A Temperature-insensitive Simple Current-mode Squarer Employing Only Multiple-output CCTAs

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Abstract—This article presents a new current-mode squarer based on MO-CCTA (Multiple output current conveyor transconductance amplifier). The circuit description is very simple, its construction consists of merely 2 MO-CCTAs. Without external passive elements, the proposed circuit is then suitable for IC architecture. The PSPICE simulation and experimental results are depicted, and agree well with the theoretical anticipation. From simulation results, the maximum power consumption is approximately 550µW at ±2V power supply voltages.

Keywords- Squarer; Current-mode, MO-CCTA

I. INTRODUCTION

A squaring circuit has been found for wide usefulness in analog instrumentation and measurement systems, such as an rms-to-de converter, a multiplier, modulator, frequency doubler, frequency divider and adaptive filter [1-3]. From our survey, we found that several implementations of square-rooting circuits using different high-performance active building blocks such as such as, OTAs [4], second-generation current conveyors (CCII) [5], second-generation current controlled current conveyor (CCCIIs) [6], have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

• Excessive use of the active/passive elements, especially external resistors [5-6].
• Absent of magnitude adjustment of output signal by electronic method [4-5].

Presently, a current-mode technique [7] has been being more popular than voltage-mode one. This is due to requirements in low-voltage environment such as in portable and battery-powered equipments. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose more than the voltage-mode one. Presently, there is a growing interest in synthesizing the current-mode circuits because of more their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and lower power consumption [7-10].

The current conveyor transconductance amplifier (CCTA) is a reported active component, especially suitable for a class of analog signal processing [11]. The fact that the device can operate in both current and voltage-modes provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, high speed, wide bandwidth and simple implementation [11].

The purpose of this paper is to introduce a novel current-mode squarer based on use of MO-CCTAs. The features of the proposed squarer are that; output gain can be adjusted via input bias current; magnitude of output signal is ideally temperature-insensitive; the proposed circuit consists of 2 MO-CCTAs and without any passive element, which is appropriate to fabricate in integrated circuit architecture. The PSPICE simulation and experimental results are also shown, which are in correspondence with the theoretical analysis.

II. CIRCUIT CONFIGURATION

A. Basic Concept of MO-CCTA

Since the proposed circuit based on MO-CCTA, a brief review of the MO-CCTA is given in this section. The voltage and current relationships of the MO-CCTA are shown in (1)

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z \\
I_{s1} \\
I_{s2} \\
I_{s3}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 1 & [V_y] \\
1 & 0 & 0 & 0 & 0 & [I_x] \\
0 & 1 & 0 & 0 & 0 & [V_z] \\
0 & 0 & 0 & 0 & \pm g_{m1} & [V_{s1}] \\
0 & 0 & 0 & 0 & \pm g_{m2} & [V_{s2}] \\
0 & 0 & 0 & 0 & \pm g_{m3} & [V_z]
\end{bmatrix},
\]

(1)

where

\[
g_{m1} = \frac{I_{b1}}{2V_T}, \quad g_{m2} = \frac{I_{b2}}{2V_T}, \quad g_{m3} = \frac{I_{b3}}{2V_T}.
\]

(2)

\( g_{m1}, g_{m2}, \) and \( g_{m3} \) are the transconductances of the MO-CCTA. \( V_T \) is the thermal voltage. The symbol and the
B. Principle of the proposed Current-mode Squarer

The proposed current-mode squarer using the MO-CCTAs is displayed in Fig. 2. By routine analysis circuit in Fig. 2 and using the properties of MO-CCTA in Section II.A, the output current at z terminal of MO-CCTA1 is obtained by

\[ i_{o1} = I_{g1} \frac{V_{i1}}{I_{g4}}, \]  

Subsequently, the output current at o1 (I_{o1}) and o2 (I_{o2}) terminals can be expressed to be

\[ I_{o1} = g_{m1} V_{i2} = \frac{I_{g3}}{I_{g4}}, \]  

and

\[ I_{o2} = g_{m2} V_{i2} = \frac{I_{g3}}{I_{g4}}. \]  

Figure 1. The MO-CCTA (a) symbol (b) equivalent circuit.

From (7)-(8), the output current (I_{out}) of the squarer is displayed as

\[ i_{out} = I_{o1} + I_{o2} = \frac{I_{g3}^2}{I_{g4}}. \]  

It is clearly seen that the output gain can be controlled by I_{g4}. Furthermore, in ideal case, it is temperature-insensitive.

C. Non-Ideal Case

For non-ideal case, the MO-CCTA can be characterized by

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z \\
I_{x1} \\
I_{x2} \\
I_{x3}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
\beta_y & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_y & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \pm \beta_y g_{m1} & 0 \\
0 & 0 & 0 & \pm \beta_y g_{m2} & 0 & 0 \\
0 & 0 & 0 & 0 & \pm \beta_y g_{m3} & 0
\end{bmatrix}
\begin{bmatrix}
V_y \\
I_x \\
V_{x1} \\
V_{x2} \\
V_{x3}
\end{bmatrix},
\]

where \( \alpha_y, \beta_y \) and \( \beta_z \) are transferred values, these values can be deviated from one. In the case of non-ideal and reanalyzing the proposed squarer in Fig. 2, it yields the output current as

\[ i_{out} = \frac{\alpha^2 \beta^2 |I_x|^2}{I_{g4}}. \]  

From (11), it is found that the proposed squar er still functions as a squarer. These deviated values effect on only output magnitude. Practically, the \( \alpha_y, \beta_y \) and \( \beta_z \) originate from intrinsic resistances and stray capacitances in the MO-CCTA. These errors affect the sensitivity to temperature and high frequency response of the proposed circuit. Consequently, the MO-CCTA should be carefully designed to achieve these errors as low as possible.

III. SIMULATION RESULTS

To prove and investigate the performances of the proposed circuit, the PSPICE simulation program was used. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameter of the NR200N and PR200N bipolar transistors of ALA400 transistor array from AT&T [12]. Fig. 3 depicts schematic description of the MO-CCTA used in the simulations. The MO-CCTA was biased with \( \pm 2 V_{cc} \), where \( I_B \) was set to 10μA. The DC transfer characteristic of the proposed circuit is shown in Fig. 4. The results of the squaring circuit for sinusoidal and triangular inputs are displayed in Figs. 5 and 6, respectively.
From Eq.(9) of the temperature, it is found that the maximum error of the temperature variations due to the intrinsic resistances and stray clearly seen that the output current is slightly dependent on the amplitude of output signal is approximately 1.8%. Fig. 7 demonstrates the output current variation for different temperature values.

To validate that the squarer can operate practically, it was constructed using commercial ICs, as shown in Fig. 10. Since the input signal is a voltage, the $CFA_1-CFA_4$ are used to be V to I converters, where $R_f$ is used to be able to measure the output current by an oscilloscope.
Figs. 11(a) and (b) show the experimental results of the proposed squarer when sinusoidal and triangular inputs are applied, respectively.

IV. CONCLUSIONS

The current-mode squarer based on the MO-CCTAs has been presented. The features of the proposed circuit are that: output gain can be adjusted via input bias current; magnitude of output signal is theoretically temperature-insensitive; the proposed squarer consists of only 2 MO-CCTAs without any passive element, which is appropriate to fabricate in integrated circuit architecture. The performances of the proposed circuit have been also investigated and discussed through PSPICE simulation and experimental results. It is shown that the proposed circuit can function as a current-mode squarer for a wide input current range of $-200\mu A$ to $200\mu A$. From simulation results, the maximum power consumption is $550\mu W$ at $\pm 2V$ supply voltages. The maximum error of the amplitude of output current signal due to variations of the temperature from 0-100°C is approximately 1.8%.

REFERENCES