A CURRENT-MODE LOGARITHMIC FUNCTION CIRCUIT

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A new current-mode analog circuit configuration that implements the function $\ln(x/y)$ is proposed. The circuit uses bipolar transistors and resistors and is suitable for integration. In the proposed circuit the ratio (x/y) can be larger or smaller than unity. Simulation results are included.

Keywords: Function generator; Bipolar transistors

1 INTRODUCTION

Logarithmic functions are widely used in many applications; for example, instrumentation, telecommunication, neural networks, medical equipment, disk drives, and active filters. This justifies the continuing interest in developing logarithmic function circuits manifested by the relatively large number of publications in this area; see for example Refs. [1–19] and the references cited therein. Traditionally, a logarithmic function circuit, with input voltage and output voltage (or current) can be realized by exploiting to advantage the inherent exponential transconductance characteristic of the pn junction in a diode [12], bipolar transistor [5], or LED [16], to introduce the required nonlinearity into a circuit based on a current-feedback-operational [12], a transimpedance-amplifier [19], an operational-amplifier [1, 16], a transconductance-feedback-amplifier [18], or a current-conveyor [13]. Alternatively, a pseudo-logarithmic function can be implemented using piecewise linear approximations and cascaded limiting amplifiers [6]. This logarithmic function can be realized in GaAs heterojunction bipolar transistor (HBT) technology [2, 3], GaAs MESFET technology [4, 15], bipolar, CMOS or BiCMOS technology [8–11, 14]. On the other hand, current mode circuits, with current inputs and current outputs, enjoy the attractive features of a wide current signal dynamic range even with low power supply voltages and wide bandwidths. Recently, a bipolar current-mode logarithmic function generator circuit has been reported [17]. This circuit can realize a logarithmic function of the form

$$I_{\text{out}} = C \ln \frac{I_{\text{in1}}}{I_{\text{in2}}}, \quad (1)$$

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where C is a constant, I_{out} is the output current, and I_{in1} and I_{in2} are the input currents. However, since I_{out} must be positive, then the condition $I_{in1} > I_{in2}$ must be satisfied. Thus, the circuit cannot realize a true logarithmic function circuit where I_{in1} and I_{in2} can attain arbitrary positive values and I_{out} can attain any positive or negative value. The major intention of this paper is, therefore, to present such a circuit.

2 PROPOSED CIRCUIT

The proposed circuit is shown in Figure 1. Ignoring the base-currents, for the translinear network formed of transistors Q_1 , Q_2 and resistor R_1 we have the following relation:

$$V_{BE2} = I_0 R_1 + V_{BE1}, \quad (2)$$

where I_0 is the current through resistor R_1 . In Eq. (2), the base-emitter voltage V_{BEi} of the transistor Q_i can be expressed as

$$V_{BEi} = V_T \ln \left[\frac{I_{Ei}}{I_{Si}} \right], \quad (3)$$

where V_T is the thermal voltage, I_{Ei} is the emitter current, and I_{Si} is the saturation current of the transistor Q_i . Equation (3) is valid only if $I_{Ei} \gg I_{Si}$, which is usually the case if the transistor Q_i is biased in the active region. Combining Eqs. (2) and (3) and ignoring the base-currents, yields

$$I_0 = \frac{V_T}{R_1} \ln \left[\frac{I_x}{I_y} \right], \quad (4)$$

where I_x and I_y are positive input currents.

FIGURE 1 Proposed logarithmic circuit.

Figure 1 and Eq. (4) show that I_o can be positive or negative. This sets no restriction on the ratio between the input currents I_x and I_y . However, to maintain the positive emitter currents of the transistors Q_3 and Q_4 it is essential to ensure that $I_o < I_x + I_B$ and that $I_o < I_y + I_B$. This can be easily achieved by proper selection of the constant current I_B .

In order to sense the current I_o and to force it through a grounded load resistor, additional current mirrors are introduced. Simple and straightforward analysis, ignoring the base-currents, shows that the current through the grounded resistor R_L is given by

$$I_L = 2I_o. \quad (5)$$

3 SIMULATION RESULTS

The proposed circuit of Figure 1 was simulated using the ICAPS circuit simulation program. The transistors used for simulation are 2N2222 for npn transistors and 2N2905 for the pnp transistors. The output current was measured by sensing the voltages across a load resistor $R_L = 1.0 \text{ k}\Omega$. The results obtained with $I_B = 0.1 \text{ mA}$, $R_1 = 2.6 \text{ k}\Omega$ and $V_{CC} = 3 \text{ V}$ are shown in Figure 2. It appears from Figure 2 that the simulated results are in good agreement with the required function.

FIGURE 2 Calculated and simulated logarithmic function of Eq. (4).

4 DISCUSSION AND CONCLUSION

In this paper a new circuit for realizing a logarithmic function has been presented. The proposed circuit of Figure 1 can realize a logarithmic function of the form of Eq. (1) for any value of I_{in1} larger or smaller than I_{in2} . This is the major advantage of this realization compared to previously published circuits, which require that I_{in1} is larger than I_{in2} . The circuit uses only transistors, a single resistor and current sources, and is therefore attractive for integration.

The simulation results were obtained assuming that the ' n ' parameters of the npn and pnp transistors are equal to unity. While this is, practically, a very good approximation, failure to meet this condition will result in an error. Another possible source of error is the effect of the collector-base voltage, through the base-width modulation (early effect) on the base-emitter voltage. Thus, transistors with large values of early voltage will result in better performance. Moreover, the base-emitter voltage is also affected by the finite ohmic resistances, especially the effective base resistance, and this will result in higher values of base-emitter voltage and may degrade the performance of the circuit of Figure 1. Finally, errors due to finite values of β frequently degrade the performance of translinear circuits and the circuit of Figure 1 is not an exception. Thus, large values of β would be preferable. Alternatively, many measures can be taken to minimize the effect of finite β s on the performance of the circuit of Figure 1 [8].

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