1 Improvements to Simple Current Mirrors

During the lab last week you were asked to analyze several versions of a simple current mirror. In this lab you will be analyzing improvements which can be made to the simple current mirror, specifically, a simple current mirror with a beta-helper, a Widlar current source and a cascode current mirror. There are two salient features which must be kept in mind when analyzing a current mirror: 1) the output impedance; the higher the output impedance the more the current mirror will look like an ideal current source (which is the goal in current mirror/current source design) and 2) the output voltage range; the output voltage range which keeps ALL transistors operating in the desired region, typically, where the transistors are each behaving like current sources (Fwd. Active for the Bipolar Transistor and Saturation for the MOS Transistor). Two examples of improvements to simple current mirrors are shown in figure 1: (a) a Simple current mirror with a Beta-helper and (b) a Widlar current source.

![Diagram of simple current mirror with a beta-helper and a Widlar current source.](image)

Figure 1. Current Mirror Diagrams: (a) Simple current mirror with a Beta-helper and (b) a Widlar current source.

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One problem with the approximate analysis with the simple current mirror in bipolar technology is that the base current is often ignored. When a device is simulated or built a small current from the reference source flows through the bases of the current mirror transistors. This creates a small error which can grow as the copied current or as the number of copied current mirrors increases. If the base current is included in the analysis then this effect can be quantified. One method used to compensate for this error is to include a 3rd transistor which provides base-current compensation; the so-called beta helper shown in figure 1 (a). A second improvement to a simple current mirror is often required when small currents are needed. If the reference current source is replaced with a resistor, a very large value will be required in order to generate a small current. A Widlar current source requires the addition of one resistor, $R_E$, to the emitter of the transistor generating the copied current. There are two advantages with this approach: 1) the output impedance is improved over $r_o$ by a significant factor and 2) the value of $R_E$ required to generate a small current is quite small.

The last improvement we will examine is the cascode current mirror shown in figure 2.

![Figure 2. Bipolar Cascode Current Mirror.](image)

This current mirror offers a considerable improvement over the simple current mirror in terms of the output impedance; however, the penalty is a limit in the output voltage range.

The Widlar current source and the cascode current mirror have versions in both Bipolar and MOS transistors. Both allow for similar improvements beyond the simple current mirrors discussed previously. The simple current mirror with the addition of a 3rd transistor to compensate for base currents is only useful with Bipolar technology.
2 Lab Description

This lab is focused on characterizing current mirrors. A generic measurement set up is shown in figure 3. The reference current, $I_{ref}$, is generated by the input voltage source, $V_{rail}$ and the resistor, $R_x$. The output voltage, $V_o$, will be controlled by the second voltage source, $V_2$.

![Figure 3. Set up to characterize the current mirror.](image)

The $I - V$ curve for the current source can be generated by varying $V_o$ from 0V to $V_{cc}$. The MPQ6XXX, Quad Dual-In-Line Complementary transistor Pairs, will be used for this lab. The data sheet with pin connections will be provided on the lab web page.

This experiment will be repeated for the simple bipolar pnp transistor current mirror.

3 Lab Instructions

1) Simulate the circuit in figure 1 (a). Find the resistor value, $R_x$ in figure 3 required to set $I_{ref} = 800\mu A$ with $V_{rail} = 10V$ (assume $V_{BE} = 0.7V$). Plot the $I - V$ curve for the simple npn Bipolar current mirror with compensation for base current, that is, $I_o$ vs. $V_o$. You will need to measure $I_o$ for selected values of $V_o$ using the SPICE simulator in MultiSim.

   i) Determine the lowest value that $V_o$ can be while still operating as a current source.

   ii) Graphically find $Z_o$, or $R_o$, the output resistance of the current mirror.

2) Construct the circuit in figure 1 (a) on a bread-board. Measure values of $I_o$ for selected values of the second voltage source.
i) Determine the lowest value that $V_o$ can be while still operating as a current source.

ii) Graphically find $Z_o$, or $R_o$, the output resistance of the current mirror.

iii) Does this match your SPICE simulation?

3) Repeat these measurements (steps #1 & #2) for the Widlar current source shown in figure 1 (b) in both SPICE and with a bread board. Select $R_x$ in figure 3 required to set $I_{ref} = 80\mu A$ with $V_{rail} = 5V$ (assume $V_{BE} = 0.7V$).

4) Repeat these measurements (steps #1 & #2) for the cascode current source shown in figure 2 in both SPICE and with a bread board. Select the value of $R_x$ required to set $I_{ref} = 800\mu A$ with $V_{rail} = 10V$.

4 Write Up

Include the following results in your write up:

1) For each of the 3 measurements:
   (a) Record the values of the resistors used in your design.

   (b) Record the SPICE simulation results.

   (c) Record the measurement results.

   (d) Record the calculations, simulated measurements and actual measurements for $Z_o$ and the lowest value for $V_o$.

2) Do the measured results compare well with the simulated results (for the simple npn and pnp current mirrors)? Explain why it does or does not agree.

3) Do the measurements and simulations agree with your calculated results (for the simple npn and pnp current mirrors)? Explain this also.
5 Questions

1) Find the relationship between $I_{ref}$ and $I_o$ for the Widlar current source shown in figure 1 (b). Ignore the base currents; e.g. $I_{ref} = I_{C1}$; $I_o = I_{C2}$. (hint: Find an expression which relates $V_{BE1}$, $V_{BE2}$ & $I_o$).

2) The current source, $I_{ref}$, was replaced with a resistor, $R_x$, in your experiment with the Widlar current source in figure 1 (b). Design a simple current mirror and a Widlar Current Source which each provide $I_o = 10\mu A$ (replace the current ideal source with a resistor, $R_x$). Assume $V_{CC} = 5V$.

   i) Select the resistor values, $R_x$ & $R_E$, for the Widlar Current Source. Select the value of $R_x$ to set $I_{ref} = 1mA$. Use the expression derived in the first question to find the value of $R_E$ required to set $I_o = 10\mu A$. Note: Assume $V_{BE} = 0.7V$ for $I_C = 1mA$ ($V_T = 26mV$).

   ii) Select the resistor, $R_x$, to set $I_o = 10\mu A$ in the Simple Current Mirror.

   iii) If $V_A = 100V$, find an expression for $Z_o = R_o$ for each source (assume $r_{\pi2} \gg R_E$ for the Widlar Current Source); compute the values and compare them.

   iv) Compare the two resistor sizes, $R_x$ & $R_E$, required for the Widlar Current Source to the size of the resistor, $R_x$, required to bias the simple current mirror at $10\mu A$. 