Novel Grounded C Biquad Circuits Using the DVCCS/DVCVS*

Eine neue biquadratische Schaltung mit differenzspannungsgesteuerter Strom- und Spannungsquelle und geerdeten Kondensatoren

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Abstract:

Three multifunction filter sections using the DVCCS/DVCVS as the active building block are given. The first circuit employs two (DVCCS/DVCVS) devices and realizes bandpass and lowpass responses at two different outputs. The other two networks employ three devices and are capable of realizing the three filter functions, namely the highpass, bandpass and lowpass responses. A novel feedforward nonminimum phase filter section using three devices is also given. In all cases design equations, passive and active sensitivities are summarized.

Übersicht:

Es werden drei Mehrzweck-Filterstufen beschrieben, die differenzspannungsgesteuerte Strom- und Spannungsquellen als aktiven Baustein enthalten Die erste Schaltung enthält zwei solche Anordnungen und realisiert Band- und Tiefpaßverhalten an zwei verschiedenen Ausgangen. Die beiden anderen Netzwerke enthalten drei Anordnungen zur Realisierung von drei Filterfunktionen mit Hoch-, Band- bzw. Tiefpaßverhalten. Weiterhin wird eine neue vorwärtsgekoppelte Siebschaltung mit nichtminimaler Phase beschrieben. In allen Fällen werden Dimensionierungsfragen, passive und aktive Empfindlichkeiten erörtert

Für die Dokumentation.

Hoch-, Band- und Tiefpaßfilter / Differenzspannungsgesteuerte Strom- und Spannungsquelle / Mehrzweck-Siebglied / Dimensionierung / passive und aktive Empfindlichkeit

1. Introduction

The differential voltage controlled current source–differential voltage controlled voltage source (DVCCS/DVCVS) is a linear versatile active building block with two outputs, one of high impedance and the other of low impedance [1]. **Fig. 1** represents the device symbol where [2]

$$I_0 = G(V^+ - V^-); \quad V_0 = \alpha V_g . \qquad (1)$$

The possibility of connection of external elements to the output 1 of the DVCCS/DVCVS makes it more versatile than the conventional operational amplifier (op amp) [2]. This active device has several applications in filter realizations [2–6] and in the simulation of inductors [7] and frequency dependent negative conductances [8]. Most recently [5] a differential integrator has been proposed which uses only a single device and a single earthed capacitor. Application of this integrator in the synthesis of a two integrator loop filter section has also been reported [5].

In this paper, novel biquad circuits using the DVCCS/DVCVS as the active building block are proposed. The first circuit is of a similar nature to the Tow-Thomas basic circuit [9–11]. Two multifunction filter sections are also given. One of them is of a similar nature to the Kerwin-Huelsman-Newcomb (KHN) biquad [12]. The main advantage of the proposed filter sections over those in [9–12] is the use of earthed capacitors.

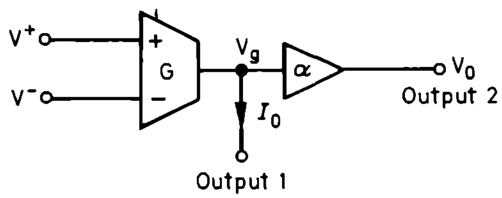


Fig. 1: Symbolic representation of the DVCCS/DVCVS

A novel realization of the generalized second order nonminimum phase transfer function based on the feedforward technique and using two earthed capacitors is also given. Design equations for the all-pass, notch, lowpass notch and highpass notch responses are given.

2. Modified Inverting BP, Noninverting LP Filter

Fig. 2a represents a canonic filter which realizes inverting bandpass (BP) and noninverting lowpass (LP) filter functions. This circuit is a modified version to that reported by the author in [5] in order to have independent control on the gain factor. The block diagram representation is shown in **Fig. 2b.** It is seen that although the filter is of a similar nature to the Tow-Thomas filter

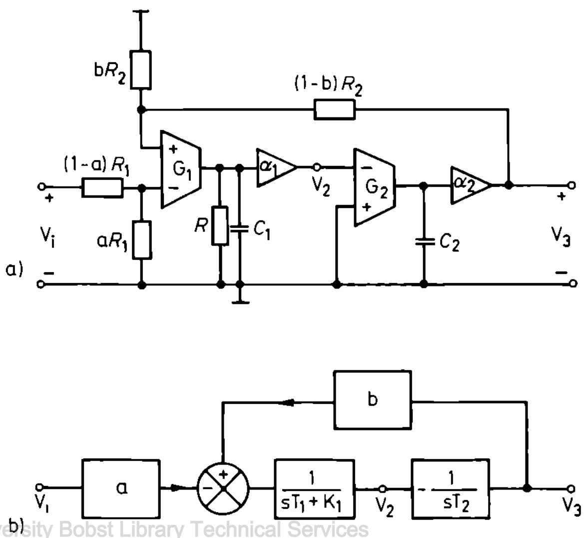


Fig. 2: A modified inverting BP – noninverting LP filter

* DVCCS/DVCVS Differential voltage controlled current source – differential voltage controlled voltage source

(since both networks realize an inverting BP and a noninverting LP filter function) the block diagram representation is different in the two cases [13]. After some simple manipulations, the following transfer functions are obtained:

$$\frac{V_2}{V_i} = \frac{-saT_2}{s^2 T_1 T_2 + sK_1 T_2 + b}, \tag{2}$$

$$\frac{V_3}{V_i} = \frac{a}{s^2 T_1 T_2 + sK_1 T_2 + b}, \tag{3}$$

where

$$T_i = \frac{C_i}{\alpha_i G_i} \qquad i = 1, 2 \tag{4}$$

and

$$K_1 = \frac{1}{\alpha_1 G_1 R}. \tag{5}$$

The gain factors, ω_p and Q_p are given in **Table 1**. It is seen that a controls the gain factor without affecting ω_p and Q_p. K_1 controls Q_p without altering ω_p. The circuit can realize any arbitrary lowpass gain. The design equations may be chosen in a variety of ways. One possible set of design equations based on the use of matched devices and equal capacitors is given in Table 1. It is seen that the potential divider R_2 is necessary if a lowpass gain more than 1 is required. On the other hand if a lowpass gain less than 1 is desirable, b may be taken as 1 resulting in a complete feedback of V_3 to the noninverting input terminal of G_1. Of course if a unity lowpass gain is required, the two potential dividers R_1 and R_2 are removed and the circuit reduces to that in [5]. The ω_p and Q_p passive and active sensitivities are very low as seen from **Table 2**.

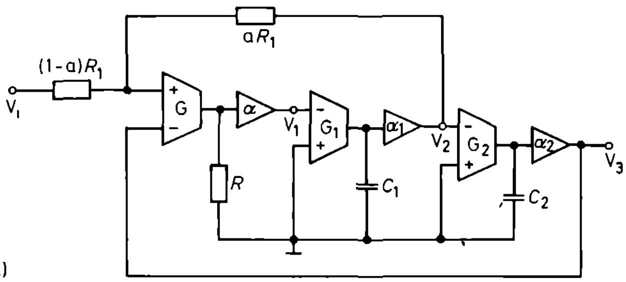
The limitation of the above filter section is that the highpass (HP) filter function is not realizable, which is the same limitation of the Tow-Thomas basic circuit.

Table 1: The characteristics and the design equations of the filters of Fig. 2, 3 and 4

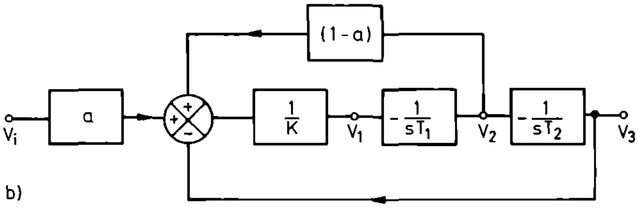
Proposed Filter	Gain Factors 1 HP	2 BP	3 LP	ω_p	Q_p	Design Equations
Fig. 2	—	$-\frac{a}{K_1}$	$\frac{a}{b}$	$\sqrt{\frac{b}{T_1 T_2}}$	$\sqrt{\frac{bT_1}{T_2}} \cdot \frac{1}{K_1}$	$a = b \cdot$ (LP gain) $R = \frac{Q_p}{\sqrt{b}\,\alpha G}$ $C_1 = C_2 = \frac{\sqrt{b}\,\alpha G}{\omega_p}$
Fig. 3	$\frac{a}{K}$	$-\frac{a}{(1-a)}$	a	$\frac{1}{\sqrt{KT_1 T_2}}$	$\sqrt{\frac{KT_1}{T_2}} \cdot \frac{1}{(1-a)}$	$a =$ LP gain $R = \frac{1}{(1-a)^2 \alpha G Q_p^2}$ $C_1 = C_2 = \frac{\alpha G}{(1-a)\,\omega_p Q_p}$
Fig. 4	$\frac{1}{K}$	$\frac{1}{(1-a)}$	$\frac{1}{a}$	$\sqrt{\frac{a}{KT_1 T_2}}$	$\sqrt{\frac{\alpha KT_1}{T_2}} \cdot \frac{1}{(1-a)}$	$a = \frac{1}{\text{LP gain}}$ $R = \frac{a}{(1-a)^2 \alpha G Q_p^2}$ $C_1 = C_2 = \frac{a\alpha G}{(1-a)\,\omega_p Q_p}$

Table 2: The ω_p and the Q_p passive and active sensitivities of the filters of Fig. 2, 3 and 4

Proposed Filter	S^{χ}_{χ}	ACTIVE α	G	α_1	G_1	α_2	G_2	PASSIVE R	C_1	C_2	a	b
Fig. 2	$S^{\omega_p}_{\chi}$	—	—	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{2}$	0	$\frac{1}{2}$
	$S^{Q_p}_{\chi}$	—	—	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{2}$	$-\frac{1}{2}$	0	$\frac{1}{2}$
Fig. 3	$S^{\omega_p}_{\chi}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	0	—
	$S^{Q_p}_{\chi}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{a}{(1-a)}$	—
Fig. 4	$S^{\omega_p}_{\chi}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	—
	$S^{Q_p}_{\chi}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2} + \frac{a}{(1-a)}$	—



a)



b)

Fig. 3: A new noninverting HP-inverting BP-noninverting LP filter

3. Multifunction Filter Sections Using Three Devices

It is well known that the KHN biquad [12] is superior to the Tow-Thomas biquad [9–10] since it realizes the three basic filter functions, namely the highpass, bandpass and lowpass at three alternative output terminals. The KHN circuit however uses two floating capacitors. In this section two novel biquad sections using three devices and two earthed capacitors are proposed. The first is of a similar nature to the KHN circuit since it realizes noninverting HP, inverting BP and noninverting LP responses. The second circuit however is of a different nature since it realizes the three basic filtering functions with positive gain factors.

Fig. 3 represents the first multifunction filter circuit together with its block diagram representation. By direct analysis the transfer functions are given by

$$\frac{V_1}{V_i}=\frac{s^2 a T_1 T_2}{s^2 K T_1 T_2+s(1-a)T_2+1}, \tag{6}$$

$$\frac{V_2}{V_i}=\frac{-saT_2}{s^2 K T_1 T_2+s(1-a)T_2+1}, \tag{7}$$

$$\frac{V_3}{V_i}=\frac{a}{s^2 K T_1 T_2+s(1-a)T_2+1}, \tag{8}$$

where

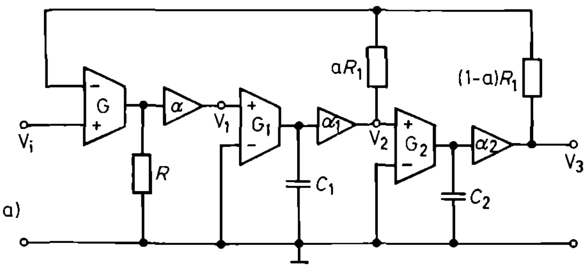
$$T_i=\frac{C_i}{\alpha_i G_i} \qquad i=1,2 \tag{9}$$

and

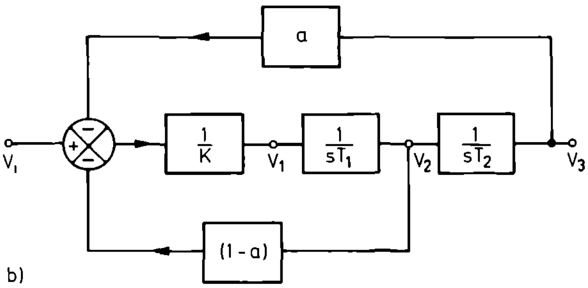
$$K=\frac{1}{\alpha G R}. \tag{10}$$

The gain factors, ω_p and Q_p are summarized in Table 1. This filter section is limited to the realization of a lowpass response with a dc gain <1. For applications requiring a dc gain >1 the following multifunction filter section is proposed.

Fig. 4 represents the noninverting HP–noninverting BP–noninverting LP filter section. The advantage of this filter section over those of Figures 2 and 3 as well as those in [9–12] is that it has an infinite input impedance. The block diagram representation is shown in Fig. 4b and is different from that of the KHN circuit. The transfer functions obtained for this filter section are given by



a)



b)

Fig. 4: A new noninverting HP–noninverting BP–noninverting LP filter

(Note that an inverting HP–noninverting BP–noninverting LP filter is also realizable by reversing the polarities of G and G_1)

$$\frac{V_1}{V_i}=\frac{s^2 T_1 T_2}{s^2 K T_1 T_2+s(1-a)T_2+a}, \tag{11}$$

$$\frac{V_2}{V_i}=\frac{sT_2}{s^2 K T_1 T_2+s(1-a)T_2+a}, \tag{12}$$

$$\frac{V_3}{V_i}=\frac{1}{s^2 K T_1 T_2+s(1-a)T_2+a}, \tag{13}$$

where T_1, T_2 and K are defined by similar equations to (9) and (10). The ω_p, Q_p and the design equations are summarized in Table 1.

Notice that the design equations given in Table 1 are based on a specified ω_p, Q_p and the lowpass dc gain. If on the other hand the bandpass gain (or the highpass gain) is specified, then another set of design equations may be obtained.

It is worth noting that the realization of the general biquadratic function is possible using any of the three proposed basic circuits together with an additional device to act as a summing amplifier, in a similar way to the biquadratic networks using the op amp as the active element [14]. An alternate way of realizing the general biquadratic function based on the feedforward technique is discussed next.

4. Novel Feedforward Biquad Using Three Devices

Fig. 5a represents the new nonminimum phase network which employs 2 capacitors, 4 resistors and 3 devices. This network is superior to that given in [4] since the capacitors are earthed and it has independent tuning capabilities. The block diagram representation is shown in

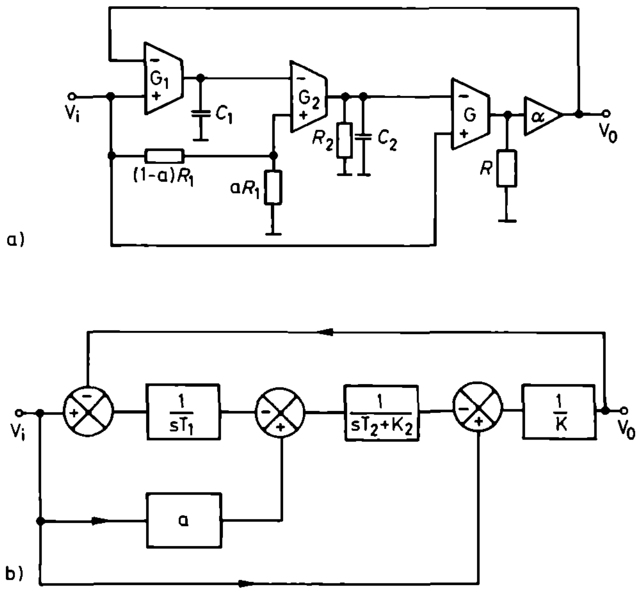


Fig. 5: A new feedforward biquad

Fig. 5b. Analyzing this circuit one gets the following transfer function:

$$\frac{V_0}{V_i}=\frac{s^2T_1T_2-s(a-K_2)T_1+1}{s^2KT_1T_2+sKK_2T_1+1}, \tag{14}$$

where

$$K=\frac{1}{\alpha GR}, \qquad K_2=\frac{1}{G_2R_2} \tag{15}$$

and

$$T_i=\frac{C_i}{G_i} \qquad i=1,2. \tag{16}$$

Thus the biquadratic parameters ω_p, Q_p, ω_z and Q_z are given by

$$\omega_p=\frac{1}{\sqrt{KT_1T_2}}, \qquad Q_p=\frac{1}{K_2}\sqrt{\frac{T_2}{KT_1}}, \tag{17}$$

$$\omega_z=\frac{1}{\sqrt{T_1T_2}}, \qquad Q_z=\frac{1}{(a-K_2)}\sqrt{\frac{T_2}{T_1}}. \tag{18}$$

It is seen that the potential divider R_1 controls the position of the zeros. For all-pass and notch responses $K=1$, resulting in a unity gain factor which is an advantage. Assuming matched devices are used, the design equations for the all-pass and notch responses are

$$R=\frac{1}{\alpha G}, \tag{19}$$

$$C_1=C_2=\frac{G}{\omega_p}, \tag{20}$$

$$R_2=\frac{Q_p}{G}, \tag{21}$$

$$a=\frac{2}{Q_p} \quad \text{all-pass}, \tag{22a}$$

$$a=\frac{1}{Q_p} \quad \text{notch}. \tag{22b}$$

It is clear that the network is capable of realizing also a lowpass notch and a highpass notch response by adjusting the grounded resistor R, such that

$$K=\left[\frac{\omega_z}{\omega_p}\right]^2. \tag{23}$$

For a lowpass notch $K>1$ and for a highpass notch $K<1$.

It is also seen that the ω_p and the Q_p sensitivities to all passive and active circuit components are $\leqq 1$.

5. Conclusions

The use of the DVCCS/DVCVS as the active building block in the realization of novel multifunction filter sections using earthed capacitors has been demonstrated by four circuits. One of them is of a similar nature to the Tow-Thomas biquad [9–11], another is similar to the KHN [12] multifunction filter. Design equations, passive and active sensitivities are given.

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