SINGLE ACTIVE ELEMENT BASED MIXED-MODE QUADRATURE OSCILLATOR USING GROUNDED COMPONENTS

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Abstract: *The paper presents a mixed mode quadrature oscillator (MMQO) using single active element and all grounded passive components. The proposed circuit employs a novel building block named as differential difference dual-X second generation current conveyor (DD-DXCCII) along with three grounded resistors and two grounded capacitors. The proposed quadrature oscillator provides three quadrature voltage outputs and two quadrature current outputs simultaneously so called mixed mode quadrature oscillator. The proposed mixed mode quadrature oscillator exhibits the feature of orthogonal control over the frequency of oscillation and condition of oscillation. Effects of non-idealities and parasitic study are also analyzed. The proposed circuit has low active and passive sensitivities. In addition, a resistorless realization of the proposed work is also given. PSPICE simulations using 0.18µm CMOS process parameters confirm the validity and practical utility of the proposed circuit.*
Keywords: *Mixed-mode, DD-DXCCII, Quadrature oscillator.*

1. Introduction

Quadrature oscillators are important analog circuits required for various communication applications, wherein there is a requirement of multiple sinusoids signals that are 90^0 phase in difference e.g. in quadrature mixers or for measurement purposes in the selective voltmeters or in vector generator [1-3]. In the literature a number of oscillators based on different active elements are reported [4-6, 8-26] and the references cited therein. Note that a number of circuits have been reported in the technical literature which provides voltage output(s), current output(s), both voltage as well as current output(s) with a phase shift giving rise to quadrature and multiphase oscillators. It may be further noted that the circuits having both voltage and current outputs are termed as mixed mode oscillators. Moreover, some of the oscillator circuits presented in the literature is based on single active element [6, 8-10, 12-13, 16, 18, 26]. A comparison study with some other previously known oscillators has been given in Table 1.

The purpose of this paper is to propose a new MMQO using a single DD-DXCCII along with five passive components (two grounded capacitors and three grounded resistor), which offers several advantages such as (i) use of single active element only, (ii) use of grounded resistors and grounded capacitors, which is attractive from the IC fabrication point of view as well as eliminating/absorbing parasitic resistances/capacitances, (iii) orthogonal control of frequency of oscillation and condition of oscillation (iv) simultaneous availability of quadrature voltage-mode and current-mode outputs, (v) low active and passive sensitivities, and (vi) resistorless realization.

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Table 1: Comparison with the existing oscillators

References	Single Active Element based oscillator / Type of Active Element used	No. of Resistors Grounded/ Floating	No. of Capacitors Grounded/ Floating	All Grounded Passive Components	No. of Current Outputs	No. of Voltage Outputs	Orthogonal/ Independent Tunability	Designed Frequency of Oscillation	Availability of Resistorless Realization	Total Power Dissipation
4	No/CC	2/0	2/0	Yes	-	2	NA	-	No	NA
5	No/OTA	-	1/2	No	-	2	No	300KHz	Yes	NA
6	Yes/CCII	3/2	0/2	No	-	1	Yes	-	No	NA
8	Yes /FTFN	2/3	2/0	No	2	-	Yes	6.9KHz	No	NA
9	Yes /FDCCII	3/0	2/0	Yes	1	-	Yes	2.25MHz	No	NA
10	Yes /FTFN	4	3	No	1	-	Yes	NA	No	NA
11	No/FTFN	1/2	1/2	No	2	-	Yes	NA	No	NA
12	Yes /FTFN	2	5	No	1	-	Yes	28KHz	No	NA
13	Yes /FTFN	1/2	2/0	No	1	-	Yes	450KHz	No	NA
14	No/DXCCII	-	2/0	No	2	-	Yes	450KHz-1MHz	Yes	NA
15	No/DVCC	2/0	2/0	Yes	2	-	Yes	-	No	NA
16	Yes/FDCCII	3/0	2/0	Yes	2	2	No	7.9KHz	No	NA
17	No/ MOCCII	2/0	2/0	Yes	8	-	No	358KHz	No	NA
18	Yes/ZC-CDTA	0/2	2/0	No	1	-	Yes	59.77KHz	No	NA
19	No/ DVCC	3/0	2/0	Yes	4	-	Yes	1MHz	No	7.5mW
20	No/ CCCII	-	2/0	Yes	4	2	Yes	140KHz	Yes	7mW
21	No/ DXCCII	2/0	3/0	Yes	3	3	Yes	1.7MHz	No	NA
22	No/ ZC-CG-CDBA	0/3	2/0	No	2	2	Yes	2.75MHz	No	NA
23	No/CCCDTA	-	2/0	Yes	4	-	Yes	-	Yes	12.1mW
24	No/DDCC	3/0	2/0	Yes	-	2	No	10.61MHz	No	7.2mW
25	No/CCII	1/2	2/0	No	-	2	Yes	3.98MHz	No	1.66mW /1.8mW
26	Yes /VDTA	1/0	2/0	Yes	3	-	Yes	10MHz	No	NA
Proposed	Yes /DD-DXCCII	3/0	2/0	Yes	2	3	Yes	15.92MHz/20MHz	Yes	0.24mW

Abbreviations: CC: Current Conveyor, OTA: Operational Transconductance Amplifier, CCII: Second Generation Current Conveyor, FTFN: Four-Terminal Floating Nullor, FDCCII: Fully Differential Second Generation Current Conveyor, DXCCII: Dual-X Second Generation Current Conveyor, DVCC: Differential Voltage Current Conveyor, MO-CCII: Multi-Output Second Generation Current Conveyor, ZC-CDTA: Z-Copy Current Differencing Transconductance Amplifier, CCCII: Current Controlled Second Generation Current Conveyor, ZC-CG-CDBA: Z-Copy Controlled Gain Current Differencing Buffered Amplifier, CCCDTA: Current Controlled Current Differencing Transconductance Amplifier, DDCC: Differential Difference Current Conveyor, VDTA: Variable Differencing Transconductance Amplifier, DD-DXCCII: Differential Difference Dual-X Second Generation Current Conveyor, NA: Not Available.

2. Proposed DD-DXCCII

A conventional DXCC-II is a combination of regular CC-II and ICC-II. Similar to other current-mode active devices, the DXCC-II has some advantages such as higher usable gain, greater linearity, less power dissipation, wider bandwidth, better accuracy and larger dynamic range over its voltage-mode counterpart [14]. Recently some innovative enhancements to DXCC-II are reported [27-29]. One of these enhancements has been employed in form of DXCC-II with buffered output [27]. Another design modification presented in [28] was the gain variable DXCC-II, where the voltage transfer gain was made variable in the AD-844 based realizations. Most recent, a controllable version of the conventional DXCCII as dual-X controlled current conveyor (DXCCCII) is reported for tunable applications [29]. Parallel to this enhancement will be another differential difference DXCC-II.

In this section a new building block termed as DD-DXCCII has been presented. The DD-DXCCII is a seven terminal analogue building block which is characterized by the following port relations:

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ I_{Y3} \\ V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{-Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ I_{X+} \\ I_{X-} \\ V_{Z+} \\ V_{-Z-} \end{bmatrix} \quad (1)$$

The symbol and CMOS implementation of DD-DXCCII is shown in Fig. 1. The CMOS implementation of Fig. 1(b) comprises of DDCC (M_{25} – M_{34}) with unemployed Z-stages and DXCCII (M_1 – M_{24}). In the CMOS implementation of DD-DXCCII, the X terminal (Drain of M_{33}) of DDCC drives the Y terminal (Gate of M_2) of the DXCCII. The Z+ and -Z- stages are realized from the drain of M_{11} and M_{16} transistors. The presented building block combines the advantages of the DDCC [7] and the DXCCII [14]. The DD-DXCCII has three high impedance input terminals (Y_1, Y_2 and Y_3), two low impedance terminals (X+ and X-) and two high impedance output terminals (Z+ and -Z-).

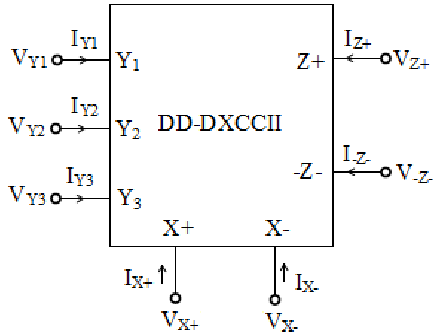

Figure 1. (a) Symbol of DD-DXCCII

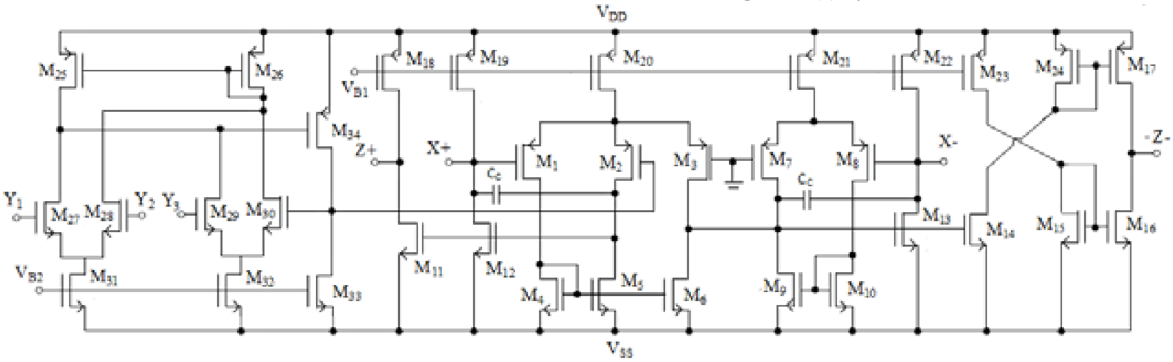

Figure 1. (b) CMOS implementation of DD-DXCCII

3. Proposed Circuit

The proposed circuit of mixed-mode quadrature oscillator is shown in Fig. 2. The proposed circuit employs single DD-DXCCII, three grounded resistors and two grounded capacitors. The proposed MMQO provides three quadrature voltage outputs and two quadrature current outputs simultaneously.

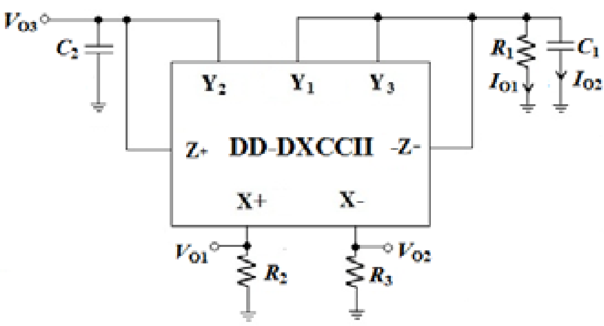

Figure 2. Proposed MMQO

The characteristic equation of the proposed circuit using (1) can be expressed as

$$s^2 + s\left(\frac{1}{C_1R_1} + \frac{1}{C_2R_2} - \frac{2}{C_1R_3}\right) + \frac{1}{C_1C_2R_1R_2} = 0 \quad (2)$$

which results in condition of oscillation (CO) as

$$\text{CO: } \frac{1}{C_1R_1} + \frac{1}{C_2R_2} \geq \frac{2}{C_1R_3} \quad (3)$$

and the frequency of oscillation (FO) as

$$\text{FO: } \omega_o = \sqrt{\frac{1}{C_1C_2R_1R_2}} \quad (4)$$

It is to be noted from equations (3) – (4) that the FO and CO are controlled orthogonally. The passive sensitivities with respect to ω_o are given as below

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_1}^{\omega_o} = S_{R_2}^{\omega_o} = -\frac{1}{2} \quad (5)$$

It is to be noted from (5) that all the passive sensitivities are less than unity in magnitude and hence the proposed circuit exhibits a good sensitivity performance.

The three voltage outputs (V_{O1}, V_{O2} and V_{O3}) and two currents outputs (I_{O1} and I_{O2}) of Fig. 2 are related as

$$V_{O1} = j\omega C_2R_2V_{O3} \quad (6)$$

$$V_{O1} = -V_{O2} \quad (7)$$

$$I_{O2} = j\omega C_1R_1I_{O1} \quad (8)$$

Thus, the proposed circuit provides three quadrature voltage outputs (V_{O1}, V_{O2} and V_{O3}) and two quadrature current outputs (I_{O1} and I_{O2}) simultaneously. The phasor diagrams depicting quadrature voltage outputs and quadrature current outputs are shown in Fig. 4 and Fig. 5, respectively.

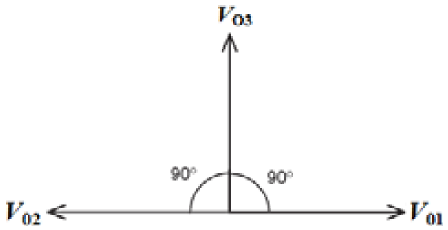

Figure 4. Phasor diagram depicting quadrature voltage outputs

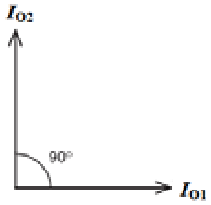

Figure 5. Phasor diagram depicting quadrature current outputs

4. Non-ideal Analysis

Taking the non-idealities of the DD-DXCCII into account, the relationship of the terminal voltages and currents can be rewritten as:

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ I_{Y3} \\ V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{-Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \beta_1 & -\beta_2 & \beta_3 & 0 & 0 & 0 & 0 \\ -\beta_4 & \beta_5 & -\beta_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \alpha_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\alpha_2 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ I_{X+} \\ I_{X-} \\ V_{Z+} \\ V_{-Z-} \end{bmatrix} \quad (9)$$

Here, β_1, β_2 and β_3 are the voltage transfer gains from Y_1, Y_2 and Y_3 terminals, respectively to the X+ terminal. Similarly β_4, β_5 and β_6 are the voltage transfer gains from Y_1, Y_2 and Y_3 terminals, respectively to the X- terminal. α_1 is the current transfer gain from X+ terminal to Z+ terminal. α_2 is the current transfer gain from X- terminal to –Z- terminal. These voltage and current transfer gains will deviate from unity by the voltage and current tracking errors, which are quite small and technology dependent. Moreover, these transfer gains, instead of being real, are in fact frequency dependent.

The proposed circuit of MMQO as shown in Fig. 2 is reanalyzed using (9), so the characteristic equation with non-ideal gains can be expressed as:

$$s^2 + s\left[\frac{1}{C_1R_1} + \frac{\alpha_1\beta_2}{C_2R_2} - \frac{\alpha_2\ \beta_4+\beta_6}{C_1R_3}\right] + \frac{\alpha_1\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \alpha_1\beta_2R_3}{C_1C_2R_1R_2R_3} = 0 \quad (10)$$

By considering non-ideal gains, the CO and the FO of the quadrature oscillator of Fig. 2 are evaluated as follows:

$$\text{CO: } \frac{1}{C_1R_1} + \frac{\alpha_1\beta_2}{C_2R_2} \geq \frac{\alpha_2\ \beta_4+\beta_6}{C_1R_3} \quad (11)$$

$$\text{FO: } \omega_o = \sqrt{\frac{\alpha_1\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \alpha_1\beta_2R_3}{C_1C_2R_1R_2R_3}}$$

(12)

The active and passive sensitivities with respect to ω_o are given as below

$$S_{\alpha_2}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (13)$$

$$S_{\beta_1}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_2\beta_1\beta_5R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (14)$$

$$S_{\beta_2}^{\omega_o} = \frac{1}{2}\left[\frac{\beta_2R_3 - \alpha_2\beta_2\ \beta_4+\beta_6\ R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (15)$$

$$S_{\beta_3}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_2\beta_3\beta_5R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (16)$$

$$S_{\beta_4}^{\omega_o} = -\frac{1}{2}\left[\frac{\alpha_2\beta_2\beta_4R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (17)$$

$$S_{\beta_5}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_2\beta_1\beta_5R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (18)$$

$$S_{\beta_6}^{\omega_o} = -\frac{1}{2}\left[\frac{\alpha_2\beta_2\beta_6R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (19)$$

$$S_{R_3}^{\omega_o} = \frac{1}{2}\left[\frac{\beta_2 - \alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (20)$$

$$S_{R_1}^{\omega_o} = -\frac{1}{2}\left[\frac{\beta_2R_3}{\alpha_2\left[\beta_5\ \beta_1+\beta_3\ -\beta_2\ \beta_4+\beta_6\ \right]R_1 + \beta_2R_3}\right] \quad (21)$$

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_2}^{\omega_o} = -S_{\alpha_1}^{\omega_o} = -\frac{1}{2} \quad (22)$$

For unity values of current and voltage transfer gains and equal capacitor and resistor design, it is evident from equations (13) – (22) that active and passive sensitivities of ω_o are less than unity in magnitude and hence the circuit exhibits a good sensitivity performance.

5. Parasitic Study

It is also worth mentioning that in the non-ideal case the parasitic resistances and capacitances appearing at the high input and output impedance terminals (Y and Z) are absorbed into the external resistors and capacitors as they are shunt with them. This feature of grounded resistors and grounded capacitors based circuits makes them particularly desirable for monolithic integration.

Moreover, if the parasitic resistances at low impedance terminals (X) are negligible (ideally they are zero), then the parasitic impedances appearing at the X terminals would be connected between virtual grounds and actual ground and thereby eliminating their effect. In practice, to alleviate the effects of the parasitic impedances, the impedances should be chosen such that

$$R_1' = R_1 // R_{Y1} // R_{Y3} // R_{-Z-}$$

$$C_1' = C_1 + C_{Y1} + C_{Y3} + C_{-Z-}$$

$$R_2' = R_2 + R_{X+}$$

$$R_3' = R_3 + R_{X-}$$

$$C' = C_2' // R' = \; C_2 + C_{Y2} + C_{Z+} \;\; // \;\; R_{Y2} // R_{Z+}$$

where, R_{Y1}, R_{Y2} and R_{Y3} are the parasitic resistances and C_{Y1}, C_{Y2} and C_{Y3} are the parasitic capacitances at the Y_1, Y_2 and Y_3 terminals, respectively, R_{Z+} and $R\text{-}_{Z-}$ are the parasitic resistances and C_{Z+} and $C\text{-}_{Z-}$ are the parasitic capacitances at the Z_+ and $-Z_-$ terminals, respectively, and R_{X+} and R_{X-} represent the parasitic resistances appearing at the X+ and X- terminals, respectively.

6. Simulation Results

To verify the theoretical analysis of the proposed quadrature oscillator (Fig. 2), the MMQO has been designed to provide three voltage and two current responses with frequency of oscillation at 15.92MHz. The MMQO has the design values for the passive components as $C_1 = C_2 = 10\text{pF}$, $R_1 = R_2 = R_3 = 1\text{k}\Omega$. The DD-DXCCII was realized using the CMOS implementation of Fig. 1 and simulated using 0.18µm, CMOS parameters. The supply voltages were taken as $V_{DD} = -V_{SS} = 1\text{V}$ and the biasing voltage as $V_{B1} = V_{B2} = -0.7\text{V}$. The simulated FO for the MMQO was found to be 15.78MHz, which is very close to the theoretical value. The simulated results for the three voltage outputs and two current outputs are shown in Fig. 6 and Fig. 8, respectively. The Fourier spectrum of the outputs of Fig. 6 and Fig. 8 are shown in Fig. 7 and Fig. 9 respectively. Total power dissipation is found to be 0.24mW.

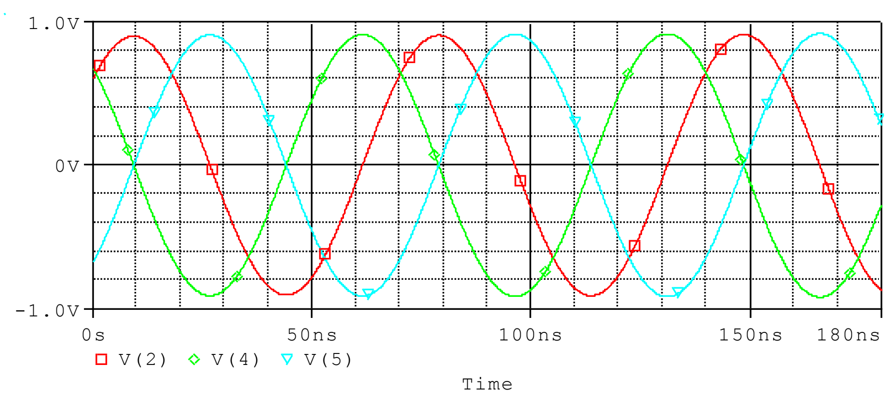

Figure 6. Three quadrature voltage outputs at 15.92MHz

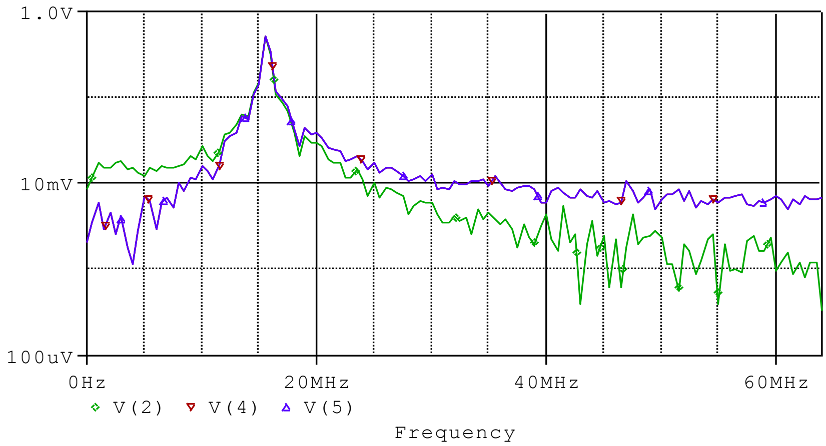

Figure 7. Fourier spectrums of voltage outputs

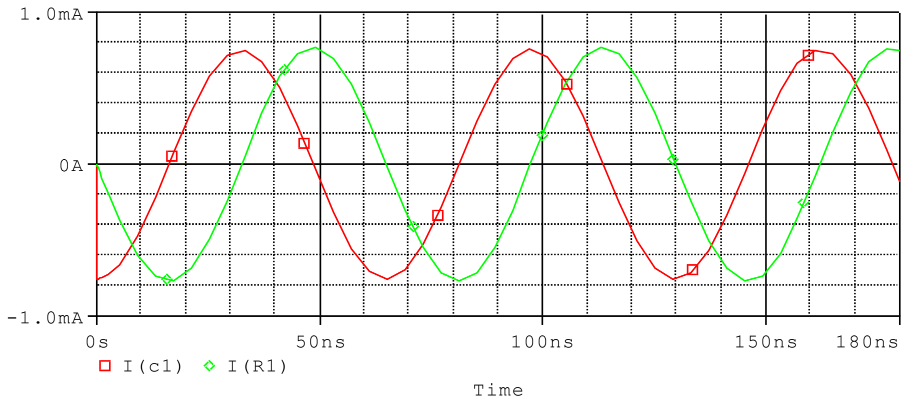

Figure 8. Two quadrature current outputs at 15.92MHz

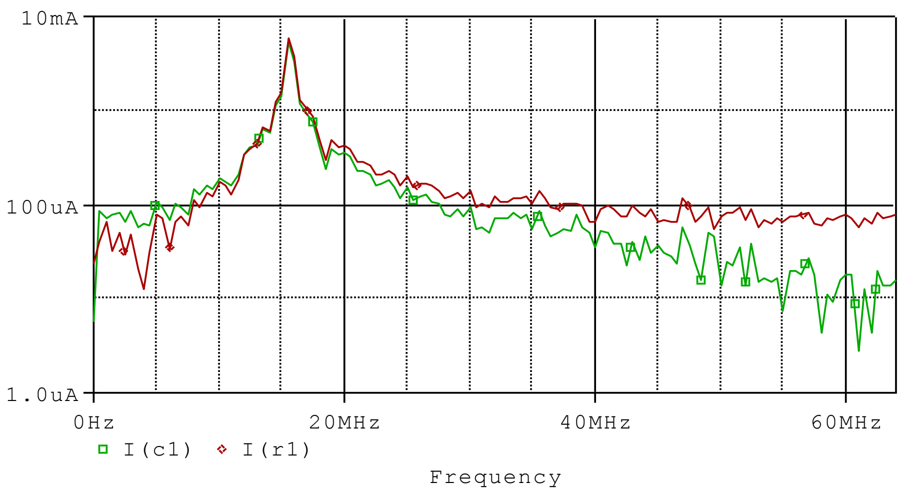

Figure 9. Fourier spectrums of current outputs

7. Resistorless MMQO

Furthermore, the proposed MMQO is made resistorless by replacing the grounded resistor with the two n-MOS transistor based grounded resistor [30]. The proposed resistorless MMQO is shown in Fig. 10. The FO and CO for the proposed resistorless MMQO can be given as

$$\text{FO: } \omega_o = \left(\frac{1}{C_1 C_2 R_{\text{MOS1}} R_{\text{MOS2}}} \right)^{\frac{1}{2}} \quad (23)$$

$$\text{CO: } \frac{1}{C_1 R_{MOS1}} + \frac{1}{C_2 R_{MOS2}} \geq \frac{2}{C_1 R_{MOS3}} \quad (24)$$

where, R_{MOSi} (i = 1, 2, 3) is the equivalent resistance of the n-MOS transistors (M_{R1} - M_{R6}) in Fig. 10 and is given by

$$R_{MOSi} = \left[\mu C_{ox} \left(\frac{W}{L} \right) V_{Cj} - V_t \right]^{-1}, \text{ where } i, j = 1, 2, 3 \quad (25)$$

where, μ, C_{OX}, V_t, W and L are the carrier mobility, gate capacitance per unit area, threshold voltage, channel width and the length of n-MOS.

The resistorless MMQO of Fig. 10 was simulated and designed for frequency 20MHz. The transistor aspect ratios for the MOS based electronic resistors are selected as $(W/L)_{MR1}$ = $(W/L)_{MR2}$ = $(W/L)_{MR3}$ = 14.4μm/0.18μm and capacitors values are selected as C_1 = C_2 = 5pF. The FO for the proposed resistorless circuit is tuned to 20MHz by selecting the control voltages $V_{C1} = V_{C2} = V_{C3} = 0.87$. The three quadrature voltage outputs and two quadrature current outputs are shown in Fig. 11 and Fig. 12, respectively. The Fourier spectrums of the outputs are shown in Fig. 13 and Fig. 14. It is to be concluded from Fig. 13 and Fig. 14 that both theoretical and simulated FO is found to be close to each other. The obtained results validate the realization of resistorless MMQO.

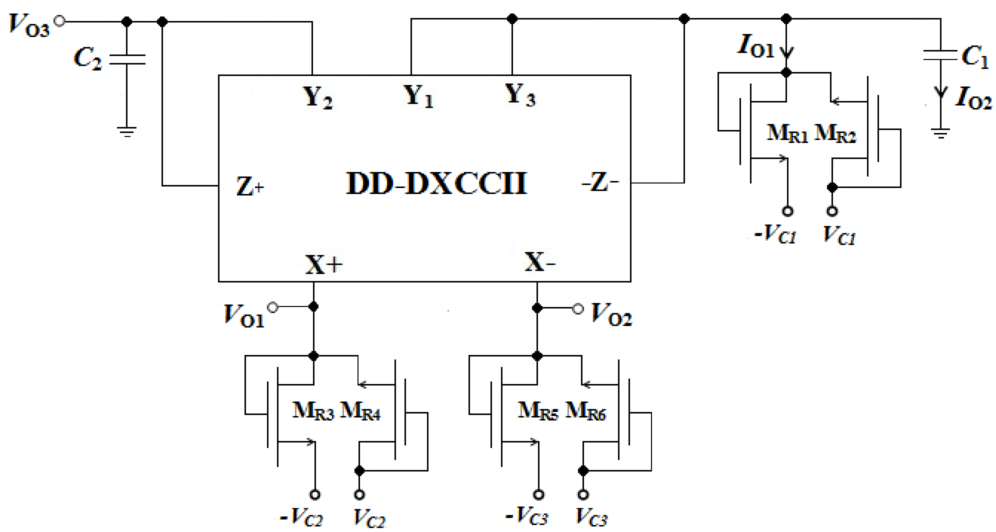

Figure 10. Proposed resistorless MMQO

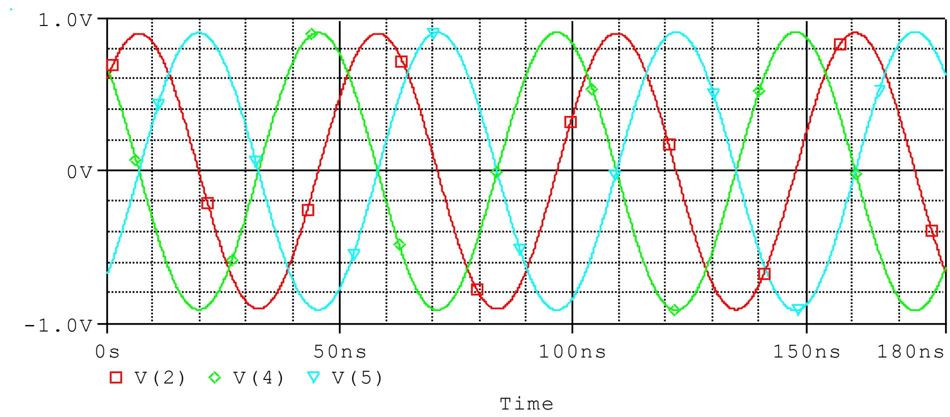

Figure 11. Three quadrature voltage outputs at 20MHz

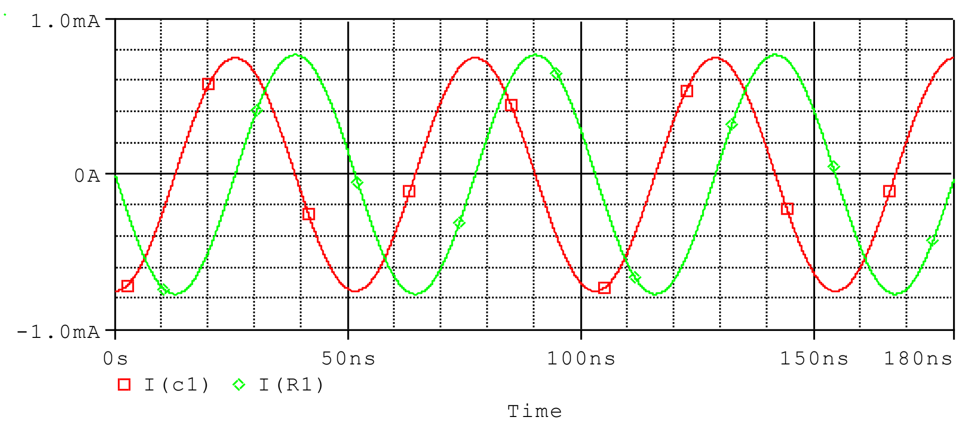

Figure 12. Two quadrature current outputs at 20MHz

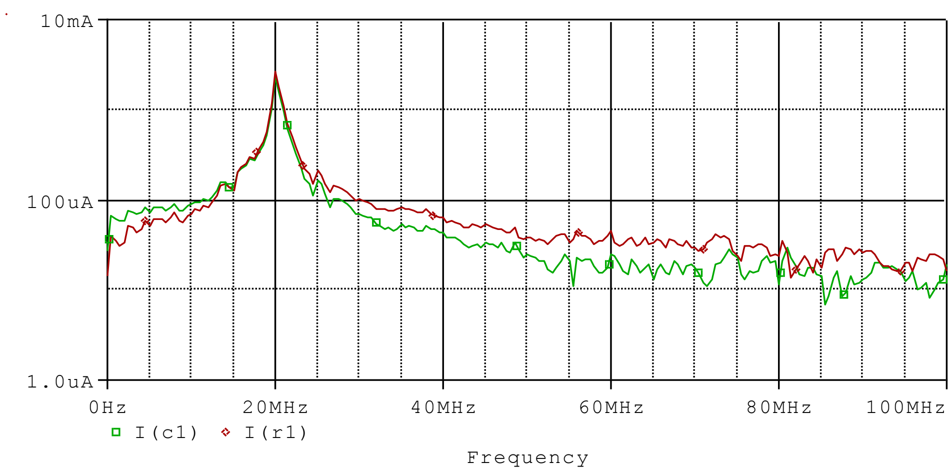

Figure 13. Fourier spectrums of current outputs

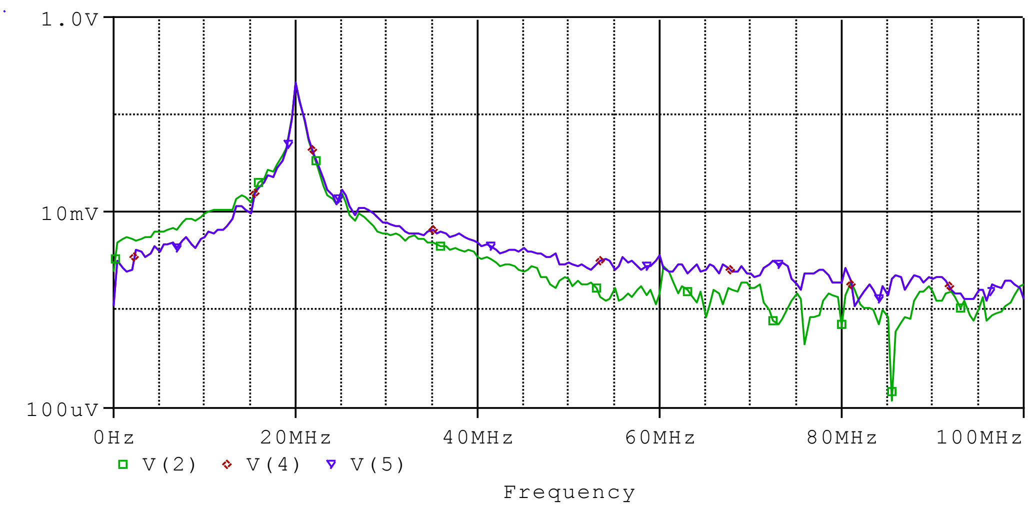

Figure 14. Fourier spectrums of voltage outputs

8. Conclusion

In this paper, a novel building block along with its application as MMQO is presented. The proposed circuit of MMQO employs single DD-DXCCII as active element and all grounded passive components, which is ideal for IC implementation. The proposed circuit provides three quadrature voltage outputs and two quadrature current outputs simultaneously from the same configuration. The proposed circuit further enjoys good active and passive sensitivities. Moreover, the proposed oscillator also exhibits the feature of orthogonal control over the frequency of oscillation and condition of oscillation. By employing DD-DXCCII, MOS based active resistors and two grounded capacitors, a resistorless MMQO is also realized. Non-ideal analysis and parasitic study are further discussed. Simulations results are given to confirm the presented theory.

9. References

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