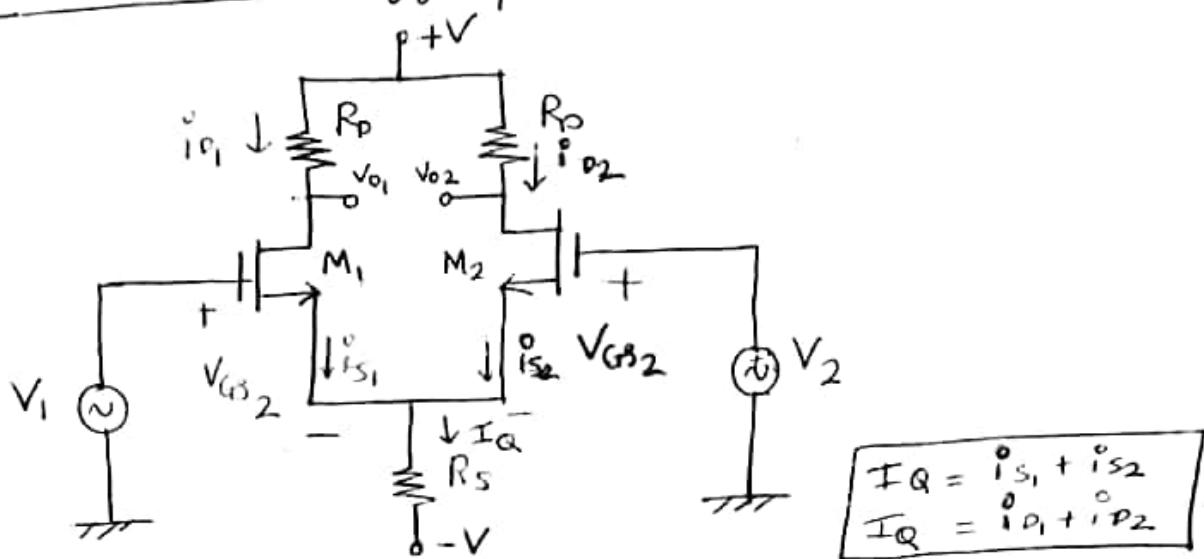


Basic MOSFET Diffamp:-



ckt ①: Basic mosfet Diffamp (DIBO) configuration

The transistors M_1 and M_2 are matched and we assume that both M_1 and M_2 are always biased in the saturation region.

The basic MOSFET diff-amp uses both positive and negative bias supply voltages, thereby eliminating the need for any coupling capacitors and voltage-divider biasing resistors at the gate terminals.

The above circuit is called "direct-coupled" diffamp.

$$V_d = V_1 - V_2$$

The dc transfer characteristics of MOSFET Dibfamp can be determined from the circuit ①.

Neglecting the op resistances of M_1 and M_2 and assuming that the two transistors are matched, we can write,

$$\overset{o}{i}_{D_1} = K_n (V_{GS_1} - V_{TN})^2 \quad - ①$$

$$\text{and } \overset{o}{i}_{D_2} = K_n (V_{GS_2} - V_{TN})^2 \quad - ②$$

Taking the square-roots of eqn ① & ② & subtracting ① & ②, we get

$$\sqrt{\overset{o}{i}_{D_1}} - \sqrt{\overset{o}{i}_{D_2}} = \sqrt{K_n} (V_{GS_1} - V_{GS_2}) = \sqrt{K_n} V_d \quad - ③$$

$$V_d = V_{GS_1} - V_{GS_2} = V_1 - V_2$$

↓ Differential-mode IP voltage.

∴ If $V_d > 0$, then $V_{GS_1} > V_{GS_2}$, which implies that $\overset{o}{i}_{D_1} > \overset{o}{i}_{D_2}$

$$\text{Since } \overset{o}{i}_{D_1} + \overset{o}{i}_{D_2} = I_Q \quad - ④$$

Eqn ③ becomes, (by squaring both sides)

$$(\sqrt{\overset{o}{i}_{D_1}} - \sqrt{I_Q - \overset{o}{i}_{D_2}})^2 = K_n V_d^2 \quad - ⑤$$

$$\text{ie } \overset{o}{i}_{D_1} + (I_Q - \overset{o}{i}_{D_1}) - 2\sqrt{\overset{o}{i}_{D_1} (I_Q - \overset{o}{i}_{D_1})} = K_n V_d^2$$

$$\sqrt{\overset{o}{i}_{D_1} (I_Q - \overset{o}{i}_{D_1})} = \frac{1}{2} (I_Q - K_n V_d^2) \quad - ⑥$$

$$\text{Squaring ⑥, we get } \overset{o}{i}_{D_1}^2 - I_Q \overset{o}{i}_{D_1} + \frac{1}{4} (I_Q - K_n V_d^2)^2 = 0 \quad - ⑦$$

Apply the quadratic formula & rearranging terms,
we get (Note: $i_{D_1} > \frac{I_Q}{2}$ & $V_d > 0$)

$$i_{D_1} = \frac{I_Q}{2} + \sqrt{\frac{k_n I_Q}{2}} \cdot V_d \sqrt{1 - \left(\frac{k_n}{2 I_Q}\right) V_d^2} \quad - (8)$$

Using eqⁿ (4), similarly we find that

$$i_{D_2} = \frac{I_Q}{2} - \sqrt{\frac{k_n I_Q}{2}} \cdot V_d \sqrt{1 - \left(\frac{k_n}{2 I_Q}\right) V_d^2} \quad - (9)$$

The normalized drain currents are,

$$\frac{i_{D_1}}{I_Q} = \frac{1}{2} + \sqrt{\frac{k_n}{2 I_Q}} \cdot V_d \sqrt{1 - \left(\frac{k_n}{2 I_Q}\right) V_d^2} \quad - (10)$$

$$\frac{i_{D_2}}{I_Q} = \frac{1}{2} - \sqrt{\frac{k_n}{2 I_Q}} \cdot V_d \sqrt{1 - \left(\frac{k_n}{2 I_Q}\right) V_d^2} \quad - (11)$$

Eqⁿ (10) and (11) describe the dc transfer characteristics
for MOSFET Diffamp

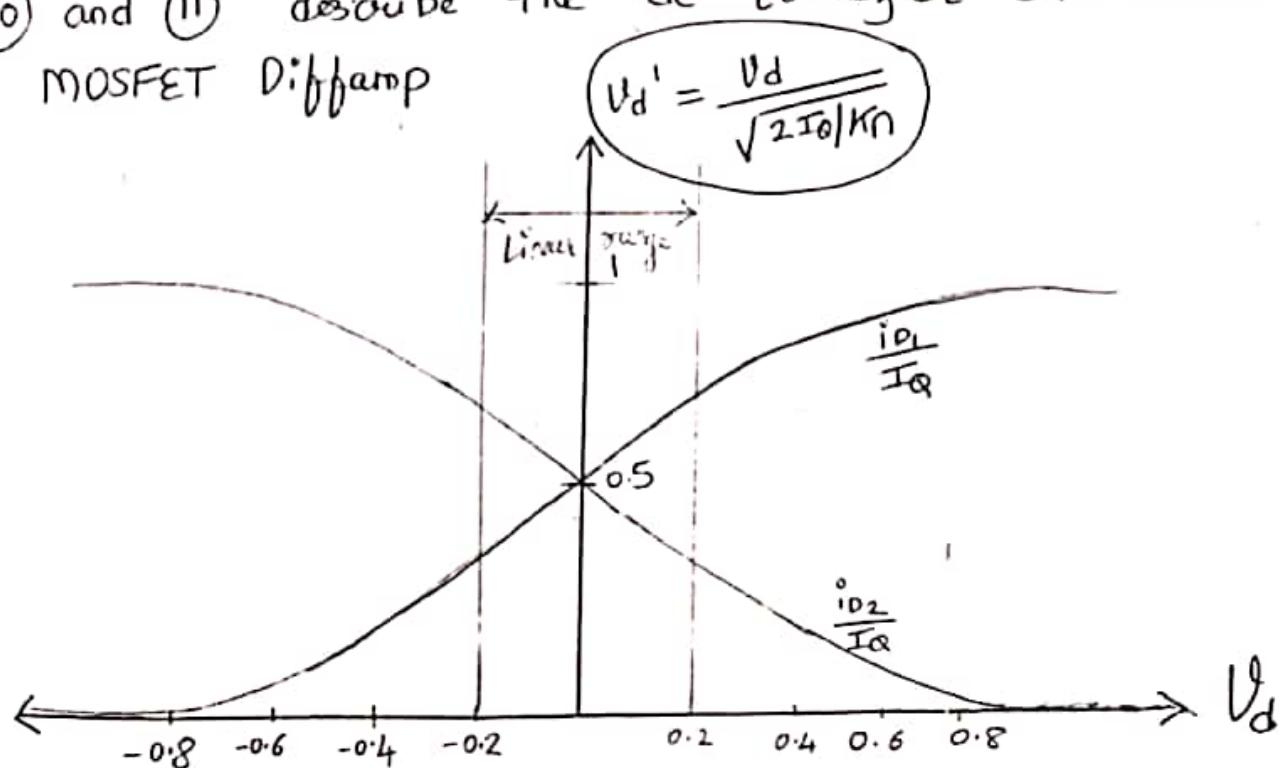


Fig 1.1: Normalized dc transfer characteristics of MOSFET diffamp.

Observations:-

- From eqn (10) and (11), and fig 1.1, at a specific differential IIP voltage, bias current I_a is switched entirely to one transistor or the other.

This occurs when

$$|V_d|_{\max} = \sqrt{\frac{I_a}{K_n}} - (12)$$

Why we go for MOSFET Diffamp?

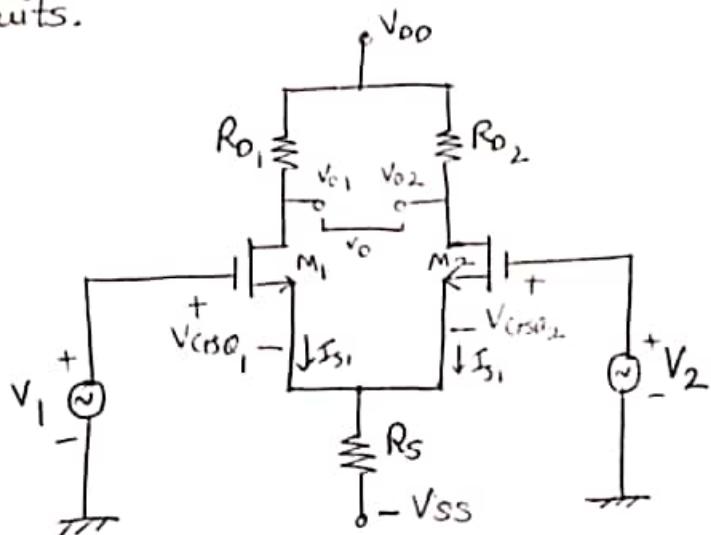
The maximum differential IIP signal for the MOSFET diffamp is much larger than for BJT diffamp.

- The primary reason is that the gain of the MOSFET diffamp, as we will see, is much smaller than the gain of the BJT diffamp.
- Many diffamp's are constructed with MOSFETs, since it provides high IIP impedances, which helps amplifiers avoid loading of source (which are instrumental in circuits like opamps, instrumentation amplifiers).
- A MOSFET diffamp cannot provide high gain but it avoid loading of source.
- Also, MOSFETs can be easily fabricated in IC form.

* Small-signal Analysis for MOSFET Diffamp:-

44.

- We can determine the basic relationships for A_d , A_{cm} and CMRR from an analysis of small-signal equivalent circuits.



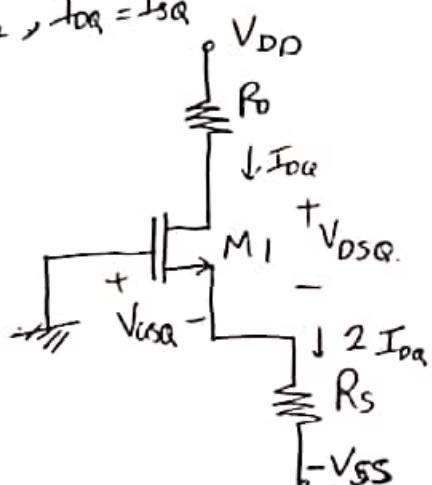
ckt(2.1): A DIBO MOSFET Diffamp.

For DC Analysis:-

- Remove all AC signal sources ($V_1 = V_2 = 0$)
- Since both sections including M_1 & M_2 are symmetric, consider only half-ckt

$$R_{O1} = R_{O2}, V_{DS1} = V_{DS2}, I_{DQ} = I_{DQ}$$

$I_G = 0$ (becoz of SiO_2 layer)



ckt: DC equivalent half-ckt
for

- Find Q-point $\equiv (V_{DSQ}, I_{DQ})$ using the equations,

$$V_{DSQ} = V_{SS} - 2I_{DQ}R_S \quad (\text{KVL to G-S loop})$$

$$I_{DQ} = k_n (V_{GSQ} - V_{Tn})^2 \quad ; \quad V_{DSQ} = (V_{DD} + V_{SS}) - 2I_{DQ}R_S - I_{DQ}R_D$$

Hence till now

2.2.

• Applying KVL to Gate-source loop, we get

$$-V_{GSQ} - 2I_{DQ}R_S + V_{SS} = 0$$

$$\therefore V_{GSQ} = V_{SS} - 2I_{DQ}R_S \quad \text{--- (1)}$$

Then, $I_{DQ} = k_n(V_{GSQ} - V_{TN})^2 \quad \text{--- (2)} \rightarrow$ Drain current of
for E-MOSFET
(n-channel)

From (1) & (2), we can find values of I_{DQ} & V_{GSQ}

Applying KVL to drain-source loop,

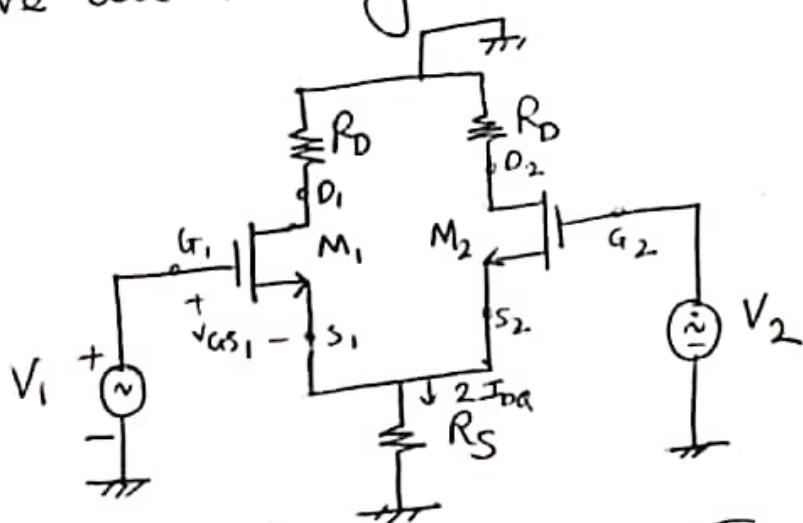
$$V_{DD} - I_{DQ}R_D - V_{DSQ} - 2I_{DQ}R_S + V_{SS} = 0$$

$$V_{DSQ} = (V_{DD} + V_{SS}) - 2I_{DQ}R_S - I_{DQ}R_D$$

$$\therefore V_{DSQ} = (V_{DD} + V_{SS}) - I_{DQ}(R_D + 2R_S) \quad \text{--- (3)}$$

AC analysis:-

• Remove all DC signal sources ($V_{DD} = -V_{SS} = 0$)



Ckt 2.3: AC equivalent of ckt 2.1.

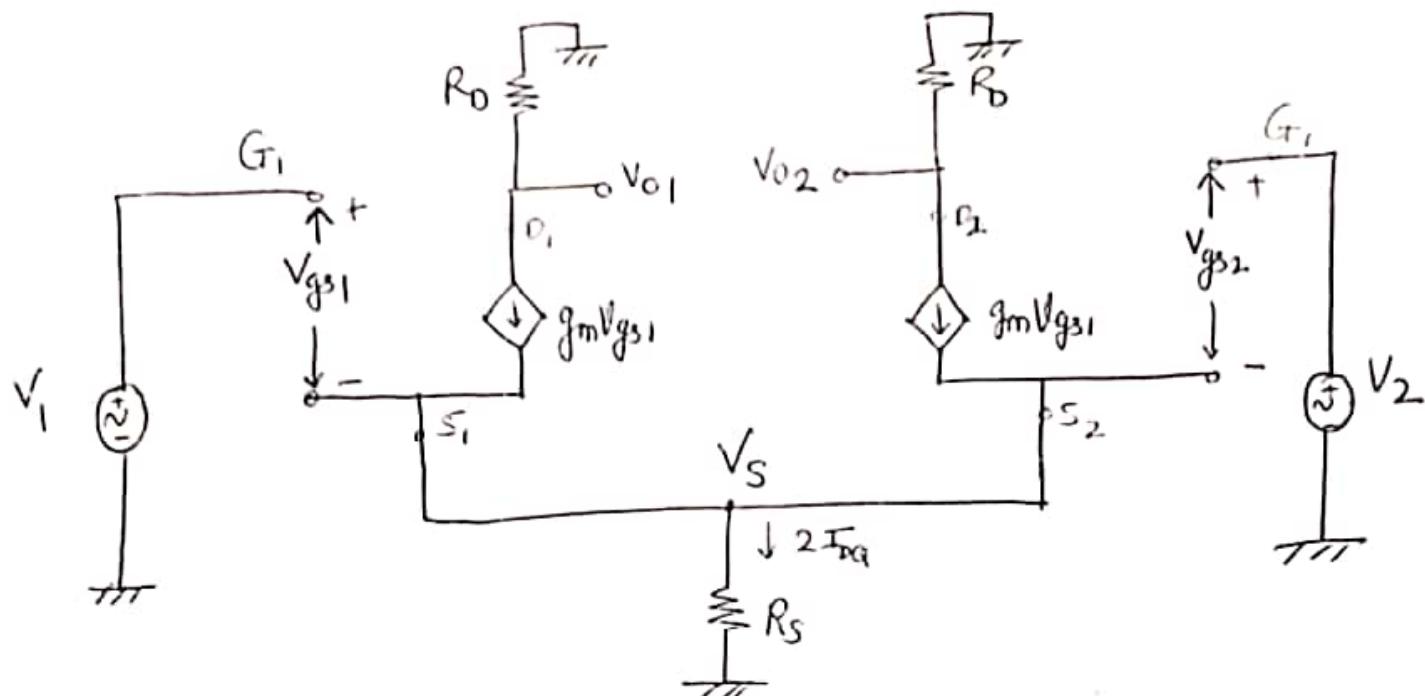


fig 2.4: Small-signal equivalent circuit for MOSFET DIBO Diffamp. with differential-mode ILP's

Note, the two transistors are biased at the same Q-point current & hence $g_{m1} = g_{m2} = g_m$.

For differential mode of operation, both ILPs are equal in magnitude's but opposite in phase with each other. i.e $V_1 = -V_2$

Writing KCL equation's at node V_S , we have

$$g_m V_{gs1} + g_m V_{gs2} = \frac{V_S}{R_S} \quad \text{--- (1)}$$

$$g_m [V_{gs1} + V_{gs2}] = \frac{V_S}{R_S}$$

Now, $V_{gs1} = V_1 - V_S$ and $V_{gs2} = V_2 - V_S$ (From fig 2.4) \rightarrow (2)

$$\therefore g_m [V_1 - V_S + V_2 - V_S] = \frac{V_S}{R_S}$$

$$\text{i.e } g_m [V_1 + V_2 - 2V_S] = \frac{V_S}{R_S}$$

$$\text{ie } g_m (V_1 + V_2) = \left(2g_m + \frac{1}{R_s}\right) V_S$$

$$\text{ie } V_S = \frac{V_1 + V_2}{2 + \frac{1}{g_m R_s}} - \textcircled{3}$$

Now, since it's an DIBO Diffam,

$$V_o = V_{o2} - V_{o1}$$

From fig (2.4), $V_{o2} = -(g_m V_{gs2}) R_D$

$$V_{o2} = -g_m R_D (V_2 - V_S) - \textcircled{4}$$

$$\text{Also, } V_{o1} = -(g_m V_{gs1}) R_D$$

$$V_{o1} = -g_m R_D (V_1 - V_S) - \textcircled{5}$$

$$\begin{aligned} V_o &= V_{o2} - V_{o1} \\ &= -g_m R_D [(V_2 - V_S) - (V_1 - V_S)] \end{aligned}$$

$$V_o = g_m R_D (V_1 - V_2) - \textcircled{6}$$

Now, $V_d = V_1 - V_2 \rightarrow \text{differential mode I/P signal.}$

$$\text{ie } A_d = \frac{V_o}{V_d}$$

$$A_d = g_m R_D - \textcircled{A}$$

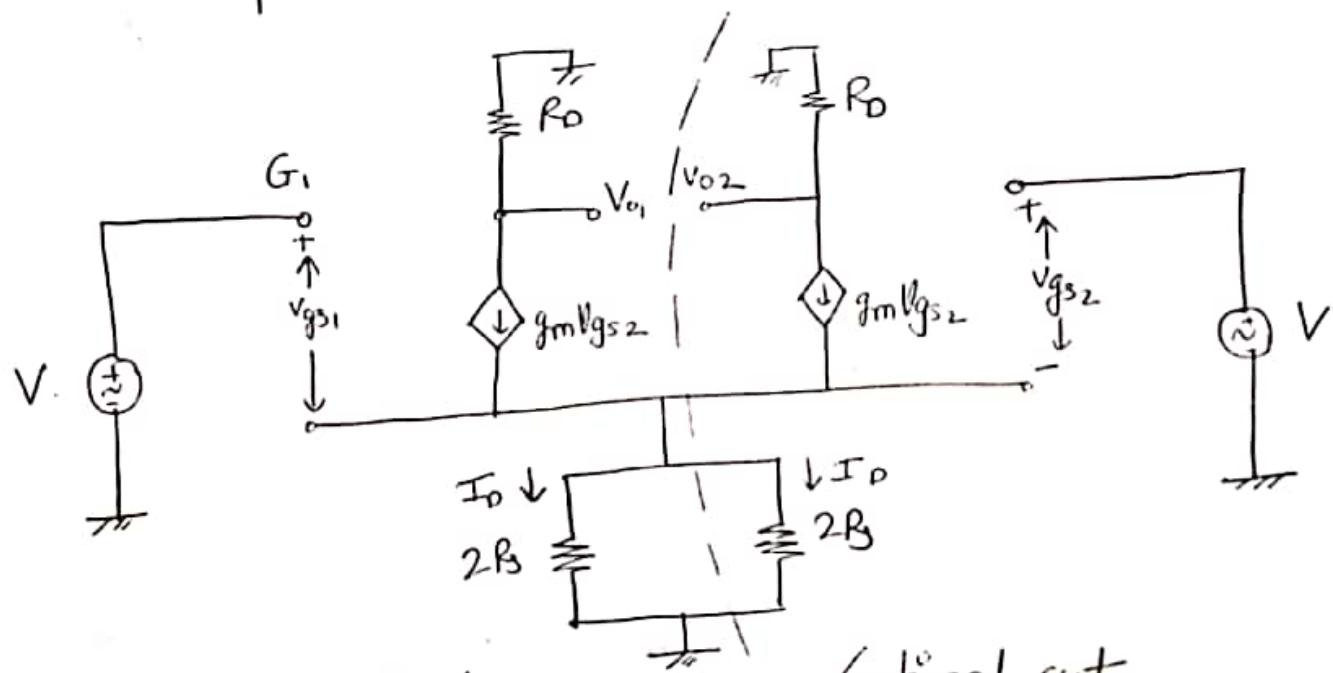
$\downarrow \rightarrow$ for DIBO MOSFET diffamp

Derivation of A_{cm} for MOSFET Diffamp

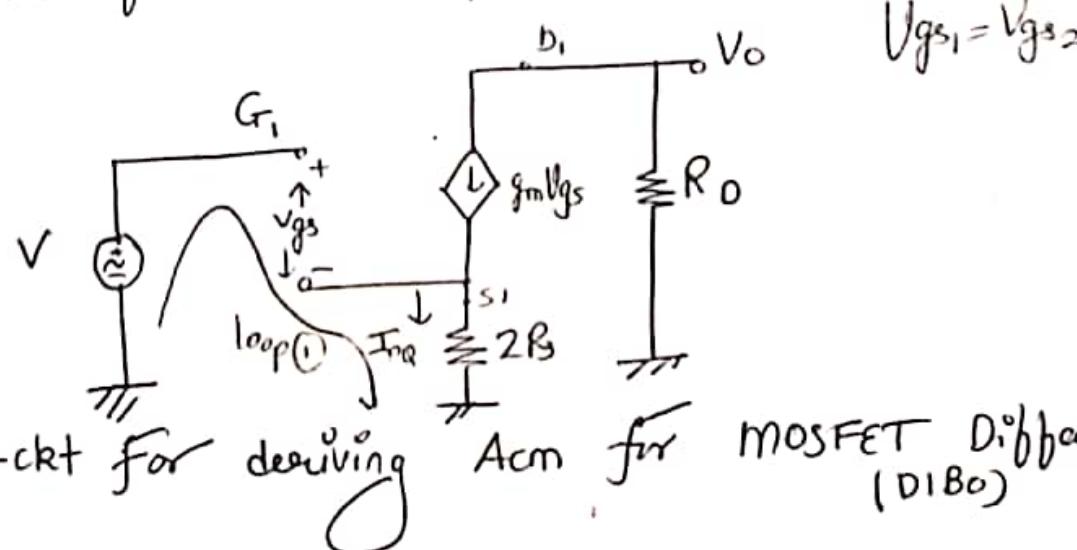
. For common-mode of operation (Find expression for A_{cm})

We select both I_D's to be equal in magnitude and phase i.e. V₁ = V₂ = V. This make the AC equivalent ckt exactly mirror image's.

Since both section's including M₁ & M₂ are symmetrical we analysis one half of the section.



Ckt 2.5: Small-signal equivalent mode for MOSFET DIBO Diffamp in Common-mode operation.



Ckt 2.6: Half-ckt for deriving A_{cm} for MOSFET Diffamp (DIBO)

From CRT 2.6,

$$V_o = -I_D R_D$$

$$\boxed{V_o = -g_m V_{gs} R_D} \quad -\text{(i)}$$

Apply KVL to loop ①, we get

$$V - V_{gs} - 2 I_D R_S = 0$$

$$V = V_{gs} + 2 g_m V_{gs} R_S \quad (I_D = g_m V_{gs})$$

$$\text{i.e } V = V_{gs} [1 + 2 g_m R_S] \quad -\text{(ii)}$$

$$\text{Now, } A_{cm} = \frac{V_o}{V_{cm}} = \frac{V_o}{V}$$

$$\text{i.e } A_{cm} = \frac{-g_m V_{gs} R_D}{V_{gs} [1 + 2 g_m R_S]}$$

$$\boxed{A_{cm} = \frac{-g_m R_D}{(1 + 2 g_m R_S)}} \quad -\text{(B)}$$

--- For DIBO Diffamp
(MOSFET)

If we neglect 1, i.e $1 + 2 g_m R_S \approx 2 g_m R_S$

$$\text{i.e } A_{cm} = \frac{-g_m R_D}{2 g_m R_S}$$

$$\boxed{A_{cm} = \left| \frac{R_D}{2 R_S} \right|} \quad -\text{(b1)}$$

$$CMRR|_{DIBO} = \left| \frac{A_d}{A_{cm}} \right|$$

$$A_d|_{DIBO} = g_m R_o$$

$$A_{cm}|_{DIBO} = \left| \frac{R_o}{2R_s} \right|$$

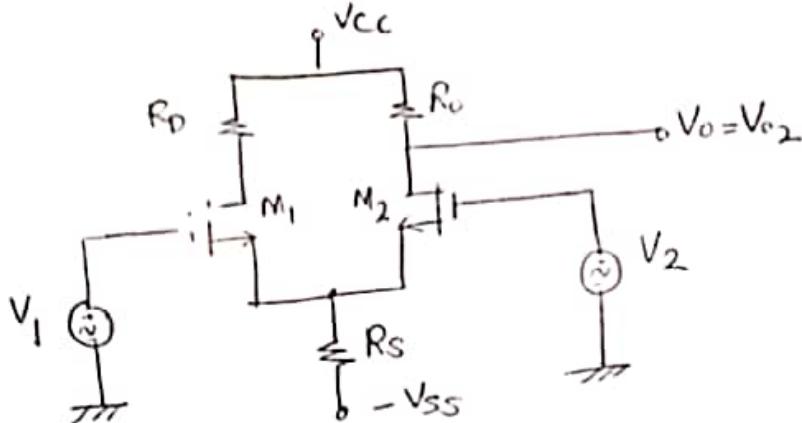
$$\therefore CMRR|_{DIBO} = \left| \frac{g_m R_o (2R_s)}{R_o} \right|$$

$$CMRR|_{DIBO} = \boxed{\left| 2g_m R_s \right|} - (C)$$

$$CMRR_{indB} = 20 \log_{10} \left| 2g_m R_s \right|$$

Thus, to use the value of CMRR, we have to use the value of source resistance.

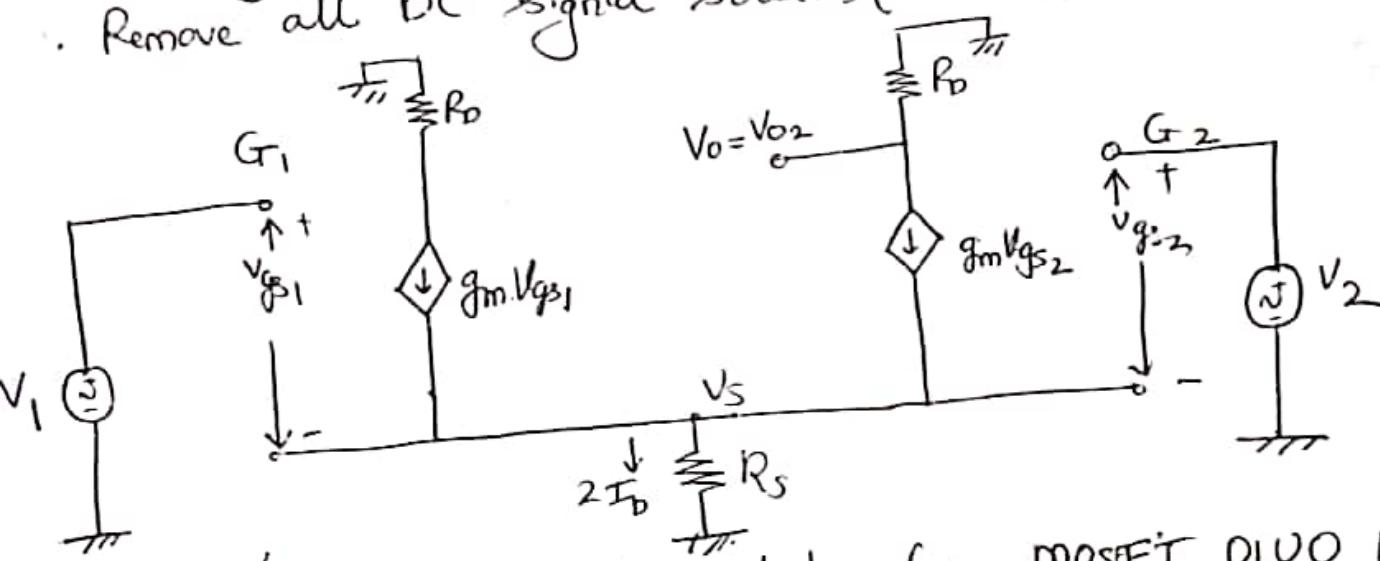
MOSFET DIUO Diffamp:-



Ckt 4.1: Basic DIUO MOSFET Diffamp

AC Analysis:

- Remove all DC signal sources (i.e. $V_{DD} = -V_{SS} = 0$)



Ckt 4.2: Small signal equivalent for MOSFET DIUO Diffamp

$$\text{From ckt 4.2, } V_{gs1} = V_1 - V_s \quad , \quad V_{gs2} = V_2 - V_s$$

At node V_s , applying KCL, we get

$$g_m V_{gs1} + g_m V_{gs2} = \frac{V_s}{R_S}$$

$$g_m [V_1 - V_s + V_2 - V_s] = \frac{V_s}{R_S}$$

$$g_m (V_1 + V_2) = \frac{V_s}{R_S} + 2V_s g_m$$

HOMIE P. K. SINGH

$$\text{ie } V_S = \frac{V_1 + V_2}{2 + \frac{1}{g_m R_s}} \quad - \textcircled{1}$$

For one-sided op at the drain of M_2 , we have

$$V_0 = V_{o2} = -g_m V_{gs2} R_o$$

$$V_0 = -g_m R_o (V_2 - V_S) \quad - \textcircled{2}$$

Put $\textcircled{1}$ in $\textcircled{2}$ we get

$$V_0 = -g_m R_o \left[V_2 - \left(\frac{V_1 + V_2}{2 + \frac{1}{g_m R_s}} \right) \right]$$

$$\text{ie } V_0 = -g_m R_o \left[\frac{V_2 \left(2 + \frac{1}{g_m R_s} \right) - V_1 - V_2}{2 + \frac{1}{g_m R_s}} \right]$$

$$\text{ie } V_0 = -g_m R_o \left[\frac{V_2 \left(1 + \frac{1}{g_m R_s} \right) - V_1}{2 + \frac{1}{g_m R_s}} \right] \quad - \textcircled{3}$$

$$\text{Now, } V_d = V_1 - V_2 \text{ and } V_{cm} = \frac{V_1 + V_2}{2}$$

$$\therefore V_1 = V_{cm} + \frac{V_d}{2} \text{ and } V_2 = V_{cm} - \frac{V_d}{2} \quad - \textcircled{4}$$

\swarrow \searrow (Refer pg 06)

Put ④ in ③, we get

53

$$V_o = -g_m R_o \left[\frac{\left(V_{cm} - \frac{V_d}{2} \right) \left(1 + \frac{1}{g_m R_s} \right) - \left(V_{cm} + \frac{V_d}{2} \right)}{2 + \frac{1}{g_m R_s}} \right]$$

$$\text{i.e } V_o = -g_m R_o \left[\frac{V_{cm} \left(\frac{1}{g_m R_s} \right) - V_d \left(1 + \frac{1}{2g_m R_s} \right)}{2 + \frac{1}{g_m R_s}} \right]$$

$$\therefore V_o = -g_m R_o \left[\frac{V_{cm} - V_d (g_m R_s) \left(1 + \frac{1}{2g_m R_s} \right)}{2g_m R_s + 1} \right]$$

$$\text{i.e } V_o = \frac{-g_m R_o}{1+2g_m R_s} V_{cm} + V_d \left(\frac{g_m R_o}{1+2g_m R_s} \right) \left(\frac{1}{2} + g_m R_s \right)$$

$$V_o = \frac{-g_m R_o}{1+2g_m R_o} V_{cm} + V_d \frac{g_m R_o}{1+2g_m R_s} \frac{1+2g_m R_s}{2}$$

$$\therefore V_o = \left(\frac{g_m R_o}{2} \right) V_d - \left(\frac{g_m R_o}{1+2g_m R_s} \right) V_{cm} - ⑤$$

$$\text{Now, } V_o = A_d V_d + A_{cm} V_{cm} - ⑥$$

Comparing ⑤ and ⑥, we get

$$A_{d|DVO} = \frac{g_m R_o}{2}$$

→

Differential mode gain

$$A_{cm|DVO} = -\frac{g_m R_o}{1 + 2g_m R_S}$$

- (C)

Common-mode voltage
gain

Differential and Common-mode IIP impedances-

- At low frequencies, the IIP impedances of a MOSFET is essentially infinite, which means that both the differential and common-mode IIP resistance of a MOSFET diffamp are infinite

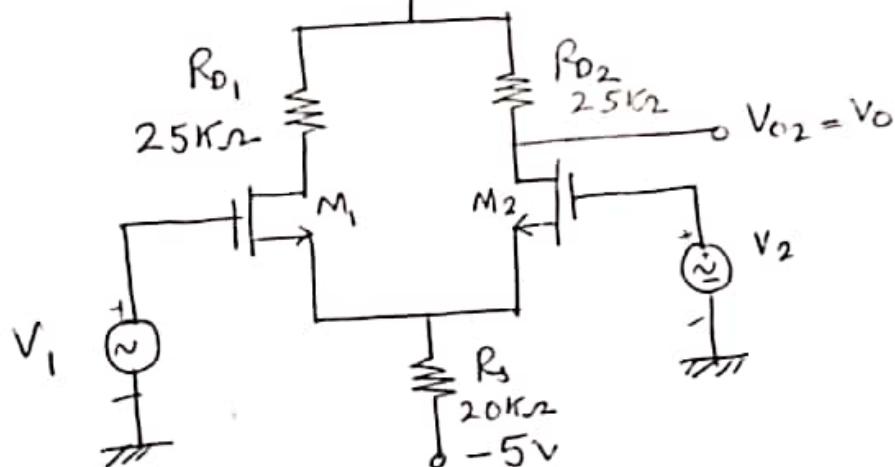
i.e $R_{icm} = \infty$

for MOSFET diffamp

$R_{id} = \infty$

- Ex: Find a) I_S , I_{D1} , I_{D2} and V_{GS1} , V_{GS2} for $V_1 = V_2 = 0$
- b) $A_d = \frac{V_{O2}}{V_d}$, $A_{cm} = \frac{V_{O2}}{V_{cm}}$
- c) CMRR in dB

Given: Transistor parameters, $k_{n1} = k_{n2} = 50 \mu A/V^2$, $V_{TN1} = V_{TN2} = 1V$



Sol:- Above ckt is a DIODO MOSFET Dibbamp.

a) DC Analysis :-

$$V_{GSA1} = V_{SS} - 2I_{DQ1}R_S$$

$$\text{i.e } V_{GSA1} = 5 - 2I_{DQ1}R_S \quad \text{(1)}$$

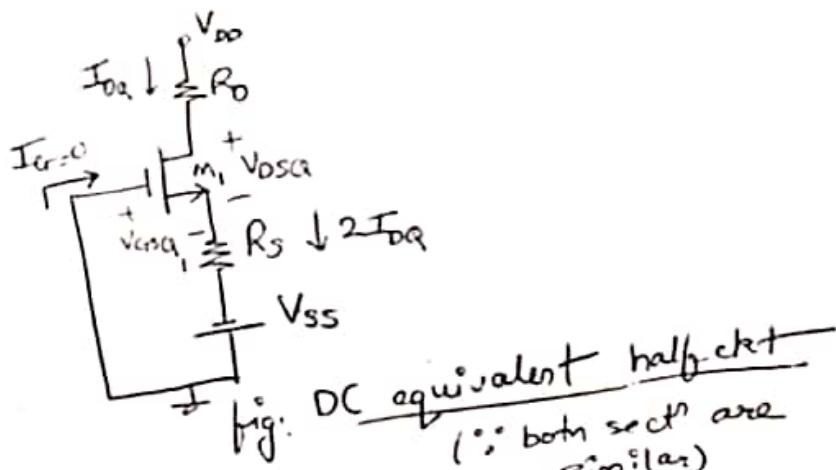
$$\text{Also, } I_{DQ1} = k_{n1} (V_{GSA1} - V_{TN1})^2$$

$$I_{DQ1} = 50 \times 10^{-6} (V_{GSA1} - 1)^2 \quad \text{(2)}$$

From (1) & (2), .

$$\begin{aligned} V_{GSA1} &= 5 - 2 \times 50 \times 10^{-6} \times R_S (V_{GSA1} - 1)^2 \\ &= 5 - 2 \times 50 \times 10^{-6} \times 20 \times 10^3 (V_{GSA1} - 1)^2 \end{aligned}$$

$$V_{GSA1} = 5 - 2(V_{GSA1}^2 - 2V_{GSA1} + 1)$$



$$2V_{GSO_1}^2 - 3V_{GSO_1} - 3 = 0$$

$$\text{ie } V_{GSO_1} = 2.186 \text{ V} , \quad V_{GSO_2} = -0.6861 \text{ V} \quad (\text{As } V_{GSO_1} < V_{IN})$$

$$\therefore I_{DQ_1} = K_{n1} (V_{GSO_1} - V_{TN_1})^2 \\ = 50 \times 10^{-6} (2.186 - 1)^2$$

$$\therefore V_{GSO_1} = V_{GSO_2} = 2.186 \text{ V}$$

$$I_{DQ_1} = 70.33 \mu\text{A} = I_{DQ_2}$$

$$\therefore I_S = 2I_D = 140.65 \mu\text{A}$$

$$g_m = 2K_n (V_{CO} - V_{TN}) = 2 \times 50 \times 10^{-6} (2.186 - 1)$$

$$g_{m1} = g_{m2} = g_m = 0.118 \text{ mA/V} = 118.6 \mu\text{A/V}$$

$$A_d = \frac{V_{O2}}{\sqrt{d}} = \frac{g_m R_o}{2} = 1.4825$$

$$A_{cm} = \left| \frac{g_m R_o}{1 + 2g_m R_s} \right| = \frac{V_{O2}}{V_{cm}}$$

$$= 0.515$$

$$CMRR = \left| \frac{A_d}{A_{cm}} \right| = \left| \frac{1.4825}{0.515} \right| = 2.874$$

$$CMRR_{indB} = 20 \log_{10} \left| \frac{A_d}{A_{cm}} \right| = 20 \log_{10} (2.874)$$

$$CMRR = 9.17 \text{ dB}$$