Harmonic Interference Elimination by An Active Comb Filter

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Abstract - A new approach for an active comb filter design is proposed to remove the difficult harmonic interference contaminating the biomedical signals. The filter consists of four narrow-band bandpass filters. The center frequency of each bandpass filters is just the unwanted frequency characterized by the harmonic interference. The circuit demonstrates the capability to eliminate the interference of 60, 180, 300, and 420Hz. The general 741 type operational amplifier has been used to realize the circuit presented. Triangular wave testing shows the effectiveness of harmonic interference cancellation.

INTRODUCTION

In the recording of biomedical signals, the power line interference degrading the measured signals is a major problem. The interference can disrupt interpretation of signals such as the standard electrocardiogram(ECG). One of the sources of interferences is electrical field characterized by noise concentrated at the fundamental frequency. The other component is magnetic field interference which is characterized by high harmonics content[1-3]. The harmonics are due to the nonlinear characteristics of transformer cores in the power supply. Thus, to design a comb filter or a high- order notch filter to reduce interferences becomes an important subject for many biomedical applications.

METHODS

In this paper, we consider the following measurement signal

$$\begin{aligned} x(t) &= s(t) + \sum_{k=1}^{N} A_k \sin(k\omega_0 t + \phi_k) \\ &= s(t) + I(t) \end{aligned} \qquad (1)$$

where $s(t)$ is uncorrupt biomedical signal and $I(t)$ is harmonic interference. The fundamental frequency ω_0 is usually 50 Hz or 60 Hz. Given the noisy signal $x(t)$, the purpose of this paper is to suppress $I(t)$ as significantly as possible using active comb filtering technique.

Based on the signal in eq(1), the specification of ideal active comb filter is given by

$$H(j\omega) = \begin{cases} 0 & \omega = k\omega_0 \text{ , } k = 1 \cdots N \\ 1 & \text{otherwise} \end{cases} \qquad (2)$$

Now, we describe a novel approach to design this filter in detail. The transfer function of proposed active comb filter is given by

$$H(j\omega) = 1 - \sum_{k=1}^{N} H_{bp}^{k}(j\omega) \qquad (3)$$

where $H_{bp}^{k}(j\omega)$ is a second order bandpass filter with unit gain and zero phase at center frequency. There is an intuitive explanation on this construction. The bandpass filter $H_{bp}^{k}(j\omega)$ is only used to extract the kth harmonic component $A_k \sin(k\omega_0 t + \phi_k)$ from input signal $x(t)$ undistortedly. To subtract the sum of each extracted component from the input signal is equivalent to eliminate the harmonic interference additive in $x(t)$. Thus, $H(j\omega)$ is a desired comb filter.

The circuit used to realize $H(j\omega)$ is shown in Fig.1 for N=4. The relation between input voltage v_i and output voltage v_o can be written theoretically for ideal operational amplifier as

$$v_o = -\frac{R_y}{R_0} v_i - \sum_{k=1}^{N} \frac{R_y}{R_k} v_k \qquad (4)$$

where v_k is the output voltage of the kth second order narrow-band bandpass filter. After the usual algebra, we obtain the transfer function of kth bandpass filter as follows[4]:

$$H_{bp}^{k}(jf) = -\frac{2R_{k2}Q_k^2}{R_{k1} + R_{k2}} \frac{(\frac{j}{Q_k})(\frac{f}{f_k})}{1 - (\frac{f}{f_k})^2 + (\frac{j}{Q_k})(\frac{f}{f_k})} \qquad (5)$$

where center frequency f_k and quality factor Q_k are given by

$$f_k = \frac{1}{2\pi\sqrt{(R_{k1}//R_{k2})R_{k3}C_{k1}C_{k2}}} \qquad (6)$$

$$Q_k = \frac{f_k}{BW_k} = \frac{1}{2}\sqrt{\frac{R_{k3}}{R_{k1}//R_{k2}}} \qquad (7)$$

Note that BW_k is the 3dB bandwidth of the kth bandpass filter and

$$R_{k1}//R_{k2} = \frac{R_{k1}R_{k2}}{R_{k1} + R_{k2}} \qquad (8)$$

Based on the above equations, we summarized the entire design procedure as follows. Given center frequency f_k and factor Q_k, $k = 1 \cdots N$, the circuit parameters can be determined by following steps:

Step 1: Suitably choose capacitance C_{k1} and C_{k2}.

Step 2: From eq(6) and eq(7) obtain resistance

$$R_{k3} = \frac{Q_k}{\pi f_k \sqrt{C_{k1}C_{k2}}} \qquad (9)$$

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Step 3: Let gain factor $\frac{2R_{k2}Q_k^2}{R_{k1}+R_{k2}}$ in eq(5) be equal to unity, we get

$$R_{k1} = \frac{Q_k}{2\pi f_k\sqrt{C_{k1}C_{k2}}}$$
$$R_{k2} = \frac{Q_k}{2(2Q_k^2-1)\pi f_k\sqrt{C_{k1}C_{k2}}} \qquad (10)$$

Step 4: Let $R_y = R_i, i = 0\ldots N$, then we have

$$v_o = -v_i - \sum_{k=1}^{N} v_k \qquad (11)$$

Note that there are phase difference of 180 degrees between v_i and v_k. For 60Hz harmonic interference elimination, we choose center frequency $f_k = 60k$ Hz and factor $Q_k = \frac{60k}{BW_k}$. In order to illustrate the effectiveness of proposed approach, a simple Spice simulation example is shown in Fig.2. The Q factors are 10, 20, 30, and 40 for the center frequencies of 100, 200, 300, and 400Hz of the bandpass filters respectively in the simulation example.

RESULT AND CONCLUSION

The triangular wave of 60Hz was arranged to simulate the harmonic noise. This wave was fed to the four order notch filter (60,180,300,and 420Hz) as the circuit shown in Fig.1. The amplitude of the output was examined to demonstrate the performance of noise cancellation. From Fig.3 we find that using merely the structure of four order notch filter, the power of the triangular wave is remarkably removed. It is evident that harmonic noise can be significantly suppressed by the circuit.

A circuit to remove four different frequencies that simulate interferent noises had been developed. The circuit contains four individually independent bandpass filters and an inverting amplifier. The architecture of the circuit reveals that it is easy to implement and test. Furthermore, the triangular wave testing shows the effectiveness of the circuit to eliminate harmonic interference.

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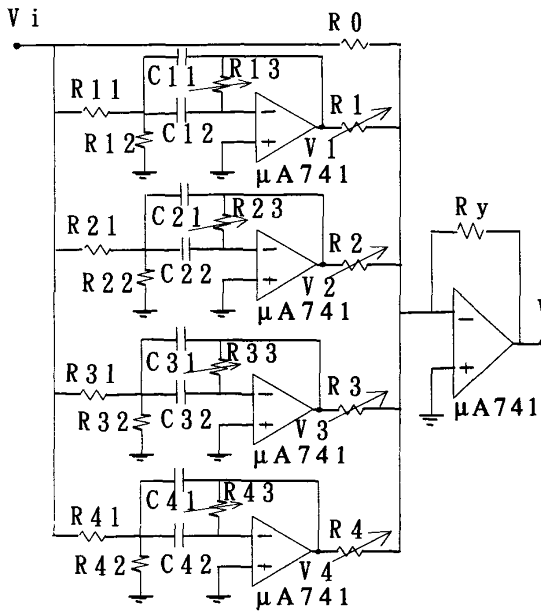

Figure 1: The circuit used to realize H(jw) of eq(3) for N=4.

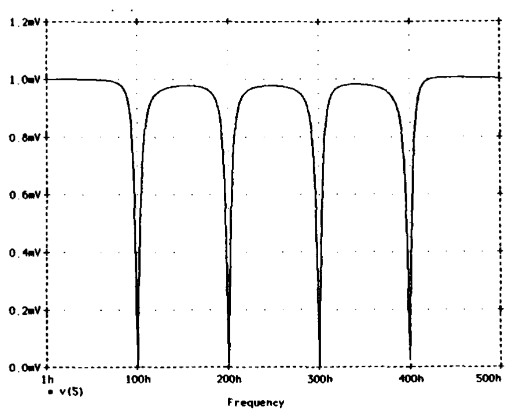

Figure 2: The simulation of active comb filter using eq(11) for fundamental frequency 100Hz and N=4.

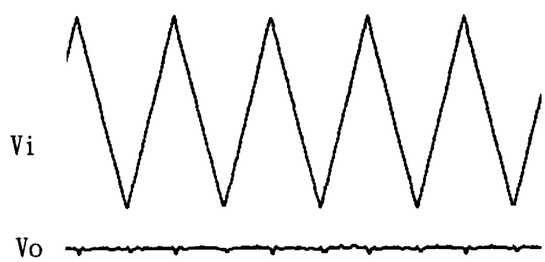

Figure 3: Effectiveness test of 4-order notch filter by triangular wave.