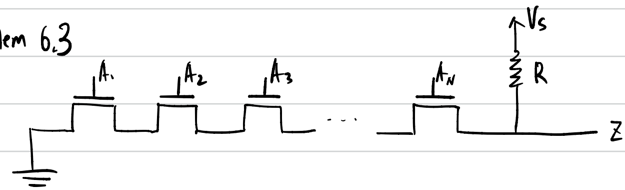
EEC HW3 2021-16988 Jaewan Park.

Problem 6.3



$NAND(A_1 \sim A_N) = 1 \rightarrow v_Z = V_S$

$NAND(A_1 \sim A_N) = 0 \Rightarrow v_Z = V_S \times \frac{N R_{ON}}{R + N R_{ON}} = V_S \times \frac{N}{100 + N}$

v_Z when $Z=0$ should satisfy $v_Z \le V_{OL}$

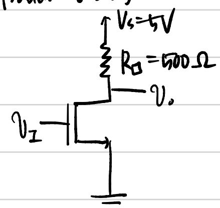
$\therefore V_S \times \frac{N}{100+N} \le 1$, $N \le \frac{100}{V_S - 1}$

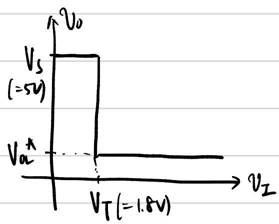
When all $A_1 = \cdots = A_N$ are on, we have maximum P.

$\therefore P_{max} = \frac{V_S^2}{\Sigma R} = \frac{V_S^2}{N R_{on} + R} = \frac{V_S^2}{(N + 100)k}$

$\therefore$ Maximum $N = \frac{100}{V_S - 1}$, Maximum Power $= \frac{V_S^2}{(N+100)k} = \frac{V_S(V_S - 1)}{100k}$

Problem 6.6 (b)





$V_{OL}^* = V_S \times \frac{R_{ON}}{R_{ON} + R} = 5 \times \frac{R_n \cdot \frac{L}{W}}{R_n \cdot \frac{L}{W} + R_\square \cdot \frac{L_R}{W_R}} \le 0.5.$

$\therefore \frac{L_R}{W_R} \ge 18 \cdot \frac{L}{W}$

Since the total area is $L \cdot W + L_R \cdot W_R$,

we have minimum area when $L = W_R = 0.5 \mu m$. Then $L_R = W = \frac{3}{\sqrt{2}} \mu m$.

$\therefore$ Minimum Area $= \frac{3}{\sqrt{2}} \mu m^2$

When the MOSFET is on, we have maximum power.

$\therefore P_{max} = \frac{V_S^2}{\Sigma R} = \frac{V_S^2}{R_{on} + R}$

Exercise 1.10

(a) $v_O = V_S - R_L \cdot i_C = V_S - R_L \cdot \beta \cdot i_B$

$$= V_S - R_L \cdot \beta \cdot \frac{v_I - 0.6}{R_I}$$

$$= 5 - 10 \cdot 100 \cdot \frac{v_I - 0.6}{500}$$

$$= 6.2 - 2v_I$$

(b) For the BJT to remain in the active region, i_B should be nonnegative.

Then we have

$$i_B = \frac{v_I - 0.6}{R_I} \geq 0, \quad v_I \geq 0.6$$

Therefore the minimum value of v_I is 0.6V

Then $i_B = 0$, $i_C = \beta i_B = 0$,

$$v_O = 6.2 - 2v_I = 5\,V$$

Problem 1.2

(a) i) $v_{GS}\ (= v_{IN}) < V_T$

$v_{OUT} = V_S$ ($\because$ open switch)

ii) $v_{GS}\ (= v_{IN}) \geq V_T$

At first, when v_{IN} is not sufficiently large, the MOSFET enters a saturation region.

Then $v_{OUT} = V_S - R\,I_{DS} = V_S - R \cdot \frac{K}{2}(v_{GS} - V_T)^2 = V_S - \frac{KR}{2}(v_{IN} - V_T)^2$

If v_{IN} gets sufficiently large, the MOSFET acts as a closed switch, so no current flows through R.

Then $v_{OUT} = 0$

Let the value of v_{IN} between the saturation and closed switch regions v_{IN_T}

$$\therefore v_{OUT} = \begin{cases} V_S & (0 \leq v_{IN} < v_T) \\ V_S - \frac{KR}{2}(v_{IN} - V_T)^2 & (v_T \leq v_{IN} < v_{IN_T}) \\ 0 & (v_{IN} \geq v_{IN_T}) \end{cases}$$

(c) At $V_{IN} = V_{IN_T}$, we should have $V_{OUT} = V_S - R\, i_{DS} = 0$, so $i_{DS} = \frac{V_S}{R}$.

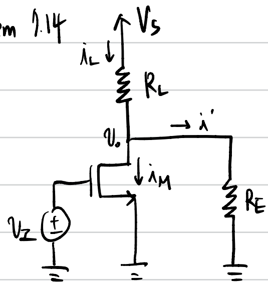
$$\therefore\ i_{DS} = \frac{V_S}{R} = \frac{K}{2}\left(V_{IN_T} - V_T\right)^2$$

$$V_{IN_T} = \sqrt{\frac{2V_S}{KR}} + V_T$$

Substituting the given values gives $v_{IN_T} = 2V$

$$\therefore\ V_{OUT} = \begin{cases} V_S = 15V & (0 \le v_{IN} < 1) \\ V_S - \frac{KR}{2}(v_{IN} - V_T)^2 = 15 - 15(v_{IN} - 1)^2 & (1 \le v_{IN} < 2) \\ 0 & (2 \le v_{IN} \le 3) \end{cases}$$

Problem 1.14



It is given that the MOSFET operates in saturation.

Then we obtain

$$v_o = R_E\, i'$$

$$V_S - R_L\, i_L = v_o$$

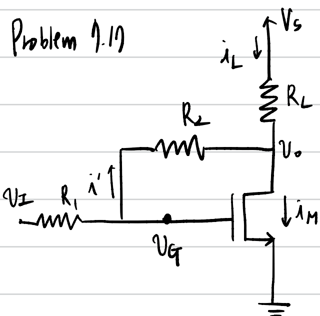
$$i_M = \frac{K}{2}(v_I - V_T)^2 \quad (\because \text{saturation})$$

Since $i_L = i' + i_M$ ($\because$ KCL).

$$\frac{V_S - v_o}{R_L} = \frac{v_o}{R_E} + \frac{K}{2}(v_I - V_T)^2$$

$$\therefore\ v_o = \frac{2V_S R_E - K R_E R_L (v_I - V_T)^2}{2(R_L + R_E)}$$

Problem 1.17



It is given that the MOSFET operates in saturation.

$$v_G = \frac{R_2}{R_1 + R_2} v_I + \frac{R_1}{R_1 + R_2} v_o \quad (\because \text{superstition})$$

$$V_S - R_L\, i_L = v_o$$

$$v_G - R_2\, i' = v_o$$

$$i_M = \frac{K}{2}(v_G - v_T)^2 \quad (\because \text{saturation})$$

Since $i_L + i' = i_M$ ($\because$ KCL),

$$\frac{V_S - v_o}{R_L} + \frac{v_G - v_o}{R_2} = \frac{K}{2}(v_G - v_T)^2 \Rightarrow \frac{V_S - v_o}{R_L} + \frac{v_I - v_o}{R_1 + R_2} = \frac{K}{2}(v_G - v_T)^2$$

v_o is the root of the above equation (quadratic equation on v_o, solvable)

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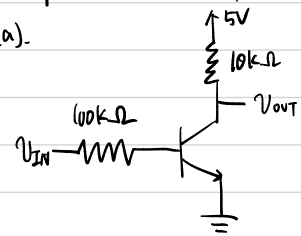
(a).



i) $V_{IN} \leq V_{ON} = 0.7V$: cutoff

$V_{OUT} = V_S = 5V$

ii) $V_{ON} \leq V_{IN} \leq V_{INT}$: active

$$V_{OUT} = V_S - R_L \cdot \beta \cdot \frac{V_{IN} - V_{ON}}{R_I}$$

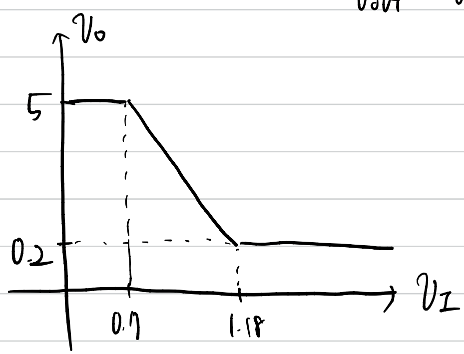
$$= 12 - 10 V_{IN}$$

V_{INT} is the voltage where $V_{OUT} = V_{sat}$ (=0.2V). so $V_{INT} = 1.18V$

iii) $V_{IN} \geq V_{INT}$: saturation

$V_{OUT} = V_{sat} = 0.2V$

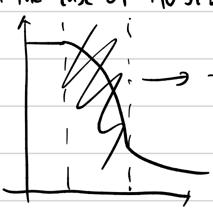
∴



(b) When active,

$$\frac{dV_o}{dV_I} = -10 \Rightarrow \text{Voltage Gain}$$

In the case of MOSFET, the gain is small since



→ this region is non-linear, so BJT amplifiers have rather better voltage gain.