BIQUAD FILTER WITH THREE TRANSFER FUNCTIONS EMPLOYING VOLTAGE CONVEYORS

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ABSTRACT

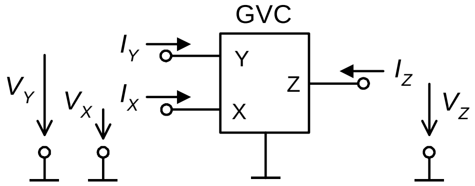
The design of a second order filter employing three voltage conveyors and offering three transfer functions is presented. The filter functionality is demonstrated by experimental measurements. The influence of parasitic conveyor properties on filter behavior is examined.

1 INTRODUCTION

Frequency filtering is one of the most widely used operations in analog signal processing. Recently the demands on high-frequency filters have been increased especially in connection with telecommunications, networking or multimedia. Signals with frequencies of tens megahertz are commonly used in these branches and thus filters with classical operational amplifiers are not fast enough for this purpose, due to their insufficient bandwidth. These problems can be solved by using modern active building blocks such as current or voltage conveyors. These elements operate in the mixed mode (with voltage and current signals), have a wide bandwidth (up to 100 MHz), unity voltage and current transfers, better noise immunity, and lower supply voltage, which is very advantageous in battery-powered portable systems [1].

2 VOLTAGE CONVEYORS

Voltage conveyors [2] are dual active elements to current conveyors [3], [4], [5]. They can be derived from particular variants of current conveyors by the interchange of voltages and currents in the describing equations. A hypothetical block called the General Voltage Conveyor (GVC) represents all variants of the voltage conveyor. Its schematic symbol and describing matrix equation are shown in Fig. 1. This element can be used in the filter design and, eventually, it is substituted by a concrete voltage conveyor by choosing concrete values of coefficients α, β and γ.



$$\begin{pmatrix} I_X \\ V_Y \\ V_Z \end{pmatrix} = \begin{pmatrix} 0 & \alpha & 0 \\ \beta & 0 & 0 \\ \gamma & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} V_X \\ I_Y \\ I_Z \end{pmatrix}, \text{ where } \begin{matrix} \alpha \in \{-1; 1\} \\ \beta \in \{-1; 0; 1\} \\ \gamma \in \{-1; 1\} \end{matrix}$$

Fig. 1: *Three-port general voltage conveyor and its definition equation*

Table 1 illustrates various variants of mutually dual current and voltage conveyors.

GCC	CCI+	CCI-	CCII+	CCII-	CCIII+	CCIII-	ICCI+	ICCI-	ICCII+	ICCII-	ICCIII+	ICCIII-
GVC	VCI+	VCI-	VCII+	VCII-	VCIII+	VCIII-	IVCI+	IVCI-	IVCII+	IVCII-	IVCIII+	IVCIII-
α	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1
β	1	1	0	0	-1	-1	1	1	0	0	-1	-1
γ	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1

Tab. 1: *Mutually dual variants of current and voltage conveyors*

3 FILTER DESIGN

Fig. 2 shows the general circuit with three VCII+ and seven admittances used in the filter design. This circuit includes one global feedback loop and it was designed such that the feedback is negative.

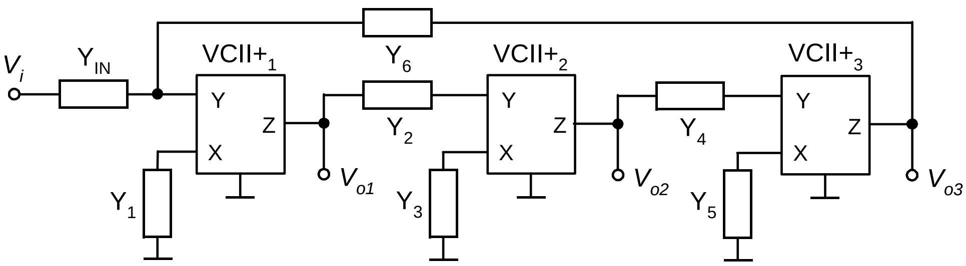


Fig. 2: *The general circuit used for filter design*

The characteristic equation of the circuit is

$$D = Y_1 Y_3 Y_5 + Y_2 Y_4 Y_6 = 0 . \qquad (3.1)$$

Pins Z can be used as filter voltage outputs because of their low impedance. Voltage input will be connected through the admittance Y_{IN} to the pin Y of the first conveyor. Let us choose this admittance resistive (G_{IN}). The circuit has the transfer functions as shown in Table 2.

Input / output	V_{o1}	V_{o2}	V_{o3}
V_i	$\frac{V_{o1}}{V_i} = \frac{-Y_3 Y_5 G_{IN}}{D}$	$\frac{V_{o2}}{V_i} = \frac{Y_2 Y_5 G_{IN}}{D}$	$\frac{V_{o3}}{V_i} = \frac{-Y_2 Y_4 G_{IN}}{D}$

Tab. 2: *Transfer functions between specified inputs and outputs*

It follows from Table 2, that admittance Y_1 or Y_6 must be a parallel connection of a resistor and a capacitor. Another two capacitors will be selected in the place of admittances Y_2, Y_4, or Y_3, Y_5 in order to get three filter transfer functions. The possibilities are summarized in Table 3.

Variant	Low-pass	Band-pass	High-pass
1	$\frac{V_{o1}}{V_i} = \frac{-R_1 R_6}{s^2 C_2 C_4 R_1 R_3 R_5 R_{IN} + s C_1 R_1 R_6 R_{IN} + R_6 R_{IN}}$	$\frac{V_{o2}}{V_i} = \frac{s C_2 R_1 R_3 R_6}{s^2 C_2 C_4 R_1 R_3 R_5 R_{IN} + s C_1 R_1 R_6 R_{IN} + R_6 R_{IN}}$	$\frac{V_{o3}}{V_i} = \frac{-s^2 C_2 C_4 R_1 R_3 R_5 R_6}{s^2 C_2 C_4 R_1 R_3 R_5 R_{IN} + s C_1 R_1 R_6 R_{IN} + R_6 R_{IN}}$
2	$\frac{V_{o3}}{V_i} = \frac{-R_1 R_6}{s^2 C_3 C_5 R_2 R_4 R_6 R_{IN} + s C_6 R_1 R_6 R_{IN} + R_1 R_{IN}}$	$\frac{V_{o2}}{V_i} = \frac{s C_5 R_1 R_4 R_6}{s^2 C_3 C_5 R_2 R_4 R_6 R_{IN} + s C_6 R_1 R_6 R_{IN} + R_1 R_{IN}}$	$\frac{V_{o1}}{V_i} = \frac{-s^2 C_3 C_5 R_1 R_2 R_4 R_6}{s^2 C_3 C_5 R_2 R_4 R_6 R_{IN} + s C_6 R_1 R_6 R_{IN} + R_1 R_{IN}}$

Tab. 3: *Transfer functions of designed filter variants between specified inputs and outputs*

These filters offer three transfer functions simultaneously (low-pass, band-pass and high-pass). Variant 2 is more advantageous, because there are fewer capacitors connected to conveyor voltage outputs Z.

4 EXPERIMENTAL MEASUREMENT

Filter variant 2 was practically constructed. Unfortunately no voltage conveyor is currently commercially available and that is why the VCII+ had to be replaced by a block with similar properties. The transconductance amplifier AD844 seemed to be a good replacement. It has a 60 MHz small-signal bandwidth and 50 Ω impedance of inverting input. The connection of AD844 as VCII+ is shown in Fig. 3.

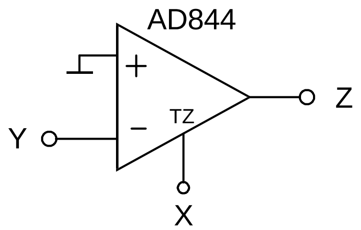


Fig. 3: *Amplifier AD844 as VCII+*

The filter was designed for characteristic frequency f_0 = 1 MHz and quality factor Q = 0.707 (Butterworth approximation). The resulting values of element parameters are $C_3 = C_5 = C_6$ = 100 pF, $R_{IN} = R_1 = R_6$ = 2250.8 Ω, $R_2 = R_4$ = 1591.55 Ω. The measured amplitude frequency responses of the designed filter are depicted in Fig. 4.

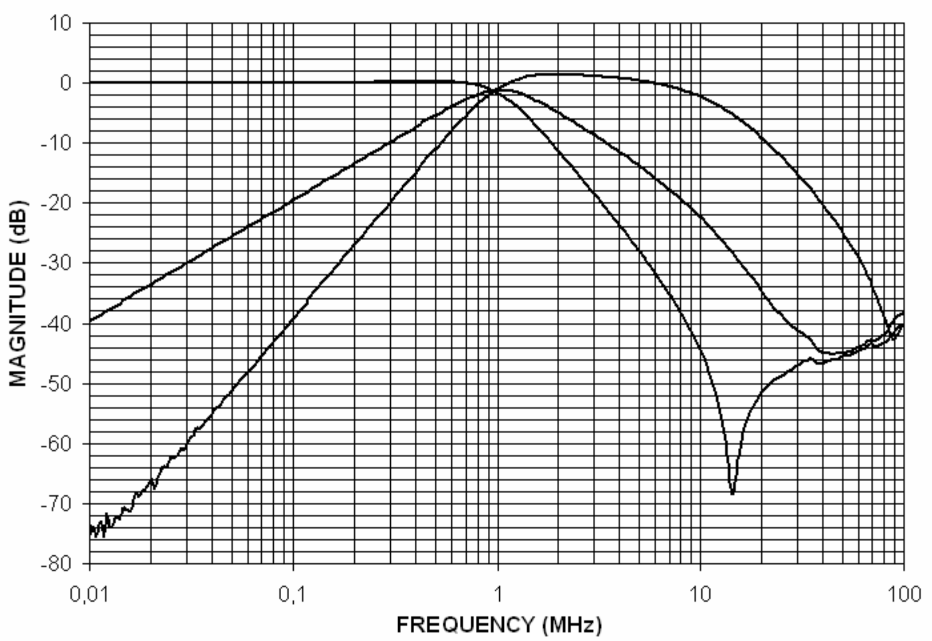


Fig. 4: *Measured amplitude frequency responses of the designed filter*

All three characteristics differ from ideal curves, especially at higher frequencies. The influence of conveyor parameters on the behavior of the filter was investigated by computer simulation. The inaccurate low-pass response at high frequencies is caused by the non-zero impedance of pins Y. The distortion of the band-pass and high-pass curves at high frequencies is due to the parasitic capacity of pins X and the frequency-limited controlled sources in AD844. The band-pass and high-pass characteristics at low frequencies are influenced by the resistance of pin X. The internal resistance of pin Z has only a negligible effect on the characteristics.

5 CONCLUSION

Current and voltage conveyors are modern active building blocks which offer high signal bandwidths (tens of MHz), lower supply voltages, and good noise parameters. A second-order filter with three voltage conveyors operating in the voltage mode as low-pass, band-pass and high-pass simultaneously was designed. The function of the filter was proved by experimental measurement. Computer simulation was used to determine which parasitic parameter of conveyors influenced the filter behavior. It has been found that the most critical parameters are the impedance of pins Y and the parasitic capacity of pins X.

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