we find that the condition $I_C < \beta I_B$ is not satisfied. Therefore, the transistor cannot be in saturation.

Problem-1: Consider the transistor amplifier shown assuming that the capacitors are large enough to be ignored (short-circuited) for AC analysis. The transistor is assumed to have β=120 and the output resistance r_O of the transistor can be ignored. Assume V_T = 26 mV.

For this amplifier, choose R_C so that a voltage gain of $A_V = v_O/v_S = -160$ can be provided.



Problem-2: For the choice of R_C as obtained in Problem 1, what would be the Q-point of the transistor? Verify that the transistor will be working in the active mode.

Solution-1: The DC equivalent circuit will be as shown.
Using this, we get –

$V_{Th} = 10 \times R_2/(R_1+R_2) = 10 \times 25/(100+25) = 2V$

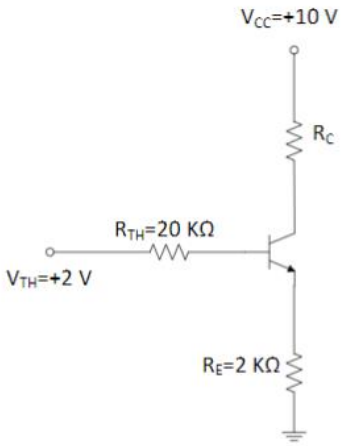
$R_{Th} = R_1R_2/(R_1+R_2) = 100 \times 25 /(100+25) = 20k\Omega$

$I_B = (V_{Th} - V_{BE})/(R_{Th} + (\beta+1) R_E)$
$= (2 - 0.7)/(20+(120+1)2) = 4.962 \times 10^{-3}$ mA

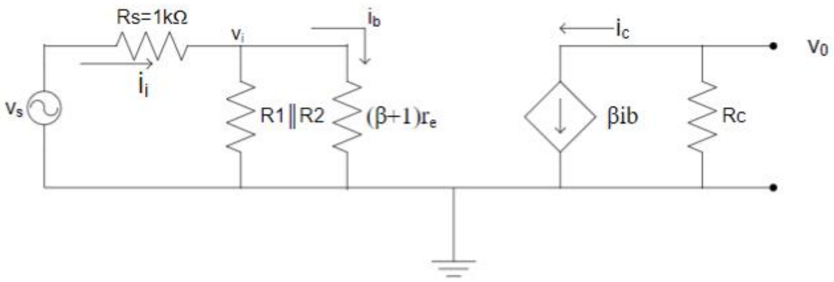
$I_C = \beta I_B = 120 \times 4.962 \times 10^{-3} = 0.595$ mA

$I_E = (\beta+1)I_B = (120+1)\times 4.962\times10^{-3} = 0.6$ mA

r_e= 26mV/I_E = 26/0.6 = 43.33Ω



The corresponding AC equivalent circuit will be as shown below



$R_1||R_2=R_{Th}=20$ KΩ, $(\beta+1)r_e=5.24$ KΩ $R_1||R_2||(\beta+1)r_e=4.15$ KΩ

So, $i_b=\left(\dfrac{v_S}{1+4.15}\right)\dfrac{20}{25.24}=0.154v_S$ or $v_S=6.494i_b$

and, $v_O=-\beta i_b R_C=-120R_C i_b$ $A_V=\dfrac{v_O}{v_S}=-\dfrac{120R_C}{6.494}=-160$

Therefore, **R_C=8.66 KΩ**

Solution-2: Assuming that the transistor is in the active region (as assumed above), we have already calculated **I_B=0.004962 mA, I_C=0.595 mA** and **I_E=0.6 mA**

(*Note that we do need to verify that assumption!*)

With R_C=8.66 KΩ, we get V_C=10-0.595(8.66)=4.85 V

Also, V_E=2*I_E =1.2 V and V_B=1.2+0.7=1.9 V

Therefore, V_{CE}=3.65 V

Bias Point is V_{CE}=3.65 V, I_B=0.004962 mA, I_C=0.595 mA

Note that the B-C junction is indeed reverse biased so the transistor is in the active region, as assumed earlier.

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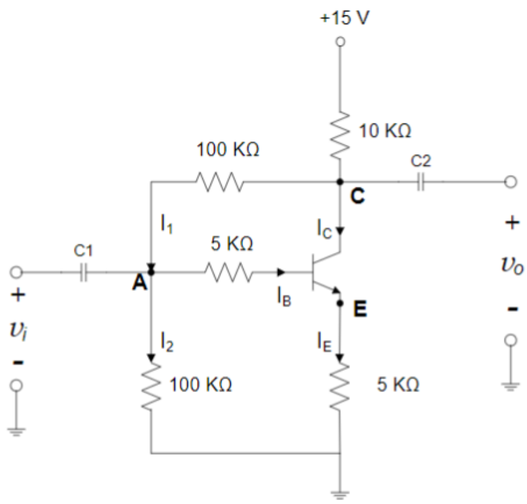
Problem-3: Your friend assembled the circuit shown in the figure in the lab and he/she measured the DC voltages at A, C and E (with respect to ground) to be V_A=3.45 V, V_C=9.39 V and V_E=2.63 V. Using these measurements, calculate the r_e and β of the transistor.

Problem-4: Consider the same circuit once again but assume that r_e=0.05 KΩ and β=20. Do the small signal analysis of this circuit and find its voltage gain, input impedance and output impedance



Solution-3:

Note that depending on how you round-off, different approaches may give slightly different answers!

This can be solved in several alternate ways, as given below (This assumes transistor to be in the active region without explicitly showing it. Why?)

$I_E=V_E/5=0.526$ mA $\Rightarrow$ $r_e=V_T/I_E=49.4\ \Omega$

$I_1=(V_C-V_A)/100=0.0594$ mA and $I_2=V_A/100=0.0345$ mA

Therefore, $I_B=I_1-I_2=0.0249$ mA $\Rightarrow$ $\beta=(I_E/I_B)-1=20.1$

Note that $V_B=V_A-5I_B=3.33$ V or $V_B=V_E+0.7=3.33$ V so B-C is reverse biased and the transistor is indeed in the active mode.

Alternatively,

$I_E=2.63/5=0.526$ mA, $V_B=2.63+0.7=3.33$ V, $I_B=(3.45-3.33)/5=0.024$ mA

Note that B-C is reverse biased so transistor is in the active mode

Therefore $r_e=V_T/I_E=0.026/0.526=49.4\ \Omega$

and $\beta=(I_E/I_B)-1=20.9$

Alternatively,

$I_B=(9.39-3.45)/100-3.45/100=0.0249$ mA

$V_B=3.45-5(0.0249)=3.33$ V $V_E=2.63$ V (as expected)

Note that B-C is reverse biased so transistor is in the active mode

$I_E=2.63/5=0.526$ mA

Therefore, $r_e=V_T/I_E=0.026/0.526=49.4\ \Omega$

and $\beta=(I_E/I_B)-1=20.1$

Alternatively,

$I_E=2.63/5=0.526$ mA

Therefore, $r_e=V_T/I_E=0.026/0.526=49.4\ \Omega$

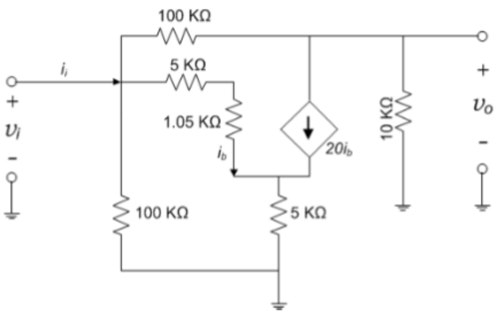
$I_C=(15-9.39)/10-(9.39-3.45)/100=0.502$ mA

$$\frac{\beta+1}{\beta}=\frac{0.526}{0.502}=1.048$$

Therefore $\beta=20.8$

Solution-4: Using r_e=50Ω and β=20

(i) The small signal equivalent circuit model for the amplifier will be as shown.



(ii) Gain Calculation

$v_i = (5+1.05)i_b + (5)21i_b = 111.05i_b$ and

$\frac{v_i - v_O}{100} = 20i_b + \frac{v_O}{10}$

$0.01v_i - 0.18v_i = 0.11v_O$

Therefore $A_V = \frac{v_O}{v_i} = \frac{0.01-0.18}{0.11} = -\frac{0.17}{0.11} = -1.545$

(iii)**Input Impedance**

$i_i = 0.01v_i + i_b + 0.01(v_i - v_O) = 0.02v_i + 0.009v_i + 0.01545v_i \quad i_i = 0.04445v_i$

Therrefor, **Z**$_i$ = $\frac{v_i}{i_i} = 22.5\,\text{K}\Omega$

(iv) Output Impedance

$v_{OC} = v_o = -1.545v_i \qquad i_{SC} = 0.01v_i - 20i_{b,SC}$

Note that, we also have $v_i = 6.05i_{b,SC} + 21\times 5i_{b,SC} = 111.05i_{b,SC} \Rightarrow i_{b,SC} = \frac{v_i}{111.05}$

Therefore, $i_{SC} = 0.01v_i - \frac{20}{111.05}v_i = -0.17v_i$ **Z**$_O$= $\frac{v_{OC}}{i_{SC}}$ = 9.09 KΩ

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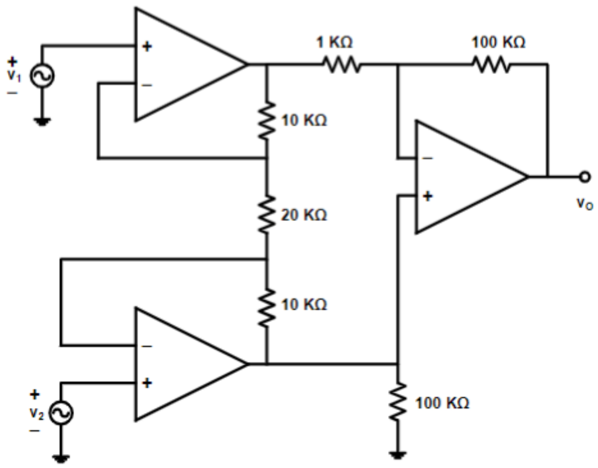
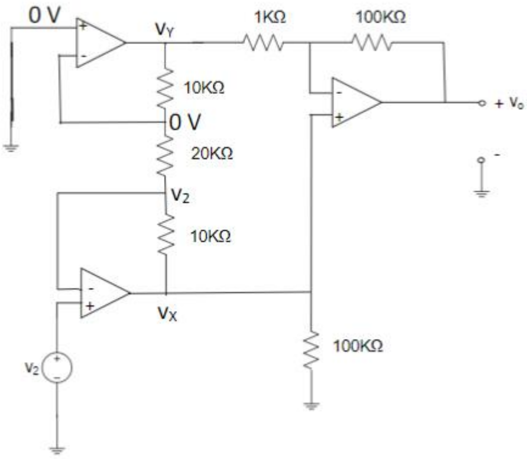
Problem-6: Find the output voltage v_o of the circuit shown.



Solution-6:

We can solve this circuit directly but it would be interesting to consider an unusual way of solving it through superposition.

Setting v_1=0 (i.e. grounding that source), the circuit becomes as shown.

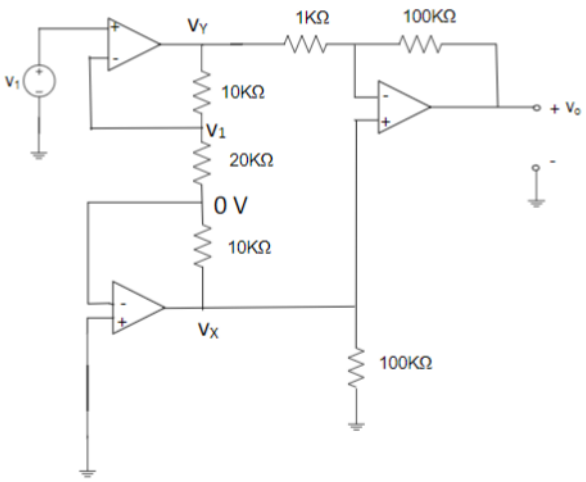


$$\frac{v_x - v_2}{10} = \frac{v_2}{20} \Rightarrow v_x = 1.5v_2$$

$$\frac{v_y}{10} = -\frac{v_2}{20} \Rightarrow v_y = -0.5v_2$$

$$v_o(\text{for } v_1=0) = -100v_y + (1+100)v_x = 201.5v_2$$

Now setting v_2=0 (i.e. grounding that source), the circuit becomes as shown



$$\frac{v_x}{10} = -\frac{v_1}{20} \Rightarrow v_x = -0.5v_1$$

$$\frac{v_y - v_1}{10} = \frac{v_1}{20} \Rightarrow v_y = 1.5v_1$$

$$v_o = -100v_y + (1+100)v_x = -200.5v_1$$

Combining the two, we get –

v_o = -200.5v_1+201.5v_2

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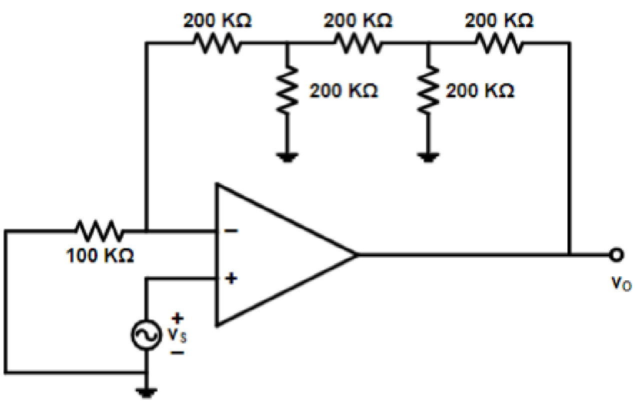
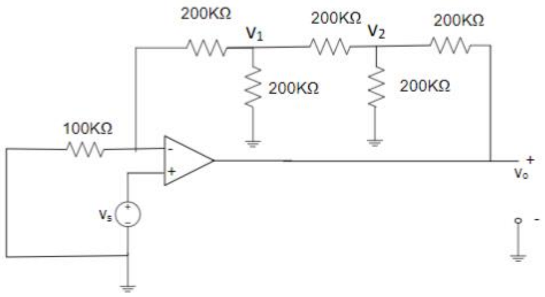
Problem-5: Find the gain $A_v = v_O/v_S$ of the circuit given below.



Solution-5:



$V_- = V_+ = V_S$

$$\frac{v_1 - v_s}{200} = \frac{v_s}{100} \Rightarrow v_1 = 3v_s$$

$$\frac{v_2 - v_1}{200} = \frac{v_1}{200} + \frac{v_s}{100} \Rightarrow v_2 = 2v_1 + 2v_s = 8v_s$$

$$\frac{v_o - v_2}{200} = \frac{v_2}{200} + \frac{v_2 - v_1}{200} \Rightarrow v_o = 3v_2 - v_1$$

$$\Rightarrow v_o = 21v_s \qquad \text{Gain} = A_V = 21$$