Passive Compensation of Inverting VCCS Structures

Passive Kompensation von invertierenden spannungsgesteuerten Stromquellen

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Abstract.

Two new circuits for the phase compensation of the inverting VCCS using a single capacitor are proposed. In both networks the condition for phase compensation depends on the load. A modified circuit which employs two compensating capacitors is also given. This is the passive equivalent network to the active circuit described recently [1].

Übersicht:

Es werden zwei neue Schaltungen vorgeschlagen zur Phasenkompensation invertierender spannungsgesteuerter Stromquellen unter Verwendung eines einzelnen Kondensators. In beiden Netzwerken hängt die Bedingung für die Phasenkompensation von der Belastung ab. Es wird auch eine modifizierte Schaltung angegeben, welche zwei kompensierende Kapazitäten enthält; sie ist das passive äquivalente Netzwerk einer bereits früher beschriebenen Schaltung [1].

Für die Dokumentation:

Operationsverstärker / Phasenkompensation / Lastabhängigkeit / spannungsgesteuerte Stromquelle

1. Introduction

The inverting voltage controlled current source (VCCS) which uses a single op amp has several applications in electronic circuits [1–2]. It is well known that the finite unity gain bandwidth of the omp amp ω_t, results in both phase and magnitude errors [1]. The magnitude error is a second order term, whereas the phase error is of a first order magnitude and therefor the VCCS requires mainly phase compensation [1]. The purpose of this paper is to propose three passive phase compensated VCCS networks.

2. A single C passive compensated VCCS network

Here two circuits are proposed for the phase compensation of the inverting VCCS using only a single capacitor. **Fig. 1** represents the first circuit. Compensation in this circuit is achieved by the capacitor C_1 which is to be chosen in order to minimize the phase error. 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.

By direct analysis to the circuit, the load current is given by

$$I_L = -\frac{V_i}{R}\,\varepsilon_1(s) \tag{2}$$

where

$$\varepsilon_1(s) = \frac{1 + C_1 R_1 s}{1 + \left[(x+1)\frac{2}{\omega_t} - \frac{x C_1 R_1}{2}\right] s + (x+1)\frac{C_1 R_1 s^2}{\omega_t}} \tag{3}$$

and

$$x = \frac{2 R_L}{R}. \tag{4}$$

From (3) it is seen that in order to reduce the phase error to a negligible level, the time constant $C_1 R_1$ should be chosen such that

$$C_1 R_1 = \frac{4}{\omega_t}\,\frac{x+1}{x+2}. \tag{5}$$

In this case the compensated error function becomes

$$\varepsilon_{C1}(s) = \frac{1 + \frac{4}{\omega_t}\frac{x+1}{x+2} s}{1 + \frac{4}{\omega_t}\frac{x+1}{x+2} s + \frac{4}{\omega_t^2}\frac{(x+1)^2}{x+2} s^2}. \tag{6}$$

The corresponding phase and magnitude errors are given by

$$\phi_{C1} \simeq -2\left(\frac{2\omega}{\omega_t}\right)^3 \frac{(x+1)^3}{(x+2)^2}; \qquad \gamma_{C1} \simeq \left(\frac{2\omega}{\omega_t}\right)^2 \frac{(x+1)^2}{x+2}; \qquad \omega \ll \frac{\omega_t}{2}. \tag{7}$$

The bandwidth is given by

$$BW_{C1} = \frac{\omega_t}{2(x+1)} \sqrt{(x+4) + \sqrt{2x^2 + 12x + 20}}. \tag{8}$$

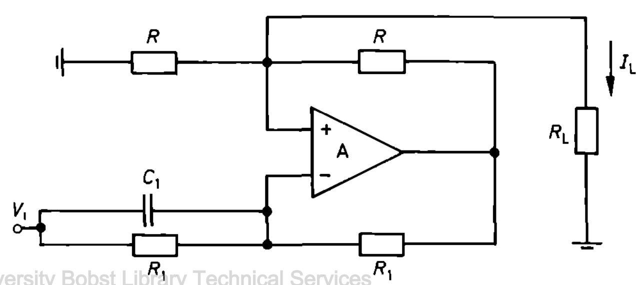

Fig 1: A passive compensated inverting VCCS

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Comparing the above equation with that of the uncompensated inverting VCCS [1], the improvement in the bandwidth is given by

$$\frac{BW_{C1}}{BW} = \sqrt{(x+4)+\sqrt{2x^2+12x+20}}\,, \tag{9}$$

which depends on the normalized load resistance x.

Fig. 2 represents another passive compensated inverting VCCS which employes a capacitor C in the positive feedback path of the op amp. The load current in this case is given by

$$I_L = -\frac{V_i}{R}\,\varepsilon_2(s) \tag{10}$$

where

$$\varepsilon_2(s) = \frac{1+CRs}{1+\left[(x+1)\dfrac{2}{\omega_t}-\dfrac{xCR}{2}\right]s+\dfrac{xCR}{\omega_t}s^2}\,. \tag{11}$$

The condition for phase compensation is given by

$$CR = \frac{4}{\omega_t}\,\frac{x+1}{x+2}\,. \tag{12}$$

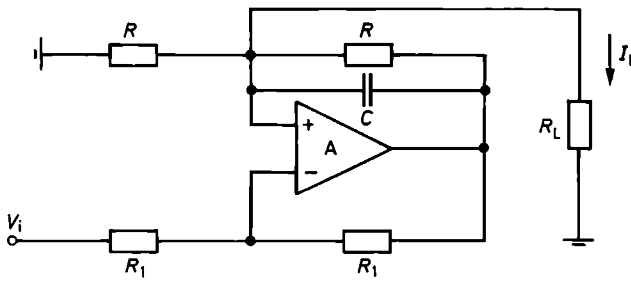

Fig. 2: Another passive compensated inverting VCCS

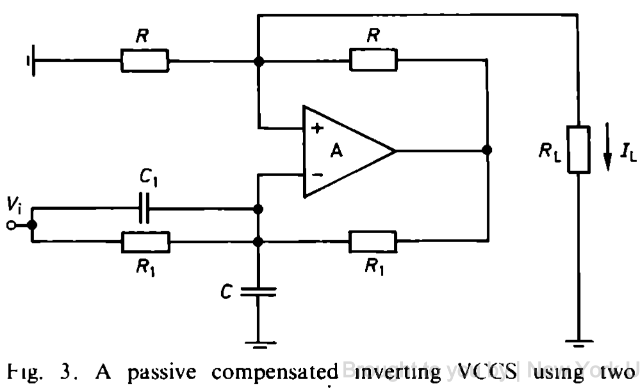

Fig. 3. A passive compensated inverting VCCS using two capacitors

In this case the compensated error function becomes

$$\varepsilon_{C2}(s) = \frac{1+\dfrac{4}{\omega_t}\dfrac{x+1}{x+2}s}{1+\dfrac{4}{\omega_t}\dfrac{x+1}{x+2}s+\dfrac{4x(x+1)}{(x+2)}\dfrac{s^2}{\omega_t^2}}\,. \tag{13}$$

It is clear that this network has smaller phase and magnitude errors than thc first network:

$$\phi_{C2} \simeq -2x\left(\frac{2\omega}{\omega_t}\right)^3\left(\frac{x+1}{x+2}\right)^2; \qquad \gamma_{C2} \simeq x\left(\frac{2\omega}{\omega_t}\right)^2\frac{x+1}{x+2}; \qquad \omega \ll \frac{\omega_t}{2}. \tag{14}$$

It is also easy to see that the bandwidth in this case is larger than that given by (8):

$$BW_{C2} = \frac{\omega_t}{2(x+1)}\sqrt{(x+5)+\frac{2}{x}\left(3+\frac{1}{x}\right)+\frac{x+1}{x}\sqrt{2x^2+12x+24+\frac{4}{x}\left(4+\frac{1}{x}\right)}}\,. \tag{15}$$

3. A compensated inverting VCCS using two capacitors

In variable load applications it is desirable to have a compensation method which is not affected by a change in the load. The circuit shown in **Fig. 3** is a modified version of that in Fig. 1 using an additional grounded capacitor C in a similar way as was used in the VCVS [3]. In this case the error function is given by

$$\varepsilon_3(s) = \frac{1+C_1R_1s}{1+\left[(x+1)\dfrac{2}{\omega_t}-\dfrac{x(C+C_1)R_1}{2}\right]s+(x+1)(C+C_1)R_1\dfrac{s^2}{\omega_t}}\,. \tag{16}$$

For phase compensation:

$$C = C_1;\; R_1C_1 = \frac{2}{\omega_t}\,. \tag{17}$$

In this case, the compensated error function reduces to

$$\varepsilon_{C3}(s) = \frac{1+\dfrac{2}{\omega_t}s}{1+\dfrac{2}{\omega_t}s+(x+1)\dfrac{4}{\omega_t^2}s^2}\,. \tag{18}$$

This is identical to the error function obtained using the active compensation method [1]. In this case:

$$\phi_{C3} \simeq -\left(\frac{2\omega}{\omega_t}\right)^3(x+1);\; \gamma_{C3} \simeq \left(\frac{2\omega}{\omega_t}\right)^2(x+1);\; \omega \ll \frac{\omega_t}{2}; \tag{19}$$

$$BW_{C3} = \frac{\omega_t}{2(x+1)}\sqrt{\left(x+\frac{3}{2}\right)+\sqrt{2x^2+5x+\frac{13}{4}}}\,. \tag{20}$$

4. Conclusions

Three modified inverting VCCS networks are proposed. Although the circuit in Fig. 3 has the smallest bandwidth among the three circuits, it is practically the most convenient to use in applications requiring a variable load.

References:

[1] Soliman, A. M.: Active phase compensation of op-amp VCCS structures. Proc. IEEE Vol. 67 (1979) 10, pp. 1451—1452.
[2] Millman, J.; Halkias, C. C.: Integrated electronics: analog and digital circuits and systems. McGraw Hill, New York, 1972.
[3] Wilson, G.: Compensation of some operational amplifier based RC active networks. IEEE CAS-23, (1976), pp. 443—446.

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Advances in Thin-Film Implementation of RC-active Filters

Fortschritte bei RC-aktiven Filtern in Dünnschichttechnik

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Report from the Institute for Network- und System's-Theory UNIVERSITY OF STUTTGART, Germany

Herrn Professor Bader zum 80. Geburtstag gewidmet

Abstract:

Building blocks are a very powerful concept for the hybrid implementation of RC-active filters in Ta-thin-film-technology. The substrate area can be decreased by transformations of the RC-network, by high sheet-resistances of up to 300 Ω/□ as well as high capacitance-densities of 69 nF/cm² and by the introduction of uniform RC-lines. A single Ta-oxinitride layer provides both R's and C's with excellent temperature compensation. Double layer dielectrics ensure a high yield. RC-lines and temperature stabilized amplifiers provide pole-Q's of up to 250 in the frequency range up to 10 MHz.

Übersicht:

Baueinheiten sind ein bewährtes Konzept zur Erstellung von RC-aktiven Filtern in Ta-Dünnschichttechnik. Die Substratfläche kann auf drei Arten vermindert werden, nämlich durch eine Transformation des RC-Netzwerkes, durch hohe Flächenwiderstände bis zu 300 Ω/□, hohe Kapazitätsdichten von 69 nF/cm² und durch die Verwendung von homogenen RC-Leitungen. Aus einer einzigen Ta-oxinitrid-Schicht können R's und C's mit guter Temperaturkompensation hergestellt werden. Zweischicht-Dielektrika führen zu einer hohen Ausbeute. RC-Leitungen und temperaturstabilisierte Verstärker liefern Polgüten bis zu 250 im Frequenzbereich bis zu 10 MHz.

Für die Dokumentation:

RC-aktives Filter / Ta-Dünnschichttechnik / Rundfunkbandfilter

1. Introduction

The trend is to implement filters by monolithic integration based on switched capacitor- or digital filter-theory. However, some features of hybrid integrated filters ensure continued interest and applications. As those filters are analog they do not encounter anti-aliasing problems and easily provide out-of-band attenuation. Because of their excellent long term stability and reliability they are especially well suited for telephone systems where typically more than a 20 year lifetime is required. This paper will report on advances in design and thin-film-technology which shrunk the substrate area needed and enhanced the yield particularly by improved capacitor processing. This progress will be outlined with building blocks [1] which turned out to be very successful circuits. The introduction of uniform RC-lines resulted in a further substantial decrease in the substrate area. In addition it will be demonstrated how RC-active filters for Q-values up to 250 and frequencies in the 10 MHz-range became feasible. This opens up applications for measuring instruments and radio frequency filtering.

2. RC-active building blocks

Bell Labs' successful building block [2] in **Fig. 1** allows the realization of the most important 2nd order filter sections by connecting the open terminals in an appropriate fashion. The two capacitors have the fixed values of 5 nF each. The resistors are tailored to the desired value e. g. by laser-cutting parts of the meanders.

The building block in **Fig. 2** [3, 4] contains the two capacitors in **Fig. 3** where the ratio C_1/C_2 can be adjusted by laser cutting the top electrode at the places marked by dotted lines. The op. amp. may be placed in two positions according to the transfer function to be realized [4]. This provides more flexibility for the implementation of various transfer functions as listed and explained in **Table 1**. A total of 40 transfer functions is described in [4]. The total area A_{tot} covered by all resistors R_i and all capacitors C_i is

$$A_{tot} = \frac{\sum_i C_i}{c_A} + 2w^2 \frac{\sum_i R_i}{r_A} = A_C + A_R$$

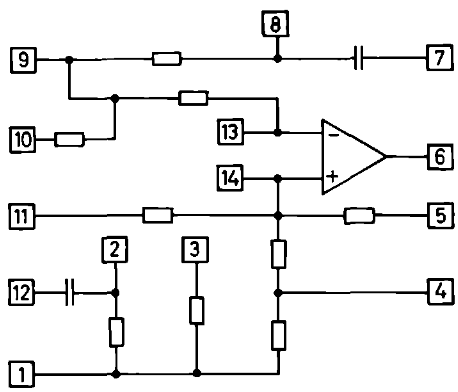

Fig. 1. Bell Lab's 2nd-order RC-active building block, called STAR