EE105 – Fall 2014
Microelectronic Devices and Circuits

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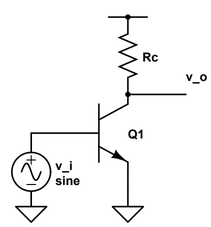
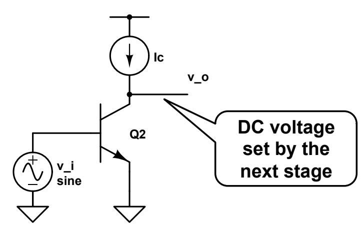
Common-Emitter Amplifiers with Ideal Current Source Load





Voltage gain:

$$A_V = -g_m(R_C \parallel r_o) = -g_m R_C$$

$$A_V = -\frac{I_C}{V_T}R_C = -\frac{V_{Rc}}{V_T}$$

Typical values:

$I_C \sim 1mA \quad R_C \sim 5k\Omega$

$A_V \sim -200$

Voltage gain:

$$A_V = -g_m(\infty \parallel r_o) = -g_m r_o$$

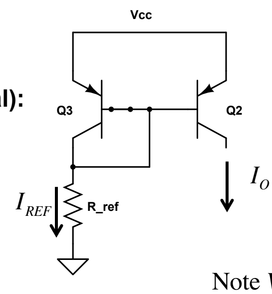
$$A_V = -\frac{I_C}{V_T}\frac{V_A}{I_C} = -\frac{V_A}{V_T}$$

Typical values:

$V_A = 100V$

$A_V \sim -4000$

Simple Current Source – Current Mirror



Q_2 and Q_3 are matched (identical):
- **Same I_S**
- **Same β**

Since $I_O \approx I_{REF}$

this is called "current mirror"

In this example,

$$I_{REF} = \frac{V_{CC} - V_{BE3}}{R_{REF}}$$

Note $V_{BE3} = V_{BE2}$

For simplicity, assume $V_A = \infty$

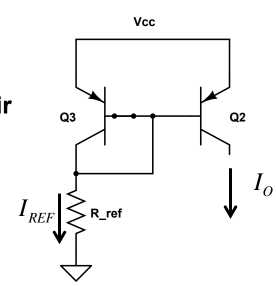
$$I_{C3} = I_S \exp\left(\frac{V_{BE3}}{V_T}\right) \qquad I_{C2} = I_S \exp\left(\frac{V_{BE2}}{V_T}\right) = I_{C3}$$

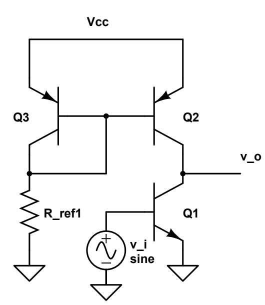
$$I_{REF} = I_{C3} + I_{B3} + I_{B2} = I_{C2} + \frac{I_{C2}}{\beta} + \frac{I_{C2}}{\beta}$$

$$I_O = \frac{I_{REF}}{1 + 2/\beta} \approx I_{REF}$$

CE Amplifier with Current Mirror Bias

Q_2 and Q_3 form a current mirror pair





$$I_O = \frac{I_{REF}}{1 + 2/\beta} \approx I_{REF}$$

$$A_V = -g_{m1}(r_{o1} \,||\, r_{o2})$$

Example:

$I_{REF} = 1mA,\ \beta_1 = \beta_2 = 100,\ V_{A1} = V_{A2} = 100V$

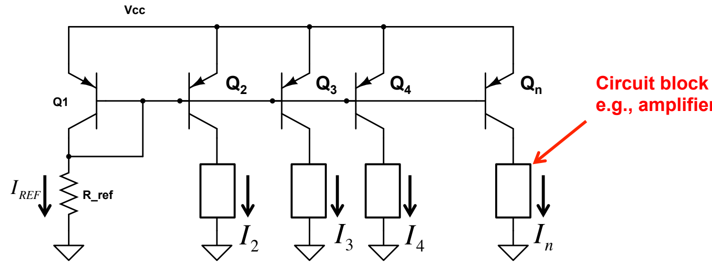
$g_{m1} = 40mS$

$r_{o1} = r_{o2} = 100V / 1mA = 100k\Omega$

$A_V = -40mS \cdot 50k\Omega = -2000$

Mirror with Multiple Current Sources

One reference current can support multiple amplifiers:



For simplicity, assume $V_A = \infty$

All V_{BE} are equal

$I_{C2} = I_{C3} = I_{C4} = ... = I_{Cn}$

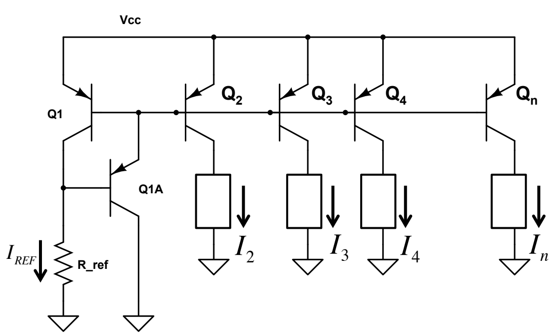
$I_{REF} = I_{C1} + I_{B1} + I_{B2} + ... + I_{Bn}$

$$I_i = \frac{I_{REF}}{1+\frac{n}{\beta}}$$

When n is large, $\frac{n}{\beta}$ is not negligible

Mirror with Multiple Current Sources

Use a BJT to boost up supplies to multiple base currents:



$V_A = \infty$

$$I_{REF} = I_{C1} + I_{B1A} = I_{C1} + \frac{I_{E1A}}{1+\beta}$$

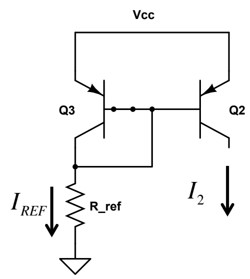
$$= I_{C1} + \frac{I_{B2} + I_{B3} + ... + I_{Bn}}{1+\beta}$$

$$= I_{C1} + \frac{nI_B}{1+\beta} = I_{C1} + \frac{I_{C1}/\beta}{1+\beta}$$

$$I_i = I_{C1} = \frac{I_{REF}}{1+\frac{n}{\beta(\beta+1)}} \approx I_{REF}$$

Current Mirror with Different Currents

Q_2 and Q_3 have same current gain, but different area.



$$I_{REF} = \frac{V_{CC} - V_{BE3}}{R_{REF}}$$

$V_{BE3} = V_{BE2}$

For simplicity, assume $V_A = \infty$

$$I_{C3} = I_{S3} \exp\left(\frac{V_{BE3}}{V_T}\right)$$

Recall $I_S = \frac{qA_E D_n}{W_B}\frac{n_i^2}{N_B} \propto A_E$

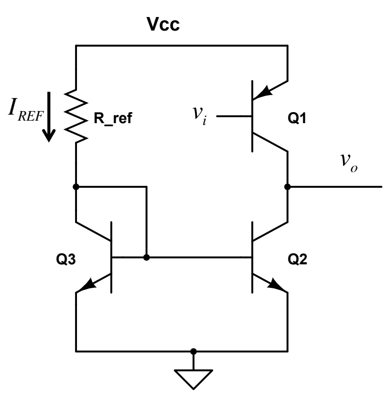
$$I_{C2} = I_{S2} \exp\left(\frac{V_{BE2}}{V_T}\right) = \left(\frac{A_{E2}}{A_{E3}}\right) I_{C3}$$

$$I_{REF} = I_{C3} + I_{B3} + I_{B2} = I_{C3} + \frac{I_{C3}}{\beta} + \frac{I_{C2}}{\beta}$$

$$I_2 = \left(\frac{A_{E2}}{A_{E3}}\right) I_{C3} = \left(\frac{A_{E2}}{A_{E3}}\right)\frac{I_{REF}}{1 + 1/\beta + \eta/\beta} \approx \left(\frac{A_{E2}}{A_{E3}}\right) I_{REF}$$

$$\eta = \frac{A_{E2}}{A_{E3}}$$

Current Mirrors for PNP CE-Amplifiers



$$I_{REF} = \frac{V_{CC} - V_{BE3}}{R_{REF}}$$

$A_V = -g_{m1}(r_{o1} \| r_{o2})$

Example:

$I_{REF} = 1mA,\ \beta_1 = \beta_2 = 100,$

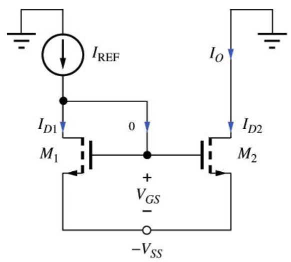
$V_{A1} = V_{A2} = 100V$

$g_{m1} = 40mS$

$r_{o1} = r_{o2} = 100V / 1mA = 100k\Omega$

$A_V = -40mS \cdot 50k\Omega = -2000$

MOS Current Mirrors
dc Analysis



$$V_{GS} = V_{TN} + \sqrt{\frac{2I_{REF}}{K_n(1+\lambda V_{DS1})}}$$

$$I_O = I_{D2} = \frac{K_n}{2}(V_{GS} - V_{TN})^2$$

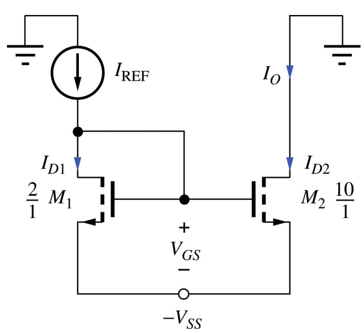
$$I_O = I_{REF}$$

MOSFETs M_1 and M_2 are assumed to have identical V_{TN}, $K_n{}'$, λ, and W/L ratios.

I_{REF} provides operating bias to mirror.

$V_{DS1} = V_{GS1} = V_{GS2} = V_{GS}$

MOS Current Mirrors
Changing the Mirror Ratio



$$K_{n1} = K_n'\left(\frac{W}{L}\right)_1 \qquad K_{n2} = K_n'\left(\frac{W}{L}\right)_2$$

$$I_O = I_{REF}\frac{K_{n2}(1+\lambda V_{DS2})}{K_{n1}(1+\lambda V_{DS1})}$$

For simplicity, $\lambda \approx 0$

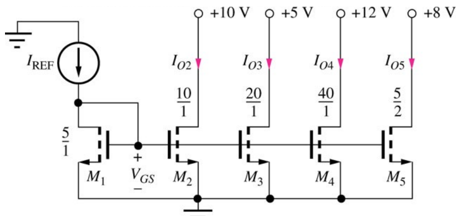
$$I_O = I_{REF}\frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

Mirror ratio can be changed by modifying W/L ratios of the two transistors forming the mirror.

In the given current mirror, $I_o = 5I_{REF}$.

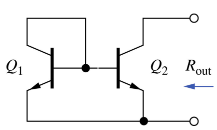
For non-zero λ, the current ratio will vary slightly due to mismatch in V_{DS}

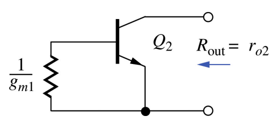
Current Mirrors with Multiple Current Sources



- Multiple sources can be operated from one reference transistor
- Reference current enters diode -connected transistor M1 establishing gate-source voltage to bias M2 through M5, each with a different W/L ratio.
- Absence of base current permits large numbers of MOSFETs to be driven by one reference transistor.

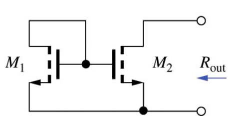
Current Mirrors
Input and Output Resistances

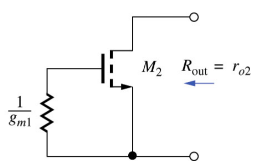




The input resistance of the current mirror is set by the diode connected transistors:

$$\therefore R_{in} \cong \frac{1}{g_{m1}}$$





The output resistance is equal to the output resistance of the Q_2 or M_2:

$$\therefore R_{out} = r_{o2}$$