Types of Amplifier (MOSFET Based)

1. Common Source
2. Common Gate
3. Common Drain or Source Follower.

Loads in Amplifier

i. Diode Connected (Active Load)
ii. Current Source Load
iii. Linear Loads
Common Source Amplifier with Source Degeneration

We know \( V_{\text{Gain}} = g_{m} \cdot I_{\text{out}} \)

Also \( g_{\text{meff}} = \left. \frac{I_{\text{out}}}{V_{\text{in}}} \right|_{V_{0}=0} = \left. \frac{\partial I_{\text{out}}}{\partial V_{\text{in}}} \right|_{V_{0}=0} \)
Then 2. ckt is

Now \( V_{in} = V_i + I_{out} \cdot R_s \) \text{ And } \( V_x = I_{out} \cdot R_s \)

\[ I_{out} = g_m (V_{in} - I_{out} \cdot R_s) + g_{mb} (-I_{out} \cdot R_s) + \frac{(0 - I_{out} \cdot R_s)}{\gamma_0} \]

\[ g_{m eff} = \frac{I_{out}}{V_{in}} = \frac{g_m \cdot \gamma_0}{R_s + [1 + (g_m + g_{mb})R_s] \gamma_0} \]
(ii) \( \text{Rout} \) \n\[ V_{in} = 0 \] & we have \( V_{out}, I_{out} \) at output.

\[
\begin{align*}
+ V_1 & \quad \rightarrow \quad G_m V_1 \quad \rightarrow \quad G_{mb} V_{as} \\
\downarrow & \quad \rightarrow \quad V_x \quad \rightarrow \quad I_{out} \quad \rightarrow \quad R_0 \\
& \quad \rightarrow \quad R_0 \quad \rightarrow \quad R_D \quad \rightarrow \quad R_{out}
\end{align*}
\]

Now \[ V_1 = -I_{out} \cdot R_s \]
\[ V_x = I_{out} \cdot R_s \]

\[ \therefore I_{out} = -G_m I_{out} R_s - G_{mb} I_{out} R_s \]
\[ + \quad V_{out} - V_x \quad \frac{\text{R}}{R_0} \]
\[ I_{\text{out}} \left[ 1 + \left( g_m + g_{mb} \right) R_s + \frac{R_s}{\gamma_0} \right] = \frac{V_{\text{out}}}{\gamma_0} \]

\[ \therefore R_0 = \frac{V_{\text{out}}}{I_{\text{out}}} = \gamma_0 \left[ 1 + \left( g_m + g_{mb} \right) R_s + \frac{R_s}{\gamma_0} \right] \]

\[ \therefore \text{R}_{\text{out}} = \text{R}_{\text{oll}} \text{R}_D \]

As \( R_0 \) is quite large, \( - \left( g_m + g_{mb} \right) R_s \gamma_0 \)

\[ \therefore \text{R}_{\text{out}} = \text{R}_D \]

\[ \therefore \text{Voltage Gain} = - g_{\text{m eff}} \cdot \text{R}_{\text{out}} \]

\[ = - g_{\text{m eff}} \cdot R_0 = \frac{- g_m \gamma_0 \text{R}_D}{R_s + \left[ 1 + \left( g_m + g_{mb} \right) R_s \right] \gamma_0} \]

\[ = - \frac{\text{R}_D}{R_s} \]
Common Gate Stage Amplifier

\[ C_{gd} = C_{gd} + C_{du} \]

\[ R_D \quad V_0 \]

\[ \text{Eq. Ckt} \]

\[ (g_m + g_{mb}) V_{in} \]

\[ C_{gs} C_{sb} = C'_{gs} \]

At low frequency it can be like

\[ V_{sb} = \ast V_1 \]
We have \( I_x = \frac{V_0}{R_D} \) \( \rightarrow \) (1)

Further \( 0 = V_{in} - I_x R_S + V_1 \) \( \rightarrow \) (2)

or \( V_1 + V_{in} - \frac{V_0}{R_D} R_S = 0 \) \( \rightarrow \) (2)

The \( V_0 = i_{x0} \cdot \gamma_0 - V_1 \) \( \rightarrow \) (3)

where \( i_{x0} = I_x - g_m V_1 - g_m b V_1 \) \( \rightarrow \) (4)

\[
\therefore V_0 = \left( \frac{V_0}{R_D} - g_m V_1 - g_m b V_1 \right) \gamma_0 - V_1
\]

\[
V_0 = \gamma_0 \left[ -\frac{V_0}{R_D} - (g_m + g_m b) \left( \frac{V_0 R_S}{R_D} - V_{in} \right) \right] + V_{in}
\]

\[
\therefore \frac{V_0}{V_{in}} = A_v = \frac{(g_m + g_m b) \gamma_0 + 1}{\gamma_0 + (g_m + g_m b) \gamma_0 R_S + R_S + R_D} \cdot R_D
\]
Output Impedance $R_0$ 

\[ I_x = \frac{V_x}{\gamma_0} + (\gamma_m + \gamma_{mb}) V_1 \]

But $I_x R_s = -V_1$

\[ I_x = \frac{V_x}{\gamma_0} + (\gamma_m + \gamma_{mb}) (-I_x R_s) \]

\[ I_x \left[ 1 + (\gamma_m + \gamma_{mb}) R_s \right] = \frac{V_x}{\gamma_0} \]

\[ \therefore R_0 = \frac{V_x}{I_x} = \gamma_0 \left[ 1 + (\gamma_m + \gamma_{mb}) R_s \right] \]
Then \( R_{out} = R_{oll} \times R_{D} \)

Since \( R_{o} \approx (g_{m} + g_{mb}) R_{s} \), it's quite large

\[ R_{o} \gg R_{D} \]

Then \( R_{out} = R_{D} \)

However, if \( R_{o} < R_{D} \) (current source load)

Then \( R_{out} = R_{o} \)

**Input Resistance/Impedance**

Take \( V_{o} = 0 \), \( V_{x} = -V_{1} \)

\[
Y_{in} = \frac{I_{x}}{V_{x}} = \frac{-g_{m} V_{x} + g_{mb} V_{x}}{-V_{x}}
\]

\[
= \frac{g_{m} + g_{mb} + \frac{1}{R_{o}}}{(g_{m} + g_{mb}) R_{o} + 1} / R_{o}
\]

As \( g_{m} R_{o} \gg 1 \), \( Y_{in} \) is quite low
Current Gain = \( A_i = \frac{I_o}{I_{in}} = \frac{I_x}{I_x} = 1 \)

At Low Frequency \( A_i = 1 \) but will be function frequency through RC effect at higher frequency.

In CA Amplifier \( R_{in} \) is low but \( R_{out} \) is quite high.

Or to say we can convert a normal current source into Great Current Source, which can be Voltage Controlled.
Common Drain Amplifier (Source Follower)

For $V_{in} > V_{TH}$

When Transistor is 'ON'

$V_o$ follows $V_{in}$ and hence the Circuit is called Source Follower

For ac circuit Drain is grounded and hence the name Common Drain.

Equivalent Ckt
Low Frequency Circuit is:

\[ V_{in} \rightarrow G \rightarrow V_1 \]

\[ R_s \downarrow V_o \]

\[ V_{SB} = -V_o \]

\[ \frac{V_o}{R_s} = G_m V_1 + G_{mb} V_{SB} = G_m V_1 - G_{mb} V_o \]

\[ \Rightarrow V_o \left( \frac{1}{R_s} + G_{mb} \right) = G_m V_1 \quad - (1) \]

Input Side \[ V_{in} = V_o + V_1 \]

\[ \Rightarrow V_1 = -V_o + V_{in} \quad - (2) \]
Substituting (2) in (1)

\[ v_o \left( \frac{1}{R_s} + g_m b \right) = -g_m v_o + g_m v_{in} \]

or \[ v_o \left[ \frac{1}{R_s} + g_m + g_m b \right] = g_m v_{in} \]

or \[ v_o \left[ 1 + (g_m + g_m b)R_s \right] = g_m R_s \cdot v_{in} \]

or \[ A_v = \frac{v_o}{v_{in}} = \frac{g_m R_s}{1 + (g_m R_s + g_m b R_s)} \]

(\(< 1\) )

In Phase output.
Input Impedance is only due to capacitance at the input side and hence very large as input capacitance $\leq C_{gd} + C_{db} + C_{gs}$.

Output Impedance

$$R_O = \frac{V_x}{I_x}$$

As $V_I = -V_x$,

$V_{SB} = -V_x$

$$I_x = g_m V_x + g_{mb} V_x$$

$$\therefore R_O = \frac{V_x}{I_x} = \frac{1}{g_m + g_{mb}}$$
Where one uses Source Followers

1. Buffer: High input impedance, low output impedance

Problems for Designer:

(i) $V_T$ is now function of $V_0$ through Body Bias.

(ii) Which leads to changes in $I_{DS}$ and $V_{OV}$ with $V_0$

If (iii) $R_s$ is low then effect of (ii) is even worse.
(iv) Input & Output Swings are lowered.

If $V_{DD} = 1.2\, V$, $V_T = 0.4\, V$, and $V_{OV} = 0.2\, V$

Then $V_h = 0.4 + 0.2 \, V = 0.6\, V$ which is
Half of $V_{DD}$.

Thus for low power, low voltage application
Source Follower is not good as it reduces 'Swings'.

(v) Small Swing applications such as LNA and Pre-Amplifier in Signal Processing System, one uses CD Amplifier
Uses of ED Amplifiers (Cont.)

2. As Level Shifter
   Output Q-Point is lower than
   Input Q-Point

3. As Load devices in Common Source Amplifier

\[ V_{in} \rightarrow V_{o} \]
\[ Q \text{ Point shift: } V_{in} + V_{T} = V_{gs} \]

Q Point of output is \( (V_{out} + V_{T}) \)
lower than Q Point at Input

Load
\[ V_{o} \]

Saturated \& Load acts as Current Source