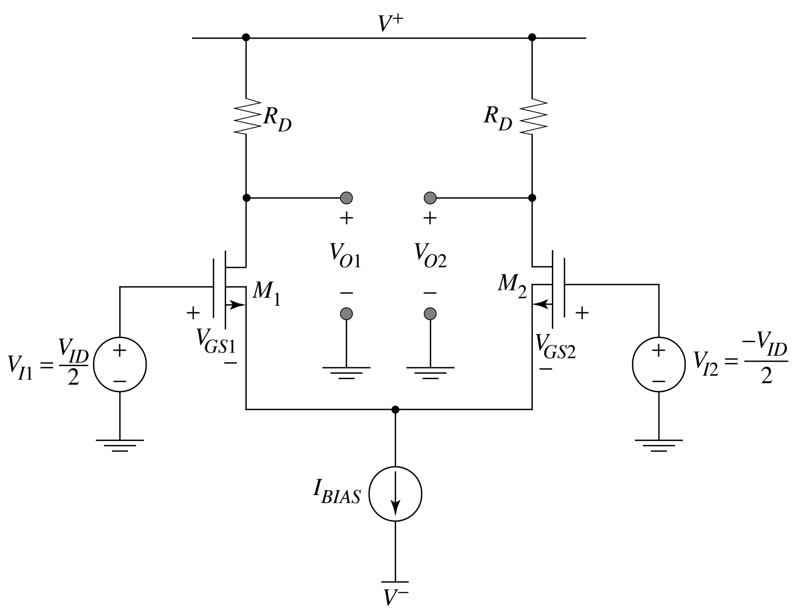
Large-Signal Response of MOS Differential Amplifiers

■ MOS differential amplifier



■ Kirchhoff's voltage law around input loop

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

For a sufficiently large positive differential input voltage, all of the current I_{BIAS} will be sunk through M_1 and M_2 will be cutoff.

Large-Signal Response of MOS Differential Amplifiers

- Solve for this critical value V_{ID}^* by setting $I_{D1} = I_{BIAS}$ and $I_{D2} = 0$ A

$$V_{ID}^* = \left(V_{Tn} + \sqrt{\frac{I_{BIAS}}{\left(\frac{W}{2L}\right)\mu_n C_{ox}}} \right) - V_{Tn} = \sqrt{\frac{I_{BIAS}}{\left(\frac{W}{2L}\right)\mu_n C_{ox}}}$$

- For $|V_{ID}| \le V_{ID}^*$ we can solve for the transfer function

$$I_{D1} = K_n(V_{GS1} - V_{Tn})^2 \text{ and } I_{D2} = K_n(V_{GS2} - V_{Tn})^2$$

where $K_n = (1/2)\mu_n C_{ox}(W/L)$

- Solving for $V_{GS1} - V_{GS2} = V_{ID}$

$$\sqrt{I_{D1}} - \sqrt{I_{D2}} = \sqrt{K_n}(V_{GS1} - V_{GS2}) = \sqrt{K_n} V_{ID}$$

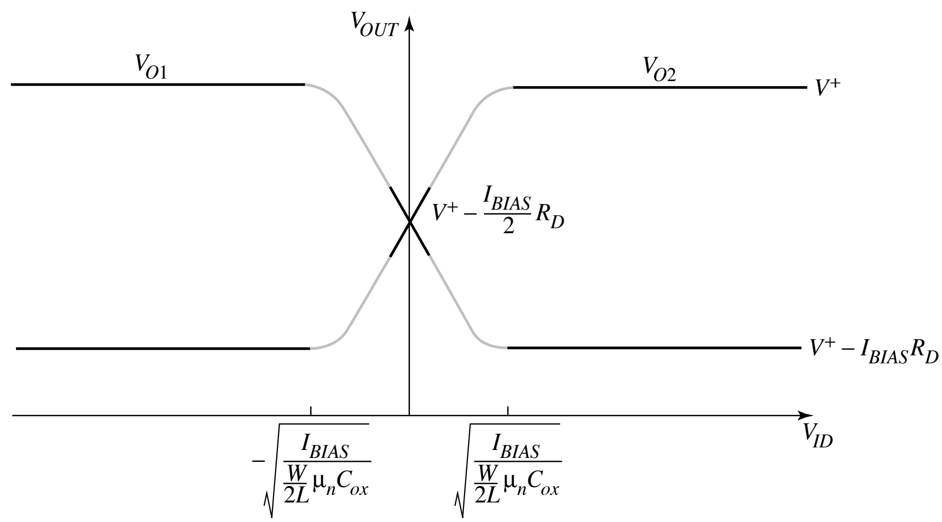
procedure:

use this equation and $I_{D1} + I_{D2} = I_{BIAS}$

solve for I_{D1} and I_{D2} as functions of V_{ID}

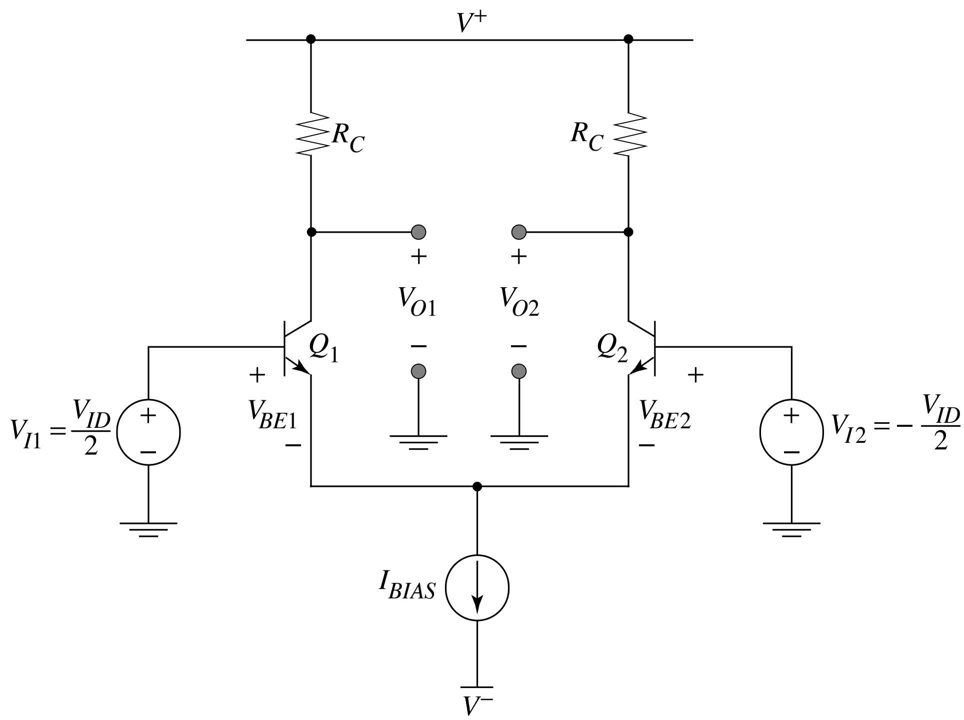
Large-Signal Transfer Function for MOS Differential Amplifier

- Transition width is adjustable via W/L and I_{BIAS}



Large-Signal Response of Bipolar Differential Amplifiers

- Find large-signal transfer curves for collector currents I_{C1} and I_{C2} and output voltages V_{O1} and V_{O2} as functions of V_{ID}



Quantitative Large-Signal Model

- $V_{ID} = V_{BE1} - V_{BE2}$

- Ebers-Moll for the forward-active region:

$$I_{C1} = I_S e^{V_{BE1}/V_{th}} = I_S e^{(V_{I1} - V_E)/V_{th}}$$

$$I_{C2} = I_S e^{V_{BE2}/V_{th}} = I_S e^{(V_{I2} - V_E)/V_{th}}$$

Dividing the two equations, the emitter voltage V_E can be eliminated:

$$\frac{I_{C2}}{I_{C1}} = e^{(V_{I1} - V_{I2})/V_{th}} = e^{V_{ID}/V_{th}}$$

Since the two emitter currents must sum to equal the bias current I_{BIAS}, the collector currents are also related by:

$$\left(\frac{1}{\alpha_F}\right)(I_{C1} + I_{C2}) = I_{BIAS}$$

Large-Signal Differential Response

- Solving for each current as a function of the differential input voltage $V_{ID} = V_{I1} - V_{I2}$:

$$I_{C1} = \frac{\alpha_F I_{BIAS}}{1 + e^{-V_{ID}/V_{th}}}$$

$$I_{C2} = \frac{\alpha_F I_{BIAS}}{1 + e^{V_{ID}/V_{th}}}$$

- Output voltages:

$$V_{O1} = V^+ - \frac{\alpha_F I_{BIAS} R_C}{1 + e^{-V_{ID}/V_{th}}}$$

$$V_{O2} = V^+ - \frac{\alpha_F I_{BIAS} R_C}{1 + e^{V_{ID}/V_{th}}}$$

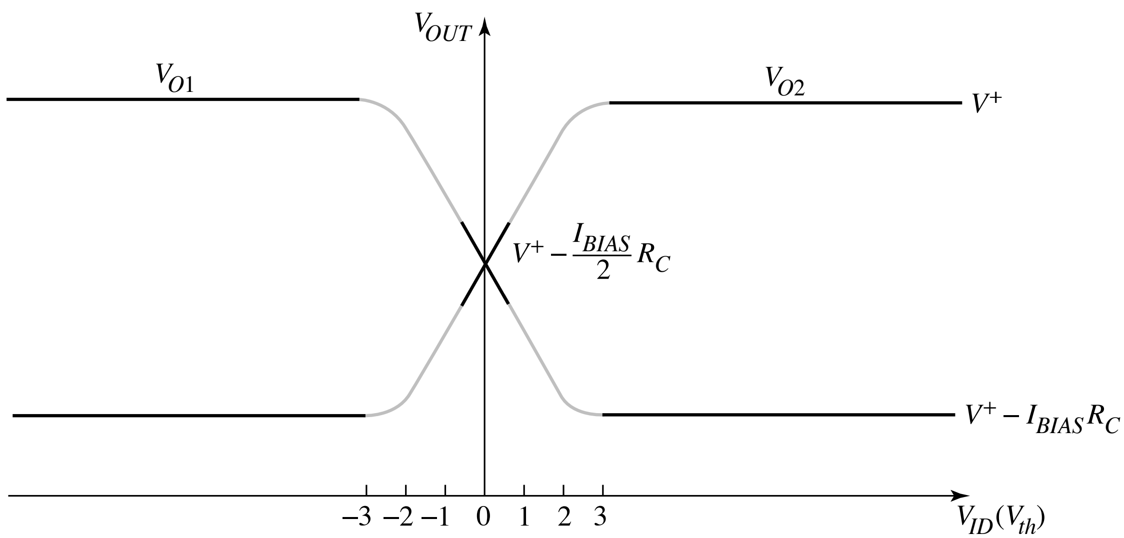
Transfer Functions for Bipolar Differential Amplifier

- Width of transition region

  look at current ratio in base 10 --

$$\frac{I_{C2}}{I_{C1}} = 10^{V_{ID}/60\ \text{mV}} \text{ --> } V_{ID} = (60\ \text{mV})\log(I_{C2}/I_{C1})$$

  factor of 10 difference --> V_{ID} = 60 mV ... practically, $\pm 3V_{th}$ will swing the output voltage between the limiting values



Large-Signal Transfer Function (Cont.)

- $V_{OD} = V_{O1} - V_{O2}$

  $V_{O1} = V_{CC} - I_{C1} R_C \quad V_{O2} = V_{CC} - I_{C2} R_C$

$$V_{OD} = (I_{C2} - I_{C1})R_C = \alpha_F I_{BIAS} R_C \left(\frac{1}{1 + e^{V_{ID}/V_{th}}} - \frac{1}{1 + e^{-V_{ID}/V_{th}}} \right)$$

... which can be written as:

$$V_{OD} = -\alpha_F I_{BIAS} R_C \tanh(V_{ID}/2V_{th})$$