**DC Voltage and Current Sources**

* Output characteristics of a BJT or MOSFET look like a family of current sources ... how do we pick one?

specify the gate-source voltage $V_{GS}$ in order to select the desired current level for a MOSFET (specify $V_{BE}$ exactly for a BJT)

how do we generate a precise voltage? ... we use a current source to set the current in a “diode-connected” MOSFET

\[ V_{DD} \quad I_{REF} \quad \downarrow \quad i_D \quad i_{OUT} \quad v_{OUT} \quad + \quad - \]

(note that this is a “one-port” ... NOT an amplifier!)

(wait a minute ... where do we find $I_{REF}$? Assume that one is available!)

\[ i_D = I_{REF} + i_{OUT} \approx \left( \frac{W}{2L} \right) \mu_n C_{ox} (v_{OUT} - V_{Tn})^2 \]
**DC Voltage Sources**

* Solving for the output voltage

\[
V_{OUT} = V_{Tn} + \frac{I_{REF} + i_{OUT}}{\sqrt{W \mu_n C_{ox}}} \frac{1}{2L}
\]

If \( I_D = 100 \mu A, \mu_n = 50 \mu AV^{-2}, (W / L) = 20, V_{Tn} = 1 V \), then

\[ V_{OUT} = 1.45 V \text{ for } I_{OUT} = 0 A. \]

* Stack up two diode-connected MOSFETs

![Diagram of diode-connected MOSFETs](image)
Totem Pole Voltage Sources

* Define a series of bias voltages between the positive and the negative supply voltages.

* In practice, output currents are small (or zero), so that the DC bias voltages are set by $I_{REF}$
MOSFET Current Sources

* Bias the n-channel MOSFET with a MOSFET DC voltage source!

![Diagram of MOSFET current source](https://via.placeholder.com/150)

* Intuitively, $V_{REF}$ is set by $I_{REF}$ and determines the output current of $M_2$

\[
V_{REF} = V_Tn + \sqrt{\frac{I_{REF}}{\left(\frac{W}{2L}\right)\mu_n C_{ox}}} = V_{GS1} = V_{GS2}
\]

Substituting into the drain current of $M_2$ (and neglecting $(1 + \lambda_n V_{DS2})$ term)

\[
i_{OUT} = i_{D2} = \left(\frac{W}{2L}\right)\mu_n C_{ox}(V_{GS2} - V_{Tn})^2
\]
MOSFET Current Sources (cont.)

* Output current is scaled from $I_{REF}$ by a geometrical ratio:

$$i_{OUT} = i_D = \left( \frac{W}{2L} \right)_2 \mu_n C_{ox} \left( V_{Tn} + \sqrt{\frac{I_{REF}}{\left( \frac{W}{2L} \right)_1 \mu_n C_{ox}}} - V_{Tn} \right)^2$$

$I_{OUT} = \left( \frac{(W/L)_2}{(W/L)_1} \right) I_{REF}$
MOSFET Current Source Equivalent Circuit

* Small-signal model: source resistance is $r_{o2}$ by inspection

* Combine output resistance with DC output current for approximate equivalent circuit ... actual $i_{OUT}$ vs. $v_{OUT}$ characteristics are those of $M_2$ with $V_{GS2} = V_{REF}$

The model is only valid for $v_{DS} = v_{OUT} > v_{DS(SAT)} = V_{GS} - V_Tn$
The Cascode Current Source

* In order to boost the source resistance, we can study our single-stage building blocks and recognize that a common-gate is attractive, due to its high output resistance

Adapting the output resistance for a common gate amplifier, the cascode current source has a source resistance of

\[ r_{oc} = (1 + g_m r_o 2)r_o 4 \approx g_m 4 r_o 4 r_o 2 \]

* Penalty for cascode:

needs larger \( V_{OUT} \) to function
MOSFET Current “Mirrors”

* n-channel current source *sinks* current to ground ... how do we *source* current from the positive supply? Answer: p-channel current sources...?

* By mixing n-channel and p-channel diode-connected devices, we can produce current sinks and sources from a reference current connected to $V_{DD}$ or ground.