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# A PROGRAMMABLE REFERENCE-VOLTAGE SOURCE

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A simple circuit for realizing a current(voltage)-controlled reference voltage is presented. The feasibility of obtaining a temperature-insensitive reference voltage is explored. SPICE simulation results are included.

## INTRODUCTION

Reference-voltage sources are widely used in many electronic circuits, especially in analog-to-digital converters, digital-to-analog converters and high-accuracy measuring instruments. Available reference-voltage sources are built around either the base-emitter voltage of the bipolar junction transistor [1] or the zener-voltage of a zener-diode [2,3]. Since the base-emitter voltage of the bipolar junction transistor is small, amplification is required. This requires a relatively large number of active and passive components, high precision operational amplifiers, and resistor arrays with a high relative thermal stability [1]. Alternatively, the zener-voltage of a zener-diode suffers from temperature dependence. Low-voltage zener-diodes with zener voltages ≤ 5V, have negative temperature coefficients. High-voltage zener-diodes with zener-voltages ≥ 8 V have positive temperature coefficients [4]. Careful choice of active and passive components used in zener diode-based reference-voltage sources is, therefore, required to provide a temperature-stabilized output voltage [2,3]. On the other hand, programmable voltage references are attractive for many applications. Programmability can be achieved either manually or by using software [3]. No attempt, however, has been reported to exploit the programmability of the operational transconductance amplifiers (OTAs) in designing programmable reference-voltage sources. Probably this is attributed to the temperature dependence of the transconduactance of the OTA.

It is the major intention of this paper to present a current(voltage)-controlled reference-voltage source using the zener-diode to provide the reference voltage and the OTA to provide programmability. Conditions under which the temperature coefficient of the OTA may compensate for the temperature coefficient of the zener-voltage, resulting in zero temperature coefficient reference-voltage source, will be discussed.

## PROPOSED CIRCUIT

Figure 1 shows the proposed programmable reference-voltage source. The resistor $R_1$ and the zener-diode establish a voltage $-V_Z$ at point A. This voltage is amplified by the inverting amplifier configuration formed of the resistor $R_2$ and the feedback resistor formed of the two OTAs. Assuming ideal OTAs with $i_0 = g_m(v_+ - v_-)$, where $v_+$ is the noninverting input voltage, $v_-$ is the inverting input voltage, and $g_m = \frac{I_{abc}}{2V_T}$ is the transconductance of the OTA, where $I_{abc}$ is the auxiliary bias current of the OTA and $V_T = \frac{kT}{q}$ is the thermal voltage where $T$ is the temperature. Routine abnalysis shows that the resistance of the feedback resistor formed of the two OTAs can be expressed as

$$R_F = \frac{1}{g_m} \quad (1)$$

Using (1), the output voltage of the operational amplifier can be expressed as

$$V_0 = \frac{2V_Z V_T}{I_{abc} R_2} \quad (2)$$

From (2), it can be seen that the output voltage can be controlled by adjusting the auxiliary bias current $I_{abc}$. This auxiliary bias current can be obtained from the output of a digital-to-analog converter. Thus, it is feasible to obtain a digitally programmable reference-voltage source. Moreover, since low-voltage zener-diodes have a negative temperature coefficient, then it is possible to cancel the effect of the temperature variation on the zener-voltage by the positive temperature coefficient of the thermal voltage $V_T$. Thus, obtaining a low-temperature coefficient programmable reference-voltage source is feasible.

## SIMULATION RESULTS

The proposed circuit of Fig. 1 was simulated using the SPICE circuit simulation program. The zener-diode was simulated using the model parameters: IS=0.5 μA, Rs=6 Ω, BV= 5.0 V , IBV=0.5 μA. The OTA was modelled using a voltage-controlled current-source with transconductance $g_m = 1mA/V - 10mA/V$, which corresponds to auxiliary bias current $I_{abc} = 50\mu A - 500\mu A$, and input resistance = $2M\Omega$. The operational amplifier was modelled using a voltage-controlled voltage-source with gain =120 dB, and input resistance = $1M\Omega$. The input voltage was set at -12 V. The results are shown in Fig. 2. Shown also in Fig. 2 are the results obtained from calculations using (1). From Fig. 2, it can be seen that the calculated and simulated results are in excellent agreement. Thus, the proposed circuit provides a current-controlled reference-voltage. This current can be obtained from a voltage source. Thus, obtaining a voltage-controlled reference-voltage is feasible. Moreover, if this voltage is obtained from the the output of a digital-to-analog converter, then obtaining a digitally programmable voltage-reference is feasible.

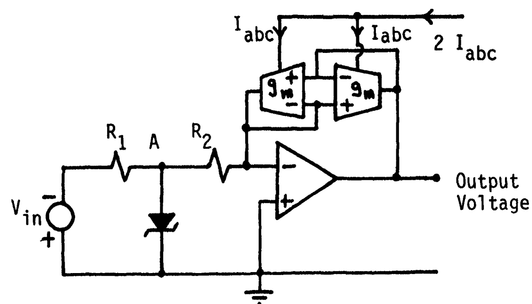


FIGURE 1 Proposed programmable reference-voltage source

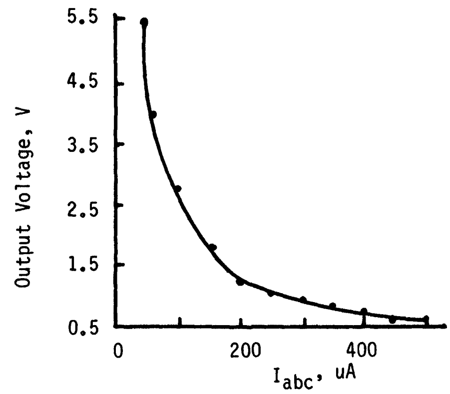


FIGURE 2 Variation of the output voltage with the auxiliary bias current of the OTAs, $I_{abc}$, –: calculated (1). ● : SPICE simulation

## CONCLUSION

A simple circuit for realizing a current(voltage)-controlled reference voltage has been presented. The circuit uses a low-voltage zener-diode, two OTAs configured as a floating resistance, one operational amplifier, and two resistors. Low-voltage zener-diodes with zener-voltage ≤ 5 V have negative temperature coefficients. The floating resistance obtained from the two OTAs has a positive temperature coefficient. Thus, obtaining a temperature-insensitive current(voltage)-controlled reference-voltage is feasible.

### *Acknowledgements*

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