CAS LETTERS

Active Compensated Summers Without Matched Operational Amplifiers

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Abstract—**Two novel active phase compensated weighted summers are presented. The proposed summers have the advantage of a phase compensation condition which does not depend on the gain bandwidth of the two operational amplifiers employed in the circuit; thus, it is not necessary to use matched operational amplifiers for realizing the summer circuits. A stability analysis based on the two pole model of the operational amplifier is given.**

INTRODUCTION

It is well known that the finite and complex open loop gain nature of the operational amplifier (opamp) degrades the magnitude and phase of conventional weighted summer structures. It has been shown that, for low frequencies, the magnitude error is a second order term and the phase error is a first order term [1]. In other words, the single opamp weighted summer structures require mainly phase compensation. Recently, a few active phase compensated weighted summers have been introduced in the literature [1–3]. In these circuits, the phase compensation condition depends on the gain bandwidth of the two opamps employed in the circuit.

The first summer presented in this paper has multiport inverting inputs and a single noninverting input; the second summer has multiport noninverting inputs and one inverting input. Design equations and stability analysis based on the two pole model of the opamp are given.

THE FIRST SUMMER

A new active compensated summer with multiport inverting inputs and a single noninverting input is shown in Fig. 1. The voltages $V_{11}, V_{12}, \cdots, V_{1n}$ represent the n inverting inputs and V_2 represents the noninverting input. By direct analysis of the circuit, the generalized expression for the output voltage V_o is given by

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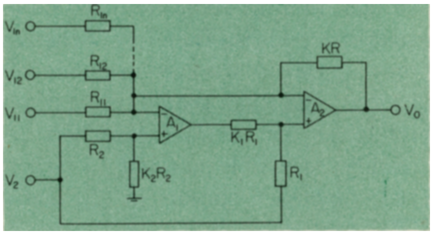

Fig. 1. A generalized actively compensated amplifier with one noninverting input and multiport inverting inputs.

$$V_o = \frac{\left[\sum_{i=1}^{n} V_{1i}G_{1i}\right]\left[-\frac{K}{G}\right]\left[1+\frac{K_1+1}{A_1}\right] + V_2\left[\frac{K_2(K+1)}{(K_2+1)}\right]\left[1+\frac{K_1(K_2+1)}{K_2A_1}\right]}{1+\frac{(K_1+1)}{A_1}+\frac{(K+1)(K_1+1)}{A_1A_2}} \tag{1}$$

where

$$G = \frac{1}{R} = \sum_{i=1}^{n} G_{1i} \tag{2}$$

and

$$G_{1i} = \frac{1}{R_{1i}} \qquad (i=1, 2, \cdots, n). \tag{3}$$

From (1), it is seen that the parameter K controls the gain of the summer, parameter K_1 controls the stability of the circuit, and K_2 controls the mode of operation. A necessary condition for the differential mode of operation is given by

$$K_2 = K_1. \tag{4}$$

In this case, (1) reduces to

$$V_o = \left\{\left[\sum_{i=1}^{n} V_{1i}G_{1i}\right]\left[\frac{-K}{G}\right] + V_2\frac{K_1(K+1)}{(K_1+1)}\right\}\cdot \epsilon_1 \tag{5}$$

where

$$\epsilon_1 = \frac{1+\frac{(K_1+1)}{A_1}}{1+\frac{(K_1+1)}{A_1}+\frac{(K+1)(K_1+1)}{A_1A_2}}. \tag{6}$$

ϵ_1 is the error function of the compensated circuit.

Representing the open loop gain A of each of the two opamps is the single pole model given by

$$A_i(s) = \frac{\omega_{ti}}{s} \qquad (i=1, 2) \tag{7}$$

where ω_t is the unity gain bandwidth of the opamp. The compensated error function becomes

$$\epsilon_1(s) = \left[1+(K_1+1)\frac{s}{\omega_{t1}}\right]\left[1+(K_1+1)\frac{s}{\omega_{t1}}+(K+1)(K_1+1)\frac{s^2}{\omega_{t1}\omega_{t2}}\right]^{-1} \tag{8}$$

It is seen from the above equation that the phase compensation condition is independent of the unity gain bandwidth of the opamps used and it is not necessary to use matched opamps with this weighted summer.

From (8), the remaining phase and magnitude errors are given by

$$\phi \equiv arg\, \epsilon_1(j\omega) \simeq -\frac{(K+1)(K_1+1)^2\omega^3}{\omega_{t1}{}^2\omega_{t2}}$$

$$\gamma \equiv |\epsilon_1(j\omega)| - 1 \simeq \frac{(K+1)(K_1+1)\omega^2}{\omega_{t1}\omega_{t2}}$$

where

$$\omega \ll \frac{\omega_{t1}}{(K_1+1)}, \quad \omega \ll \frac{\omega_{t2}}{(K+1)}. \tag{9}$$

In order to choose a proper design value for K_1, consider the error function as given by (6), using the two pole

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model of the opamp given in [4]:

$$A(s) \simeq \frac{\omega_t}{s\left(1+\dfrac{s}{\omega_2}\right)} \tag{10}$$

where ω_2 is the magnitude of the second opamp pole.

Substituting from (10) into (6) and assuming matched opamps are used, it follows that a necessary condition for the summer stability is given by

$$\frac{\omega_2}{\omega_t} > \frac{2}{(K_1+1)} - \frac{0.5}{(K+1)}. \tag{11}$$

As an example, $K_1 = 1$ results in a stable summer (for $\omega_2 > \omega_t$) for any magnitude of the gain parameter K. Also, $K_1 = K$ results in a stable operation for $K > 0.5$ and $\omega_2 > \omega_t$. In this case, the compensated error function will be similar to that of the summer given in [1]. It is worth noting that for $V_2 = 0$, the circuit reduces to the phase compensated inverting weighted summer reported in [5].

The Second Summer

A novel active compensated weighted summer with multiport noninverting inputs and a single inverting input is shown in Fig. 2. The voltages V_{21}, $V_{22}, \cdots, V_{2n}$ represent the n noninverting inputs, and V_1 the inverting input. Straightforward analysis of the circuit yields the following expression for the output voltage:

$$V_o = \frac{\left[\sum_{i=1}^{n} V_{2i}G_{2i}\right]\left[\dfrac{1}{G^+}\right][K(a+1)+1]\left[1+\dfrac{K_1+K_2+1}{A_1}\right] - V_1K\left[1+\dfrac{K_1[K(a+1)+1]}{KA_1}\right]}{1+\dfrac{K_2[K(a+1)+1]}{A_1}+\dfrac{[K(a+1)+1][K_1+K_2+1]}{A_1A_2}} \tag{12}$$

where

$$G^+ = \sum_{i=1}^{n} G_{2i}$$

and

$$G_{2i} = \frac{1}{R_{2i}} \qquad (i = 1, 2, \cdots, n) \tag{13}$$

The parameter K controls the gain of the summer, K_1 controls the phase compensation condition, a controls the stability of the circuit, and K_2 controls the mode of operation. From (12), it is seen that for the three port mode of operation it is necessary to have

$$K_2 = K_1\left(a+\frac{1}{K}\right) - 1. \tag{14}$$

In this case, the generalized expression for V_o simplifies to

$$V_o = \left\{\left[\sum_{i=1}^{n} V_{2i}G_{2i}\right]\left[\frac{1}{G^+}\right] \times [K(a+1)+1] - V_1K\right\} \cdot \epsilon_2 \tag{15}$$

where

$$\epsilon_2 = \frac{1+\dfrac{K_1[K(a+1)+1]}{KA_1}}{1+\dfrac{\left[K_1\left(a+\dfrac{1}{K}\right)-1\right][K(a+1)+1]}{A_1}+\dfrac{K_1[K(a+1)+1]^2}{KA_1A_2}} \tag{16}$$

From the above equation, it is seen that the phase compensation condition is given by

$$K_1 = \frac{1}{a}. \tag{17}$$

Thus, the compensated error function becomes

$$\epsilon_{2c}(s) = \frac{1+\left[\dfrac{K(a+1)+1}{Ka}\right]\dfrac{s}{\omega_{t1}}}{1+\left[\dfrac{K(a+1)+1}{Ka}\right]\dfrac{s}{\omega_{t1}}+\dfrac{[K(a+1)+1]^2}{Ka}\dfrac{s^2}{\omega_{t1}\omega_{t2}}} \tag{18}$$

This circuit is a generalization to the differential voltage-controlled-voltage-source (VCVS) recently described in [6]. An additional control on the noninverting gain may be obtained by connecting a resistor between the inverting input terminal of A_1 and ground.

In conclusion, a generalized weighted summer with multiport inverting and noninverting inputs, and a phase

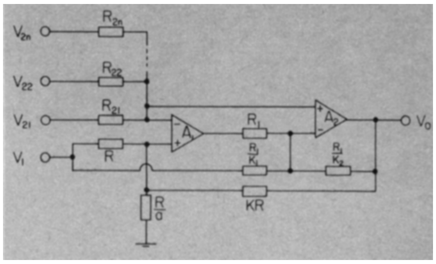

Fig. 2. A generalized actively compensated amplifier with one inverting input and multiport noninverting inputs.

compensation condition independent of the gain bandwidth of both opamps will be welcomed.

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