

MOSFET Tutorial

1. $V_{Tn} = 1V$, $i_D = 0.8mA$, $V_{GS} = 3V$, $V_{DS} = 4.5V$.

Calculate i_D while, a) $V_{GS} = 2V$, & $V_{DS} = 4.5V$

b) $V_{GS} = 3V$, & $V_{DS} = 1V$

Soln.

Mode/region of operation:

$$V_{DS} = 4.5V > V_{DS(\text{sat.})} = V_{GS} - V_{Tn} = 3 - 1 = 2V$$

↪ Saturation region of opern.

$$I_{D_{\text{sat.}}} = K_n (V_{GS} - V_{Tn})^2$$

$$\Rightarrow 0.8m = K_n (3-1)^2$$

$$\Rightarrow K_n = 0.2 \text{ mA/V}^2$$

a) $I_D = (0.2m)(2-1)^2 = 0.2 \text{ mA}$

b) For non-saturation, since $V_{DS} < V_{DS(\text{sat.})}$

$$I_D = (0.2m) [2(3-1)(1) - 1^2] = 0.6 \text{ mA}$$

$$\left[\because I_{D_{\text{non-sat}}} = K_n [2(V_{GS} - V_{Tn})V_{DS} - V_{DS}^2] \right]$$

or in ch. MOSFET

2. NMOS e-mode transistor: $V_{Tn} = 0.8V$, $K_n = 0.1mA/V^2$, $V_{GS} = 2.5V$. Calculate I_D while $V_{DS} = 2V$ & $10V$, for $\lambda = 0$ & $\lambda = 0.02 V^{-1}$. Calculate r_o .

Soln. a) $\lambda = 0$: $V_{DS_{\text{sat.}}} = V_{GS} - V_{Tn} = 2.5 - 0.8 = 1.7V$

For, $V_{DS} = 2V$ (saturation $\Rightarrow V_{DS} > V_{DS_{\text{sat.}}}$)

$$I_D = K_n (V_{GS} - V_{Tn})^2$$

$$= (0.1m)(2.5 - 0.8)^2 = 0.289 \text{ mA}$$

$$r_o = \frac{1}{A_i D} = \frac{1}{0.289m} = \infty$$

b) $\lambda = 0.02 V^{-1}$

$$I_D = K_n (V_{GS} - V_{Tn})^2 (1 + \lambda V_{DS})$$

For $V_{DS} = 2V$

$$I_D = (0.1m)(2.5 - 0.8)^2 (1 + (0.02)(2)) = 0.300 \text{ mA}$$

For, $V_{DS} = 10V$,

$$I_D = (0.1m) [(2.5 - 0.8)^2 (1 + (0.02)(10))] \\ = 0.347 \text{ mA}$$

$$r_o = \frac{1}{K_n I_D} = \frac{1}{(0.02)(0.1m)(2.5 - 0.8)^2} = 173 \text{ k}\Omega$$

3. PMOS e-mode MOSFET:

$V_{TP} = -1.2V$, $V_{SG} = 2V$, $W = 40\mu\text{m}$, $L = 2\mu\text{m}$,
 $t_{ox} = 350\text{ \AA}$, $\mu_p = 300 \text{ cm}^2/\text{V-s}$.

Find K_p .

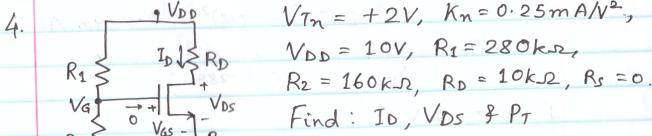
$$\text{Sol'n. } K_p = \frac{W}{L} \cdot \mu_p \cdot C_{ox} \cdot \frac{1}{2}$$

$$C_{ox} = \frac{\epsilon}{t_{ox}} = \frac{(\epsilon)(8.85 \times 10^{-12})}{350 \times 10^{-8}}$$

Per unit area
(Area is missing from: $C = \frac{\epsilon A}{d}$)

$$= \frac{(8.9)(8.85 \times 10^{-12})}{350 \times 10^{-8}} \text{ Convert into cm}^2$$

$$\therefore K_p = \frac{40\mu}{2\mu} (300)(98.61 \text{ nF}) \frac{1}{2} = 2.96 \text{ } \mu\text{A/V}^2$$



Sol'n: $V_G = \frac{R_2}{R_1 + R_2} \cdot V_{DD} = \frac{160k}{280k + 160k} \cdot 10 = 3.636V = V_{GS}$

$$V_D(\text{Sat.}) = V_{GS} - V_{TN} = 3.636V - 2 = 1.636V$$

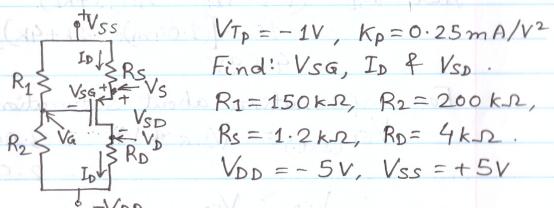
MOSFET in Saturation.

$$\therefore I_D = K_p (V_{GS} - V_{TN})^2 = (0.25m)[3.636 - 2]^2 \\ = 0.669 \text{ mA}$$

By KVL: $V_{DS} = V_{DD} - I_D \cdot R_D = 10 - [0.669m] \cdot 10k = 3.31V$

$$\therefore P_T = I_D \cdot V_{DS} = (0.669m)(3.31) = 2.21 \text{ mW}$$

5.



Sol'n: $V_G = \frac{R_2}{R_1 + R_2} \cdot (V_{SS} - V_{DD}) = \frac{200k}{150k + 200k} (5 + 5)$

$$= 0.714V$$

$$V_S = V_{SS} - I_D \cdot R_S = 5 - I_D \cdot (1.2k)$$

$$\therefore V_{SG} = V_S - V_G = 5 - (1.2k) I_D - 0.714$$

$$\Rightarrow I_D = \frac{4.286 - V_{SG}}{1.2k} = K_p (V_{SG} + V_{TP})^2$$

[∴ PMOS in saturation]

$$\Rightarrow 4.286 - V_{SG} = (1.2k)(0.25m) [V_{SG}^2 - 2V_{SG}(-1) + (-1)^2]$$

$$\Rightarrow 4.286 - V_{SG} = 0.3 \cdot V_{SG}^2 - 0.6 V_{SG} + 0.3$$

$$\Rightarrow 0.3 V_{SG}^2 + 0.4 V_{SG} - 3.986 = 0$$

TYU 3.13 The transistor in the circuit shown in Figure 3.48 has parameters $K_n = 4 \text{ mA/V}^2$ and $V_{TN} = 0.8 \text{ V}$, and is used to switch the LED on and off. The LED cutin voltage is $V_f = 1.5 \text{ V}$. The LED is turned on by applying an input voltage of $v_I = 5 \text{ V}$. (a) Determine the value of R such that the diode current is 12 mA. (b) From the results of part (a), what is the value of v_{DS} ? (Ans. (a) $R = 261 \Omega$, (b) $v_{DS} = 0.374 \text{ V}$)

TYU 3.14 In the circuit in Figure 3.46, let $R_D = 25 \text{ k}\Omega$ and $V_{TN} = 1 \text{ V}$. (a) Determine the value of the conduction parameter K_n required such that $V_O = 0.10 \text{ V}$ when $V_1 = 0$ and $V_2 = 5 \text{ V}$. (b) Using the results of part (a), find the value of V_O when $V_1 = V_2 = 5 \text{ V}$. (Ans. (a) $K_n = 0.248 \text{ mA/V}^2$, (b) $V_O = 0.0502 \text{ V}$)

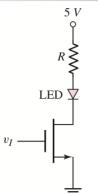


Figure 3.48

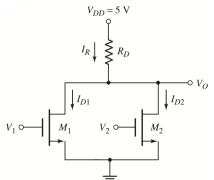


Figure 3.46 A two-input NMOS NOR logic gate

By solving the quadratic equation,

$$V_{SG} = \frac{-0.4 \pm \sqrt{(0.4)^2 + 4(0.3)(3.986)}}{2(0.3)}$$

$$= +3.04 \text{ V} \quad (\text{Considering only the +ve answer})$$

$$\text{Now, } I_D = (0.25m)[3.04+1]^2 \\ = 1.04 \text{ mA} \quad (\text{Ans})$$

$$\text{Also, } V_{SD} = (V_{SS} - V_{DD}) - I_D(R_S + R_D) \\ = 10 - [(1.04m)(1.2k + 4k)] \\ = 4.59 \text{ V} \quad (\text{Ans})$$

For confirmation about saturation mode,

$$V_{SD(\text{sat})} = V_{SG} + V_{TP} = 3.04 + 1 \\ = 2.04 \text{ V}$$

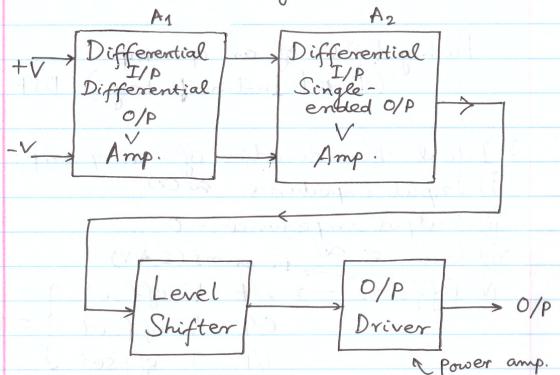
$$\therefore V_{SD} > V_{SD(\text{sat})}$$

Operational Amplifier

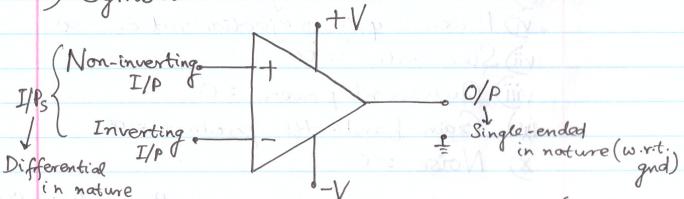
→ V-amp.
Op-Amp

A versatile and generic amplifier block/circuit for performing a variety of operations.

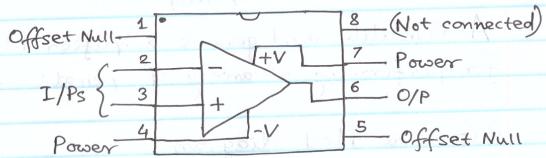
a) Generic block diagram:



b) Symbol:

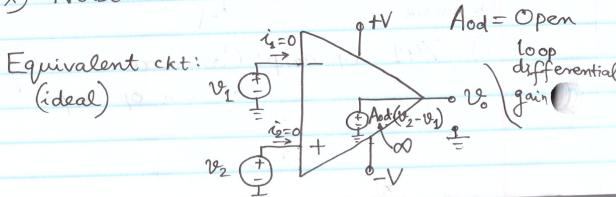


c) 741 op-amp: Commercial integrated circuit (IC) of an op-amp.



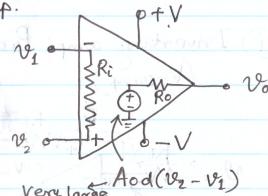
Packaged IC of an op-amp
(Dual In-line package) DIP

- d) Ideal characteristics of an op-amp:
- i) Input impedance $\approx \infty$
 - ii) Output impedance = 0
 - iii) Gain = ∞ DC errors ($I \neq V$)
 - iv) Offsets \rightarrow I/P V-offset
O/P V-offset
I/P I-offset } = 0
 - v) Common mode rejection ratio = ∞
 - vi) Power Supply rejection ratio. = ∞
 - vii) Slew rate = ∞
 - viii) Quiescent power = 0
 - ix) Gain bandwidth product = ∞
 - x) Noise = 0

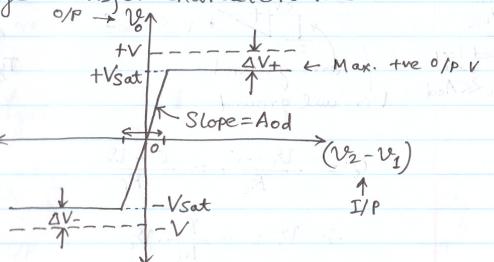


e. Practical op-amp:

Equivalent ckt
(practical)



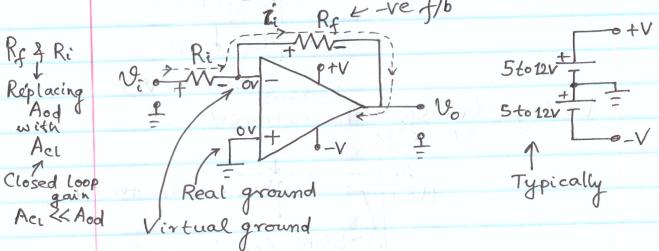
Voltage transfer characteristics:



f. Op-amp circuits:

- i) Inverting amplifier: (I/P to -ve I/P of op-amp)
- ii) Non-inverting amp.: (" " +ve " " ")
- iii) Summing amp. : V-adder with gain
- iv) Difference amp. : V-subtractor with gain
- v) Log & anti-log amp.: Calculates log/anti-log
- vi) Instrumentation amp.: Improved version of (iv)
- vii) Active rectifier : No Vf loss rectifier
- viii) Wien Bridge oscillator : Waveform generator
- ix) Integrator & differentiator: LPF & APF

i) Inverting amp: Provides 180° phase shift
(V-amp) at V_o , w.r.t. V_i



$$i_i = \frac{V_i - 0}{R_i} = \frac{0 - V_o}{R_f}$$

$$\Rightarrow V_o = - \frac{R_f}{R_i} \cdot V_i$$

$$\text{Gain (Av)} = - \frac{R_f}{R_i} \quad (\text{or } A_{cl})$$

$$\text{I/P resistance (R}_i\text{)} = \frac{V_i}{i_i} = R_i$$

Note: No coupling capacitor is used \Rightarrow DC & AC
V-amp.

ii) Non-inverting amp: 0° phase shift.

