LECTURE #35:  04/23
Differential Pair with single-ended output:

* We analyzed the single-ended current output which was the difference of the collector currents i.e. \( io = ic_1 - ic_2 \)

* We can realize the single-ended output by adding a current mirror load as shown in figure below:
Small-signal Analysis of the Differential Pair

* We concluded from the large signal analysis that the differential pair is linear around $\Delta V_{id} = 0$ for approximately $\Delta V_{id} = 2V_T$.

* Therefore, we'll derive all our small-signal parameters at $V_{id} = 0$ which implies

$$g_{m1} = g_{m2} = \frac{I}{V_T}$$

$$g_{m3} = g_{m4} = \frac{I}{V_T}$$

* Small-Signal Model: $R_0$ neglected
In this small-signal analysis we'll assume $B=\infty$ so the current through $I_{R_1}=0$ or $R_1=\infty$ and $V_A=0$ or $R_0=\infty$ for all the transistors.

\[ g_m3 \cdot V_3 = g_m1 \cdot V_1 \]

or \[ V_3 = \frac{g_m1 \cdot V_1}{g_m3} \]

\[ i_0 = g_mq \cdot V_3 - g_m2 \cdot V_2 \]

\[ = \frac{g_m \cdot g_m1 \cdot V_1}{g_m3} - g_m2 \cdot V_2 \]

Since, \[ g_m3 = g_mq \quad \text{and} \quad g_m1 = g_m2 = g_m. \]

\[ i_0 = g_m \cdot (V_1 - V_2) \]

And \[ V_1 - V_2 = V_{ip} - V_{im} = V_{id} \]

\[ \therefore i_0 = g_m \cdot V_{id} \]
Differential Pair:

\[ g_{m1} = g_{m2} \]
\[ g_{m3} = g_{m4} \]

\[ I + g_{m1} \cdot \Delta V_{id} \]
\[ I_0 = g_m \cdot \Delta V_{id} \]
\[ I - g_{m2} \cdot \Delta V_{id} \]
\[ V_{cm} - \Delta V_{id} \]

\[ V_{cc} \]

Differential Input Impedance: \( R_{id} \)

\[ R_{id} = \frac{V_{id}}{I_i} \]
\[ = \frac{V_{id}}{\frac{V_{id}}{2} \times \frac{1}{m}} \]
\[ = 2 \cdot R_m \]

\[ R_{id} = 2 \cdot R_m \]
Differential Pair Model:

\[ V_{ip} \quad + \quad V_{id} \quad \text{Rid} \quad g_m \cdot V_{id} \quad V_{im} \quad - \quad V_{o} \quad \text{Rod} \]

Where Rod is the output impedance of the differential pair.

* We'll delay the derivation of Rod for a later time.