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

Sol^n. Mode/region of operation:
$v_{DS} = 4.5 > V_{DS(sat.)} = V_{GS} - V_{Tn} = 3-1 = 2V$
↳ Saturation region of oper^n.

$I_{D_{Sat.}} = K_n.(V_{GS}-V_{Tn})^2$
$\Rightarrow 0.8m = K_n (3-1)^2$
$\Rightarrow K_n = 0.2 \ mA/V^2$

a) $I_D = (0.2m)(2-1)^2 = 0.2mA$

$I_D = K_n[2(V_{GS}-V_{Tn})v_{DS} - v_{DS}^2]$ (Ans)

b) For non-saturation, since $v_{DS} < v_{DS(sat.)}$
$I_D = (0.2m)[2(3-1)(1) - 1^2] = 0.6mA$ (Ans)
$[\because I_{D_{non\text{-}sat}} = K_n[2(V_{GS}-V_{Tn})v_{DS} - v_{DS}^2]]$

2. NMOS (or n-ch. MOSFET) 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.

Sol^n. a) $\lambda = 0$: $v_{DS_{sat.}} = v_{GS} - V_{Tn} = 2.5 - 0.8 = 1.7V$
For, $v_{DS} = 2V$ (saturation $\Rightarrow v_{DS} > v_{DS_{sat.}}$)
$I_D = K_n(V_{GS} - V_{Tn})^2$
$= (0.1m)(2.5-0.8)^2 = 0.289mA$ (Ans)
$r_o = \dfrac{1}{\lambda.I_D} = \dfrac{1}{0\cdot(0.289m)} = \infty$ (Ans)

b) $\lambda = 0.02 \ V^{-1}$
$I_D = K_n(V_{GS} - V_{Tn})^2(1+\lambda.V_{DS})$ [Sat. reg.]
For $v_{DS} = 2V$
$I_D = (0.1m)(2.5-0.8)^2(1+(0.02)(2)) = 0.300mA$ (Ans)

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

$$I_D = (0.1m)\left[(2.5-0.8)^2\left(1+(0.02)(10)\right)\right]$$

$$= 0.347 \text{ mA} \quad \text{(Ans)}$$

$$r_o = \frac{1}{\lambda . I_D} = \frac{1}{(0.02)\underbrace{(0.1m)}_{k_n}(2.5-0.8)^2} = 173 \text{ k}\Omega \quad \text{(Ans)}$$

3. PMOS e-mode MOSFET:

$V_{Tp} = -1.2V$, $v_{SG} = 2V$, $W = 40\mu m$, $L = 2\mu m$,

$t_{ox} = 350$ Å, $\mu_p = 300 \text{ cm}^2/V\text{-}s$.

Find K_p.

Solⁿ. $K_p = \frac{W}{L} \cdot \mu_p \cdot C_{ox} \cdot \frac{1}{2}$ $\qquad \underbrace{\epsilon_{SiO_2}}_{\text{Gate insulator material}} = 3.9$

$$C_{ox} = \frac{\epsilon}{t_{ox}} = \frac{(\epsilon)(8.85 \times 10^{-14})}{t_{ox}}$$

Per unit area

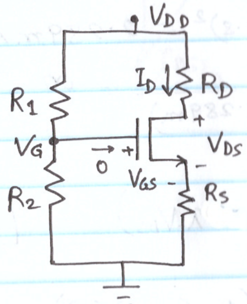
(Area is missing from: $C = \frac{\epsilon A}{d}$)

$$= \frac{(3.9)(8.854 \times 10^{-14})}{350 \times 10^{-8}}$$ ← Convert into 'cm'.

$= 98.61$ nF per unit area

$$\therefore K_p = \frac{40\mu}{2\mu}(300)(98.61 n)\cdot\frac{1}{2} = 296 \ \mu A/V^2 \quad \text{(Ans)}$$

4.



$V_{Tn} = +2V$, $K_n = 0.25 mA/V^2$,

$V_{DD} = 10V$, $R_1 = 280k\Omega$,

$R_2 = 160k\Omega$, $R_D = 10k\Omega$, $R_S = 0$.

Find: I_D, V_{DS} & P_T

Solⁿ. $V_G = \frac{R_2}{R_1+R_2} \cdot V_{DD} = \frac{160k}{280k+160k} \cdot 10 = 3.636V = V_{GS}$.

$$V_{D(sat.)} = \overset{= V_G\ (\because R_S = 0)}{V_{GS}} - V_{Tn} = 3.636V - 2 = 1.636V$$

MOSFET in saturation.

$$\therefore I_D = K_n(V_{GS}-V_{Tn})^2 = (0.25m)[3.636-2]^2$$

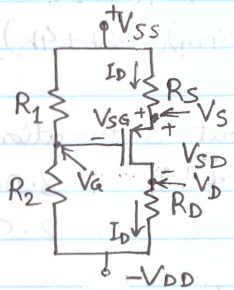
$$= 0.669 mA \quad \text{(Ans)}$$

By KVL,

$$\therefore V_{DS} = V_{DD} - I_D . R_D = 10 - [(0.669m) \cdot 10k] = 3.31V \quad \text{(Ans)}$$

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

5.



$V_{Tp} = -1V$, $K_p = 0.25 mA/V^2$

Find: V_{SG}, I_D & V_{SD}.

$R_1 = 150k\Omega$, $R_2 = 200k\Omega$,

$R_S = 1.2k\Omega$, $R_D = 4k\Omega$.

$V_{DD} = -5V$, $V_{SS} = +5V$

Solⁿ.

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

$$= 0.714V$$

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

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

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

[$\because$ PMOS in saturation]

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

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

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

By solving the quadratic equation,

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

$$= +3.04V$$ (Considering the +ve answer only).

(Ans)

Now, $I_D = (0.25m)\left[3.04+1\right]^2$

$= 1.04\ mA$ (Ans)

Also, $V_{SD} = (V_{SS} - V_{DD}) - I_D(R_S + R_D)$

$= 10 - \left[(1.04m)(1.2k+4k)\right]$

$= 4.59V$ (Ans)

For confirmation about saturation mode,

$V_{SD(sat.)} = V_{SG} - V_{TP} = 3.04 + 1$

$= 2.04V$

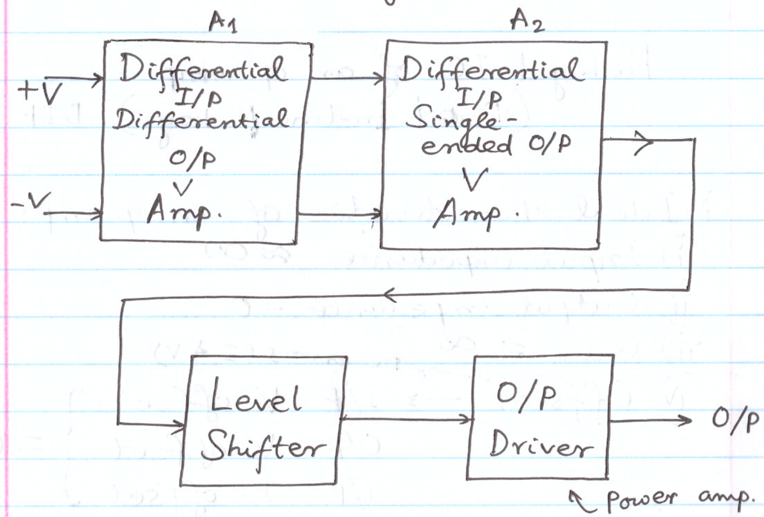
$\therefore V_{SD} > V_{SD(sat)}$

Operational Amplifier → V- amp.

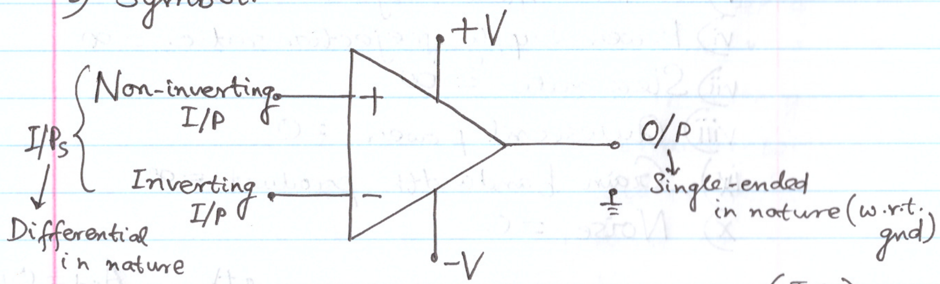
Op-Amp

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

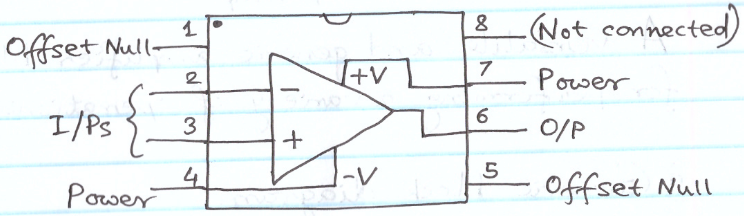
a) Generic block diagram:



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 $= \infty$

iv) Offsets $\rightarrow$ DC errors (I & V)
- I/P V-offset
- O/P V-offset
- I/P I-offset

$\} = 0$

v) Common mode rejection ratio $= \infty$

vi) Power Supply rejection ratio. $= \infty$

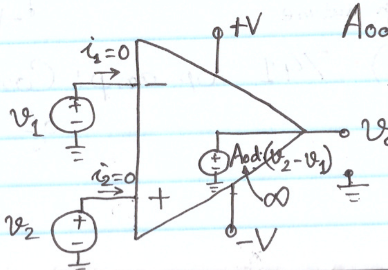
vii) Slew rate $= \infty$

viii) Quiescent power $= 0$

ix) Gain bandwidth product $= \infty$

x) Noise $= 0$

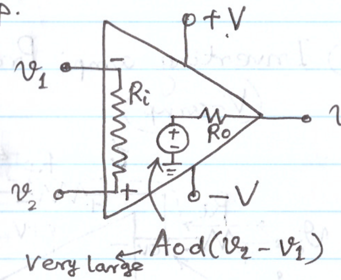
Equivalent ckt: (ideal)



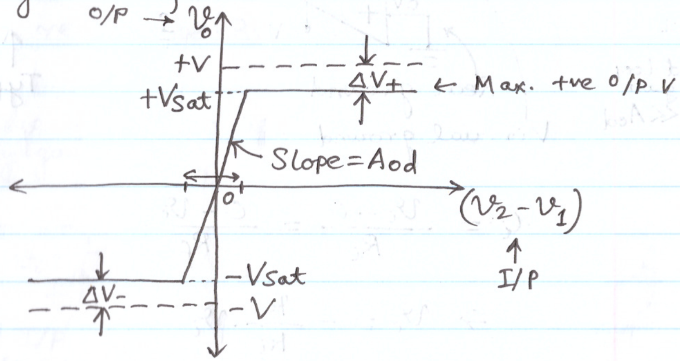
A_{od} = Open loop differential gain

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) V-amp

ii) Non-inverting amp.: (" +ve " " ") V-amp

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)

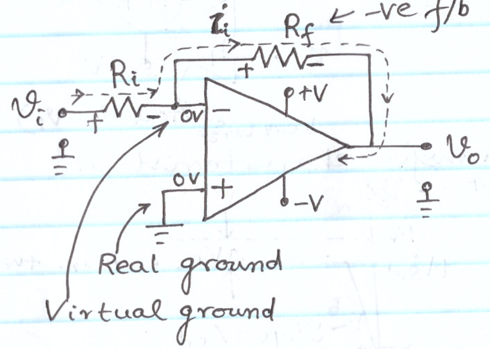
vii) Active rectifier : No V_γ loss rectifier

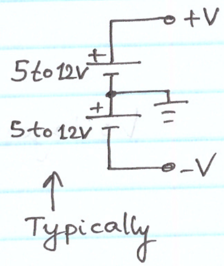
viii) Wein Bridge oscillator: Waveform generator

ix) Integrator & differentiator: LPF & HPF

i) Inverting amp : Provides $180°$ phase shift at v_o, w.r.t. v_i
(V-amp)

R_f & R_i
↓
Replacing A_{od} with A_{cl}
↑
Closed loop gain
$A_{cl} \ll A_{od}$





$$i_i = \frac{v_i - 0}{R_i} = \frac{0 - v_o}{R_f}$$

$$\Rightarrow v_o = -\frac{R_f}{R_i} \cdot v_i$$

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

↑ 180° phase shift

$$\text{I/P resistance } (R_I) = \frac{v_i}{i_i} = R_i$$

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

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