A CURRENT-MODE SQUARE-ROOTING CIRCUIT WITH ELECTRONICALLY TUNED BASED ON OFF-THE-SHELF IC

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ABSTRACT

This paper presents a current-mode square-rooting circuit with electronically tuned based on off-the-shelf IC. The proposed circuit has a simple structure. It has been designed by using three LT1228s without the employment of additional passive elements. The output current can be linearly/electronically adjusted with a wide input dynamic range. The proposed circuit's performance is proved by real-practical testing. Its experimental results agree well with the theory. Furthermore, the output current of the proposed circuit is temperature-insensitive.

KEYWORDS

square-rooting circuit, current-mode, off-the-shelf IC

1. INTRODUCTION

The square-rooting circuit is one of the essential circuits in electrical engineering. It is frequently used in analog measurement and measurement systems. For example, it is used to calculate the root mean square (RMS) of different signal types [1]. It is also helpful for signal processing from liquids or gases [2]. From researching past literature, the voltage-mode square-rooting circuits designed by Op-amp and CMOS were proposed in [3]. The circuit has a simple structure and is cheap. But this circuit has a low-frequency range due to the Op-amp's bandwidth restriction and uses a large number of passive devices. Moreover, it isn't electrically controlled. The current-mode square-rooting circuit using an operational transconductance amplifier (OTA) is presented in [4]. The circuit can operate in the frequency range of approximately 500 *kHz* without affecting temperature and is designed using a cheap commercial IC. However, the circuit has no actual circuit performance test, and the circuit's current input range is only 100 μA. [5] presents a square root circuit employing quasi-floating gate technique MOS transistor (QFG MOST), which can operate in a frequency range larger than 10 *MHz*. But there are a lot of passive components in this circuit's design. A square-rooting circuit was presented using many active building blocks such as OTA, MOCFTA, and CCCCTA. These circuits are structured as transistors without any combination of passive devices. These circuits are structured as transistors without any combination of passive devices. It can be electronically controlled and temperature insensitive. Suitable for fabricating ICs. The BJT construction used in [8] offers linearity and a large input range of 400 μA. Research in [6], [7], and [9] are designed using MOS transistors. Its advantage over BJT is that it provides high frequencies at *MHz* and has a lower power consumption. Furthermore, the actual circuit performance was evaluated using off-the-shelf ICs in [7]. The output gain in [6-9] can be electrically tuned, and the output signal isn't temperature sensitive.

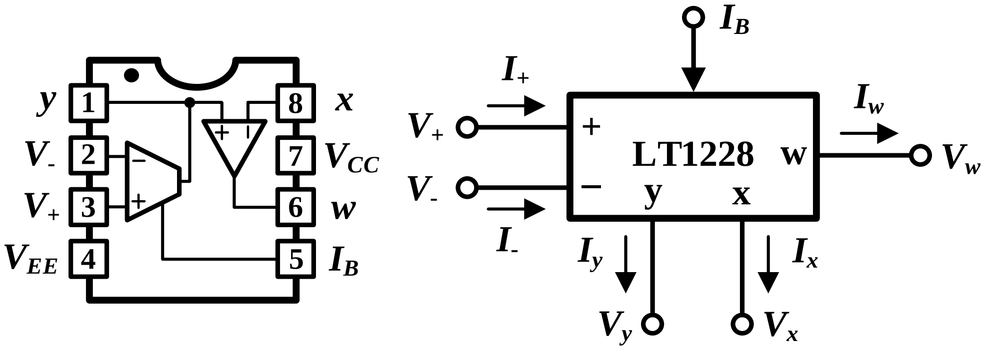
DOI: 10.14810/elelij.2022.114011

As can be seen from the above, square root circuits can be designed employing off-the-shelf ICs and BJT/MOS transistors. The transistor circuit design is appropriate for fabricating ICs [6-9], rendering it advantageous to follow, such as: making the circuit smaller, compact, and consuming less power. However, the fabrication of ICs requires a high cost. As illustrated in [7], off-the-shelf ICs can provide circuits with similar performance to those of manufactured ICs, but they are more convenient and low-priced.

This article aims to show a square-rooting circuit using off-the-shelf ICs with a simple structure, which has a wide input dynamic range and is electronically tuned. It is comfortable and cost-effective for a variety of applications.

2. DESCRIPTION OF LT1228

LT1228 [10] is a commercial IC manufactured by Linear Technology Inc that combines an operational transconductance amplifier (OTA) and a current feedback amplifier (CFA). Figure. 1 (a) shows the pin position of LT1228. Its symbol used in this article is shown in Figure. 1 (b). The relationship between voltage and current is as follows:



(a) (b)

Figure.1 (a) The pin, (b) the symbol of LT1228.

$$\begin{bmatrix} I_+ \\ I_- \\ I_y \\ V_y \\ V_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & Z_T & 0 \end{bmatrix} \begin{bmatrix} V_+ \\ V_- \\ V_x \\ I_x \\ I_w \end{bmatrix}, \tag{1}$$

and

$$g_m = \frac{I_B}{3.87V_T} \tag{2}$$

The g_m is a transconductance gain controlled by the input bias current (I_B) but still depends on the thermal voltage (V_T). At room temperature (27 °C), VT is about 26 *mV*. Z_T is the trans-resistance gain, and it is about 190 *kΩ*.

3. THE PROPOSED CURRENT-MODE SQUARE-ROOTING CIRCUIT

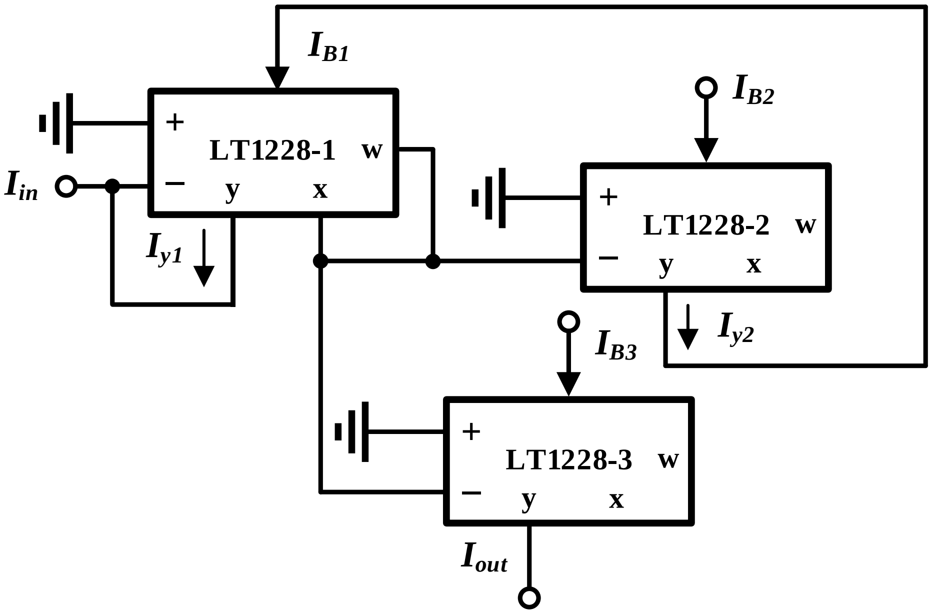


Figure.2 The proposed current-mode square-rooting circuit.

The proposed circuit is shown in Figure. 2. The circuit structure consists of three LT1228 without passive devices. From the properties of the LT1228 described in Section 2 and taking the input current (I_{in}) at pin 2 of the LT1228-1, the output current from the pin y of the LT1228-1 (I_{y1}) can be found as follows:

$$I_{y1} = I_{in} = g_{m1}\left(V_{1+} - V_{1-}\right), \tag{3}$$

and since the input voltage of the LT1228-1 (V_{1+}) is grounded, it has a value of 0 V, and pin y is I_{y1}. So, I_{y1} is obtained by

$$I_{y1} = I_{in} = -g_{m1}V_{1-} \tag{4}$$

Considering the LT1228-2 and LT1228-3, the output current of LT1228-2 (I_{y2}) and LT1228-3 (I_{out}) can be found as follows:

$$I_{y2} = -g_{m2}V_{2-} \tag{5}$$

and

$$I_{out} = -g_{m3}V_{3-} \tag{6}$$

From Figure.2, $V_{1-} = V_{y1}$, $V_{x1-} = V_{w1-} = V_{y2-} = V_{y3}$ and using the LT1228's characteristics in (1). So, I_{y2} and I_{out} can be rewritten as

$$I_{y2} = \frac{I_{in}g_{m2}}{g_{m1}}, \tag{7}$$

and

$$I_{out} = \frac{I_{in}g_{m3}}{g_{m1}} \tag{8}$$

Replace$g_m$with (7) and (8). So, I_{y2} and $I_{out}$are shown as

$$I_{y2} = \frac{I_{in} I_{B2}}{I_{B1}} \tag{9}$$

and

$$I_{out} = \frac{I_{in} I_{B3}}{I_{B1}} \tag{10}$$

From the proposed circuit, I_{B1} is equal toI_{y2} because I_{y2} is transmitted as the bias current of LT1228-1. Equations (9) and (10) are rewritten as

$$I_{y2} = \sqrt{I_{in}}\sqrt{I_{B2}} \tag{11}$$

and

$$I_{out} = \frac{I_{in} I_{B3}}{I_{y2}} \tag{12}$$

Substituting (11) into (12) and defining $I_{B2} = I_{B3} = I_B$. Thus, the output current of the proposed circuit is demonstrated as follows:

$$I_{out} = \sqrt{I_B}\sqrt{I_{in}} \tag{13}$$

From (13), it is obviously devoid of V_T. So, the output current is temperature-insensitive. Furthermore, the output gain can be easily adjusted by electrical adjustment with I_B.

4. THE EXPERIMENTAL RESULTS

The results of the experiment at 9 V power supplies confirm the performance of the proposed current-mode square-rooting circuit. Measuring the output signal used a RIGOL DS1054 oscilloscope with a resistance load of 10$k\Omega$ (to convert current to voltage).

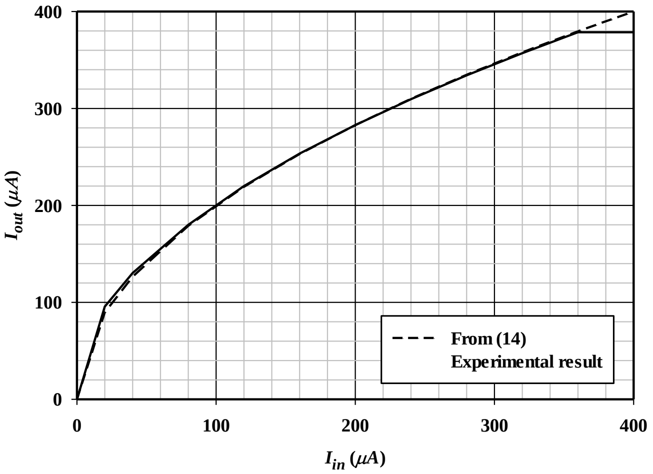


Figure.3. DC transfer characteristic of the proposed circuit.

Figure. 3 shows the DC transfer characteristic of the proposed circuit when I_{in} is varied from 0 to 400 $\mu A$with a given I_B =400 μA. The experimental results are consistent with (14). It has a maximum error of 6.9%. The sinusoidal signal was applied to the input signal by assigning its amplitude at 200$\mu A_{p\text{-}p}$ with different frequencies of 1 kHz, 10 kHz, and 100 kHz. The proposed circuit can generate a correctly square-rooting output waveform when the input is 1 kHz, 10 kHz, and 100kHz, as shown in Figure.4, Figure.5, and Figure.6, respectively.

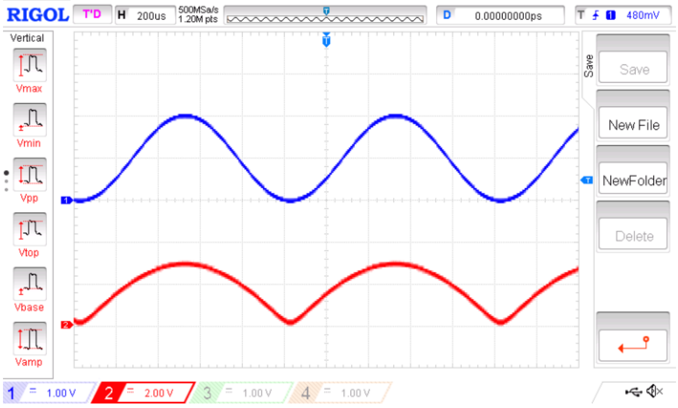


Figure.4. The input signal and output signal have a frequency of 1 *kHz*.

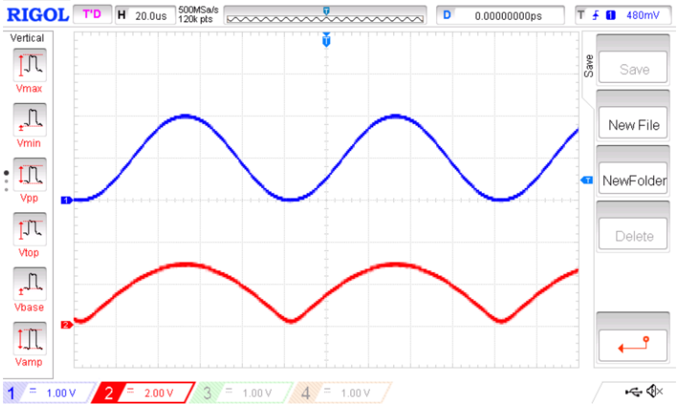


Figure.5. The input signal and output signal have a frequency of 10 *kHz*.

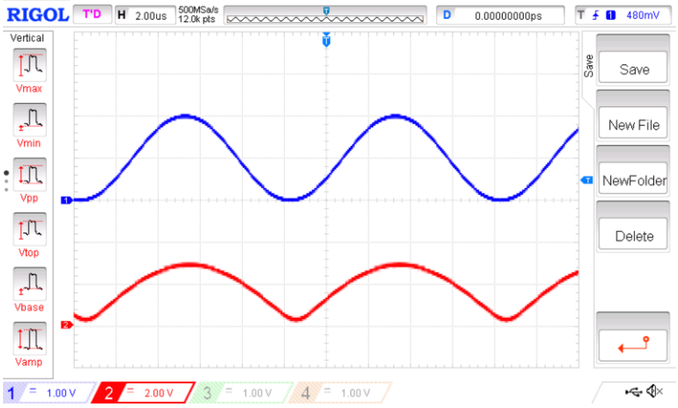


Figure.6. The input signal and output signal have a frequency of 100 *kHz*.

The triangular signal was applied to the input signal by setting its amplitude at 200 $\mu A_{p\text{-}p}$ using different biased currents (I_B) of 200 μA, 300 μA, 400 μA, and 500 μA. The suggested circuit can properly generate an output waveform at the square root with gains of 1, 1.24, 1.44, and 1.62 times the input signal, as shown in Figure.7, Figure.8, Figure.9, and Figure.10, respectively. The gain has a maximum error of 2.45%.

Figure.7. The input signal and output signal where the bias current value is 200 μA.

Figure.8. The input signal and output signal where the bias current value is 300 μA.

Figure.9. The input signal and output signal where the bias current value is 400 μA.

Figure.10. The input signal and output signal where the bias current value is 500 μA.

The graph in Figure. 11 shows the current gain while I_B is adjusted from 50 to 500 μA at the input amplitude and frequency are $200\mu A_{p\text{-}p}$ and 1 kHz, respectively.The experimental results are consistent with the theory in the range of I_B from 50 $\mu A$to 500 μA with a maximum error of 2%. Because the bias current below 50 $\mu A$is too small, making the circuit unable to work.

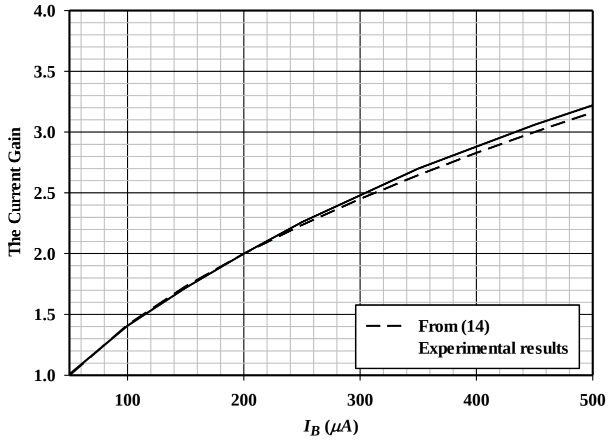


Figure.11. The current gain of the proposed circuit for I_B variations.

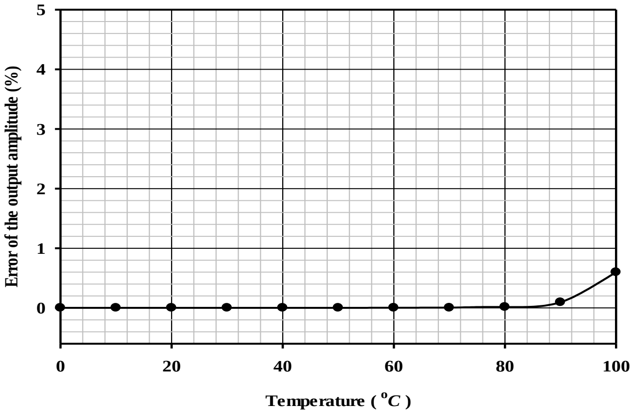


Figure.12. The output amplitude's error versus temperature.

From Figure.12, the temperature affecting the output amplitude is inspected by the PSpice simulator program from 0 to 100 degrees Celsius, which has a maximum error of less than 0.6%. It is summarized that it suffers slightly from temperature variation.

5. CONCLUSIONS

The current-mode square-rooting circuit is designed without an external passive element using an off-the-shelf IC., which utilizes only three LT1228s. The experimental results confirmed that the proposed circuit is efficient, operates at a wide input range of 0 µA to 400 µA, and external current can electronically control the gain of the output amplitude. This can be adjusted up to 500 µA with a maximum error of 2%. The experimental results are highly consistent with the theory. In addition, the maximum error of temperature-sensitivities is less than 0.6%. It concludes that the output amplitude is temperature insensitive.

ACKNOWLEDGEMENTS

The research described in the paper was supported by Department of Electrical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University (Sanam Chandra Palace Campus).

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