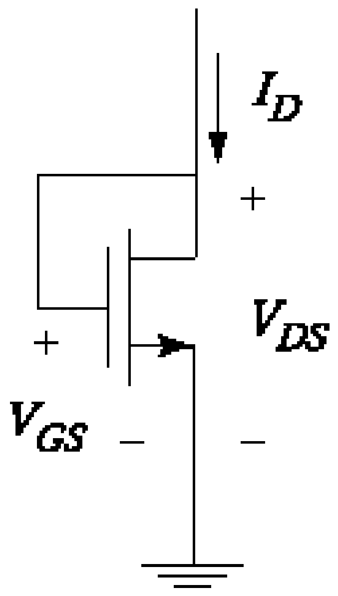
Lecture Ten

Differential Amplifier

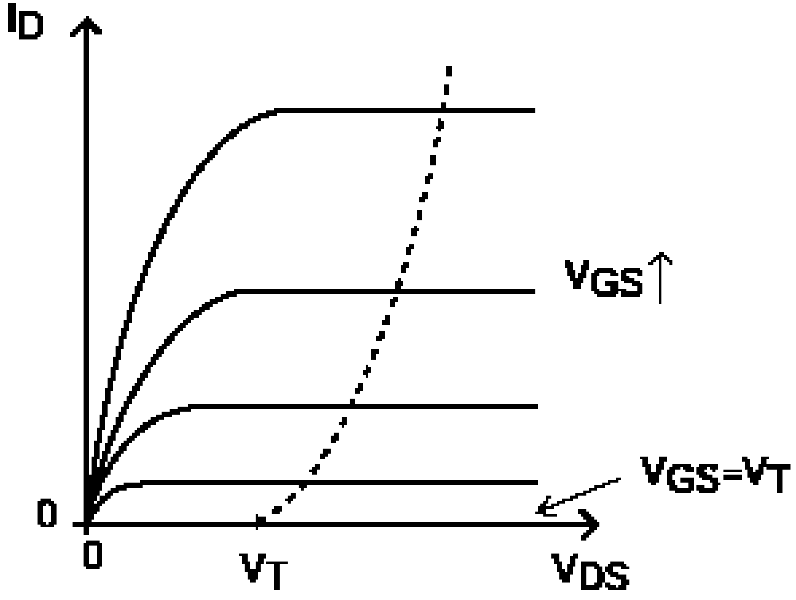
Differential amplifiers apply gain not to one input signal but to the *difference* between two input signals. This means that a differential amplifier naturally eliminates noise or interference that is present in both input signals.

Why Differential?

- **Differential circuits are much less sensitive to noises and interferences**
- **Differential configuration enables us to bias amplifiers and connect multiple stages without using coupling or bypass capacitors.**

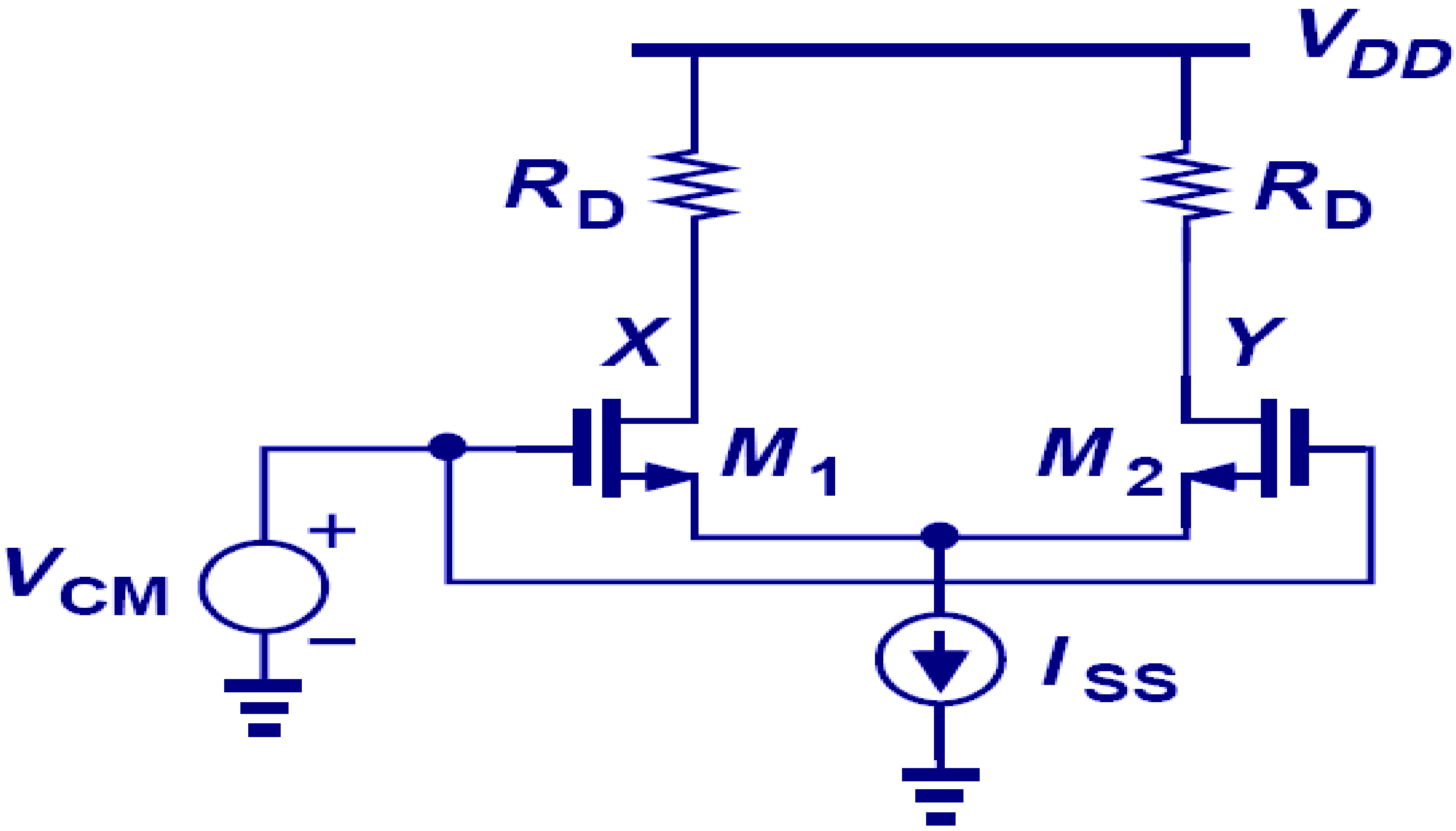


I_D
+
V_{DS}
+
V_{GS}
–
–



I_D
$V_{GS}\uparrow$
$V_{GS}=V_T$
0
0
V_T
V_{DS}

MOS Differential Pair’s Common-Mode Response



I_{D1}= I_{D2}=$\frac{I_{SS}}{2}$

$V_X = V_Y$= V_{DD}-R_D $\frac{I_{SS}}{2}$

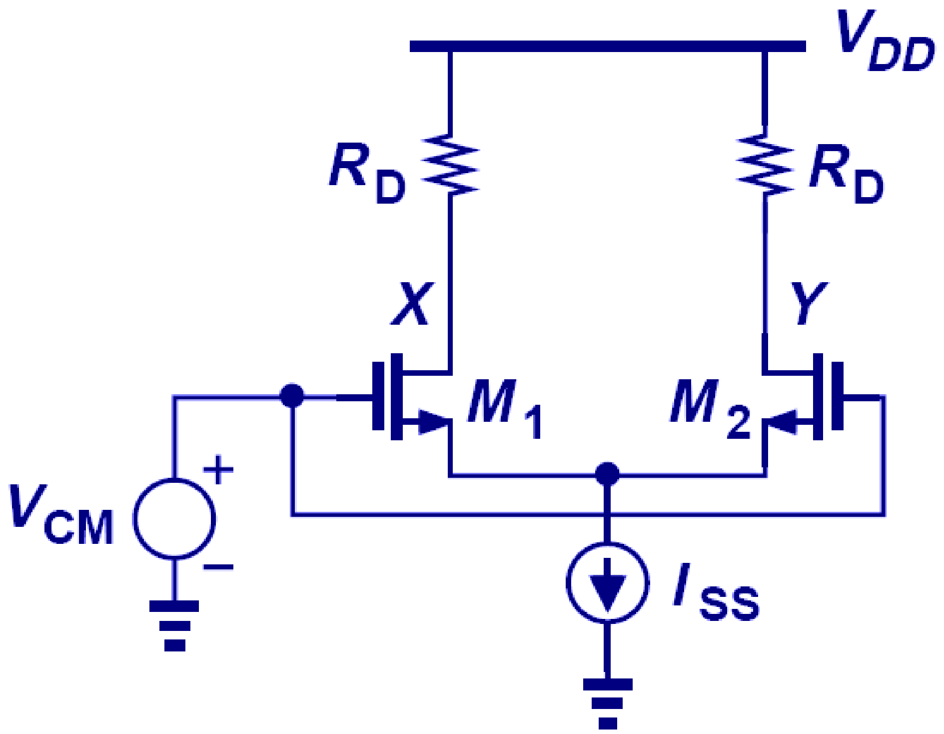
I_D= $\frac{I_{SS}}{2}$

I_D = $\frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS} - V_{GS(TH)}\right)^2$

$\left(V_{GS} - V_{GS(TH)}\right)_{equil}$=$\sqrt{\frac{I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}$

The equilibrium overdrive voltage is defined as the overdrive voltage seen by M1 and M2 when both of them carry a current of $\frac{I_{SS}}{2}$.

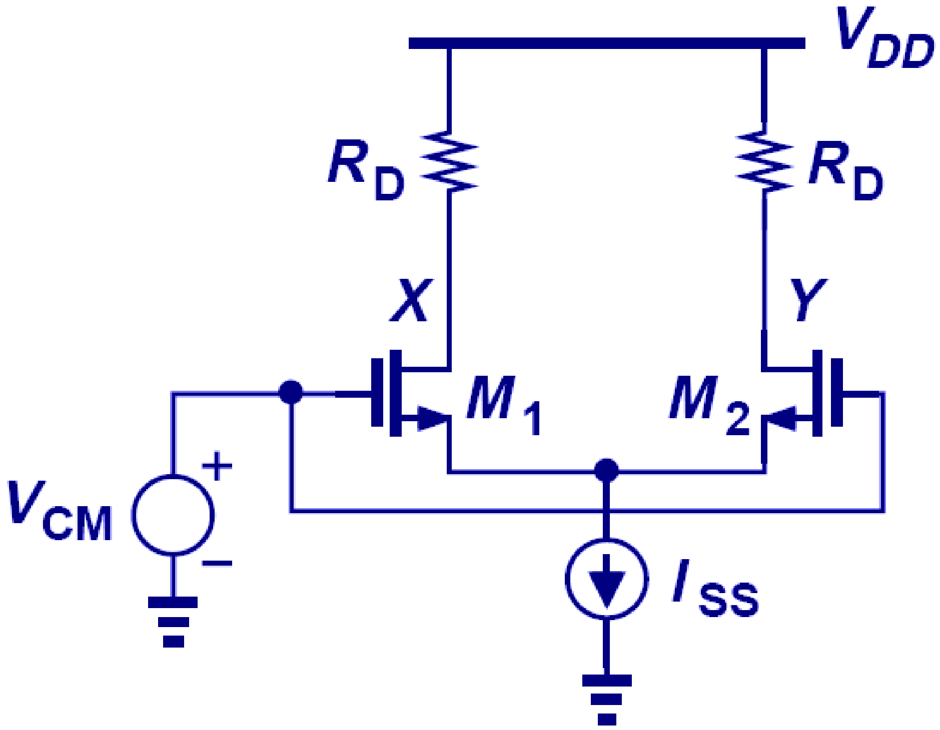
Minimum Common-mode Output Voltage



$$V_{DD}\text{-}R_D\,\frac{I_{SS}}{2} > V_{CM} - V_{GS(TH)}$$

- In order to maintain M1 and M2 in saturation, the common mode output voltage cannot fall below the value above.
- This value usually limits voltage gain.

A MOS differential pair is driven with an input CM level of 1.6V. If I_{SS}=0.5mA, $V_{GS(TH)}$ =0.5 V, and V_{DD} =1.8 V, what is the maximum allowable load resistance?



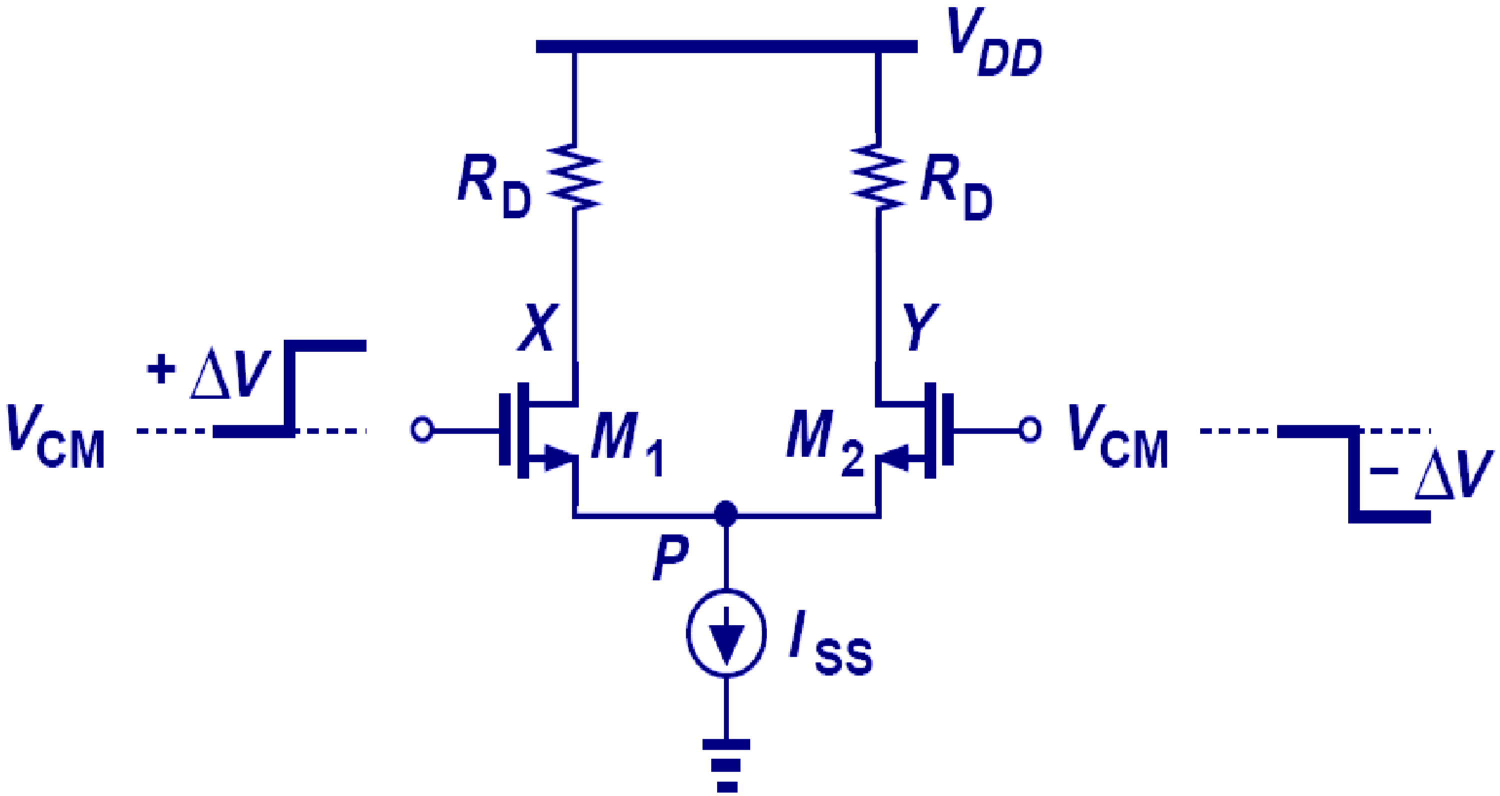
Solution:-

V_{DD}-$R_D \frac{I_{SS}}{2} > V_{CM} - V_{GS(TH)}$

$R_D < 2\frac{V_{DD} - V_{CM} + V_{GS(TH)}}{I_{SS}}$

$R_D < 2.8\ K\boldsymbol{\Omega}$

Small-Signal Response



ΔV_P=0

ΔI_{D1}=$g_m \Delta V$

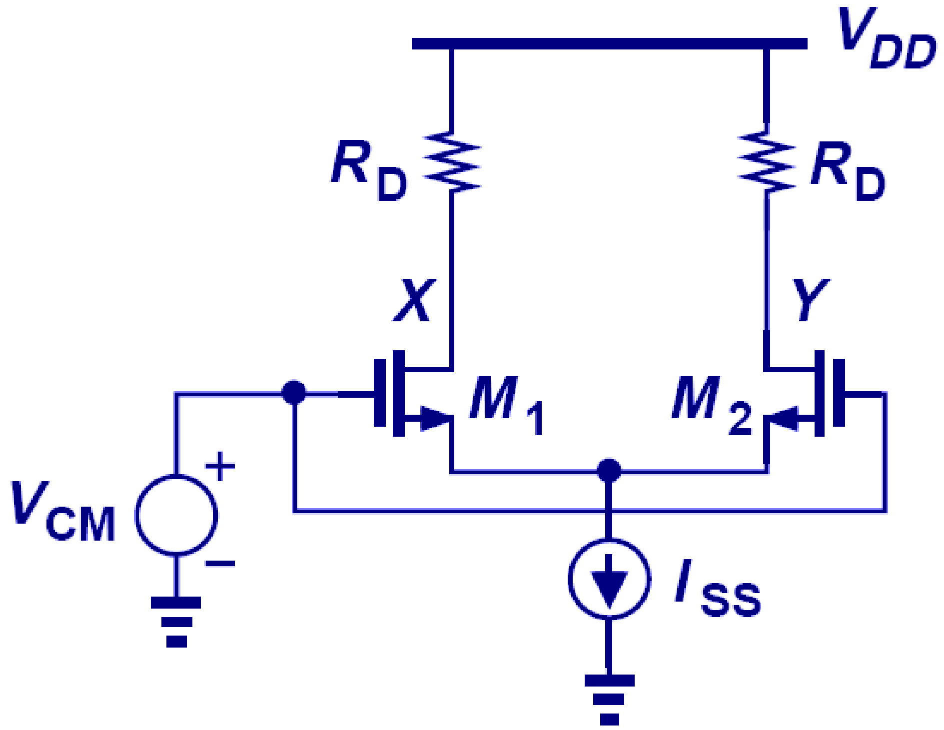
ΔI_{D2}=$-g_m \Delta V$

ΔV_X- ΔV_Y=-2 $g_m R_D$ ΔV

A_V=- $g_m R_D$

Similar to its bipolar counterpart, the MOS differential pair exhibits the same virtual ground node and small signal gain.

- Design an NMOS differential pair for a voltage gain of 5 and a power budget of 2 mW subject to the condition that the stage following the differential pair requires an output CM level of at least 1.6V. Assume $\mu_n C_{ox}$=100 μA/V^2, λ=0, and V_{DD}= 1.8 V.



Solution:-

I_{ss}=$\frac{2\ mW}{1.8\ V}$ = 1.11 mW

V_{CM}= V_{DD}-R_D $\frac{I_{SS}}{2} \geq 1.6\ V$

$R_D \leq 360\boldsymbol{\Omega}$

For R_D= $360\boldsymbol{\Omega}$

g_m=$\frac{A_V}{R_D}$=$\frac{5}{360\boldsymbol{\Omega}}$=$\sqrt{2\mu_n C_{ox} \frac{W}{L} \frac{I_{ss}}{2}}$

$\frac{W}{L}$=1738