Gain cell

\[ V_o \]

\[ V_i \]

\[ V_{th} \]

\[ 0 \]

\[ V_i \]

\[ V_o \]

\[ \Delta V_o \]

\[ R_D \]

\[ V_D \]

\[ M1 \]

Assume \( A = 0 \)

\( (\Gamma_o \rightarrow \infty) \)

\[ M1 \]

1. Cutoff
2. Active
3. Triode

Small-signal gain \( \frac{V_o}{V_i} \) is \( \frac{\partial V_o}{\partial V_i} \)

So \( \frac{V_o}{V_i} = 0 \) in 1

\( \frac{V_o}{V_i} \) small in 3
IN ② (ACTIVE)

GAIN DEPENDS ON $g_m$ WHICH DEPENDS ON $I_D$

$$\frac{V_o}{V_i} = -g_m R_D$$

$$g_m = \frac{2I_D}{V_{OV}}$$

$$V_{OV} = V_{GS} - V_{TN}$$

$$V_{OV} = V_I - V_{TN}$$

LARGEST GAIN OCCURS NEAR $V_I = V_i$

FOR A GIVEN TRANSISTOR & $I_D$

(HENCE GIVEN $g_m$) TO INCREASE $\frac{V_o}{V_i}$

NEED TO INCREASE $R_D$ BUT THEN

$V_{RD}$ TOO LARGE.

REPLACE $R_D$ WITH CURRENT SOURCE.
ASSUME $A = 0$  
($R_0 \to \infty$)

M1

1. CUTOFF
2. ACTIVE BUT $I_D < I_X$
3. ACTIVE $I_D = I_X$
4. TRIDEB

$V_1$ occurs when

$I_D = \frac{\mu W C}{2} \left( \frac{W}{L} \right) (V_1 - V_{tn})^2 = I_X$

Gain $\frac{V_D}{V_i}$ in 3 is $\infty$!!
IDEAL CURRENT SOURCE
THAT GOES TO \( I = 0 \) IF \( V \geq 0 \)

\[
\begin{align*}
V_{DD} & \quad \downarrow I \\
V & \quad \uparrow I_x \\
(\text{LOAD}) & \quad I = I_x \quad V > 0 \\
0 & \quad I = 0 \quad V \leq 0 \\
\end{align*}
\]
NOW ASSUME $x \neq 0$ (if finite)

\[ V_0 \]

\[ V_1 \]

\[ V_2 \]

\[ V_{en} \]

\[ V_I \]

\[ \text{FINITE SLOPE} \]

\[ \text{In 3) } \]

\[ g_m = \frac{2I_D}{V_0V} \]

\[ R_0 = \frac{L}{x^2 I_D} = \frac{V_A'L}{I_D} \]

\[ \frac{V_0}{V_i} = -g_m R_0 = - \frac{2I_D}{V_0V} \frac{V_A'L}{I_D} \]

\[ = - \frac{2V_A'L}{V_0V} \]

**TYPICAL**

\[ V_{0V} \approx 0.2 \text{ V} \]

\[ V_A' \approx 10 \text{ V/mm} \]

\[ \text{INTRINSIC GAIN} \]

\[ \approx 20 \text{ V/V} \]

\[ L = 0.2 \text{ mm} \]
BJT

\[ V_{cc} \]

\[ I_x \]

\[ V_i \]

\[ I_c \]

\[ V_o \]

VA FINITE

ACTIVE WHEN

\[ I_c = I_x \]

\[ \text{WHEN ACTIVE} \quad g_m = \frac{I_c}{V_T} \]

\[ \Gamma_0 = \frac{V_A}{I_c} \]

\[ \text{GAIN} \quad \frac{V_o}{V_i} = -g_m \Gamma_0 \]

\[ = - \frac{I_c}{V_T} \frac{V_A}{I_c} = -\frac{V_A}{V_T} \]

TYPICAL \quad V_A \approx 15V \quad \text{INTRINSIC GAIN}

\[ \sqrt{V_T} \approx 25mV \quad \approx 600 \frac{V}{V} \]

MUCH HIGHER THAN MOSFETS
PRACTICAL CURRENT SOURCE LOAD

\[ V_B \quad G \quad M_2 \quad V_B \text{ is constant} \]

DC VOLTAGE TO GENERATE \( I_X \)

\[ V_1 \quad M_1 < g m_1, \quad R_0 \]

SMALL-SIGNAL MODEL FOR \( M_2 \)

\[ V_B = 0 \quad \text{for small-signal} \]

\[ V_D = 0 \quad \text{for small-signal} \]

So INTRINSIC GAIN IS

\[ \frac{V_O}{V_I} = -g m_1 \left( \frac{R_0_1}{R_0_2} \right) = -\frac{1}{2} g m_1 \frac{R_0}{R_0} \]

IF \( R_0 = R_0_1 = R_0_2 \)