A Simple 4 Quadrant Multiplier in Current-mode Employing Only Single CC-CCTA

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Abstract

This paper proposes a 4 quadrant current-mode multiplier. It is implemented by only single CC-CCTA (Current controlled current conveyor transconductance amplifier) without passive element. The output current is independent from V_T (Thermal voltage). Furthermore, the amplitude of output current can be electronically adjusted by bias current. The circuit is designed and simulated using PSpice simulator by the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T. The maximum power consumption is approximately 0.208mW at ±1.5V supply voltages.

Keywords

Multiplier, Current-mode, CC-CCTA

I. Introduction

Analog multipliers are importance building block of signal processing, telecommunication, control, and instrumentation applications [1-2]. Several conventional applications require them, such as in modulators, phase locked loop, automatic controlling, nonlinear filtering, peak detector, frequency translation, RMS-DC etc [3-5]. From literature review, it has been found that several implementations of current-mode multiplier using different high-performance active building blocks such as, CDTA [6], CC-CDTA [7-8], current controlled current conveyors (CCCII) [9], current controlled current differencing buffered amplifiers (CC-CDBAs) [10]. Unfortunately, the circuits in [7-8] and [10] are 2 quadrant multiplier. Thus, they cannot be work directly in real-time multiplication of two bipolar current signals [11].

In two decade, the researcher of analog system have been much attempted to relieve the supply voltage. Since the low-voltage analog circuits are need to use for portable and battery-powered equipments. Therefore, the current–mode technique is ideally suited for the design circuit. Because, the circuits is designed by the current-mode technique, their potential advantages such as higher signal bandwidth, larger dynamic range, simpler circuitry, greater linearity, and lower power consumption [12-15].

The CC-CCTA is presented in 2008 by M. Siripruchyanun, and W. Jaikla [16], it is developed from CCTA (Current conveyor transconductance amplifier) [17]. It can operate both voltage and current modes provides flexibility and enables a variety of circuit designs. Moreover, the parasitic resistance at $x\left(R_x\right)$ port can be electronically tuned. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth and simple implementation.

The aim of this paper is to introduce a new multiplier in current-mode based on CC-CCTA. The advantages of the proposed divider are that; the proposed multiplier can multiply two bipolar current signals throughout four-quadrant, without changing the circuit topology: the circuit is ideally insensitive to temperature variations: the proposed circuit consists of only single CC-CCTA and without any passive element, which is appropriate to fabricate in integrated circuit architecture. The PSpice simulation results are also shown, which are in correspondence with the theoretical analysis

II. Circuit Configuration

A. Basic Concept of CC-CCTA

The operating of CC-CCTA is realized by BJT technology, it is depicted in this section. The symbol and equivalent circuit of CC-CCTA is shown in Figs 1(a) and (b). The relationship of current and voltage of CC-CCTA can be shown as

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_{zc} \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ I_z \\ V_z \\ V_o \end{bmatrix}, \tag{1}$$

and

$$R_x = \frac{V_T}{2I_{B1}}, \; g_m = \frac{I_{B2}}{2V_T}. \tag{2}$$

R_x and g_m are the parasitic resistance and transconductances of the CCCCTA at x and o terminals, respectively. They can be adjusted via bias currents. V_T is the thermal voltage, its values is about 26mV at $27°C$. From (1) and Fig. 1, it can be seen that the CC-CCTA is used in the proposed multiplier, it is slightly modified from general CC-CCTA. The current output at z terminal is copy to zc terminal.

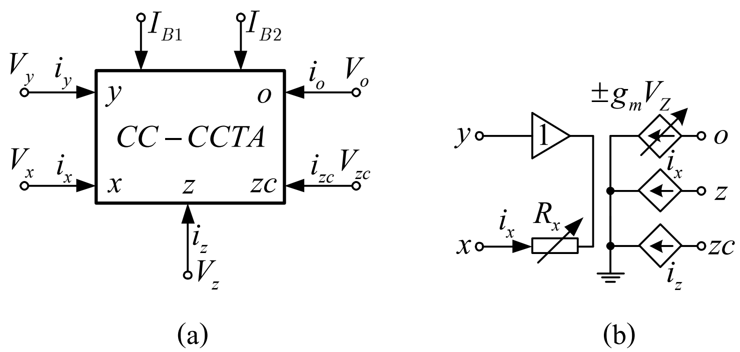

Fig. 1. The CC-CCTA (a) symbol (b) equivalent circuit.

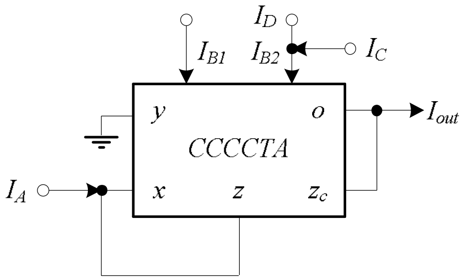

Fig. 2. The proposed current-mode multiplier.

B. Proposed Current-mode 4 Quadrants Divider

The proposed current-mode 4 quadrants multiplier employing CC-CCTA is display in Fig. 2 where I_{B1} and I_{B2} are bias currents of the CC-CCTA. It consists of only single CC-CCTA. By routine of analysis circuit in Fig. 2 and using the properties of CC-CCTA as explained in Section II.A, the output current at x and z terminals $\left(I_x \; and \; I_z\right)$ of CCCCTA is obtained as

$$I_A - I_z - I_x = 0, \tag{3}$$

From (1), it can be found that $I_x = I_z$. Then (3) can be rewritten to be

$$I_A - 2I_x = 0, \tag{4}$$

and
$$\frac{I_A}{2} = I_x. \tag{5}$$

From Fig. 2, it can be seen that $V_z = V_x$. Thus the voltage at z terminal can be express to be

$$V_x = V_z = I_x R_x = \frac{I_A R_x}{2} \tag{6}$$

From (6), the output current at o terminal $\left(I_o\right)$ can be found to be

$$I_{out} = g_m V_z = \frac{I_A R_x g_m}{2}. \tag{7}$$

From (3), $R_x = \dfrac{V_T}{2I_{B1}}$ and $g_m = \dfrac{I_C + I_D}{2V_T}$, The I_{out} can be obtained as

$$I_{out} = I_A\left(\frac{I_C + I_D}{8I_{B1}} - \frac{1}{2}\right). \tag{8}$$

I_D is set to be $4I_{B1}$, The I_{out} can be ultimately found to be

$$I_{out} = \frac{I_A I_C}{8 I_{B1}}. \tag{9}$$

From (10), it can be seen that it is independent from V_T. Thus it is temperature-insensitive. In addition, the output amplitude can be electronically controlled by I_{B1}.

C. **Non-ideal Case**

Taking the tracking errors of the CC-CCTA into account, the relationship of the terminal voltages and currents of the CC-CCTA can be rewritten as:

$$V_x = \beta_y V_y + R_x I_x, \tag{10}$$

$$I_z = \alpha_x I_x + \varepsilon_z, \tag{11}$$

$$I_o = \beta_z g_m V_z + \varepsilon_o, \tag{12}$$

and

$$I_{zc} = \alpha_z I_z + \varepsilon_{zc}. \tag{13}$$

where the parameters ε_z, ε_{zc} and ε_o are DC offset of z, zc, and o terminals, respectively. α_x and α_z are current gain, β_y and β_z are voltage gain, they are deviated from unity. In the case of non-ideal and reanalyzing the proposed current-mode multiplier in Fig. 2, it yields the output current as

$$I_{out} = \left\{ \begin{array}{l} \dfrac{\beta_z I_A I_C + 4 I_{B1} I_A \left(2\beta_z - \alpha_x \alpha_z\right)}{4 I_{B1}\left(\alpha_x + 1\right)} \\ + \left[\dfrac{\beta_z I_C + 4 I_{B1}\left(2\beta_z - \alpha_x \alpha_z\right)}{\alpha_x + 1} - \alpha_z \right] \varepsilon_z + \varepsilon_o - \varepsilon_{zc} \end{array} \right\} \tag{14}$$

From (14), it is found that the current-mode multiplier still functions as a current-mode multiplier. These deviated values effect on only output magnitude and DC offset. Practically, the α_x, α_z, β_y, β_z, ε_z, ε_{zc} and ε_o originate from intrinsic resistances and strayed capacitances in the CC-CCTA. These errors affect the sensitivity to temperature and high frequency response of the proposed circuit.

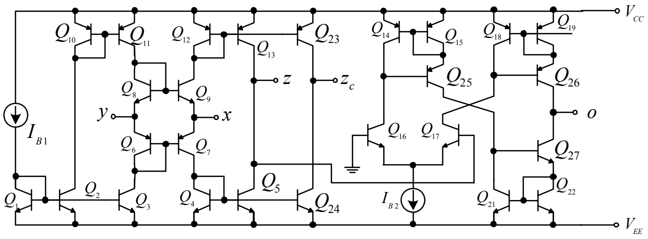

Fig. 3. Schematic of the BJT CC-CCTA.

III. Simulation Results

The performance of the proposed multiplier was verified using PSpice. Fig. 3 display the implementation of the CC-CCTA using BJTs. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [18] as shown in Table 1 with ±1.5V supply voltages.

Table I : Parameter of bipolar junction transistor

NPN
.MODEL NR200N NPN(RB=262.5 IRB=0 RBM=12.5 RC=25 RE=0.5 +IS=242E-18 EG=1.206 XTI=2 XTB=1.538 BF=137.5 +IKF=13.94E-3 NF=1 VAF=159.4 ISE=72E-16 NE=1.713 +BR=0.7258 IKR=4.396E-3 NR=1 VAR=10.73 ISC=0 NC=2 +TF=0.425E-9 TR=0.425E-8 CJE=0.428E-12 VJE=0.5 +MJE=0.28 CJC=1.97E-13 VJC=0.5 MJC=0.3 XCJC=0.065 +CJS=1.17E-12 VJS=0.64 MJS=0.4 FC=0.5)
PNP
.MODEL PR200N PNP(RB=163.5 IRB=0 RBM=12.27 RC=25 RE=1.5 +IS=147E-18 EG=1.206 XTI=1.7 XTB=1.866 BF=110 +IKF=4.718E-3 NF=1 VAF=51.8 ISE=50.2E-16 NE=1.650 +BR=0.4745 IKR=12.96E-3 NR=1 VAR=9.96 ISC=0 NC=2 +TF=0.610E-9 TR=0.610E-8 CJE=0.36E-12 VJE=0.5 +MJE=0.28 CJC=0.328E-12 VJC=0.8 MJC=0.4 XCJC=0.074 +CJS=1.39E-12 VJS=0.55 MJS=0.35 FC=0.5)

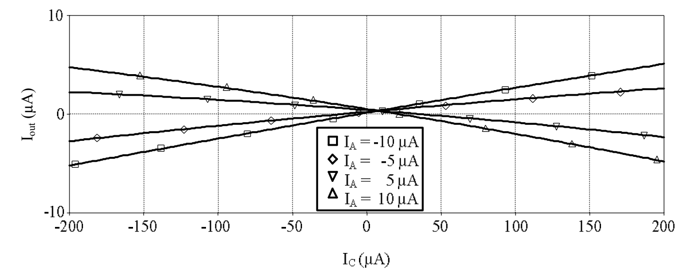

Fig. 4. DC transfer characteristic of the proposed multiplier.

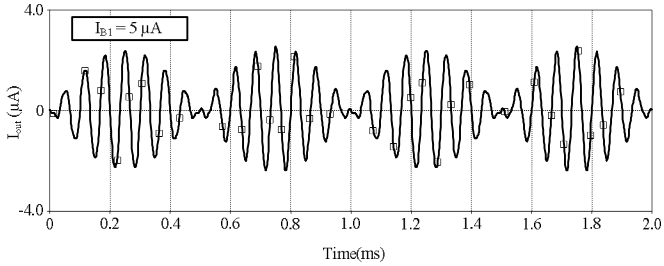

Fig. 5. Transient respond of the proposed multiplier.

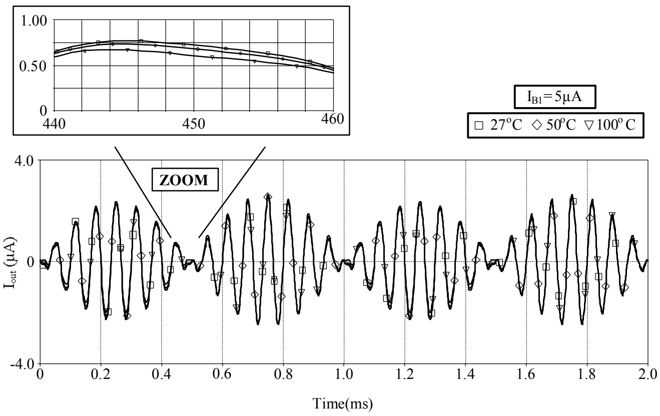

Fig. 6. Output current deviations for different temperature values.

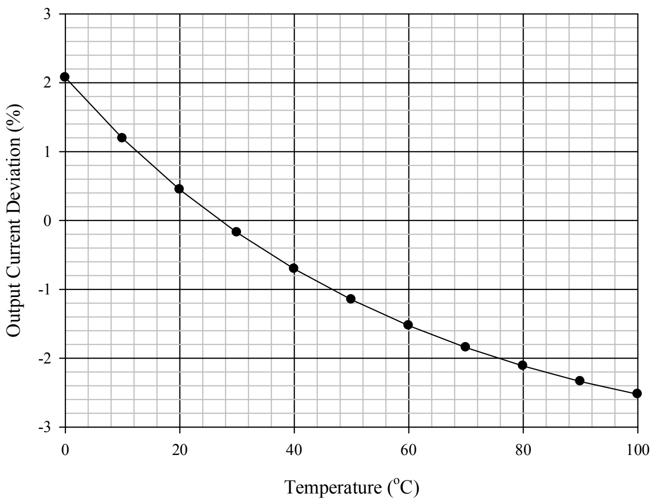

Fig. 7. The amplitude deviation of the output current where temperature is varied.

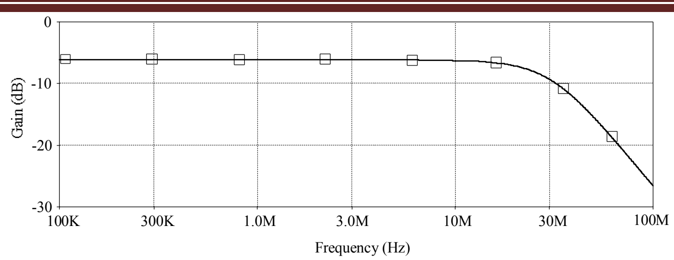

Fig. 8. Frequency response of the proposed multiplier.

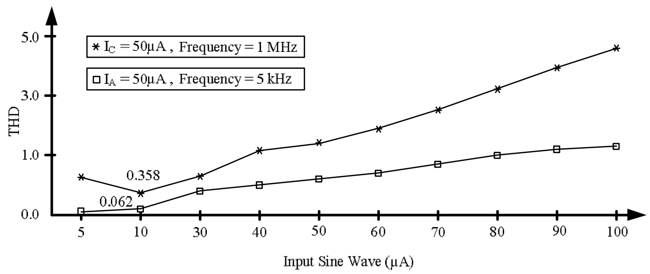

Fig. 9. The THD of the output waveform for different input amplitudes.

The DC transfer characteristic of the proposed multiplier is illustrated in Fig. 4. It can be found that the proposed circuit still operates as a 4 quadrants multiplier. However, it can be seen that the DC offset affect to the output signal, it accordance with theoretical analysis in Section II.C. The transient respond of the proposed multiplier is demonstrated in Fig. 5. Fig. 6 shows the output signal of the proposed circuit relative to temperature variations from $27°C$, $50°C$ and $100°C$. It is clearly seen that the output current is slightly dependent on the temperature variations due to the intrinsic resistances and strayed capacitances in the CC-CCTA, as depicted in non-ideal case, its rate to change is $0.0087\mu A/°C$. Fig. 7 depicts amplitude deviation relative to variations of the temperature from $0°C$ to $100°C$, it is displayed that the maximum error of the output amplitude current is approximately ±2.52%. The frequency response of the proposed multiplier is display in Fig.8. It can be found that the -3dB bandwidths of the multiplier is 29.309MHz. The last result, it is the THD of the output waveform for different input amplitudes. as shown in Fig. 9. The minimum THD is 0.062% and 0.358% when $I_A = 5\mu A$ and $I_C = 10\mu A$, respectively.

IV. Conclusion

In this brief, a new 4 quadrant current-mode multiplier based on CC-CCTA has been presented. The proposed configuration is very simple, it comprise only on CC-CCTA without passive component. The performance of the multiplier has been estimated using PSpice simulation.. It can be found that the simulation results are depicted, and agree well with the theoretical anticipation. Moreover, its advantages of the proposed analog multiplier circuit are high bandwidth, low power consumption and temperature insensitive. Thus, it is suitable in fully IC technology

References

[1] M. A. Abou El-Atta, M. A. Abou El-Ela, and M.K. El Said, "Four-quadrant current multiplier and its application as a phasedetector," Proceedings of the Nineteenth National Radio Science Conference (NRSC 2002), pp. 502-508. Mar. 2002.

[2] S. Kaedi and E. Farshidi, "A new low voltage four-quadrant current mode multiplier ," 2012 20th Iranian Conference on Electrical Engineering (ICEE), pp. 160-164, 2012.

[3] A. Naderi, A. Khoei and K. Hadidi, "High speed, low power four-quadrant CMOS current-mode multiplier" ICECS 2007. 14th Electronics, Circuits and Systems , pp. 1308-1311, 2007.

[4] J. M. A. Miguel, C. A. de la Cruz Blas and A. J. Lopez-Martin, "Fully differential current-mode CMOS triode translinear multiplier," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 58, no. 1 pp. 21- 25, 2011.

[5] M. Gravati, M. Valle, G. Ferri, N. Guerrini and N. Reyes, "A novel current-mode very low power analog CMOS four quadrant multiplier," Proceedings of ESSCIRC 2005 the 31st European Solid-State Circuits Conference , vol. 58, no. 1 pp. 495-498 , 2005.

[6] P. Silapan and C. Chanapormma, "A temperature-insensitive simple current-mode multiplier/divider employing only multiple-output CDTA," International Journal on Electrical & Power Engineering, vol. 2, no. 3, pp. 42-45, November 2011

[7] M. Siripruchyanun and W. Jaikla, "A current-mode analog multiplier/divider based on CCCDTA," AEU- Int. J. Electron. Commun., vol. 62, pp. 223-227, 2008.

[8] M. Siripruchyanun and W. Jaikla, "Realization of current controlled current differencing transconductance ampli¯er (CCCDTA) and its applications," ECTI Trans. Electr. Eng. Electron. Commun., vol. 5, pp. 41-50, 2007.

[9] E. Yuce, "Design of a simple current-mode multiplier topology using a single CCCII+," IEEE Transactions on Instrumentation and Measurement, vol. 57, no. 3, pp. 631-637, 2008.

[10] M. Siripruchyanun, "A design of analog multiplier and divider using current controlled current differencing buffered amplifiers," Proc. Int. Symp. Integrated Circuits (ISIC), pp. 616-619, 2007.

[11] A. Lahiri, and A. Chowdhury, "Four quadrant analog multiplier using dual-current-controlled current differencing buffered amplifier," Journal of Circuits, Systems, and Computers, vol. 20, no. 2, pp. 223-231, 2011.

[12] C. Toumazou, F. J. Lidegy and D. Haigh, Analog IC design: the current-mode approach, Peter Peregrinus, Exeter, UK, 1990.

[13] H. Schmid, "Why the terms 'current mode' and 'voltage mode' neither divide nor qualify circuits," IEEE ISCAS 2002, pp. II-29-II-32, 2002.

[14] S. Khucharoensin and V. Kasemsuwan, "High performance CMOS current-mode precision full-wave rectifier," IEEE ISCAS 2003, pp. I-41-I-44, 2003.

[15] D.R. Bhaskar, V. K. Sharma, M. Monis and S. M. I. Rizvi, "New current-mode universal biquad filter," Microelectronics Journal, vol. 30, pp. 837-839, 1999.

[16] M. Siripruchyanun, W. Jaikla, "Current controlled current conveyor transconductance amplifier (CCCCTA): a building block for analog signal processing," Electrical Engineering, vol. 90, No. 6, pp. 443-453, June 2008.

[17] R. Prokop, V. Musil, "New modern circuit block CCTA and some its applications," The Fourteenth International Scientific and Applied Science Conference - Electronics ET'2005, Book 5. Sofia: TU Sofia, pp. 93-98, 2005.

[18] D.R. Frey "Log-domain filtering: an approach to current-mode filtering". IEE Proc. Circuit Devices Syst., vol. 140, pp. 406-416, 1993..