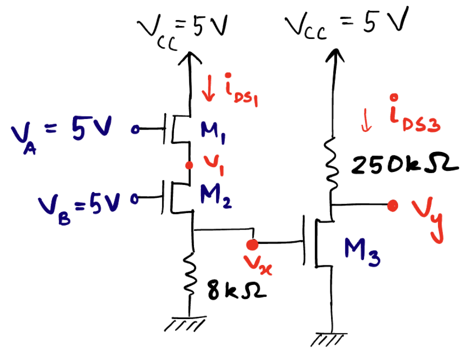
Q1

MOSFET Design: Set A [CO3]



For the following circuit with MOSFETs, assume that V_T=**1 V**, $k_n' = 50$ μ**A**/V^2 and the aspect ratio **W/L** is 1 for all the MOSFETS.

a) If the gate voltage to **M3** MOSFET, $V_x = 0.938$ **V**, and MOSFET **M2** is in <u>triode mode</u>, find the voltage V_1. *[3]*

b) Find V_y. *[2]*

c) If **W/L=2**, then $V_1 = 2.1454$ V. Find V_x for this case. [2]

d) Can you explain, whether there will be any changes in the output voltage at V_y for **W/L = 2** from that in **'b)'**. Also, comment on whether a larger or smaller value of **W/L** ratio is preferred in this case. [2+1]

Solution:

(a.) $i_{DS1} = \frac{V_x}{8} = \frac{0.05}{2}(5 - V_1 - 1)^2$

$V_1 = 4 \pm \sqrt{\frac{0.938}{8} \times \frac{2}{0.05}}$

$= 1.835V$

[Verify: M_1: $V_{G1} = V_A = 5V$

$V_{D1} = V_{cc} = 5V$

$\therefore V_{D1} > V_{G1} - V_t \rightarrow$ Sat.

M_2: $V_{G2} = 5$

$V_{DS2} = 1.835V < V_{G2} \rightarrow$ Triode]

(b.) $V_x < V_T$: $V_y = 5V$.

(c.) $\frac{W}{L} = 2$:

$i_{DS1} = \frac{V_x}{8} = \frac{0.05}{2}\left(\frac{W}{L}\right)(5 - 2.145 - 1)^2$

$\Rightarrow V_x = 1.377 \ V$

(d.) Assuming saturation:

$V_{GS} = 1.377$

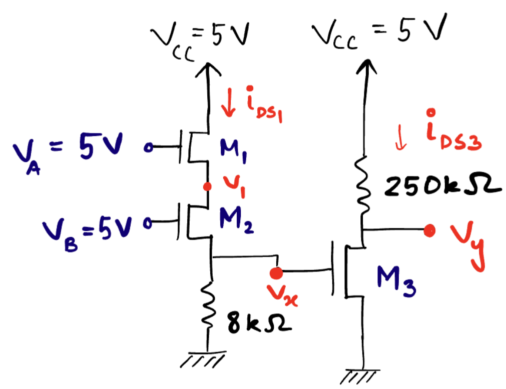
$V_{ov} = 0.377$. | $V_y = ?$

$i_{DS} = (0.377)^2 \times \frac{0.1}{2} = 7.1\mu A$.

$\therefore V_y = 5 - i_{DS} \cdot 250 = 3.223 > V_{ov}$

$\rightarrow$ Sat. verified.

MOSFET Design: Set B [CO3]



For the following circuit with MOSFETs, assume that V_T=**1 V**, $k_n{}' = 20\ \mu A/V^2$ and the aspect ratio **W/L** is 1 for all the MOSFETS.

a) If the gate voltage to **M3** MOSFET, $V_x = 0.492$ **V**, and MOSFET **M2** is in <u>triode mode</u>, find the voltage V_1**.** Verify the modes for both **M1 and M2** *[3]*

b) Find V_y. *[2]*

c) If **W/L=4**, then $V_1 = 2.04$ V. Find V_x for this case. [2]

d) Can you explain, whether there will be any changes in the output voltage at V_y for **W/L = 4** from that in **'b)'**. Also, comment on whether a larger or smaller value of **W/L** ratio is preferred in this case. [2+1]

Solution

a. $i_{DS1} = \frac{V_x}{8} = \frac{0.02}{2}(5 - V_1 - 1)^2$

$$V_1 = 4 \pm \sqrt{\frac{0.492}{8} \times \frac{2}{0.02}}$$

$= 1.52\ V$

[Verify: M_1: $V_{G1} = V_A = 5V$
$V_{D1} = V_{CC} = 5V$
$\therefore V_{D1} > V_{G1} - V_t \rightarrow$ Sat

M_2: $V_{G2} = 5$
$V_{DS2} = 1.52V < V_{G2} \rightarrow$ Triode]

(b.) $V_x < V_T$: $V_y = 5\,V$.

(c.) $\frac{W}{L} = 4$:

$$i_{DS1} = \frac{V_x}{8} = \frac{0.02}{2}\left(\frac{W}{L}\right)\left(5 - 2.04 - 1\right)^2$$

$$\Rightarrow V_x = 1.229312\,V$$

(d.) Assuming saturation:

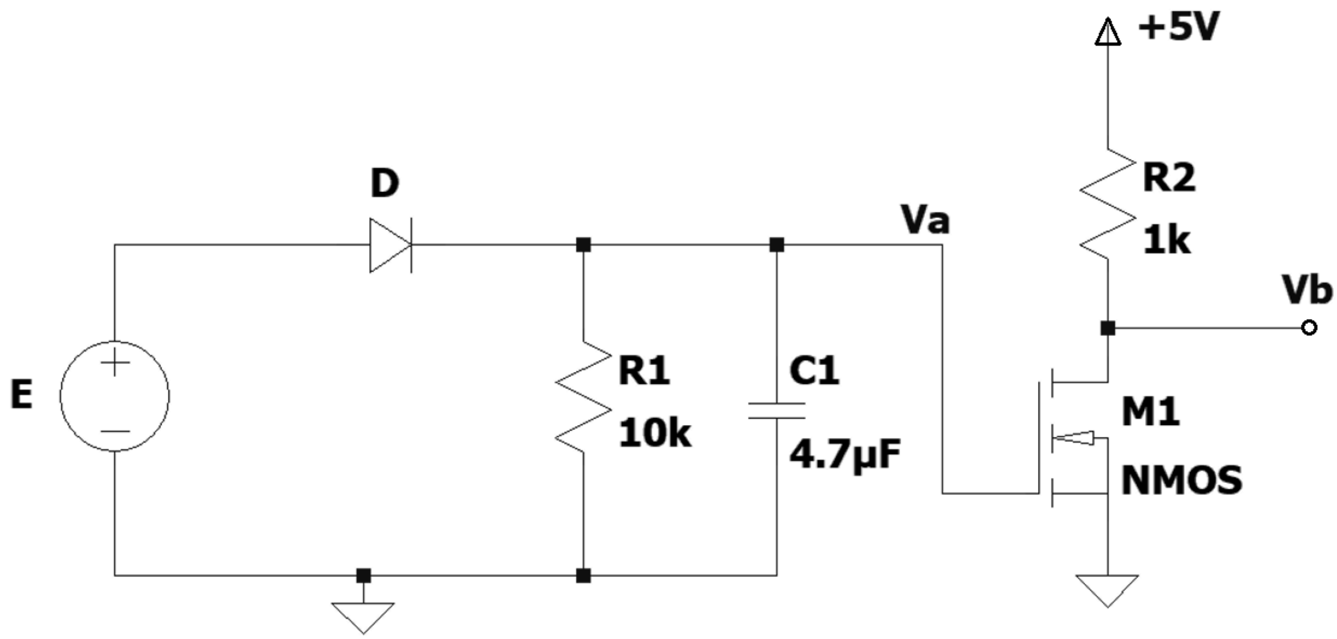
$$\left.\begin{array}{l} V_{GS} = 1.229312 \\ V_{ov} = 0.22913 \end{array}\right| V_y = ?$$

$$i_{DS} = (0.22913)^2 \times \frac{0.08}{2} = 2\,\mu A.$$

$$\therefore V_y = 5 - i_{DS} \cdot 250 = 4.475\,V > V_{ov}$$

$\longrightarrow$ Sat. verified.

Q2 **MOSFET+HW: Set A [CO2]**



The Half-wave rectifier circuit has been cascaded with an inverter. You are given the following information about the circuit: [For HW: Vo = Vdc ± Vrpp/2]

$E\ =\ 5\ sin(400\pi t)\ V$	$K_n =\ 2\ mA/V^2$	$V_T =\ 1\ V$	$V_{D0} =\ 0.7\ V$

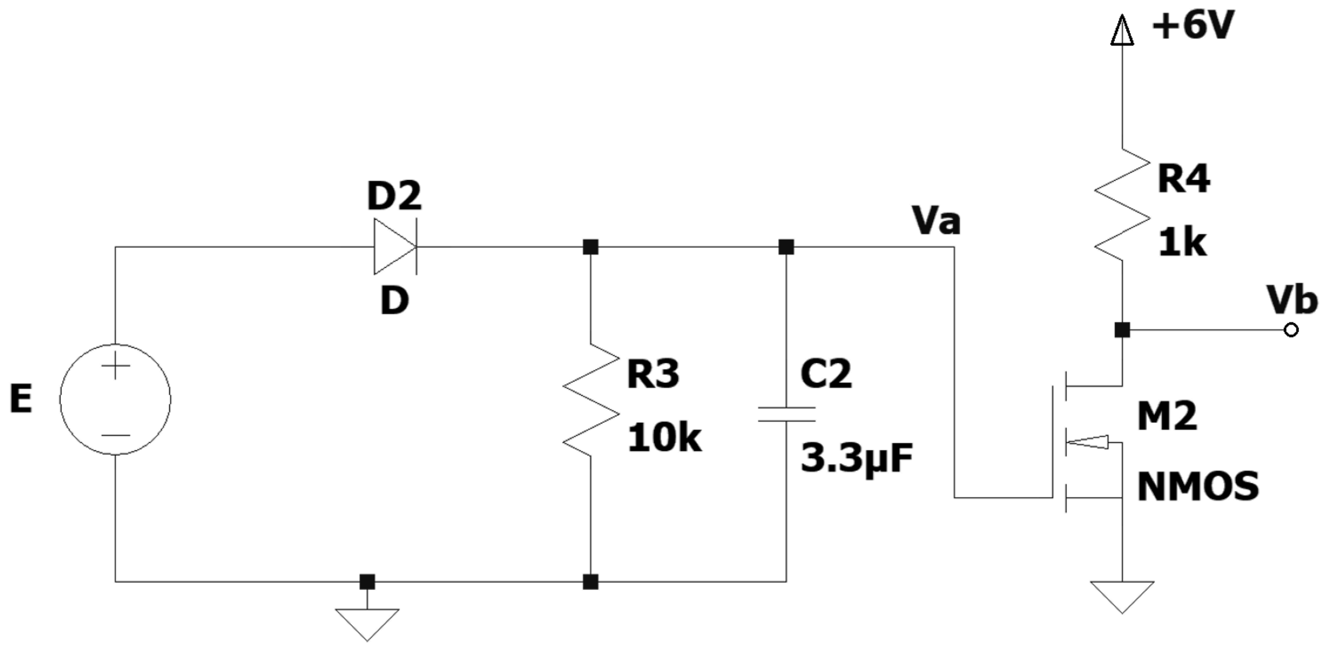
(a) Determine the peak-to-peak ripple value of the half-wave rectifier output, V_a . What is the lowest value of V_a? [3+1]

(b) At the lowest value of V_a , determine the output V_b of the inverter. [4]

(c) Now disconnect the capacitor. In this case, what will be the voltage V_b for the lowest value of V_a ? [2]

(d) **BONUS:** Draw an approximate plot of V_b without the capacitor connection. [2]

(MJA) **MOSFET+HW: Set B [CO2]**



The Half-wave rectifier circuit has been cascaded with an inverter. You are given the following information about the circuit: [For HW: Vo = Vdc ± Vrpp/2]

$E = 6\,sin(400\pi t)\ V$	$K_n = 2\ mA/V^2$	$V_T = 1\ V$	$V_{D0} = 0.7\ V$

(a) Determine the peak-to-peak ripple value of the half-wave rectifier output, V_a. What is the lowest value of V_a? [3+1]

(b) At the lowest value of V_a, determine the output V_b of the inverter. [4]

(c) Now disconnect the capacitor. In this case, what will be the voltage V_b for the lowest value of V_a? [2]

(d) **BONUS:** Draw an approximate plot of V_b without the capacitor connection. [2]

Solution : Set A

Set A

(a) $E = 5\sin(400\pi t)$

$f_r = 200\ Hz$; $V_p = 5 - 0.7 = 4.3V$

$V_{r(p-p)} = 4.3/(f_r \times 10k \times 4.7\mu) = \underline{\underline{0.457V}}$

lowest voltage of

$V_a = 4.3 - 0.457$

$= \underline{\underline{3.843V}}$

(b) $V_a(\text{lowest}) = V_G = 3.843V = V_{GS}$

Assume triode region:

$I_D = k\{(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\}$

$\Rightarrow 5 - V_b = 2(3.843 - 1)V_b - V_b^2 = 5.686V_b - V_b^2$

$\Rightarrow V_b^2 - 6.686V_b + 5 = 0$

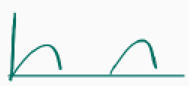
$\Rightarrow V_b = 0.858V, \cancel{5.828V}$

Verify: $V_{DS} = V_b = 0.858 < V_{GS} - V_T = 2.843$

$\therefore$ Triode mode is correct

$\boxed{\text{Ans}}$ $V_b = \underline{\underline{0.858V}}$

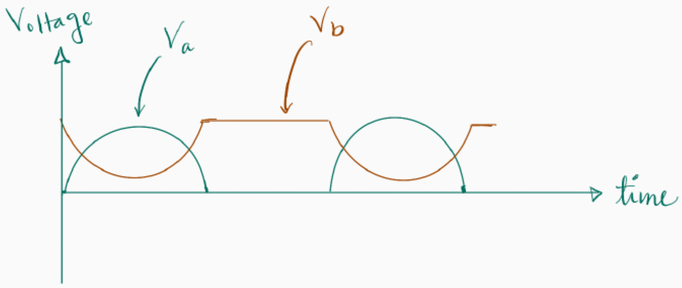
(c) Capacitor disconnected: V_a :



$\Rightarrow V_a(\text{lowest}) = 0V$

$\hookrightarrow$ mosfet cutoff $\rightarrow V_b = 5V$ (Ans)

(d) Bonus :- (Just the approx. shape)



Solution : Set B

(a) $E = 6\sin(400\pi t)$

$f_r = 200\ Hz$; $V_p = 6 - 0.7 = 5.3V$

$V_{r(p-p)} = 5.3/(f_r \times 10k \times 3.3\mu) = \underline{\underline{0.803\ V}}$

lowest voltage of

$V_a = 5.3 - 0.803$

$= \underline{\underline{4.497\ V}}$

$\boxed{\text{Set B}}$

(b) $V_a(\text{lowest}) = V_G = 4.497\ V = V_{GS}$

Assume triode region :

$I_D = K\{(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\}$

$\Rightarrow 6 - V_b = 2(4.497 - 1)V_b - V_b^2 = 6.994 V_b - V_b^2$

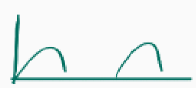
$\Rightarrow V_b^2 - 7.994 V_b + 6 = 0$

$\Rightarrow V_b = 0.839\ V,\ \cancel{7.155\ V}$

Verify : $V_{DS} = V_b = 0.839 < V_{GS} - V_T = 3.497V$

$\therefore$ Triode mode is correct

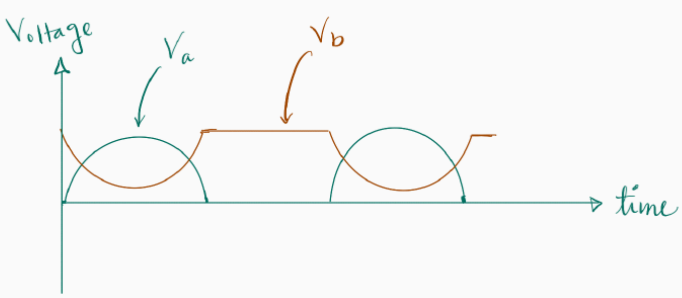
$\boxed{\text{Ans}}$ $V_b = \underline{\underline{0.839V}}$

(c) Capacitor disconnected : V_a : 

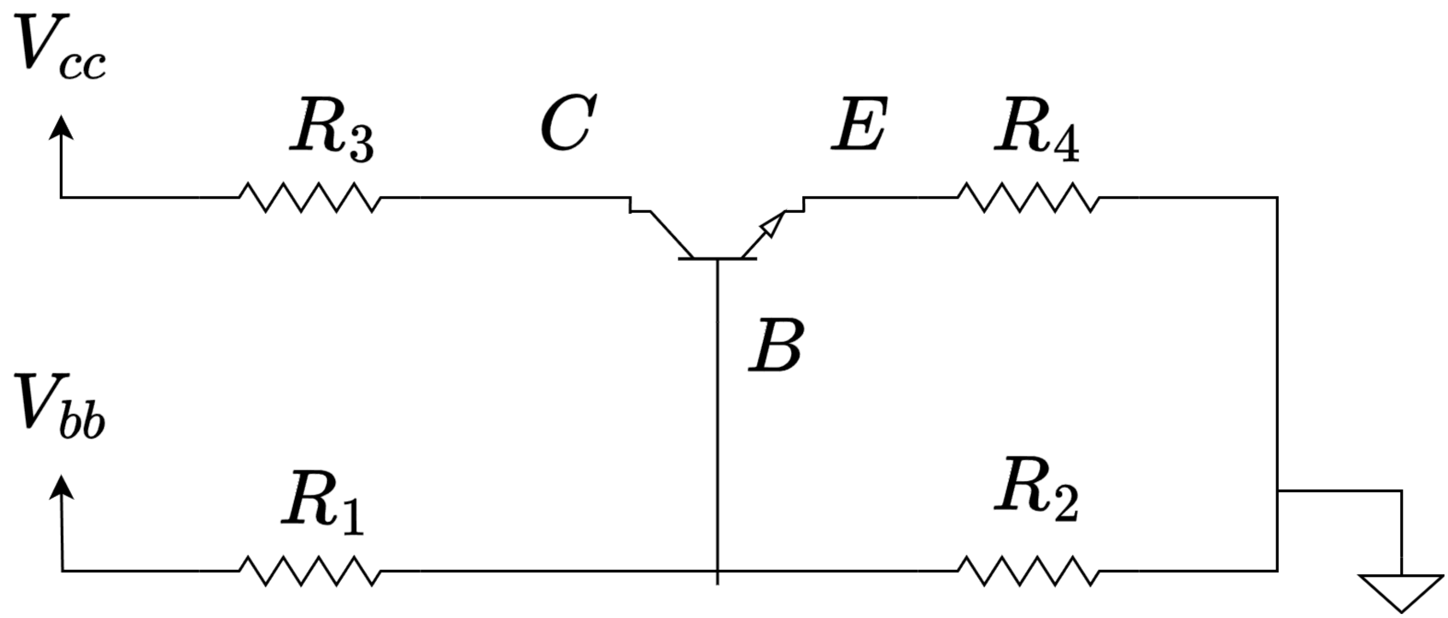
$\Rightarrow V_a(\text{lowest}) = 0V$

$\longrightarrow$ mosfet cutoff $\longrightarrow V_b = 6\ V$ Ans

(d) Bonus :- (Just the approx. shape)



Q3 BJT:



In the above circuit, V_{bb} = 5V, V_{cc} = 15V, R_1 = 20kΩ(40kΩ), R_2 = 80kΩ(60kΩ), R_3 = 2kΩ and R_4 = 1kΩ. Also, assume current gain, Ic/Ib = 100.

a) Draw the equivalent circuit of BJT during saturation and active modes. [2]

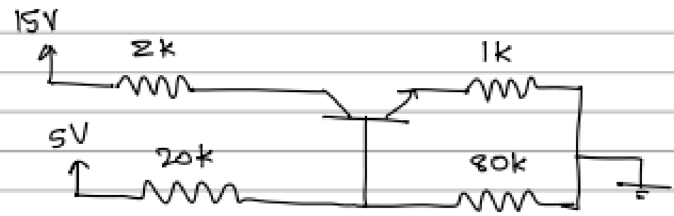
b) Solve the above circuit and calculate I_B, I_C, I_E, V_{CE} and V_C using the method of assumed states. [Hint: try to find the Thevenin equivalent of the left hand side circuit from the B terminal and ground] [3]

c) If V_{bb} is changed from 5V to 5.1V, what happens to the outputs of the circuits? Calculate I_B, I_C, I_E, V_{CE} and V_C again. Now for a 0.1V increase in input V_{bb}, what is the change of I_c? Use $\Delta I_C = I_{C,new} - I_{C,old}$. [3+1]

d) Explain any use case of the differences in voltage increase between input and output. What could the use case be to such a phenomenon? [1]

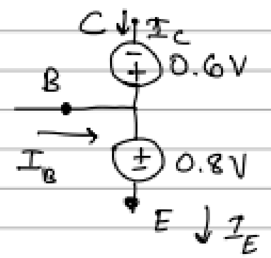
BJT: Solution

Set A

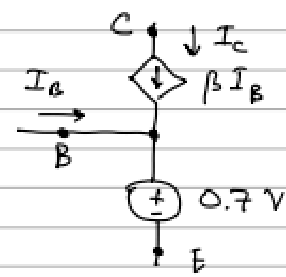


$\beta = 100$

(a) BJT equiv. ckt: i) saturation

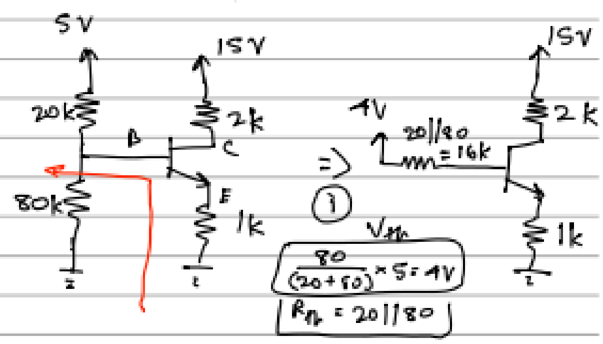


ii) active



(b) Redraw ckt for clarity:
(Assume saturation)

(i) Applying thevenin at B node and gnd



from KVL in base ckt:

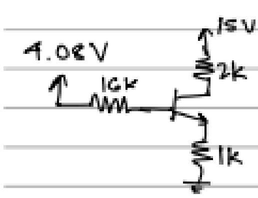
$$I_B = \frac{4 - 0.7}{16 + (1+\beta)1} = 0.0282 \text{ mA}, \quad I_C = \beta I_B = 2.82 \text{ mA}$$

$$I_E = I_B + I_C = (1+\beta) I_B = 2.8482 \text{ mA}, \quad V_C = 15 - I_C \times 2 = 9.36 V$$

$$V_E = I_E \times 1 = 2.8482 V \qquad V_{CE} = V_C - V_E = 6.5118 V$$

$\rightarrow V_{CE} > 0.2V$, $I_B, I_C, I_E > 0$ ∴ Assumption correct

(c) Same calc. as above but with $V_{BB} = 5.1V$



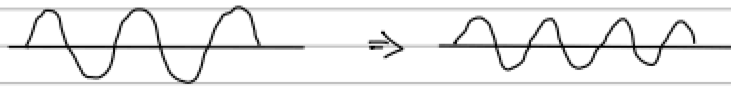
$$I_B = \frac{4.08 - 0.7}{16 + 101 \times 1} = 0.0289 \text{ mA}, \; I_C = 2.89 \text{ mA}, \; I_E = 2.918 \text{ mA}$$

$$V_C = 15 - I_C \times 2 = 9.22V, \; V_E = 2.918 V, \; V_{CE} = V_C - V_E = 6.302 V$$

$$\Delta V_{BB} = 0.1V, \quad \Delta I_C = 2.89 - 2.82 = 0.07 \text{ mA}$$

(d) input change of 0.1 V ⟶ output change of 0.07 mA

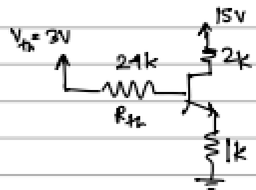
I any signal can be attenuated, can be used as attenuator to reduce the swings of a signal



Set B

Same as set-A, R_1, R_2 values changed

(b)

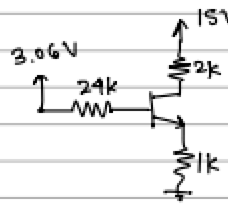


$$I_b = \frac{3-0.7}{24 + 101\times1} = 0.0184\ mA,\ I_c = 1.84\ mA$$

$I_E = 1.8584\ mA$, $V_{CE} = (15 - 2I_c) - 1\times I_E = 9.4616\ V$

$V_c = 15 - 2I_c = 11.32V$, $V_E = 1.8584\ V$

(c)

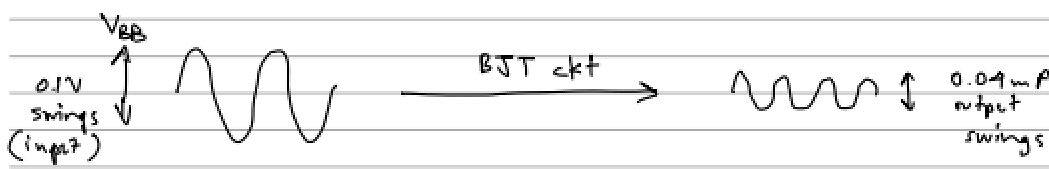


$I_b = 0.0188\ mA$, $I_c = 1.88\ mA$, $I_E = 1.907\ mA$

$V_C = 15 - 2I_c = 11.24V$, $V_E = 1.907\ V$

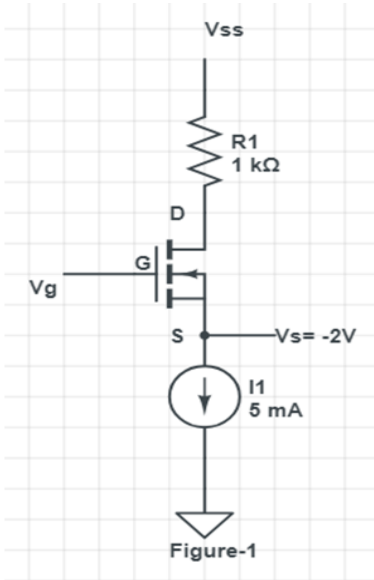
$V_{CE} = 9.333\ V$

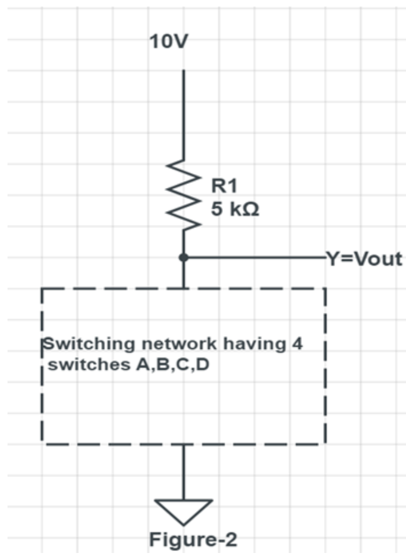
$\Delta V_{BB} = 0.1\ V$, $\Delta I_c = 1.88 - 1.84 = 0.04\ mA$



* Acts as a kind of signal swing attenuator.

Q4 **Mosfet**





Conditions for Network on
i) switch A must be on
ii)Switches B,C simultaneously on or D on

a)For figure-2, place the switches as nmos devices and write the output logic function Y in terms of A,B,C,D assuming nmos switch model. 2

b)From figure-2, assuming SR model for nmos find the output voltage when only A and D switches are ON(Assume Ron= 0.1 KΩ) 3

c)For figure-1, $k=2\ mA/V^2$, $V_T = 1\ V$ 3+2

i)Find the gate voltage so that the mosfet is in saturation mode.

ii) Then find the minimum supply voltage Vss to operate the device in this condition. [Hints , $V_{ov}=V_{DS}$]

d)**Bonus** - from figure-2 is it possible to drive a not gate cascaded to Vout ?
[V_T =0.5V, Vout(low)=Vout of question(b)] 2

Mosfet : Solution

Q4

a) Set A

$I_{DS} = \frac{1}{2} k V_{ov}^2$

$\Rightarrow 5 = \frac{1}{2} \times 2 \times V_{ov}^2$

$\Rightarrow V_{ov} = \sqrt{5}$

$\therefore V_{gs} - V_T = \sqrt{5}$

$\Rightarrow V_{gs} = \sqrt{5} + V_T = \sqrt{5} + 1 = 3.24$

$\therefore V_g - V_s = 3.24$

$\Rightarrow V_g = 3.24 + V_s = 3.24 - 2$

$= 1.24 V$

2nd part minimum V_{ss}

$\Rightarrow V_{SS} = 5 \times 1 + V_{DS} + V_s$

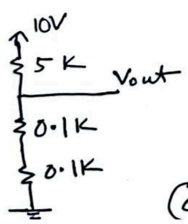
$= 5 + \sqrt{5} - 2$

$= 5.24 V$

$V_{DS} = V_{ov} = \sqrt{5}$

b) $Y = \overline{A(BC + D)}$

c)

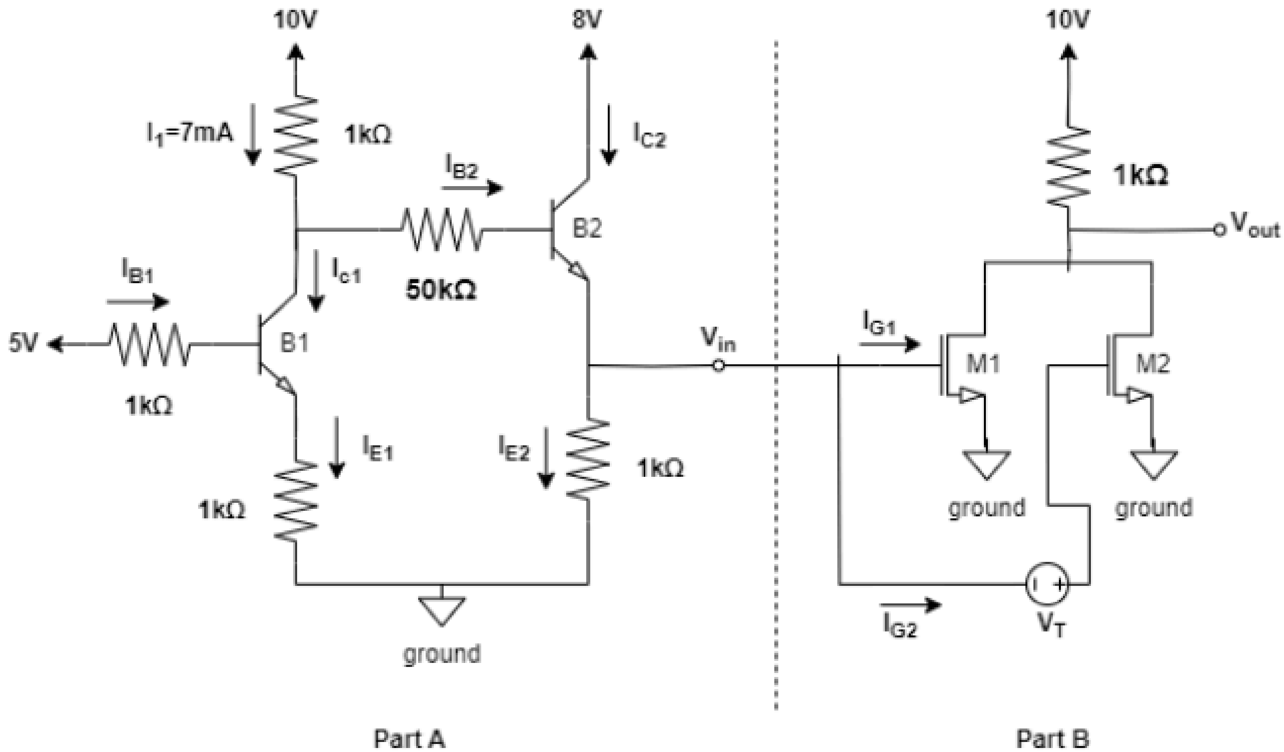


$V_{out} = 10 \times \frac{0.2}{5 + 0.2}$

$= 0.385 V$

d) $V_{out} < V_T$, so possible to turn off

Q5 (both setA and setB)



In the circuit above, the BJTs have the following specification: β=100, Forward Active Region: $V_{BE} = 0.7\,V,\ I_C = \beta I_B$, Saturation Region: $V_{BE} = 0.8\,V,\ V_{CE} = 0.2\,V$,or the MOSFETs: $V_T = Threshold\ Voltage\ of\ M1\ and\ M2.$

(a) Determine i_{g1} and i_{g2}

(b) **Justify** why the SR model of MOSFET is more efficient than the S model ? [1]

(c) Assume, B1 and B2 are in the **Saturation region. Calculate i_{c2}**

(d) Assume, B1 is in the **Forward Active region. Calculate Vin.**

(e) **Draw the VTC** of Part- B assuming, $V_T = 8\,V$. [Use <u>S model</u> of MOSFETs]

Solution

(a) $i_{G1} = i_{G2} = 0$

(b) SR Model considers channel resistance.

(c) From B_1

\# $5 - 0 = I_{B1} + 0.8 + 1 I_{E1}$

$I_{B1} + I_{E1} = 4.2$

\# $10 - 0 = 7 + 0.2 + 1 I_{E1}$

$I_{E1} = 2.8$

$\therefore I_{B1} = 4.2 - 2.8 = 1.4\,mA$

$\therefore I_{C1} = 2.8 - 1.4 = 1.4\,mA$

$\therefore I_{B2} = I_1 - I_{C1} = 2.8 - 1.4 = 5.6\,mA$

From B_2

$8 - 0 = 0.2 + I_{E2}$

$\therefore I_{E2} = 7.8\,mA$

$\therefore I_{C2} = I_{E2} - I_{B2} = 7.8 - 5.6 = 2.2\,mA$

$\boxed{I_{C2} = 2.2\,mA}$

(d) B_1 in Forward Active.

$\therefore 5 - 0 = I_{B1} + 0.7 + I_{E1}$

$I_{E1} = 4.3 - I_{B1}$

$I_{C1} = \beta I_{B1} = 100 I_{B1}$

$I_{E1} = I_{B1} + I_{C1}$

$\Rightarrow 4.3 - I_{B1} = I_{B1} + 100 I_{B1}$

$\therefore I_{B1} = 0.042156 \text{ mA}$

$\therefore I_{C1} = 100 I_{B1} = 4.21568 \text{ mA}$

$I_{B2} = I_1 - I_{C1} = 7 - 4.21568 = 2.78432 \text{ mA}$

For B_2

Assumption $\Rightarrow$ saturation

$8 - 0 = 0.2 + I_{E2}$

$\therefore I_{E2} = 7.8 \text{ mA}$

$\therefore I_{C2} = I_{E2} - I_{B2} = 7.8 - 2.78432$
$= 5.0157 \text{ mA}$

Verification

$$\frac{I_{C2}}{I_{B2}} = \frac{5.0157}{2.78432} = 1.8021 < \beta = 100$$

[correct]

$\because 8 - V_{in} = 0.2$

$\therefore \boxed{V_{in} = 7.8 V}$

(c)