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Active Phase Compensation of Op Amp VCCS Structures

AHMED M. SOLIMAN

***Abstract*—A generalized active compensated three-port voltage controlled current source (VCCS) is proposed. The compensation is affected by adding to the uncompensated VCCS another op amp and two resistors. The compensated VCCS (which may be used as an inverting or a noninverting VCCS) has a negligible phase error and an improved bandwidth.**

I. Introduction

Recently, an active compensation method for the finite unity gain bandwidth of op amps when used in voltage-controlled voltage-source (VCVS) structures has been reported [1].

The three-port voltage-controlled current-source (VCCS) shown in Fig. 1 has been introduced in the literature [2] as a generalization of the well-known inverting VCCS [3]-[4]. This generalized three-port VCCS can be used as an inverting VCCS by shorting port 2 to ground or as a noninverting VCCS by shorting port 1 to ground.

The purpose of this contribution is to demonstrate the applicability of the recently described method of phase compensation [1] to the VCCS structures.

II. The Uncompensated VCCS

First a brief analysis of the effect of the finite unity gain bandwidth ω_t of the op amp on the performance of the VCCS is given. Let the open loop gain of the op amp be represented by the single pole model; thus

$$A(s) \simeq \frac{\omega_t}{s}. \tag{1}$$

By direct analysis to the circuit in Fig. 1, the load current is given by

$$I_L = -\frac{V_1}{R}\epsilon_1(s) + \frac{V_2}{R}\epsilon_2(s) \tag{2}$$

where

$$\epsilon_1(s) = \frac{1}{1 + (2/\omega_t)(1+x)s} \tag{3}$$

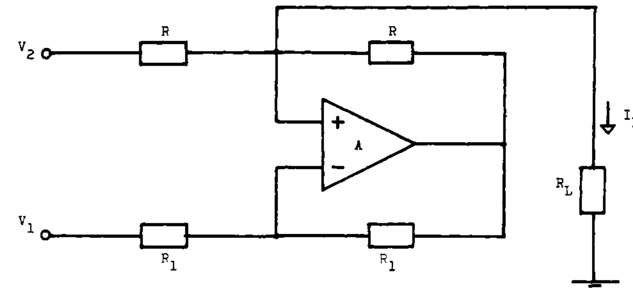

Fig. 1. The generalized uncompensated VCCS.

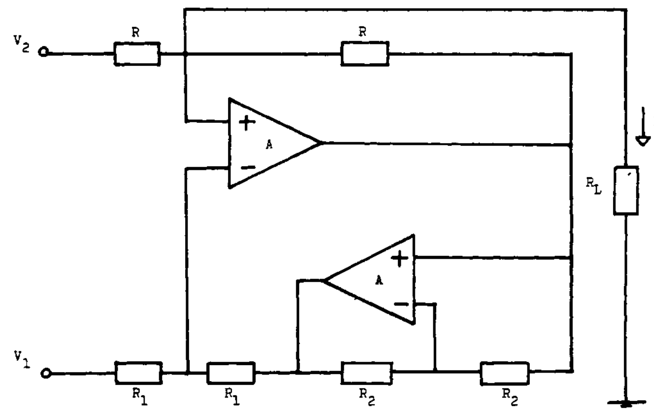

Fig. 2. The new generalized active compensated VCCS, using low cost dual op amps.

$$\epsilon_2(s) = \frac{1 + (2/\omega_t)s}{1 + (2/\omega_t)(1+x)s} \tag{4}$$

and

$$x = \frac{2R_L}{R}. \tag{5}$$

$\epsilon_1(s)$ and $\epsilon_2(s)$ are the inverting and noninverting error functions contributed by the finite ω_t of the op amp. Ideally these error functions must have a unity magnitude and a zero phase. From (3), however, it is seen that the phase error and the magnitude error of the inverting VCCS are given by

$$\left.\begin{aligned}\phi_1 &\equiv \arg \epsilon_1(j\omega) \simeq -\left(\frac{2\omega}{\omega_t}\right)(1+x)\\ \gamma_1 &\equiv |\epsilon_1(j\omega)| - 1 \simeq -2\left(\frac{\omega}{\omega_t}\right)^2(1+x)^2\end{aligned}\right\}\ \frac{2\omega}{\omega_t} << 1. \tag{6}$$

Similarly from (4) for the noninverting VCCS it is seen that

$$\left.\begin{aligned}\phi_2 &\equiv \arg \epsilon_2(j\omega) \simeq -\left(\frac{2\omega}{\omega_t}\right)x\\ \gamma_2 &\equiv |\epsilon_2(j\omega)| - 1 \simeq -2\left(\frac{\omega}{\omega_t}\right)^2[(1+x)^2 - 1]\end{aligned}\right\}\ \frac{2\omega}{\omega_t} << 1. \tag{7}$$

The above expressions indicate that the magnitude error is a second-order term, whereas the phase error is of a first-order magnitude. Thus the VCCS structures require only phase compensation.

III. The Active Compensated VCCS

The modern low cost matched op amp integrated circuits which are currently available in dual packages are used here for active phase compensation of the VCCS structures. Fig. 2 represents the new active

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phase compensated VCCS. For this universal active compensated three-port VCCS and assuming matched op amps are used, the load current is given by

$$I_L = -\frac{V_1}{R}\,\epsilon_{1C}(s) + \frac{V_2}{R}\,\epsilon_{2C}(s). \tag{8}$$

$\epsilon_{1C}(s)$ and $\epsilon_{2C}(s)$ are the compensated error functions of the inverting and noninverting VCCS's, respectively, and are given by

$$\epsilon_{1C}(s) = \frac{1 + (2/\omega_t)\,s}{1 + (2/\omega_t)\,s + (4/\omega_t^2)\,(1+x)\,s^2} \tag{9}$$

$$\epsilon_{2C}(s) = \frac{1 + (2/\omega_t)\,s + (4/\omega_t^2)\,s^2}{1 + (2/\omega_t)\,s + (4/\omega_t^2)\,(1+x)\,s^2}. \tag{10}$$

The Compensated Inverting VCCS: From (9) the phase and the magnitude errors of the compensated inverting VCCS are given by

$$\left.\begin{aligned}\phi_{1C} &\simeq -\left(\frac{2\omega}{\omega_t}\right)^3 (1+x)\\ \gamma_{1C} &\simeq \left(\frac{2\omega}{\omega_t}\right)^2 (1+x)\end{aligned}\right\}\ \frac{2\omega}{\omega_t} << 1. \tag{11}$$

Comparing (6) and (11) it is seen that the phase error is reduced to a negligible level. The magnitude error however remains as a second-order term.

The bandwidth (the half-power frequency in rad/s) of this compensated inverting VCCS is obtained from (9) as

$$BW_{1C} = \omega_t\,\frac{\sqrt{(3/2+x) + \sqrt{(5/4+x) + 2(1+x)^2}}}{2(1+x)}. \tag{12}$$

Thus the improvement in the bandwidth is given by

$$(BW_{1C}/BW_1) = \sqrt{(3/2+x) + \sqrt{(5/4+x) + 2(1+x)^2}} \tag{13}$$

which is a function of the normalized load resistance x. As an example for $x = 1$, the bandwidth improvement = 2.39.

The Compensated Noninverting VCCS: Similarly from (10) the phase and the magnitude errors of the noninverting VCCS are obtained and the results are summarized in Table I. The bandwidth of this compensated noninverting VCCS is given by

$$BW_{2C} = \frac{\omega_t}{2}\sqrt{\frac{(x-1/2) + \sqrt{(x-1/2)^2 + [(1+x)^2 - 2]}}{(1+x)^2 - 2}},\quad (x > \sqrt{2} - 1). \tag{14}$$

Thus the improvement in the bandwidth is given by

$$(BW_{2C}/BW_2) = \sqrt{(x-1/2) + \sqrt{(x-1/2)^2 + [(1+x)^2 - 2]}},\quad (x > \sqrt{2} - 1). \tag{15}$$

It is clear that as the normalized load resistance x is increased improvement in the bandwidth is achieved. As an example for $x = 1$, the bandwidth improvement is 1.414 and for $x = 2$ the improvement is 2.13.

IV. Conclusions

A new active phase compensated generalized VCCS is given. The compensation is achieved by adding to the uncompensated VCCS an active building block consisting of another op amp (having matched characteristics to the original op amp) and two resistors [1]. The identical op amps are currently available in dual packages at low cost. It is worth noting that although the resistors R, R_1, and R_2 may be different, it is recommended to use equal resistors in order to limit the spread in the resistor values. It is clear that the compensation applies directly to the external characteristic of the circuit rather than (as a stabilization type of compensation) to the loop gain characteristics of the amplifier. Table I demonstrates the improvement achieved for both inverting and noninverting VCCS structures.

TABLE I
THE APPROXIMATE PHASE AND MAGNITUDE ERRORS OF THE UNCOMPENSATED AND THE COMPENSATED VCCS'S WHERE, $x = 2R_L/R$, $2\omega/\omega_t << 1$

VCCS Network Type	Approximate Phase Error Φ	Approximate Magnitude Error γ
The Uncompensated Inverting VCCS.	$-2\left(\frac{\omega}{\omega_t}\right)(1+x)$	$-2\left(\frac{\omega}{\omega_t}\right)^2(1+x)^2$
The Compensated Inverting VCCS.	$-\left(\frac{2\omega}{\omega_t}\right)^3(1+x)$	$\left(\frac{2\omega}{\omega_t}\right)^2(1+x)$
The Uncompensated Noninverting VCCS.	$-2\left(\frac{\omega}{\omega_t}\right)x$	$-2\left(\frac{\omega}{\omega_t}\right)^2[(1+x)^2-1]$
The Compensated Noninverting VCCS.	$-\left(\frac{2\omega}{\omega_t}\right)^3 x$	$\left(\frac{2\omega}{\omega_t}\right)^2 x$

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Comments on "A New Continuously Tunable Sinusoidal Oscillator Without External Capacitors"

S. VENKATESWARAN AND Y. VENKATARAMANI

***Abstract*—Bhattacharyya and Natarajan have established the condition for oscillation of a three operational amplifier (OA) active-*R* oscillator. This letter shows that the integrator model used by them is incorrect. Analysis, based on single pole model, indicates the absence of oscillations. However, conditions for oscillations exist when a two pole model of the OA's is taken.**

Introduction

Bhattacharyya and Natarajan have proposed a new continuously tunable sinusoidal oscillator [1], without external capacitors, that employs three operational amplifiers (OA's). Their analysis is based on the integrator model for the OA's; it establishes a pair of poles on the $j\omega$ axis. They have provided experimental results over a limited frequency range.

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