Experiment #3

Transistor current sources

I. INTRODUCTION

Transistor current sources are important circuit blocks both for biasing analog circuits such as emitter-coupled pairs and for use as load elements of transistor amplifiers. In this experiment we will explore the simple current source, the Widlar current source, and the cascode current source from the standpoint of output current and output resistance. You should read the first part of Chapter 4 in the text book before starting.

II. BACKGROUND

A simple current source consists of two transistors with their bases and emitters connected (see figure 1). This configuration is often called the current mirror. Since the base-emitter voltage is the same for both transistors, the collector currents will be identical, provided that:

a) the two transistors are "matched"
b) both are forward active (Q1 is always forward active. Why?)
c) $\beta_F >> 1$
d) $V_A$ large

![Figure 1. Simple current source](image-url)
The collector current of Q2 ($I_{OUT}$) will match that of Q1 ($I_{C1}$), provided that all the previous conditions have been met. A plot of $I_{OUT}$ versus $V_{OUT}$ of transistor Q2 is shown in figure 2.

Figure 2. $I_{OUT}$ versus $V_{OUT}$

Figure 2 shows that as $V_{OUT}$ increases above $V_{CE\ SAT}$, transistor Q2 enters the forward active region. When in this region, transistor Q2 can be modeled as a current source in parallel with a resistance $R_O$ (figure 3):

Figure 3. Equivalent model of current source
where $1/R_0$ is the slope of the $I_{\text{OUT}}$ vs. $V_{\text{OUT}}$ curve in the forward active region, and $I_0$ is the Y-intercept when this curve is extended (fig. 2).

III. SIMPLE CURRENT SOURCE

Design a simple current source to realize a current output of 100μA, with $V_{\text{cc}}=10$ volts. Use your calculated value for $R_1$ and build the following circuit.

![Simple current source circuit](image)

Figure 4. Simple current source

Now measure the output current as a function of $V_{\text{OUT}}$ from 0 to 0.5 volts in 0.1 volt steps, and from 0.5 to 10 volts in 0.5 steps. From this data, plot $I_{\text{OUT}}$ vs. $V_{\text{OUT}}$ and determine the equivalent $I_0$, $R_0$ (see figure 3) and the equivalent open circuit voltage $V_{\text{TheV}}$ for the current source ($V_{\text{TheV}} = I_0 R_0$).

IV. MULTIPLE CURRENT SOURCES

Two (or more) current sources can be built by "chaining" more transistors to the basic configuration of figure 4. Build a second current source by adding transistors Q4 & Q5 to the circuit built in part III (see figure 5). Be sure to tie the unused collector of Q2 to $V_{\text{cc}}$ so that Q2 will not saturate and $I_{B2}$ will remain small.
Again, measure the output current \( I_{\text{OUT}} \) as \( V_{\text{OUT}} \) varies between 0 and 10 volts. Determine the equivalent \( I_0 \), \( R_0 \), & \( V_{\text{Thev}} \). Compare these values with the values obtained from part III. How are they different or similar? Why?

![Figure 5. Multiple current sources](image)

V. WIDLAR CURRENT SOURCES

Using the Widlar circuit shown below (figure 6), design a current source to realize a current output of 10\( \mu \)A, with the same \( R_1 \) and \( V_{\text{CC}} \) as in part III. Measure the output current for \( V_{\text{OUT}} = 1, 5, \) & 10 volts. Determine \( I_0 \) and \( R_0 \). Calculate \( R_0 \) using small-signal analysis (use data from lab 1 as needed), and compare the calculated and measured values. Notice the high value of \( R_0 \).
VI. CASCODE CURRENT SOURCE

Construct the cascode current source shown below (figure 7) using two transistor pairs. Compute $R_O$ and $V_{Thev}$ by measuring the output current $I_{OUT}$ for $V_{OUT} = 1$ volt & 10 volts. Note that you will be measuring very small changes in current because of the very high output resistance. Calculate $R_O$ using small-signal analysis (see text, Sec. 4.2.5.1) and compare the calculated and measured values.

Figure 7. Cascode current source
EEC114 Lab Results:

Experiment #3 - TRANSISTOR CURRENT SOURCES

III. SIMPLE CURRENT SOURCE

\[ R_1 = \_
\]
\[ I_0 = \_
\[ R_0 = \_
\]
\[ V_{Thev} = \_
\]

IV. MULTIPLE CURRENT SOURCE

\[ I_0 = \_
\[ R_0 = \_
\]
\[ V_{Thev} = \_
\]

V. WIDLAR CURRENT SOURCE

\[ R_2 = \_
\]
\[ I_0 = \_
\]

measured \[ R_0 = \_
\]

\[ V_{Thev} = \_
\]

calculated \[ R_0 = \_
\]

VI. CASCODE CURRENT SOURCE

\[ I_0 = \_
\]

measured \[ R_0 = \_
\]

\[ V_{Thev} = \_
\]

\[ \text{calculated } R_0 = \_
\]