Resistor-less mixed-mode quadrature sinusoidal oscillator

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Abstract— **The paper presents a realization of mixed-mode quadrature sinusoidal oscillator variants of current differencing transconductance amplifier. The proposed circuit is created using one modified current differencing transconductance amplifier (MCDTA), one current follower transconductance amplifier (CFTA) and two grounded capacitors. The circuit is resistor-less and the tuning laws for the condition of oscillation (CO) and the frequency of oscillation (FO) are independent. The circuit also provides two quadrature voltage outputs and two explicit quadrature current outputs. PSPICE simulation results have been included to verify the theoretical results.**

Index Terms— **Mixed-mode, Quadrature sinusoidal oscillators (QO), modified current differencing transconductance amplifier (MCDTA), current follower transconductance amplifier (CFTA)**

I. INTRODUCTION

In the last decade, current-mode (CM) active building blocks (ABBs) have received considerable attention owing to their large bandwidth and high slew-rates [1]-[2]. Of them, current differencing transconductance amplifier (CDTA) is a very versatile for CM signal processing and its use has reportedly provided several circuit solutions [3]-[8]. CDTA has also been used to create sinusoidal oscillators with electronic tuning properties [9]-[14]. The motivation of this paper is to present new mixed-mode quadrature sinusoidal oscillator (QO) using CDTA variants and compare the circuit with the previously reported counterparts.

The proposed circuit is created using two CDTA variants, namely modified CDTA (MCDTA) and current follower transconductance amplifier (CFTA) [15]. The MCDTA has two different balanced transconductance units at its back-end and thus is more versatile than conventional CDTA [3]. CFTA is created by grounding *p* or *n* terminal of the conventional CDTA, which reduces the front-end current differencing unit into a current follower unit. The uses of these hybrid elements have been explained in subsequent sections.

The proposed QO employs one MCDTA, one CFTA and two grounded capacitors. The resulting circuit is resistor-less and provides:

(i) non interactive / independent control of the condition of oscillation (CO) and the frequency of oscillation (FO) and (ii) two explicit quadrature current outputs and two quadrature voltages. The sensitivity analysis of the circuit indicates good active and passive sensitivity performance. PSPICE simulation results are provided which verify the workability of the proposed circuit.

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II. PROPOSED CIRCUIT

Ideally, the MCDTA is characterized by the following equations

$$V_p = V_n = 0,\ I_z = I_n - I_p,$$
$$I_{x1+} = -I_{x1-} = g_{m1}V_z \text{ and } I_{x2+} = -I_{x2-} = g_{m2}V_z \quad (1)$$

Where, g_{m1} and g_{m2} represents transconductance gains of two different balanced operational transconductance amplifiers (BOTAs). The transconductance gains g_{m1} and g_{m2} are tunable by means of the bias currents I_{B1} and I_{B2}, respectively. Similarly, the characterizing equations of an ideal CFTA are given as

$$V_f = 0,\ I_z = I_f,\text{ and } I_{x+} = -I_{x-} = g_m V_z \quad (2)$$

The elements have been defined in compliance with network convention i.e. all currents are flowing into the terminals. It is clear from (2) that this CFTA can be created by grounding the *p* terminal of the conventional CDTA of [3]. The practical implementation of MCDTA and CFTA using commercially available components, viz. current feedback amplifiers (CFAs) and BOTAs are shown in Fig. 1 and 2, respectively.

The proposed QO is shown in Fig. 3. The circuit has been derived from the CM QO in [14] and Fig. 2(a) of [12]. Using (1) and (2) and doing routine circuit analysis of yields the following characteristic equation for the oscillator

$$s^2C_1C_2 + sC_2(g_{m2} - g_{m1}) + g_{m2}g_{m3} = 0 \quad (3)$$

It is evident from (3) that the condition of oscillation (CO) of the QO is

$$g_{m1} \geq g_{m2} \quad (4)$$

And, the frequency of oscillation (FO) is given as

$$f_o = \frac{1}{2p}\sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}} \qquad (5)$$

It is clear from (4) and (5) that the CO and FO tuning laws are non-interactive and independent; CO is tunable by g_{m1} and FO is tunable by means of g_{m3}. Thus CO and FO are controllable by the bias currents I_{B1} and I_{B3}, respectively. The two marked voltage outputs in the circuit are related as

$$V_{o1} = -jk_1V_{o2} \quad \text{Where} \quad k_1 = \frac{w_oC_2}{g_{m2}} \qquad (6)$$

The two marked current outputs are related as

$$I_{o1} = jk_2I_{o2} \quad \text{Where} \quad k_2 = \frac{g_{m1}w_oC_2}{g_{m2}g_{m3}} \qquad (7)$$

From (6) and (7), it is clear that the two voltages V_{o1} and V_{o2} and the two currents I_{o1} and I_{o2} are 90º phase shifted and would have equal amplitudes for $k_1=k_2=1$.

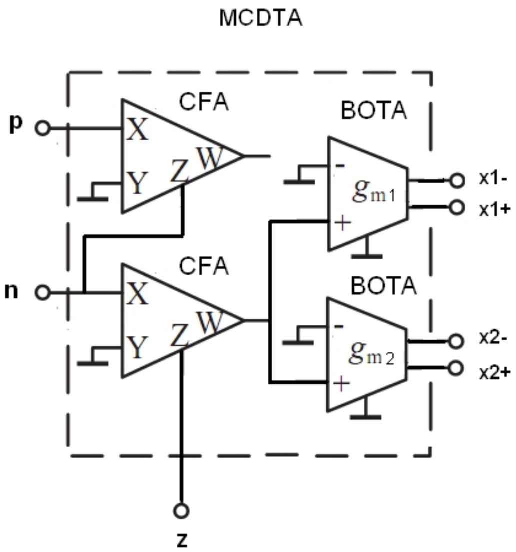

Fig.1 The implementation of MCDTA using CFA and BOTA

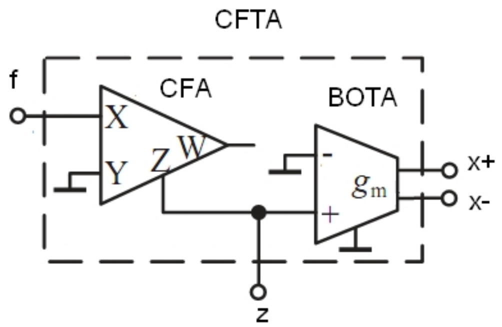

Fig.2 The implementation of CFTA using CFA and BOTA

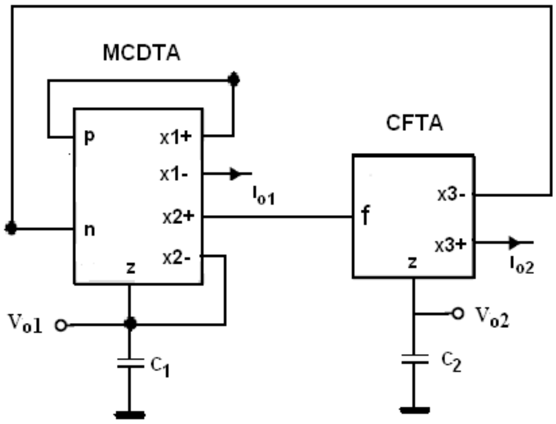

Fig.3 The proposed mixed-mode QO using MCDTA and CFTA

The sensitivity study of the FO indicates that

$$|S^{fo}_{g_{m2},g_{m3},C_1,C_2}| = \frac{1}{2} \qquad (8)$$

It is evident from (8) that active and passive f_o sensitivities are less than unity in magnitude and hence the circuit exhibits a good sensitivity performance. It is also worth mentioning that in the non-ideal case the parasitic capacitances appearing at the high output impedance z terminals and ground are absorbed into the external capacitors as they are shunt with them. This feature of grounded capacitor based circuits makes them particularly desirable for monolithic integration. Also, if the parasitic resistances at terminal *p*, *n* and *f* are negligible (ideally they are zero), then the parasitic impedances appearing at the *x* terminals would be connected between virtual ground and actual ground and thereby eliminating their effect. In practice, to alleviate the effects of the parasitic impedances, the operating angular frequency ω_o should be chosen such that $w_o < \frac{1}{C_xR_x}$, where C_x and R_x represent the parasitic resistance and capacitance appearing between the high output impedance *x* terminals.

III. Comparative Study

In this section comparisons between the proposed circuit and previously reported CDTA based oscillators, are provided.

1) As pointed in [13], the circuit of [9] is a current-mode QO created by cascade of two first-order all-pass filtering sections. It uses excessive number of passive components, including floating capacitors in the non-ideal sense and thus, the circuit is not suitable for monolithic integration.
2) The circuit in [10] also employs a floating capacitor. Moreover, it is not capable of providing any QO functionality in either current-mode (CM) or voltage-mode (VM).
3) The circuit in [11] uses reduced number of components, but compromises on the tuning laws, which are interactive. Thus the control of CO and FO are not independent.
4) The circuits in [12] provide non-interactive tuning of CO and FO, while also employing grounded capacitors. The availability of two explicit quadrature current

outputs and quadrature voltage outputs was, however, not investigated. The first circuit in [12] had been modified in [13] to provide ECOs and mixed-mode operation. But the circuits in [12] and [13] did not exploit the full functionality of the CDTA block, since either of the *p* or *n* terminals was grounded in both the CDTAs. Thus CDTA was reduced to a CFTA and hence the circuits in [12] and [13] were overlarge.

5) The circuit in [14] is similar to the first circuit in [12], i.e. Fig. 2(a) and mixed-mode operation was not investigated. The difference, however, is the availability of multiple quadrature explicit current outputs. Just like [12], the circuit in [14] was overlarge due to partial utilization of the CDTA terminals. The external linear resistor appearing at the *z* terminal of the first CDTA in Fig. 2(a) of [12] was simulated by means of a CDTA in [14]. This is an overkill, since a resistor can be easily simulated by only one OTA, rather than using a CDTA. This justifies the use of MCDTA and CFTA units which removes the redundancies in the circuit.

The basic structure of most of the previously reported oscillators providing single resistance/transconductance control of the CO and FO, can be derived from the classical papers dealing with SRCO by Senani et al [16]-[17]. The oscillators creating nowadays using modern hybrid ABBs, although have similar structures (using lossy and lossless integrators), are expected to provide additional features as compared to the classical SRCOs. With non-interactive tuning laws, use of grounded capacitors, mixed-mode QO functionality and reduced and non-redundant component count, the proposed circuit in this paper provides features which are simultaneously not available in any previously reported CDTA based oscillator.

IV. Simulation Results

In order to confirm the above given theoretical analysis, the proposed circuit is simulated using PSPICE simulations. The MCDTA and CFTA are constructed from CFAs (AD844AN) and OTAs (LM3080) as according to the implementation provided in Fig. 2. (Note that two LM3080 are used to construct a single BOTA). It should also be pointed out here that the use of such an equivalent circuit does not mean that MCDTA or CFTA have a complicated internal structure. Alternate bipolar implementation as in [6] or CMOS implementation as in [9], [13]-[14], could be used for testing.

As an example, the circuit was designed using the following component values: $C_1=C_2=1nF$, $g_{m2}=g_{m3}=2mS$ and the DC supply voltage used was $\pm 5V$. The value of g_{m1} is kept slightly more than $2mS$ to start the oscillations. The simulated output waveforms for *Vo1, Vo2* and *Io1, Io2* at steady stage are shown in Fig. 4 and Fig. 5, respectively. The values of total harmonic distortion (THD) at both voltage and current outputs are less than *3%*.

V. Conclusions

The paper presents a new resistor-less realization of mixed-mode quadrature sinusoidal oscillator using variants of current differencing transconductance amplifier (CDTA), namely modified CDTA (MCDTA) and current follower transconductance amplifier (CFTA). PSPICE simulation results have confirmed the workability of the circuit.

The MCDTA variant introduced here can be further used to create compact realizations of previously known CDTA based circuit solutions. Additional, more compact realizations of similar mixed-mode quadrature oscillators are not ruled out and can be investigated further.

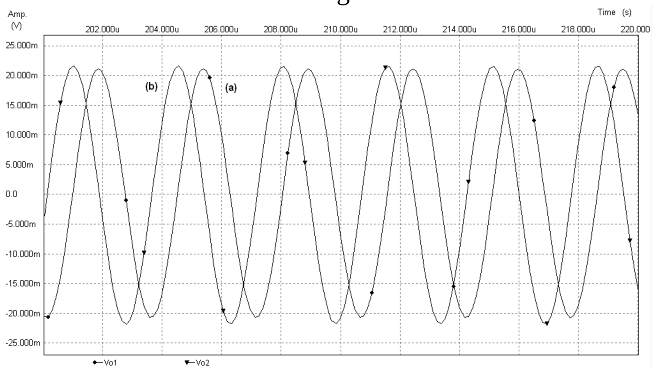

Fig.4 The steady-state waveforms for the quadrature voltages (a) V_{o1} and (b) V_{o2}

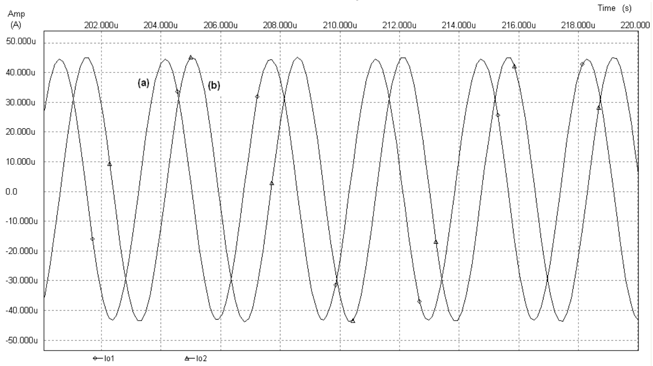

Fig.5 The steady-state waveforms for the quadrature voltages (a) I_{o1} and (b) I_{o2}

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