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# Electronically Controllable Quadrature Sinusoidal Oscillator Using VD-DIBAs

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## Abstract

A new voltage-mode quadrature sinusoidal oscillator (QSO) using two voltage differencing-differential input buffered amplifiers (VD-DIBAs) and only three passive components (two capacitors and a resistor) is presented. The proposed QSO circuit offers advantages of independent electronic control of both oscillation frequency and condition of oscillation, availability of two quadrature voltage outputs and low active and passive sensitivities. SPICE simulation results have been included using 0.35 μm MIETEC technology to confirm the validity of the proposed QSO oscillator.

## Keywords

Voltage Differencing-Differential Input Buffered Amplifier, Voltage-Mode, Quadrature Sinusoidal Oscillator

## 1. Introduction

Quadrature sinusoidal oscillators (QSOs) are important blocks in the synthesis of modern transceivers. A QSO provides two sinusoids with a 90˚ phase difference. QSOs are useful in telecommunications for quadrature mixers and single sideband generators [1], in direct-conversion receivers, used for measurement purposes in vector generators and selective voltmeters [2]. Because of these applications number of QSOs has been realized employing different active building blocks in the open literature [3]-[8]. VD-DIBA is one of the active building blocks among the various active building blocks introduced in reference [9] which is emerging as a very flexible and versatile building block for analog signal processing/signal generation and has been used earlier for realizing a number of functions. VD-DIBA has been used in single resistance controlled oscillators, simulation of inductors, realization of active filters [10]-[17]. Recently VD-DIBA has also been used in the realization of QSO where independent electronic control of CO and FO is not available [18]. Therefore, the purpose of this paper is to propose a new QSO having electronic control of both CO and FO by separate transconductance of the VD-DIBAs. This property is very attractive for realizing current controlled oscillators as FO can be controlled independently without disturbing CO, whereas the flexibility of being able to adjust CO independently is useful in amplitude stabilization. The proposed configuration also offers low active and passive sensitivities. The validity of proposed structure has been confirmed by SPICE simulation with 0.35 μm MIETEC technology.

## 2. The Proposed New Oscillator Configuration

The symbolic notation and the equivalent circuit model of the VD-DIBA are shown in **Figure 1(a)** and **Figure 1(b)** respectively. The circuit model includes two controlled sources: the voltage source controlled by differential voltage $(V_z - V_v)$ with the unity voltage gain and the current source controlled by differential voltage $(V_+ - V_-)$, with the transconductance $g_m$. The corresponding voltage-current relationship of input-output terminals of VD-DIBA can be expressed by the following matrix:

$$\begin{pmatrix} I_+ \\ I_- \\ I_z \\ I_v \\ V_w \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 \end{pmatrix} \begin{pmatrix} V_+ \\ V_- \\ V_z \\ V_v \\ I_w \end{pmatrix}. \quad (1)$$

A straight forward circuit analysis of the circuit of **Figure 2** yields the following characteristic equation (CE):

$$\text{CE:}\quad s^2 C_1 C_2 + sC_1\left(\frac{1}{R_0} - g_{m_2}\right) + \frac{g_{m_1}}{R_0} = 0. \quad (2)$$

From Equation (2), the CO and FO are given by

CO:

$$\left(\frac{1}{R_0} - g_{m_2}\right) \le 0 \quad (3)$$

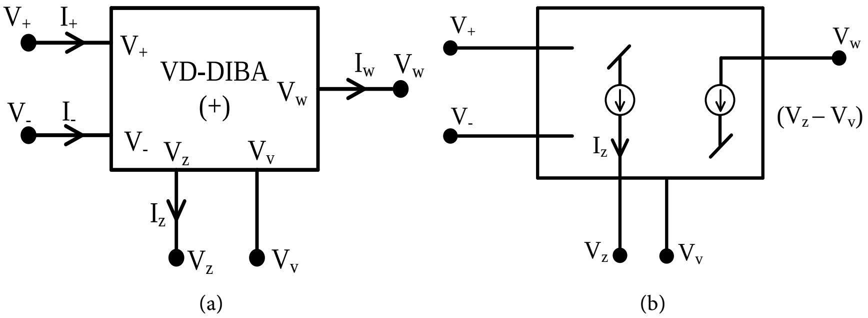

**Figure 1.** (a) Symbolic notation of; and (b) Equivalent circuit model of VD-DIBA.

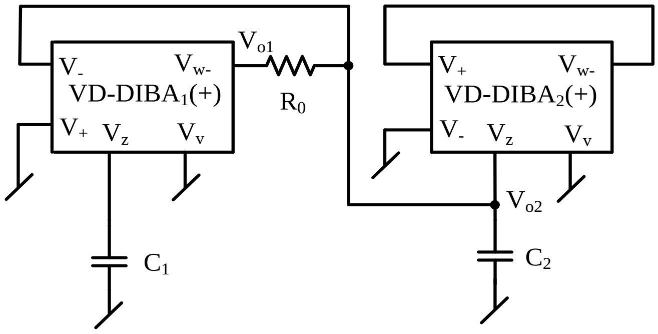

**Figure2.** Proposed electronically controllable quadrature sinusoidal oscillator.

FO:

$$\omega_0 = \sqrt{\frac{g_{m_1}}{R_0 C_1 C_2}} . \tag{4}$$

Thus from Equations (3) and (4), it is clear that CO is electronically controllable by the transconductance $g_{m2}$, whereas FO is electronically controllable through the transconductance $g_{m1}$. Therefore both CO and FO are independently controllable by two separate transconductance of VD-DIBAs.

## 3. Non-Ideal Analysis and Sensitivity Performance

Considering $R_Z$ and $C_Z$ as parasitic resistance and parasitic capacitance respectively of the Z-terminal of the VD-DIBA, taking the non-idealities into account, namely the voltage of W-terminal $V_W = \left(\beta^+ V_Z - \beta^- V_V\right)$ where $\beta^+ = 1 - \varepsilon_p$ ($\varepsilon_p \ll 1$) and $\beta^- = 1 - \varepsilon_n$ ($\varepsilon_n \ll 1$) denote the voltage tracking errors of Z-terminal and V-terminal of the VD-DIBA respectively, then the expressions for CE, CO and FO can be given as:

CE:

$$\begin{aligned} & s^2\left(C_1+C_z\right)\left(C_2+C_z\right)+s\left\{\left(C_1+C_z\right)\left(\frac{1}{R_0}+\frac{1}{R_z}-g_{m_2}\beta^+\right)+\frac{1}{R_z}\left(C_2+C_z\right)\right\} \\ & +\frac{1}{R_z}\left(\frac{1}{R_0}+\frac{1}{R_z}-g_{m_2}\beta^+\right)+\frac{\beta^+ g_{m_1}}{R_0}=0 \end{aligned} \tag{5}$$

CO:

$$\left\{\left(C_1+C_z\right)\left(\frac{1}{R_0}+\frac{1}{R_z}-g_{m_2}\beta^+\right)+\frac{1}{R_z}\left(C_2+C_z\right)\right\} \le 0 \tag{6}$$

FO:

$$\omega_0 = \sqrt{\frac{R_0 + R_z - R_0 R_z g_{m_2}\beta^+ + R_z^2 \beta^+ g_{m_1}}{R_0 R_z^2 \left(C_1+C_z\right)\left(C_2+C_z\right)}} . \tag{7}$$

The passive and active sensitivities can be expressed as:

$$S_{C_1}^{\omega_0} = -\frac{1}{2}\frac{C_1}{C_1+C_z},\quad S_{C_2}^{\omega_0} = -\frac{1}{2}\frac{C_2}{C_2+C_z},\quad S_{C_z}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{C_1+C_z}+\frac{1}{C_2+C_z}\right)C_z \tag{8a}$$

$$S_{\beta^+}^{\omega_0} = -\frac{1}{2}\frac{\beta^+ R_z\left(R_0 g_{m_2} - R_z g_{m_1}\right)}{R_0 + R_z - R_0 R_z g_{m_2}\beta^+ + R_z^2\beta^+ g_{m_1}},$$

$$S_{g_{m_1}}^{\omega_0} = \frac{1}{2}\frac{R_z^2\beta^+ g_{m_1}}{R_0 + R_z - R_0 R_z g_{m_2}\beta^+ + R_z^2\beta^+ g_{m_1}} \tag{8b}$$

$$S_{g_{m_2}}^{\omega_0} = -\frac{1}{2}\frac{R_0 R_z g_{m_2}\beta^+}{R_0 + R_z - R_0 R_z g_{m_2}\beta^+ + R_z^2\beta^+ g_{m_1}},$$

$$S_{R_0}^{\omega_0} = -\frac{1}{2}\frac{R_z\left(1 + R_z\beta^+ g_{m_1}\right)}{R_0 + R_z - R_0 R_z g_{m_2}\beta^+ + R_z^2\beta^+ g_{m_1}} \tag{8c}$$

$$S_{R_z}^{\omega_0} = -\frac{1}{2}\left(1 + \frac{2R_0 + R_z}{R_z + R_0 - R_0 R_z\beta^+ g_{m_2} + R_z^2\beta^+ g_{m_1}}\right) \tag{8d}$$

In the ideal case, the various sensitivities of $\omega_0$ with respect to $C_1$, $C_2$, $R_0$, $C_z$, $R_z$, $g_{m1}$, $g_{m2}$ and $\beta^+$ are found to be

$$S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = S_{R_0}^{\omega_0} = S_{R_z}^{\omega_0} = -\frac{1}{2},\ S_{g_{m_1}}^{\omega_0} = S_{\beta^+}^{\omega_0} = \frac{1}{2},\ S_{C_z}^{\omega_0} = S_{g_{m_2}}^{\omega_0} = 0. \tag{9}$$

Considering the typical values of various parasitic e.g. $C_z$ = 0.81 pF, $R_z$ = 53 kΩ, $\beta^+ = \beta^- = 1$ along with $g_{m1}$ = 310.477 μ℧, $g_{m2}$ =291.186 μ℧, $C_1 = C_2$ = 10 nF, and $R_0$ = 4 kΩ, the various sensitivities are found to be $S_{C_1}^{\omega_0} = -0.006$, $S_{C_2}^{\omega_0} = -0.006$, $S_{C_Z}^{\omega_0} = -0.987$, $S_{R_0}^{\omega_0} = -0.533$, $S_{R_Z}^{\omega_0} = -0.535$, $S_{g_{m_1}}^{\omega_0} = 0.502$, $S_{g_{m_2}}^{\omega_0} = -0.0355$, and $S_{\beta^+}^{\omega_0} = 0.466$ which are all quite low.

## 4. Frequency Stability

Frequency stability is an important figure of merit of an oscillator. The frequency stability factor is defined as $S^F = \mathrm{d}\varphi(u)/\mathrm{d}u$, where $\omega/\omega_0$ is the normalized frequency, and $u = \varphi(u)$ represents the phase function of the open loop transfer function of the oscillator circuit. With $C_1 = C_2 = C$, $R_0 = 1/g_{m2} = 1/g$, $g_{m1} = ng$, $S^F$ for the proposed SECO is found to be:

$$S^F = 2\sqrt{n}. \tag{10}$$

Thus, the new proposed configuration offers very high frequency stability factor larger values of n.

## 5. Simulation Results

The proposed QSO was simulated using CMOS VD-DIBA (as shown in **Figure 3**) to verify its theoretical analysis. The passive elements are selected as $R_0$ = 4 kΩ, and $C_1 = C_2$ = 10 nF. The transconductances of VD-DIBAs were controlled by bias voltages $V_{B1}$, $V_{B2}$ respectively. The simulated output waveforms for transient response and steady state response are shown in **Figure 4** and **Figure 5** respectively. These results, thus, confirm the validity of the proposed structure. **Figure 6** shows the simulation results of the output spectrum, where the total harmonic distortion (THD) is found to be about 1.9% for both outputs $V_{o1}$ and $V_{o2}$. The generated waveforms relationship within quadrature circuit has been confirmed by Lissajous pattern shown in **Figure 7**. The CMOS VD-DIBA is

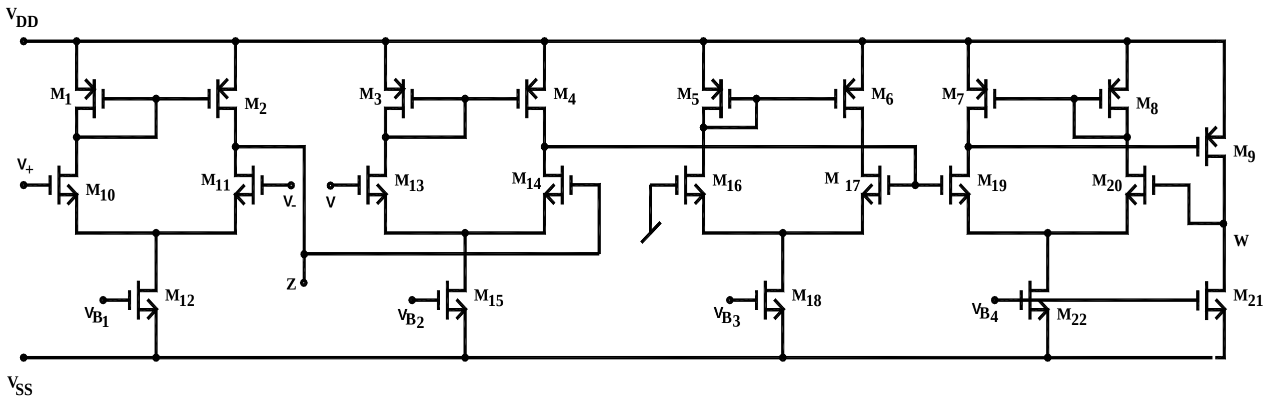

**Figure 3.** A CMOS transistor implementation of VD-DIBA, $V_{B2} = V_{B3} = -0.22$ V and $V_{B4} = -0.9$ V, $V_{DD} = -V_{SS} = 2$ V [16].

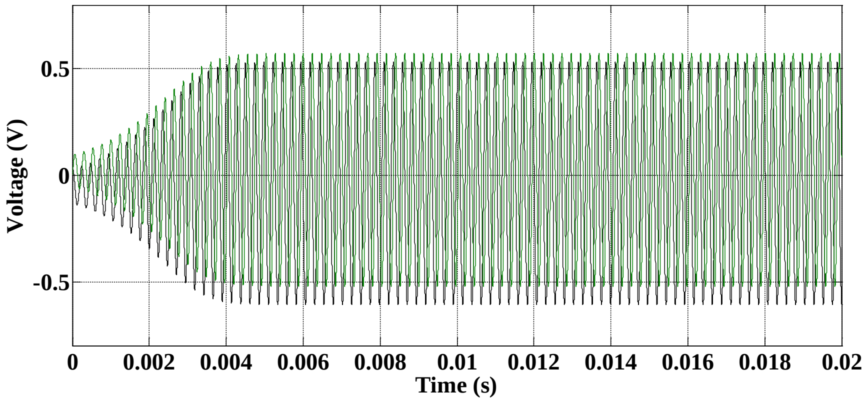

**Figure 4.** Transient response of proposed QSO.

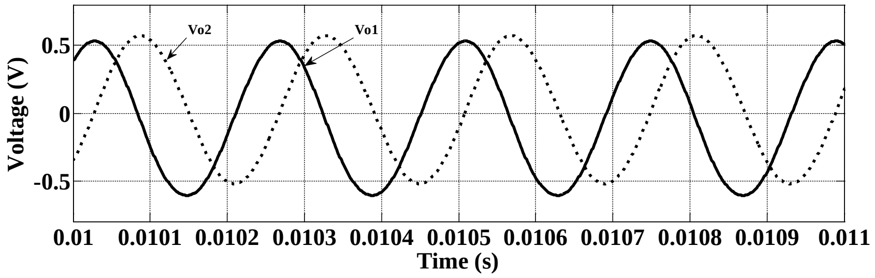

**Figure 5.** Steady state response of proposed QSO.

implemented using 0.35 μm MIETEC technology. The transistor model parameters used for CMOS VD-DIBA are listed in Table 1 and aspect ratios (W/L ratios) of the MOSFETs used in Figure 3 are shown in Table 2. Comparisons of previously known quadrature sinusoidal oscillators are Table 3.

## 6. Conclusion

In this communication, an electronically tunable voltage-mode quadrature sinusoidal oscillator enabling independent electronic control of frequency of oscillation and condition of oscillation is presented. The proposed QSO circuit employs only two VD-DIBAs, two grounded capacitors and a resistor. The

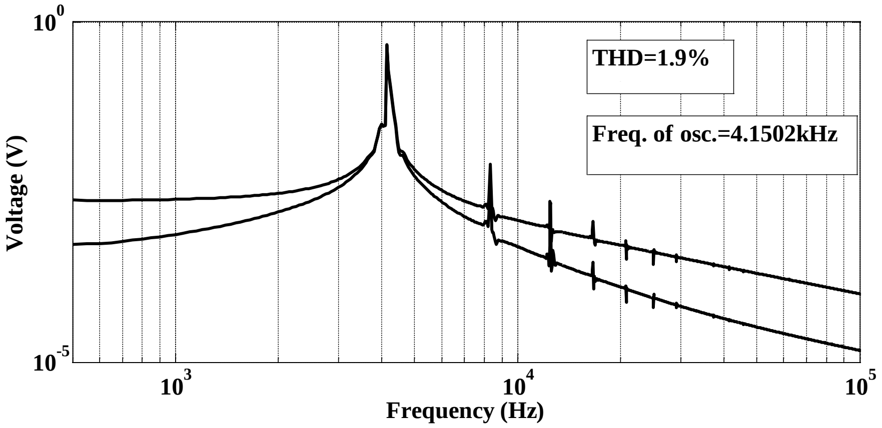

Figure 6. Frequency response of proposed QSO.

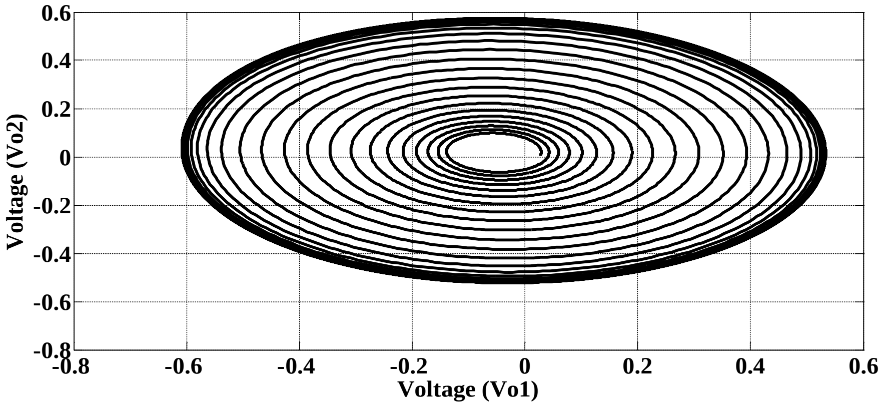

Figure 7. Lissajous pattern of proposed QSO.

Table 1. Transistors process parameters in SPICE simulations.

.MODEL N NMOS (LEVEL = 3; TOX = 7.9E−9; NSUB = 1E17; GAMMA = 0.5827871; PHI = 0.7; VTO = 0.5445549; DELTA = 0; UO = 436.256147; ETA = 0; THETA = 0.1749684; KP = 2.055786E−4; VMAX = 8.309444E4; KAPPA = 0.2574081; RSH = 0.0559398; NFS = 1E12; TPG = 1; XJ = 3E−7; LD = 3.162278E−11; WD = 7.046724E−8; CGDO = 2.82E−10; CGSO = 2.82E−10 CGBO = 1E−10; CJ = 1E−3; PB = 0.9758533; MJ = 0.3448504; CJSW; = 3.777852E−1; MJSW = 0.3508721)

.MODEL P PMOS (LEVEL = 3; TOX = 7.9E−9; NSUB = 1E17; GAMMA = 0.4083894; PHI = 0.7; VTO = −0.7140674; DELTA = 0; UO = 212.2319801; ETA = 9.999762E−4; THETA = 0.2020774; KP = 6.733755E−5; VMAX = 1.181551E5; KAPPA = 1.5; RSH = 30.0712458; NFS = 1E12; TPG = −1; XJ = 2E−7; LD = 5.000001E−13; WD = 1.249872E−7; CGDO = 3.09E−10; CGSO = 3.09E−10; CGBO = 1E−10; CJ = 1.419508E−3; PB = 0.8152753; MJ = 0.5; CJSW = 4.813504E−10; MJSW = 0.5)

Table 2. Aspect ratios of CMOS transistors used in Figure 3.

| Transistor | W/L (μm) |
|---|---|
| M1 - M6 | 14/1 |
| M7 - M9 | 14/0.35 |
| M10 - M18 | 4/1 |
| M19 - M22 | 7/0.35 |

Table 3. Comparison of previously known quadrature sinusoidal oscillators.

| Reference | Active Elements | No. of Passive Components | | Electronic Controllability of: | |
|---|---|---|---|---|---|
| | | No. of Grounded C | No. of C + R | CO | FO |
| [18] | 2VD – DIBA + UGC | 2 | 0 + 0 | NO | YES |
| [19] | 2CDBA | 1 | 1 + 3 | NO | NO |
| [20] | 2OTRA | 2 | 0 + 4 | NO | NO |
| [21] | 2CDBA | 2 | 0 + 3 | NO | NO |
| [22] | 2VDIBA + 2MOS | 1 | 1 + 0 | YES | YES |
| [23] | 3CFTA | 2 | 0 + 0 | YES | YES |
| **proposed** | 2VD – DIBA | 2 | 0 + 1 | YES | YES |

proposed QSO is capable of simultaneously providing two explicit quadrature voltage outputs. The condition of oscillation and the frequency of oscillation of the proposed circuit are controllable electronically through separate transconductance of the VD-DIBAs. The workability of the proposed structure has been demonstrated by PSPICE simulations using 0.35 µm MIETEC technology.

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