IJASRM
International Journal of Advanced Scientific Research and Management, Volume 3 Issue 9, Sept 2018
www.ijasrm.com
ISSN 2455-6378

Characteristics of voltage controlled current conveyor transconductance amplifier (VCCCTA)

Vinod Kumar[1], Rockey Gupta[2] and Susheel Sharma[3]

[1]Department of Physics, University of Jammu, Jammu, J&K State (India)

[2]. Department of Electronics, University of Jammu, Jammu, J&K State (India)

[3]. Department of Electronics, University of Jammu, Jammu, J&K State (India)

Abstract

The second generation current controlled current conveyor has been widely used for implementing current mode analog circuits due to its high bandwidth, high slew rate and electronic tunability. In this paper, we have presented a new device named as voltage controlled current conveyor transconductance amplifier (VCCCTA) which has been designed as a modification of current controlled current conveyor transconductance amplifier (CCCCTA) where in the parasitic resistance at current input port has been controlled by bias voltage rather than bias current as in CCCCTA resulting in its bias controlled characteristics. The paper presents the current and voltage transfer characteristics of the VCCCTA and it has been found that VCCCTA offers a current transfer ratio of 1.013 with a bandwidth of 18.815 kHz. The voltage transfer ratio of the proposed VCCCTA is found to be 0.9989 having a bandwidth of 35.481 MHz with a total power dissipation of 1.01 mW.

Keywords: *CCCII, parasitic resistance, CCCCTA and VCCCTA*

1. Introduction

Current conveyor is an important and versatile current mode active building block which has been considered superior to conventional voltage mode operational amplifier and offers higher design flexibility [Smith K. C. & Sedra S., 1968, Smith K. C. & Sedra S., 1970, Sedra S., Roberts et.al, 1990, Kurashina T., 2002, Duhan M. et. al, 2014, Chaudhary J. and Singh S., 2015]. The second generation current conveyor (CCII) has been used as active element for designing filters and oscillators operating at low voltage [Kumar M. et. al, 2010, Rajput S. S., & Jamuar, S. S., 2002, Gilbert B., 1975]. Despite number of applications, CCII lacks electronic tunability resulting in no scope of post fabrication design alterations [Gilbert B., 1975 & Seevinck E., 1988]. This limitation has been overcome by current controlled current conveyor (CCCCII) wherein parasitic resistance at current input port can be controlled by a bias current [Fabre A. & Saaid O., 1996, Minaei S., 2001, Rajput S. S. & Jamwar S. S., 2002, Chairicharoen R. & Chipipop B., 2010 and Prokop R. & Musil V., 2005]. The authors R. Prokop and V. Musil in 2005 presented a new active element named as current controlled transconductance amplifier (CCTA) in which an operational transconductance amplifier (OTA) has been placed at the current output port of current conveyor and the device exhibits attractive features like high bandwidth, large dynamic range and high linearity. Inspite of all these desirable features, CCTA lacks control of its characteristics through parasitic resistance at its current input port, thus requiring some external passive components like resistors to make it suitable for tunable filter applications. However, this modification makes the CCTA unsuitable for IC implementation. M. Siripruchyanun et. al in 2008 presented the modified version of CCTA called as current controlled current conveyor transconductance amplifier (CCCCTA) wherein the parasitic resistance at the current input port has been controlled by input bias current and does not require external resistors for practical applications [Prokop R. & Musil V., 2005, Khatib F. & Kumngern M., 2015, Siripruchyanun M. & Jaikla

W., 2008, Chen Hua-pin and Yang Wan-Shing , 2017].

The block diagram of CCCCTA is shown in Figure-1.

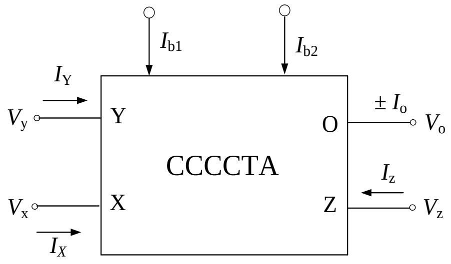

Figure-1 Block diagram of CCCCTA

In Figure-1, X is the hybrid port which acts both as current input port and voltage output port, Y is the voltage input port, Z is the current output port of CCCII and O is the current output port of the CCCCTA. I_{b1} and I_{b2} are the bias currents applied to CCCII and OTA respectively. The port relations of CCCCTA can be characterized by the following matrix equation.

$$\begin{bmatrix} I_y \\ V_X \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_Y \\ V_z \\ V_o \end{bmatrix} \quad \text{(i)}$$

where R_x is the parasitic resistance at current input port X and g_m is the transconductance of the CCCCTA.

The expression for R_x is given by

$$R_X = \frac{1}{\sqrt{8\beta_n I_{b1}}} \quad \text{(ii)}$$

where β_n is the physical parameter of MOSFET and g_m is the transconductance of the CCCCTA and is given by [Siripruchyanun M. & Jaikla W., 2008]

$$g_m = \sqrt{\beta_n I_{b2}} \quad \text{(iii)}$$

However, the CCCCTA has limitation that it is required to be biased by two external current sources I_{b1} and I_{b2}. As a result we require two current sources for this circuit, one for biasing CCCII and other for biasing OTA which makes this circuit complicated. In this paper, we have replaced these two external current sources by a single floating-gate MOSFET (FGMOS) based voltage controlled current source (VCCS) and named it as voltage controlled current conveyor transconductance amplifier (VCCCTA) [Sharma S. & Gupta R., 2012, Sharma S. et. al , 2005]. The controlling voltage known as bias voltage would now controls both the parasitic resistance and transconductance of the proposed device thus imparting better tunability in resulting applications.

2. Circuit description of VCCCTA

The block diagram of voltage controlled current conveyor transconductance amplifier (VCCCTA) as shown in Figure-2 comprises of three functional blocks VCCS, CCCII and operational transconductance amplifier (OTA). The first block is a FGMOS based voltage controlled current source (VCCS) where the output current is controlled by the bias voltage (V_{bias}) and is given by following equation[Sharma S., Gupta R., 2012, Sharma S. Rajput S. S., Mangotra L. K. & Jamuar S. S., 2005 and Sharma S. & Rajput S. S and Jamuar S. S., 2008].

$$I_{out} = \frac{\beta}{2}\left[\left(\frac{C_2/C_1}{1+C_2/C_1}\right)V_{bias} - V_T\right]^2 \quad \text{(iv)}$$

Now, this bias controlled current known as bias current is fed to both CCCII and OTA.

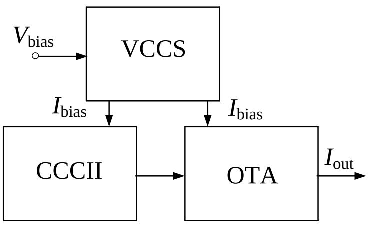

Figure-2 Block diagram of VCCCTA

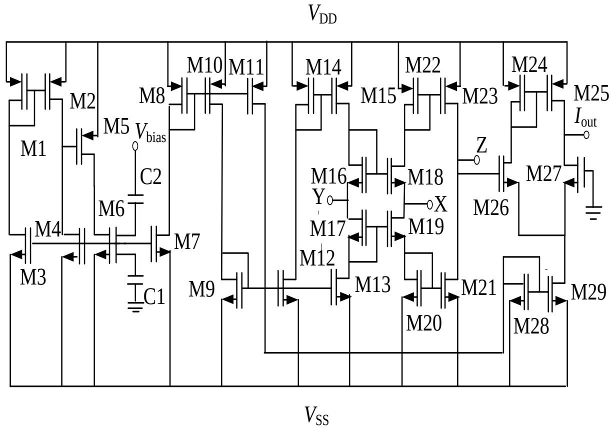

Figure-3 Circuit of VCCCTA

The circuit diagram of VCCCTA is shown in Figure-3. MOSFETs from M1 to M9 form voltage controlled current source (VCCS), M10 and M11 form the current mirror further MOSFETs from M12 to M23 form CCCII in which M16 to M19 form the translinear structure, while MOSFETs M24 to M29 form the operational transconductance amplifier (OTA) This OTA is biased through the drain of M11. The value of R_x has been obtained by modifying equation (ii) with the help of equation (iv) and is given as:

$$R_X = \frac{3}{2\mu C_{OX}\left(\frac{W}{L}\right)[2V_{bias} - 3V_T]}$$

ISSN 2455-6378

(v)

where symbols have their usual meaning. Now the arrangement used to find the values of parasitic resistance of voltage controlled current conveyor transconductance amplifier is shown in Figure-4. We have found the values of input resistance by varying the bias voltage from 0 V to 1 V and the resulting dependence of parasitic resistance on bias voltage is depicted in Figure-5.

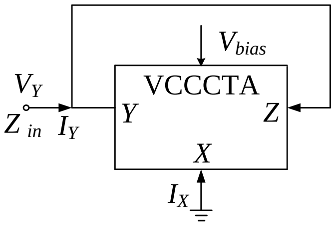

Figure-4 VCCCTA as transresistor

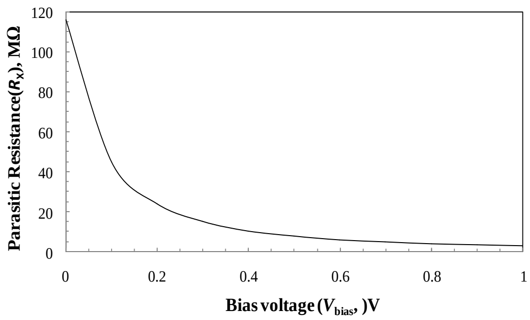

Figure-5 Variation of R_x with V_{bias} of VCCCTA

As evident, the parasitic resistance decreases from 116 MΩ to 2.94 MΩ as bias voltage is increased from 0 V to 1V thus validating equation (v). Further by making use of equations (iii) and (v), the transconductance (g_m) of the proposed device is given by

$$g_m = \frac{\mu C_{OX}\left(\frac{W}{L}\right)\left[2V_{bias} - 3V_T\right]}{3\sqrt{2}} \quad \text{(vi)}$$

The variation of transconductance of the proposed VCCCTA with bias voltage is shown in Figure-6.

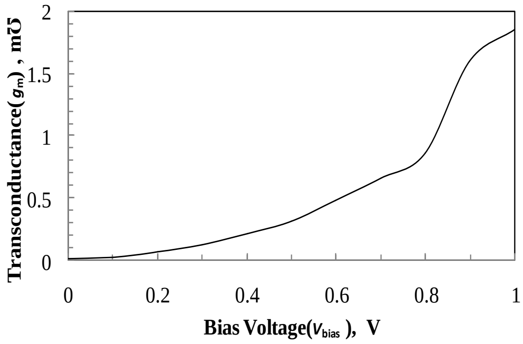

Figure-6 Variation of g_m with V_{bias} of VCCCTA

This graph shows that the transconductance increases with the bias voltage from 0.0104 m℧ to 1.85 m℧ as bias is increased from 0V to 1V as predicted by equation (vi).

3. Simulation results

The circuit of VCCCTA shown in Figure-3 has been simulated by using level 3 P-Spice simulations parameters of 0.5µm technology with supply voltage of ± 0.5V by choosing W/L ratio of 50µm/0.5 µm for M1 & M2, 50 µm /1 µm for M3, M4, M6 & M7, 100 µm/0.5 µm for M5 and 400 µm/0.5 µm for M8. W/L ratio of M8, M14, M15, M17, M19, M22 & M23 chosen as 400µm/0.5 µm W/L ratio of M11, M12, M13, M16, M18, M20 & M21 is 200 µm/0.5 µm and W/L ratio of M9 & M10 is 500 µm /0.5 µm. The current transfer characteristics of VCCCTA have been obtained by applying an input current at port X and measuring the output current at port O keeping port Y grounded for different values of bias voltage V_{bias}. The input resistance of the circuit at port X has been found to be 5.141 kΩ while output resistance at port O is 70.70 GΩ. The current transfer ratio of the proposed VCCCTA has been found to be 1.013 (Figure 7) having bandwidth of 18.815 kHz as shown in Figure 8.

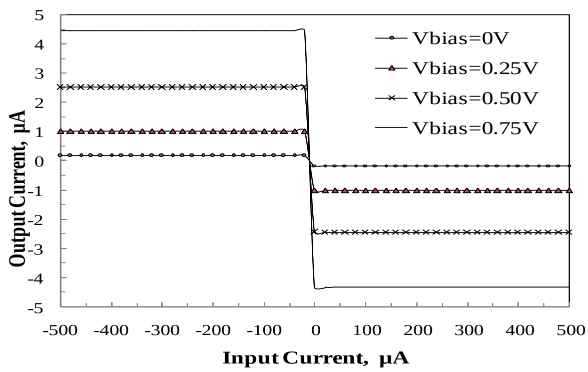

Figure-7 Current transfer characteristics of VCCCTA

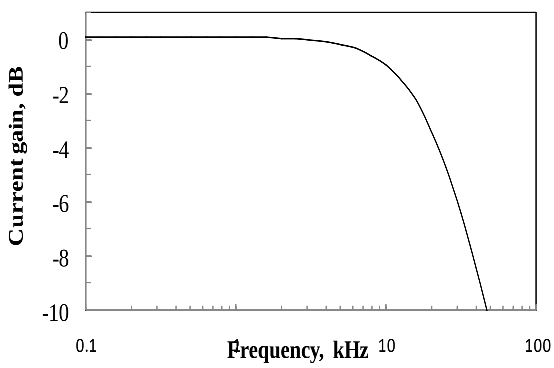

Figure-8 Frequency response of current transfer characteristics

The voltage transfer ratio of the proposed VCCCTA has been found to be 0.9989 with a bandwidth of 35.481MHz as shown in Figures 9 and 10 respectively. Input resistance at port Y has been found to be 14.19 MΩ with output resistance at port X as 5.098 kΩ. Total power dissipated by the circuit is 1.01 mW.

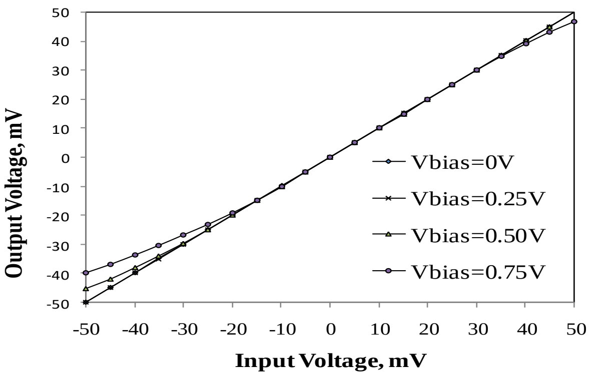

Figure-9 Voltage transfer characteristics of VCCCTA

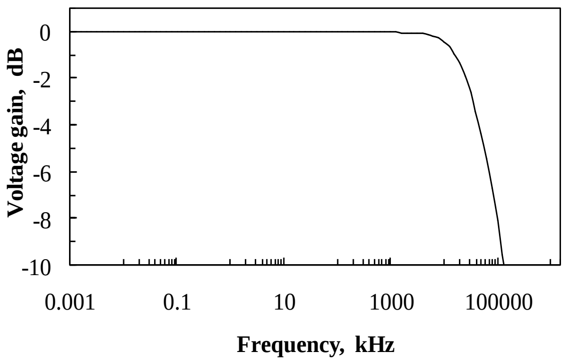

Figure-10 Frequency response of voltage transfer characteristics

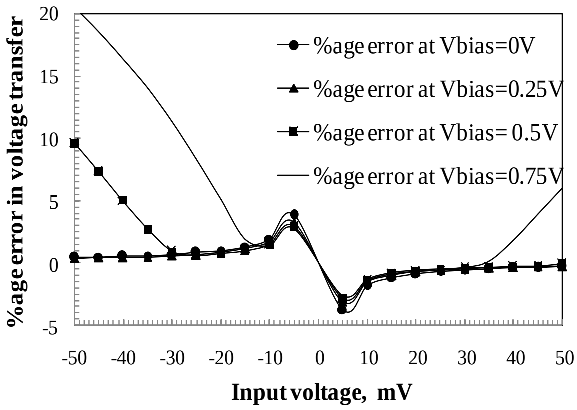

Figure-11 Percentage error in voltage transfer of VCCCTA

The variation of percentage error for voltage transfer characteristics with input voltage is shown in Figure 11. As evident from the figure, the percentage error lies in the range of 0 to 10% as bias voltage is increased from 0 to 0.5V, while at bias voltage of 0.75 V the percentage error is 20%.

4. Conclusion

In this paper, we have proposed a novel device known as voltage controlled current conveyor transconductance amplifier (VCCCTA).The proposed device is a modified version of CCCTA and consists of voltage controlled current source, a translinear CCCII and a OTA. The parasitic resistance at current input port of the VCCCTA has been controlled by a bias voltage rather than by a bias current, thus imparting post fabrication design flexibility and prove to be a useful design element for implementing various filters and oscillators. It has also been found that VCCCTA offers a current transfer ratio of 1.013 with a bandwidth of 18.815 kHz. The voltage transfer ratio of the proposed VCCCTA has been found to be 0.9989 with a bandwidth of 35.481MHz.

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