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Design of the Second-Order Voltage-Controlled Multifunctional Filter

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***Abstract*-This paper proposes a method that analog multiplier and current feedback operational amplifier have been used to form second-order voltage-controlled multifunctional filter. The designed circuit has been achieved theoretical analysis, PSPICE simulation and actual measurement. It can simultaneously realize low-pass, high pass and band pass filter function. Results show that the pass band can be adjusted with the frequency range of the input signal, and can be used in the field of frequency characteristic analysis, harmonic analysis, frequency measurement, signal detection. Furthermore, it shows more importance in theoretical significance and application prospects.**

Keywords- voltage-controlled; multifunctional filter; multiplier; current feedback

I. INTRODUCTION

At present, there are three main methods to design a controllable filter[1-3]. The first one called active filter is composed of the resistance, capacitance and an operational amplifier, and to change the values of the network for realizing adaptive function are mainly by simulating the analog switch or the digital potentiometer resistance. The filter circuit is complex, the pass band range is small and finite number of discrete values can be taken in the cut-off or center frequency of the filter. The second way is adopting the existing integrated filter chip can realize low-pass, high-pass, band-pass, band-stop, all pass filtering, and better stability, cut-off or center frequency controllable (generally below 200KHz), but in the process of circuit exists noise, signal aliasing problems; the last method is that the signal is sampled by the ADC, the DSP chip to implement digital filter and then output from DAC. This filter’s cut-off frequency using the method is limited mainly by the ADC/DAC speed. The above three methods have a common drawback, namely the filter cut-off or center frequency is not high and is not easy to adjust, which is difficult to meet the requirements of high-speed and broadband signal processing. Therefore, this paper designs a second-order voltage-controlled multifunctional filter. It takes the high performance multiplier and current feedback amplifier to achieve multifunction filter.

II. THE CURRENT FEEDBACK OPERATIONAL AMPLIFIER

Current feedback operational amplifier is a new kind of current mode amplifier[4-8], which is simplified as shown in Figure 1, the input impedance is very high, complementary emitter follower is composed by Q1 and Q2, the input signal can be directly buffered to the inverting terminal. In an ideal case, emitter resistance can be ignored as zero, so the inverting input impedance is very low (typically 10 euro -100). This is the basic difference between the current feedback operational amplifier and voltage feedback operational amplifier. This feature makes the current operational amplifier has more advantages than the voltage amplifier.

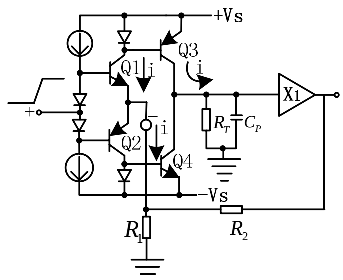

FIGURE I. SIMPLIFIED CURRENT FEEDBACK OPERATIONAL AMPLIFIER.

The collector output of Q1 and Q2 drives the mirror current source, the latter is the inverting input high impedance node current mirror to RT and CP at the end, this node is buffered by complementary unity-gain emitter follower. The output to the inverting input forces inverting feedback input current be zero, this is the definition of current feedback. Ideally, the inverting input impedance is zero, namely there is no small signal voltage, only small signal current.

Figure 2 shows the model and the corresponding current feedback operational amplifier of the Bode diagram. It adopts logarithmic coordinate axis, and the open loop gain is expressed as mutual resistance T (S), which the units is ohms. R0 represents the output impedance, I is input error current. According to the negative feedback theory, it can obtain the transfer function of the operational amplifiers is:

$$\frac{v_{out}}{v_{in}} = \frac{1+R_2/R_1}{1+jwC_P R_2(1+R_o/R_2+R_o/R_1)} \tag{1}$$

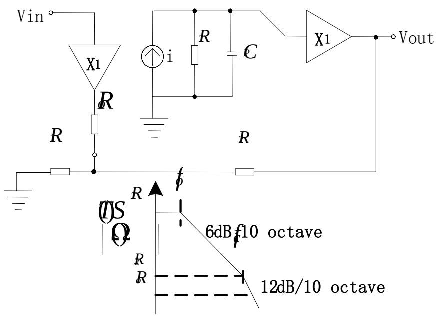

FIGURE II. CURRENT FEEDBACK OPERATIONAL AMPLIFIER MODEL AND BODE DIAGRAM.

Operational amplifier in 3dB closed loop bandwidth of the corresponding frequency is:

$$f_{c1} = \frac{1}{2\pi C_P R_2(1+R_o/R_2+R_o/R_1)} \tag{2}$$

When R0 is much less than R1and R2, so that

$$f_{c1} = \frac{1}{2\pi C_P R_2} \tag{3}$$

It can be seen from formula (3) that the closed-loop bandwidth of current operational amplifier is decided together by internal dominant pole capacitor CP and external feedback resistors R2, ignoring the gain setting resistor R1. Thus, current feedback operational amplifier can arbitrarily change the gain size without changing the bandwidth. Because bandwidth and an external feedback resistor R2 are closely related, so the current feedback resistor often uses special optimization.

III. SECOND-ORDER VOLTAGE-CONTROLLED MULTIFUNCTION FILTER DESIGN AND IMPLEMENTATION

Based current feedback operational amplifier, active filter is designed as follows: at first, the operational amplifier in voltage mode filter is replaced by that in a current feedback, then the original network is replaced by the adjoin network. This filter is the current mode filter.

Second-order voltage-controlled multifunction filter is designed as shown in Figure 3,it can simultaneously realize low pass, high pass, band pass filter function. The circuit is consisting of 6 resistors, 2 capacitors, 3 operational amplifiers and 2 analog multipliers. The specific circuit is shown as follows , U1, R1, R2, R5, R6 form in phase summation circuit; U3, R3, C2form integral circuit; U5, R4, C1form differential circuit; U2, U4 analog multiplier MLT04 realize the basic multiplication, so as to realize the voltage control function. The characteristic of this circuit is: one input, three output; the filter cut-off frequency and quality factor Q is equal; but the filter gain is different.

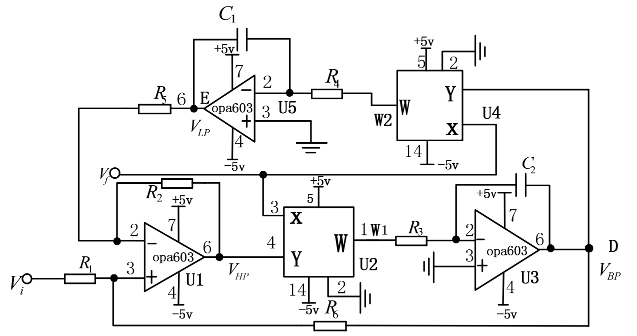

FIGURE III. SECOND-ORDER VOLTAGE-CONTROLLED MULTIFUNCTION FILTER CIRCUIT.

According to Kirchhoff's law and figure 3, transfer function of the filter can be respectively:

$$H_{LP}(s) = \frac{\frac{R_6(R_2+R_5)V_f^2}{(R_1+R_6)2.5R_3R_4R_5C_2C_1}s}{s^2+\frac{R_6(R_2+R_5)V_f}{(R_1+R_6)C_2 2.5R_3R_5}s+\frac{V_f^2 R_2}{2.5^2 R_3R_4R_5C_1C_2}} \tag{4}$$

$$H_{BP}(s) = \frac{\frac{R_6(R_2+R_5)V_f^2}{(R_1+R_6)2.5R_3R_5C_2}s}{s^2+\frac{R_6(R_2+R_5)V_f}{(R_1+R_6)C_2 2.5R_3R_5}s+\frac{V_f^2 R_2}{2.5^2 R_3R_4R_5C_1C_2}} \tag{5}$$

$$H_{HP}(s) = \frac{\frac{R_6(R_2+R_5)}{R_5(R_1+R_6)}s^2}{s^2+\frac{R_6(R_2+R_5)V_f}{(R_1+R_6)C_2 2.5R_3R_5}s+\frac{V_f^2 R_2}{2.5^2 R_3R_4R_5C_1C_2}} \tag{6}$$

Each filter cut-off orcenter frequency and Q value are the same, respectively:

$$f_{LP} = f_{BP} = f_{HP} = \frac{v_f\sqrt{R_2}}{5\pi\sqrt{R_3R_4R_5C_1C_2}} \tag{7}$$

$$Q = (1+\frac{R_6}{R_1})\frac{1}{\sqrt{R_5/R_2+R_2/R_5}}\sqrt{\frac{R_3C_2}{R_4C_1}} \tag{8}$$

The gain of the filter circuit, respectively

$$A_{LP} = \frac{R_6(R_2+R_5)}{R_2(R_1+R_6)} \tag{9}$$

$$A_{BP} = \frac{R_6}{R_1} \tag{10}$$

$$A_{HP} = \frac{R_6(R_2+R_5)}{R_5(R_1+R_6)} \tag{11}$$

From equation (7), it can be seen that all the cut-off or center frequency of the filter is proportional to the control voltage Vf. From the equation (8)-(11)，it can be get that quality factor Q and gain A type can be adjusted independently, which are not controlled by Vf. Figure 4 shows the result of the amplitude-frequency characteristic when the input signal range is 1V, the output frequency is 9M. Figure 5 shows the result of the amplitude-frequency characteristic when the input signal range is 0.2V,0.4V,0.6V,0.8V and 1.0V.

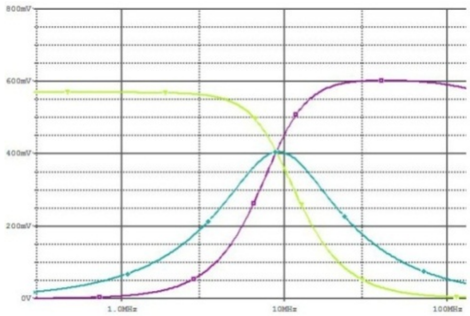

FIGURE IV. AMPLITUDE-FREQUENCY CHARACTERISTIC DIAGRAM (A).

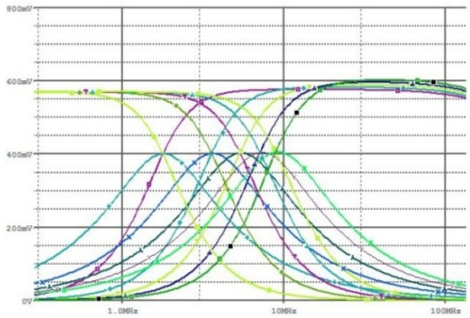

FIGURE V. AMPLITUDE-FREQUENCY CHARACTERISTIC DIAGRAM (B).

IV. SUMMARY

This paper introduces in detail the high performance multiplier and current feedback operational amplifier to achieve high speed second-order voltage-controlled multifunction filter, which can simultaneously realize low-pass, high pass, band pass filter function. Through theoretical analysis, circuit simulation and hardware measurement, it realizes the multifunction filter function. This circuit filter design is used in frequency characteristics, domain analysis, frequency measurement, signal detection, which has an important application foreground.

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REFERENCE

[1] GaoMingfu Yang Yong Kong Lingbin. Design of Low-pass Filter of Second-order Voltage-controlled Voltage Source[J]. Electronic Component & Device,2010,03,73-75.

[2] 2.R. Punchalard, A. Lorsavatsiri, W. Loetwassana, J. Koseeyaporn, P. Wardkein, A. Roeksabutr, Direct frequency estimation based adaptive algorithm for a second-order adaptive FIR notch filter[J]. Signal Process, 2008,8 (2), 315-325.

[3] ZHANG Li,WUEnde,WANGZhihua,CHENHongyi. CMOS voltage-controlled oscillatorwith automatic amplitude control[J]. Journal of Tsinghua University(Science and Technology),2006,46(7),1337-1340.

[4] [DUAN Xiao-feng, CHEN Xiang-dong, LI Wen-mo.A New- style CMOS Cur r ent- feedback OperationalAmplifiers[J]. Microelectronics & Computer,2006,23(7),182-188.

[5] SHI Huijie, WANG Weidong. LowVoltage and HighDrive CMOS Current Feedback Operational Amplifier[J]. Microelectronics,2011,41(3),323-327.

[6] Ma.S.Q, Ran.X.P, Fan.M.H. The design of the self-adaptive low-pass filter[J]. Piezoelectrics& Acoustooptics.2013,35(2): 245-249.

[7] Sheng-qian Ma, Yan-ping Ji, Xing-ping Ran, etc. Design of the Voltage-controlled Bandpass Filter Based on CurrentFeedback Op Amp[C].Advanced Materials Research Vols. 2014:1081-1085.

[8] Ma Shengqian, Yang Yang, Liu Juanfang. Adaptive low pass filter circuit implemented by ADPLL[J]. Computer Engineering and Applications, 2014, 50(3):181-184.