

Design of Self-tracking High-pass Filter

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Abstract. A novel self-tracking high-pass filter by using analog multiplier and current feedback op-Amp (CFA) is proposed in this paper. The frequency-voltage (F/V) converter transforms the input pulse signal into the voltage, and then the output of F/V converter controls the cut-off frequency of voltage controlled high-pass filter. Thus, the cut-off frequency of designed filter is linear with the frequency of input signal in case that resistors and capacitors are reasonable adjusted. The experiment and simulation results show that the cut-off frequency of designed filter is 1 kHz-100 kHz.

1 Introduction

Filters are widely used in information processing, automatic control, communications, and other fields. In the process of signal transmission, the signal is usually contaminated by noise. Using filtering technology can extract the useful signal, while suppressing the noise. The fixed cut-off frequency filter can be used in the situation of narrow range of the signal frequency. The frequency of the input signal often changes with the time. Therefore, the fixed cut-off frequency of the filter is difficult to meet the requirements. A self-tracking high-pass filter is proposed in this paper, and its cut-off frequency follows the frequency of the input signal.

There are three ways to regulate the cut-off frequency of filter. Firstly, the cut-off frequency of filter can be adjusted by variable resistors and capacitors [1, 2]. In these filters, the cut-off frequency can only take the limited discrete value. What's more, variable resistors and capacitors may be cause unpredictable effects on signal amplitude and phase. Secondly, filter can be realized by the current mode technique, the cut-off frequency can be adjusted by bias current [3-6]. In these circuits, floating capacitor is used, and X terminal of the CCII is connected with a capacitor, which is easy to cause the circuit self-oscillates. Thirdly, the monolithic active filter chip, such as MAX26X, MAX29X, MAX27X, can be used [7, 8]. Although the cut-off frequency of these chips can be programmed (generally less than 1MHz), it is difficult to realize the continuous adjustment of the cut-off frequency. In this paper, a new self-tracking high-pass filter is proposed. It is based on the high performance of F/V converter LM331, the analog multiplier MLT04 and CFA (AD8001). The cut-off frequency of filter can automatically follows the frequency variation of input signal.

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2 The principle of self-tracking high-pass filter

The principle of self-tracking high-pass filter is shown in figure 1, which is composed of six parts: signal conditioning circuit, shaping circuit, F/V converter, programmable gain amplifier, control circuits based on FPGA and voltage controlled high-pass filter. At first, the input signal (V_{in}) amplified by signal conditioning circuit is converted into rectangular wave by shaping circuit. Since the bandwidth of F/V converter is no more than 3MHz, the frequency dividing circuit is designed, which scales down the frequency of input signal to the bandwidth range of F/V converter. Then the output voltage of F/V converter (V_f) multiplied frequency dividing coefficients is frequency-voltage conversion of the input signal. At last, the cut-off frequency of high-pass filter is continuously controlled by adjusting V_f . In order to realize the fast and real-time measurement, the frequency measurement circuit and frequency dividing circuit are designed by FPGA.

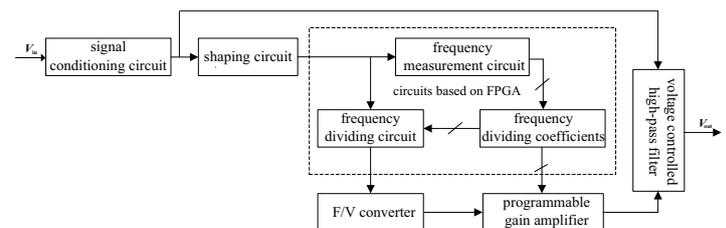


Figure 1. The principle diagram of self-tracking high-pass filter

2.1 Wide-band signal conditioning circuit

The wide-band signal conditioning circuit mainly realizes the gain adjustment of the input signal, including the

variable gain control circuit and the fixed gain control circuit. The circuit diagram is shown in figure 2(a) and figure 2(b). The AD603 is a low noise, voltage-controlled amplifier for using in RF and IF AGC systems. It provides accurate, pin-selectable gains of -11 dB to +31 dB with a bandwidth of 90 MHz or 0~+40dB with a bandwidth of 30 MHz or +9 dB to 51+ dB with a bandwidth of 9 MHz. The variable gain control circuit consists of two pieces of cascaded AD603 at the gain of -11 dB to +31 dB with a bandwidth of 90 MHz. Thus, the voltage gain of -20dB~60dB can be realized by adjusting the voltage of VREF1_0 and VREF2_0. The gain of the fixed gain control circuit is 12db.

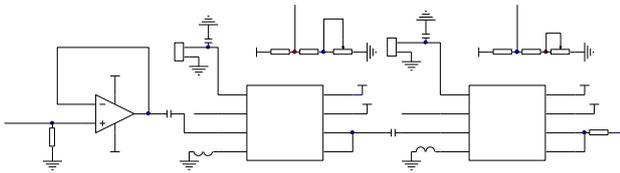


Figure 2(a). The variable gain control circuit

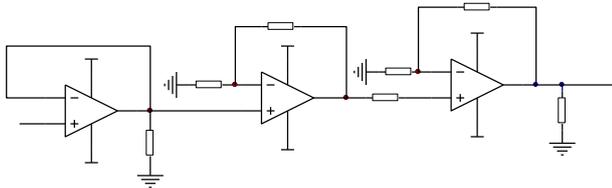


Figure 2(b). The fixed gain control circuit

The Amplitude-frequency characteristic curve of signal conditioning circuit measured by the 3577A HP network analyzer is shown in figure 3. The analysis shows that the 3dB cut-off frequency of signal conditioning circuit can reach 70MHz with the 55dB gain of voltage.

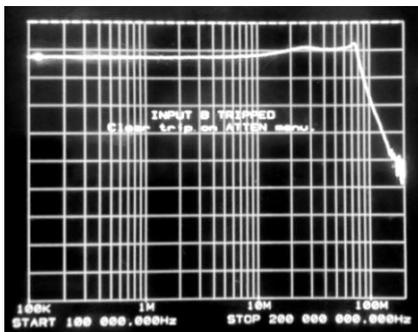


Figure 3. The Amplitude-frequency characteristic curve of signal conditioning circuit

2.2 F/V converter

F/V converter transforms the input pulse signal into voltage output. The output voltage is linear with the frequency of input pulse signal. Thus, the frequency of input pulse signal can be measured indirectly by measuring the output voltage of F/V converter. The F/V converter consists of LM331, a few resistors and capacitors [9].

The relationship between the output voltage V_f and the input frequency f_i of F/V converter can be expressed as:

$$V_f = \frac{2.09 * R_L * R_t * C_t}{R_s} * f_i \quad (1)$$

Where $R_s = R_{s1} + R_{s2}$. From (1) the output voltage V_f is linear with the input frequency f_i in case that resistors and capacitors are reasonable adjusted.

2.3 Analog multiplier

The MLT04 is a complete, four-channel, voltage output analog multiplier. The input voltage range of MLT04 is -2.5V ~ +2.5V, DC and AC is allowed. Without considering of the nonlinearity of MLT04, the output voltage of MLT04 can be given as:

$$V_w = 0.4V_x * V_y \quad (2)$$

The combination of MLT04 and operational amplifier can also constitute analog divider as shown in figure 4:

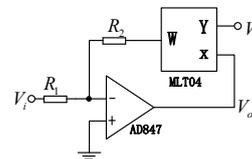


Figure 4. The analog divider

Defining equation can be given as:

$$V_o = -\frac{2.5R_2V_i}{R_1V_x} \quad (3)$$

Here, $R_1 = R_2$ is chosen, the equation can be written as:

$$V_o = -\frac{2.5V_i}{V_x} \quad (4)$$

3 The principle and design of self-tracking filter

3.1 The self-tracking first-order filter

As shown in figure 5, the self-tracking first-order high-pass filter circuit consists of F/V converter, an analog divider, an operational amplifier, a few resistances and capacitances. U3 (MLT04), U4 (AD8001), a few capacitances and resistances constitute first-order voltage controlled high-pass filter. U1 (AD847) and U2 (MLT04) constitute divider. The control voltage V_f is from the output of F/V converter [10].

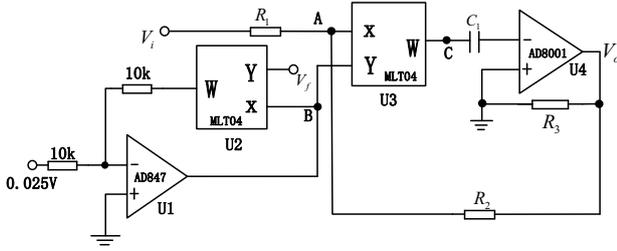


Figure 5. The self-tracking first-order high-pass filter

According to Kirchoff's law and figure 5, the transfer function can be expressed as:

$$H(s) = \frac{V_o}{V_i} = \frac{\frac{R_2}{R_1} s}{s + \frac{40V_f(R_1 + R_2)}{R_1 R_3 C_1}} \quad (5)$$

Therefore, the 3dB cut-off frequency f_0 and the gain factor a_0 of this transfer function can be given as:

$$f_0 = \frac{20V_f(R_1 + R_2)}{\pi R_1 R_3 C_1} \quad (6)$$

$$a_0 = \frac{R_2}{R_1} \quad (7)$$

The sensitivity of components is $S_{R_1}^{f_0} = 0$, $S_{R_2}^{f_0} = 1$, $S_{R_3}^{f_0} = S_{C_1}^{f_0} = -1$. It shows that the change of component value has little effect on the performance of filter. Here, $R_1 = R_2 = R_3 = R$ is chosen, the equation (6) can be written as:

$$f_0 = \frac{40V_f}{\pi R C_1} \quad (8)$$

The equation (9) can be derived from equation (8) and equation (1):

$$f_0 = \frac{40 * 2.09 R_t R_L C_t f_i}{\pi R C_1 R_s} \quad (9)$$

From (9), it can be known that the 3dB cut-off frequency f_0 is linear with the input frequency f_i in case that resistors and capacitors are reasonable adjusted.

3.2 The self-tracking second-order filter

As shown in figure 6, a second-order voltage controlled high-pass filter is implemented by using three AD8001s, two MLT04s, a few resistances and capacitances. The control voltage V_f is from the output of F/V converter.

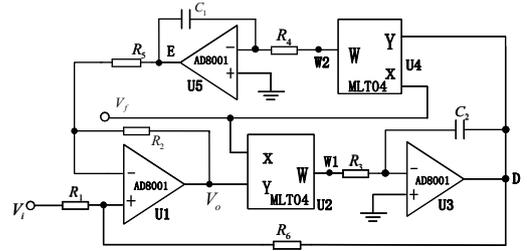


Figure 6. The self-tracking second-order high-pass filter

According to Kirchoff's law and figure 6, the transfer function can be expressed as:

$$H(S) = \frac{\frac{R_6(R_2 + R_5)}{R_3(R_1 + R_6)} s^2}{s^2 + \frac{V_f R_1(R_2 + R_5)}{2.5 R_3 R_5(R_1 + R_6) C_2} s + \frac{V_f^2 R_2}{(2.5)^2 R_3 R_4 R_5 C_1 C_2}} \quad (10)$$

Therefore, the 3dB cut-off frequency f_0 and the gain factor a_0 of this transfer functions can be given as:

$$f_0 = \frac{V_f}{5\pi} \sqrt{\frac{R_2}{R_3 R_4 R_5 C_1 C_2}} \quad (11)$$

$$a = \frac{R_6(R_2 + R_5)}{R_3(R_1 + R_6)} \quad (12)$$

The sensitivity of components is $S_{R_2}^{f_0} = \frac{1}{2}$, $S_{R_3}^{f_0} = S_{R_4}^{f_0} = S_{R_5}^{f_0} = S_{C_1}^{f_0} = S_{C_2}^{f_0} = -\frac{1}{2}$. It shows that the change of component value has little effect on the performance of filter. Here, $R_2 = R_3 = R_4 = R_5 = R$, $C_1 = C_2 = C$ is chosen, the equation (11) can be written as:

$$f_0 = \frac{V_f}{5\pi R C} \quad (13)$$

The equation (14) can be derived from equation (13) and equation (1):

$$f_0 = \frac{2.09 R_t R_L C_t f_i}{5\pi R C R_s} \quad (14)$$

From (14), it can be known that the 3dB cut-off frequency f_0 is linear with the input frequency f_i in case that resistors and capacitors are reasonable adjusted.

4 Simulation result

As the maximum input voltage of MLT04 is 2.5V, the 3dB cut-off frequency of filter is 1 kHz-100 kHz. As to first-order high-pass filter, when taking $C = C_t = 10nF$, $R_t = 910\Omega$, $R_L = 18.73k\Omega$, $R_s = 14.25k\Omega$ and $R = 31.84k\Omega$, the equation (9) becomes to be: $f_0 = f_i$.

When taking the frequency of input signal is 1kHz, 5kHz, 10kHz, 50kHz, 100kHz, the amplitude-frequency characteristic curve of first-order high-pass filter is shown in figure 7 by the PSPICE simulations.

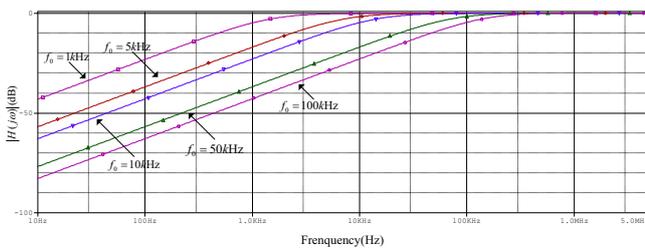


Figure 7. The amplitude-frequency characteristic curve of first-order high-pass filter

When taking the frequency of input signal is 1kHz, 5kHz, 10kHz, 50kHz, 100kHz, the experiments comparison of f_i and f_0 of first-order high-pass filter is shown in table 1, δ is the relative error.

Table1. The experiments comparison of f_i and f_0 of first-order high-pass filter

f_i (kHz)	1	5	10	50	100
f_0 (kHz)	0.991	4.898	9.887	49.885	99.882
δ (%)	0.9	2.04	1.13	0.23	0.12

As to the second-order high-pass filter, when taking $C = C_i = 10nF$, $R_i = 910\Omega$, $R_L = 18.73k\Omega$, $R_c = 14.25k\Omega$ and $R = 159\Omega$, the equation (14) becomes to be: $f_0 = f_i$.

When taking the frequency of input signal is 1kHz, 5kHz, 10kHz, 50kHz, 100kHz, the amplitude-frequency characteristic curve of second-order high-pass filter is shown in figure 8 by the PSPICE simulations.

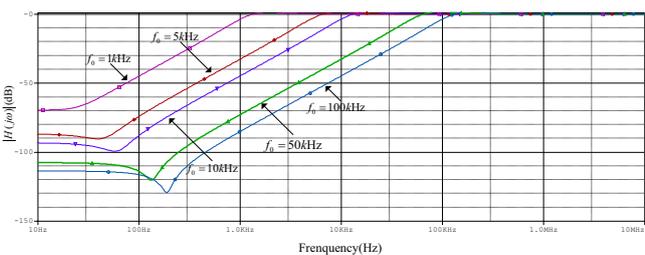


Figure 8. The amplitude-frequency characteristic curve of second-order high-pass filter

When taking the frequency of input signal is 1kHz, 5kHz, 10kHz, 50kHz, 100kHz, the experiments comparison of f_i and f_0 of second-order high-pass filter is shown in table 2, δ is the relative error.

Table2. The experiments comparison of f_i and f_0 of second-order high-pass filter

f_i (kHz)	1	5	10	50	100
f_0 (kHz)	0.989	4.892	9.881	49.878	99.872
δ (%)	1.10	2.16	1.19	0.24	0.13

From the above simulation and experiment results, it can be seen that the cut-off frequency of designed filter can be adjusted automatically according to the input signal frequency.

5 Conclusion

In this paper, a self-tracking high-pass filter by using analog multiplier and CFA is proposed. Firstly, the F/V converter transforms the input pulse signal into output voltage V_f . Then the cut-off frequency of voltage controlled high-pass filter is controlled by V_f . The simulation and experiment results show that the cut-off frequency of designed filter is 1 kHz-100 kHz. If using the higher frequency characteristics of analog multiplier (i.e., AD835), the cut-off frequency of filter can be extended 30MHz.

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