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REALISATION OF FREQUENCY-DEPENDENT NEGATIVE-RESISTANCE CIRCUITS USING TWO CAPACITORS AND A SINGLE CURRENT CONVEYOR

Indexing terms: *Active networks, Negative-resistance resonators, Variable-frequency oscillators*

Abstract

A new canonic active *RC* circuit using the second-generation current conveyor as the active building block is introduced. The circuit can realise an ideal frequency-dependent negative resistance (f.d.n.r.), a lossy f.d.n.r., a parallel resonant circuit incorporating an f.d.n.r., and an oscillator which can be voltage-controlled.

List of symbols

C = capacitance
D = frequency-dependent negative resistance
f = frequency
G = conductance
i = current
Q = quality factor of the resonant circuit
R = resistance
s = complex frequency variable
v = voltage
Y_{in} = input admittance
ω = angular frequency

Introduction

Schmidt and Lee[1] gave a multipurpose simulation network which realises an ideal frequency-dependent negative resistance (f.d.n.r.) using a single operational amplifier. Their realisation* is canonic; i.e. it requires the minimum number of capacitors namely two. Recently, a canonic active *RC* circuit for realising a parallel resonant circuit formed from a resistance, a capacitance and an f.d.n.r. and using a single operational amplifier has been described.[2]

The second-generation current conveyor (CC II) is a grounded 3-port network. The symbol of the positive CC II is shown in Fig. 1 where its instantaneous port relations are given by[3]

$$i_b = 0 \quad v_a = v_b \quad i_c = i_a \tag{1}$$

Several active *RC* networks using CC II as the active element have been described.[4-7] Canonic active *RC* circuits for realising an ideal f.d.n.r. using CC II as the active building block are available.[6] These realisations, however, require three conveyors, two of positive polarity and one of negative polarity.

The purpose of this paper is to introduce a novel canonic active *RC* circuit for realising an ideal f.d.n.r. using only a single CC II. The circuit can also realise a lossy f.d.n.r., comprising an f.d.n.r. in parallel with a capacitor, a parallel-tuned circuit using an f.d.n.r. and an oscillator.

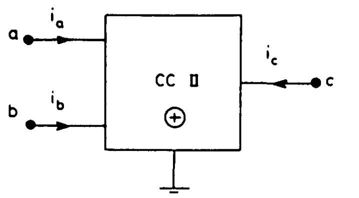

Fig. 1
Symbolic representation of the second-generation current conveyor

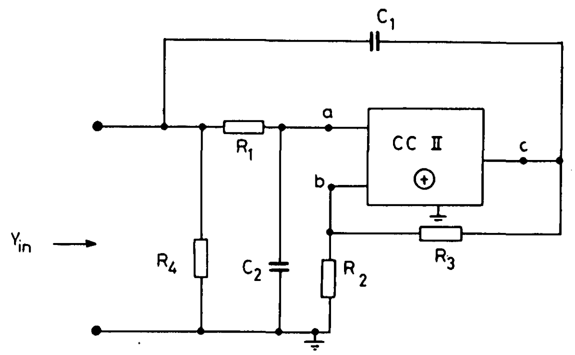

Fig. 2
New canonic circuit realising an ideal f.d.n.r., a lossy f.d.n.r., a parallel-tuned circuit and an oscillator

*The circuit may also realise a parallel resonant circuit formed from a resistance, a capacitance and an f.d.n.r.; however its ω_0 and Q are dependable. The realisation given in Reference 2 has the advantage that the quality factor of the circuit Q can be independently controlled by tuning a single grounded resistor.

Basic configuration

The new canonic circuit is shown in Fig. 2. By direct analysis it can be shown that

$$Y_{in} = \frac{a_1 + b_1 s + d_1 s^2}{a_2 + b_2 s} \tag{2}$$

where

$$a_1 = \frac{R_2 - R_1}{R_4} - 1 \tag{3}$$

$$b_1 = C_2 R_2 \left(1 + \frac{R_1}{R_4}\right) - C_1 R_1 \left(1 + \frac{2R_3}{R_1} + \frac{R_2 + R_3}{R_4}\right) \tag{4}$$

$$d_1 = C_1 C_2 R_1 R_2 \tag{5}$$

$$a_2 = R_2 - R_1 \tag{6}$$

$$b_2 = R_1 [C_2 R_2 - C_1 (R_2 + R_3)] \tag{7}$$

It will be shown that the network is capable of realising an ideal f.d.n.r. $[Y_{in} = d_1 s^2/a_2]$, a lossy f.d.n.r. $[Y_{in} = (b_1 s + d_1 s^2)/a_2]$, a parallel-tuned circuit $[Y_{in} = (a_1 + b_1 s + d_1 s^2)/a_2]$, and an oscillator $[Y_{in} = (a_1 + d_1 s^2)/a_2]$. For all realisations we require $b_2 = 0$; hence,

$$C_2 = C_1 \left(1 + \frac{R_3}{R_2}\right) \tag{8}$$

Ideal f.d.n.r.

When the coefficients a_1 and b_1 are set to zero the circuit realises an ideal f.d.n.r. The design equations are

$$R_1 = R_3 = R_4 \quad R_2 = 2R_1 \quad C_2 = 1{\cdot}5 C_1 \tag{9}$$

and in this case the f.d.n.r. is given by

$$D = 3C_1^2 R_1 \tag{10}$$

Lossy f.d.n.r.

When the coefficient a_1 is set to zero the circuit realises a lossy f.d.n.r., formed from a capacitance C in parallel with the f.d.n.r. element D.

From eqn. 3 and for $a_1 = 0$ hence

$$R_2 = R_1 + R_4 \tag{11}$$

The magnitudes of D and C are given in Table 1.

Parallel-tuned circuit

A parallel-tuned circuit composed of an f.d.n.r. D in parallel with a capacitance C and a conductance G is realisable from the given circuit. The realisability conditions are given in Table 1. The ω_0 and the Q of the resonant circuit are given by

$$\omega_0 = \frac{1}{C_1}\left\{\frac{R_2 - (R_1 + R_4)}{R_1 R_4 (R_2 + R_3)}\right\}^{1/2} \tag{12}$$

$$Q = \frac{1}{R_2 - (R_1 + R_3)}\left\{\frac{R_1 (R_2 + R_3)[R_2 - (R_1 + R_4)]}{R_4}\right\}^{1/2} \tag{13}$$

It is clear from eqns. 12 and 13 that ω_0 is controlled by the capacitor C_1 without affecting Q of the resonant circuit.

Oscillator

When the coefficient b_1 is set to zero the network realises a

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Table 1
SUMMARY OF REALISABILITY CONDITIONS AND EQUIVALENT-CIRCUIT PARAMETERS OF THE CIRCUIT IN FIG. 2

Realisable input admittance		Ideal f.d.n.r.	Lossy f.d.n.r.	Parallel-tuned circuit	Oscillator
Realisability		$C_2 = C_1\left(1+\frac{R_3}{R_2}\right)$	$C_2 = C_1\left(1+\frac{R_3}{R_2}\right)$	$C_2 = C_1\left(1+\frac{R_3}{R_2}\right)$	$C_2 = C_1\left(1+\frac{R_3}{R_2}\right)$
conditions		$R_2 = R_1 + R_3$	$R_2 = R_1 + R_4$	$R_2 > R_1 + R_3$	$R_2 = R_1 + R_3$
		$R_4 = R_3$	$R_4 > R_3$	$R_2 > R_1 + R_4$	$R_4 < R_3$
Equivalent-	f.d.n.r. D	$C_1^2 R_1\left(2+\frac{R_1}{R_3}\right)$	$C_1^2 R_1\left(\frac{R_1+R_3+R_4}{R_4}\right)$	$C_1^2 R_1\left(\frac{R_2+R_3}{R_2-R_1}\right)$	$C_1^2 R_1\left(2+\frac{R_1}{R_3}\right)$
circuit	capacitance C	0	$C_1\left(\frac{R_4-R_3}{R_4}\right)$	$C_1\left(\frac{R_2-(R_1+R_3)}{R_2-R_1}\right)$	0
parameters	conductance G	0	0	$\frac{1}{R_4}-\left(\frac{1}{R_2-R_1}\right)$	$\left(\frac{1}{R_4}-\frac{1}{R_3}\right)$

sinusoidal oscillator. The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi C_1}\sqrt{\left\{\frac{\frac{1}{R_4}-\frac{1}{R_3}}{R_1\left(2+\frac{R_1}{R_3}\right)}\right\}} \qquad (14)$$

It is seen that the grounded resistor R_4 controls the oscillation frequency without affecting the oscillation conditions as seen from Table 1.

The design equations for this oscillator are

$$R_1 = R_3, \quad R_2 = 2R_1, \quad R_1 > R_4 \quad C_2 = 1{\cdot}5C_1 \qquad (15)$$

and in this case the oscillation frequency reduces to

$$f_0 = \frac{1}{2\pi C_1 R_1}\sqrt{\left\{\frac{1}{3}\left(\frac{R_1}{R_4}-1\right)\right\}} \qquad (16)$$

Since the resistor R_4 can be realised by an f.e.t. working in the range below pinchoff,[8] the circuit is seen to provide a voltage-controlled oscillator.

Conclusions

A new canonic active *RC* circuit for realising an ideal f.d.n.r., a lossy f.d.n.r., a parallel resonant circuit and a voltage-controlled oscillator is described. The active building block used is the second-generation current conveyor. Table 1 summarises the results for these cases. It is noted that with the introduction of this new circuit several realisations of active *RC* filters may be obtained using Bruton's transformation[9] and element-replacement technique.[2]

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SPTC132 E

RAPID ESTIMATION OF SPECTRA FROM IRREGULARLY SAMPLED RECORDS

Dr. Roberts and Dr. Gaster (*Proc. IEE*, 1978, 125, (2), pp. 92–96) in Paper 8032 E report on a technique for spectral analysis using rectangular waves instead of sine and cosine waves. An estimate of power was formed from rectangular waves, and an approximate relationship between this power and the conventional Fourier power was derived. Using this approximation, the Fourier power was calculated.

A similar technique has been used by Clarke,[A] which avoids this approximation. In essence, 'rectangular' sine and cosine coefficients $\{\ulcorner s_n \urcorner : n = 1, \ldots, N\}$ and $\{\ulcorner c_n \urcorner : n = 1, \ldots, N\}$ were calculated using

$$\ulcorner s_n \urcorner = \frac{1}{T}\int_{-T}^{T} f(t)\,\mathrm{sgn}\,\{\sin(n\pi t/T)\}dt \qquad (A)$$

$$\ulcorner c_n \urcorner = \frac{1}{T}\int_{-T}^{T} f(t)\,\mathrm{sgn}\,\{\cos(n\pi t/T)\}dt \qquad (B)$$

where $f(t)$ is the waveform to be analysed.

For a band-limited waveform $f(t)$, these 'rectangular' coefficients are related to the Fourier sine and cosine coefficients by

$$\ulcorner s \urcorner = Gs \qquad (C)$$

$$\ulcorner c \urcorner = Hc \qquad (D)$$

where

$s = \{s_n\}^T$ is the vector of Fourier sine coefficients

$c = \{c_n\}^T$ is the vector of Fourier cosine coefficients

$\ulcorner s \urcorner = \{\ulcorner s_n \urcorner\}^T$

$\ulcorner c \urcorner = \{\ulcorner c_n \urcorner\}^T$

$$G = [g_{ij}] = [\delta(2m-1, j/i)\, i/j], \qquad (E)$$

$$H = [h_{ij}] = [(-1)^{m+1}\delta(2m-1, j/i)\, i/j], \qquad (F)$$

m is any positive integer. G and H are sparse upper-triangular matrices.

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