Systematic Realization of Low-Frequency Oscillators Using Composite Passive–Active Resistors

Ahmed S. Elwakil

***Abstract*— A systematic method for realizing low-frequency oscillators is described. The method is applicable to any simple harmonic oscillator configuration and is based on replacing a selected passive resistor with a composite passive–active resistor. Two possible configurations for the composite resistor are discussed. The classical Wien-bridge oscillator is then modified using one of these configurations. PSPICE circuit simulations and experimental results are included.**

***Index Terms*— Active resistors, current feedback opamp, harmonic oscillators, low-frequency oscillators, sinusoidal oscillators.**

I. Introduction

LOW-FREQUENCY harmonic oscillators are of specific importance in many research areas, especially biological and biomedical applications. In order to realize such RC oscillators it is straightforward to scale the values of the capacitors and resistors which determine the frequency of oscillation. However, in many cases this results in nonpractical values. An approach that has thus been proposed [1]–[3] is to multiply the RC oscillating frequency (ω_o) by a reducing factor, resulting in a much smaller frequency of oscillation $(\omega_{\rm osc})$. This reducing factor has two general forms

$$\Delta\omega = \frac{\omega_{\rm osc}}{\omega_o} = \sqrt{1-n} \quad \text{or} \quad \Delta\omega = \frac{\omega_{\rm osc}}{\omega_o} = \sqrt{K}. \tag{1}$$

Evaluating the sensitivity expression of $\Delta\omega$ with respect to n and K, it can be shown that

$$\begin{aligned} S_n^{\Delta\omega} &= \frac{n}{\Delta\omega}\frac{\partial\Delta\omega}{\partial n} = -\frac{1}{2}\frac{n}{1-n} \\ S_K^{\Delta\omega} &= \frac{K}{\Delta\omega}\frac{\partial\Delta\omega}{\partial K} = \frac{1}{2}. \end{aligned} \tag{2}$$

From (2) it is clear that the sensitivity will be quite large when $(1-n)$ is small, while it remains constant independent of K. Hence, oscillators that employ the second form for the reduction factor are preferred; nevertheless both types are still used.

Currently available oscillators in literature that possess one of the above reduction factor forms have been especially designed for this purpose. It is the aim of this work to introduce a method that can be applied to any oscillator configuration and result in one of the above reduction forms. This allows for a wide variety of oscillator circuits with different features to be systematically modified for low-frequency applications.

Manuscript received March 21, 1998; revised December 14, 1998.
The author is with the Department of Electronics and Electrical Engineering, University College Dublin, Dublin 4, Ireland.
Publisher Item Identifier S 0018-9456(98)09916-1.

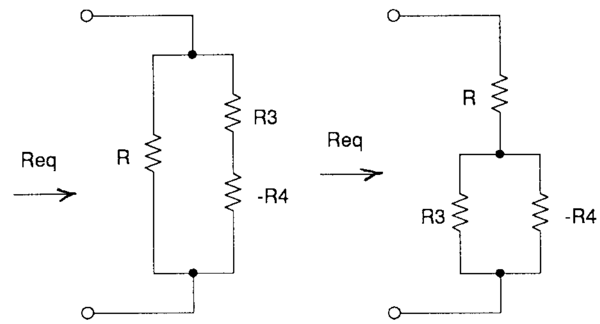


Fig. 1. Proposed composite passive–active resistors.

The method is based on replacing a suitable passive resistor with a composite passive–active resistor.

II. The Proposed Method with Application to a Wien-Bridge Oscillator

Fig. 1(a) and (b) represents two composite passive–active resistors. Resistors R and R_3 are passive, whereas resistor R_4 is active. Such an active resistor is realized with a linear negative impedance converter (NIC). Routine analysis of Fig. 1(a) results in an equivalent resistance $(R_{\rm eq})$ given by

$$R_{\rm eq} = \frac{R}{1+n} \tag{3}$$

where $n = R/(R_3 - R_4)$. Two cases are possible.

1) If $R_3 > R_4$, then n is positive and $(1+n) > 1$.
2) If $R_3 < R_4$, then n is negative and $(1+n) < 1$. Equivalently, $R_{\rm eq} = R/(1-|n|)$.

For a general second-order sinusoidal oscillator, the frequency of oscillation is given by

$$\omega_o = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}. \tag{4}$$

By choosing one of the passive resistors R_1 or R_2 to be replaced with the composite resistor of Fig. 1(a), a new frequency of oscillation $(\omega_{\rm osc})$ results. It can then be shown that

$$\Delta\omega = \sqrt{1 \pm |n|}. \tag{5}$$

Hence, for the case $R_3 > R_4$, the oscillating frequency can be extended to higher frequencies. However, for the case $R_3 < R_4$, the oscillating frequency is reduced with a factor $\sqrt{1-|n|}$. The composite configuration of Fig. 1(a) is thus

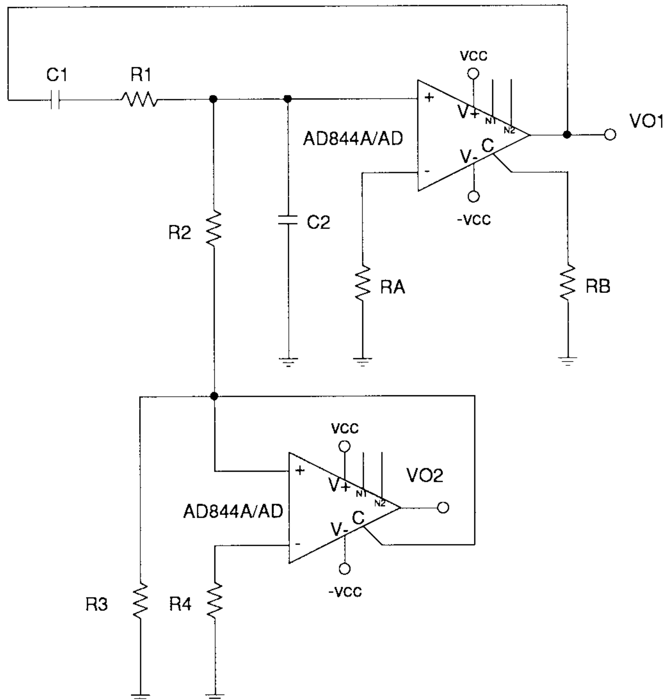


Fig. 2. Wien-bridge oscillator employing the composite resistor of Fig. 1(b).

suitable for extending or reducing the oscillation frequency. Poor sensitivity for reduction results as shown by (2).

For the composite resistor of Fig. 1(b), analysis shows that

$$R_{\text{eq}} = R(1 - n) \tag{6}$$

where $n = R_3R_4/R(R_3 - R_4)$. Similarly, for an oscillator employing this composite and with $R_3 < R_4$, one obtains

$$\Delta\omega = \sqrt{K} \tag{7}$$

where $K = 1/(1 + |n|)$. The oscillation frequency can thus be reduced with a sensitivity of 1/2 as shown by (2).

In order to investigate the applicability of this method, the well-known Wien-bridge oscillator is constructed and modified using the composite resistor of Fig. 1(b). The complete circuit is shown in Fig. 2 implemented using current feedback opamps (CFOA's) of the type AD844. Although CFOA's are often used for high-frequency applications, they can equally well be used for low frequencies. In particular, the benefits of the four-terminal device are clear from Fig. 2 since both resistors R_A and R_B, which are used to provide gain, are grounded. Moreover, the implementation of the active resistor requires a single CFOA, connected to perform as a linear NIC, and a single grounded resistor (R_4). This CFOA is actually employed as a current conveyor (CCII). An additional buffered output voltage (V_{O2}) is also provided. The total modification overhead is thus two additional passive resistors (R_3 and R_4) and a single CFOA. PSPICE simulations representing the two output voltages (V_{O1} and V_{O2}) and the corresponding frequency spectrum are shown in Fig. 3. Simulations were carried out with $R_1 = 10$ KΩ, $R_2 = 100$ Ω, $R_3 = 50$ KΩ,

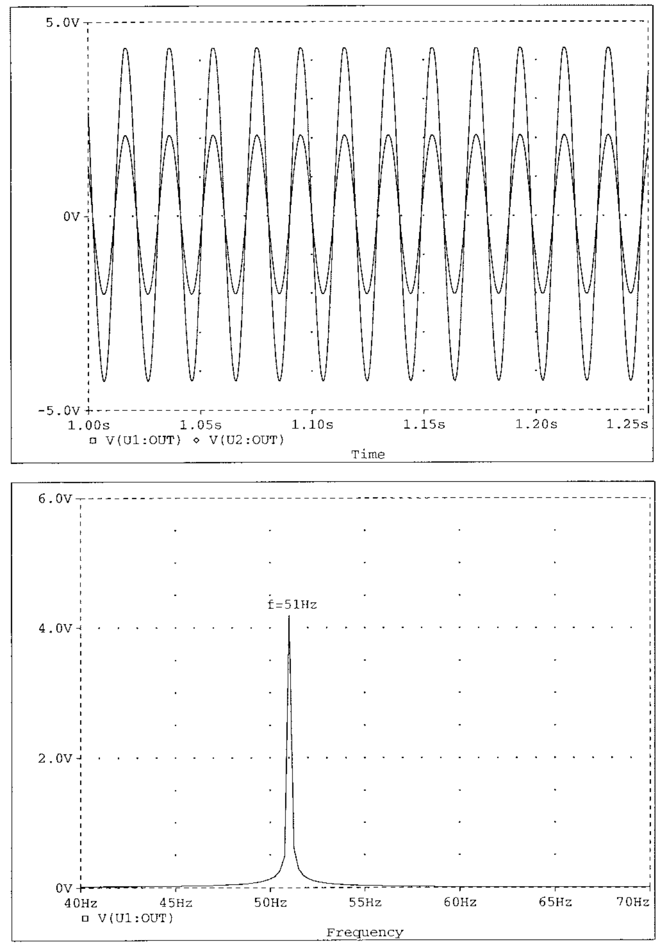


Fig. 3. PSPICE simulations of the oscillator in Fig. 2.

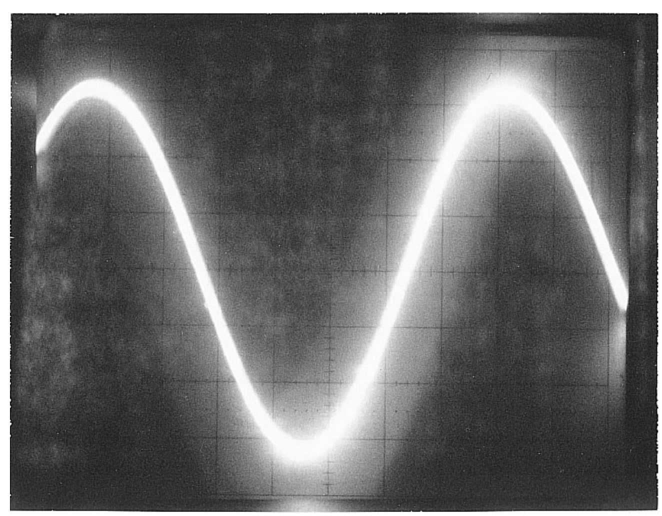


Fig. 4. Experimental waveform obtained from the circuit of Fig. 2. Horizontal axis: 2 ms/div; vertical axis: 0.5 V/div.

$R_4 = 100$ KΩ, $R_A = 1$ KΩ, $R_B = 2.18$ KΩ, $C_1 = C_2 = 100$ nF, and using ±9 V supplies. These values result in $n = -1000$ and hence $\Delta\ \omega \cong 0.032$. The oscillating frequency of the Wien oscillator is thus reduced from 1.592 kHz to approximately 51 Hz. Note that the theoretical gain required for the oscillator after employing the composite resistor is also reduced. For the above values the required gain $(G = R_B/R_A)$ is $G = 2.1$. In order to start oscillations, G was increased to 2.18. It is worth noting that since the composite resistor requires an NIC realization, it is easier to replace a grounded resistor with the composite avoiding the realization of a floating NIC. It is also worth noting that with the same supply voltages used for both CFOA's in Fig. 2, the CFOA employed as an NIC is guaranteed to operate only in the linear region since the gain required for a Wien-bridge oscillator is at least two.

The circuit was experimentally constructed with the same values used for the simulations. The observed waveform is shown in Fig. 4.

III. Conclusion

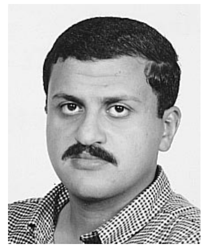
A systematic method for designing low-frequency simple harmonic oscillators was presented. The method requires one passive resistor and one active resistor to modify a harmonic oscillator.

References

[1] G. Wilson, "Insensitive very low frequency RC oscillators," *Electron. Lett.*, vol. 10, pp. 413–439, 1984.

[2] R. Senani, "Novel sinusoidal oscillator employing grounded capacitors," *Electron. Lett.*, vol. 16, pp. 62–69, 1980.

[3] R. Senani and D. R. Bhaskar, "Single op amp sinusoidal oscillators suitable for generation of very low frequencies," *IEEE Trans. Instrum. Meas.*, vol. 40, pp. 777–779, 1991.



Ahmed S. Elwakil was born in Cairo, Egypt, in 1972. He received the B.Sc. and M.Sc. degrees from the Department of Electronics and Communications, Faculty of Engineering, Cairo University, in 1995 and 1997, respectively.

After graduation, he joined the staff at the Egyptian Nuclear Research Center. In 1997, he was offered a Ph.D. scholarship from the National University of Ireland (University College Dublin), where he is currently carrying out research in the area of nonlinear dynamics and chaos generation. He has published several scientific papers reporting novel designs for harmonic as well as chaotic oscillator circuits.