then,

$$a_i + k_2 b_i = C_{2,i}(1 + k_2 b_n), \quad i = 0, 1, \cdots, n - 1 \tag{5}$$

Since a_i are determined from (3), b_i can be obtained from (4) and (5) directly if $n = 1$, or solved approximately by the method of least squares if $n > 1$. Now, the parameters of the transfer function (1) are identified completely.

Compared to the authors' previous work [3], this method does not have the stability problem. And compared to [2], the advantages of this method are that we do not need to know the initial conditions, and it is unnecessary to use an exponential signal for system excitation.

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A Novel Sine-Wave Generator Using a Single Operational Amplifier

AHMED M. SOLIMAN AND SELIM S. AWAD

Abstract—**A new realization of a variable frequency active *RC* oscillator using a single operational amplifier is given. The frequency variation is obtained by controlling a single grounded capacitor in the network.**

Recently Genin [1] gave a new active-*RC* oscillator circuit based on the concept of the frequency-dependent negative conductance [2]. Genin's oscillator uses two operational amplifiers. The purpose of this letter is to propose a novel active-*RC* oscillator circuit which uses only a single operational amplifier.

Fig. 1(a) represents the new oscillator circuit. By direct analysis, the state equations of the circuit is given by

$$\begin{bmatrix} \dot{v}_i \\ \dot{v}_0 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} v_i \\ v_0 \end{bmatrix} \tag{1}$$

where

$$a_{11} = -\frac{1}{2R_1C_0} - \frac{3}{2R_3C_0}, \quad a_{12} = \frac{1}{R_3C_0}$$

$$a_{21} = -\frac{1}{2}\left(1 + \frac{C_1}{C_2}\right)\left(\frac{1}{2R_1C_0} + \frac{3}{2R_3C_0}\right) - \frac{1}{2R_3C_2},$$

$$a_{22} = \frac{1}{2}\left(1 + \frac{C_1}{C_2}\right)\frac{1}{R_3C_0} \tag{2}$$

and for simplicity it is assumed that

$$R_1 = R_2$$
$$R_3 = R_4.$$

The condition for oscillation is given by $a_{11} + a_{22} = 0$ which implies that

$$C_1/C_2 = 2 + R_3/R_1. \tag{3}$$

The frequency of oscillation is given by

$$f_0 = \frac{\sqrt{a_{11}a_{22} - a_{12}a_{21}}}{2\pi}$$

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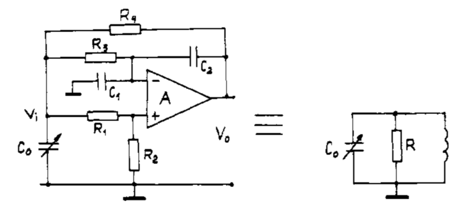

Fig. 1. A single operational amplifier oscillator.

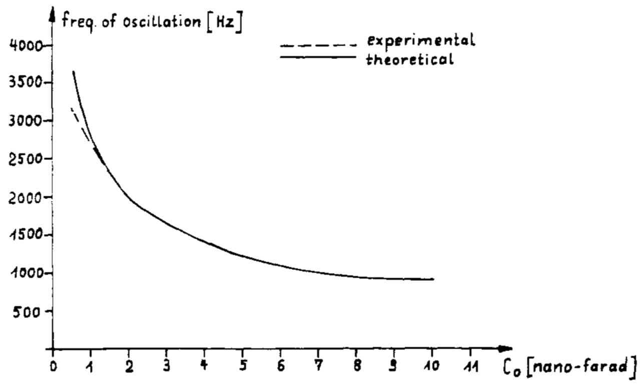

Fig. 2. Oscillation frequency versus C_0.

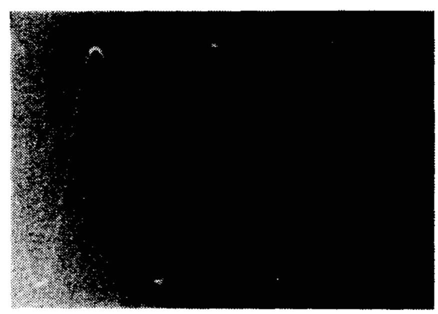

Fig. 3. Typical output waveform at f_0 = 1kHz ($V_{PP} \simeq 25$ V).

which implies that

$$f_0 = \frac{1}{2\pi R_3\sqrt{2C_0C_2}}. \tag{4}$$

The above equations can also be arrived at by obtaining R and L of the equivalent circuit of Fig. 1(b), setting $1/R = 0$ will give (3), and (4) is obtained by substituting the value of L in

$$f_0 = \frac{1}{2\pi\sqrt{LC_0}}$$

Experimental Results

The oscillator of Fig. 1(a) was built in the laboratory using an operational amplifier type LM 741 (National Semiconductor Corp.) with $V_{cc} = \pm 15V$ with the circuit components listed as follows:

$$R_1 = R_2 = 255\ k\Omega$$
$$R_3 = R_4 = 12.5\ k\Omega$$
$$C_1 = 21\ nF, \quad C_2 = 10\ nF.$$

The frequency of oscillation f_0 was varied from 900 Hz to 3 kHz by varying C_0. Fig. 2 represents the experimental results obtained, and the theoretical plotted ones. The distortion of the output sine wave was measured by a distortion-factor meter, and it was found that the distortion is less than 2 percent in the frequency range from 900 Hz to 3 kHz.

Fig. 3 shows the waveform at $f_0 = 1$ kHz. It was noticed that increasing C_1 increases the distortion, and at the same time allows faster growing up of oscillations.

It is noted that due to the fact that the operational amplifier is not ideal, the oscillator requires sophisticated AGC to maintain reasonable distortion levels and amplitude control. Otherwise, amplitude limiting results from amplifier saturation.

ACKNOWLEDGMENT

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Active-*R* Resonator Realization

AHMED M. SOLIMAN AND MAHMOUD FAWZY

***Abstract*—A technique for simulating a series resonator is presented. Then, using only resistors and two internally compensated operational amplifiers, three circuits for realizing an active-*R* series resonator are introduced.**

INTRODUCTION

Active-*R* design using the 6 dB/octave rolloff characteristics of operational amplifiers has recently received considerable attention. The active-*R* synthesis of an impednace is interestingly a new subject which was attacked earlier by Allen and Means [1] who dealt with inductor simulation.

Here, a general procedure for simulating a driving-point impedance is presented. The synthesis of a specific impedance function imposes some restrictions on the network used for the realization.

Consequently, the realization of a series resonator employing only resistors and two operational amplifiers is illustrated by three circuit examples. Each of the proposed circuits resembles a series resonator containing a capacitor, a resistor, and a FDNR element which, according to Bruton [2] transformation, is equivalent to an *LCR* series resonance circuit.

DCR RESONATOR REALIZATION

From Fig. 1(a)

$$Z_{\text{in}} = \frac{V_1}{I_1} \tag{1}$$

$$I_1 = \frac{V_1 - V_2}{R_0} \tag{2}$$

$$\frac{V_2}{V_1} = T(s). \tag{3}$$

From the above equations, it is seen that

$$Z_{\text{in}} = \frac{R_0}{1 - T(s)}. \tag{4}$$

By taking $T(s)$ of the form

$$T(s) = \frac{a_1 s + a_2}{b_0 s^2 + b_1 s + b_2} \tag{5}$$

with

$$b_1 = a_1, b_2 = a_2 \tag{6}$$

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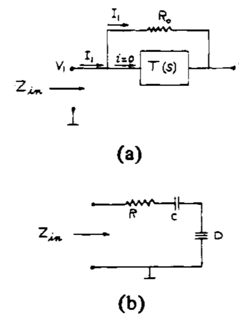

Fig. 1. (a) Basic block for generating a driving point impedance. (b) Series resonator equivalent circuit.

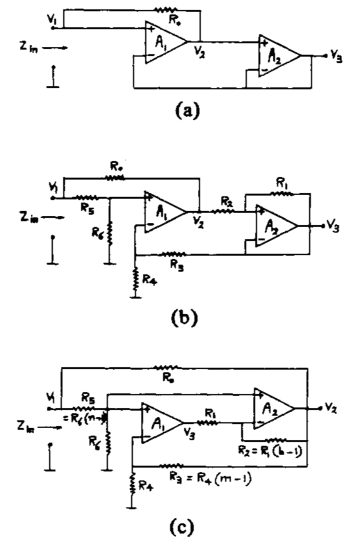

Fig. 2. Active-R series resonators. (a) Circuit 1. (b) Circuit 2. (c) Circuit 3.

and by applying (4), it follows that

$$Z_{\text{in}} = R + \frac{1}{Cs} + \frac{1}{Ds^2} \tag{7}$$

which represents a series *DCR* resonator whose equivalent circuit is shown in Fig. 1(b) with

$$R = R_0, C = \frac{b_0}{a_1 \cdot R_0}, D = \frac{b_0}{a_2 \cdot R_0}. \tag{8}$$

Equation (7) is that of Bruton [2]. With the aid of the equivalent *RLC* series resonance circuit, it can be proved that

$$W_0 = \frac{1}{\sqrt{RD}} \qquad Q = C\sqrt{\frac{R}{D}}. \tag{9}$$

ACTIVE-*R* SERIES RESONATORS

Let

$$A_i = \frac{\text{GB}_i}{s} = \frac{2\pi f_{ci}}{s}, \quad i = 1, 2 \tag{10}$$

where GB is the gain-bandwidth product, or the unity gain crossover radian frequency of the operational amplifier.

By applying the previous equations on the circuits of Fig. 2 the results shown in Table I are obtained. A quick survey of the circuits under consideration reveals that:

1) It is too difficult for circuit 1 to guarantee $A_1 = A_2$ unless both operational amplifiers are integrated on the same chip. Also, for a given GB it is possible to separately specify only one performance factor, namely R or C or D while the other two factors are dependent.

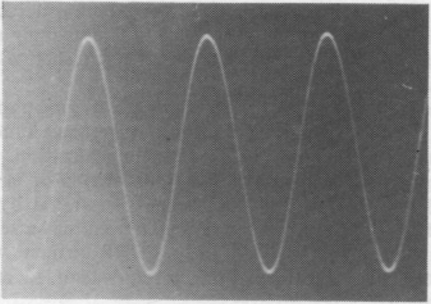

Fig. 3. Typical output waveform at f_0 = 1kHz ($V_{PP} \simeq$ 25 V).