why Nmos is Preferred over pmos?

Maj carrier - Nmos ($\bar{e}$), Pmos (h)

→ Mobility $\simeq 2.5\,\mu_p$

Si → μ_n 1400 $cm^2/v\text{-}sec$

μ_p → 450 $cm^2/v\text{-}sec$

Ge: μ_n → 3900 $cm^2/v\text{-}sec$

μ_p → 1900 $cm^2/v\text{-}sec$

→ If mob more then Conductivity more

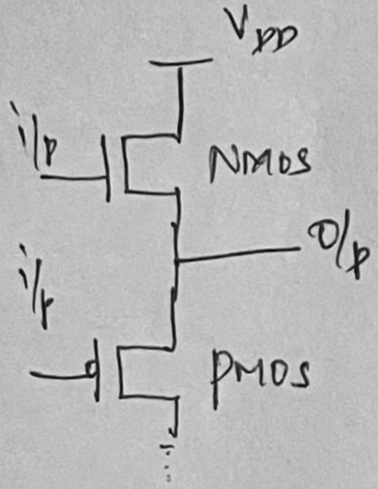
→ Nmos fast

→ " Small in size

→ As size is less the packing density is more

} features

→ Speed



2nd term → time varying drain current component that is linearly related to v_{gs}.

3rd term → proportional to the square of signal voltage.

For sine i/p, This squared term produces undesirable harmonics, or non linear distortion i the o/p voltage.

To minimise the harmonics, we require

$v_{gs} << 2(V_{GSQ} - V_{TN}) \rightarrow (4)$

Eqn (4) <u>represents the small signal condition that must be satisfied by all linear amplifiers.</u>

Neglecting v_{gs}^2 term,

$i_D = I_{DQ} + i_d$

linearity → total current can be seperated into a dc & ac component. The ac component of drain current is given by

$i_d = 2K_n(V_{GSQ} - V_{TN})\, v_{gs}$

$\frac{i_d}{v_{gs}} = \boxed{g_m = 2k_n(V_{GS} - V_{TN})} \rightarrow (5)$

g_m - transconductance is a transfer coefficient relating output current to input voltage and can be thought of as the gain of the transistor

$g_m = \frac{\partial I_D}{V_{GS}} \Big|_{V_{GS} = V_{GSQ} = \text{constant}} = 2k_n(V_{GS} - V_{TN})$

2nd term → time varying drain current component that is linearly related to v_{gs}.

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$$g_m = \frac{\partial I_D}{V_{gs}}\Bigg|_{v_{gs} = V_{gsQ} = \text{constant}} = 2k_n(V_{GS}$$

From ② $i_D = k_n (v_{gs} - V_{TN})^2$

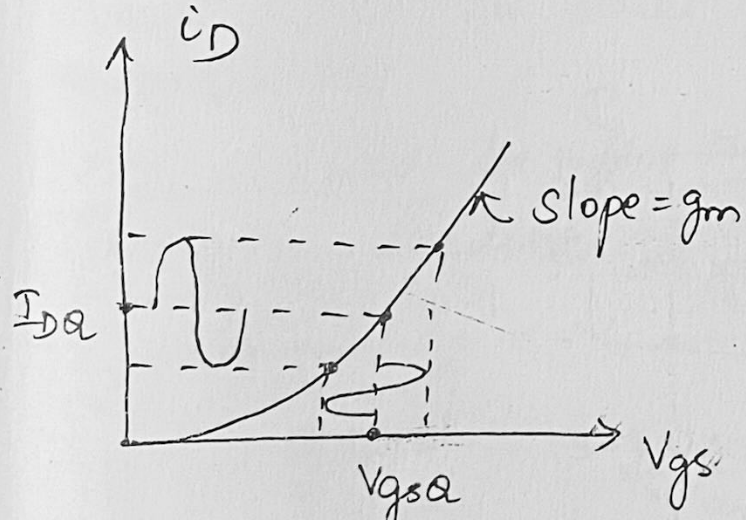
$$i_{DQ} = k_n (v_{gsQ} - V_{TN})^2$$

$$\therefore v_{gsQ} - V_{TN} = \sqrt{\frac{i_{DQ}}{k_n}}$$

Sub in ⑤

$$g_m = 2k_n \sqrt{\frac{i_{DQ}}{k_n}} = 2\sqrt{k_n I_{DQ}}$$

$$\boxed{g_m = 2\sqrt{k_n I_{DQ}}}$$



If v_{gs} is small, g_m is constant. With Q point in the saturation region, the transistor operates as current source that is linearly controlled by v_{gs}.

$\boxed{g_m \propto k_n}$ (function of width to length ratio)

When the width of the transistor increases the gain increases.

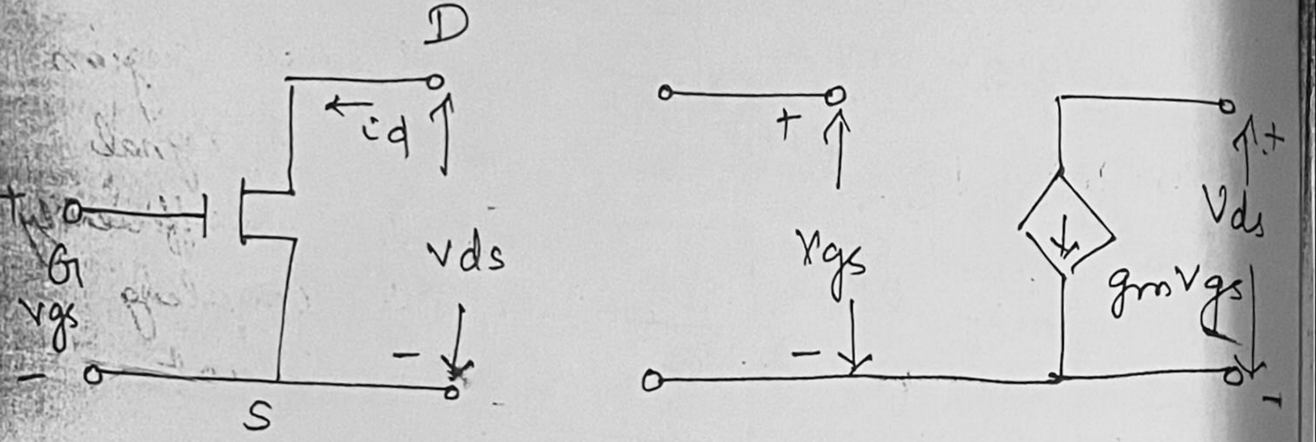
Small signal equivalent circuit :-

$$V_{DS} = V_{DD} - i_D R_D$$

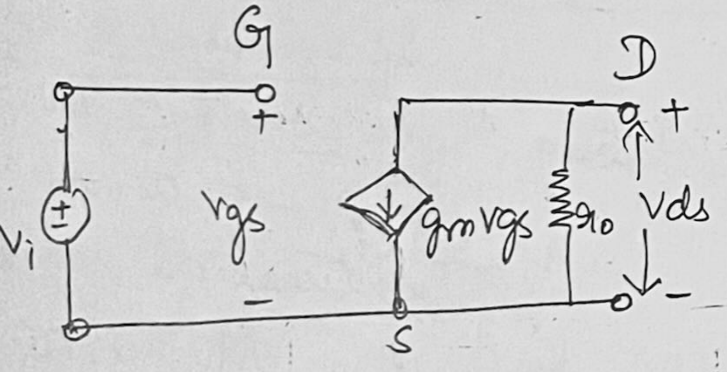
$$V_o = v_{ds} = -i_D R_D$$

$i_d = g_m v_{gs}$

$v_{gs} = v_i$



Expanded small signal equivalent circuit



N-channel MOSFET.

AC Analysis of Basic MOSFET Amplifier configu[ration] using classical discrete circuit bias arrangem[ent]

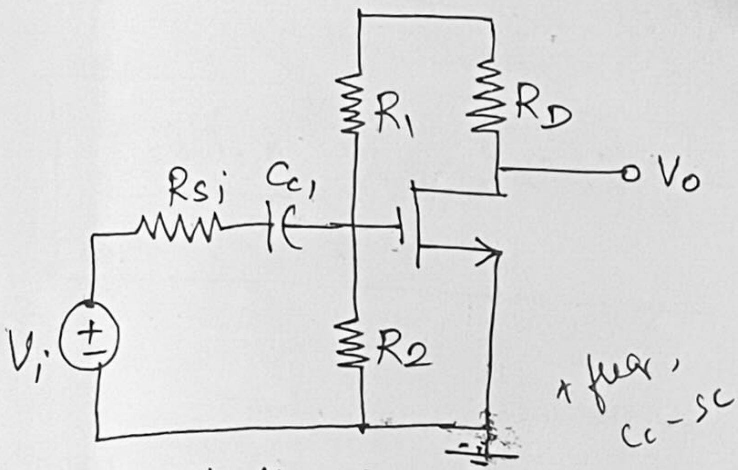
MOSFET is a 3 terminal device. It has the following configuration:

→ Common Source

→ Common Drain

→ Common Gate.

The Common Source Amplifier

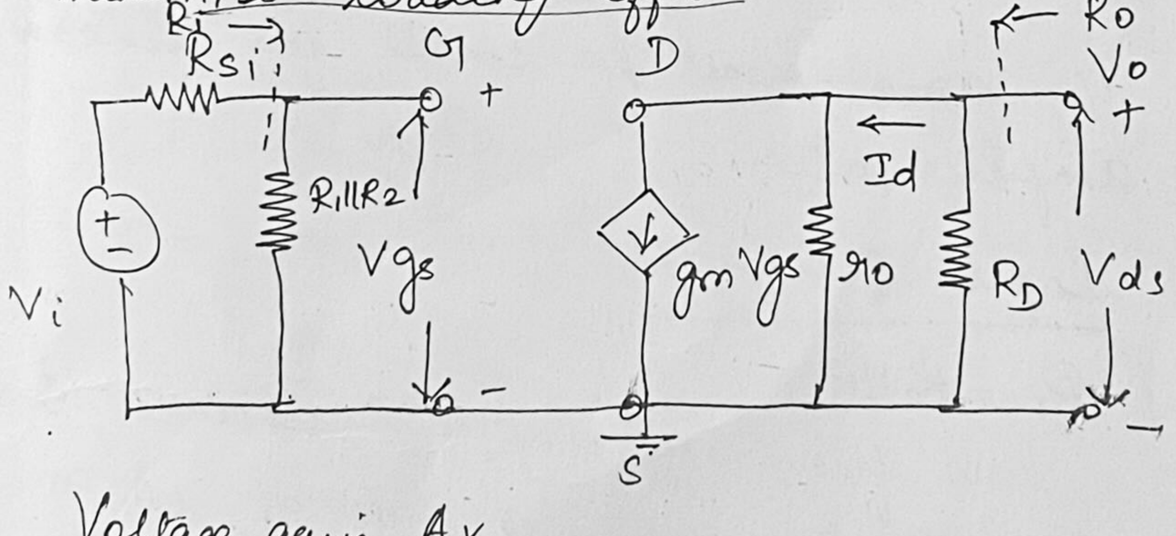


* Assume that the transistor is biased in saturation region by R_1 & R_2 & signal frequency is sufficiently large for coupling capacitor to act essentially as a short circuit.

* freq, Cc - SC

* The signal source is represented by Thevenin's equivalent circuit, in which the signal voltage source V_i is in series with an equivalent resistor R_{si}.

R_{si} should be less than $R_i = R_1 \| R_2$ to minimise loading effect.



Voltage gain Av

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs} \times (r_o \| R_D)$$

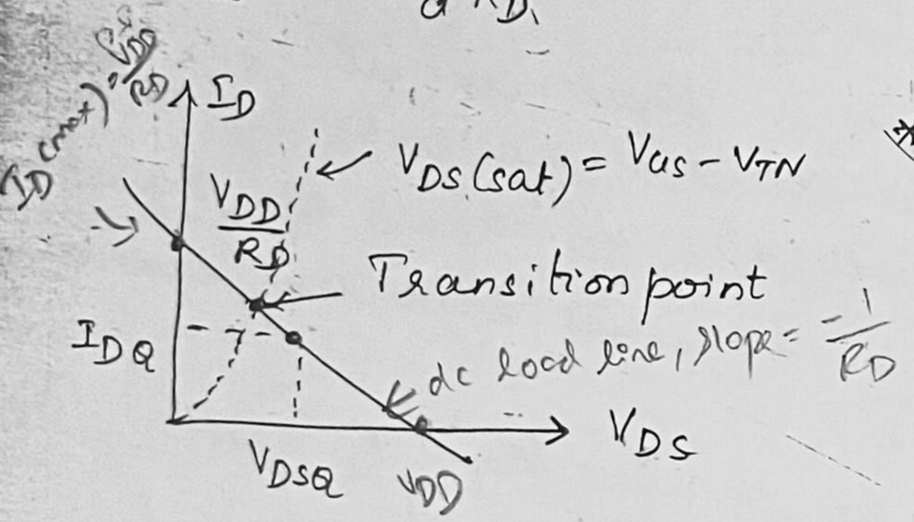
$$V_{gs} = \frac{V_i \times R_1 \| R_2}{R_{si} + R_1 \| R_2}.$$

Sub in v_o

$$\therefore V_o = -g_m (r_o \| R_D) \frac{V_i \times (R_1 \| R_2)}{R_1 \| R_2 + R_{Si}}$$

$$\boxed{A_v = \frac{V_o}{V_i} = -g_m (r_o \| R_D) \frac{(R_1 \| R_2)}{R_1 \| R_2 + R_{Si}}}$$

$V_{ds} = -I_d R_D$



* transistor should be biased in saturation & Q-point must be near the middle of the saturation region.

* i/p signal must be small for linear amplification.

Input resistance

$R_i = R_1 \| R_2$

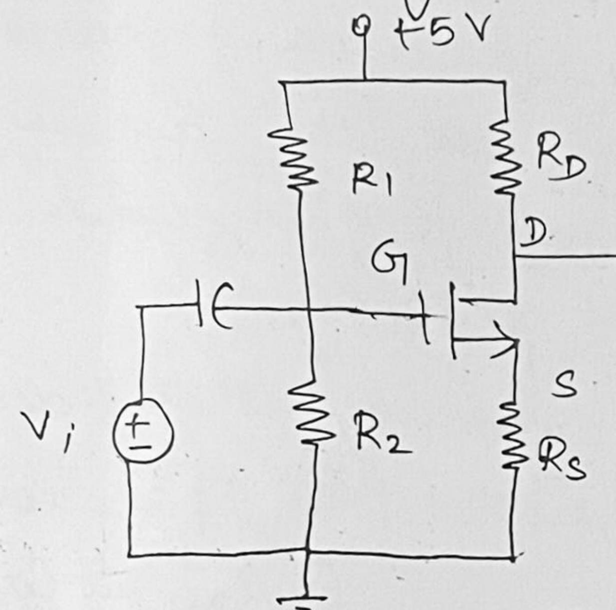
low frequency input resistance looking into the gate of MOSFET is ∞.

Output Resistance :- is found by setting $v_i \Rightarrow v_{gs} = 0$

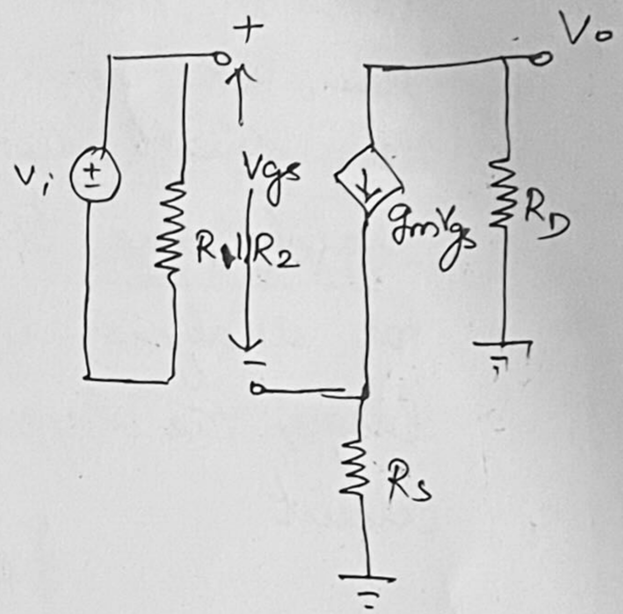
$\therefore R_o = R_D \| r_o$.

Common Source Amplifier with Source Resistor

R_S tends to stabilise the Q-point against variations in transistor parameters. But it reduces the gain.



Equivalent Circuit



$r_o \simeq (\lambda I_{DQ})^{-1} = \infty$

Voltage Gain Av

$$A_V = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs} R_D$$

$$V_i = V_{gs} + g_m V_{gs} R_S$$

$$= V_{gs}(1 + g_m R_S)$$

$$V_{gs} = \frac{V_i}{1 + g_m R_S}$$

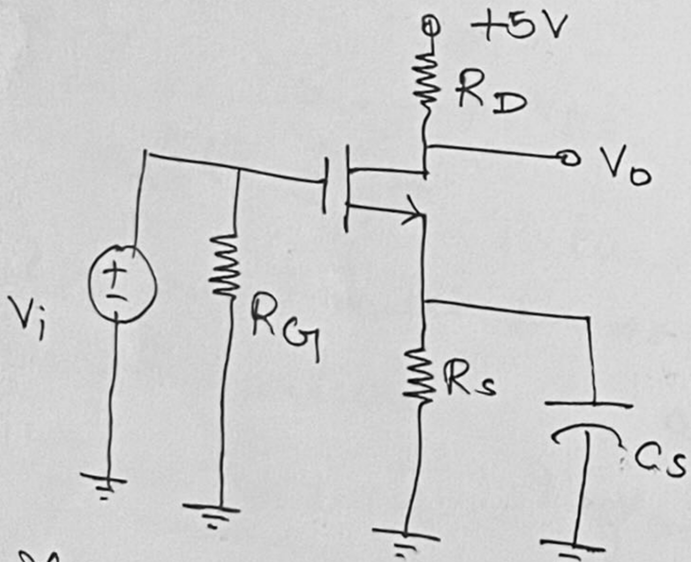
$$V_o = \frac{V_i}{1 + g_m R_S}(-g_m R_D)$$

$$\therefore A_V = \frac{V_o}{V_i} = \frac{-g_m R_D}{1 + g_m R_S}.$$

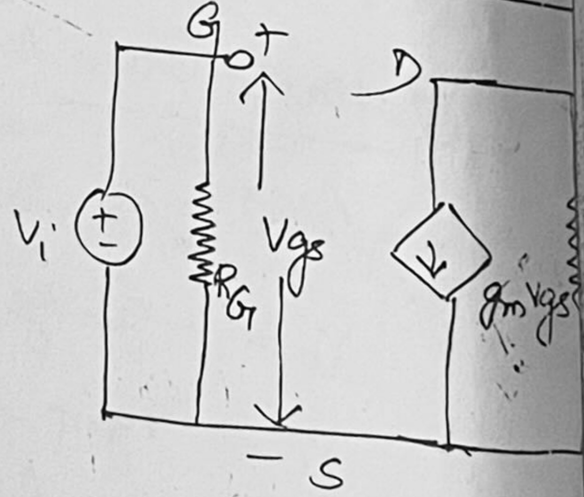
Common Source Circuit with Source Bypass Capacitor

A source capacitor added to the common source circuit with a source resistor will minimise the loss in the small signal voltage gain, while maintaining Q-point stability.

For analysis, if the frequency is sufficient large, the bypass capacitor acts as a short circuit.



Equivalent Circuit



Voltage Gain A_V

$$A_V = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs} R_D$$

$\lambda = 0$

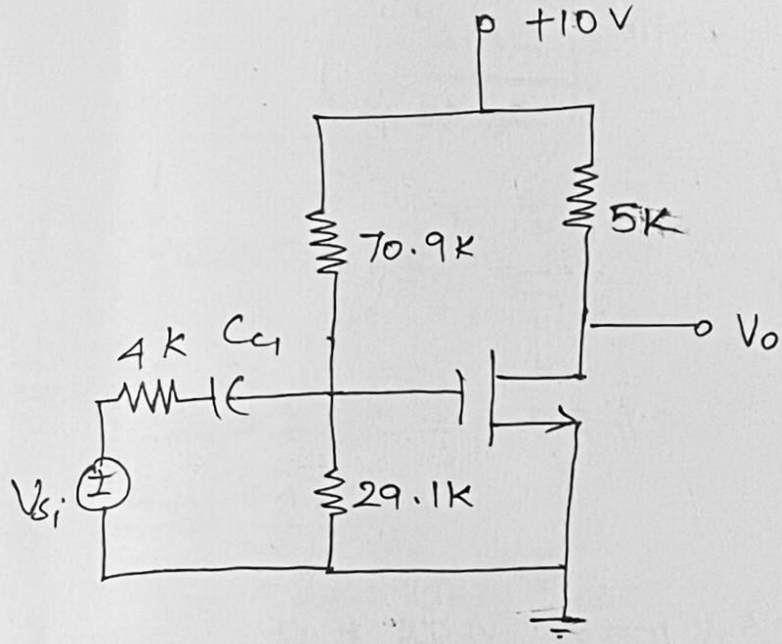
$V_i = V_{gs}$

$$\therefore A_V = \frac{V_o}{V_i} = -g_m R_D$$

$$\boxed{A_V = -g_m R_D}$$

Examples :-

① Determine the small signal voltage gain and input & output resistances of CS amplifier.



$V_{TN} = 1.5V$

$K_n = 0.5\,mA/V^2$

$\lambda = 0.01\,V^{-1}$.

Solution:-

$$A_V = -g_m(r_o \| R_D)\frac{R_i}{R_i + R_{si}}$$

$$g_m = 2K_n(V_{GSQ} - V_{TN})$$

$$r_o = [\lambda I_{DQ}]^{-1}$$

To find V_{GSQ} & I_{DQ}

$$V_{GSQ} = \left(\frac{R_2}{R_1+R_2}\right)V_{DD} = \left(\frac{29.1}{70.9+29.1}\right)(10) = 2.91$$

$$I_{DQ} = K_n(V_{GSQ} - V_{TN})^2 = (0.5)(2.91 - 1.5)^2 = 1\,mA.$$

To find g_m & r_o :

$$g_m = 2K_n(V_{GSQ} - V_{TN})$$

$$= 2(0.5)(2.91 - 1.5) = 1.41\,mA/V$$

$$r_o = [\lambda I_{DQ}]^{-1} = [(0.01)(1)]^{-1} = 100\,K\Omega$$

To calculate A_V:

$$A_V = -g_m (r_o \| R_D)\left(\frac{R_i}{R_i + R_{si}}\right).$$

$$= (-1.41)(100 \| 5)\left(\frac{20.6}{20.6+4}\right)$$

$$\boxed{A_V = -5.62}$$

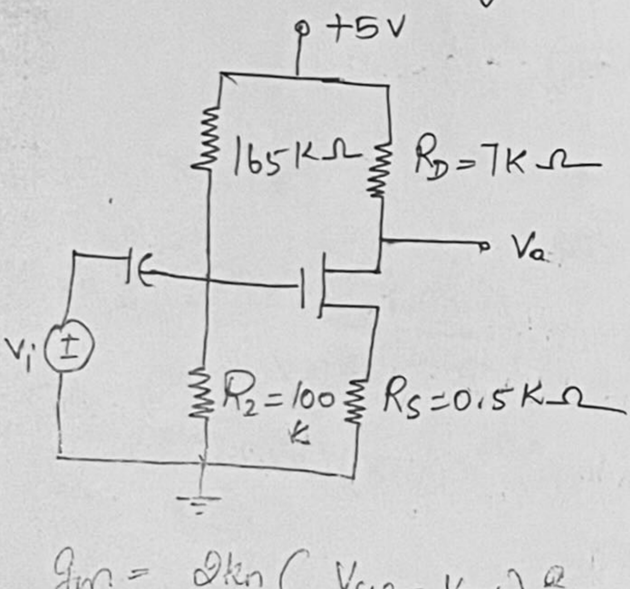
Input resistance

$R_i = R_1 \| R_2 = 70.9 \| 29.1 = 20.6\ k\Omega$

O/P resistance

$R_o = R_D \| r_o = 5 \| 100 = 4.76\ k\Omega$

(2) Determine a small signal voltage gain of a circuit containing a source resistor. (9)



$V_{TN} = 0.8V$

$K_n = 1\ mA/V^2$

$\lambda = 0$

$V_{GSQ} = 1.5V.$

$I_{DQ} = 0.5\ mA$

$V_{DSQ} = 6.25V.$

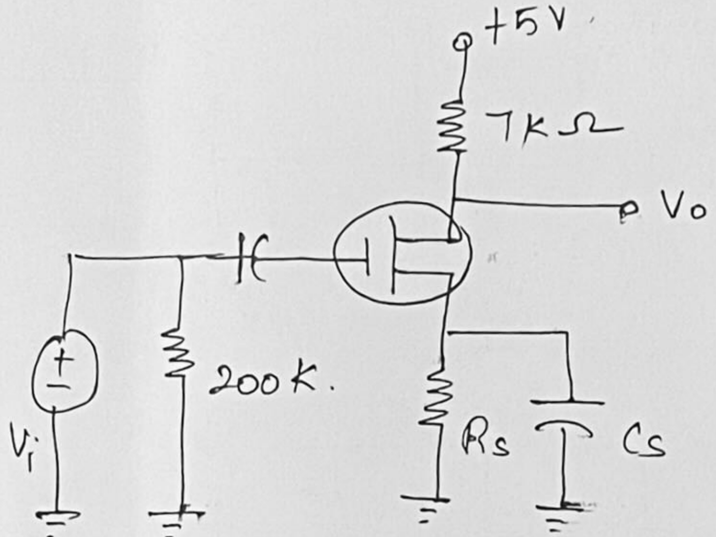
$g_m = 2k_n (V_{GS} - V_{TN})^2 = 2(1)(1.5 - 0.8) = 1.4\ mA$

$r_o = [\lambda I_{DQ}]^{-1} = \infty$

To find A_V:

$$A_V = \frac{-g_m R_D}{1 + g_m R_S} = \frac{-(1.4)(7)}{1 + (1.4)(0.5)} = -5.7$$

③ Determine the small signal voltage gain of CS circuit with source bypass capacitor.



$V_{TN} = 0.8\,V$

$K_n = 1\,mA/V^2$

$\lambda = 0.$

$I_{DQ} = 0.5\,mA$

Solution:-

$I_{DQ} = I_Q = K_n(V_{GSQ} - V_{TN})^2$

$0.5 = (1)(V_{GSQ} - 0.8)^2 = 1.51\,V$

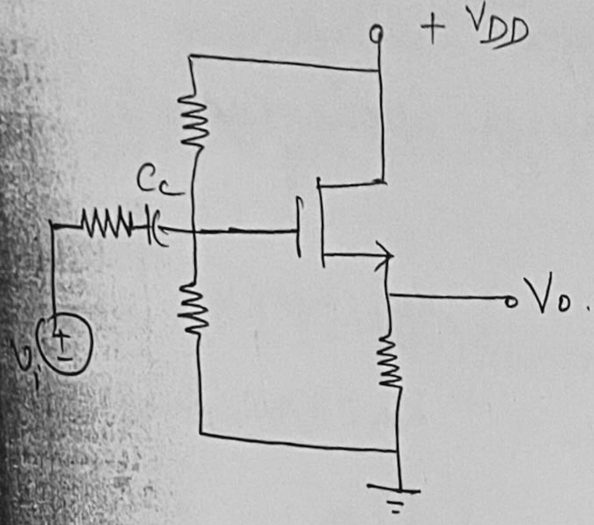
$g_m = 2K_n(V_{GS} - V_{TN}) = 1.4.$

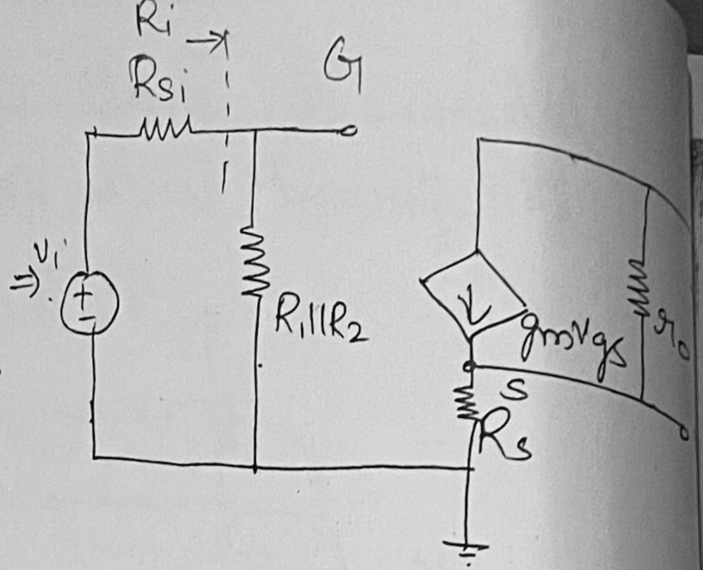
To find Av.

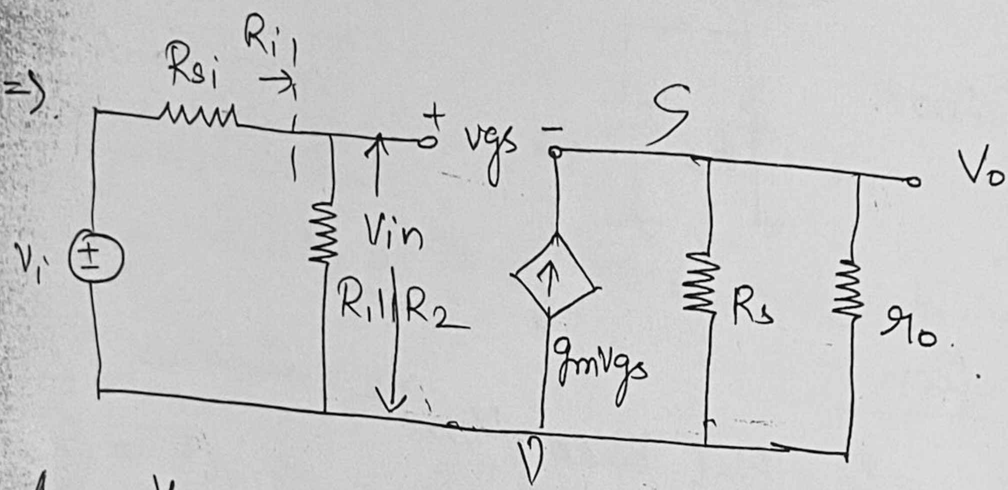
$A_V = \dfrac{V_o}{V_i} = -g_m R_D = -(1.4)(7) = -9.8$

Common Drain Circuit: The Source Follower

The output is taken off the source with respect to ground and the drain is connected to V_{DD} directly. Since V_{DD} becomes ground in ac analysis we have the name common drain. The more common name is source follower.







$$A_v = \frac{V_o}{V_i}$$

$$V_o = g_m v_{gs} (R_s \| r_o)$$

$$V_{in} = \frac{V_i \times R_1 \| R_2}{R_{si} + R_1 \| R_2} \rightarrow (1)$$

But

$$V_{in} = V_{gs} + (g_m V_{gs})(R_s \| r_o)$$

$$V_{in} = V_{gs}[1 + g_m (R_s \| r_o)]$$

$$V_{gs} = \frac{V_{in}}{1 + g_m (R_s \| r_o)}$$

$$V_o = \frac{g_m V_{in} (R_s \| r_o)}{1 + g_m (R_s \| r_o)} \rightarrow (2)$$

Substitute ① in ②

$$V_o = \frac{g_m V_i (R_1 \| R_2)(R_s \| r_o)}{(R_{si} + R_1 \| R_2)(1 + g_m (R_s \| r_o))}$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{g_m (R_s \| r_o)}{1 + g_m (R_s \| r_o)} \cdot \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2}}$$

(Or)

$$A_v = \frac{R_s \| r_o}{\frac{1}{g_m} + (R_s \| r_o)} \; \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2}.$$

* magnitude of voltage gain is always less than unity.
* O/P resistance is less than that of common Source circuit.

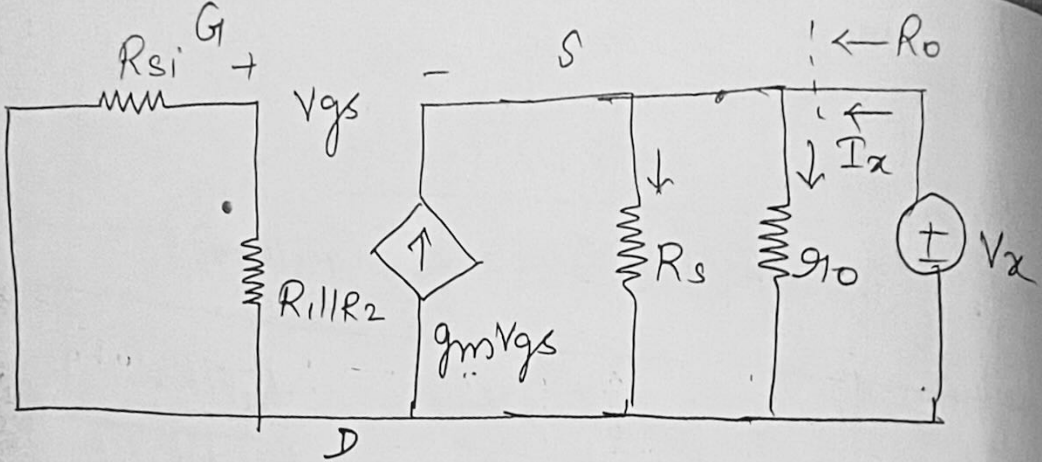
Input Impedance

$R_i = R_1 \| R_2$

Output Impedance

A small O/P resistance is desirable when the circuit is to act as ideal voltage source & drive load circuit without suffering loading effects.

To find the O/P resistance let $V_i = 0$ & test voltage is applied to the O/P.



$R_o = \frac{V_x}{I_x}$ $\qquad V_x + V_{gs} = 0$ $\qquad \therefore V_x = -V_{gs}$ or $V_{gs} = -V_x$.

Apply KCL at the o/p terminal.

$$I_x + g_m V_{gs} = \frac{V_x}{r_o} + \frac{V_x}{R_s}$$

Sub $V_{gs} = -V_x$ in the above equation

$$I_x = \frac{V_x}{r_o} + \frac{V_x}{R_s} + g_m V_x$$

$$I_x = V_x \left[\frac{1}{r_o} + \frac{1}{R_s} + g_m \right]$$

$$V_x = I_x \left(r_o \,||\, R_s \,||\, \frac{1}{g_m} \right)$$

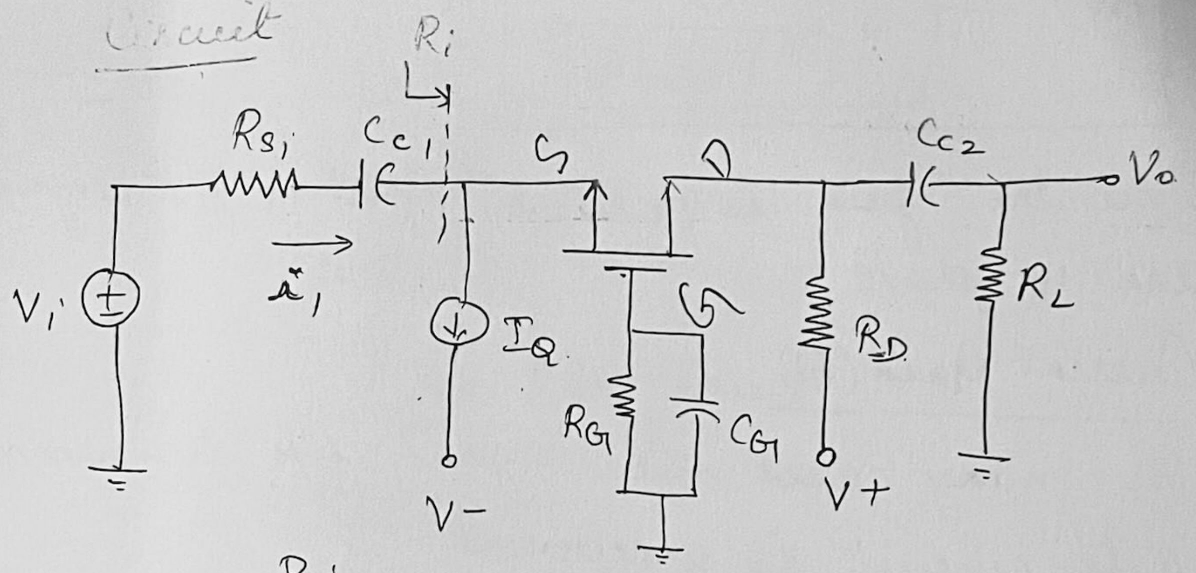
$$\boxed{R_o = \frac{V_x}{I_x} = \left(r_o \,||\, R_s \,||\, 1/g_m \right)}$$

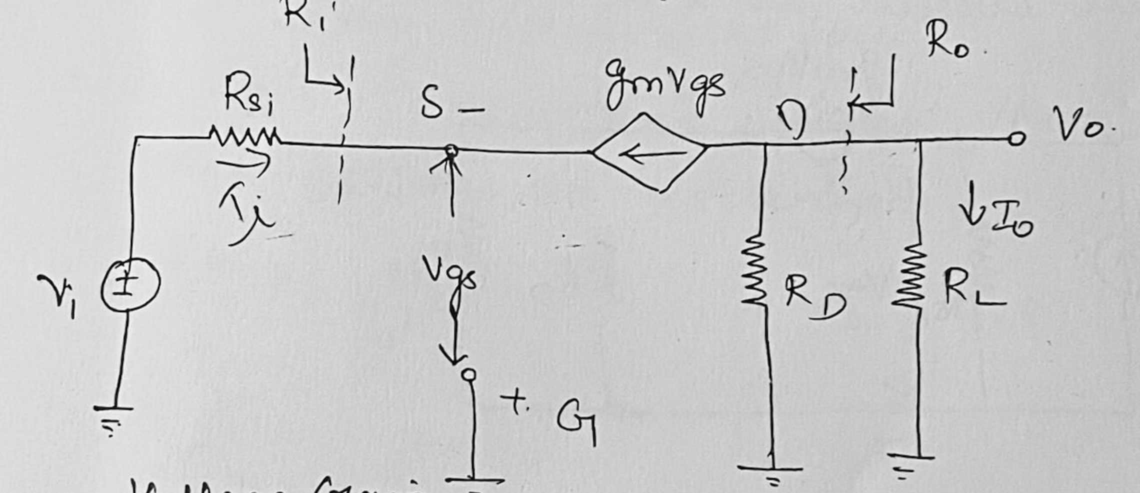
Common Gate Configuration

* The input is applied to the source terminal and gate is at signal ground.
* Biasing current I_Q.

Circuit Diagram &

Circuit





Voltage Gain:

$$A_v = \frac{V_o}{V_i} \qquad V_o = -g_m V_{gs} (R_D \| R_L)$$

$$V_i = I_i R_{si} - V_{gs}$$

$$I_i = -g_m V_{gs}$$

$$V_i = -g_m V_{gs} R_{si} - V_{gs}$$

$$V_i = -V_{gs}\left[1 + g_m R_{si}\right]$$

$$V_{gs} = \frac{-V_i}{1 + g_m R_{si}}$$

Sub in V_o:

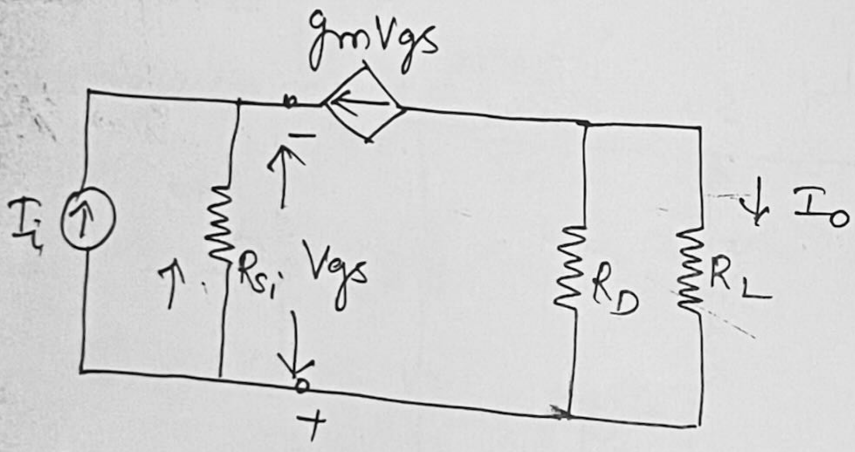
$$V_o = \frac{+g_m V_i (R_D \| R_L)}{1 + g_m R_{si}}$$

$$\boxed{A_V = \frac{V_o}{V_i} = \frac{g_m (R_D \| R_L)}{1 + g_m R_{si}}}$$

Since the gain is positive input & o/p signal are in phase.

Current Gain (A_i)

In many cases the signal i/p to common gate circuit is a current.



$$A_i = \frac{I_o}{I_i} \qquad I_o = -g_m V_{gs} \times \frac{R_D}{R_L + R_D} \quad \text{—} (1)$$

Apply KCL to the i/p :.

$$I_i + \frac{V_{gs}}{R_{si}} + g_m V_{gs} = 0$$

$$V_{gs}\left(\frac{1}{R_{si}} + g_m\right) = -I_i$$

$$V_{gs}\left(\frac{1 + g_m R_{si}}{R_{si}}\right) = -I_i \Rightarrow V_{gs} = \frac{-I_i \times R_{si}}{1 + g_m R_{si}}$$

subs in (1)

$$I_o = \frac{g_m R_D}{R_D + R_L} \cdot \frac{R_{si}}{1 + g_m R_{si}} I_i$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{g_m R_D R_{si}}{(R_D + R_L)(1 + g_m R_{si})}}$$

when $R_D >> R_L$ &

$g_m R_{si} >> 1$

$\boxed{A_i \simeq 1}$ for CG circuit.

<u>Input Impedance</u>

* The input resistance is low.
* If the i/p signal is current, then low i/p resistance has an advantage.

$$R_i = \frac{-V_{gs}}{I_i}$$

$$I_i = -g_m V_{gs}$$

$$\therefore R_i = \frac{-V_{gs}}{-g_m V_{gs}} = 1/g_m$$

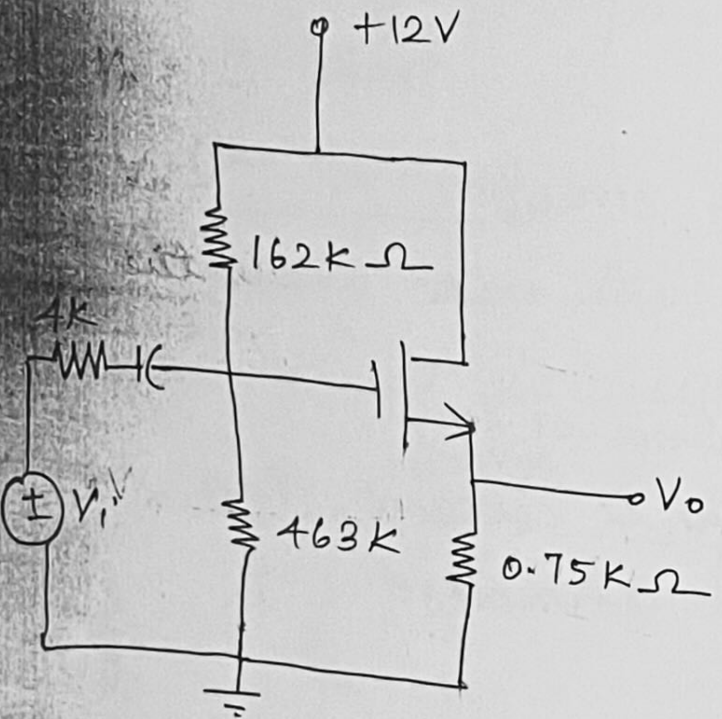
$$\boxed{R_i = 1/g_m}$$

<u>Output Resistance</u>

$R_o = R_D$.

Source Follower Amplifier

1) Calculate the small signal voltage gain, input & O/P resistance of the source follower circu[it]



$V_{TN} = 1.5V$

$K_n = 4mA/V^2$

$\lambda = 0.01V^{-1}$

Solution :-

$I_{DQ} = 7.97\ mA \qquad V_{GSQ} = 2.91V$

$g_m = 2k_n(V_{GSQ} - V_{TN}) = 2(4)(2.91 - 1.5) = 11.3\ m$

$r_o \simeq [\lambda I_{DQ}]^{-1} = [(0.01)(7.97)]^{-1} = 12.5\ k\Omega$

$R_i = R_1 \| R_2 = 162 \| 463 = 120\ k\Omega$

Voltage gain A_v

$$A_v = \frac{g_m (R_s \| r_o)}{1 + g_m (R_s \| r_o)} \cdot \frac{R_i}{R_i + R_{si}}$$

$$= \frac{(11.3)(0.75 \| 12.5)}{1 + (11.3)(0.75 \| 12.5)} \cdot \frac{120}{120 + 4} = 0.86$$

$\underline{R_i} = R_1 \| R_2 = 120\ k\Omega.$

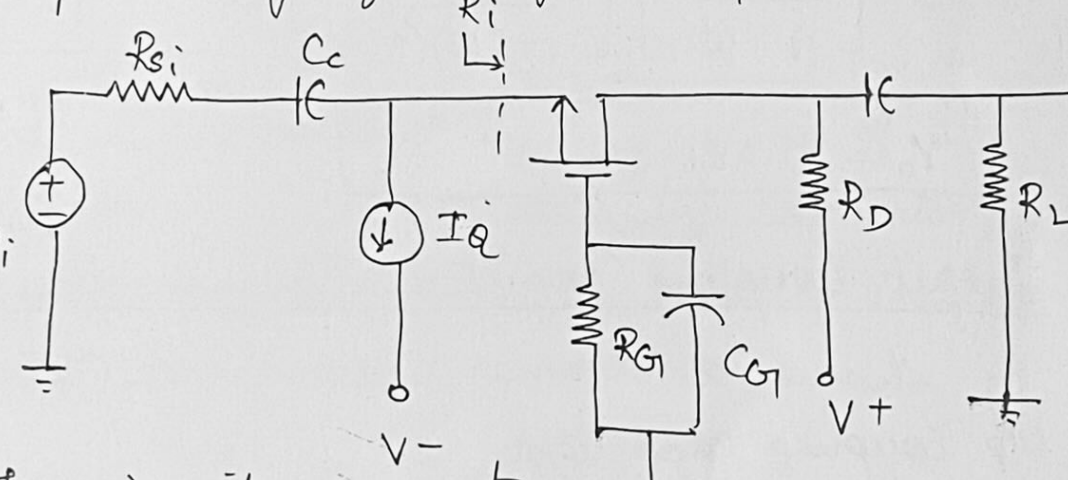
$R_{o} = \frac{1}{g_m} \| R_s \| r_o = \frac{1}{11.3} \| 0.75 \| 12.5$

$R_o = 0.0787 K\Omega = 78.7 K\Omega$

Since R_o is less, source follower acts like a voltage source.

Common Gate Amplifier

(1) For the common gate circuit, determine the output voltage for a given i/p current.



The circuit parameters are:
$I_Q = 1mA$, $V^+ = +5V$, $V^- = -5V$, $R_G = 100k\Omega$, $R_D = 4K\Omega$, $R_L = 10K\Omega$, The transistor parameters are $V_{TN} = 1V$, $k_n = 1mA/V^2$, and $\lambda = 0$. Assume the i/p current is $100 \sin \omega t$ μA & $R_{si} = 50K\Omega$.

Solution:

$$I_Q = I_{DQ} = k_n (V_{GSQ} - V_{TN})^2$$

$$1 = 1 (V_{GSQ} - 1)^2$$

$$V_{GSQ} = 2V$$

$g_m = 2K_n(V_{GSQ} - V_{TN}) = 2(1)(2-1) = 2\,mA/V$

From A_i, we can write —

$$I_o = I_i\left(\frac{R_D}{R_D+R_L}\right)\left(\frac{g_m R_{si}}{1+g_m R_{si}}\right)$$

$$V_o = I_o R_L$$

$$V_o = I_i\left(\frac{R_D}{R_D+R_L}\right)\left(\frac{g_m R_{si}}{1+g_m R_{si}}\right) \times R_L$$

$$= \left[\frac{(10)(4)}{4+10}\right]\left[\frac{(2)(50)}{1+(2)(50)}\right](0.1)\sin\omega t$$

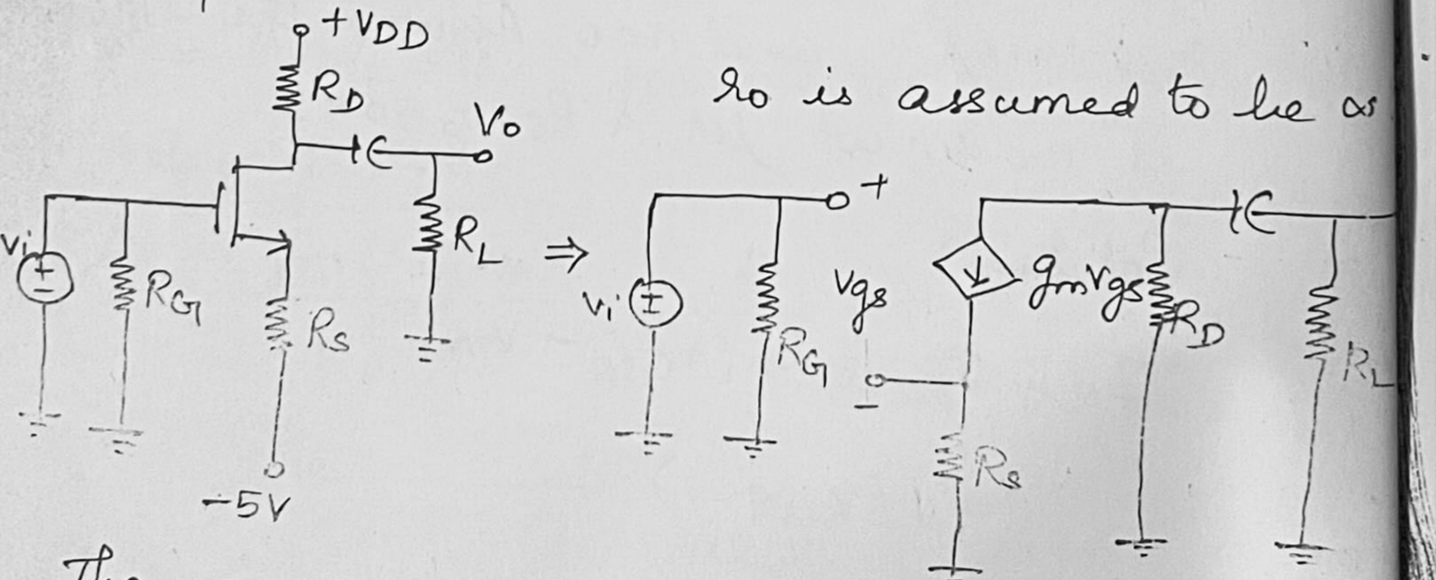
$$\boxed{V_o = 0.283 \sin\omega t \quad V}$$

Output Coupling Capacitor : Common Source Ckt

Fig shows a common source MOSFET with O/P coupling capacitor.

* $R_{si} << R_G$ ∴ R_{si} is neglected.
* O/P is connected to the load through a coupling capacitor.

r_o is assumed to be ∞



The maximum O/P voltage assuming C_c is a short circuit is,

$$|V_o|_{max} = g_m V_{gs} (R_D || R_L)$$

$$V_i = V_{gs} + g_m V_{gs} R_s$$

$$V_i = V_{gs}(1+g_m R_s) \Rightarrow V_{gs} = \frac{V_i}{1+g_m R_s}$$

$$V_o = g_m \frac{V_i}{1+g_m R_s} (R_D || R_L)$$

$$\boxed{\frac{V_o}{V_i} = A_{V max} = \frac{g_m (R_D || R_L)}{1+g_m R_s}}$$

The time constant is a function of the effective resistance seen by capacitor C_c, which is determined by setting independent sources equal to zero.

$V_i = 0$, $g_m V_{gs} = 0$ then

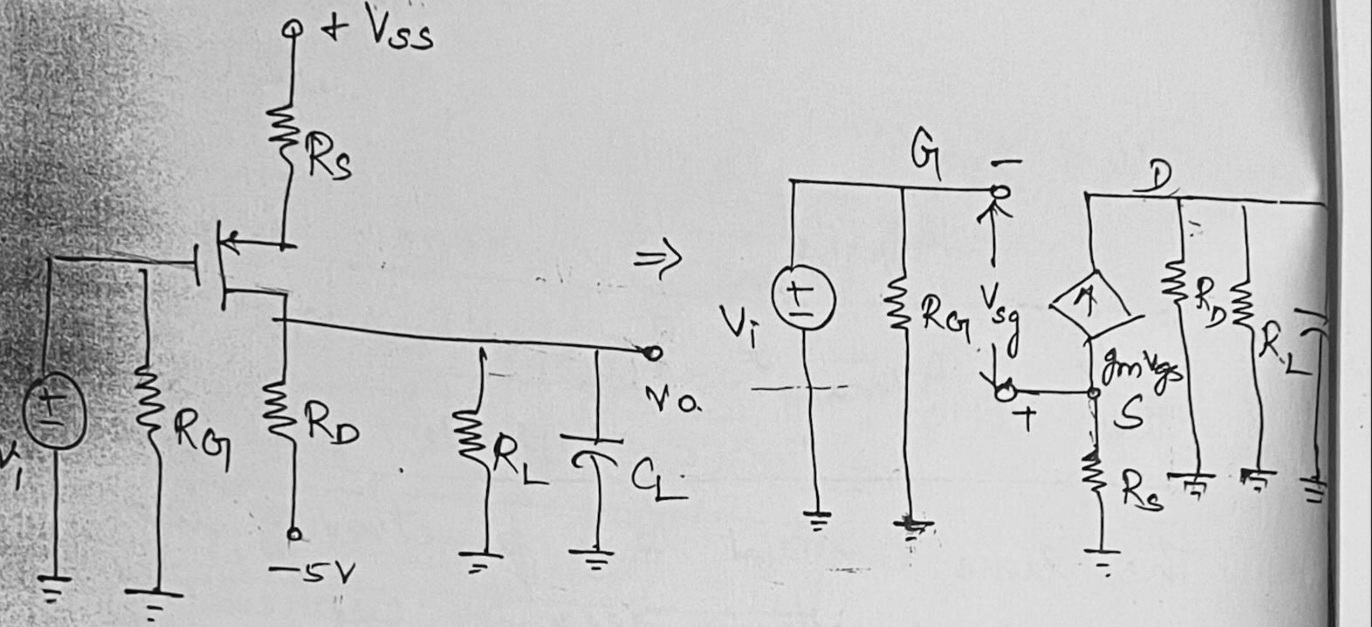
$$\tau_S = C_c (R_D + R_L)$$

$$\boxed{f_L = \frac{1}{2\pi \tau_S}}$$

Load capacitor Effects:-

* Fig shows a MOSFET Common source amplifier with a load resistor R_L & a load capacitor C_L, connected to the O/P.
* For the ac equivalent circuit r_o is assumed to be ∞.
* The circuit is like a Low pass filter.

* At high frequencies, the impedance of C_L decreases & acts as a shunt between o/p & ground., & the o/p voltage is zero.



* The equivalent resistance seen by load capacitor C_L is $(R_D \| R_L)$.

* Since we set $V_i = 0$ then $g_m V_{gs} = 0$ which means that the dependant current source does not affect the equivalent resistance.

Time constant

$$\boxed{\tau_p = (R_D \| R_L) C_L}$$

The maximum gain asymptote with C_L is open circuit, is

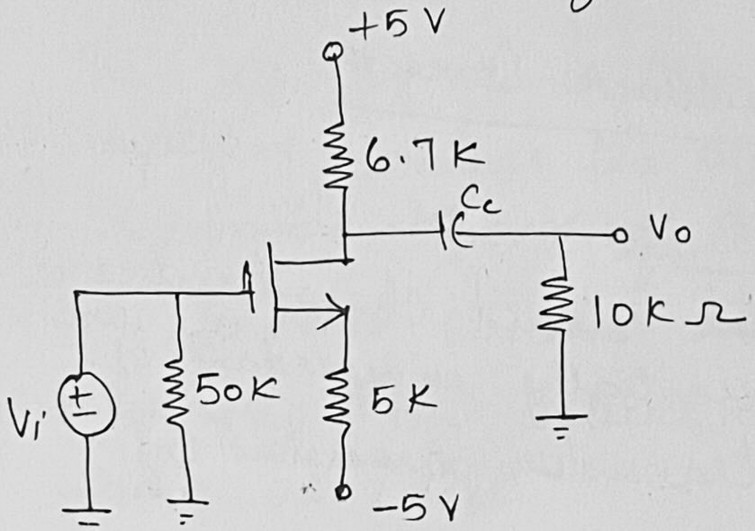
$$\boxed{|A_V|_{max} = \frac{g_m (R_D \| R_L)}{1 + g_m R_S}}$$

(Note: derivation done already. Refer.)

Same Ans

Examples:

1. The circuit shown below is to be used as a simple audio amplifier. Design the circuit such that the lower corner frequency $f_L = 20Hz$.



Solution:

$$f_L = \frac{1}{2\pi\tau_s} \Rightarrow \tau_s = \frac{1}{2\pi f} = \frac{1}{2\pi(20)} = 7.96ms$$

$$C_c = \frac{\tau_s}{R_D + R_L} = \frac{7.96\times10^{-3}}{6.7\times10^3 + 10\times10^3} = 4.77\times10^{-7}F$$

$$\boxed{C_c = 0.477\,\mu F}$$

2. Determine the corner frequency & max. gain asymptote of a MOSFET Amplifier