UTILIZATION OF BOOTSTRAP TECHNIQUE TO CONTROL FREQUENCY FILTER PARAMETERS

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Abstract

The principle of controlling parameters of active filters electronically by VCVSs is described. The discrete realizations of active filters with controlled parameters are discussed for the frequency band of about 1 MHz utilizing integrated voltage amplifiers with controlled gain.

Introduction

Today a number of fast voltage amplifiers are available whose gain can be continuously controlled by an auxiliary voltage or current. Let us mention, for exampe, types VCA610 (Burr-Brown), CLC520, CLC522 and CLC5523 (National Semiconductor), LT1251 and LT1256 (Linear Technology), and AD603 (Analog Devices). This opens up interesting possibilities of discrete realization of active filters with controlled parameters in the frequency band of about 1 MHz.

Filter parameters can be controlled by modifying some of its impedances. In the paper, we analyze immittance transformations by using VCVSs. We focus on two variants that are easily implemented in the active filters with grounded-input OpAmps [1,2].

Methods of modifying impedance by using voltage bootstrap

Let us mention the principle of voltage bootstrap. The originally grounded impedance outlet is reinforced with a voltage derived from the input voltage by an ideal VCVS with gain A' (see Fig. 1a). From the viewpoint of input terminal X, the impedance seems to be modified:

$$Z \to \frac{Z}{1-A'} \quad (1)$$

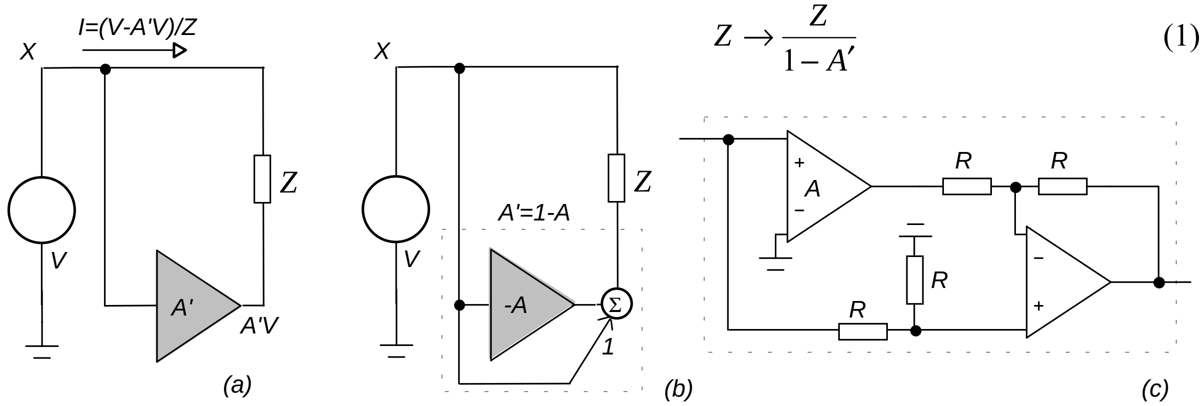

Fig. 1. Principle of voltage bootstrap (a). Controlling proportionally the grounded impedance by modifying the signal circuit part (b). Example of circuit realization (c).

In the case of controlling A' electronically, e.g. in the interval <-99,0>, impedance Z would appear with respect to the X terminal as grounded impedance, changing in the interval <0.01, 1>Z.

The principle mentioned above can be extended to an ungrounded impedance whose one outlet is connected to the OpAmp virtual ground [2,3]. Let us analyze the circuit in Fig. 2. This circuit is described by the following equations:

$$V_3 = -\frac{Z_3 + Z_4/A_2}{Z_1}V_1 - \frac{Z_3 + Z_4/A_2}{Z_2/A_1}V_2, \; V_4 = -\frac{A_2 Z_3 + Z_4}{Z_1}V_1 - \frac{A_2 Z_3 + Z_4}{Z_2/A_1}V_2 .$$

If we are interested in the input/output voltage relations, then the A amplifier works as an impedance transformer according to one of the formulae:

$$Z \to \frac{Z}{A} \text{ or } Z \to Z.A \tag{2}$$

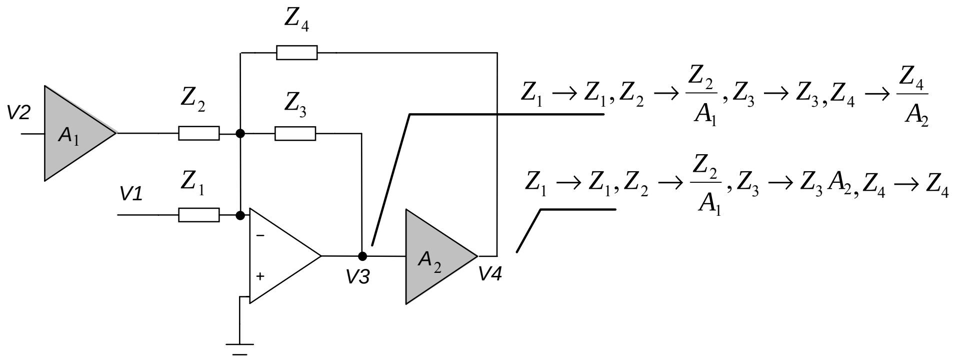

Fig. 2. Impedance transformation due to VCVS in OpAmp circuit.

The relativity of these transformations shows in different results according to which voltage is regarded as output voltage. As results from Fig. 2, the transformation of impedances Z_3 and Z_4 depends on whether voltage V_3 or V_4 is regarded as output voltage for further processing.

Inserting controlled voltage sources in various filter branches we can divide or multiply the given impedances by amplification and thus achieve controlling the filter parameters. If it is necessary to control according to Fig. 1 simultaneously a classical grounded impedance, the problem of different control formulae must be solved (see equations 1 and 2).

Methods of the gain setting

The problem of setting the gain will be demonstrated on the example of VCA610 integrated amplifier. As shown in Fig. 3, the gain in dB is practically a linear function of controlling voltage V in the range of 80dB for voltage in the interval from -2V to 0V. The cutoff frequency does not depend on the adjusted gain and it is approximately 30MHz. Because of VCA610 difference inputs, both the positive and the negative gains are easily to achieved.

The gain is then dependent upon the controlling voltage according to the formula

$$A_{dB} = -40(V+1) \quad [dB,V] \text{ for } V \in \langle -2,0 \rangle V \text{, or}$$
$$A = 10^{-2(V+1)} \quad [-,V] \text{ for } V \in \langle -2,0 \rangle V . \tag{3}$$

Consider an extreme case of synchronous impedance control according to three different formulae (1) and (2). Control of A gains is done synchronously by the joint control voltage according to (3). The problem of controlling a grounded impedance according to (1) consists in that controlling the filter parameters mostly leads to the following task: how many times we increase one impedance, so many times we have to increase (decrease) further impedances. This proportionality is only guaranteed for controlling the "virtual ground" impedances according to formulae (2).

The synchronous „proportional“ control is basically realizable by two different approaches: by modifying either the signal part of amplifier circuit or the circuit of gain control.

Consider the case when impedances Z_a, Z_b, and Z_c have to be controlled according to the functionality

$$Z_a \to Z_a / A,\ Z_b \to Z_b.A,\ Z_c \to Z_c / A, \tag{4}$$

where Z_a and Z_b are impedances with one outlet connected to the OpAmp virtual ground, and Z_c is a grounded impedance. An example of controlling Z_a and Z_b is given in Fig. 2 for the case of $Z_a = Z_2$, $Z_b = Z_3$, $A_1 = A_2 = A$, output V_4. However, impedance Z_b can also be controlled by front-end amplifier as in Z_a but with an inverse gain of $1/A$. This inversion can be achieved by two different methods: either connecting the controlled amplifier to an OpAmp feedback loop, or controlling the gain by voltage *V'*=-2-*V* [*V*,*V*] for $V \in \langle -2{,}0 \rangle V$ instead of the original voltage *V*. The second solution is definitely preferable: it is simpler and it does not modify the signal filter part with possible undesirable real influences.

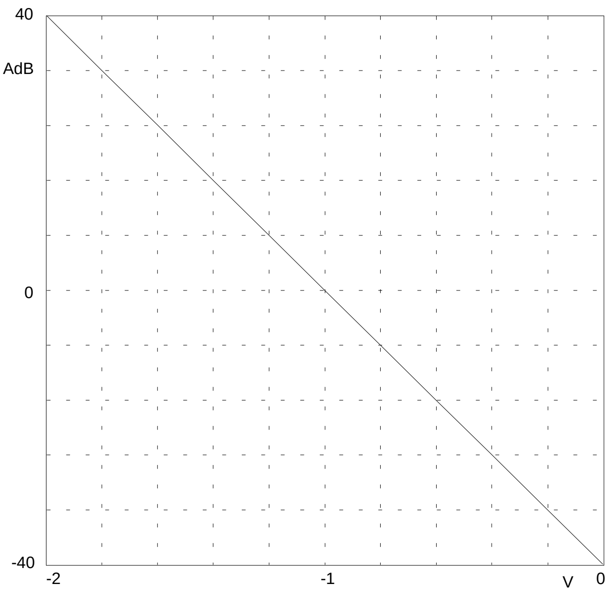

Fig. 3. DC gain of VCA610 versus controlling voltage.

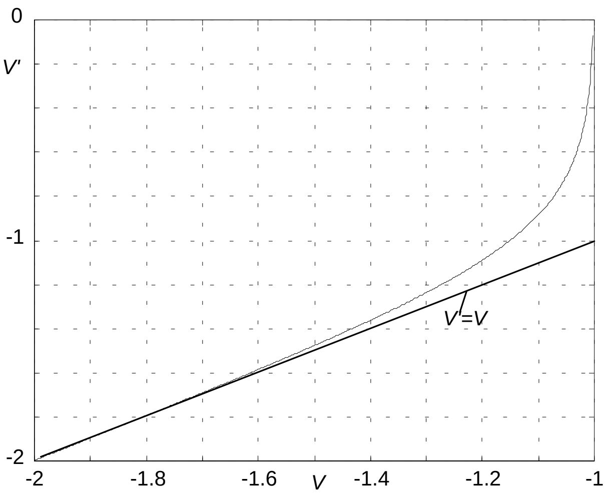

Fig. 4. Nonlinear gain control ensures proportional modification of grounded impedance.

The „proportional" control of grounded impedance is most problematic. It is necessary to ensure the correspondence

$$1 - A' = A \text{, or } 1 - A' = 1/A \qquad (5)$$

for the widest steering range.

The solution of the signal circuit part is shown in Figs. 1*b* and *c*. A disadvantage lies in the additional OpAmp, which can potentially impair the real properties of filter.

The solution in the circuit part of gain control will be shown on the assumption of *A* being controlled from 1 upwards. According to the graph in Fig. 3, the corresponding controlled voltage *V* will be in the range of <-1V, -2V>. Amplifier *A'* must be inverting. Let us also apply the inverting input of controlled amplifier with a gain of *A''*=-*A'*>0. This amplifier should be controlled by voltage *V'* to fulfill the condition

$$1 + A''(V') = A(V).$$

Substituting the controlling equation of VCA610 (3) and rearranging yield

$$V' = -0.5 \log\left(10^{-2V} - 100\right) \qquad (6)$$

The conversion characteristic of nonlinear circuit is in Fig. 4. This circuit modifies the voltage for controlling the inverting amplifier, which transforms the grounded impedance. The main disadvantage is half the controlling dynamics as compared to the solution in Fig. 1b.

Experimental verification

The controlling principles described above have been applied to the 2nd order bandpass filter in Fig. 5. Resonance frequency ω_0, quality factor *Q*, and peak gain K_{MAX} are as follows:

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}},\ Q = \sqrt{\frac{R_2 C_2}{R_1 C_1}},\ K_{MAX} = \frac{C_3}{C_1} \qquad (7)$$

Tuning the filter without modifying *Q* and K_{MAX}, or changing *Q* without modifying ω_0 and K_{MAX} can be accomplished, for instance, by the following transformation of R_1 and C_2:

$$R_1 \to aR_1, \quad C_2 \to aC_2 \quad \Rightarrow \quad \omega_0 \to \omega_0 / a, \quad Q \to Q, \quad K_{MAX} \to K_{MAX}\,, \tag{8}$$

or

$$R_1 \to aR_1, \quad C_2 \to C_2 / a \quad \Rightarrow \quad \omega_0 \to \omega_0, \quad Q \to Q / a, \quad K_{MAX} \to K_{MAX}\,. \tag{9}$$

Capacitor C_2 is grounded. That is why we control it either by the method in Fig. 1b, or we connect the bottom outlet by the output of VCA610 with the nonlinear gain control $V'=V'(V)$. Controlling the resistance R_1 will be ensured by another VCA610 amplifier, which will be connected instead of OPA2. Its classical control $V'=V$ leads to scheme (9), the inverse control $V'=-2-V$ then to scheme (8). In this simple way, modifying the circuit for setting the control voltage causes the different mechanisms of electronic control of filter parameters.
The mechanisms described have been simulated by using SPICE models in MicroCap VI program and finally verified by measuring with an HP 4195 A circuit analyzer. Setting Q or the bandwidth while ω_0 is constant (9) operates well in the range of 4 decades. The tuning of ω_0 is affected at both limits of frequency interval (100 Hz, 1 MHz) by real properties of VCA610 (substantial modification of frequency response in the lower limit, unstable behaviour in the upper limit).

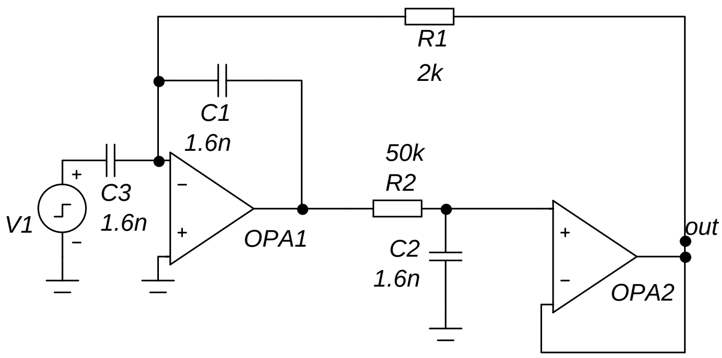

Fig. 5. Bandpass filter, f_0 = 10kHz, and Q = 5.

Conclusion

The principle of voltage bootstrap can be utilized for electronic control of filter parameters indirectly by transforming the impedances of individual components. The transformation is easy when one component outlet is connected to the OpAmp virtual ground. The methods of transforming grounded impedances are also discussed, namely by the circuit solution of either the signal or the gain control filter parts.

Acknowledgement

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