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# Effects of Parasitic Elements on Oscillation Frequency of OTA-C Sinusoidal Oscillators

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**Abstract**

*An oscillator circuit which incorporates Operational Transconductance Amplifiers is presented. The circuit is designed using three OTAs and two grounded capacitors. The frequency of oscillation is tunable over a wide frequency range. The effects of the parasitic elements on the oscillation frequency and the oscillation condition are studied. The theoretical results are compared with the experimental results for a practical oscillator circuit.*

## 1. Introduction

Sinusoidal oscillators play an important role in instrumentation, communication and control systems. In the recent past, a number of OTA-C sinusoidal oscillators, have been proposed [1]-[4]. In most of these oscillators the oscillation frequency is varied by simultaneous variation of the transconductances of the OTAs or the grounded capacitors. Moreover, the frequency and the condition of oscillation are dependent on each other. Therefore, the frequency of oscillation cannot be changed without affecting the condition of oscillation.

The importance of the OTA-C sinusoidal oscillator circuits lies in the fact that they can be manufactured in integrated-circuit form using MOS technology with minimum chip area since they do not contain resistors floating capacitors. The OTA-C oscillators facilitate the generation of linearly tunable variable frequency oscillations through an external current.

In this paper, the aim is to present a simple OTA-C sinusoidal oscillator structure. The parasitic equivalent circuit of the OTA is given [5,6] and the values of the parasitic elements are obtained as a function of the controlling current amplitudes [7]. The deviation of the frequency of oscillation owing to the parasitic elements is investigated. The paper is organized as follows: an ideal OTA-C circuit is presented in Section 2.1; the parasitic elements on the nonideal equivalent circuit of the OTA are defined, and the effects of the parasitic capacitors and resistors on the oscillation frequency and the oscillation condition are given in Section 2.2; simulation and experimental results are compared in Section 3.

## 2. OTA-C Sinusoidal Oscillator Circuit

### 2.1. Ideal OTA-C oscillator

An ideal OTA-C oscillator circuit is shown in Figure 1. Assuming the operational transconductance amplifiers are ideal, their terminal equations can be written as

$$\begin{aligned} i_1 &= g_{m_1} v_{C_2} \\ i_2 &= g_{m_2}(v_{C_2} - v_{C_1}) \\ i_3 &= g_{m_3} v_{C_2} \end{aligned} \quad (1)$$

where $g_{m_i}$ is the ideal transconductance gain of the ith OTA and it is a function of the control current as

$$g_{m_i} = \gamma_5 I_{C_i}. \quad (2)$$

From equations (1) and (2) we have

$$C_1 \frac{dv_{C_1}}{dt} = g_{m_1} v_{C_2} \quad (3)$$

$$C_2 \frac{dv_{C_2}}{dt} = (g_{m_2} - g_{m_3}) v_{C_2} - g_{m_2} v_{C_1} \quad (4)$$

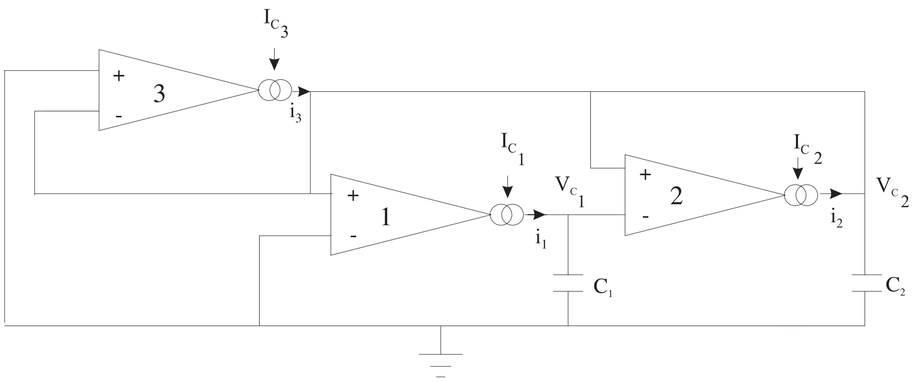


**Figure 1.** OTA-C sinusoidal oscillator.

The characteristic equation of the circuit follows as

$$s^2 + \frac{g_{m_3} - g_{m_2}}{C_2} s + \frac{g_{m_1} g_{m_2}}{C_1 C_2} = 0 \quad (5)$$

The full conditions for the oscillation and start-up are obtained by finding the roots of the characteristic equation. The two roots of (5) are

$$p_1, p_2 = \frac{g_{m_2} - g_{m_3}}{2C_2} \pm \sqrt{\left(\frac{g_{m_3} - g_{m_2}}{2C_2}\right)^2 - \frac{g_{m_1} g_{m_2}}{C_1 C_2}} \quad (6)$$

These roots must lie on the closed right-half plane (condition of oscillation) so that

$$\frac{g_{m_2} - g_{m_3}}{2C_2} \geq 0$$

and

$$\frac{g_{m_1} g_{m_2}}{C_1 C_2} > \left(\frac{g_{m_3} - g_{m_2}}{2C_2}\right)^2.$$

The frequency of oscillation is then

$$\omega_o = \sqrt{\frac{g_{m_1} g_{m_2}}{C_1 C_2} - \left( \frac{g_{m_3} - g_{m_2}}{2C_2} \right)^2}. \tag{7}$$

From equation (7), it can be seen that the oscillation frequency can be varied linearly by changing the control current of the OTAs, which directly affects the transconductance. Equating the values of $g_{m_2}$ and $g_{m_3}$ (not easy in practice), the oscillation frequency becomes (8)

$$\omega_o = \sqrt{\frac{g_{m_1} g_{m_2}}{C_1 C_2}}. \tag{8}$$

The resonant frequency, $\omega_o$ sensitivity of the oscillator shown in Figure 1 is obtained:

$$S_{g_{m1}}^{\omega_o} = S_{g_{m2}}^{\omega_o} = 1/2$$

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_2} = -1/2$$

Note that the sensitivities are independent of the network parameters and are equal to 1/2 in magnitude. Hence the oscillator has good sensitivity performance.

## 2.2. Nonideal OTA-C oscillator

The nonideal OTA model is shown in Figure 2. The output and input impedances are the bandwidth-limiting parasitics, and their values are dependent on the control current:

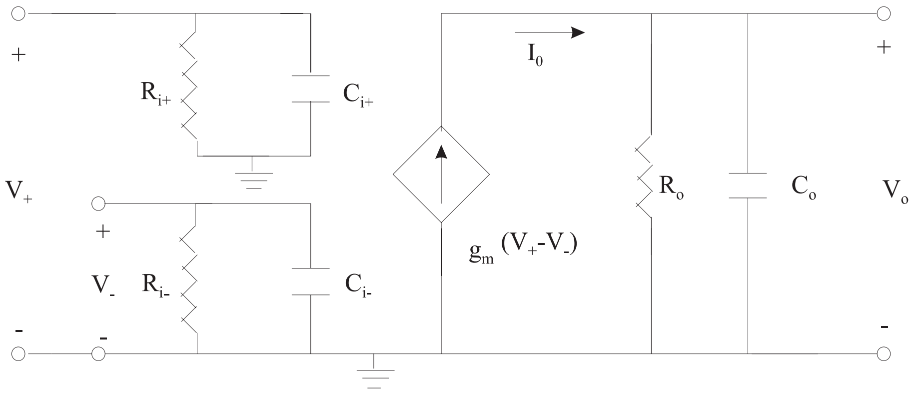


**Figure 2.** An OTA model with input and output impedances.

$$\begin{array}{llll} R_i & = & \frac{1}{G_i}\gamma_1 (I_C)^{-\beta_1} & \text{ohms} \\ C_i & = & \gamma_2 (I_C)^{\beta_2} & \text{pF} \\ R_o & = & \frac{1}{G_o} = \gamma_3 (I_C)^{-\beta_3} & \text{ohms} \\ C_o & = & \gamma_4 (I_C)^{\beta_4} & pF \end{array} \tag{9}$$

where $\gamma_i$ and $\beta_i$ are positive constants. Including the parasitic elements, the ideal OTA-C oscillator circuit given in Figure 1 can be modified as shown in Figure 3.

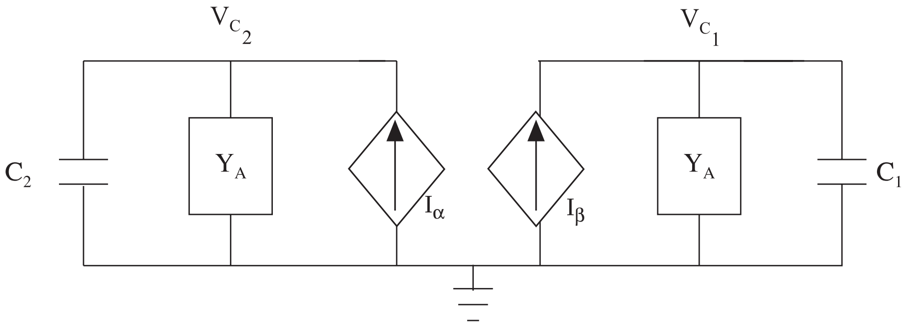


**Figure 3.** Nonideal equivalent model of the OTA-C sinusoidal oscillator given in Figure 1.

In Figure 3,

$$\begin{aligned} I_\alpha &= g_{m_2}(v_{C_2} - v_{C_1}) - g_{m_3} v_{C_2} \\ I_\beta &= g_{m_1} v_{C_2}. \end{aligned} \tag{10}$$

The admittances $Y_A$ and $Y_B$ are the combination of the equivalent parasitic elements given in Figure 2 as

$$Y_A = G_A + sC_A = (G_{o_3} + G_{o_2} + G_{i_1} + G_{i_2} + G_{i_3}) + s(C_{o_3} + C_{o_2} + C_{i_1} + C_{i_2} + C_{i_3}) \tag{11}$$

$$Y_B = G_B + sC_B = (G_{o_1} + G_{i_2}) + s(C_{o_1} + C_{i_2}) \tag{12}$$

The characteristic equation for the circuit of Figure 3 is written as

$$as^2 + bs + c = 0 \tag{13}$$

following the same steps used in the derivation of (5), where

$$\begin{aligned} a &= (C_2 + C_A)(C_1 + C_B) \\ b &= (C_2 + C_A)G_B + (C_1 + C_B)(G_A + g_{m_3} - g_{m_2}) \\ c &= g_{m_1} g_{m_2} + G_A G_B - g_{m_2} G_B + g_{m_3} G_B \end{aligned}$$

The two roots of equation (13) are

$$p_{n_1}, p_{n_2} = -\frac{b}{2a} \pm \sqrt{\frac{b^2 - 4ac}{2a^2}}. \tag{14}$$

The condition of oscillation is satisfied if

$$g_{m_2}(C_1 + C_B) \geq (G_A + g_{m_3})(C_1 + C_B) + G_B(C_2 + C_A) \tag{15}$$

and

$$\begin{aligned} &4(C_2 + C_A)(C_1 + C_B)(g_{m_1} g_{m_2} + G_A G_B - g_{m_2} G_B + g_{m_3} G_B) \\ &> \left[C_2 + C_A)G_B + (C_1 + C_B)(G_A + g_{m_3} - g_{m_2})\right]^2 \end{aligned} \tag{16}$$

The frequency of oscillation is then

$$\omega_o = \frac{1}{2a}\sqrt{4ac - b^2}. \tag{17}$$

The resonant frequency sensitivity of the oscillator in the nonideal case is

$$S_x^{\omega_o} = \frac{1}{4ac - b^2}\left[\frac{x(b^2 - 2ac)}{a}\frac{\delta a}{\delta x} - xb\frac{\delta b}{\delta x}\right] \tag{18}$$

where $x$ is $C_1$ or $C_2$. In the ideal case, the resonant frequency sensitivity is -0.5. including the parasitic elements, this sensitivity decreases according to the controlling current.

# 3. Simulation and Experimental Results

The operational transconductance amplifier capacitor sinusoidal oscillator circuit shown in Figure 1 is obtained using LM13700 OTAs and the parameters given in equation (9) are measured with the values: $\gamma_1 = 49.34, \beta_1 = 0.85, \gamma_2 = 5.14, \beta_2 = 0.0082, \gamma_3 = 1164.07, \beta_3 = 1.02, \gamma_4 = 4.62 \beta_4 = 0.004$ and $\gamma_5 = 20$. The parasitic element values and the resonant frequency sensitivities are calculated to be $R_i = 3446k\Omega, C_i = 4.62pF, R_o = 757M\Omega, C_o = 4.38pF, S_{C_1}^{\omega_o} = -0.4955$ and $S_{C_2}^{\omega_o} = -0.4888$ for 2 $\mu A$ control current.

To satisfy the oscillation condition, referring to equations (15) and (16), $g_{m_2}$ should be greater than $g_{m_3}$ which requires different control currents for the second and third OTAs. The oscillation frequency of the ideal OTA-C sinusoidal oscillator circuit is calculated using (7), and it is sketched against the control current in Figure 4 (curve I). The effect of the parasitic elements on the oscillation frequency is also shown in Figure 4 (curve II) which is obtained using (17). The external capacitances $C_1$ and $C_2$ are taken as $1nF$ (large enough compared to parasitic capacitances) and $I_{C_1} = I_{C_3} = I_C$ and $I_{C_2} = 1.1\, I_C$ in simulation. The comparison of curves I and II shows the variation in the resonant frequency with respect to the control currents. It should be noted that the ideal curve (curve I) is a linear function of the control current. In the nonideal case, the deviation of the resonant frequency becomes greater with higher values for the control current. The circuit shown in Figure 1 is set up and the variation of the resonant frequency versus control current is measured for $C_1 = C_2 = 1nF$, $I_{C_1} = I_{C_3} = I_C$ and $I_{C_2} = 1.1 I_C$. It is sketched in Figure 4 (curve III).

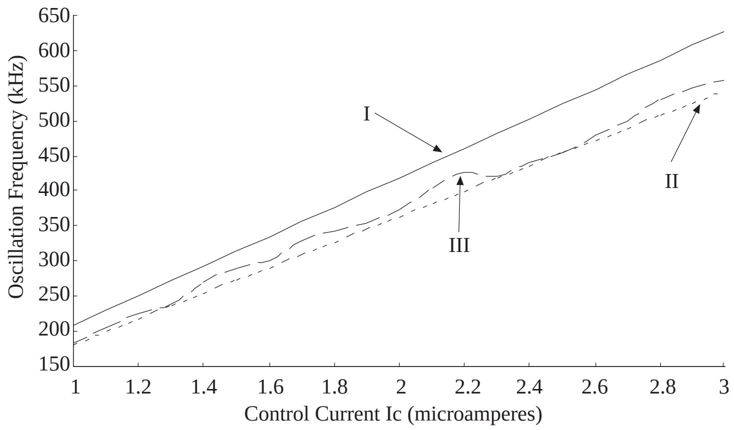


**Figure 4.** Effect of control current on the oscillation frequency of the OTA-C circuit given in Figure 1 (curve I) for ideal case, (curve II) including parasitic elements and (curve III) experimentally measured.

# 4. Conclusions

This paper has presented a simple OTA-C sinusoidal oscillator structure obtained using three OTAs and two grounded capacitors. The frequency of the oscillation and the oscillation condition are obtained for both ideal and parasitic cases. In the ideal case, the minimum condition for the oscillation is $g_{m_2} > g_{m_3}$ and it can be satisfied by adjusting the control currents of the second and third OTAs. In practice, the proposed conditions for the oscillation and the oscillation frequency change owing to the parasitic shunt capacitors and resistors. The magnitudes of the Parasitic elements are affected by the control currents and the oscillation frequency is almost the linear function of the control currents and the capacitances of external capacitors. Referring to Figure 4, it can be concluded that the difference in the oscillation frequency in the ideal and parasitic cases increases with a higher control current $I_C$. It is also obvious from Figure 3 and equations (11) and (12) that the external capacitance values chosen should be much greater than the parasitic capacitances of the OTAs. It is calculated that if the external capacitances $C_1$ and $C_2$ are taken as 100 pF, the deviation from the ideal case becomes 13.5% while it is 3.05% for $C_1 = C_2 = 500pF$ and 1.52% for $C_1 = C_2 = 1nF$.

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