Electronically Tunable Mixed-mode Sinusoidal Oscillator using Simple Transconductors

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***Abstract*—This paper offers a tunable mixed-mode oscillator. Only two grounded capacitors and three transconductors are used in the oscillator. It has the advantageous characteristics of a simple structure, mixed voltage- and current-mode operation, and suitable IC implementation because of no external passive resistor and the use of a grounded capacitor. Furthermore, the oscillation frequency and condition can be separately changed by varying the bias current of the transconductors. The investigation of the effect of parasitic elements of transconductors on the proposed oscillator is included. The simulation results of the suggested circuit using PSPICE with 0.18 µm CMOS TSMC technology and ±0.75 V power supply confirm the analytical theory.**

Keywords—oscillator, transconductor, grounded capacitor, no external passive resistor, mixed-mode

I. Introduction

The sinusoidal oscillator is a crucial circuit and finds many applications in communication, signal processing, instrumentation, and measurement systems. The literature survey presents that several sinusoidal oscillators employing active elements such as modified current backward transconductance amplifier (MCBTA) [1], inverting second generation current conveyor (ICCII) [2], voltage differencing-differential input buffered amplifier (VD-DIBA) [3], operational transresistance amplifier (OTRA) [4, 6], current controlled current conveyor transconductance amplifier (CCCCTA) [5], and voltage differencing inverting buffered amplifier (VDIBA) [7] have been proposed. Several of the oscillators use grounded capacitors [1-3, 5]. Therefore, the oscillators are suitable for integrated circuit (IC) fabrication. However, most of the oscillators employ external resistors [1-3, 4-7] and require an excess number of transistors (more than 12 transistors) [1-6]. Some of the presented oscillators lack electronic tuning [2, 4, 6]. Moreover, there are two types of oscillators: voltage mode [1-4, 6, 7] and current mode [5]. No presented circuit has been done in the mixed-mode oscillator. Therefore, this paper is a tunable mixed-mode oscillator without an external resistor. The comparison of the proposed oscillator and previously published works are shown in TABLE I.

TABLE I. COMPARISON OF SEVERAL SINUSOIDAL OSCILLATORS

Ref.	**Active components**	**External resistor**	**Grounded capacitor**	**Electronic tuning**
[1]	1 MCBTA (20 MOSs)	yes	yes	yes
[2]	1 ICCII (18 MOSs)	yes	yes	no
[3]	2 VD-DIBAs (48 MOSs)	yes	yes	yes
[4]	1 OTRA (17 MOSs)	yes	no	no
[5]	1 CCCCTA (33 MOSs)	no	yes	yes
[6]	1 OTRA (14 MOSs)	yes	no	no
[7]	2 VDIBAs (12 MOSs)	yes	no	yes
Proposed circuit	3 transconductors (12MOSs)	no	yes	yes

This paper proposes a tunable mixed-mode oscillator using only two grounded capacitors and three simple transconductors. The attractive features of the proposed oscillator include few component counts, no external resistor, mixed-mode function without modifying the structure, use of the grounded capacitor, and are suitable for IC implementation. In addition, the circuit offers electronic tuning of oscillation conditions and oscillation frequency. SPICE simulation has been used to confirm the viability of the proposed oscillator.

II. Proposed Circuit Description

The proposed oscillator based on a simple transconductor is introduced as previously discussed. The CMOS transconductor implementation as shown in Fig. 1 (a) consists of four transistors and two current sources [8]. The transconductance parameters are the same if all transistors operate in the saturation region. Fig. 1 (b) shows the equivalent circuit of an ideal transconductor with parasitic elements. It is demonstrated that the low-value capacitances of C_+ and C_- at the input terminals and C_P and C_N at the output terminals are included. Moreover, the output terminal conductances of *GP* and g_N at output terminals are also included. The ideal transconductor current outputs are shown as follows:

$$I_P^{'} = -I_N^{'} = g_m(V^+ - V^-)\ , \tag{1}$$

where

$$g_m = \sqrt{\mu_0 C_{ox} \frac{W}{L} I_0}\ , \tag{2}$$

where g_m is the transconductance of the transconductor. The parameters of μ_0, C_{ox}, W, and L represent the standard parameters of the CMOS transistor and I_0 expresses the bias current of the transconductor.

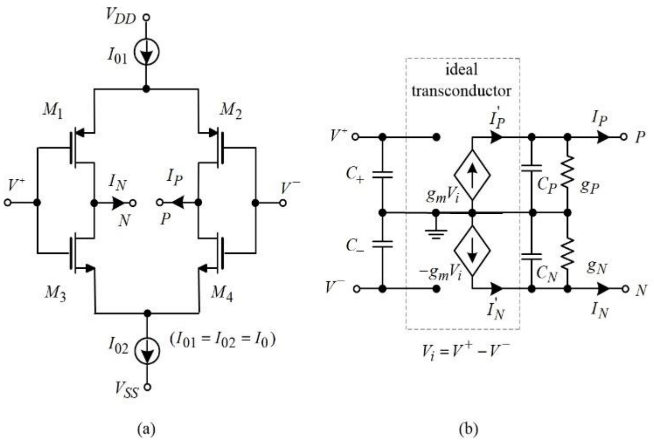

Fig. 1. Transconductor (a) schematic (b) equivalent circuit with parasitic elements.

The proposed tunable mixed-mode oscillator is shown in Fig. 2. The circuit requires three simple transconductors and two grounded capacitors without an external resistor. It offers the sinusoidal outputs of voltage-mode and current-mode.

Routine circuit analysis as shown in Fig. 2 including the parasitic elements of transconductors gives the following equations:

$$(y_A - g_{m3})\, y_B + g_{m1} g_{m2} = 0\,, \tag{3}$$

$$I_{out} = -g_{m1} V_{out} - y_C V_C\,, \tag{4}$$

where

$$y_A = g_{N2} + g_{P3} + s(C_1 + C_{+1} + C_{N2} + C_{+3} + C_{P3})\,, \tag{5}$$

$$y_B = g_{P1} + s(C_2 + C_{P1} + C_{+2})\,, \tag{6}$$

and

$$y_C = g_{P2} + sC_{P2}\,, \tag{7}$$

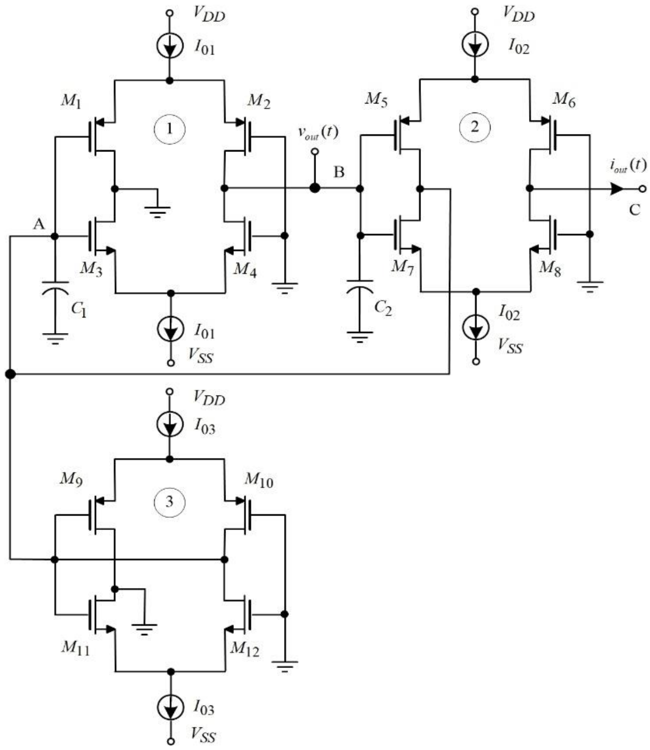

Fig. 2. Proposed tunable mixed-mode oscillator.

where g_{Pm}, g_{Nm}, C_{+m}, C_{Pm}, and C_{Nm} are the parasitic conductances and the parasitic capacitances of the m^{th} transconductor, respectively. It is noted that the term y_C works at extremely high frequencies. Assuming the operation frequency of the proposed oscillator is much lower than the corner frequency of $\omega_C = g_{P2}/C_{P2}$. So, (4) modifies to

$$I_{out} = -g_{m1} V_{out}\,, \tag{8}$$

To minimize the impact of the parasitic capacitances of y_A and y_B, taking the value of the external capacitors of C_1 and C_2 are much more than these parasitic capacitances, then (3) modifies to

$$\begin{aligned} &s^2 C_1 C_2 + s[C_1\, g_{P1} + C_2(g_{N2} + g_{P3} - g_{m3})] \\ &+ g_{m1} g_{m2} + g_{P1}(g_{N2} + g_{P3} - g_{m3}) = 0. \end{aligned} \tag{9}$$

Selecting $g_{m1}g_{m2} >> g_{P1}(g_{N2}+g_{P3}-g_{m3})$, (9) simplifies the characteristic equation of the proposed oscillator as:

$$s^2 C_1^2 + sC_1(g_{P1} + g_{N2} + g_{P3} - g_{m3}) + g_{m1} g_{m2} = 0\ . \tag{10}$$

From (10), it is possible to express the oscillation condition (OC) and oscillation frequency (OF) as

$$(g_{P1}+g_{N2}+g_{P3}-g_{m3})\leq 0\,, \qquad (11)$$

$$\omega_0=\sqrt{\frac{g_{m1}g_{m2}}{C_1^2}}\,. \qquad (12)$$

From (11) and (12), it can be seen that the OC can be electronically tuned by adjusting the transconductance g_{m3}, whereas the OF can be electronically controlled by adjusting the transconductances of g_{m1} and g_{m2}. OC and OF are each electronically tuned individually.

III. SIMLATION RESULTS

To confirm the theoretical analysis of the proposed oscillator, Fig.2 used a PSPICE simulation with 0.18 µm CMOS TSMC parameters at ±0.75 V supply voltages [9]. The aspect ratio parameter of NMOS and PMOS transistors is L_N.= L_P = 0.54 µm, W_N = 3.6 µm and W_P = 9µm.

Fig. 3 and Fig. 4 show the simulated voltage and current output waveforms of Fig. 2 using $C_1 = C_2$ = 100 pF, I_{01} = 50 uA, and $I_{02} = I_{03}$ = 20 µA for the transconductor parameters of g_{m1} = 0.23 mA/V, $g_{m2} = g_{m3}$ = 0.13 mA/V, g_{p1} = 90 µA/V, $g_{P2} = g_{P3} = g_{N2}$ = 22 µA/V, $C_{+1} = C_{+2} = C_{+3}$ = 0.04 pF, and $C_{P1} = C_{P2} = C_{P3} = C_{N2}$ = 0.02 pF.

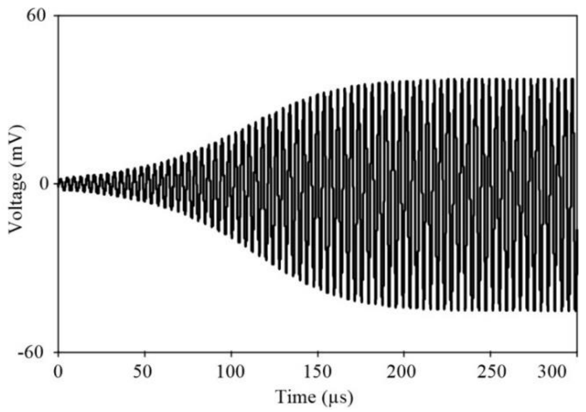

Fig. 3. The voltage output signal of the proposed mixed-mode oscillator.

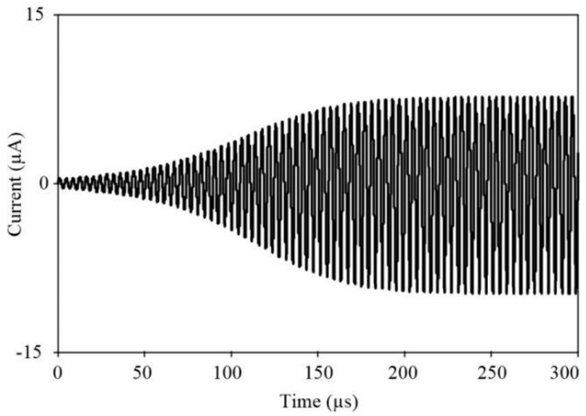

Fig. 4. The current output signal of the proposed mixed-mode oscillator.

The spectrum of the voltage output in Fig. 3 is displayed in Fig.5 with OF of 250 kHz and its total harmonic distortion (THD) of 0.076 %.

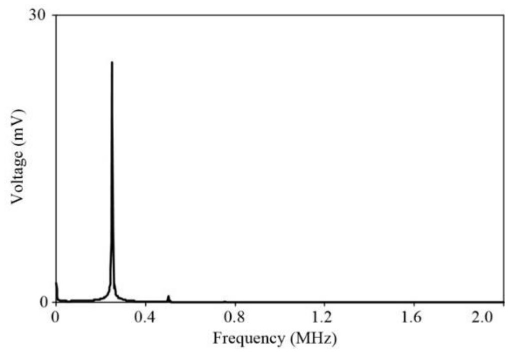

Fig. 5. The spectrum of the voltage output waveform in Fig. 3.

To illustrate the application of the proposed oscillator, Fig. 6 shows the amplitude modulation (AM) system. The carrier signal is the output of the proposed oscillator at a frequency of 250 kHz. The AM waveform of the system is depicted in Fig. 7.

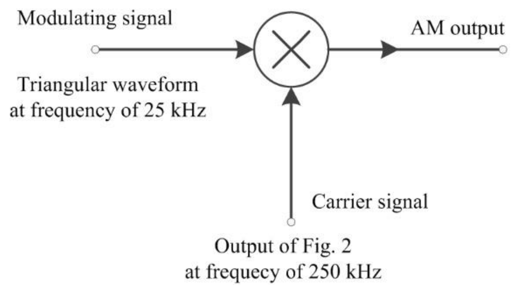

Fig. 6. AM system.

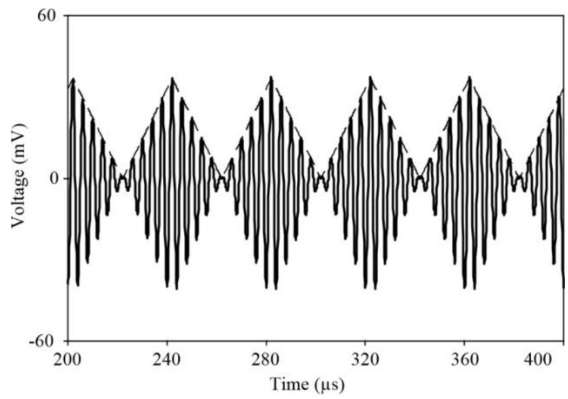

Fig. 7. AM signal of the AM system in Fig. 6.

IV. CONCLUSION

A circuit of tunable mixed-mode sinusoidal oscillator has been proposed in this paper. It consists of two grounded capacitors and three simple transconductors without demanding an external resistor. The oscillator offers mixed-mode operation without altering its configuration. The oscillation condition and oscillation frequency of the circuit can be independently adjusted with electronic tuning. By using a SPICE simulation with 0.18 m CMOS TSMC technology, the performance of the oscillator was verified.

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