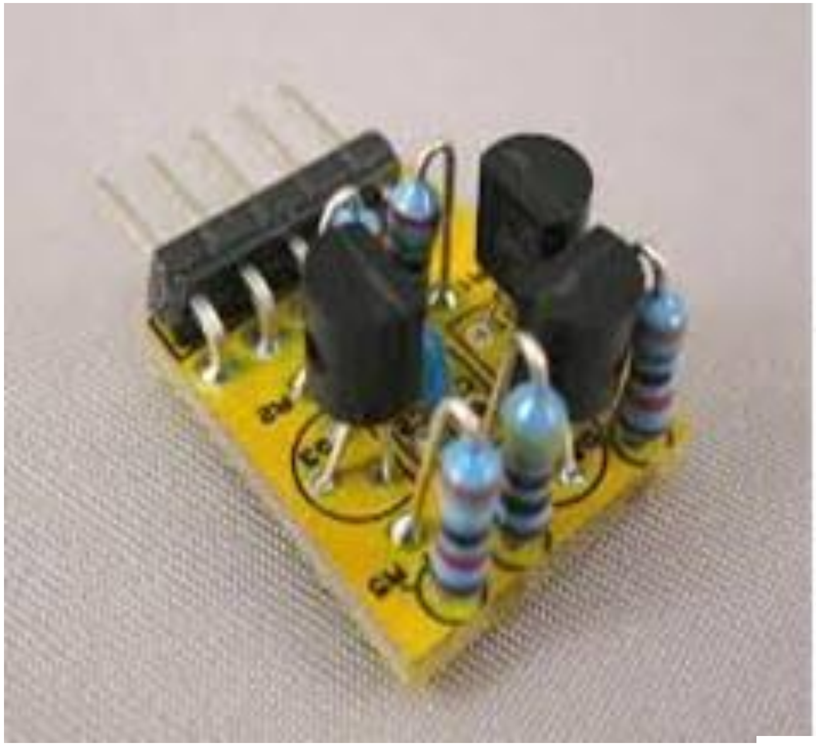
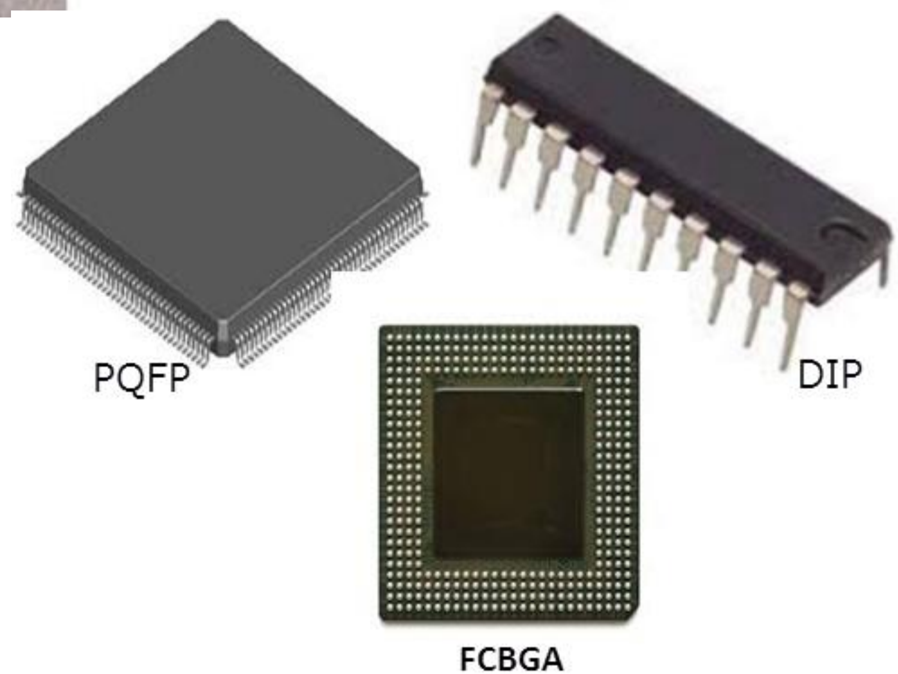
Module 3

MOSFET Active Biasing and Differential Amplifiers

Introduction to Current Mirror – Basic, Wilson and Cascode Current Mirror,MOSFET Basic Differential Pair, Large Signal and Small Signal Analysis of Differential Amplifier, Differential Amplifier with active load.




PQFP
DIP
FCBGA

Integrated circuits are made up of several components such as R, C, L, diodes and transistors. They are built on a small single block or chip of a semiconductor known as an integrated circuit (IC). All of them work together to perform a particular task. The IC is easily breakable, so to be attached to a circuit board, it is often housed in a plastic package with metal pins

The conventional method of making circuits was to select components like R, C, L, diode and semiconductors. There are so many factors stopping to build off big circuits like:

1. Bulky in size.
2. Not entirely shockproof
3. Reliability
4. More power consumption
5. Less durability

Current Mirror

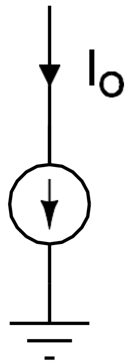
- **Current mirror method is a simple way to replicate well defined DC current sources in several independent circuit branches and is very popularly used in analog circuit design.**

- **Current source is also widely used as active load to improve amplifier gain.**

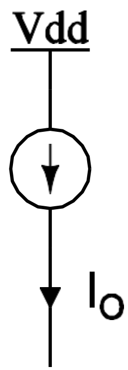
- **Current mirror is also a basic building block in current domain signal processing circuits.**

The current mirror is an analog circuit that senses the reference current and generates the copy or number of copies of the reference current, with the same characteristics. The replicated current is as stable as the reference current source. The replicated current could be the same as the reference current ($I_{copy} = I_{REF}$), or it could be either multiple or fraction of the reference current. ($I_{copy} = N*Iref$ or $I_{copy} = (1/N)*I_{REF}$).

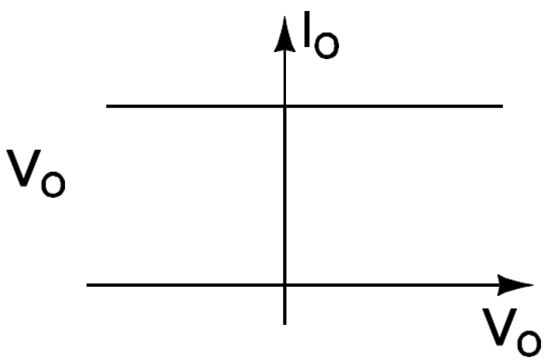
Types of Current Source



current sink

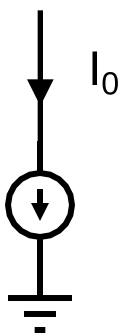


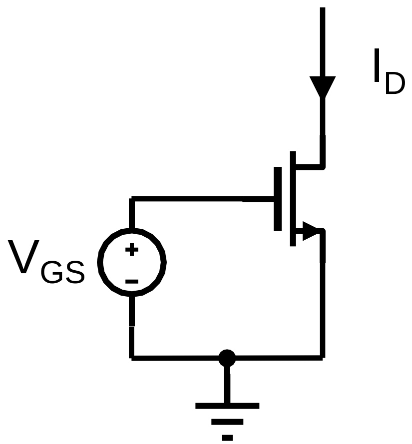
current source

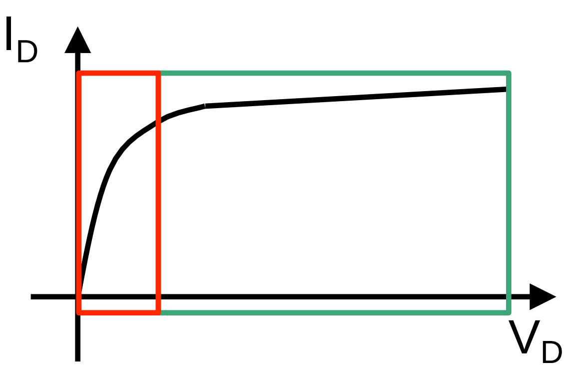


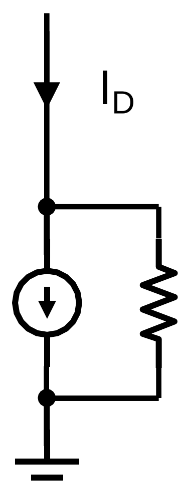
- Current source provides current to external circuit.
- Current sink receives current from the external circuit.
- we refer both current source and sink as current source.
- I-V plot of an ideal current source is shown.
- Current is not a function of the voltage across the current source.

Realization of Current Source

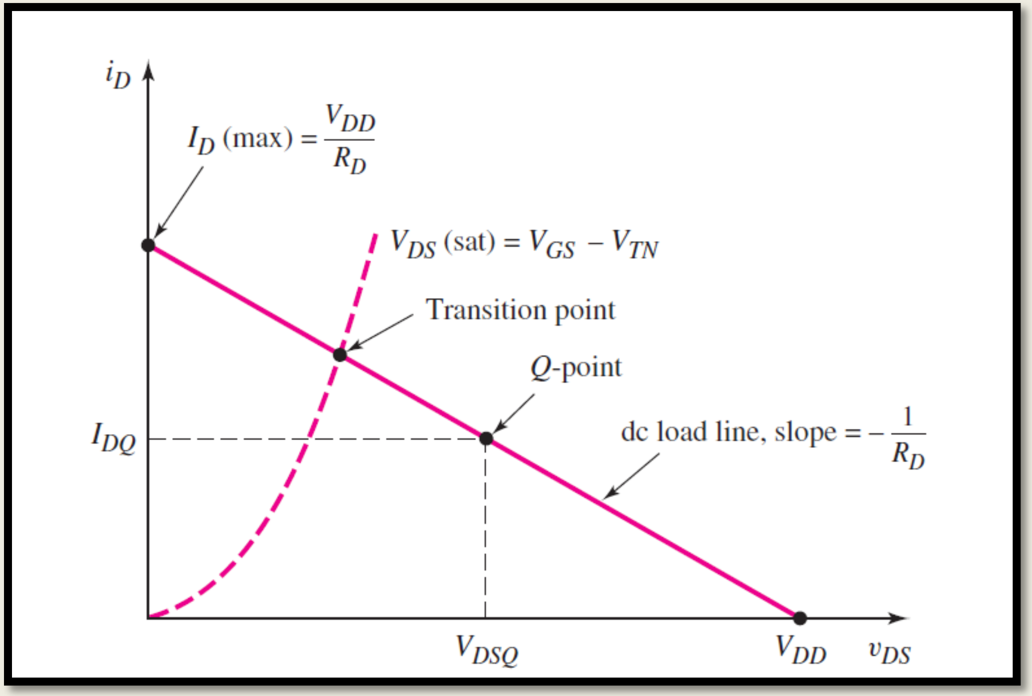


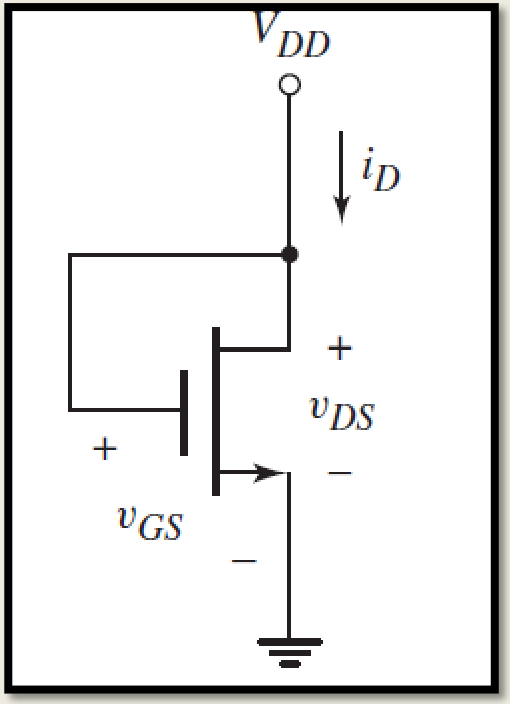






- Realization of current source by MOSFET in saturation region by providing certain V_{GS}.
- I_D is a function of V_{GS}.
- Due to the channel length modulation effect of the MOSFET, the output resistance of the current is finite.
- There is a minimum output voltage for the MOSFET current source, V_{DSsat} to keep the transistor in saturation region.

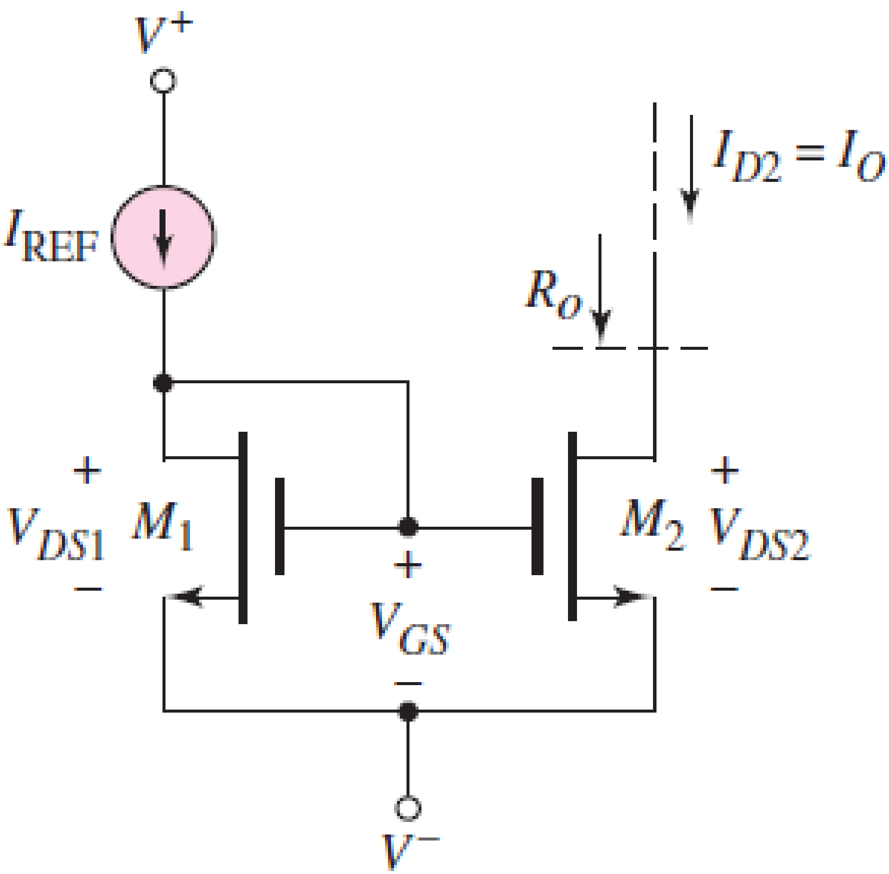




$$\boxed{v_{DS} = v_{GS} > v_{DS}(\text{sat}) = v_{GS} - V_{TN}}$$

$$\boxed{i_D = K_n(v_{GS} - V_{TN})^2 = K_n(v_{DS} - V_{TN})^2}$$

Current Mirror Basic

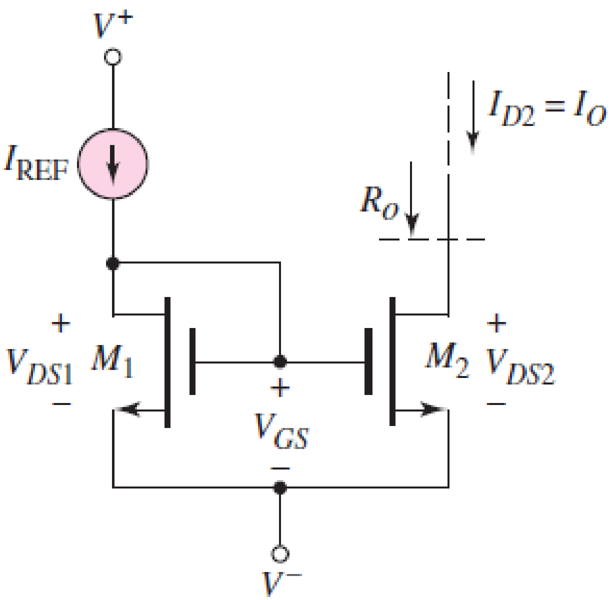


The drain and source terminals of the enhancement-mode transistor M1 are connected, which means that M1 is always **biased in the saturation region**.

Assuming Channel Length Modulation $\lambda = 0$ The drain current of M1 is given by

(1)

Current Mirror Basic



$$I_{REF} = I_{D1}$$

$$= \frac{1}{2} K'n \left(\frac{W_1}{L_1} \right) (V_{GS} - V_{TN1})^2$$

$$I_{REF} = K_{n1}(V_{GS} - V_{TN1})^2$$

Solving for V_{GS} yields

$$V_{GS} = V_{TN1} + \sqrt{\frac{I_{REF}}{K_{n1}}}$$

$$\frac{I_{REF}}{K'_n} = (V_{GS} - V_{TN1})^2$$

(1)

Wkt:

$$I_{REF} = I_{D1}$$

$$I_{REF} = \frac{V_{DD} - V_{GS}}{R}$$

The MOSFET M2 has the same VGS as M1; We assume that its operating in saturation we have

$$I_O = I_{D2} = \frac{1}{2} K'_{n2} \left(\frac{W_2}{L_2} \right) (V_{GS} - V_{TN})^2 = K_{n2} (V_{GS} - V_{TN2})^2$$

2

Wkt

Solving for V_{GS} yields

$$V_{GS} = V_{TN1} + \sqrt{\frac{I_{REF}}{K_{n1}}}$$

Substituting Equation we have

$$I_O = K_{n2}\left[\sqrt{\frac{I_{REF}}{K_{n1}}} + V_{TN1} - V_{TN2}\right]^2$$

Taking the ratio of equations 1 and 2 we get

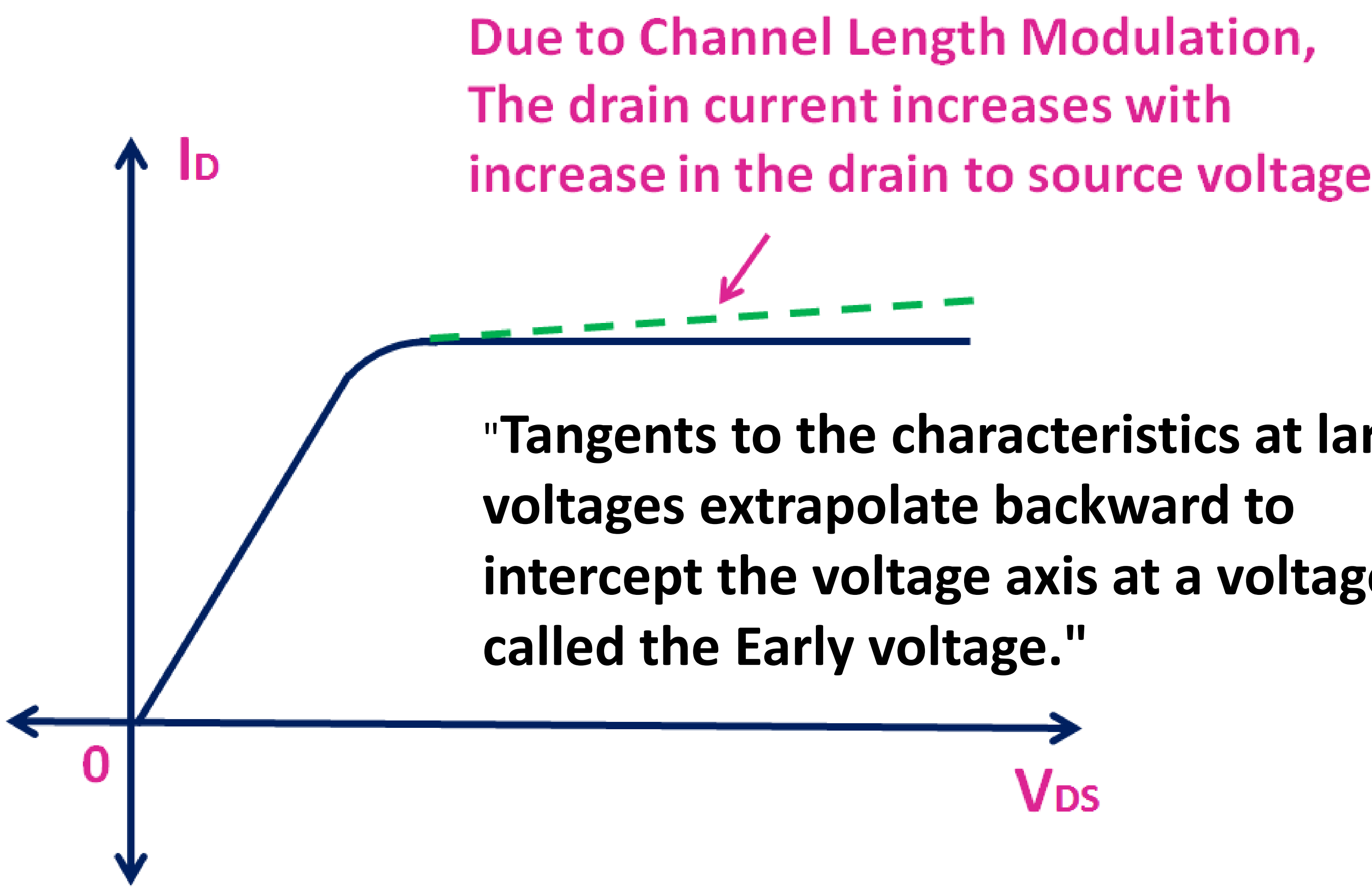
$$\frac{I_O}{I_{REF}} = \frac{I_{D2}}{I_{D1}} = \frac{\left(\frac{W_2}{L_2}\right)}{\left(\frac{W_1}{L_1}\right)}$$

If *M1 and M2 are identical transistors, then VT N1 = VT N2 and Kn1 = Kn2*

Since there is **NO GATE CURRENT in MOSFETS, the induced load current is identical to** the reference current, **provided the two transistors are matched.**

$$I_O = I_{REF}$$

Channel Length Modulation



"Tangents to the characteristics at large voltages extrapolate backward to intercept the voltage axis at a voltage called the Early voltage."

we can write the load and reference currents as follows:

$$I_O = K_{n2}(V_{GS} - V_{TN2})^2(1 + \lambda_2 V_{DS2})$$

and

$$I_{REF} = K_{n1}(V_{GS} - V_{TN1})^2(1 + \lambda_1 V_{DS1})$$

Since transistors in the current mirror are processed on the same integrated circuit, all physical parameters, such as V_{TN}, μ_n, C_{ox}, and λ, are essentially identical for both devices. Therefore, taking the ratio of I_O to I_{REF}, we have

$$\frac{I_O}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1} \cdot \frac{(1 + \lambda V_{DS2})}{(1 + \lambda V_{DS1})}$$

$$V_{DS2} + \Delta V_{DS2} = I_O + \Delta I_O$$

that $V_{DS1} = V_{GS1}$ = constant for a given reference current.

Normally, $\lambda V_{DS_1} = \lambda V_{GS1} < 1$, *and if* $(W/L)2 = (W/L)1$,

then the change in bias current with respect to a change in V_{DS2} is

Initial analysis we have neglected CLM

However it has significant effect on the operation of the current source circuit

1. **Vo increases above this value,Io also increases according to the incremental output resistance ro2 of M2**

Its given by

$$\frac{I_O}{I_{ref}} = \frac{1}{1}\frac{(1+\lambda V_{DS2})}{1}$$

$$I_O = I_{ref}(1+\lambda V_{DS2})$$

$$\frac{1}{R_0} = \frac{dI_O}{dV_{DS2}} = \frac{1}{r_O} = \lambda I_{\mathrm{Re}\,f}$$

Where

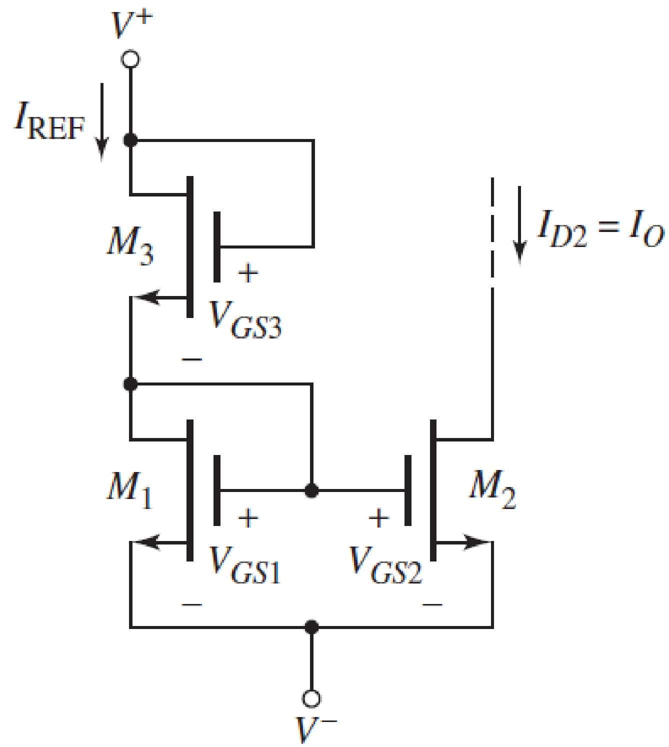
$$r_O = \frac{1}{\lambda I_{\mathrm{Re}\,f}}$$

$$\lambda = \frac{1}{V_A}$$

Replacing R by MOSFET

The reference current in bipolar current-source circuits is generally established by
the bias voltages and a resistor.

Since MOSFETs can be configured to act like a resistor, the reference current in MOSFET current mirrors is usually established by using additional transistors.



MOSFET current source

Transistors *M1 and M3 are in* series; assuming λ = *0, ALSO* $I_{D1}=I_{D3}$

$$K_{n1}(V_{GS1} - V_{TN1})^2 = K_{n3}(V_{GS3} - V_{TN3})^2$$

From the circuit, we see that

$$V_{GS1} + V_{GS3} = V^+ - V^-$$

Therefore,

$$V_{GS1} = \frac{\sqrt{\frac{(W/L)_3}{(W/L)_1}}}{1 + \sqrt{\frac{(W/L)_3}{(W/L)_1}}} \cdot (V^+ - V^-) + \frac{\left(1 - \sqrt{\frac{(W/L)_3}{(W/L)_1}}\right)}{\left(1 + \sqrt{\frac{(W/L)_3}{(W/L)_1}}\right)} \cdot V_{TN} = V_{GS2}$$

$$k_{n1}[V_{GS1} - V_{TN1}]^2 = K_{n3}[V_{Gs3} - V_{TN3}]^2$$

$$\left[\frac{W}{L}\right]_1 [V_{GS1} - V_{TN1}]^2 = \left[\frac{W}{L}\right]_3 [V_{Gs3} - V_{TN3}]^2$$

$$[V_{GS1} - V_{TN1}]^2 = \frac{\left[\frac{W}{L}\right]_3 [V_{Gs3} - V_{TN3}]^2}{\left[\frac{W}{L}\right]_1}$$

$$V_{GS1} - V_{TN1} = \sqrt{\frac{\left[\frac{W}{L}\right]_3 [V_{Gs3} - V_{TN3}]^2}{\left[\frac{W}{L}\right]_1}}$$

$$V_{GS1} - V_{TN1} = \sqrt{\frac{\left[\frac{W}{L}\right]_3}{\left[\frac{W}{L}\right]_1}}[V_{Gs3} - V_{TN3}]$$

$$X = \sqrt{\frac{\left[\frac{W}{L}\right]_3}{\left[\frac{W}{L}\right]_1}}$$

$$V_{GS1} - V_{TN1} = \sqrt{X}\left(V_{Gs3}\right) - \sqrt{X}\left(V_{TN3}\right)$$

$$V_{GS1} = \sqrt{X}\left(V_{Gs3}\right) - \sqrt{X}\left(V_{TN3}\right) + V_{TN1}$$

$$V_{GS1} = \sqrt{X}\left(V_{Gs3}\right) + \left[1 - \sqrt{X}\right]\left(V_{TN}\right)$$

$KVL:$

$$V_{Gs1} + V_{Gs3} = V^{+} - V^{-}$$

$$V_{Gs3} = V^{+} - V^{-} - V_{Gs1}$$

$$V_{GS1} = \sqrt{X}\left(V^{+} - V^{-} - V_{Gs1}\right) + \left[1 - \sqrt{X}\right]\left(V_{TN}\right)$$

$$V_{GS1} + \sqrt{X}\left(V_{Gs1}\right) = \sqrt{X}\left(V^{+} - V^{-}\right) + \left[1 - \sqrt{X}\right]\left(V_{TN}\right)$$

$$V_{GS1}(1 + \sqrt{X}) = \sqrt{X}\left(V^{+} - V^{-}\right) + \left[1 - \sqrt{X}\right]\left(V_{TN}\right)$$

$$V_{GS1} = \frac{\sqrt{X}}{(1 + \sqrt{X})}\left(V^{+} - V^{-}\right) + \frac{\left[1 - \sqrt{X}\right]}{(1 + \sqrt{X})}\left(V_{TN}\right) = V_{GS2}$$

Therefore,

$$V_{GS1} = \frac{\sqrt{\frac{(W/L)_3}{(W/L)_1}}}{1 + \sqrt{\frac{(W/L)_3}{(W/L)_1}}} \cdot (V^{+} - V^{-}) + \frac{\left(1 - \sqrt{\frac{(W/L)_3}{(W/L)_1}}\right)}{\left(1 + \sqrt{\frac{(W/L)_3}{(W/L)_1}}\right)} \cdot V_{TN} = V_{GS2}$$

Finally, the load current, for $\lambda = 0$, is given by

$$I_O = \frac{k_n'}{2} \cdot \left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN})^2$$

Cascode Current Mirror

1.In order to supress the effect of λ,we can force

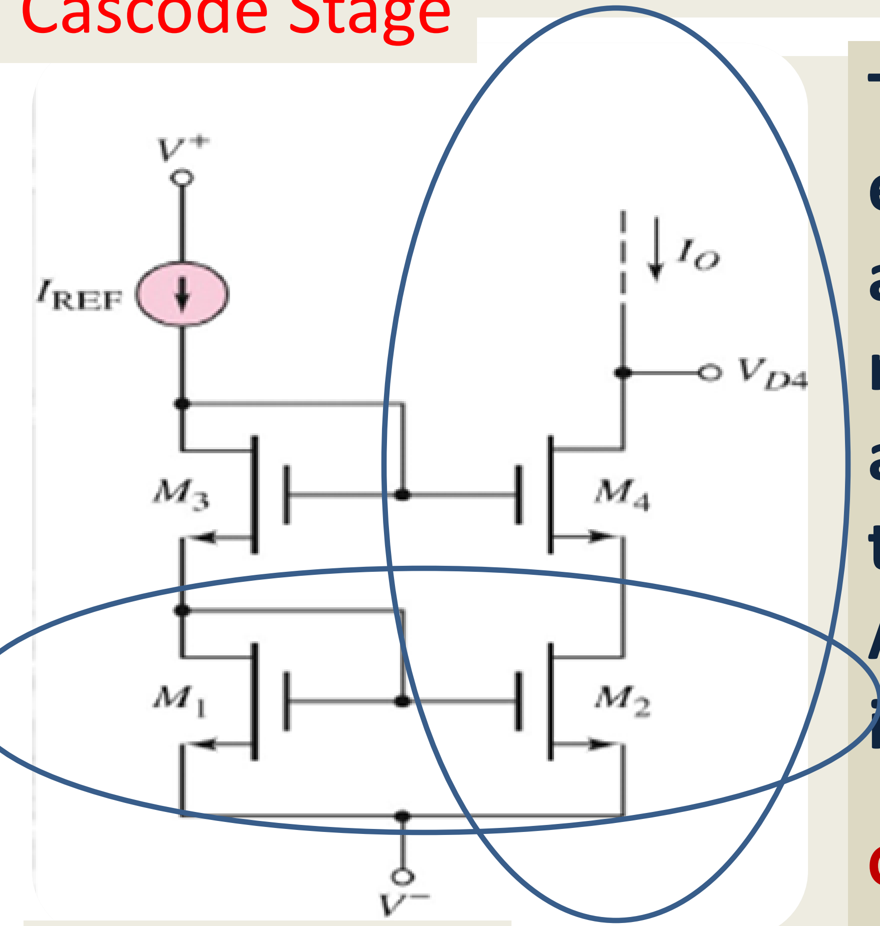
$$V_{DS1} = V_{DS2}$$

2.Its ensured by introducing cascode in the output stage

3. In MOSFET current-source circuits, the output resistance is a **measure of the stability with respect to changes in the output voltage**. This output resistance can be increased by modifying the circuit

Cascode Current Mirror

Cascode Stage



Current Mirror

The reference current is established by including another MOSFET in the reference branch of the circuit as was done in the basic two-transistor current mirror. Assuming all transistors are identical, then *IO* = *I*REF.

Gate voltages of M1 and M3 are constant, hence M2 and M4 also constant

Assume :

Generation of $\mathrm{V_B}$

$$V_{GS4} = V_{G4} - V_{S4} = V_B - V_Y$$

$$V_{DS2} = V_X, V_{DS1} = V_Y; \textit{For } \mathrm{V_{DS2}}=\mathrm{V_{DS1}}; V_Y = V_X$$

$$V_B = V_{GS4} + V_Y = V_{GS4} + V_X = V_{GS4} + V_{GS1} \ (\mathrm{WKT:}V_{DS1} = V_{GS1})$$

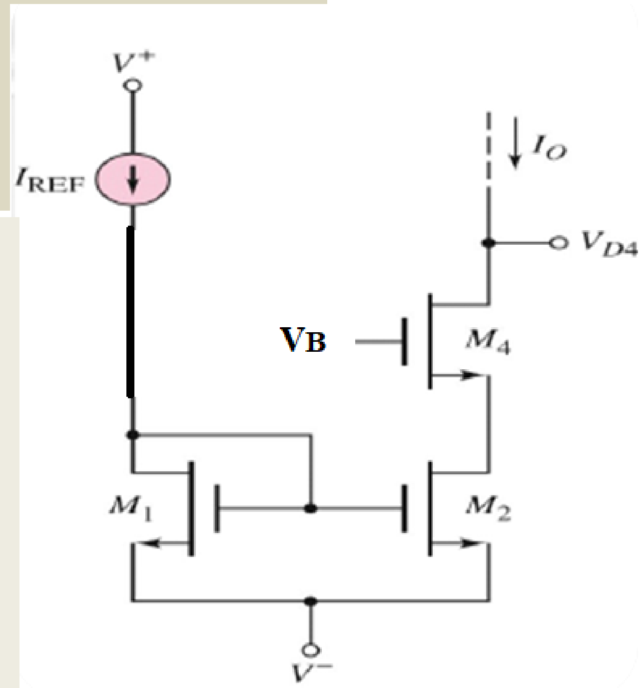
$$V_{DS1} \neq V_{DS2}$$

$$V_B = V_{GS4} + V_X$$

$$+V_B - V_{GS4} - V_Y = 0$$

$$V_{GS4} + V_X - V_{GS4} - V_Y = 0$$

$$V_X = V_Y$$



M1 is diode connected hence its in saturation

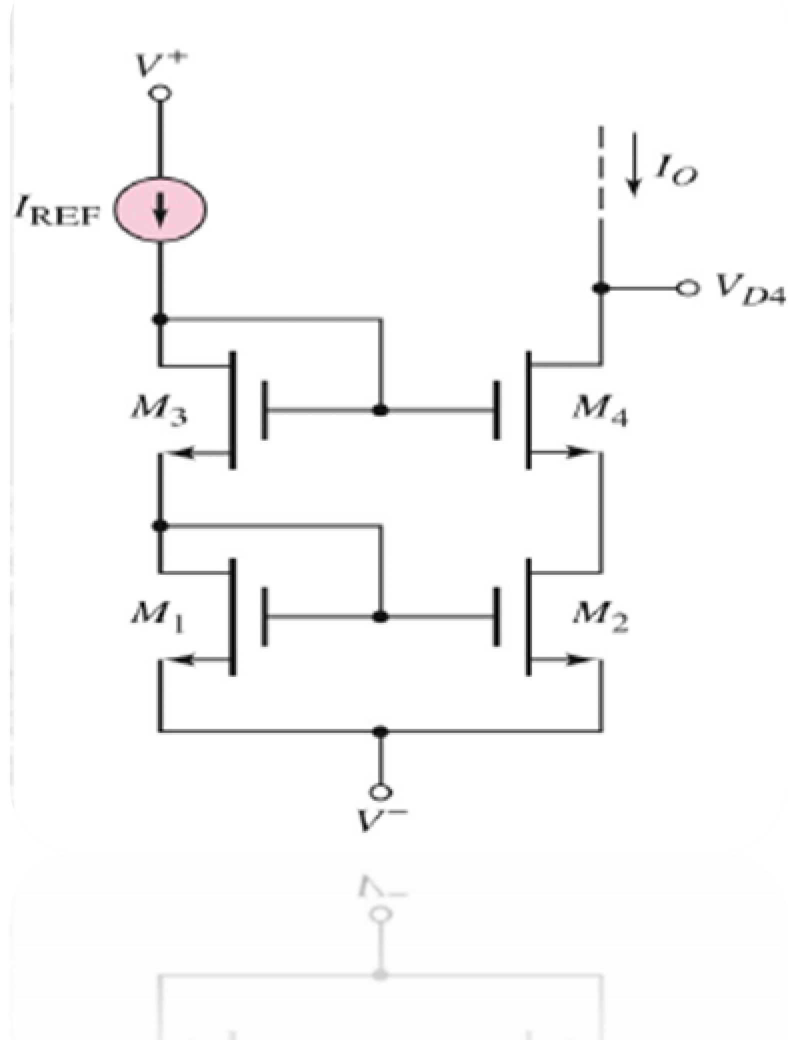
VGS1=VGS2 ,same current ID1 flow through M2 (Saturation)

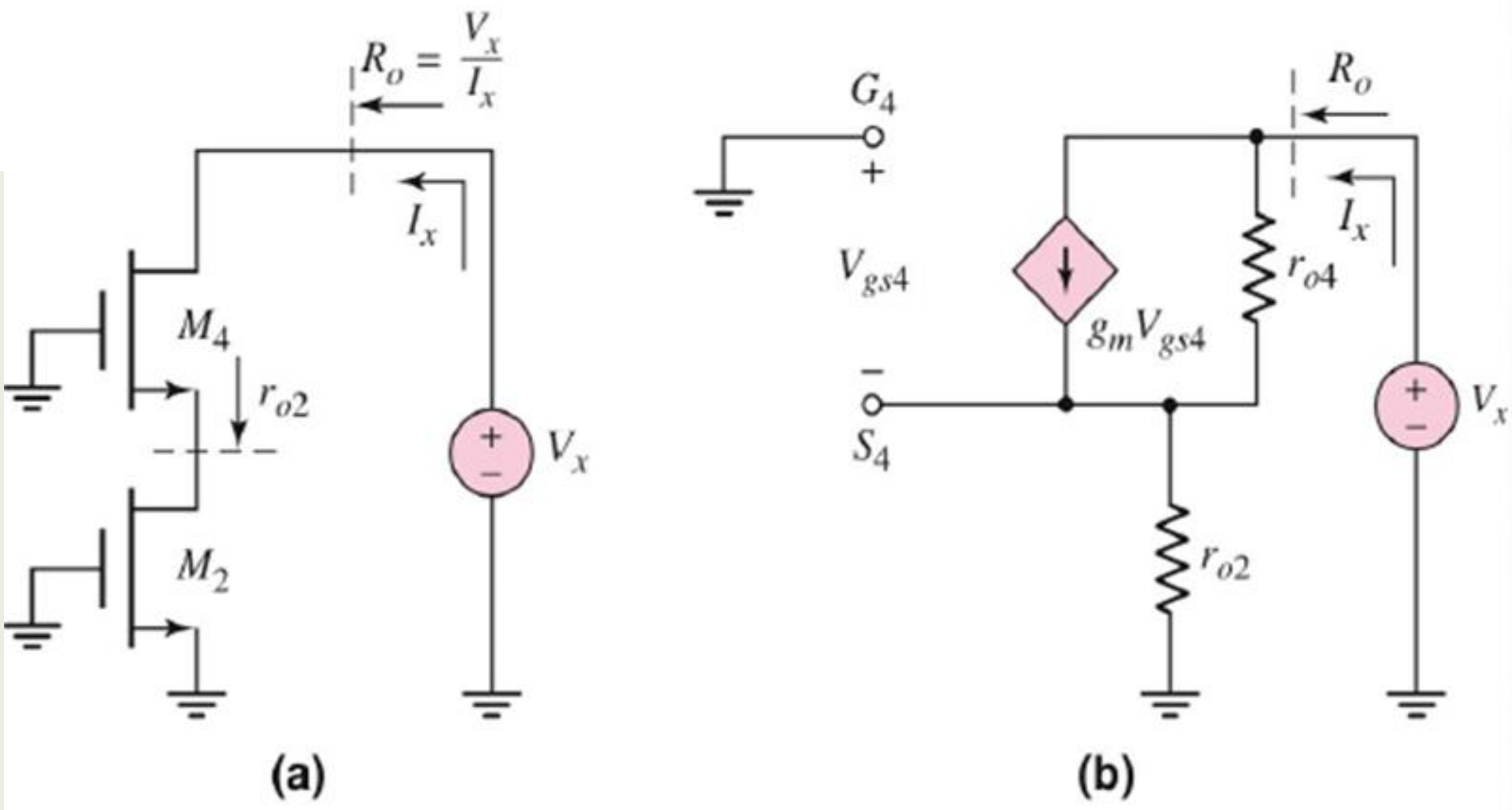
VB (Bias Voltage)=Saturation

Output Impedance

Draw the small signal equivalent

A diode connected MOSFET being fed by a constant current Behave as constant DC potential





For determining Ro

$$I_x = g_m V_{gs4} + \frac{V_x - (-V_{gs4})}{r_{o4}}$$

$$V_{gs4} = -I_x r_{o2}$$

$$I_x + \frac{r_{o2}}{r_{o4}} I_x + g_m r_{o2} I_x = \frac{V_x}{r_{o4}}$$

$$R_O = \frac{V_x}{I_x} = r_{o4} + r_{o2}\left(1 + g_m r_{o4}\right)$$

Normally

$$g_m r_{o4} >> 1 \Rightarrow g_m r_{o4} r_{o2} >> r_{o4}$$

$$R_O \cong g_m r_{o4} r_{o2}$$

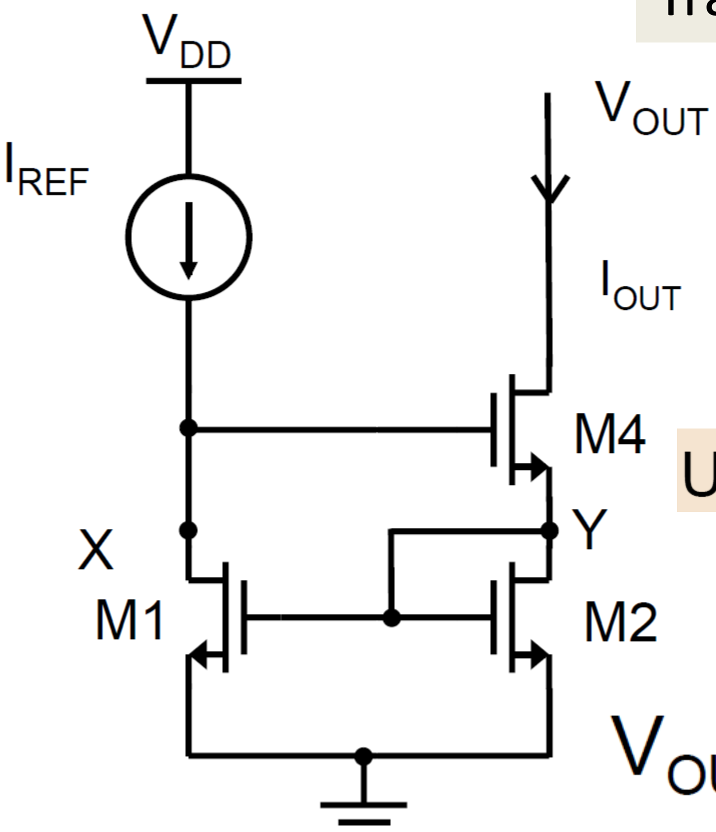
Output resistance of this cascode configuration much larger than basic two transistor Logic

dIO is proportional to 1/Ro

The load current in the cascode circuit is more stable against variations of the output voltage

Wilson Current Mirror

Transistor M1 and M2 have the same overdrive



$$\frac{I_{OUT}}{I_{IN}} = \frac{\left(W/L\right)_2 (1+\lambda V_Y)}{\left(W/L\right)_1 (1+\lambda V_X)}$$

Use feedback to stabilize the output current

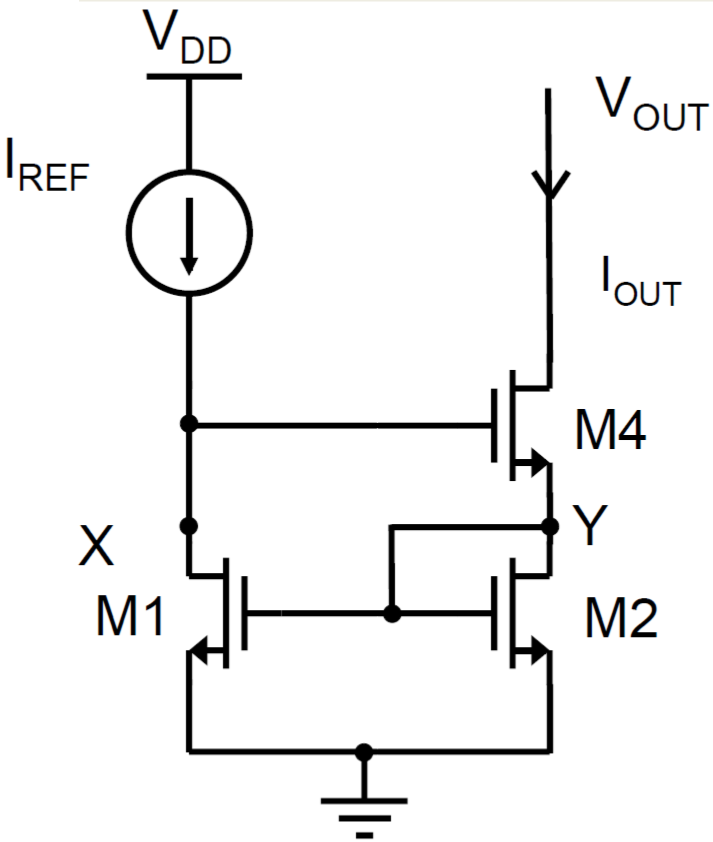
$V_{OUT}\uparrow \rightarrow I_{OUT}\uparrow \rightarrow V_Y\uparrow \rightarrow V_X\downarrow \rightarrow I_{OUT}\downarrow$

Circuit Source: Donald Neamen

- MOSFET IC Biasing
- Current source circuit

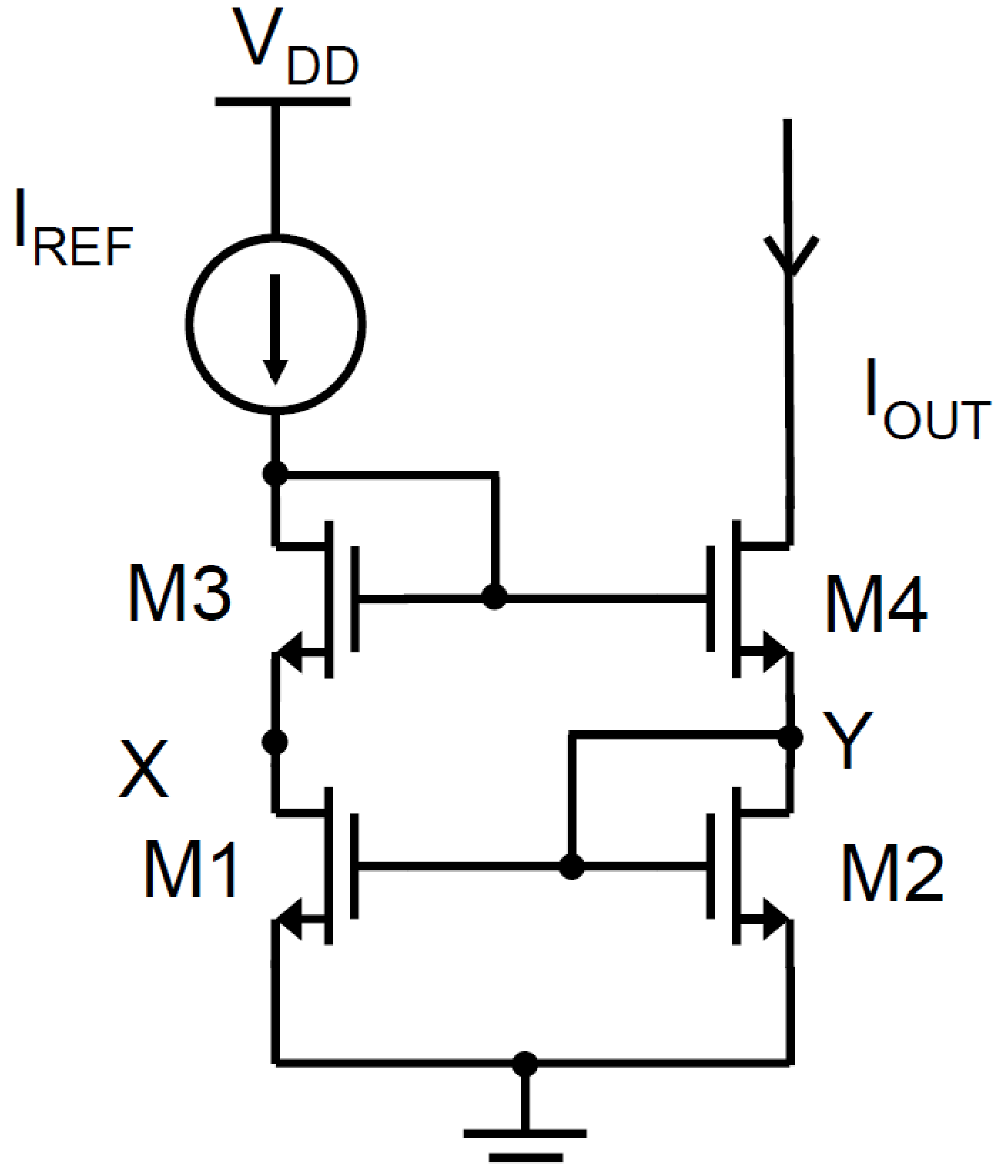
$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left[\frac{W}{L}\right]_1 (V_{GS} - V_{TN})^2(1+\lambda V_{DS1})$$

$$I_{out} = \frac{1}{2}\mu_n C_{ox}\left[\frac{W}{L}\right]_1 (V_{GS} - V_{TN})^2(1+\lambda V_{DS})$$



$V_{OUT}\uparrow \rightarrow I_{OUT}\uparrow \rightarrow V_Y\uparrow \rightarrow V_X\downarrow \rightarrow I_{OUT}\downarrow$

Modified Wilson current source



Two additional multi-MOSFET current sources are shown in Figure (a) The circuit is the **Wilson current source.**

Note:

V_{DS} *values of* $M1$ *and* $M2$ *are not equal. Since* λ *is not zero the ratio* $\frac{I_O}{I_{REF}}$ *is slightly different from the aspect ratios.*

This problem is solved in the **modified Wilson current source,** shown in Figure b, which includes transistor $M4$. For a constant reference current, **the drain-to-source voltages of** $\boldsymbol{M1}$**,** $\boldsymbol{M2}$**, and** $\boldsymbol{M4}$ **are held constan**t. **The primary advantage of these circuits is the increase in output resistance, which further stabilizes the load current**