International Journal of Electrical Electronics & Computer Science Engineering
Special Issue - TeLMISR 2015, ISSN : 2348-2273
Available Online at www.ijeecse.com

A Review and Evolution of Current Mode Circuits and Realization of CDTA using CMOS

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Abstract: ***This paper presents a brief introduction of some prominent current mode circuits which have been finding its attention in the area of analog signal processing. High performance current differencing transconductance amplifier (CDTA) has been realized using CMOS, provides a wider bandwidth, low power consumption and requires less space in integrated circuits implementation. Pspice simulation results using TSMC 0.35µm CMOS process model were also included to verify the theory.***

Keywords: ***Evolution, CDTA, analog signal processing, analog MOS integrated circuits.***

I. INTRODUCTION

Digital signal processing is becoming increasingly more powerful while advances in IC technology that provide compact and efficient implementation of its algorithms on silicon chips. Although many types of signal processing have indeed moved to digital domain but analog circuits are fundamentally necessary in many of today's complex and high performance system. The development of VLSI (very large scale integration) technology, together with the ever increasing demand for fully integrated systems containing a large number of digital as well as analog circuits on a single chip, has ensured continued interest on analog circuit design which is very compatible with the CMOS technology. Many analog circuits such as continuous time filter, D/A (digital to analog) converters, A/D (analog to digital) converters, voltage comparators, current and voltage amplifiers, rectifiers etc. are mainly analog circuits which cannot be realized by digital techniques.

Basically analog circuit design has been viewed as a voltage dominated form of signal processing. Now day's current mode analog circuits have emerged in the implementation of analog functions. In current mode circuits the complete circuit response is determined by the currents and the input/output signals are primarily currents. Current mode signals can be defined as a circuit in which current is used as an active variable either throughout the whole circuit or only in some critical areas. The nodes inside current mode circuits are low impedance nodes, where the resultant voltage swings are also small. The low impedance transforms them into low time constant circuits and the bandwidth is quite high. The slew rate is also very high if the rate of output changing is high. Current mode circuits have simple architecture and their operations do not depend on the supply voltages. The analog circuits should have rail-to-rail input and output voltage swing capability for high SNR, which can be received using the current mode circuits.

In addition to the advancement in current mode analog signal processing, another development is the emergence of new current mode analog building blocks among which the most popular and most common has been the current conveyor (CC) [1, 3, 13]. The current mode circuits such as current conveyors (CCs) have emerged as an important class of circuits in the field of electronics. In CCs the use of current rather than voltage as the active parameter can result in higher usable gain, accuracy and bandwidth due to reduced voltage excursion at sensitive nodes. The concept of current conveyor was first introduced by Smith and Sedra in 1968. They were not only considered to be used as controlled voltage and current sources, impedance converters and inverters etc., but also as function generators, filters, etc., in current processing circuits mainly for instrumentation and measurement applications [5, 6]. CCs [1] are parts of a number of very often used circuits, like active filters, transimpedance and current feedback operational amplifiers, voltage and current operational amplifiers and many more, and their main application areas are in high speed, high frequency circuits for both voltage and current signal processing. It is a three or more port (X, Y, Z) network and the port variables characterized by $i_y=i_x$, $v_x=v_y$ and $i_z=\pm i_x$. The second generation current conveyor (CCII) was developed in 1970 [3] and is characterized by $i_y=0$, $v_x=v_y$ and $i_z=\pm i_x$ and further developed to the third generation current conveyor (CCIII) [4, 7] was developed in 1995 which was characterized by $i_y=-i_x$, $v_x=v_y$ and $i_z=\pm i_x$. Since then, several works available in the literature in the area of current mode circuits and it progressed very fast and several thousand research papers have been published in this area so far. The application of filters and oscillators in communication circuits requires extended high frequency performance in fully integrated circuit. Circuit designers started to search for a more suitable active element that provides the transconductance amplifiers (OTAs), Current feedback amplifier (CFA), differential unavoidable gain without imposing severe frequency limitations and to keep the circuit simple so that it can be realized in IC technologies enabling easy synthesis procedures for active circuits, so there are many active building blocks introduced for this purpose. After extending the performance of current mode active elements, the most widespread element for on chip implementation is undoubtedly operational difference current conveyor (DDCC), current differencing buffered amplifier (CDBA) and many more.

In the late sixties, one of the major leaders in linear semiconductor came out with the operational Transconductance Amplifier called (OTA). The name means essentially a controllable resistance amplifier. The control input is a current. Like an operational amplifier, there are different inputs. These inputs are used to modulate the control current. Unlike an op-amp, the output of the OTA is a current. OTA structures offer several advantages over conventional op-amp based circuits as well as provide the evaluation of fully integrated circuits in VLSI design with CMOS technology. It is well known that OTAs provide highly linear electronic tunability of their transconductance and require just a few or even no resistors for their internal circuitry and have more reliable high frequency performance. An OTA is a voltage controlled current source, more specifically the term operational comes from the fact that it takes the difference of two voltages as the input for the current conversion. The ideal transfer characteristics is therefore

$$I_{out}=g_m\,(V_{in+}-V_{in-}) \qquad (1.1)$$

Or by taking the pre computed difference as the input,

$$I_{out}=g_m\,V_{in} \qquad (1.2)$$

With the ideally constant transconductance as the proportionality factor between the two.

The current feedback operational amplifier known as CFA is a type of electronic amplifier whose inverting input is sensitive to current rather than to voltage as in a conventional voltage feedback operational amplifier (VFA). The CFA was invented by David Nelson at Comlinear Corporation and was first sold in 1982 as a hybrid amplifier. The term current feedback is used because the error signal entering at the feedback node of the op-amp is in the form of a current and this gives to the amplifier a constant closed loop bandwidth capability. Ideally the bandwidth of the current feedback op-amp is independent of the closed loop gain. Therefore the closed loop gain bandwidth product increases linearly with the closed loop gain.

Chiu *et al.* proposed a new current conveyor circuit called the differential difference current conveyor (DDCC). The DDCC has the advantage of both the CCII and the differential difference amplifier (DDA) (such as high input impedance and arithmetic operation capability). It has three voltage input terminals: Y_1, Y_2 and Y_3 which have high input impedance. Terminal X is a low input impedance current input terminal. There is a high impedance current output terminal Z. The input output characteristics of ideal DDCC is described by matrix and equations:

$$\begin{bmatrix} V_x \\ I_{y1} \\ I_{y2} \\ I_{y3} \\ I_z \end{bmatrix} = \begin{bmatrix} 1 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{y1} \\ V_{y2} \\ V_{y3} \\ I_x \end{bmatrix} \qquad (1.3)$$

$$V_x=V_{y1}-V_{y2}+V_{y3}$$

$$I_{y1}=I_{y2}=I_{y3}=0$$

$$I_z=I_x \qquad (1.4)$$

The current differencing buffered amplifier (CDBA) is an active element intended to simplify the design of analog signal processing filters. It is a multi terminal active component with two differential current inputs and two voltage outputs and was developed by Cevdet Acar and Serdar in 1999. It can be derived from the (CFA). It offers advantageous features such as high slew rate, absence of parasitic capacitance, wide bandwidth, and simple implementation. Since the CDBA consists of a unity gain current differential amplifier and a unity gain voltage amplifier, this element would be suitable for the implementation of voltage and current mode signal processing applications. CDBA being a current mode universal active component provides wide bandwidth and high slew rate as distinct advantage.

Current Differencing Transconductance Amplifier (CDTA) [9], a five terminal active element, proposed by Biolek, is a versatile component in the realization of a class of analog signal processing circuits, especially in the realization of analog frequency filters. It consists of an input current subtractor and dual output transconductance stage. The CDTA element can be directly realized by replacing the buffer output of a CDBA with a dual output balanced transconductor stage. It is also possible to realize this element using a dual output current operational amplifier. CDTA consists of a unity gain current source controlled by the difference of the input currents and a multi output transconductance amplifier providing electronic tenability through its transconductance gain thereby making this device very suitable for the synthesis of active filters especially in current mode [11, 12]. Moreover, the use of the CDTA as an active element provides the circuit implementation with a reduced number of passive elements, thereby leading to compact structures in some applications. Good linearity, high accuracy, and high output resistance can be obtained by using high performance current mirrors and adequate input stages in the structure of CDTA. All these

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Special Issue - TeLMISR 2015, ISSN : 2348-2273
Available Online at www.ijeecse.com

advantages together with its current mode operation nature make the CDTA a promising choice for implementing the current mode continuous time signal processing circuits consecutively [13, 15].

In this paper there is an improved CMOS configuration of a CDTA that provides low input impedance, very high output impedance, an extended linearity range, and high transconductance. So for this configuration, cascode current mirrors and regulated cascode current mirrors were used. To demonstrate the performance of the CDTA circuit, biquad filter is chosen. It includes the PSpice simulations of the CDTA device characteristics and the filter characteristics.

II. CURRENT DIFFERENCING TRANSCONDUCTANCE AMPLIFIER

A CDTA consists of an input current subtractor and a dual output transconductance stage. The input stage takes the difference of input signals and transfers this difference current to the intermediate z terminal, where this current is converted to voltage via external impedance. The symbolic notation of CDTA is shown in figure 2.1 and its characteristics are represented by the following set of equations.

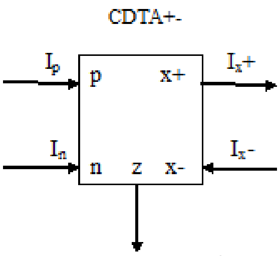

Figure 2.1 Symbol of CDTA

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & \pm gm & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_z \\ V_x \end{bmatrix} \qquad (2.1)$$

$$V_p = V_n = 0$$
$$I_z = I_p - I_n$$
$$I_{x+} = g_m V_z$$
$$I_{x-} = -g_m V_z \qquad (2.2)$$

Where p and n are input terminals and z and ±x are output terminals and g_m is the transconductance gain. Considering the deviation of the voltage and current gains from their ideal values, the characteristic equation becomes:

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha_p & -\alpha_n & 0 & 0 \\ 0 & 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_z \\ V_x \end{bmatrix} \qquad (2.3)$$

Where α_n and α_p are current gains, $\alpha_p=1-\xi_p$ and $\alpha_n= 1-\xi_n$. Here ξ_p and ξ_n are the current tracking errors, and their absolute values are much less than the unit value. The differential input current flows over the z terminal. Now according to equation (2.1), the current I_z follows the difference of the currents through the terminals p and n and flows from the terminal z into an impedance Z_z. The voltage drop at the terminal z is transferred to a current at the terminal x by a transconductance gain which is electronically controllable by an external bias current [10].

III. SIMULATION OF CDTA USING CMOS

The proposed CMOS based CDTA circuit is shown in figure 3.1. Additional X+ terminal has been introduced using current mirrors.

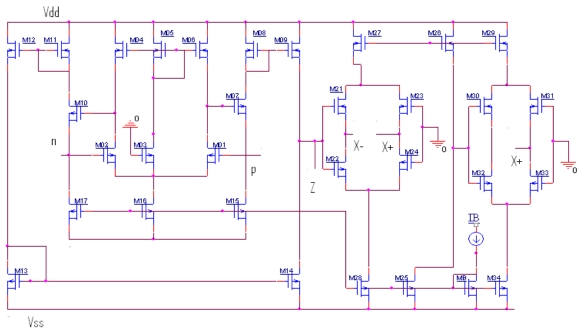

Figure 3.1 CMOS based CDTA

One of the major applications of CDTA is in filter circuits. The proposed CMOS based CDTA circuit has been verified using the PSPICE simulation program. The CDTA model employed n-well CMOS process TSMC 0.35mm. The transconductance is set to 888µS via a bias current of 40µA. Power consumption is 0.1402mW.

IV. SIMULATION RESULTS

4.1 *DC behaviour of CDTA:* The DC behaviour of CDTA is shown in figure4.1. Input current is applied at input terminal p. Input terminal n is connected to output terminal x+. The output current at terminal x+ is given as

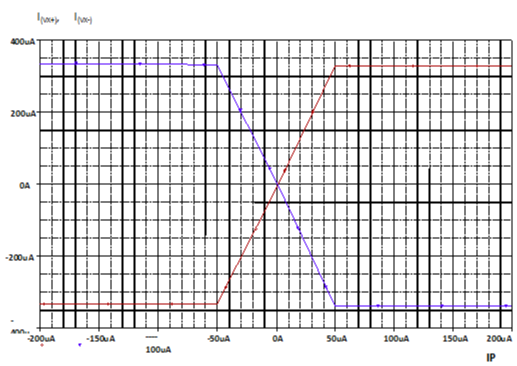

Figure 4.1 DC behaviour of CDTA

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4.2 *Gain Bandwidth Study:* Gain-Bandwidth study of CDTA is conducted in figure 4.2 and figure 4.3. Two frequency responses of current gains from p to x+ and n to x+ are obtained separately. Figure 4.2 below shows -3dB bandwidths of the current gain I_{X+} / I_p, when current input I_n at n-input terminal is equal to zero. It can be seen from the figure that –3 dB bandwidth is nearly 1GHz for I_{X+}/I_p. Similar results are obtained for -3dB bandwidths of the current gain I_{X+} / I_n in figure 4.3 when input current at p terminal is zero. From the above equation (2.2), when I_n = 0, then I_z = I_p which shows that the output current I_z follows the current input Ip linearly and shows increasing linear characteristic. Similarly, when I_p = 0, then I_z = -I_n which shows the decreasing linear characteristic between I_z and I_n. Figure 4.2 below shows -3dB bandwidth graph between the output current I_z at z terminal and input current at p terminal (I_p) when current input I_n at n-input terminal is equal to zero. It can be seen from the figure that –3 dB bandwidth is 390 MHz for I_x/I_p. Its gain is constant up to this frequency. It means that CDTA will give stable performance up to 390 MHz.

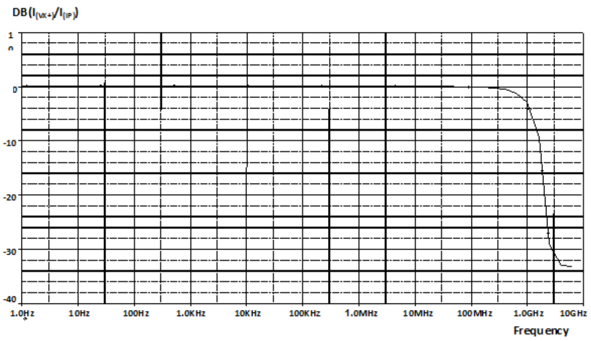

Figure 4.2 I_{X+}/I_p -3dB bandwidth when I_n = 0

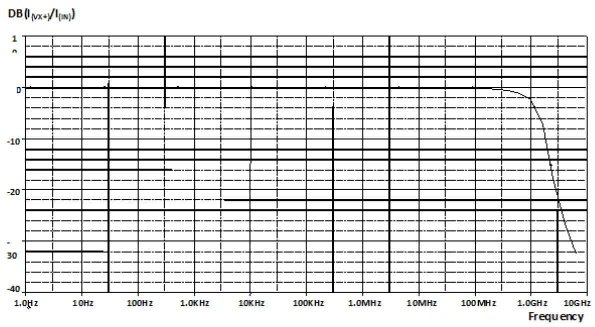

Figure 4.3 I_{X+}/I_n -3dB bandwidth when I_p = 0

As seen from the above two figures 4.2 and 4.3, bandwidth of CDTA is much larger. Hence, CDTA can be used in high frequency applications.

V. CONCLUSION

This paper presented a brief introduction of current mode circuits and high performance CMOS implementation of CDTA has been realized which greatly reduces the power consumption and space requirement for the IC implementation. The simulation results confirmed the high performance provided by the circuit in terms of wider bandwidth and a wide linearity range for both the voltage and current operations. Pspice simulation results also verified the theory. It is believed that this exposition /would be very useful to the analog circuit designers and researchers.

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