Diode-connected BJT
Current Mirrors

- Current sources are created by mirroring currents
- Example: with infinite $\beta$, $I_o = I_{\text{REF}}$
Current Mirrors

- Example: with finite $\beta$

- What is the other reason for $I_{\text{REF}} \neq I_o$?
Output Resistance of Current Source, $R$

- What is the small signal output resistance of this current source, and why do we care?
Simple $I_{REF}$ Model

- Select $R$ to establish the required reference current
**Widlar current source**

- For a given Vcc, you need large resistor \( R \) values to obtain small current!
- Large resistors are expensive, Widlar current source uses smaller resistor in emitter to reduce achieve the same current?

\[
\begin{align*}
\text{I}_{o}\text{R}_E &= V_{BE1} - V_{BE2} \\
V_{BE1} &= V_T \ln \left( \frac{I_{REF}}{I_s} \right) \\
V_{BE2} &= V_T \ln \left( \frac{I_o}{I_s} \right) \\
V_{BE1} - V_{BE2} &= V_T \ln \left( \frac{I_{REF}}{I_o} \right) \\
\text{I}_{o}\text{R}_E &= V_T \ln \left( \frac{I_{REF}}{I_o} \right)
\end{align*}
\]
Widlar current source vs. ordinary current mirror

- Let us say we need \( I_0 = 10 \mu A \)
- Assume that for \( I = 1mA \) \( V_{BE} = 0.7 \)

\[
I_o R_E = V_T \ln(I_{REF}/I_o)
\]
Widlar current source - output resistance

- If we neglect $R \parallel r_{e1}$, base of $Q_2$ is on ac ground

- Presence of $R_E$ is increases output resistance to $(1+g_m R_E \parallel r_\pi)r_o$.
  (Read Sec. 6.4 in the textbook!)
Current Steering

- With an $I_{REF}$ established, steer and/or scale the reference value
Reading IC circuit schematics

- Find a path between + power supply and - power supply which sets the reference current (very often there is only one even in a large circuit): Only $V_{BE}$ and resistors are in this path.

- Type of transistor will tell you the expected direction of current: npn - current sink, pnp - current source.

- Identify current mirror configurations (Widlar, Wilson, etc.) and respective emitter areas.

- Proceed from the reference current branch and calculate subsequent currents independently.
Beta Dependence

- When “steered” to several points, the $I_o$ dependence on $\beta$ can be a problem.
Simple Opamp Example

- First stage is used to reject common mode voltages
- The 2nd diff amp and level shifting stage provide the gain
- The input diff amp also provides the large input resistance
- Why is Q6 designed to be 4x larger than Q3?
Differential Amplifiers: Active Loads

- IC resistors are impractical
- Active loads provide current-source-like loads, hence large small signal gains
Differential Amplifiers: Active Loads

- The output in this example is single-sided, but behaves sort of differentially
- The output is a current, proportional to $v_d$ --- transconductance amplifier

![Circuit Diagram]

- Assuming infinite $\beta$, what is the output current when $v_d = 0$?
Common Mode Gain

- If all of the parameter values are exactly matched to one another, and $\beta=100$, will there be any common mode gain?

- Will there be any dc offset?
Small Signal Gain, $G_m$
Small Signal Gain, $G_m$
Transconductance Stage of Opamp Model

- The voltage gain of stage 1 depends on the output impedance of stage 1 and the input impedance of stage 2
Transconductance Amplifier Voltage Gain

- Active loads are often designed to maximize $R_o$