High-Frequency Filter with UVCs Derived from RLC Structure

DAVID KUBANEK, KAMIL VRBA, RADEK SPONAR
Department of Telecommunications, Faculty of Electrical Engineering and Communication
Brno University of Technology
Purkynova 118, 612 00 Brno
CZECH REPUBLIC

Abstract: - An active filter derived from passive ladder structure is presented. It is based on integrators employing universal voltage conveyors. These building blocks provide high bandwidth, low supply voltage and good noise immunity. The proper function of the filter is proved by computer simulation and experimental measurement.

Key-Words: - High-frequency active filter, universal voltage conveyor

1 Introduction

Modern communication and information systems are still faster and require introducing new circuits that are capable to process high-frequency signals. Frequency filtering is one of the most often used operations in signal processing and analog filters belong to the most widely used electronic circuits. Recent development in networking and communications is especially oriented towards broadband multimedia signals and that is why it is necessary to use modern high-frequency active filters that employ new active elements. Utilization examples of such filters, made as integrated circuits, are transceivers for WLANs, fast Ethernet, cable modems or hard disk drive interfaces.

The designers today increasingly use elements operating in the mixed mode, i.e. current and voltage conveyors. They have some advantages compared to the classical active elements like opamps. They offer better frequency properties and the possibility to reduce supply voltage while preserving of noise immunity.

We will present the design of an active filter based on passive ladder structure [1]. Such filters retain the convenient low sensitivities of passive networks [1], do without bulky coils, and combined with modern active devices, they also have good frequency parameters. Voltage conveyors [2] - [7] will be used as the main building blocks.

2 Filter Design

2.1 Passive Prototype

We will use the third-order passive RLC prototype (Fig. 1) for the filter design. It is a low-pass (LP) filter with one zero (Cauer LP filter).

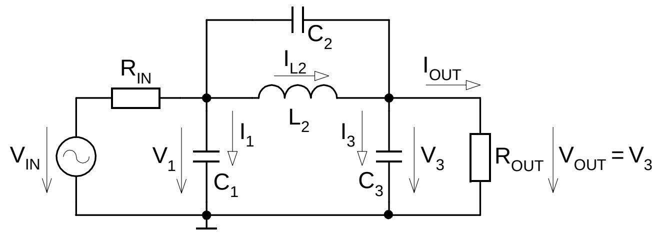

Fig.1. Passive filter prototype chosen for the design

The synthesis is based on the simulation of voltage-current relations in the RLC prototype. The following equations describe the filter in Fig.1; ($s = j\omega$ is the complex variable).

$$V_1 = \frac{1}{sC_1} I_1 , \tag{1}$$

$$V_3 = \frac{1}{sC_3} I_3 , \tag{2}$$

$$I_1 = \frac{1}{R_{IN}}\left(V_{IN} - V_1\right) - I_{L2} + sC_2\left(V_3 - V_1\right), \tag{3}$$

$$I_3 = I_{L2} + sC_2\left(V_1 - V_3\right) - \frac{V_3}{R_{OUT}} , \tag{4}$$

$$I_{L2} = \frac{1}{sL_2}\left(V_1 - V_3\right). \tag{5}$$

We modify these equations into a form that is more advantageous for our design:

$$V_1 = \frac{R_{IN}}{sR_{IN}(C_1 + C_2) + 1} I_1' , \quad \text{where } I_1' = V_{IN} / R_{IN} - I_{L2} + sC_2 V_3 , \tag{6}$$

$$V_3 = \frac{R_{OUT}}{sR_{OUT}(C_2 + C_3) + 1} I_3' , \quad \text{where } I_3' = I_{L2} + sC_2 V_1 , \tag{7}$$

$$I_{L2} = \frac{1}{R_{P2}} \cdot \frac{R_{P1}R_{P2}}{sL_2} \cdot \frac{1}{R_{P1}} V_1 - \frac{1}{R_{P2}} \cdot \frac{R_{P1}R_{P2}}{sL_2} \cdot \frac{1}{R_{P1}} V_3 , \quad (8)$$

where R_{P1} and R_{P2} are the new established arbitrary resistances.

The block diagram shown in Fig. 2 can be created according to equations (6) – (8).

The current branches are specified by the filled arrows and the voltage branches by the normal arrows. One lossless and two lossy integrators with current input and voltage output and current summers can be advantageously realized by simple networks with voltage conveyors as will be shown in the next chapter. The blocks with voltage input and current output can be easily realized by resistors or capacitors.

2.2 Summing integrator with UVC

The universal voltage conveyor (UVC) [5], [6], [7] is a new building block for high-speed analog circuits. Its internal structure is being developed in our workplace. It consists of simple current mirrors and voltage followers and thus it can reach high cut-off frequency up to 100 MHz. The schematic symbol of the UVC is shown in Fig.3.

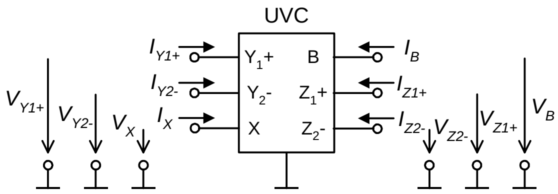

Fig.3 Universal voltage conveyor

It is described by the following equations: $I_X = I_{Y1+} - I_{Y2-}$, $V_{Y1+} = V_{Y2-} = V_B$ and $V_{Z1+} = -V_{Z2-} = V_X$. The pin B is grounded in most cases and thus $V_{Y1+} = V_{Y2-} = 0$. The main advantage of the UVC is that it can substitute all voltage conveyor variants which are dual to known current conveyor variants [10]. Furthermore, UVC is very useful in circuits with many feedbacks and feedforwards, such as state-variable or leap-frog circuits.

Summing lossy integrator with current inputs and voltage outputs employing a UVC is depicted in Fig.4. Its output voltages at pins Z_1+ and Z_2- referenced to the ground are

$$V_{Z1+} = -V_{Z2-} = -\frac{R}{sRC+1}\left(I_1 + I_2 + ... + I_N\right). \quad (9)$$

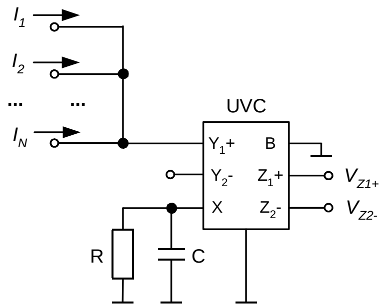

Fig.4 Summing lossy mixed-mode integrator with UVC

It can be seen that circuits like the one in Fig. 4 can supply lossy integrators with current summers at their inputs in Fig. 2.

2.3 Designed Filter with UVCs

If we substitute all blocks in the block diagram in Fig. 2 by networks with UVCs and passive elements, we get the resulting filter which is depicted in Fig. 5. It has the transfer function (10) which has the same form as the transfer function of the passive filter in Fig.1.

2.4 Computation of component values

We choose the Cauer approximation with a pass band ripple of 1 dB and a pass-band frequency of 5 MHz for the design of component values. First we will determine the component values of the passive prototype (see Fig. 1). We choose $R_{IN} = R_{OUT} = 100\ \Omega$ and compute $C_1 = C_3 = 636$ pF, $C_2 = 9.77$ pF, $L_2 = 3.1\ \mu$H. The subsidiary resistances chosen are $R_{P1} = R_{P2} = 563.4\ \Omega$ so that the capacitance C_P at port X of UVC_2 is equal to C_2. The element values in Fig. 5 are chosen from the standard EIA values E48: $R_{IN} = R_{OUT} = 100\ \Omega$, $C_{IN} = C_1 + C_2 = 649$ pF, $C_{OUT} = C_2 + C_3 = 649$ pF, $C_2 = 10$ pF, $C_P = L_2/(R_{P1}R_{P2}) = 10$ pF, $R_{P1} = R_{P2} = 562\ \Omega$.

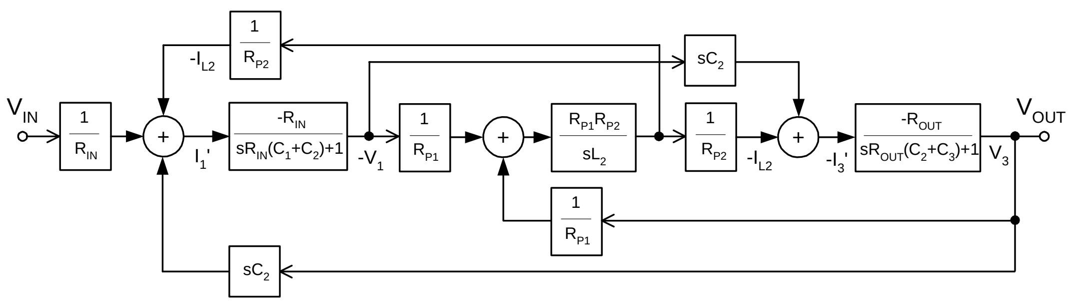

Fig.2 Block diagram derived from RLC filter

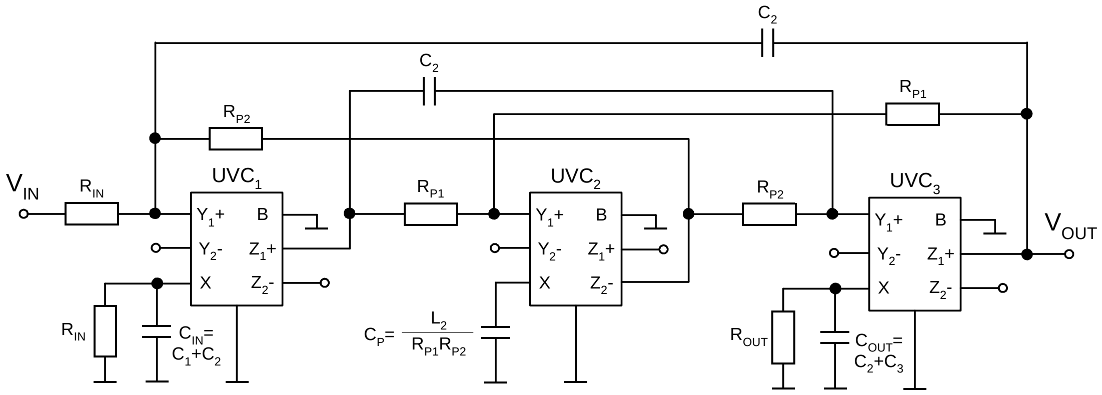

Fig.5 Designed filter with UVCs

$$\frac{V_{OUT}}{V_{IN}}=\frac{s^2R_{OUT}C_2L_2+R_{OUT}}{s^3R_{IN}R_{OUT}L_2(C_1C_2+C_1C_3+C_2C_3)+s^2L_2(R_{IN}C_1+R_{IN}C_2+R_{OUT}C_2+R_{OUT}C_3)+s(L_2+R_{IN}R_{OUT}C_3+R_{IN}R_{OUT}C_1)+R_{IN}+R_{OUT}} \quad (10)$$

3 Computer Simulation

Unfortunately no UVC has been manufactured yet, so we used a frequency-dependent model of UVC (Fig. 6) for PSpice simulation. This model includes parasitic properties that can be expected in a real UVC. Internal controlled sources are modelled by one-pole models with a cut-off frequency of 50 MHz. Terminals Y_1+, Y_2–, Z_1+ and Z_2– have internal series resistances of 5 Ω. A shunt resistance of 50 kΩ and a capacitance of 5 pF are connected to the X terminal. The simulated magnitude frequency characteristic of the designed filter is depicted in Fig.7.

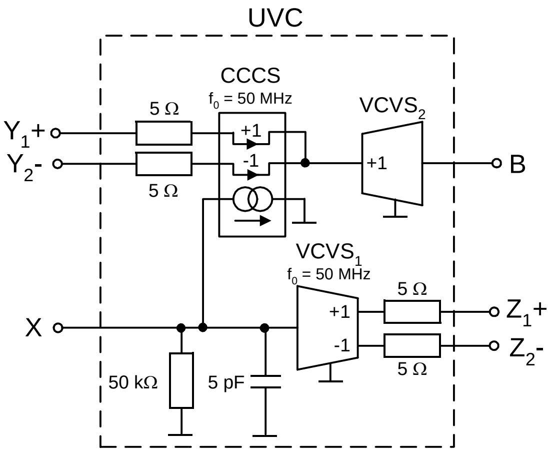

Fig.6 The UVC model used

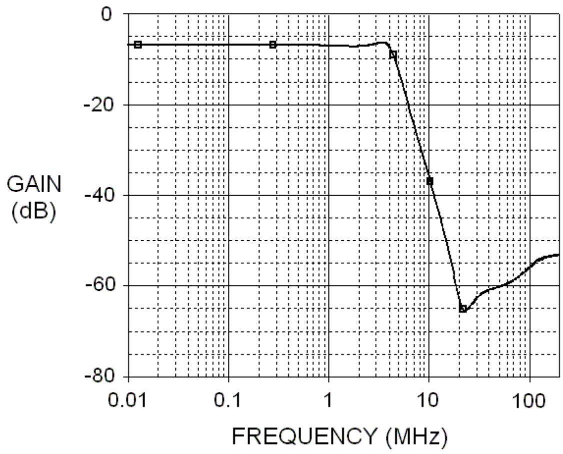

Fig.7 The simulated magnitude frequency characteristic of the designed filter

The module frequency characteristic is shifted 6 dB down the same as in passive filters with equal resistive termination. We can get the 0 dB low-frequency transfer by using half the resistance R_{IN} at filter input. The non-idealities at frequencies above 30 MHz are caused by non-zero input impedances of ports Y and output impedances of ports Z.

4 Experimental Results

UVC can be partially replaced by the commercially available amplifier AD844. The measured magnitude frequency characteristic of the designed filter is in Fig.9.

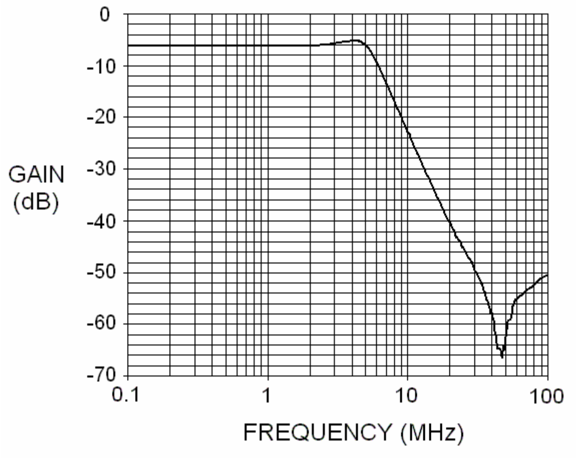

Fig.9 The measured magnitude frequency characteristic of the designed filter

4 Conclusion

A third-order low-pass active filter has been designed. The design was based on a passive ladder RLC prototype. The voltage-current relations in the ladder structure were simulated by a network that includes integrators as the main building blocks. Universal voltage conveyors were used in the integrators. These elements allow high-frequency signal processing, lower supply voltage, and provide better noise parameters. The filter retains the good sensitivity parameters of the passive prototype. The simulation in PSpice and experimental measurement proved the correct functioning of the filter at relatively high frequencies.

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