Current Mirrors

- We've been using resistive loads for our amps - I've preceded a change

\[ A_v = g_m \left( R_c || R_o \right) \quad \text{Fails like } R_c \text{ limits gain} \]
\[ A_{v, max} = g_m R_0 \]

- But making \( R_c \) really big crashes \( V_o \)
\[ V_o = V_{cc} - I_c R_c \quad \text{and } I_c \text{ is fixed} \]

- Merging equations reveals \( A_v = \Delta V/V_{th} \)

- Our swing/DC operating point is coupled to our gain, limits performance

- Fix this by biasing w/ current source

\[ A_v = g_m \left( R_c || R_{oi} \right) \quad \text{unrelated to DC value of} \]
\[ V_{out} \quad \text{(both in FAR)} \]

- Issue 1: How to make
- Issue 2: What is large signal \( V_o \)
We make $H$ using current mirrors (see on PSET)

- Take a closer look @ analysis today
- Basic idea $\bar{x}_c = T(u_{be})$ on left
  $\bar{x}_c = T^{-1}(u_{be})$ on right
  $= T(T^{-1}(u_{be}))$

- Figures of merit $\text{Vin}$ - watt minimized
  $\text{Vout, min}$ - minimize to max output swing
  $E = \frac{\text{Iout}}{\text{Vin}}$ - can have ERROR
  $R_{out}$ - small signal output impedance ($\rightarrow$ gain)

- Must evaluate different mirrors @ same $I_C$, $h_{fe}$ attains $V_{in}$,

In simple mirror draw KVL loop through $V_{be}$ drops

$V_{be1} = V_{be2}$ --- All mirrors have KVL @ heat

- surprisingly useful : translinearchat, etc.

  $I_b = I_s_1(e^{\frac{V_{be1}}{h_{fe}} - 1}) = I_s_2(e^{\frac{V_{be2}}{h_{fe}} - 1})$

- Current gain $h_F I_s_1 \neq I_s_2 \text{ Ohm same}$

  $I_{in} = I_{b1} + I_{c1} = (B+1) I_{b1}$

  $\bar{E} = \frac{B}{B+2}$

  $I_{out} = B I_{b1}$

- $V_{out, min} = V_{CC, sat}$ & $V_{in} = V_{be}$

- $R_{out} = r_o$
Use this as a load on a CE

- Set our base current, handy
- Need to pick $V_B$ so is far
- Still don't know DC Volt (1 mV)
  so don't have upper bound on $V_B$

Find $V_{out}$ using load line analysis (qualitative understanding)
or simulator (exact number)

- Large signal problem w/ many exponentials not tractable, little insight

Load line $I_C$

1. Pick $I_C$ here

Intersections define op. point, pick $I_C$ so in middle

Only have curve w/ $I_C$ for $Q_2$

2. Leads to $V_{out}$ here

- Actually simulate to make this graph when designing active loads
Simple mirror implies there are non-simple mirrors...

- One very common mirror is the cascaded mirror

\[ V_{in} = 2 \cdot V_{be}, \text{on} \]
\[ V_{out}, \text{on} = 2 \cdot V_{ce}, \text{get} \]

- Improved - Rgb is good, but gets worse &

\[ I_{E1} = I_{C2} + \frac{2 \cdot I_{E2}}{\beta} \quad \text{& note kul used to get} \quad I_{B2} = I_{B4} \]
\[ I_{IN} = I_{E1} + I_{C3}/\beta \quad \text{& assumes Vce4 = Vce1 by following diode drops around loop} \]
\[ I_{IN} = I_{C2} \left( 1 + \frac{2}{\beta} + \frac{1}{\beta^2} \right) \quad \text{& note} \quad I_{C3} = \frac{\beta}{\beta+1} I_{C2} \]

- Dynamics

\[ I_{out} = \frac{\beta \cdot I_{C2}}{\beta+1} \]
\[ \varepsilon = \frac{\beta}{\beta+1} - \frac{1}{1 + \frac{2}{\beta} + \frac{1}{\beta^2}} \]

- Cm shorted by or diode connection

- Cm sees diode so looks into \( \frac{1}{\gamma} \) \n
- Very approximate, OCTE covers

- One point is that it's usually PSD fast, not the issue