LETTERS TO THE EDITOR

A NOVEL PASSIVE COMPENSATED INVERTING WEIGHTED SUMMER

AHMED M. SOLIMAN*
San Francisco State University, San Francisco, California 94132, U.S.A.

AND

MOHAMMED ISMAIL
Arab Organization for Industrialization, Cairo, Egypt

It is well known that the finite and complex open loop gain nature of the op-amp degrades significantly the performance of the inverting voltage controlled voltage sources (VCVS) employing them.[1–3] Wilson[2] has proposed a passive compensation method for the inverting VCVS using two compensating capacitors. Recently[3] it has been found that the addition of only one compensating capacitor instead of two results in less phase and magnitude errors than in Wilson's compensation.[2] The compensation of an m input inverting weighted summer using the recently proposed method by the authors[3] requires m capacitors.

The purpose of this contribution is to introduce a novel passive compensation method for the inverting weighted summer which requires only a single capacitor, regardless of the number of input ports. Moreover, the new compensation circuit has smaller phase and magnitude errors than those obtained using other passive compensation methods.

Figure 1 represents the new passive compensated inverting weighted summer. Compensation is achieved here by using two passive circuit components, a capacitor C and a resistor r. Let the open loop gain of the op-amp be represented in the form

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

where ω_t is the unity gain bandwidth of the op-amp. By direct analysis of the circuit in Figure 1, the output voltage V_o is obtained as

$$V_o = -R_f\left[\sum_{i=1}^{m} \frac{V_{1i}}{R_i}\right]\varepsilon(s) \tag{2}$$

where

$$\varepsilon(s) = \frac{1+sCr}{1+s(\tau-KCr)+s^2\tau Cr} \tag{3}$$

$$K = R_f\left[\sum_{i=1}^{m} \frac{1}{R_i}\right] \tag{4}$$

$$\tau = \frac{(K+1)}{\omega_t} \tag{5}$$

$\varepsilon(s)$ is the remaining error function of the compensated circuit.

---

* Now with the Department of Electrical Engineering, Florida Atlantic University, Boca Raton, FlA. 33431, U.S.A.

0098–9886/80/0108–0081$01.00

Received 15 November 1978
Revised 24 July 1979

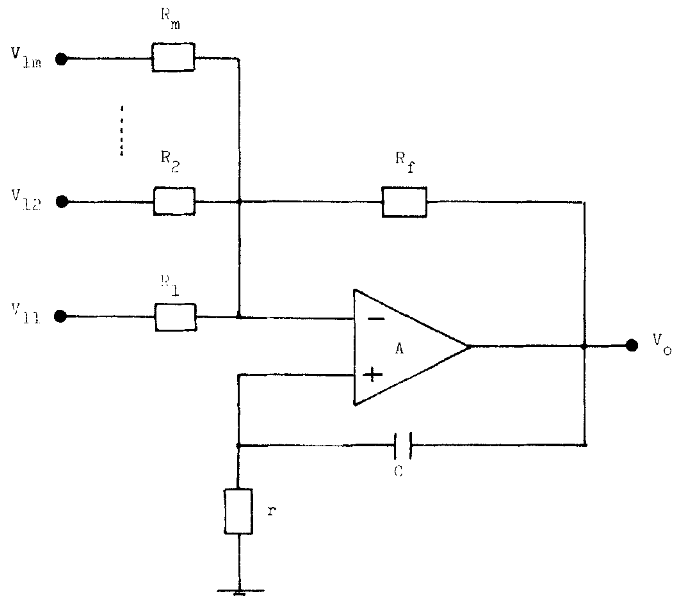

Figure 1. The proposed passive compensated inverting weighted summer

From equation (3) it is seen that in order to reduce the phase error to a negligible level, the time constant Cr should be chosen such that

$$Cr = \frac{\tau}{(K+1)} = \frac{1}{\omega_t} \tag{6}$$

In this case the error function becomes

$$\varepsilon_I(s) = \frac{1 + s\tau_I}{1 + s\tau_I + s^2\tau\tau_I} \tag{7}$$

where

$$\tau_I = \frac{1}{\omega_t} \tag{8}$$

$\varepsilon_I(s)$ is the remaining error function of the phase compensated inverting structure. Its phase and magnitude are expressed as

$$\left.\begin{aligned} \arg[\varepsilon_I(j\omega)] &\simeq -\omega^3\tau\tau_I^2 \\ |\varepsilon_I(j\omega)| &\simeq 1 + \omega^2\tau\tau_I \end{aligned}\right\} \omega\tau \ll 1 \tag{9}$$

From the above expressions it is seen that the phase error is equal to $-(\omega/\omega_t)^3(K+1)$ and the magnitude error is equal to $(\omega/\omega_t)^2(K+1)$. These errors are smaller than the errors obtained using other passive compensation methods,[2-3] as seen from Table I.

As a matter of fact the useful extended frequency range obtained using this new structure is comparatively dependent on the realized parameter K and the ω_t of the used op-amp. To clarify this dependence a set of calculated curves for the phase and the magnitude of $\varepsilon_I(s)$ plotted versus (ω/ω_t) with K taken as a parameter are shown in Figure 2. It is seen that the useful frequency range is reduced as K takes higher values. It is also noted that outside the frequency range of interest $\varepsilon_I(s)$ has a bandpass response with a quality factor of $\sqrt{(K+1)}$.

Table 1. Approximate phase and magnitude errors obtained using different methods of passive compensation for the inverting VCVS, where $\tau = (K+1)/\omega_t$, $\tau_S = K/\omega_t$, $\tau_I = 1/\omega_t$ and $\omega\tau \ll 1$

	Condition for phase compensation	Error function $\varepsilon(s)$	Approximate phase error	Approximate magnitude error
The uncompensated inverting VCVS		$\varepsilon_0(s) = \dfrac{1}{1+s\tau}$	$-\omega\tau$	$-\frac{1}{2}\omega^2\tau^2$
Wilson's[2] compensated VCVS	$CR = \tau$	$\varepsilon_W(s) = \dfrac{1+s\tau}{1+s\tau+s^2\tau^2}$	$-\omega^3\tau^3$	$\omega^2\tau^2$
Soliman–Ismail[3] compensated VCVS	$CR = \tau$	$\varepsilon_S(s) = \dfrac{1+s\tau}{1+s\tau+s^2\tau\tau_S}$	$-\left[\dfrac{K}{K+1}\right]\omega^3\tau^3$	$\left[\dfrac{K}{K+1}\right]\cdot\omega^2\tau^2$
New proposed compensated VCVS	$Cr = \tau_I$	$\varepsilon_I(s) = \dfrac{1+s\tau_I}{1+s\tau_I+s^2\tau\tau_I}$	$-\dfrac{1}{(K+1)^2}\cdot\omega^3\tau^3$	$\dfrac{1}{(K+1)}\cdot\omega^2\tau^2$

A phase compensated inverting VCVS can be obtained as a special case from the circuit in Figure 1 by taking $R_2, R_3, \ldots,$ and R_m as open circuited. In this case the resulting transfer function is

$$\frac{V_o}{V_{11}} = -K\varepsilon_I(s) \tag{10}$$

where $K = R_f/R_1$ is the ideal gain factor.

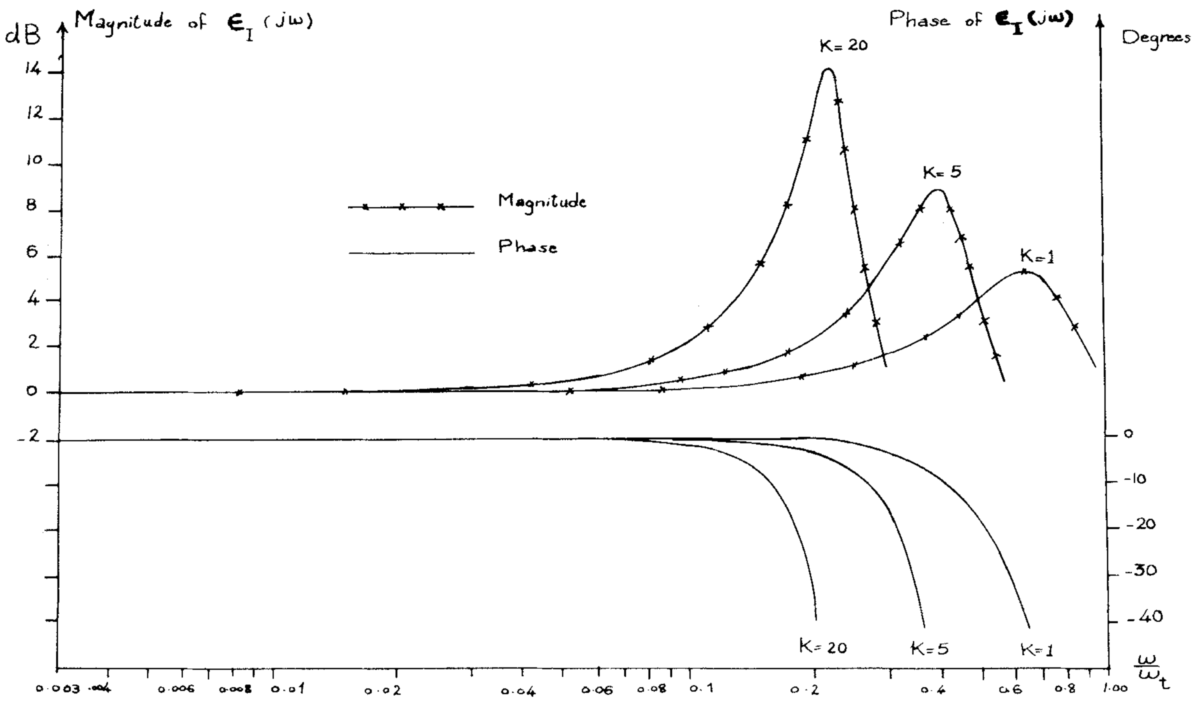

Figure 2. Magnitude and phase of $\varepsilon_I(s)$ versus (ω/ω_t) with K taken as a parameter

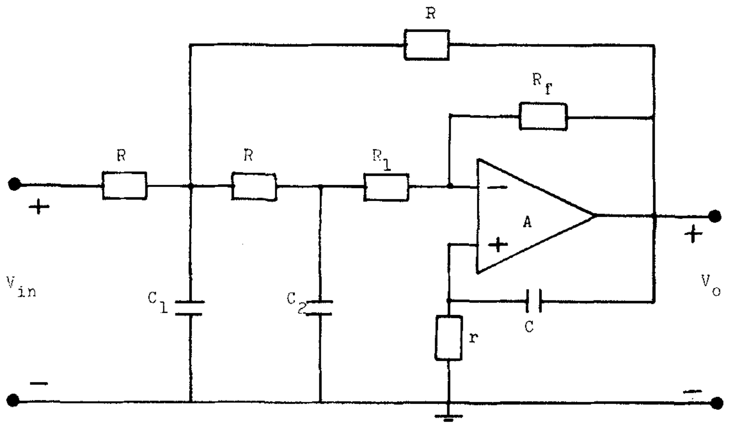

Figure 3. The improved Sallen–Key lowpass filter using the compensated inverting VCVS

As an application of the proposed passive phase compensated inverting VCVS, consider the well-known Sallen–Key second-order lowpass filter[4] which employs a single op-amp arranged to realize an inverting VCVS. The filter has been built in the laboratory (designed for a pole Q of 1·562 and a natural frequency f_0 of 6·983 kHz). First the magnitude frequency response of the filter with the ordinary uncompensated inverting VCVS has been measured. Then the magnitude frequency response of the filter with the compensated inverting VCVS as shown in Figure 3 has also been measured. Figure 4 shows plots for the uncompensated, the compensated and the theoretical responses. Close agreement is clearly observed between the compensated and the theoretical responses. On the other hand, the uncompensated response is entirely shifted from the theoretical one.

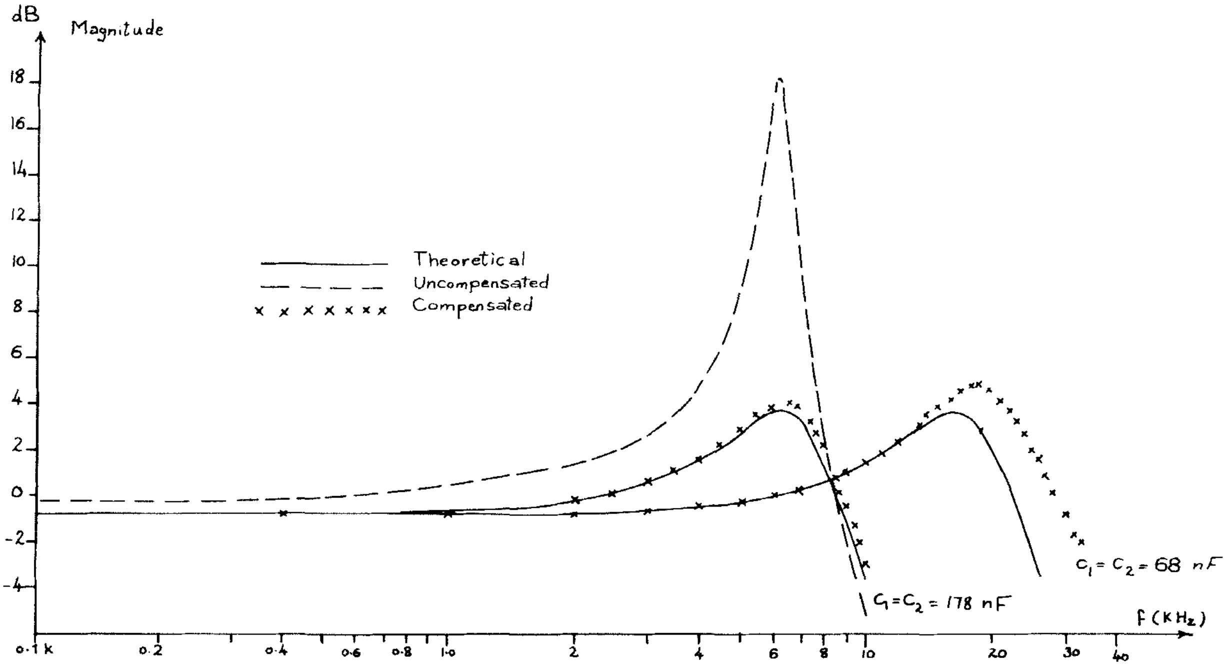

Figure 4. Magnitude vs. frequency response of the uncompensated and the compensated Sallen–Key lowpass filters

For carrying out the experiment above, the following components have been used:

± 15 V op-amp type ML 741 having a measured unity gain bandwidth of $f_t = 700$ kHz, $R_f = 56$ kΩ, $R = R_1 = 1$ kΩ, $C_1 = C_2 = 178$ nF.

The compensating components used are $r = 68$ Ω and $C = 3{\cdot}3$ nF.

Five per cent capacitors and precise resistors have been used. Thus the errors due to passive component tolerances are quite small.

The experiment has been repeated with the filter designed at a higher value of natural frequency $f_0 = 18{\cdot}279$ kHz by using a value of $C_1 = C_2 = 68$ nF. Figure 4 shows plots for the compensated and the theoretical responses. In this case it has been observed experimentally that the filter with the ordinary uncompensated VCVS introduces oscillations with large amplitudes at a frequency near f_0.

It is worth noting that the above design is directed towards the compensation of the phase error (which is of a first-order magnitude equal to $-\omega\tau$ for the uncompensated VCVS). The compensated structure proposed, however, is very general and may realize different responses by proper choice of the time constant Cr. For example a maximally flat magnitude response may be obtained by choosing

$$Cr = \frac{\tau}{(K-1)}\left\{1 + \sqrt{\left[\frac{2}{(K+1)}\right]}\right\}, \qquad K > 1 \tag{11}$$

REFERENCES

1. A. Budak, *Passive and Active Network Analysis and Synthesis*, 211–218, Houghton Mifflin, Boston, 1974.
2. G. Wilson, 'Compensation of some operational amplifier based RC active networks', *IEEE Trans. Cir. Syst.*, **CAS-23**, 443–446 (1976).
3. A. M. Soliman and M. Ismail, 'Passive compensation of op-amp VCVS and weighted summer building blocks', *IEEE Trans. Cir. Syst.* (to be published).
4. R. P. Sallen and E. L. Key, 'A practical method of designing RC active filters', *IRE Trans. Cir. Theor.*, **CT-2**, 74–85 (1955).

TRANSFER FUNCTION DETERMINATION FROM IMPULSE RESPONSE *VIA* WALSH FUNCTIONS

P. N. PARASKEVOPOULOS

Chair of Automatic Control Systems, School of Engineering, Democritus University of Thrace, Xanthi, Greece

AND

S. J. VAROUFAKIS

Computer Department, Nuclear Research Center 'Democritos', Athens, Greece

SUMMARY

This paper presents a new method for calculating a rational transfer function matrix using a Walsh expansion of the impulse response matrix. The algorithm proposed appears to be computationally convenient owing to certain properties of the Walsh functions. An example is given to illustrate the method.

INTRODUCTION

One particular form of the problem of determining a mathematical model of a system is one in which the information given about the system is its impulse response curve and the mathematical model sought is its transfer function. This problem has been considered in the past by Kukk[1] for single-input single-output systems using Laguerre series.

Received 19 September 1978 Revised 19 July 1979