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DIGITALLY PROGRAMMABLE PARTIALLY ACTIVE-R SINUSOIDAL OSCILLATORS

MUHAMMAD TAHER ABUELMA'ATTI, ABDULRAHMAN KHALAF AL-ALI, SAMI SAUD BUHALIM AND SYED TAUSEEF AHMED

King Fahd University of Petroleum and Minerals, Box 203, Dhahran 31261, Saudi Arabia

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New, simple sinusoidal oscillator circuits are proposed. Each circuit uses an internally compensated operational amplifier, a resistor, and a capacitor. The feasibility of obtaining digitally programmable sinusoidal oscillation is studied and a new digitally programmable capacitorless resistorless sinusoidal oscillator is developed.

1. INTRODUCTION

In active-RC circuits, it is highly desirable to have all the capacitors grounded [1–8]. This is attributed to several reasons. First, grounded capacitors are suitable for monolithic IC technology [9–11] and thin film fabrication [2]. In thin-film fabrication, if the capacitors are grounded, the etching process is eliminated and the number of contacts is reduced. Also, the parasitic capacitors surrounding the main capacitors can be easily accounted for or tuned out as they are now in parallel with the grounded capacitors [3]. Secondly, in CMOS technology, the use of grounded capacitors is an advantage as the bottom plate parasitic capacitor is eliminated altogether and the top plate parasitic capacitor can be accounted for easily as it becomes parallel to the main capacitor [12]. This explains the considerable interest in designing RC oscillators with grounded capacitors [1, 3, 5, 6, 13].

In a recent publication, Senani [12] presents a grounded-capacitor sinusoidal oscillator using operational amplifier compensation poles. This circuit can provide voltage-controlled oscillation by employing three operational amplifiers; at least two of them are internally compensated, one resistor, a grounded capacitor, and two dc power supplies; at least one of them is variable.

The purpose of this paper is to show that a simple digitally programmable voltage(current)-controlled oscillator can be implemented using a grounded capacitor, an internally compensated operational amplifier, two operational transconductance amplifiers (OTAs), and only one fixed dc power supply.

2. PROPOSED CIRCUIT

The new proposed circuit is shown in Fig. 1a and its equivalent circuit is shown in Fig. 1b with [14]

$$R = \frac{1}{g_m} \tag{1}$$

$$g_m = \frac{I_{ABC}}{2V_T} \tag{2}$$

where $V_T = 26mV$ is the thermal voltage at room temperature and I_{ABC} is the auxiliary bias current of the OTAs. Assuming that the operational amplifier is characterized by

$$G = \frac{G_o\omega_a\omega_b}{(s + \omega_a)(s + \omega_b)} \tag{3}$$

routine analysis shows that the characteristic equation of the circuit of Fig. 1a is given by

$$\alpha G_o\omega_a\omega_b + (\omega_a + s)(\omega_b + s)(1 + s\tau) = 0 \tag{4}$$

where

$$\tau = CR_o//(R + R_{\text{inp}}) \tag{5}$$

$\alpha = R_{\text{inp}}/(R_{\text{inp}} + R + R_o)$, R_o is the output resistance of the operational amplifier, and R_{inp} is the differential input resistance of the operational amplifier. The frequency of oscillation and the condition of oscillation are, therefore, given by

$$\omega_o^2 = \omega_a\omega_b + \frac{\omega_a + \omega_b}{\tau} \tag{6}$$

and

$$G_o = \frac{1}{\alpha}\left(1 + \frac{1}{\tau\omega_a} + \frac{1}{\tau\omega_b}\right)\frac{1}{1 + \tau(\omega_a + \omega_b)} \tag{7}$$

The condition of (7) can be easily satisfied in practical operational amplifiers.

From (1) and (6) it follows that the frequency of oscillation can be expressed as

$$\omega_o^2 = \omega_a\omega_b + \frac{\omega_a + \omega_b}{CR_o//(R_{\text{inp}} + 2V_T/I_{ABC})} \tag{8}$$

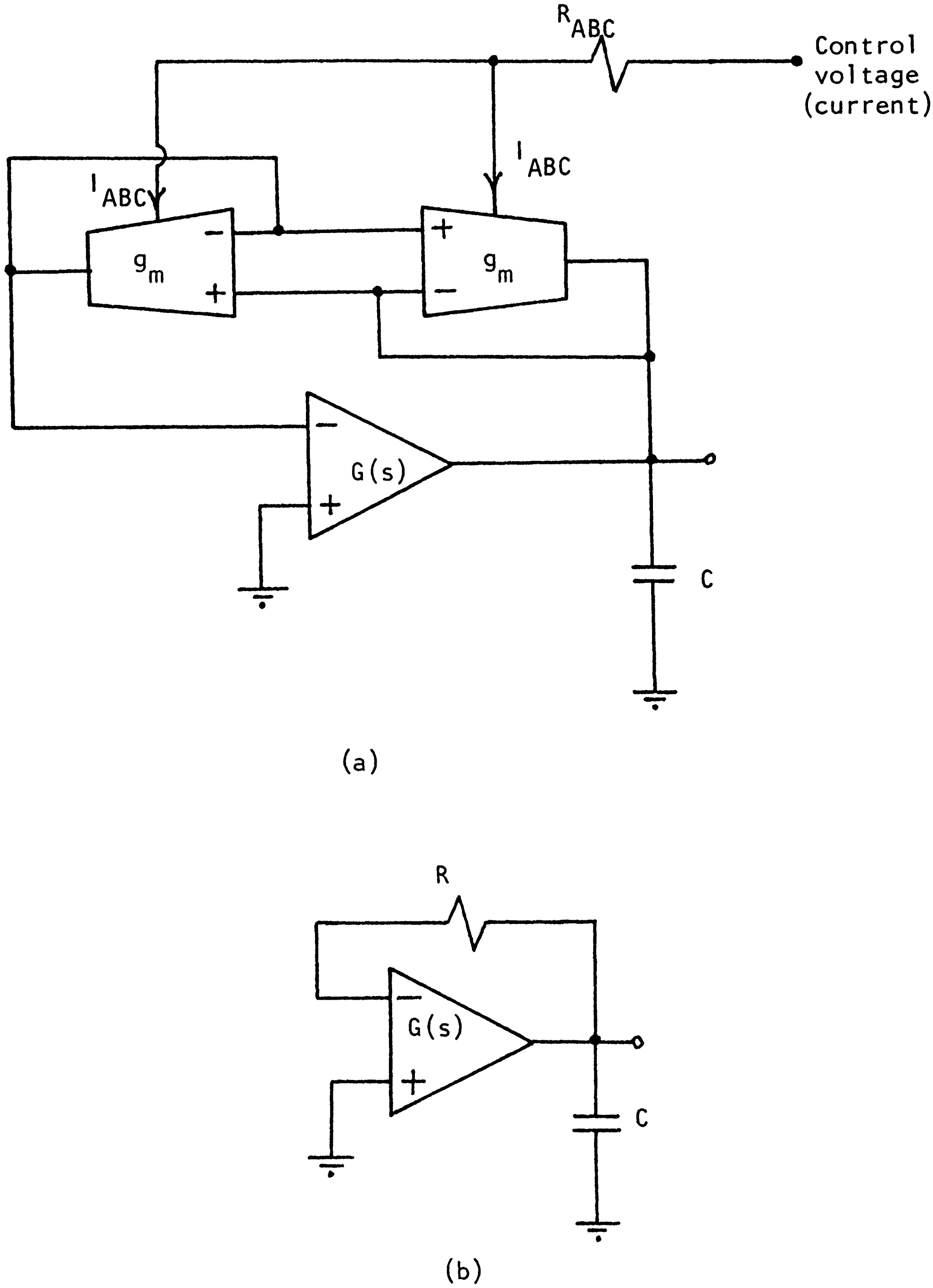


FIGURE 1 Proposed oscillator circuit (a) and its equivalent circuit (b)

From (8) it is obvious that the frequency of oscillation can be tuned by adjusting the auxiliary bias current I_{ABC} of the OTAs and, thus, by obtaining this current from the output of a digital-to-analog converter (DAC), the realization of a digitally programmable tunable oscillator is feasible.

An alternative oscillator circuit, shown in Fig. 2a with its equivalent circuit shown in Fig. b, can be obtained by moving the capacitor C from the output terminal of the operational amplifier to the inverting input terminal. Assuming that the operational amplifier is characterized by the two-pole model of (2), routine analysis shows that the characteristic equation of this circuit is given by [15]

$$(1 + sCR)(\omega_a\omega_b + s(\omega_a + \omega_b) + s^2) + G_o\omega_a\omega_b = 0 \tag{9}$$

The frequency of oscillation and the condition of oscillation are, therefore, given by

$$\omega_o^2 = \omega_a\omega_b + \frac{\omega_a + \omega_b}{RC} \tag{10}$$

and

$$G_o = \frac{\omega_b}{\omega_a} + \frac{1}{\omega_a CR} + \omega_b CR \tag{11}$$

The condition of (11) can be easily satisfied in practical operational amplifiers.

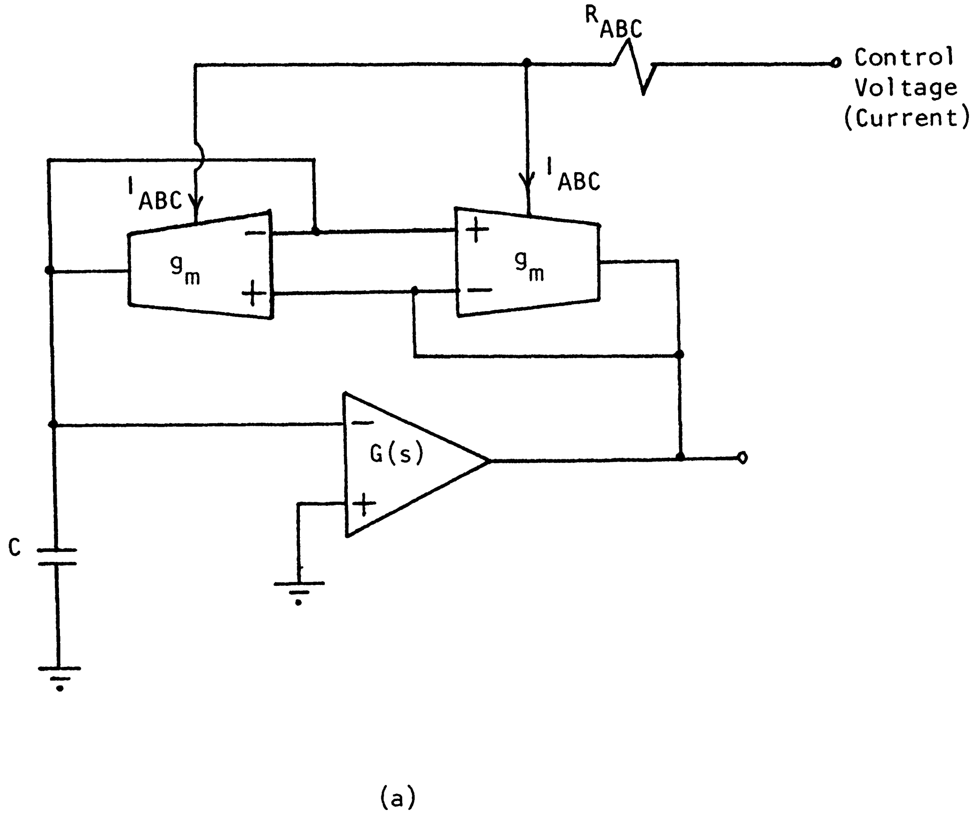
From (1) and (10) it follows that the frequency of oscillation can be expressed as

$$\omega_o^2 = \omega_a\omega_b + \frac{\omega_a\omega_b}{C}\frac{I_{ABC}}{2V_T} \tag{12}$$

From (12) it is obvious that the frequency of oscillation can be tuned by adjusting the auxiliary bias current I_{ABC} of the OTAs. By obtaining this current from the output of a digital-to-analog converter (DAC), the realization of a digitally programmable electronically tunable oscillator is feasible. It is worthwhile mentioning that a capacitorless oscillator circuit can be obtained from the circuit of Fig. 2. This can be achieved by exploiting the differential input capacitance of the operational amplifier to advantage rather than connecting an external capacitance C.

3. EXPERIMENTAL RESULTS

The oscillator circuit of Fig. 1 was built and tested using the operational amplifier 741, the OTA 3080, and an externally connected capacitor $0.01\mu F$. Variation of the frequency of oscillation with the control voltage of the operational transconductance amplifier is shown in Fig. 3. When the control voltage was varied from -4 V to 7 V, the frequency of oscillation varied from 87 KHz to 416 KHz. The



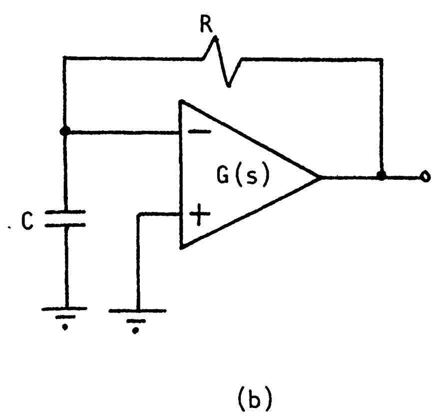


FIGURE 2 Another oscillator circuit (a) and its equivalent circuit (b) [15]

oscillator circuit of Fig. 3 was also built and tested using the operational amplifier 741, the operational transconductance amplifier 3080, and an external capacitor $0.01\mu F$. Variation of the frequency of oscillation with the control voltage of the operational transconductance amplifier is shown in Fig. 3. When the control voltage was varied from -4 V to 7 V, the frequency of oscillation varied from 10 KHz to

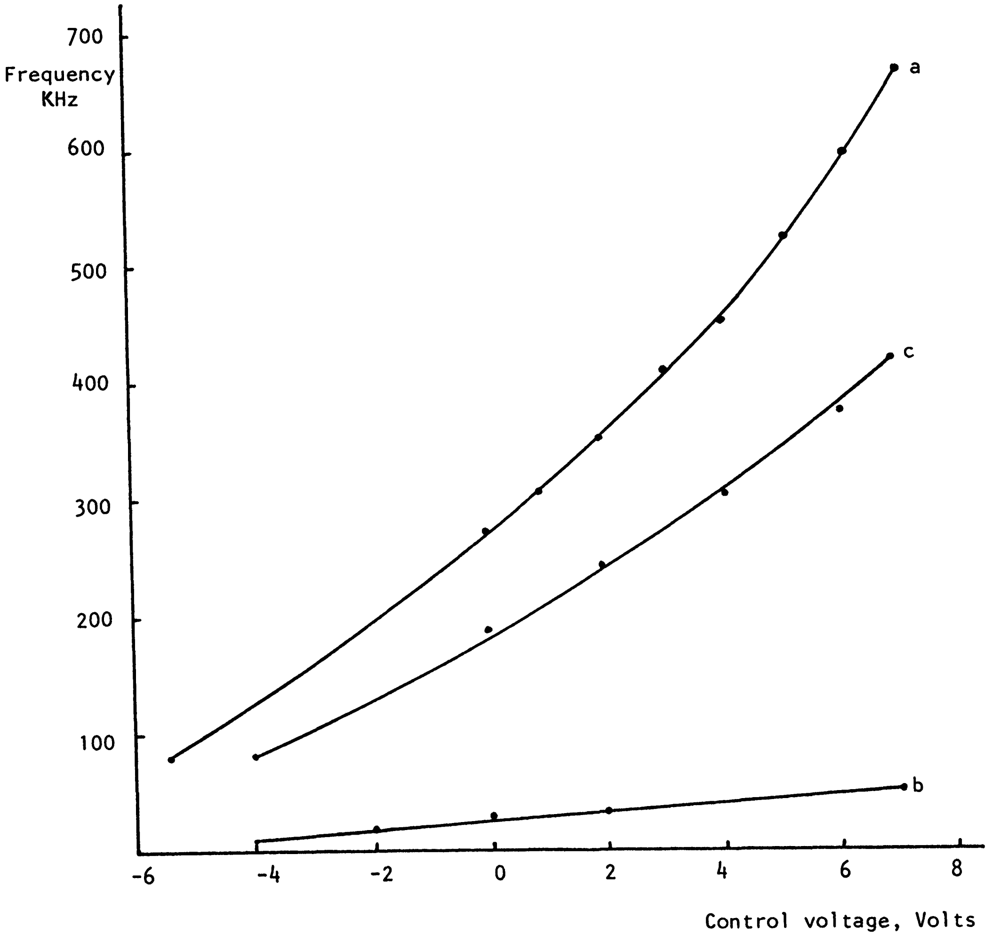


FIGURE 3 Variation of the frequency of oscillation with the control voltage for: (a) Circuit of Fig. 2 without external capacitor, but with cable and oscilloscope capacitances; (b) Circuit of Fig. 2 with external capacitor = 0.01 uF; (c) Circuit of Fig. 1 with external capacitor = 0.01 uF. In all cases R_{ABC} = 400 K

52 KHz. The operation of the circuit was also tested with no external capacitor added other than the oscilloscope and cable capacitances, which may be about 120 pF. Variation of the frequency of oscillation with control voltage of the operational transconductance amplifier is shown in Fig. 3. When the control voltage was varied from -5.5 V to 7 V, the frequency of oscillation varied from 86 KHz to 666 KHz. By obtaining this control voltage from the output of a digital-to-analog converter, the frequency of oscillation was varied from 100 KHz to 239 KHz when the hexadecimal input varied from 60 to E0.

CONCLUSION

In this paper, new digitally programmable partially active-R oscillator circuits, using the operational amplifier poles, have been presented. It has been shown that by exploiting the differential input capacitance of the operational amplifier, a capacitorless, resistorless, sinusoidal oscillator can be obtained using only an operational amplifier and two operational transconductance amplifiers. For stable operation of the proposed circuits, the operational amplifier parameters G_o, ω_a, and ω_b must be stabilized. Therefore, we recommend a temperature compensated operational amplifier such as the LM324. Moreover, since V_T is involved in the expression of the frequency of oscillation, temperature compensation of the operational transconductance amplifiers is recommended particularly if the circuit is to be used under varying environmental conditions. This can be easily achieved using readily available techniques [16].

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