A current sink controlled by two reference voltages

Abstract. This article describes the biasing circuit of a BJT operating as a current sink with two reference voltage sources, the first reference voltage controls the load current, while the second reference voltage controls the collector-base junction voltage of the BJT. As a result, the estimator of the correlation coefficient between the load current and the load resistance was obtained about four times smaller compared to the classical current sink.

Keywords: current source, effect of a base width modulation, automatic bias point control, load current standard deviation, correlation coefficient

Introduction

Current sources, performed in different technology, are widely used in measurement applications such as electron-impact mass spectrometers, ionization gauges [1, 2], bio-impedance spectrometers [3-5] and other, for example, Hall effect instruments. Bipolar junction transistors (BJT) are characterized by good temperature properties and low costs. However, a one-BJT current source or sink cannot ensure a stable collector current as a function of a load resistance because of changes in a base current with changes in a collector-base junction voltage. This unwanted dependency is caused by the effect of a base width modulation, known as the Early effect [6]. The diagram of the basic BJT current sink (BJTCS), consisting of the transistor \( T_1 \), the emitter resistance \( R_E \) for a current feedback, the reference voltage source \( V_{ref1} \) and additionally, the operational amplifier OA1, operating as an error amplifier, is shown in figure 1 in full lines.

![Fig. 1. A simplified diagram of the basic BJT current sink (full lines, switch S(a)) and with additions (broken lines, switch S1(b)) introduced in this work.](image)

The present additions marked in broken lines will be discussed later in this text. Assuming infinite input resistance and voltage gain for the operational amplifier OA1 and consequently a virtual short circuit between its inputs (+ and −), the voltage drop across resistor \( R_E \) is equal to the reference voltage \( V_{ref1} \), which leads to:

\[
I_E = \frac{V_{ref1}}{R_E}
\]

The emitter current is maintained at a pre-set constant value, but the load current, \( I_L \), is also dependent on the collector-base junction voltage [7]:

\[
I_L = \frac{I_{E1}}{1 + \frac{\beta_0 \exp(V_{CBI}/V_A)}}
\]

where \( \beta_0 \) is a dc current gain factor of the transistor \( T_1 \) at \( V_{CBI}=0 \) and \( V_A \) is the “Early voltage”. According to the diagram of the basic BJT current sink the collector-base junction voltage, \( V_{CBI} \), may be written as follows:

\[
V_{CBI} = V_{CC} - I_L R_L - V_{BE1} - I_{E1} R_E
\]

where \( V_{BE1} \) is the base-emitter voltage of BJT1.
The plot in figure 3 shows an example of the collector-base junction voltage as a function of the load resistance $R_L$ at a constant load current value for the basic BJTCS. The measurements have been done for the transistor BF459 (Siemens), the operational amplifier CA 3140 (Intersil Corporation) and the reference voltage stabilizer REF 01 (Analog Devices). It can be seen while $R_L$ increases $V_{CB1}$ decreases and consequently, according to expression (2), the load current changes as shown in figure 4. The dependency of $I_L$ on $V_{CB1}$ may be reduced by using an open loop system to control the collector-emitter voltage of the output BJT [8], but to achieve a satisfactory solution an automatic control of $V_{CB1}$ should be applied [9].

This work describes the BJTCS, which allows additionally setting and automatic controlling the collector-base junction voltage of the output BJT. Owing to that, the high load current quality has been obtained. The presented biasing circuit can be used optionally as a basic or novel BJTCS and is therefore highly suitable to quickly and easily compare considered current sinks (important for corresponding undergraduate laboratories). The biasing circuit is characterized by a simple and original design and a relatively low cost in terms of components, manufacturing and testing.

**Fundamental concepts of the design**

The complete schematic diagram of the present BJTCS is shown in figure 1, with the circuit upgrade shown in broken lines.

The switch $S_1(b)$ connects the output of the operational amplifier OA1 with the load resistor $R_L$. The collector-base junction voltage stabilizer is based on the operational amplifier OA2. The resistor $R_{T1}$, the collector-base junction of $T_1$ and the instrumental amplifier $I_{A1}$ form the negative feedback loop for OA2. The $I_{A1}$ operates as a differential amplifier. A unity dc voltage gain. The operational amplifier, OA2, single-ended collector-base junction voltage converter with a high load current quality has been obtained. The presented biasing circuit is characterized by a simple and original design and a relatively low cost in terms of components, manufacturing and testing.

![Diagram](image_url)

**Circuit details**

Most of the current sink details are shown in figure 2.

![Diagram](image_url)

**Results and conclusions**

In order to verify the presented idea, the measurements of $V_{CB1}$ and $I_L$ were performed. Figures 3 and 4 show plots of the collector-base junction voltage of the $T_1$ and the load current, respectively, as a function of the load resistance for the current sinks considered above.
It is seen from these figures that the stabilized collector-base junction voltage, $V_{CB}$, of the T1 (figure 3) improves the load current quality as a function of the load resistance (figure 4). The present BJTCs can maintain $I_L$ constant within 0.06% (it is a value of load current standard deviation in the full range of load resistance). The load voltage, in our case, is in the range from 0V to 93.636V.

The measurements were performed by means of digital multimeters, Agilent 34461A. The total current measurement error (including the reading error and the range error) is less than 0.030% over the full measurement range and the tolerance of the load resistance is less than 0.05%.

To compare the performance of the discussed circuits the estimator, $r$, of the correlation coefficient between the load current and the load resistance has been determined with the following formula:

$$r(I_L, R_L) = \frac{\sum_{i=1}^{N} (I_{L_i} - \overline{I_L})(R_{L_i} - \overline{R_L})}{\sqrt{\sum_{i=1}^{N} (I_{L_i} - \overline{I_L})^2 \sum_{i=1}^{N} (R_{L_i} - \overline{R_L})^2}}$$

where: where $\overline{I_L}$, $\overline{R_L}$ are, respectively, average values of load current and load resistance and $N$ is the number of measurement points.

The obtained values of $r$ were 0.99 and 0.25 for the basic and novel current sinks, respectively.

The designed biasing circuit of BJT can be operated optionally as the basic or novel current sink (a choice can be realised with one switch), which can be utilized to quickly and easily study and compare their parameters, for this reasons it could be a useful supplement for corresponding undergraduate courses.

The advantages of the present BJTCs can be listed as follows:

1. The percentage standard deviation of the load current is of 0.06% in the full range of the output voltage (0-93.6)V.
2. The collector-base junction voltage of BJT is kept at a pre-set constant value over the whole operating range.
3. A constant value of the collector-base voltage allows a stable electrical collector-base junction capacitance to be maintained.
4. The novel BJTCs is simple, convenient in operation and inexpensive.

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REFERENCES