Double dual slope square rooter

Krishnagiri Chinnathambi Selvam

Department of Electrical Engineering, Indian Institute of Technology, Chennai 600 036, Tamil Nadu, India
E-mail: kcselvam@ee.iitm.ac.in

Published in *The Journal of Engineering*; Received on 22nd November 2013; Accepted on 27th December 2013

Abstract: A circuit which accepts input dc voltage V_I and produce an output voltage $V_O = \sqrt{V_I V_T}$ by using double dual slope principle is described in this Letter. V_T is a constant voltage which is fixed by two resistors and a power supply voltage. By using precision resistors and a stable constant power supply, an acceptable level of accuracy can be obtained.

1 Introduction

Square rooters find applications in many measurement and instrumentation system. Few examples are (i) phase sensitive detector and (ii) impedance measurement. There are several square rooting circuits: (i) Liu's [1] square rooter in which second generation current conveyors are used as high-performance active building block (ii) Riewruja [2] square rooter in which operational transconductance amplifiers are used (iii) Netbut *et al.* [3] square rooter in which second generation current controlled current conveyors (CCCCIIs) (iv) Tangsrirat *et al.* [4] square rooter in which current differentiating transconductance amplifiers are used (v) Mongkolwai *et al.* [5] square rooter in which current follower transconductance amplifiers are used (vi) Selvam and Latha [6] square rooter in which a multiplier is used in the feedback path of an operational amplifier (OP-AMP). A new square rooter using double dual slope integrators, double control amplifiers and a peak detector is explained in this Letter.

2 Circuit analysis

The proposed circuit diagram is shown in Fig. 1. Let us assume initially output of comparator OA_3 is at $+V_{cc}$, where $\pm V_{cc}$ is the power supply voltage to the circuit. This forces the transistor Q_1 to ON and the non-inverting terminal of the OP-AMP OA_1 to GROUND. Hence, OA_1 acts as an inverting amplifier and $+V_O$ is applied to the integrator OA_2. A constant current $+V_O/R$ flow through capacitor C to give a negative going ramp at the output of the integrator OA_2, as shown in Fig. 2. Therefore one end of R_3–R_4 voltage divider is at a voltage $+V_{cc}$ and the other end at the negative going ramp. When the negative going ramp reaches a certain value $-V_T$, the effective voltage at point 'P' becomes slightly below 0 V.

As a result, the output of comparator OA_3 switches from $+V_{cc}$ to $-V_{cc}$. The transistor Q_1 becomes OFF and the amplifier OA_1 will work as non-inverting amplifier. $-V_O$ is given to the integrator. This forces a reverse constant current through the capacitor C to give a positive going ramp at the output of integrator OA_2 as shown in Fig. 2. When the positive going ramp reaches $+V_T$, the effective voltage at the point 'P' becomes slightly above 0 V. As a result, the output of comparator OA_3 switches from $-V_{cc}$ to $+V_{cc}$. This sequence therefore repeats to give a triangular wave with peak value of $\pm V_T$ at the output of integrator OA_2 and a square wave at the output of OA_3. When the comparator output is $+V_{cc}$ and the input to the integrator is $+V_O$, the effective voltage at point 'P' is given by

$$-V_T + \frac{R_3}{R_3 + R_4}[+V_{cc} - (-V_T)] \quad (1)$$

When the effective voltage at P becomes 0 V, we can write the above equation as

$$-V_T + \frac{R_3}{R_3 + R_4}[+V_{cc} - (-V_T)] = 0 \quad (2)$$

From (2), we can obtain

$$-V_T = -\frac{R_3}{R_4}(+V_{cc}) \quad (3)$$

Similarly, when the comparator output is at $-V_{cc}$

$$+V_T = \frac{R_3}{R_4}(-V_{cc}) \quad (4)$$

The integrator OA_2 output V_P for one transition, that is, when $-V_O$ is at its input will be

$$V_P(t) = \frac{1}{RC}\int_0^{t_1}(+V_O)\,dt = \frac{V_O}{RC}t_1 \quad (5)$$

From the waveform shown in Fig. 2 and the fact that at $t_1 = T/2$, $V_P(t) = 2V_T$, we obtain

$$2V_T = \frac{+V_O}{RC}\frac{T}{2}, \quad T = \frac{V_T}{V_O}4RC \quad (6)$$

The square waveform thus generated at the output of OP-AMP OA_3 is controlling the transistor switch Q_2. During ON time of square wave, the transistor Q_2 is ON which makes the OP-AMP OA_4 to work as inverting amplifier. $+V_I$ is given to the integrator OA_5. Its output V_K will be

$$V_K(t) = \frac{1}{RC}\int_0^{t_2} -V_I\,dt = -\frac{V_I}{RC}t_2 \quad (7)$$

During OFF time of square wave, the transistor Q_2 is OFF and makes the OP-AMP OA_4 to work as non-inverting amplifier. $-V_I$ is given to the integrator OA_5. Its output V_K will be

$$V_K(t) = \frac{1}{RC}\int_0^{t_1} V_I\,dt = \frac{V_I}{RC}t_1 \quad (8)$$

Another triangular wave with peak values $\pm V_O$ is generated at the output of the integrator OA_5. From Fig. 2 and from the above (8),

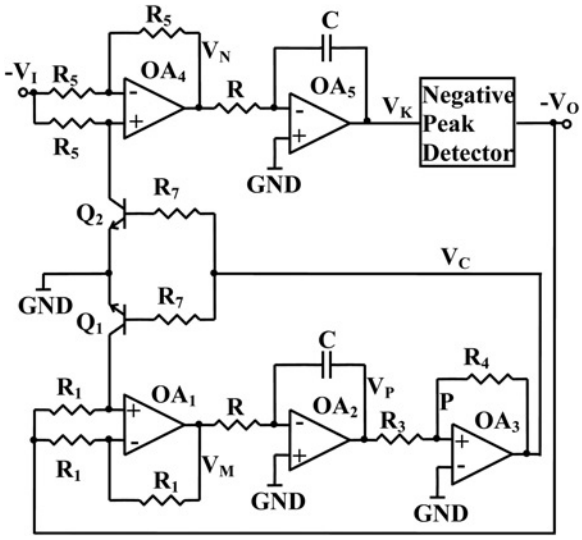

Fig. 1 *Circuit diagram of the proposed square rooter*

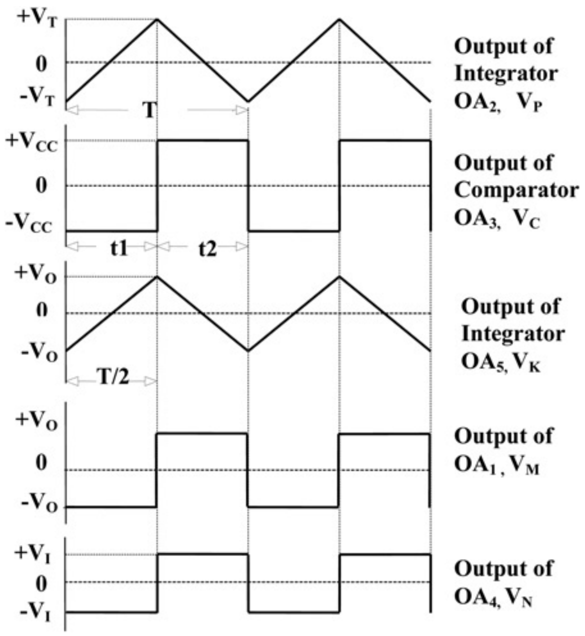

Fig. 2 *Associated waveforms of Fig. 1*

the fact that at $t_1 = T/2$, $V_K(t) = 2V_0$

$$2V_O = \frac{V_I}{RC}\frac{T}{2}, \quad V_0 = \frac{V_I}{V_O}V_T \tag{9}$$

$$V_O = \sqrt{V_I V_T} \tag{10}$$

The negative peak detector at the output of the integrator OA_5 gives the negative peak value $-V_O$.

3 Experimental results

The circuit shown in Fig.1 is tested in our laboratory. LF 356 ICs are used for all OP-AMPs OA_1–OA_5. A power supply of ±15 V is used. The test results are given in the graph of Fig. 3.

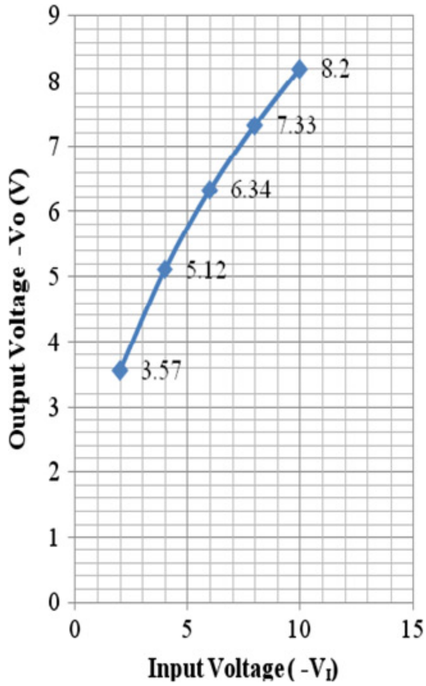

Fig. 3 *Test results (V_T = 10 V)*

4 Conclusion

A new circuit for square rooting applications is described. The polarity of the input voltages should only be negative. This circuit can be used for phase sensitive detector or tracking amplifier which plays important role in modern measurement and instrumentation.

5 Acknowledgments

The author is highly indebted to his loving wife Mrs. S. Latha for circuit drawing and discussion. He also thanks Prof. Dr. S. Srinivasan, Prof. Dr. V. Jagadeesh Kumar, Prof. Dr. Sridharan and Dr. Bharath Bhikkaji, Department of Electrical Engineering, Indian Institute of Technology, Madras, for their constant encouragement throughout this work.

6 References

[1] Liu S.I.: 'Square-rooting and vector summation circuits using current conveyors', *IEE Proc. Circuits Devices Syst.*, 1995, **142**, pp. 223–226

[2] Riewruja V.: 'Simple square rooting circuit using OTAs', *Electron. Lett.*, 2008, **44**, pp. 1000–1002

[3] Netbut C., Kumngern M., Prommee P., Dejhan K.: 'New simple square rooting circuits based on translinear current conveyors', *ECTI Trans. Electr. Eng. Electron. Commun.*, 2007, **5**, pp. 10–17

[4] Tangsrirat W., Pukkalanun T., Mongkolwai P., Surakampontorn W.: 'Simple current mode analog multiplier, divider, square-rooter and square based on CDTAs', *Int. J. Electron. Commun. (AEU)*, 2011, **65**, (3), pp. 198–203

[5] Mongkolwai P., Prasertsom D., Tangsrirat W.: 'CFTA – based current controlled current amplifier and its application'. The 25th Int. Technical Conf. Circuits/Systems, Computers and Communications (ITC – CSCC 2010), Pattaya, Thailand, 4–7 July 2010, pp. 624–627

[6] Selvam K.C., Latha S.: 'A simple square rooting circuit based on operational amplifiers (OPAMPs)', *Eng. Technol. Appl. Sci. Res.*, 2013, **3**, (1), pp. 349–351