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MOCCCDTA-based Current Mode Tunable Universal Biquad Filter for Bluetooth Applications

Jyoti Sharma and Shantanu Chakraborty
Department of ECE, BIT Mesra, Jaipur Campus, India

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ABSTRACT

In the last decade, there has been much effort to reduce the supply voltage of electronic circuits due to the demand for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose more than the voltage-mode one. In this paper, performance of multi output current controlled current differencing transconductance amplifier (MOCCCDTA) is evaluated using 180nm, 90nm and 45nm CMOS technology. It is found that the 45nm CMOS-based MOCCCDTA provides highest frequency i.e. 33GHz. Further a Universal biquad filter has been designed using a single MOCCCDTA as an active element and two capacitors. Filter offers high frequency in GHz. Tunability of all the filter outputs with respect to a bias current has been analyzed. The tunability of the filter circuit for Bluetooth applications is also shown in this work. The performances of MOCCCDTA circuit and Universal biquad filter are illustrated by HSPICE. The simulation results are found to be in agreement with the theoretical predictions.

Corresponding Author:
Jyoti Sharma
Assistant Professor
BIT Mesra, Jaipur Campus
9929655006
jyotisharma@bitmesra.ac.in

1. INTRODUCTION

With the advent of integrated circuit technology, it has become possible to design larger electronic circuits on a single chip. Mixed-signal ICs are chips that contain both digital and analog circuits on the same chip. All the above mentioned circuits can be designed individually/ on a single chip by using either voltage mode or current mode techniques. Similarly, the general trend in CMOS technology is to make the devices smaller and smaller to increase the density and speed of digital circuits. It is also common to reduce the thickness of the gate oxide in order to increase the driving capability of the transistor [1]- [3]. In addition, the thickness reduction implies that the supply voltage must be decreased to avoid excessive electric field in the devices. Also the number of components is increasing on a single chip, but it can only dissipate a limited amount of power per unit area. Since the increasing density of components allows more electronic functions per unit area, the power per electronic function has to be lowered in order to prevent overheating of the chip [4]- [6].

Earlier the operational amplifier (OA) has served as the basic voltage mode building block in analog circuit design [1]- [3]. Voltage-mode operational amplifier (OA) circuits have limited bandwidth at high closed-loop gains due to the constant gain-bandwidth product. The moderate slew-rate of the operational amplifier limits the large-signal, high frequency operation. Also in the applications where wide bandwidth is required, low power consumption and low voltage operation are needed simultaneously. In that case, voltage-mode operational amplifier becomes too complex. Therefore, voltage mode circuits based on operational amplifier (OA) are not suitable for use in high frequency applications. Thus their limited performance as mentioned above, led the analog designer to search for other possibilities and other building blocks [7]. Voltage-mode circuits are those in which signal information is represented by voltage at the nodes of the circuit, where as in current-mode circuits, signal information is represented by current owing in the branches of the circuit. In current mode circuits (CMCs) the complete circuit response is determined by the currents and the input/ output signals are primarily represented in current form. CMCs have simple architecture and their operations do not depend on the supply voltages [6]- [7]. The current mode circuits also offer high linearity, wide bandwidth, lower power consumption, simpler circuitry and better high frequency performance [2, 8–11].

In this work, a CMOS-based Multi Output Current Controlled Current Differencing Transconductance Amplifier (MOCCCDTA) has been presented. Performance evaluation of MOCCCDTA has been carried out using HSPICE through Transient and AC responses. Next a universal biquad filter has been designed using MOCCCDTA that is capable of generating low-pass, high-pass, band-pass and band-reject responses. Circuit uses only a single MOCCCDTA and two capacitor and no resistors. The proposed circuit offers several advantages such as minimum number of active and passive components required, appropriate for high frequency operation in GHz and resistor less implementation.

The paper is arranged as follows. Section II presents brief description of MOCCCDTA. Section III discusses the universal biquad filter. The simulation results of all the filter responses are discussed in section IV. The tunability of filter responses with the variation of bias current is also presented in section IV. Section V shows the tuning of band pass filter for Bluetooth applications. Section VI concludes the paper.

2. BRIEF INTRODUCTION TO MULTI OUTPUT CURRENT CONTROLLED CURRENT DIFFERENCING TRANSCONDUCTANCE AMPLIFIER (MOCCCDTA)

The MOCCCDTA consists of the current differencing transconductance amplifier (CDTA) as the basic building block. The CDTA takes two inputs Ip and In as currents and produces the current Iz at the impedence terminal. The current I_z is proportional to the difference between the input currents. An equivalent voltage V_z is produced on the impedence terminal due to the finite resistance of the terminal and the voltage drop across it. The voltage Vz so generated is then trans-conducted across to the output terminal and the output current thus produced is proportional to the value of transconductance across the circuit given by g_m. It has finite input resistances Rp and Rn at input terminals. These parasitic resistances are equal and can be controlled by biasing currents. The MOCCCDTA is represented by a set of characteristic equation shown in Eq.1.

$$V_p = V_n = 0; I_z = I_p - I_n; I_x \pm = \pm g_m V_z \quad (1)$$

where p and n are input terminals, z and x are output terminals and g_m is the transconductance gain. The parasitic resistances R_p, R_n and the transconductance gain g_m are given by Eq. 2 and 3.

$$R_p = R_n = \frac{V_T}{2I_{B1}} \quad (2)$$

$$g_m = \frac{I_{B2}}{2V_T} \quad (3)$$

where I_{B1} and I_{B2} are the bias currents of the MOCCCDTA and V_T is the thermal voltage . The basic building block of the MOCCCDTA is shown in Fig. 1 where Ip and In are the two input currents and Iz is the transimpedence current produced. At x terminal, we see that the output current is either in inverted mode or in non-inverted mode which is proportional to the transconductance.

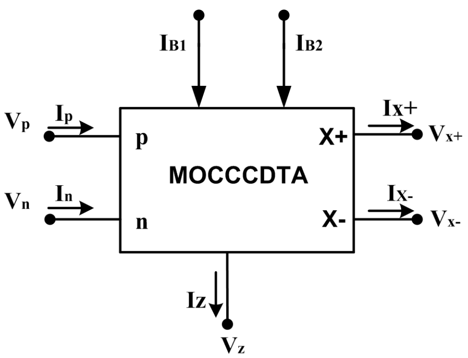


Figure 1. Block Diagram of Multi-output Current Controlled Current Differencing Transconductance Amplifier

Fig. 2 shows the internal CMOS based circuit of MOCCCDTA. Port p and n are the input ports and Z1, Z2 and Z3 are the positive and negative output current ports. Port X is also the output current port. IB1 and IB2 are the bias currents.

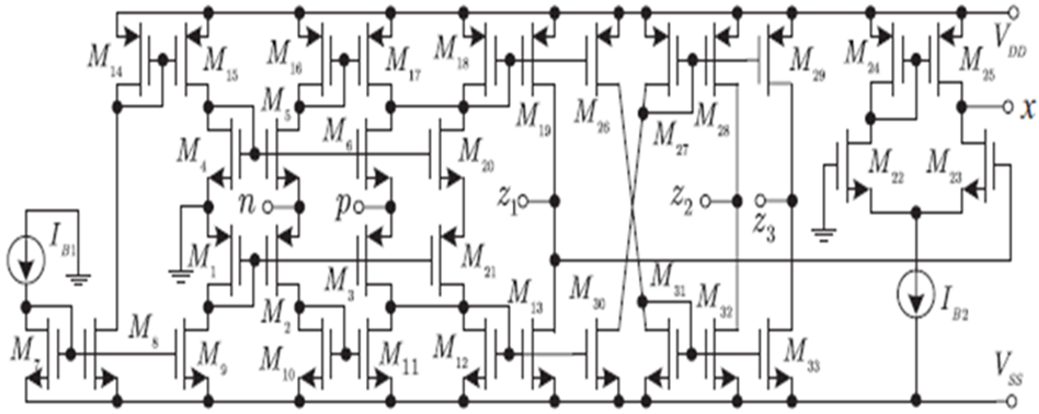


Figure 2. Internal Circuit of Multi-output Current Controlled Current Differencing Transconductance Amplifier

3. UNIVERSAL BIQUAD FILTER

The current mode universal biquad filter is designed using single MOCCCDTA as an active element and two grounded capacitors, which is easy to fabricate. The block diagram of the filter is shown in Fig. 3. In this filter, the multi-output CCCDTA of Fig. 2 is used where currents I_{z2} and I_{z3} are obtained in opposite directions from I_{z1}. Capacitors are used for high pass and band pass applications.

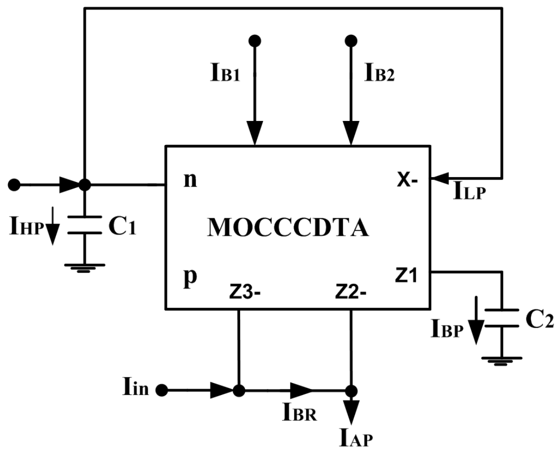


Figure 3. Block Diagram of Universal Biquad Filter

The transfer functions of high-pass, low-pass and band-pass filters are given in Eq. 4-6.

$$\frac{I_{HP}}{I_{in}} = \frac{s^2}{s^2 + \frac{s}{C_1 R_n} + \frac{g_m}{C_1 C_2 R_n}} \tag{4}$$

$$\frac{I_{LP}}{I_{in}} = \frac{\frac{g_m}{C_1 C_2 R_n}}{s^2 + \frac{s}{C_1 R_n} + \frac{g_m}{C_1 C_2 R_n}} \tag{5}$$

$$\frac{I_{BP}}{I_{in}} = \frac{\frac{s}{C_1 R_n}}{s^2 + \frac{s}{C_1 R_n} + \frac{g_m}{C_1 C_2 R_n}} \tag{6}$$

The band-reject transfer function may be achieved by IBR= Iin-IBP and is given in Eq.7.

$$\frac{I_{BR}}{I_{in}} = \frac{s^2 + \frac{g_m}{C_1 C_2 R_n}}{s^2 + \frac{s}{C_1 R_n} + \frac{g_m}{C_1 C_2 R_n}} \tag{7}$$

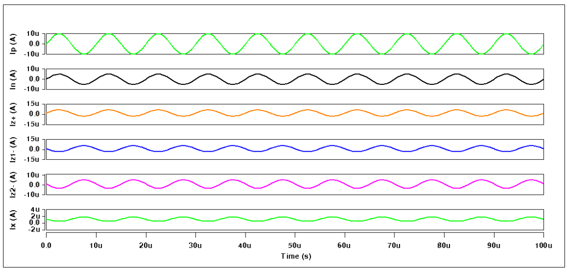
The pole frequency ω_0 and quality factor Q are given in Eq. 8 and 9.

$$\omega_0 = \sqrt{\frac{g_m}{C_1 C_2 R_n}} = \sqrt{\frac{\beta_n \sqrt{8 I_{B1} I_{B2}}}{C_1 C_2}} \tag{8}$$

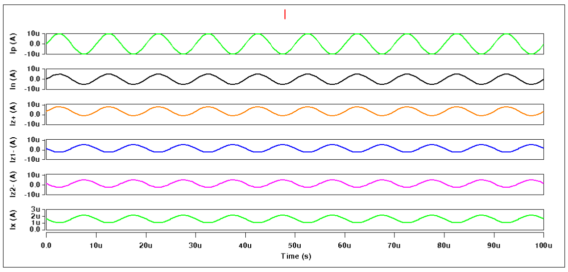
$$Q = \sqrt{\frac{C_1 g_m R_n}{C_2}} = \sqrt{\frac{C_1 \sqrt{I_{B2}}}{C_2 \sqrt{8 I_{B1}}}} \tag{9}$$

4. RESULTS AND DISCUSSIONS

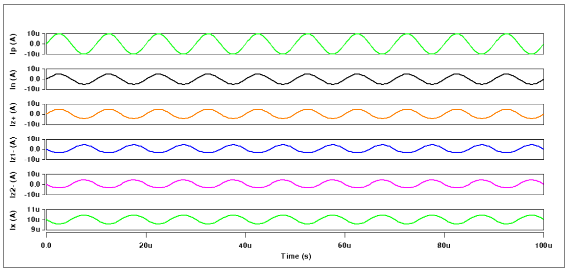
The MOCCCDTA circuit has been implemented in 180nm, 90nm and 45nm CMOS technology. In order to ascertain the correct operation of the CMOS-based MOCCCDTA, transient and AC analyses were carried out using HSPICE. Transient analysis has been carried out with 100 MHz sinusoidal input, for which the current relationship equations i.e. $I_z = I_p - I_n$ and $I_x = g_m V_z$ are successfully verified for all the three technology nodes. AC analysis for the CMOS-based MOCCCDTA reveals excellent conformity between the input currents $(I_p and I_n)$ and the output current (I_x) till about 1GHz, 5Ghz and 10 GHz for 180nm, 90nm and 45nm technology nodes respectively. The simulation results of transient and AC analyses of MOCCCDTA are shown in Fig. 4.



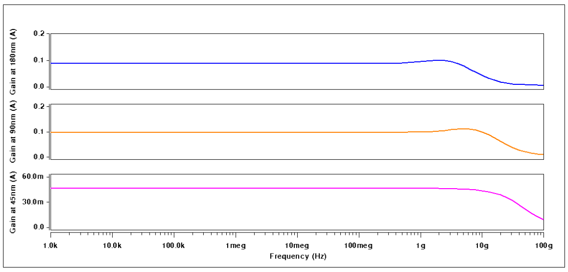
(a) Transient Response at 180nm Technology



(b) Transient Response at 90nm Technology



(c) Transient Response at 45nm Technology



(d) AC Response at 180nm, 90nm and 45nm Technology

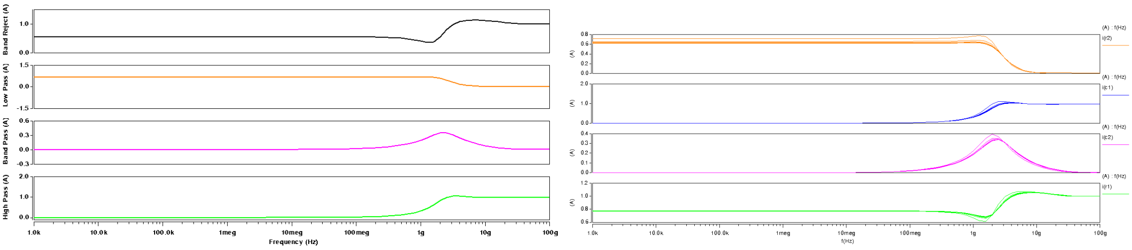
Figure 4. Results of HSPICE simulations for $Z+$, $Z-$ and X outputs of the MOCCCDTA of Fig. 2: (a)Transient Analysis at 180nm (b) Transient Analysis at 90nm (c) Transient Analysis at 45nm and (d) AC Analysis at 180nm, 90nm, 45nm Technology

The values of power supplies, bias currents and bandwidth obtained for different technologies are shown in Table 1. It is observed that MOCCCDTA circuit offers highest bandwidth among three for lower values of power supplies and bias current, thus more efficient.

Table 1. Parameter Values for Different Technologies

Technology	180nm	90nm	45nm
Vdd	1.25V	0.9V	0.45V
Vss	1.25V	0.9V	0.45V
Bias Current (I_{B1})	50μA	50μA	40μA
Bias Current (I_{B2})	80μA	60μA	40μA
Band Width (GHz)	6.6	15	33

The universal biquad filter circuit of Fig. 3 is simulated using HSPICE in 45 nm technology. The high-pass, low-pass, band-pass and band-stop responses are shown in Fig. 5(a). Effect of variation in the filter characteristics with bias current I_{B1} and I_{B2} of the MOCCCDTA was also explored using HSPICE simulations. Fig. 5(b) depicts the change in various filter characteristics as the bias currents is varied from 10A to 50A in steps of 10A for all the four filter functions.



(a) Band-Reject, Low-Pass, Band-Pass and High-Pass Filter Responses

(b) Variation in Filter Responses with the Variation in Bias Currents

Figure 5. Results of Responses of Filter in Fig. 3: (a)Filter Responses in 45 nm Technology and (b)Responses of various filter functions with the variation of bias currents from 10μA to 50μA in steps of 10μA

Table 2 shows the values of peak-frequency and bandwidth obtained from the universal biquad filter of Fig. 3. It is observed that the frequency obtained is in GHz. Thus the filter is suitable for high frequency applications.

Table 2. Peak-frequency and 3dB bandwidth of Universal Biquad Filter

Filter	Low-Pass	High-Pass	Band-Pass
Peak Frequency (GHz)	1.27	3.34	2.36
Bandwidth (GHz)	2.44	1.95	2.71

The present work [7, 12–15] has also been compared with the work done in the previous year on different technologies according to the active element used, bias currents, passive elements used etc. THe comparison has been shown in table 6.

	Technology	**Active Building Block**	**Passive Components**	**Bias Currents**	**Bandwidth**
[13]	360nm	CCCDTA	C1=C2=0.16nF Rp=Rn=821-25.1KΩ	Ib1=Ib2=50µA	282MHz
[17]	350nm	CDTA	C1=C2=1nF R1=R2=1kΩ	Ib1=Ib2=100µ A	130kHz
[18]	350nm	FDCCII	C1=C2=0.16nF R1=R2=0.71kΩ	Ib1=Ib2=35µA	1MHz
[19]	350nm	CCCCTA	C1=C2=7.5pF	Ib1=Ib2=7.5µA	1.8MHz
[20]	250nm	CCDDCCTA	C1=C2=100pF R1=R2=1kΩ	Ib1=25µA Ib2=200µA	1.28MHz
[21]	180nm	VDTA	C1=C2=0.01nF R=1.58 kΩ	Ib1=150µA Ib2=42.38µA	1MHz
This Work	45nm	MOCCCDTA	C1=10fF C2= 3fF	Ib1=20µA Ib2=10µA	2.71GHz

Figure 6. Comparison of the present work with the previous works

4.1. TUNING OF BAND PASS FILTER FOR BLUETOOTH APPLICATION

Bluetooth is a wireless technology standard for exchanging data over short distances using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz from fixed and mobile devices, and building personal area networks (PANs). Invented by telecom vendor Ericsson in 1994, it was originally conceived as a wireless alternative to RS-232 data cables. It can connect several devices, overcoming problems of synchronization. The universal filter circuit of Fig. 3 is also tuned for Bluetooth applications. The simulation result for the tuning of the filter for Bluetooth application is shown in Fig. 7.

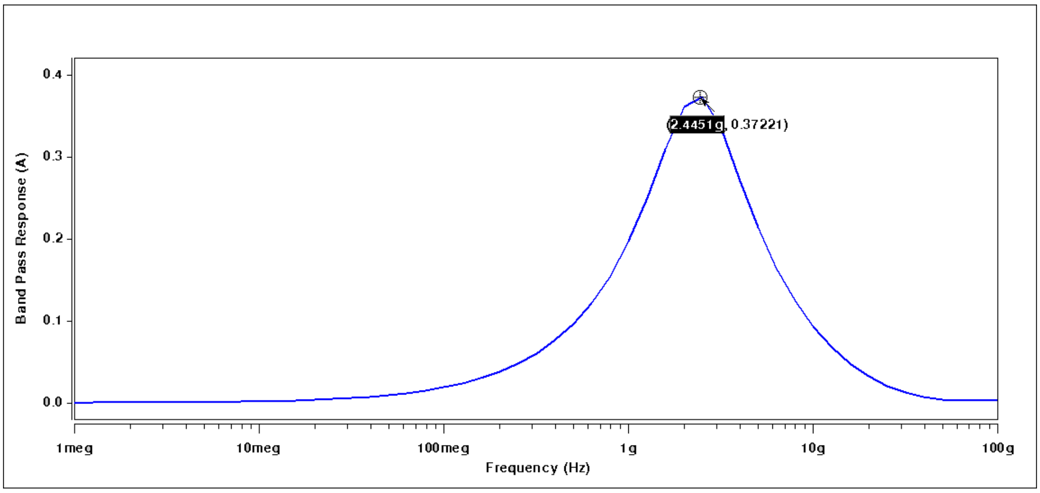


Figure 7. Tuning of Band Pass Filter for Bluetooth Applications

5. CONCLUSION

A CMOS-based implementation of multi output current controlled current differencing transconductance amplifier (MOCCCDTA) was presented. The performance comparison of MOCCCDTA has been done by performing transient and AC analyses for 180nm, 90nm and 45nm CMOS technology nodes using HSPICE simulations. It was found that the MOCCCDTA circuit offers highest bandwidth at 45nm CMOS technology node. A current mode universal biquad filter was then discussed that employs a MOCCCDTA as an active element and two grounded capacitors. The filter provides low-pass, high-pass, band-pass and band-reject responses. Also the tunability of the low-pass, high-pass, band-pass and band-reject filter was analysed by varying the bias current. Next the tunability of the filter for the Bluetooth application has been discussed. The filter circuit is suitable for high frequency Bluetooth applications.

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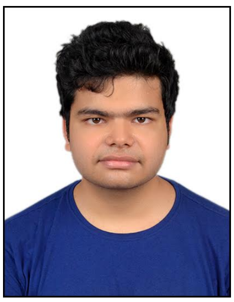
BIOGRAPHIES OF AUTHORS

Jyoti Sharma is Assistant Professor in the Department of ECE at BIT MESRA, Jaipur Campus with Master of Technology from NIT, Jaipur. She is pursuing Ph.D. in the field of VLSI Circuit Design from BIT Mesra. Her researches are in fields of electronics, analog systems, VLSI Circuits, Nanotechnology, Current Mode Circuits. She is a member of the IETE(Institution for Electronics and Telecom engineers)



Shantanu Chakraborty is currently persuing his undergraduate degree of Bachelor Of Engineering in Electronics and Communication Engineering at BIT MESRA,Jaipur Campus. He is presently a student member of the IETE(Institution for Electronics and Telecom engineers) and has actively participated in National Students' Congress Forum organised by IETE at BIT MESRA. He is also actively involved in the technical committee of the University as a student coordinator.He has involved himself in minor project works in the institution as a student coordinator.