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ARC FILTERS WITH DIAMOND TRANSISTORS AND BUFFERS

Tomáš DOSTÁL
Institute of Radioelectronics
Technical University of Brno
Purkynova 118, 612 00 BRNO
Czech Republic

tel: 425-41149151, fax: 425-41149192,
E-mail: dostal@urel.fee.vutbr.cz

Abstract

Active RC first and second order filters using diamond transistors (voltage controlled current sources) and voltage diamond buffers (voltage controlled voltage sources) are given in this paper. Circuits are simulated and experimentally compared.

Keywords

analogue signal processing, ARC filters, high-frequency continuous-time filters, filters using special components and functional blocks, diamond transistor and buffer.

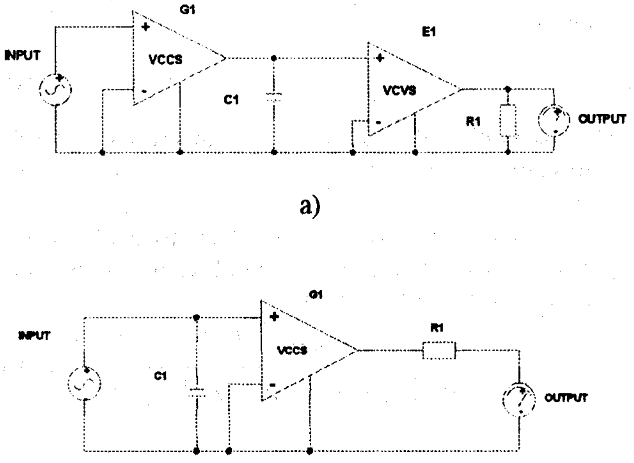
1.Introduction

Recently high-frequency continuous-time ARC filters have received great attention. A progress of the analogue technology has produced several functional blocks and monolithic IC components versatile and suitable for video and RF ranges. One from them is diamond transistor and buffer OPA660 from Burr-Brown company [1]. Similar is LM13700 from National semiconductor [5]. These both IC include two wideband subcircuits, or functional blocks, namely a voltage-controlled current source (VCCS) and a voltage buffer (VCVS). The two blocks share common supplies but otherwise operate independently. The VCCS or the transconductance amplifier (OTA) can be viewed as an ideal transistor (with only one parameter g_T), that is why the name [2], so-called diamond transistor (DT). The transconductance of the diamond transistor (g_T) can be adjusted with external current (I_Q), to give possibility of tuning or optimising the parameters of the filter. Similarly the VCVS has the structure of the so-called diamond buffer (push-pull buffer) too [2].

Active RC filters are usually designed with standard operational amplifiers, however in low-frequency (audio) range only. The well known classical ARC filters can not be straightforward used for the OPA660. One ingenious modification of the Sallen-Key low-pass (LP) filter was given in [3], where the OPA660 was used as a current-feedback amplifier. Here the 1st and 2nd order structures are given and studied, using directly both above controlled sources (namely VCCS and VCVS).

2.First order ARC filters using VCCS and VCVS

For the purpose of this paper, we assume 1st order LP filter - integrator (Fig. 1) as a suitable building subcircuit of the higher order filters. The Fig. 1a shows a conventional integrator G_m - C in voltage mode (VM), which comprises a transconductor (VCCS), used for converting an input voltage to proportional amount of current, and an integrating capacitor (C_1), used for integrating and converting current back to the voltage form. A voltage buffer (from the VCVS) separates a load (R_L). Alternatively, a typical G_m - C integrator in an adjoint current mode (CM) is shown in Fig. 1b.



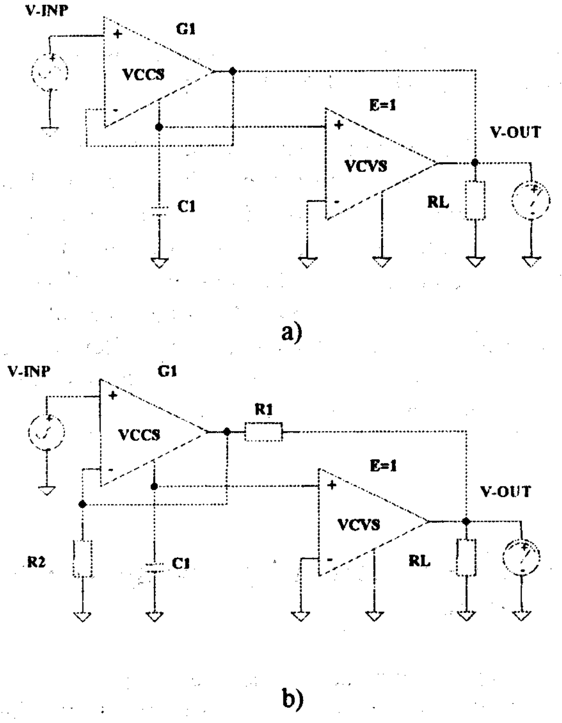
a)

b)

Fig. 1. ARC integrator using VCCS & VCVS
a) in voltage mode,
b) in current mode.

The both integrators given above (VM and CM) are characterized by the same transfer function (V or I)

$$\frac{V_{out}}{V_{inp}} = \frac{I_{out}}{I_{inp}} = \frac{g_1}{sC_1}, \tag{1}$$



a)

b)

Fig. 2. First order LP-ARC filter structure using VCCS & VCVS
a) with full 100% current feedback,
b) with smaller feedback, using resistive divider.

Furthermore a lost integrator with following transfer function

$$\frac{V_{out}}{V_{inp}} = \frac{g_1}{sC_1 + g_1}, \tag{2}$$

is shown in Fig. 2a. The critical cutoff- frequency (-3dB) is given by

$$\omega_c = \frac{g_1}{C}. \tag{3}$$

There is a full (100%) negative, current - series feedback in this circuit of Fig. 2a.

A modification where the feedback is smaller using resistive divider R_1 & R_2 is shown in Fig. 2b. In this case the voltage transfer function is

$$\frac{V_{out}}{V_{inp}} = \frac{g_1(R_1 + R_2)}{sC_1(R_1 + R_2 - g_1 R_1 R_2) + g_1 R_2}, \tag{4}$$

One other modification has $R_2 = \infty$ and then the voltage transfer function as follows

$$\frac{V_{out}}{V_{inp}} = \frac{g_1}{sC_1(1 - g_1 R_1) + g_1}, \tag{5}$$

The network structure of Fig. 2b has been realized using OPA660 and LM13700 respectively, with the following values of the passive components: R_1 = 1 kΩ, R_2= 100 Ω, C_1 = 150 pF, R_L = 10 kΩ and resistive divider at the input R_3 = 1 kΩ, R_4= 100 Ω.

The cutoff- frequency (-3dB) is approximately given by eq. (3), specially if $R_1 << R_2$, but exactly by

$$\omega_c = \frac{g_1 R_2}{(R_1 + R_2)C}. \tag{6}$$

There the transconductance (g_1) can be adjusted over four decades (g_1 = 20 μS - 200 mS) with external bias current (I_Q = 2 μA - 20 mA). Tracking of the g_1 gives a possibility of a tuning of the critical cutoff- frequency to obtain the current-controlled filter, what is demonstrated by PSpice simulation in Fig. 3. There are resulting magnitude responses for several values of the dc controlling current I_Q = 5 μA, 50 μA, 0.5 mA and 5 mA. Note that in this circuit greater controlling effect was obtained with the LM13700 (Fig. 3) than with the OPA660.

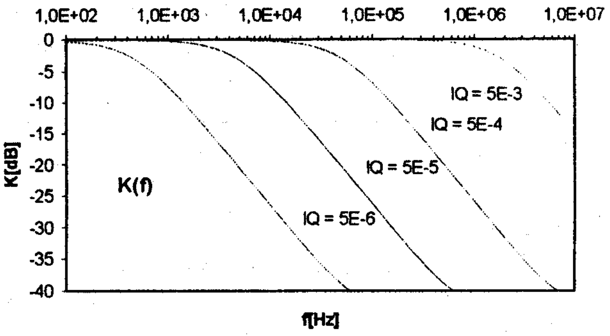


Fig. 3. Magnitude responses of the current-controlled (IQ = 5 μA – 5 mA) ARC-LP filter of the structure from Fig. 2b using LM13700.

3. Second order ARC filters using VCCS and VCVS

One suitable second order ARC filter structure with the given controlled sources, namely with two VCCS (DT) and one VCVS (DB) and using a current feedback (R_1), consequential upon the mentioned in [3], is shown in Fig. 4. By a routine symbolical nodal analysis doing by computer aided tool SNAP the transfer function results in this form

$$\frac{V_{out}}{V_{in}} = \frac{g_1}{s^2 C_1 C_2 R_2 (1 - g_1 R_1) + sC_1 (1 - g_1 R_1) + g_1} \tag{7}$$

looking visibly with the character of the 2nd order LP filter.

Assuming a full current feedback (R_1 = 0), the transfer function (7) becomes simpler

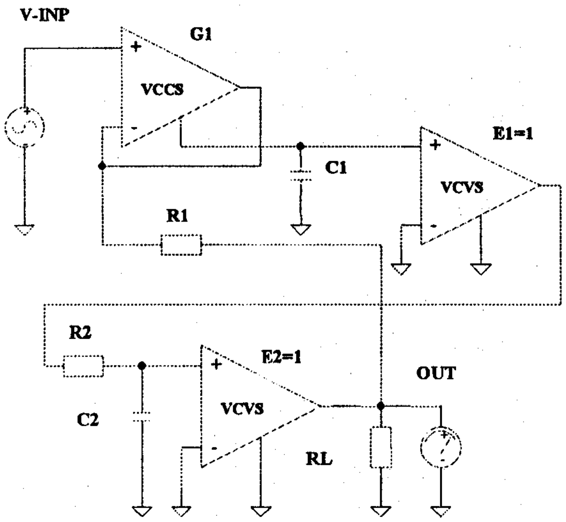


Fig. 4. Second order LP-ARC filter structure using two VCCS (DT) one VCVS (DB) and current feedback.

$$\frac{V_{out}}{V_{in}} = \frac{g_1}{s^2 C_1 C_2 R_2 + s C_1 + g_1} . \tag{8}$$

From the above function (8), the natural frequency (9) and the quality factor of poles (10) are

$$\omega_o = \sqrt{\frac{g_1}{C_1 C_2 R_2}} , \tag{9}$$

$$Q = \sqrt{\frac{C_2 g_1 R_2}{C_1}} . \tag{10}$$

Thus both parameters are controlled by the transconductance (g_1) of the VCCS (DT), but not independently. Note that the desired quality factor can be adjusted by ratio of the capacitances.

There (in Fig. 4) the first voltage buffer (E1) can be omitted (replaced by short circuit) to obtain the transfer function in following form

$$\frac{V_{out}}{V_{in}} = \frac{g_1}{s^2 C_1 C_2 R_2 + s(C_1 + C_2) + g_1} . \tag{11}$$

Then the natural frequency is at the same formula (9), however the quality factor is now given by

$$Q = \frac{\sqrt{C_1 C_2 g_1 R_2}}{C_1 + C_2} . \tag{12}$$

Another structure, little complicated but more versatile is shown in Fig. 5. For the output B of this circuit (Fig. 5) the voltage transfer function can be derived in the LP following symbolic form

$$\frac{V_B}{V_{in}} = \frac{g_1 g_2}{s^2 C_1 C_2 + s C_2 g_1 + g_1 g_2} . \tag{13}$$

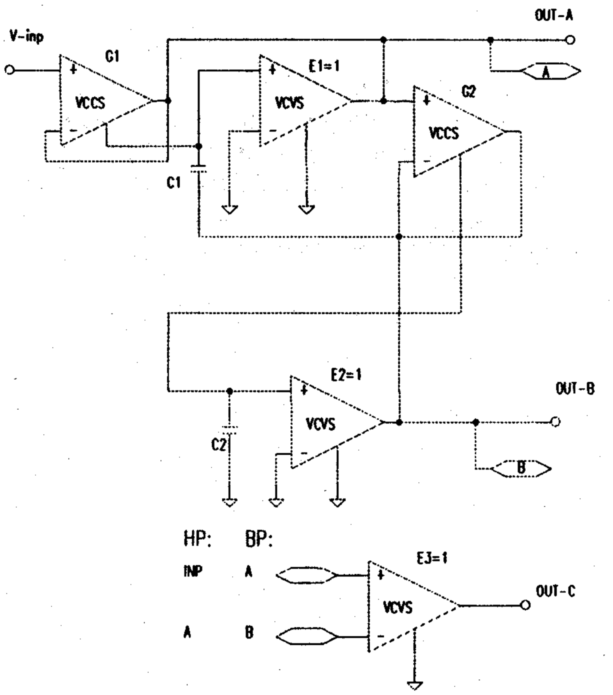


Fig. 5. Versatile ARC biquad structure (LP, ELP, BP, HP) with two VCCS (DT) and two VCVS (DB).

From the eq. (13) the pole frequency (14) and quality factor (15) are written in terms of the network parameters as

$$\omega_0 = \sqrt{\frac{g_1 g_2}{C_1 C_2}} , \tag{14}$$

$$Q = \sqrt{\frac{C_1 g_2}{C_2 g_1}} . \tag{15}$$

If the gain of the voltage buffers (DB) is not exactly equal one, then the transfer function is

$$\frac{V_B}{V_{in}} = \frac{A_1 A_2 g_1 g_2}{s^2 C_1 C_2 + s(A_1 g_1 C_2 + A_2 g_2 C_1 - A_1 A_2 g_2 C_1) + A_1 A_2 g_1 g_2} \tag{16}$$

what allows to evaluate the corresponding mistakes.

The signal V_A at the output A of the biquad in Fig. 5 is given by

$$\frac{V_A}{V_{in}} = \frac{g_1 g_2 + s C_2 g_1}{s^2 C_1 C_2 + s C_2 g_1 + g_1 g_2} , \tag{17}$$

what can be used with V_A in the other supplemental adder (follower with differential input) to obtain

$$V_C = V_A - V_B . \tag{18}$$

Then the transfer function has the band-pass (BP) character of the resultant formula

$$\frac{V_C}{V_{in}} = \frac{s C_2 g_1}{s^2 C_1 C_2 + s C_2 g_1 + g_1 g_2} . \tag{19}$$

Similarly the high-pass biquad can be obtained changing the configuration of the adder, realising the equation

$$V_C = V_{IN} - V_A . \qquad (20)$$

The concluding structure with controlled sources VCCS and VCVS is shown in Fig. 6. There, for the output A, the voltage transfer function has the form of the BP given by eq. (19) and for the output B of the LP given by eq. (13) respectively. The voltage buffer *E4* provides a sum of the output voltages (V_A+V_B).

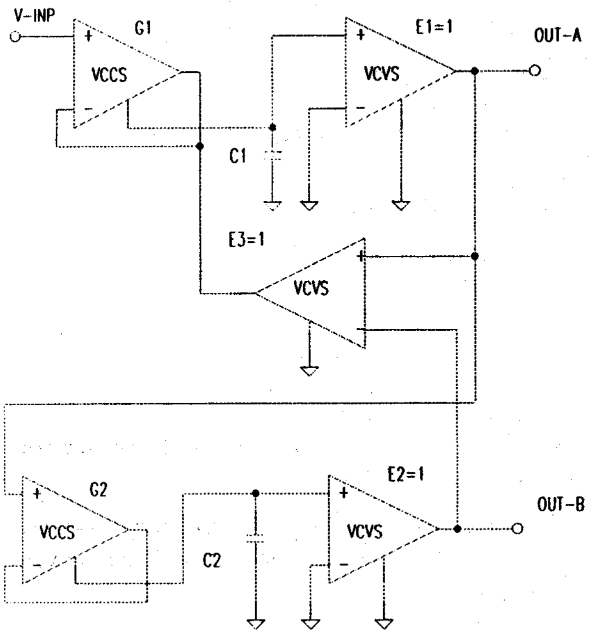


Fig. 6. ARC biquad structure with two VCCS (DT), two VCVS (DB) and one adder (VCVS).

4. BIQUAD REALIZATION AND SIMULATION

To evaluate the performance of above structures, the real circuit (Fig. 7) was designed with two OPA660, namely realising the structure of Fig. 6. There the adder (*E3* in Fig. 6) is replaced ingeniousty by simpler resistive circuit (summing voltage divider R_3,R_4 and R_8 in Fig. 7). Similarly voltage dividers (R_1,R_2 a R_5,R_6), with higher ratio of the resistances, are in the inputs (B, E) of the both diamond transistors (DT_1 a DT_2) to reduce nonlinear distortion (instead linearizing diods). The transconductance (g_m) of the diamond transistors is adjusted on the basic value g_m = 1,9 mS, with external DC current source I_Q = - 0,1 mA. As mentioned before the change of this current gives the possibility of tuning or optimising the parameters of this filter.

The proposed circuit (Fig. 7) was simulated with PSpice using professional macro model of the OPA660. Resulting magnitude responses are in Fig. 8. They are quite good over a wide frequency range. The simulation results confirm the symbolical analysis and theoretical assumptions.

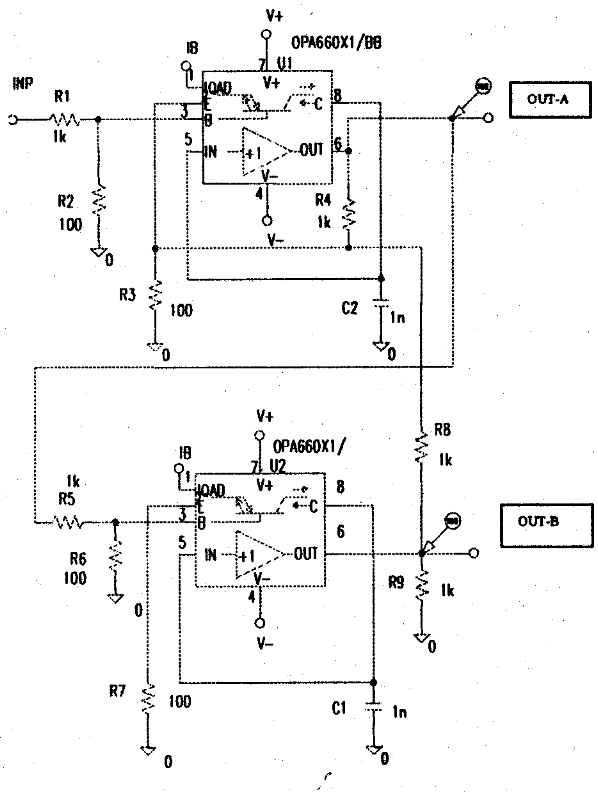


Fig. 7. Realisation of the biquad structure from the Fig. 6 using two OPA660.

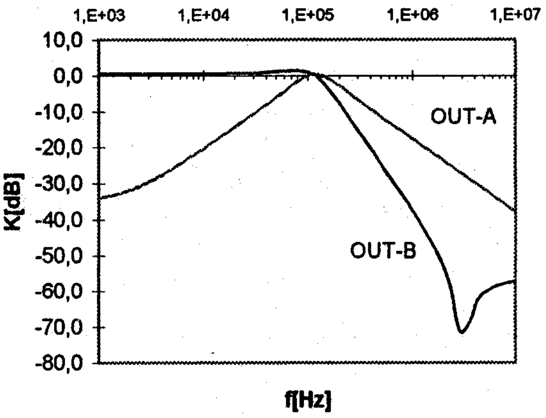


Fig. 8.. Magnitude responses of the simulated biquad from Fig. 7.

5. Conclusion

Several active RC first and second order filter structures were proposed and studied. These configurations are given using diamond transistors (VCCS) and voltage diamond buffers (VCVS), what is something else that the OTA-C structures in [4], which consists of the VCCS only.

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About author

Tomáš DOSTÁL was born in Brno, in 1943. He has received the CSc. (Ph.D) and DrSc. degree in electrical engineering from the Technical University Brno in 1976 and 1989 respectively. From 1973 to 1978, and from 1980 to 1984, he was with Military Academy Brno, from 1978 to 1980 with Military Technical College Baghdad. Since 1984 he has been with the Technical University Brno, where he is now Professor of Radioelectronics. His present interests are in the circuit theory, filters, switched capacitor networks and circuits in current mode.

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