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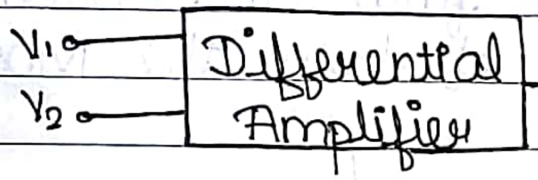
4. DIFFERENTIAL AMPLIFIER

INTRODUCTION

A differential amplifier is a circuit which is so designed that it has two I/P terminals and it is such that it amplifies the I/P of difference of signals.



$V_o \propto (V_1 - V_2)$

$V_o = A_d (V_1 - V_2)$

where V_1 & V_2 are I/Ps of DA. V_o is the O/P of DA. A_d is known as differential mode gain. The main advantage of DA is that it amplifies the actual signal and rejects / cancels noise signal at its I/P.

CIRCUIT DIAGRAM OF MOS DA

The DA is a basically two stage amplifier. The fig. (a) shows two independent CS amplifier employing dual power supply biasing.

In order to convert it to ~~both~~ the ~~circuit~~ DA we perform following steps:-

(1) Make +ve supply of both the circuits common.

(2) Make -ve supply of both the circuits common.

(3) Short/Connect source terminal of both Tx with each other.

(4) Take the final O/P between the drain terminal of both the MOSFET.

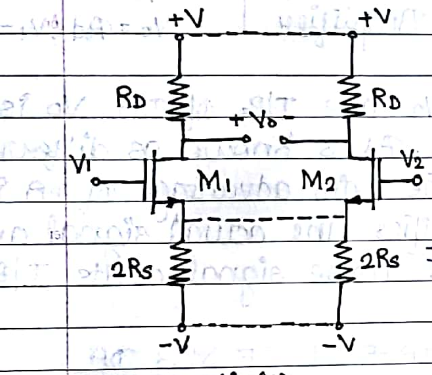


fig.(a)

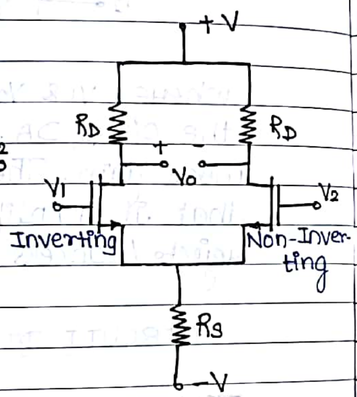


fig (b)

DA is having two I/P terminals and they are named as

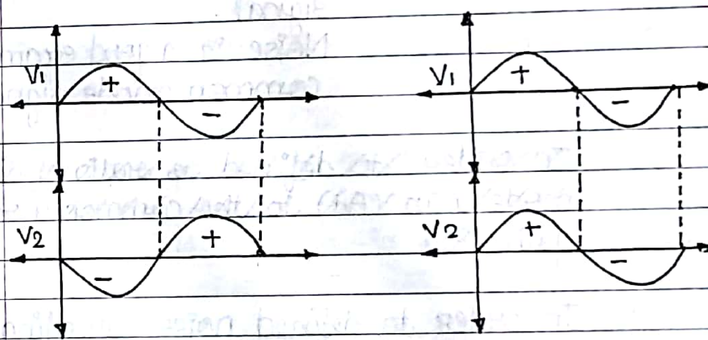
(1) Inverting - The signal applied to this terminal will appear at the O/P in amplified form with 180° phase shift.

(2) Non Inverting - The signal applied to this

terminal will appear at the O/P in amplified form with 0° phase shift.

I/P SIGNAL OF DA

I/P SIGNALS
- DIFFRENTIAL MODE SIGNAL
- COMMON MODE SIGNAL



Normally we apply two types of signal to DA. They are :-

(1) Differential mode signal - When the two signal is having either same or different amplitude but if they are 180° out of phase with each other then they are known as differential

mode signal.
It is a actual signal which differential amplifier is supposed to amplify.

Common mode signal - When the two signals is having same amplitude and same phase then they are known as common mode signal.
Noise is a good example of common mode signal.

~~In order to defined as ratio of differential mode gain (Ad) to the common mode gain (Ac)~~

In order to define noise cancelling capability of DA we define a parameter known as CMRR (Common Mode Rejection Ratio).

CMRR (COMMON MODE REJECTION RATIO)

It is defined as ability of DA to amplify differential mode signal and to reject common mode signal.
It is also defined as ratio of differential

mode gain (Ad) to the common mode gain (Ac).

$$CMRR = \frac{Ad}{Ac}$$

Ideally $Ac = 0$ $\therefore$ $CMRR = \infty$.
Practically the value of CMRR should be as high as possible.

In case of DA, the expression for O/P is given as

$$V_o = Ad\,V_{id} + Acm \cdot V_{cm}$$

where $V_{id} = V_1 - V_2$ is differential mode s/g

$V_{cm} = \frac{V_1 + V_2}{2}$ is common mode s/g

Ad = differential gain

Ac = Common mode gain

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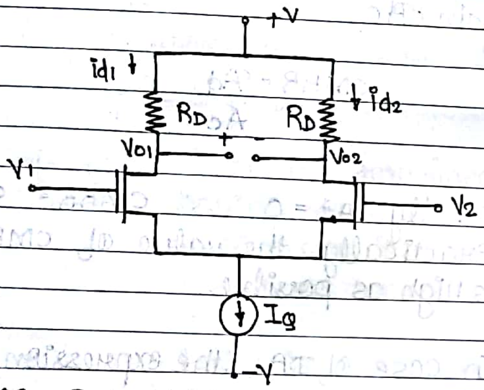
DC TRANSFER CHARACTERISTIC OF MOS DA



MOS DIFFERENTIAL AMPLIFIER

The figure shows circuit diagram of MOS differential amplifier or differential pair employing constant current source biasing. Both the MOSFETs are biased in saturation region. Hence their I_D is given as,

$$I_{D1} = K_n (V_{GS1} - V_{TN})^2 \quad \ldots (1)$$

$$I_{D2} = K_n (V_{GS2} - V_{TN})^2 \quad \ldots (2)$$

Taking the square root of (1) & (2) and substracting them

$$\sqrt{I_{D1}} = \sqrt{K_n}\,(V_{GS1} - V_{TN})$$

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$$\sqrt{I_{D2}} = \sqrt{K_n}\,(V_{GS2} - V_{TN})$$

$$\sqrt{I_{D1}} - \sqrt{I_{D2}} = \sqrt{K_n}\,(V_{GS1} - V_{GS2}) \quad \ldots (3)$$

From the circuit diagram

$$I_{D1} + I_{D2} = I_Q$$

$$\therefore I_{D2} = I_Q - I_{D1}$$

$$V_{GS1} - V_{GS2} = V_{id}$$

Putting this in eq^n (3)

$$\sqrt{I_{D1}} - \sqrt{I_{D2}} = \sqrt{K_n}\,V_{id}$$

$$\sqrt{I_{D1}} - \sqrt{I_Q - I_{D1}} = \sqrt{K_n}\,V_{id}$$

Squaring the above eq^n & rearranging the term we get

$$\sqrt{I_{D1}(I_Q - I_{D1})} = \frac{1}{2}\left(I_Q - K_n V_{id}^2\right)$$

Squaring the above equation we get quadratic eq^n

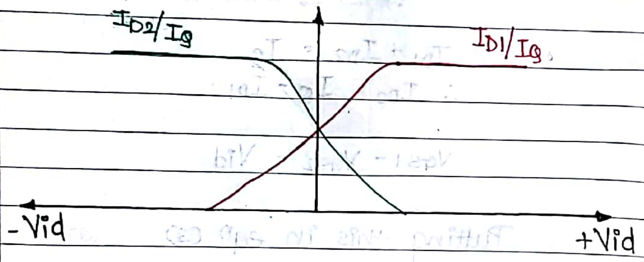
$$I_{D1}^2 - I_Q I_{D1} + \frac{1}{4}\left(I_Q - K_n V_{id}\right)^2 = 0$$

The roots of above eq^n are given as

$$I_{D1} = \frac{I_Q}{2} + \sqrt{\frac{K_n I_Q}{2}}\cdot V_{id}\sqrt{1 - \left(\frac{K_n}{2I_Q}\right)V_{id}^2}$$

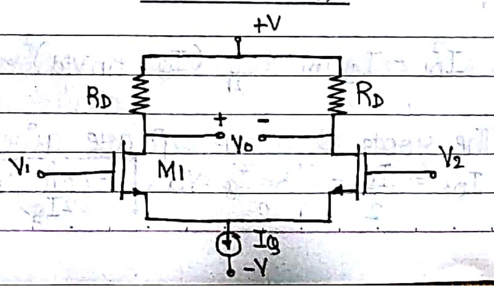
$$\frac{I_{D1}}{I_Q} = \frac{1}{2} + \sqrt{\frac{k_n}{2I_Q}} \cdot V_{id}\sqrt{1-\left(\frac{k_n}{2I_Q}\right)V_{id}^2} \quad \ldots(5)$$

IIIy $$\frac{I_{D2}}{I_Q} = \frac{1}{2} - \sqrt{\frac{k_n}{2I_Q}} \cdot V_{id}\sqrt{1-\left(\frac{k_n}{2I_Q}\right)V_{id}^2} \quad \ldots(6)$$



From the transfer characteristics, it is cleared that when the value of Vid is +ve then M_1 conducts more and M_2 conducts less. Hence I_{D1} increases whereas I_{D2} decreases. When Vid is -ve then M_1 conducts less and M_2 conducts more. Therefore I_{D1} decreases and I_{D2} increases.

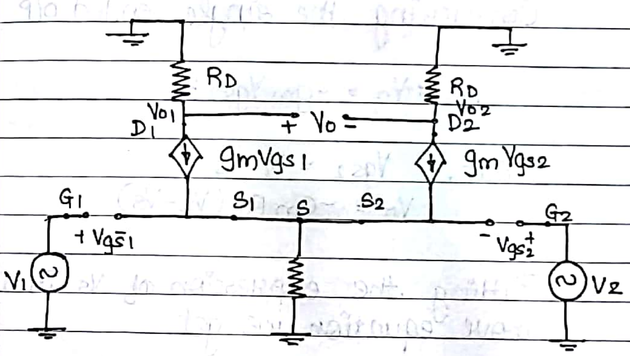
AC ANALYSIS OF DIFFERENTIAL AMPLIFIER



The figure shows circuit diagram of dual I/P balanced o/p DA with constant current source biasing.

Let R_o be o/p resistance offered by constant current source.

In order to perform AC analysis making the DC supply zero & replacing MOSFET with its transconductance model.



Applying KCL at node S

$$g_m V_{gs1} + g_m V_{gs2} = \frac{V_S}{R_o} \quad \ldots(1)$$

From the circuit

$V_{gs1} = V_1 - V_S$

$V_{gs2} = V_2 - V_S$

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Putting this in eq^n (1)

$$g_m(V_1 - V_s) + g_m(V_2 - V_s) = \frac{V_s}{R_o}$$

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

$$\boxed{V_s = \frac{V_1 + V_2}{2 + \frac{1}{g_m R_o}}}$$

Considering the single ended o/p

$$V_{o2} = V_o = -g_m V_{gs2} R_D$$

But, $V_{gs2} = V_2 - V_s$

$$V_o = -g_m R_D (V_2 - V_s)$$

Putting the expression of V_s in the above equation we get

$$V_o = -g_m R_o \left(V_2 - \frac{V_1 + V_2}{2 + \frac{1}{g_m R_o}} \right) \dots (2)$$

As we know that, in DA

$$V_{id} = V_1 - V_2$$
$$V_{cm} = \frac{V_1 + V_2}{2}$$

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Solving the above two eq^n simultaneously we get,

$$V_1 = V_{cm} + V_{id}/2$$
$$V_2 = V_{cm} - V_{id}/2$$

Putting the expression of V_1 & V_2 in eq^n(2) and solving them we get

$$V_o = \frac{g_m R_D}{2} \cdot V_{id} - \frac{g_m R_D}{1 + g_m R_D} V_{cm}$$

Comparing the above equation with standard o/p eq^n of DA

$$V_o = A_d V_{id} + A_{cm} V_{cm}$$

$\therefore A_d = \frac{g_m R_D}{2}$ for SIUO (single I/P, unbalanced o/p)

$A_{cm} = -\frac{g_m R_D}{1 + g_m R_D}$ for SIUO

Similarly we can prove for DIBO

$$A_d = g_m R_D$$

$$A_{cm} = \frac{-g_m R_D}{1 + g_m R_D}$$

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CMRR

As we know that CMRR is given as

$$CMRR = \frac{|A_d|}{|A_c|}$$

For Balanced O/P

$$A_d = g_m R_D$$

$$|A_{cm}| = \frac{g_m R_D}{1 + g_m R_o}$$

$$\therefore CMRR = 1 + g_m R_o$$

For Unbalanced O/P

$$A_d = g_m R_D / 2$$

$$|A_{cm}| = \frac{g_m R_D}{1 + g_m R_o}$$

$$\therefore CMRR = \frac{1 + g_m R_o}{2}$$

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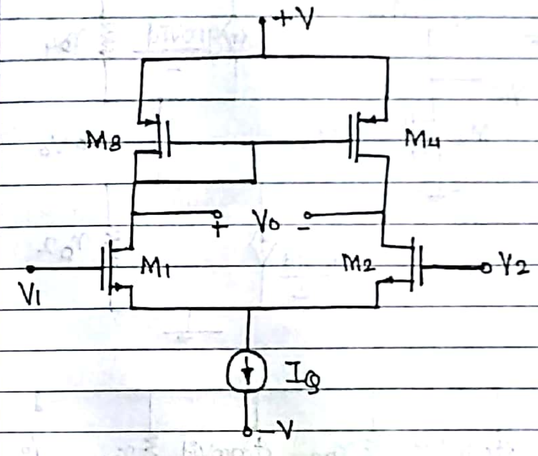
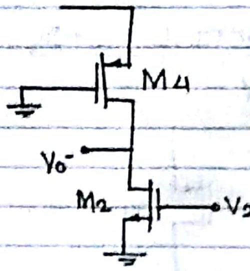
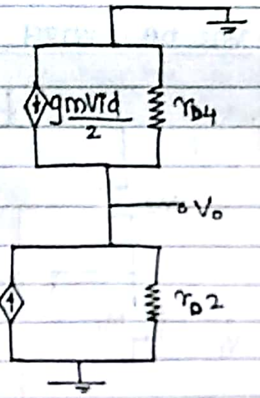
Imp MOS DA WITH ACTIVE LOAD

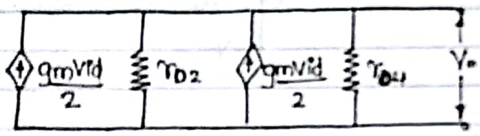


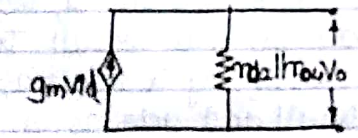
The figure shows diagram of MOS DA with Active load. In this circuit Tx M1 & M2 are main amplifying Tx where as M3 & M4 forms a current mirror circuit and acts as an active load. Thus O/P resistance of R_{o3} of M3 acts as drain resistance for M1. Similarly O/P resistance R_{o4} of M4 acts as drain resistance for M2.

Drawing the small signal equivalent circuit by simply considering the Tx M3 & M4 (Half equivalent circuit)









Thus $V_o = g_m V_{id} (r_{o2} \parallel r_{o4})$

$\therefore \frac{V_o}{V_{id}} = g_m (r_{o2} \parallel r_{o4})$

$\therefore A_d = g_m (r_{o2} \parallel r_{o4})$

Similarly, $A_{cm} = \frac{-g_m (r_{o2} \parallel r_{o4})}{1 + g_m R_o}$

$CMRR = \left| \frac{A_d}{A_{cm}} \right| = 1 + g_m R_o$

ADVANTAGES OF ACTIVE LOAD :

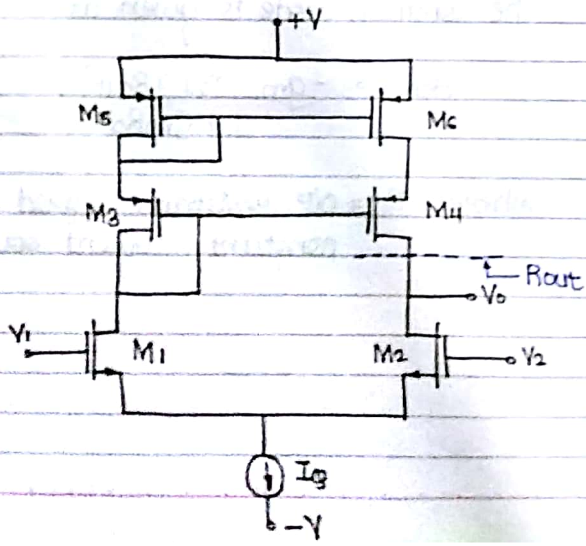
(1) Due to use of active load, overall size of the circuit reduces. Hence it is easy to fabricate the circuit inside the IC.

(2) Overall power consumption of the circuit reduces.

(3) Due to the use of active load overall value of differential mode gain increases.

(4) Due to increase in differential mode gain, overall value of CMRR increases.

MOS DA WITH CASCODE ACTIVE LOAD



The figure shows MOS DA with cascode active load in which the Tx M_1 & M_2 are main amplyfing Tx. The Tx M_3, M_4, M_5 & M_6 forms cascode current source and acts as an active load. The overall differential gain of the circuit is given as

$$A_d = g_m (r_o \parallel R_{out})$$

where, R_{out} = O/P resistance offered by cascode current source and it is given as

$$R_{out} = r_{o4} + r_{o6}(1 + g_m r_{o4})$$

$$R_{out} \simeq r_{o4} r_{o6} g_m$$

The common mode is given as

$$A_{cm} = \frac{-g_m (r_{o2} \parallel R_{out})}{1 + g_m R_o}$$

where R_o = O/P resistance offered by constant current source.