Circuits and Systems, **2013, 4, 264-268**
http://dx.doi.org/10.4236/cs.2013.43035 Published Online July 2013 (http://www.scirp.org/journal/cs)

Fully Uncoupled Electronically Controllable Sinusoidal Oscillator Employing VD-DIBAs

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Received March 21, 2013; revised April 22, 2013; accepted April 30, 2013

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ABSTRACT

Recently, voltage differencing-differential input buffered amplifiers (VD-DIBA)-based electronically controllable sinusoidal oscillator has been presented that it does not have the capability of complete independence of frequency of oscillation (FO) and condition of oscillation (CO) as well as electronic control of both CO and FO. In this article, a new fully-uncoupled electronically controllable sinusoidal oscillator using two VD-DIBAs, two grounded capacitors and two resistors has been proposed which offers important advantages such as 1) totally uncoupled and electronically controlled condition of oscillation (CO) and frequency of oscillation (FO); 2) low active and passive sensitivities; and 3) a very good frequency stability factor. The effects of non-idealities of the VD-DIBAs on the proposed oscillator are also investigated. The validity of the proposed formulation has been confirmed by SPICE simulation with TSMC 0.18 µm process parameters.

Keywords: Sinusoidal Oscillator; Voltage-Mode; VD-DIBA

1. Introduction

Sinusoidal oscillators find various applications in signal processing, instrumentation, measurement, communication and control systems. The class of single resistance controlled oscillators (SRCOs) using different active element(s)/device(s) has been of particular interest during the last four decades because of their applications in variable frequency oscillators. However, in these SRCOs, electronic control of CO and FO can be obtained by replacing the respective controlling resistor(s) with FET based or CMOS voltage controlled resistor(s). A careful inspection of the available SRCOs reveals that while many oscillators enjoy independent single element control of CO and FO, the class of fully uncoupled oscillators has not been considered adequately in the literature. In fully uncoupled oscillator circuits CO and FO are determined by two completely different sets of active and/or passive components, that is none of the active and/or passive components appeared in CO are involved in FO and vice versa. This feature is very useful for realizing voltage controlled oscillators as FO can be controlled independently without disturbing CO, whereas the flexibility of being able to control CO independently is advantageous to incorporate amplitude stabilization. In the recent past, number of fully-uncoupled sinusoidal oscillators employing different active element(s)/devices has been introduced see [1-7] and the references cited therein. In references [1-5] the CO and FO of the proposed oscillators are adjustable through resistors (the electronic tunability can be established by replacing one of the grounded resistors by JFETs/MOSFETs [8,9]), whereas in case of oscillators presented in references [6,7], both CO and FO are electronically controllable. The VD-DIBA was introduced by Biolek, Senani, Biolkova and Kolka in [10] since then it has been found to be a useful new active building block in realizing all voltage-mode pass filters [11], inductance simulation [12], universal biquad filter [13] and an electronically controllable sinusoidal oscillator [14]. Although the paper presented by the authors in [14] employs two VD-DIBAs, two grounded capacitors and one grounded resistor but this circuit does not have the capability of complete independence of CO and FO as well as electronic control (only FO is electronically controllable). Therefore, the purpose of this

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paper is, to propose a new fully uncoupled electronically controllable sinusoidal oscillator employing two VD-DIBAs, two grounded capacitors and two resistors, which offers 1) fully uncoupled and electronically controlled CO and FO, 2) low active and passive sensitivities, and 3) a very good frequency stability factor. The feasibility of the proposed oscillator has been demonstrated by SPICE simulation with TSMC 0.18 μm process parameters.

2. The Proposed Fully Uncoupled Oscillator

The schematic symbol and behavioral model of the VD-DIBA are shown in **Figures 1(a)** and **(b)** respectively [11]. The VD-DIBAs can be described by the following set of equations:

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

The proposed new fully-uncoupled electronically controllable sinusoidal oscillator circuit is shown in **Figure 2**.

Assuming that the VD-DIBAs are characterized by Equation (1), the characteristic equation (CE) of **Figure 2** can be given by:

$$s^2 + s\frac{1}{C_1}\left(\frac{1}{R_1} - g_{m_1}\right) + \frac{g_{m_2}}{R_2 C_1 C_2} = 0 \qquad (2)$$

From this CE, the CO and FO can be found as:
CO

$$\left(\frac{1}{R_1} - g_{m_1}\right) \le 0 \qquad (3)$$

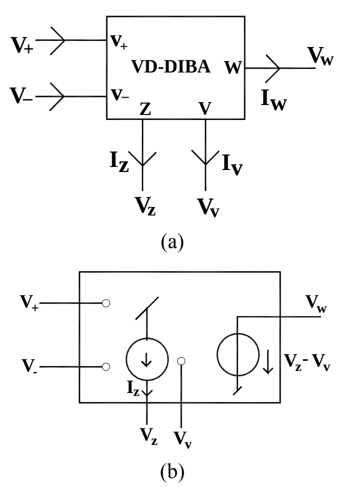

Figure 1. (a) Schematic symbol; (b) Behavioral model of VD-DIBA.

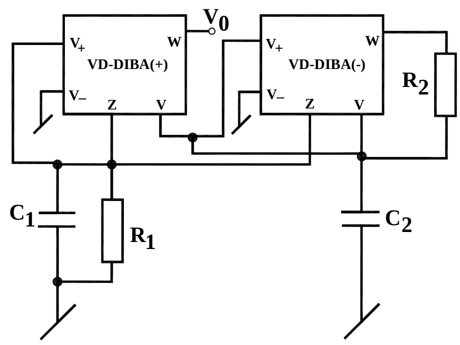

Figure 2. The proposed fully-uncoupled electronically controllable sinusoidal oscillator.

and
FO

$$\omega_0 = \sqrt{\frac{g_{m_2}}{R_2 C_1 C_2}} \qquad (4)$$

Therefore, from Equations (3) and (4) it is clear that FO and CO are fully decoupled and electronically controllable *i.e*. FO is independently controllable by transconductance g_{m_2} of the VD-DIBA(−), whereas CO is also electronically controllable through the transconductance g_{m_1} of VD-DIBA(+).

3. Non-Ideal Analysis

Considering the parasitics of VD-DIBA *i.e*. R_Z and C_Z, the parasitic resistance and the parasitic capacitance of the Z-terminal respectively. Taking the non-idealities into account, namely the voltage of W-terminal $V_W = \left(\pm\beta^+ V_Z \mp \beta^- V_V\right)$ where $\beta^+ = 1-\varepsilon_p\left(\varepsilon_p \ll 1\right)$ and $\beta^- = 1-\varepsilon_n\left(\varepsilon_n \ll 1\right)$ denote the voltage tracking errors of Z-terminal and V-terminal of the VD-DIBA (+/−) respectively, then the expression for CE becomes:

$$\begin{aligned} & s^2\left(C_1 + 2C_z\right)C_2 \\ & + s\left\{C_2\left(\frac{1}{R_1} - g_{m_1} + \frac{2}{R_z}\right) + C_1\frac{\left(1-\beta_2^-\right)}{R_2} + C_z\frac{2\left(1-\beta_2^-\right)}{R_z}\right\} + \frac{\beta_2^+ g_{m_2}}{R_2} \\ & + \frac{\left(1-\beta_2^-\right)}{R_2}\left(\frac{1}{R_1} - g_{m_1} + \frac{2}{R_z}\right) = 0 \end{aligned} \qquad (5)$$

From Equation (5), the CO and FO can be given by:
CO:

$$\begin{aligned} & \left\{C_2\left(\frac{1}{R_1} - g_{m_1}\right)\right\} + C_1\frac{\left(1-\beta_2^-\right)}{R_2} \\ & + \frac{1}{R_z}\left\{2C_z\left(1-\beta_2^-\right) + 2C_2\right\} \le 0 \end{aligned} \qquad (6)$$

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FO:

$$\omega=\sqrt{\frac{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)}{\left(C_1+2C_z\right)C_2}} \tag{7}$$

The sensitivities of ω_0 with respect to active and passive elements are calculated as:

$$S_{g_{m_1}}^{\omega_0}=-\frac{\left(1-\beta_2^-\right)g_{m_1}}{2R_2\left\{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)\right\}}$$

$$S_{g_{m_2}}^{\omega_0}=\frac{\beta_2^+ g_{m_2}}{2R_2\left\{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)\right\}}$$

$$S_{\beta_2^+}^{\omega_0}=\frac{1}{2}$$

$$S_{\beta_2^-}^{\omega_0}=-\frac{\beta_2^-\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)}{2\left\{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)\right\}}$$

$$S_{R_1}^{\omega_0}=-\frac{\left(1-\beta_2^-\right)}{2R_1R_2\left\{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)\right\}}$$

$$S_{R_2}^{\omega_0}=-\frac{1}{2}$$

$$S_{R_z}^{\omega_0}=-\frac{\left(1-\beta_2^-\right)}{R_zR_2\left\{\dfrac{\beta_2^+ g_{m_2}}{R_2}+\dfrac{\left(1-\beta_2^-\right)}{R_2}\left(\dfrac{1}{R_1}-g_{m_1}+\dfrac{2}{R_z}\right)\right\}} \tag{8}$$

$$S_{C_1}^{\omega_0}=-\frac{1}{2}=S_{C_2}^{\omega_0},S_{C_z}^{\omega_0}=-1$$

An inspection of Equation (8) reveals that the active and passive sensitivities of ω_0 are found to be low.

4. Frequency Stability

Frequency stability is an important figure of merit for any sinusoidal oscillator. Using the definition of the frequency stability factor S^F as given in [5,8] $S^F=\left.\left(\dfrac{\mathrm{d}\phi(u)}{\mathrm{d}u}\right)\right|_{u=1}$ (where $u=\dfrac{\omega}{\omega_0}$ is the normalized frequency and $\phi(u)$ denotes the phase of the open-loop transfer function), with $C_1=C_2=C,g_{m_1}=\dfrac{1}{R_1}=\dfrac{1}{R_2}=g_m$ and $g_{m_2}=ng_m$, the S^F of this oscillator is found to be $2\sqrt{n}$. Thus the new proposed oscillator circuit offers very high frequency stability factor for larger values of n.

5. Simulation Results

The proposed sinusoidal oscillator circuit has been simulated using the CMOS-based VD-DIBA [14]. The various component values used were $C_1=C_2=0.05$ nF, $R_1=1.67$ KΩ and $R_2=10$ K, the CMOS VD-DIBA was biased with ±1 V D.C. power supplies with $I_{B1}=I_{B2}=I_{B3}=I_{B4}=I_{B5}=I_{B6}=150$ µA and $I_{B7}=30$ µA. The transconductances of VD-DIBAs were controlled through the respective bias currents. The SPICE generated output waveforms indicating transient and steady state responses are shown in **Figures 3(a)** and **(b)** respectively. From SPICE simulations {**Figures 3(a)** and **(b)**}, the oscillations are observed to be quite stable and the frequency of generated sine wave was found as 731.88 KHz. The THD of the output waveform was found as 1.159%. **Figure 4** shows the Monte-Carlo simulations which provide the robustness of the oscillator circuit of **Figure 2** by taking sample result for ±10% variations in R_1. Simulation results, thus, confirm the workability of the pro-

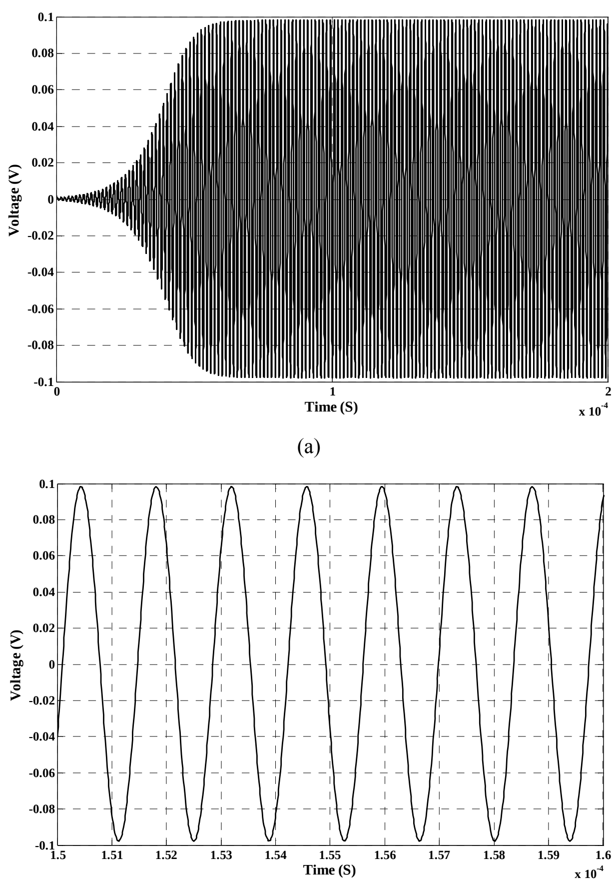

Figure 3. (a) Transient output waveform; (b) Steady state response of the output.

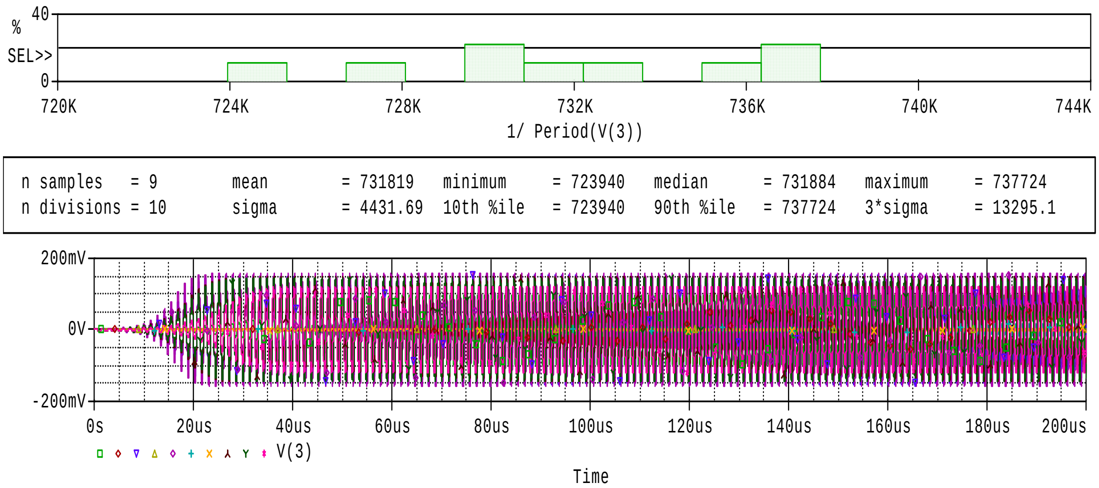

Figure 4. Result of Monte-Carlo simulation of oscillator circuit of Figure 2.

Table 1. Comparison with other previously known fully uncoupled sinusoidal oscillators.

Reference Number	No. of Active Elements	No. of Passive Elements	No. of Grounded Capacitors	Independent Electronic Tunability in Both CO and FO
[1]	2	6	2	NO
[2]	3	4 - 6	2 - 3	NO
[3]	3	5	2	NO
[4]	1 - 3	3 - 7	2 - 3	NO
[5]	3	6	2	NO
[6]	4	2	2	YES
[7]	2	2	2	YES
[14]	2	3	2	NO
Proposed	2	4	2	YES

posed oscillator. A comparison with other previously known fully uncoupled sinusoidal oscillators has been given in **Table 1**.

6. Concluding Remarks

A new sinusoidal oscillator with fully decoupled and electronically controllable both frequency of oscillation and condition of oscillation has been presented. The new oscillator configuration also enjoys 1) low active and passive sensitivities and 2) a very good frequency stability factor for larger values of n. The robustness of the proposed oscillator circuit has been confirmed by the Monte-Carlo analysis. The workability of the proposed configuration has been established by SPICE simulations with TSMC 0.18 μm process parameters.

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