A multifunction filter configuration based on CFA

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Abstract. A new multifunction filter configuration using two CFAs and six impedances is presented in this paper. The proposed circuit can realize the different function using the different impedances. The natural frequency ω0 and quality factor Q can be orthogonal controlled, and the quality factor Q can also be independently controlled by the impedance. Both the active and passive sensitivities are no more than unity. At the end, the theoretical analysis is verified using PIPICE simulations of the filter designs.

Introduction

In analog signal processing, the current mode circuits have drawn more and more attentions. Many current mode circuits have been put forward recently, such as static current mirror, cross wire circuit, current transmitter, current feedback operational amplifier (transimpedance operational amplifier), etc. Strictly speaking, current transmitter and current feedback amplifier should be the current/voltage hybrid circuits[1]. However, the current mode is the main, and plays a main role in the current performance. Therefore, put them in the current mode circuits.

Current Feedback Operational Amplifier (CFA for short), also called transimpedance Operational Amplifier, it is a new type of ultra high speed amplifier which developed very quickly in the early 1990s[2].When the negative Feedback closed loop works, the input feeds in low resistance, the feedback of the Reversed-Phase input is current, it is a kind of transimpedance amplifiers with input voltage buffer. Compared with the traditional voltage mode operation amplifier also named Voltage Feedback Operational Amplifier (VFA for short), it has completely different topology and working principle, and it is the latest achievement of integrated operational amplifier[3]. In this paper, the structure of a multifunction filter is composed of two CFA and six impedance elements. The function of the filter can be realized by changing the impedance elements without changing the structure. The natural frequency ω_0 and quality factor Q can be orthogonal controlled, and the quality factor Q can also be independently controlled by the impedance. Both the active and passive sensitivities are no more than unity. The results obtained from the PSPICE simulations are consistent with the theoretical analysis.

Port Properties of Current Feedback Amplifier

As a four terminal network, CFA's ideal port properties is[4]

$$\begin{pmatrix} V_x \\ I_y \\ I_z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \pm 1 \end{pmatrix} \begin{pmatrix} V_y \\ V_z \\ I_x \end{pmatrix}, \text{ and } \quad V_o = V_z \tag{1}$$

Its representative symbol is shown in Fig. 1, where "x" is Reversed-Phase input (current input), "Y" is in-phase input (voltage input). "+" for CFA+, "-" for CFA-.

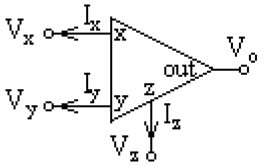

Fig.1. Symbol of CFA

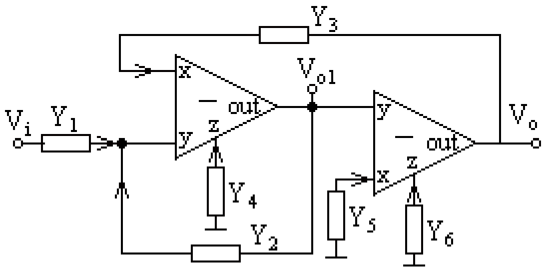

Fig.2. Multifunction Filter Configuration

Circuit Description

The structure of the multifunction filter with two CFA- and six impedance elements is shown in Fig. 2. According to the circuit of Fig. 2 and the port properties of CFA, it is available[5]:

$$V_o = \frac{Y_1Y_3Y_5}{D}V_1 \quad , \quad V_{o1} = -\frac{Y_1Y_3Y_6}{D}V_1 \tag{2}$$

Where

$$D = Y_1Y_3Y_5 + Y_2Y_3Y_5 + Y_2Y_3Y_6 + Y_1Y_4Y_6 + Y_2Y_4Y_6 \tag{3}$$

Considering the non ideal characteristic of CFA:

$$I_z = aI_x, V_x = bV_y, V_o = gV_z \tag{4}$$

Where $a = 1 - e_1$ ($e_1 << 1$) is current transmission error of CFA , $b = 1 - e_2$ ($e_2 << 1$) is input voltage transmission error, $g = 1 - e_3$ ($e_3 << 1$) is output voltage transmission error. Transmission function of the filter can be rewritten as[6]:

$$V_o = \frac{a_1a_2b_1b_2g_1g_2Y_1Y_3Y_5}{T}V_1,\ V_{o1} = -\frac{a_1b_1g_1g_2Y_1Y_3Y_6}{T}V_1 \tag{5}$$

Where

$$\mathrm{T} = a_1a_2b_2g_1g_2\mathrm{Y}_1\mathrm{Y}_3\mathrm{Y}_5 + a_1a_2b_1b_2g_1g_2\mathrm{Y}_2\mathrm{Y}_3\mathrm{Y}_5 + a_1b_1g_1g_2\mathrm{Y}_2\mathrm{Y}_3\mathrm{Y}_6 + \mathrm{Y}_1\mathrm{Y}_4\mathrm{Y}_6 + b_1\mathrm{Y}_2\mathrm{Y}_4\mathrm{Y}_6 \tag{6}$$

When the six impedance elements are different, the functions are also different:

(1)When $Y_4 = SC_4, Y_6 = SC_6$, the rest of the components are resistance, the circuit can achieve two order low-pass and band-pass filter, the transmission function of the circuit is written as:

$$V_o = \frac{G_1G_3G_5}{D_1}V_1\ ,\ V_{o1} = -\frac{SG_1G_3C_6}{D_1}V_1 \tag{7}$$

Where D can be rewritten as

$$D_1 = S^2C_4C_6(G_1+G_2) + SC_6G_2G_3 + (G_1+G_2)G_3G_5 \tag{8}$$

The natural frequency ω_0 and quality factor Q :

$$w_o = \frac{1}{\sqrt{C_4C_6R_3R_5}}\ ,\ Q = (1+\frac{R_2}{R_1})\sqrt{\frac{C_4R_3}{C_6R_5}} \tag{9}$$

Considering the non ideal characteristic of CFA, the natural frequency ω_0 and quality factor Q :

$$w_o=\sqrt{\frac{a_1a_2b_2g_1g_2}{C_4C_6R_3R_5}}\ ,\ Q=(1+\frac{R_2}{b_1R_1})\sqrt{\frac{a_2b_2C_4R_3}{a_1g_1g_2C_6R_5}} \tag{10}$$

The sensitivities of passive and active components caused by ω_o、Q are respectively:

$$S^{w_o}_{C_4,C_6,R_3,R_5}=-\frac{1}{2},S^{Q}_{C_4,R_3}=\frac{1}{2}=-S^{Q}_{C_6,R_5}\ ,\quad S^{Q}_{R_2}=1=-S^{Q}_{R_1},S^{w_o}_{a_1,a_2,b_2,g_1,g_2}=\frac{1}{2},$$

$$S^{Q}_{b_1}=-1,S^{Q}_{a_2,b_2}=\frac{1}{2}=-S^{Q}_{a_1g_1g_2} \tag{11}$$

(2)When $Y_3=SC_3,Y_5=SC_5$, the rest of the components are resistance, the circuit can achieve two order high-pass and band-pass filter, the transmission function of the circuit is written as:

$$V_o=\frac{S^2G_1C_3C_5}{D_2}V_1\ ,\ V_{o1}=-\frac{SG_1C_3G_6}{D_2}V_1 \tag{12}$$

Where D can be rewritten as

$$D_2=S^2C_3C_5(G_1+G_2)+SC_3G_2G_6+(G_1+G_2)G_4G_6 \tag{13}$$

The natural frequencyω_0 and quality factor Q :

$$w_0=\frac{1}{\sqrt{C_3C_5R_4R_6}}\ ,\ Q=(1+\frac{R_2}{R_1})\sqrt{\frac{C_5R_6}{C_3R_4}} \tag{14}$$

Considering the non ideal characteristic of CFA, the natural frequency ω_0 and quality factor Q :

$$w_o=\frac{1}{\sqrt{a_1a_2b_2g_1g_2C_3C_5R_4R_6}}\ ,\ Q=(1+\frac{R_2}{b_1R_1})\sqrt{\frac{a_2b_2C_5R_6}{a_1g_1g_2C_3R_4}} \tag{15}$$

The sensitivities of passive and active components caused by ω_o、Q are respectively:

$$S^{w_o}_{C_3,C_5,R_4,R_6}=-\frac{1}{2}\ ,\ S^{Q}_{C_5,R_6}=\frac{1}{2}=-S^{Q}_{C_3,R_4}\ ,\ S^{Q}_{R_2}=1=-S^{Q}_{R_1}\ ,\ S^{w_o}_{a_1,a_2,b_2,g_1,g_2}=-\frac{1}{2}\ ,$$

$$S^{Q}_{b_1}=-1\ ,\ S^{Q}_{a_2,b_2}=\frac{1}{2}=-S^{Q}_{a_1g_1g_2} \tag{16}$$

It is known from Eq. (9)(10)and Eq.(14)(15), for the two cases, the natural frequency ω_0 and quality factor Q of the filter can be orthogonal controlled by impedance elements Y_3,Y_4,Y_5 and Y_6 independently, and quality factor Q can also is controlled by resistors R_1 and R_2 separately. Moreover, both the active and passive sensitivities are no more than unity.

(3)When $Y_2=SC_2,Y_3=SC_3$, the rest of the components are resistance, both the outputs of the circuit can achieve two order band-pass filter. While the previous two cases has been able to achieve band-pass filtering, so the third case need not be considered.

The circuit structure is designed to achieve the function of the two order filter, and this structure can also achieve the three order filter:

(4)When $Y_1=SC_1,Y_3=SC_3,Y_5=SC_5$,the rest of the components are resistance, the circuit can achieve three order high-pass and band-pass filter, the transmission function of the circuit is written as:

$$V_o=\frac{S^3C_1C_3C_5}{D_4}V_1\ ,\ V_{o1}=-\frac{S^2C_1C_3G_6}{D_4}V_1 \tag{17}$$

Where D can be rewritten as

$$D_4 = S^3 C_1 C_3 C_5 + S^2 C_3 C_5 G_2 + S G_6 (C_3 G_2 + C_1 G_4) + G_2 G_4 G_6 \tag{18}$$

(5)When $Y_2 = SC_2, Y_3 = SC_3, Y_5 = SC_5$,the rest of the components are resistance, the circuit can achieve three order high-pass and band-pass filter, the transmission function of the circuit is written as:

$$V_o = \frac{S^2 G_1 C_3 C_5}{D_5} V_1 \ , \ V_{o1} = -\frac{S G_1 C_3 G_6}{D_5} V_1 \tag{19}$$

Where D can be rewritten as

$$D_5 = S^3 C_2 C_3 C_5 + S^2 C_3 (C_5 G_1 + C_2 G_6) + S C_2 G_4 G_6 + G_1 G_4 G_6 \tag{20}$$

(6)When $Y_2 = SC_2, Y_4 = SC_4, Y_6 = SC_6$,the rest of the components are resistance, the circuit can achieve three order low-pass and band-pass filter, the transmission function of the circuit is written as:

$$V_o = \frac{S^3 G_1 G_3 G_5}{D_6} V_1 \ , \ V_{o1} = -\frac{S^2 G_1 G_3 C_6}{D_6} V_1 \tag{21}$$

Where D can be rewritten as

$$D_6 = S^3 C_2 C_4 C_6 + S^2 C_6 (C_4 G_1 + C_2 G_3) + S C_2 G_3 G_5 + G_1 G_3 G_5 \tag{22}$$

Computer Simulation

The two order circuit is simulated using PSPICE. In case 1, when R_i=10kΩ,(i=1,2,3,5),C_4=C_6=1.59nF. In case 2, when R_i=10kΩ,(i=1,2,4,6),C_3=C_5=1.59nF, The response curves can be obtained respectively as shown in Fig. 3 and Fig.4.

In case 1, when R_i=10kΩ,(i=1,2,3,5),change the value of C_4 and C_6, observing the change of the natural frequency ω_0 and quality factor Q. From Fig. 5 and Fig. 6, which can be seen that the natural frequency ω_0 and quality factor Q can be orthogonal controlled by capacitance C_4 and C_6.

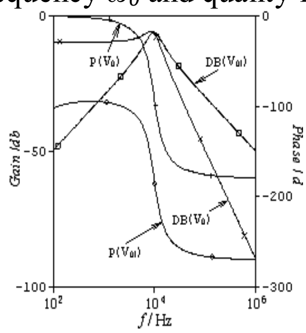

Fig.3. Response curves In case 1

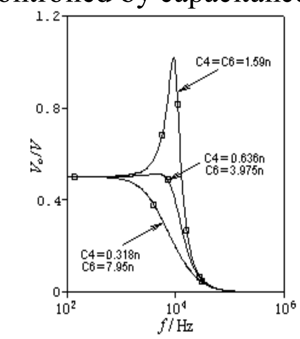

Fig.5.Low-pass amplitude-frequency curves

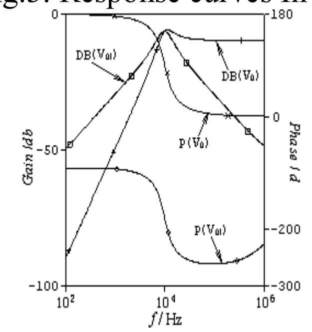

Fig.4. Response curves In case 2

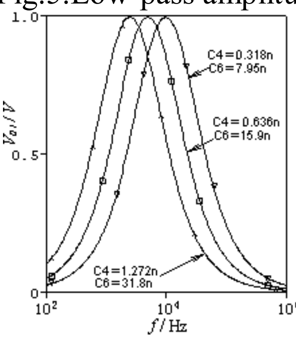

Fig.6.Band-pass amplitude-frequency curves

Conclusions

In this paper, a multifunction filter is designed with two CFA- and six impedance elements. Without changing the circuit structure, the different filter function can be realized by changing the impedance elements. The natural frequencyω0 and quality factor Q can be orthogonal controlled, and the quality factor Q can also be independently controlled by the impedance. Both the active and passive sensitivities are no more than unity. Although the quality factor Q can be adjusted by the impedance element, but at the same time, it will affect the amplitude of the output signal. At the end, the circuit is simulated by PSPICE. The simulation results are in agreement with the theoretical analysis.

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