SIMPLE HIGH-Q COMB FILTER FOR MAINS INTERFERENCE SUPPRESSION

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This paper presents a simple digital high-Q comb filter for power-line (PL) (or other periodical) interference suppression. The filter concept relies on a correlated signal average resulting in alternating constructive and destructive spectrum interference i.e. to the so called a comb frequency response. The presented filter is evaluated by Matlab simulations with real ECG signal contaminated with high amplitude PL interference. The made simulations show that this filter has minimal influence on processed ECG signal. Due to its allpass (flat) frequency response and high-Q notches only at PL harmonics the presented filter is appropriate for most biosignal acquisition applications: ECG, EEG, EMG, etc. The filter is suitable for real-time operation with popular low-cost microcontrollers.

Keywords: power-line interference, comb filter, moving-average filter, FIR filter, IIR filter

1. INTRODUCTION

Power-line (PL) interference (hum) is a common problem in almost all biosignal acquisition applications. Because the body serves as a capacitively coupled antenna, a part of the picked up PL interference currents traverses the electrodes and produces a common mode voltage over an amplifier common mode input impedance. At the amplifier output some AC noise remains as a consequence of electrode impedance imbalance and/or due to the finite value of the amplifier CMRR [1], even when special signal recording techniques are applied (shielding, driven right leg, body potential driving, etc.). A further reduction of the interference should be implemented by either post-digital or post-analog filters.

The most common option for PL suppression is to use low-pass averaging digital filters with firs zero at the PL frequency. The name of such a filter is known also as averager, smoother, moving-average, rolling average or running-mean filter. Because of introduced additional signal bandwidth limitation these filters significantly attenuate important frequency components. A special FAS (Filtration-Addition-Subtraction) algorithm can partially improve their high-frequency response [2].

Smart approaches such as adaptive noise cancellation [3], subtraction procedure [4] and various lock-in techniques [5] require sophisticated software organization.

Although in presence of many different approaches, the problem of interference removal still exists and the researchers continue to find a simple solution resulting to 'high fidelity' and 'clean' records.

This paper presents a simple digital high-Q allpass comb filter for PL (or other periodical) interference suppression. Based on a recursive (IIR) feedback extension of a simple comb filter, a very narrow-band (high-Q) frequency response can be achieved. One filter stage rejects only the odd harmonics of PL interference. The high-Q frequency response allows more stages to be cascaded for suppression in addition of eventual PL even harmonics.

2. FILTER CONCEPT

The comb filters are widely used in digital signal processing. They are widely spread in either audio signal processing to achieve special sound effects (echo, flanging, etc.), or in TV signal processing for separating the luminance (black & white) and chrominance (color) signals from composite video signal [6].

In a nutshell, a simple comb filter is achieved when incoming signal samples are added to their delayed copy. Thus alternating constructive and destructive spectrum interference is produced as a function of the time delay between original and delayed signals. The filter name comes from the shape of its frequency response which resembles the teeth of regular hair comb.

A simple first order feedforward (FIR) comb filter is shown in Fig. 1. Its frequency response is shown in Fig. 2.

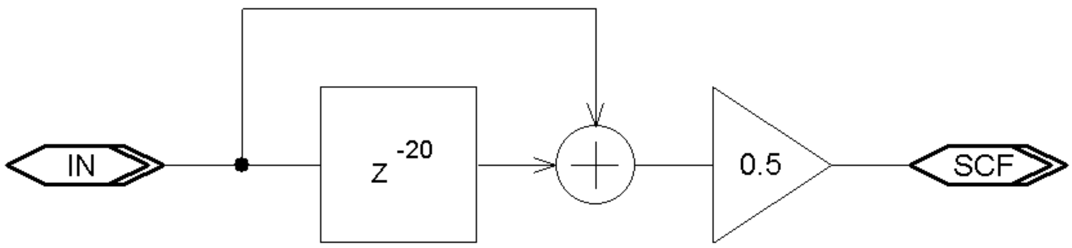

Fig. 1 Simple comb filter for PL interference rejection. Sampling frequency is 2 kHz, i. e. z^{-20} corresponds to frequency independent (pure) delay of 10 ms

For certain frequency components, where the delayed samples are appeared in-phase towards its original, the amplitude of these components is increased two times. For other frequencies, where the delayed samples are in opposite phase, they are canceled out. Thus all odd harmonics of the rated PL frequency are effectively canceled out. To make unity gain transmission in the pass-band, the output should be divided by 2. The frequency response of this filter is shown in Fig. 2.

The quality (sensitivity) factor Q is:

$$Q = f_o/\Delta f = 1,$$

here f_o is the filter first notch frequency, and Δf is the rejected bandwidth at 3dB. Although, this filter has very simple structure and linear phase response, its Q factor is too low, and results in rejected bandwidth from 25Hz to 75Hz. So, the filter application for biosignal processing is limited.

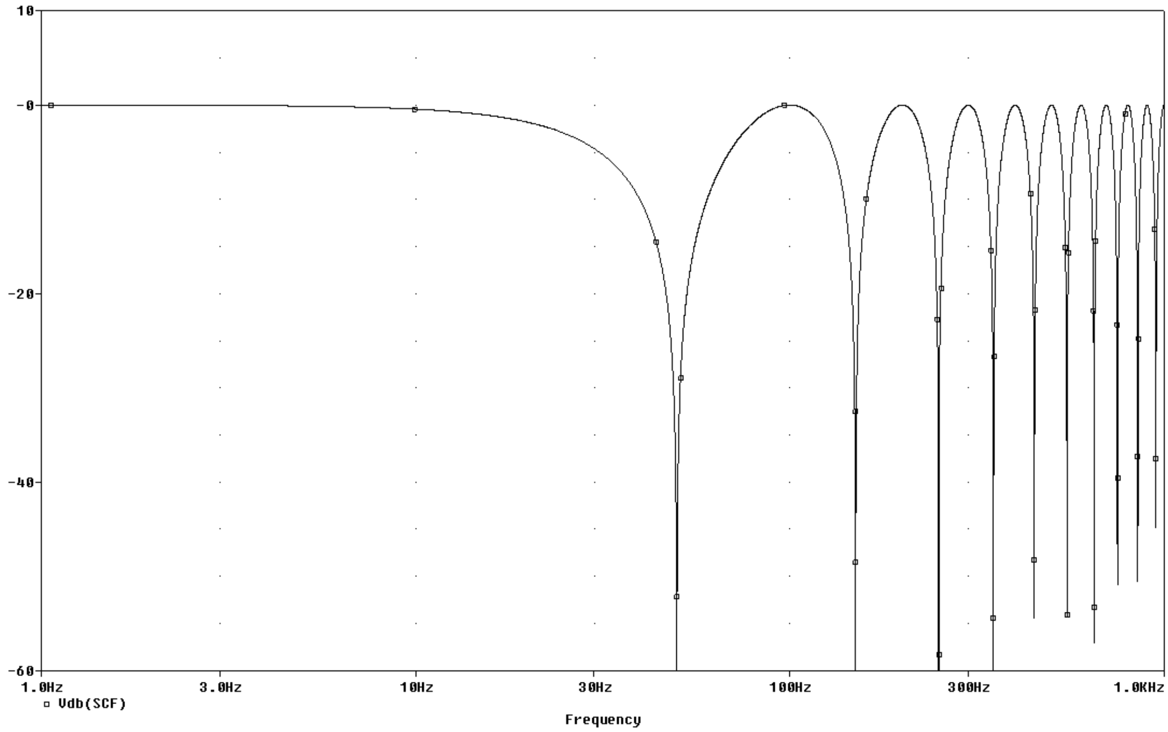

Fig. 2 Frequency response of simple comb filter from Fig. 1

Adding a simple feedback loop with coefficient k, the filter Q factor can be significantly improved and set to this value, which is needed. The improved Q factor filter structure is shown in Fig. 3.

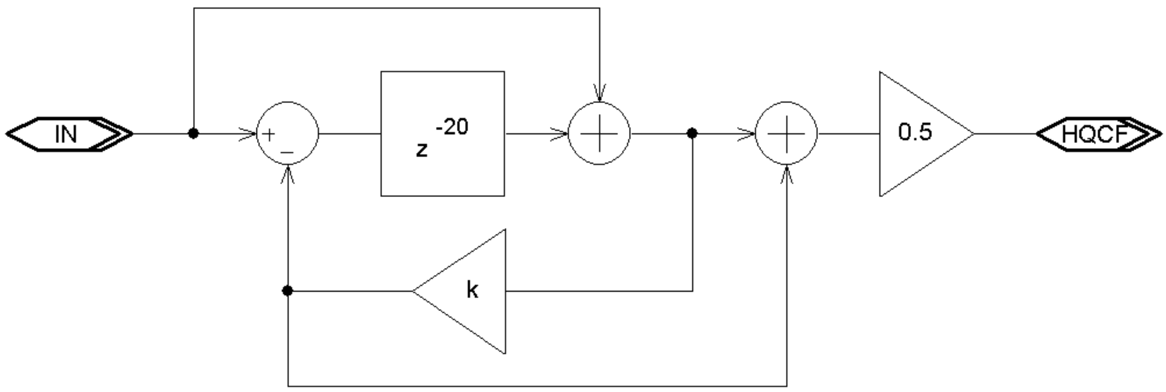

Fig. 3 High-Q comb filter for PL interference rejection. Sampling frequency is 2 kHz

The filter is stable for $0 \leq k < 1$. We note that when $k = 0$ the structure is converted to simple comb filter shown in Fig. 1. The filter has the following transfer function:

$$T(z) = \frac{1+z^{-20}}{1+k \cdot z^{-20}} \cdot \frac{1+k}{2}$$

The quality factor Q depends on *k* and can be approximated as:

$$Q \approx 1.5 / (1-k)$$

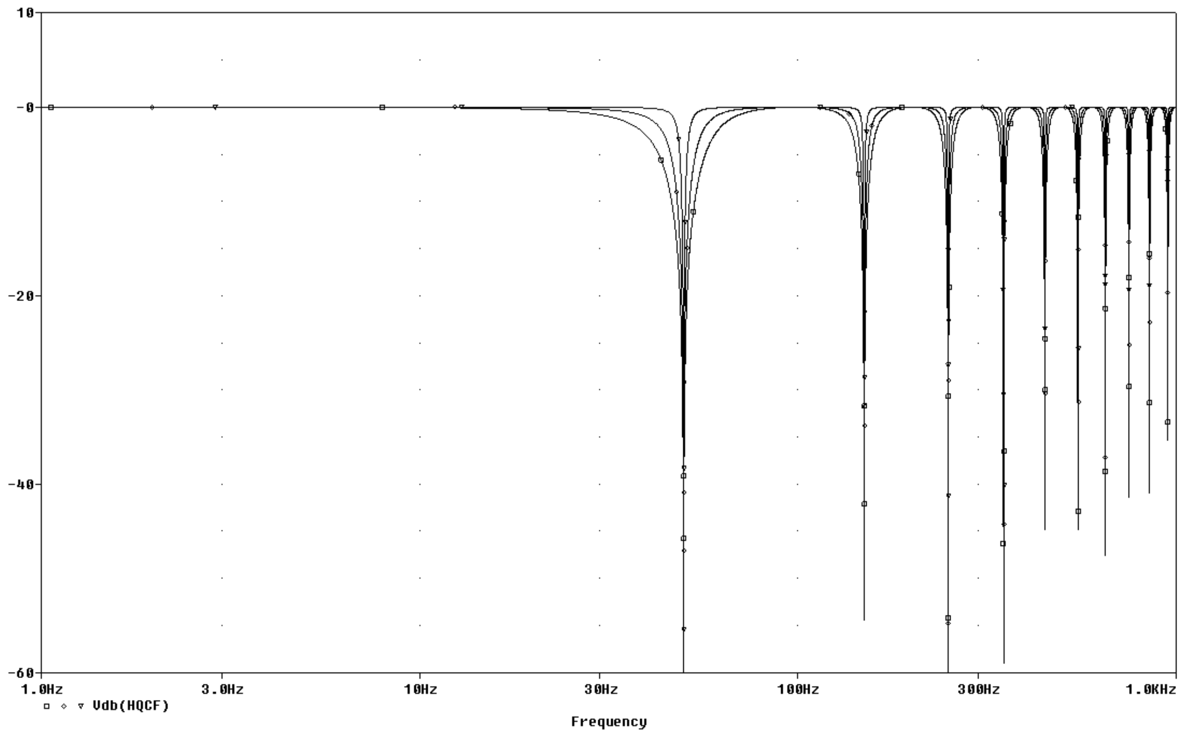

Fig. 4 Frequency response of High-Q comb filter from Fig. 3.
Coefficient *k* takes values: 0.5, 0.7 and 0.9

As seen from Fig. 4 the filter rejects only the odd harmonics of PL interference. Because of its high Q factor, for rejection of desired even PL harmonics, more stages could be cascaded, as shown in Fig. 5. Also, the coefficient k can be selected to be different for each stage. The frequency response of cascaded high-Q comb filter from Fig. 5 is shown in Fig. 6.

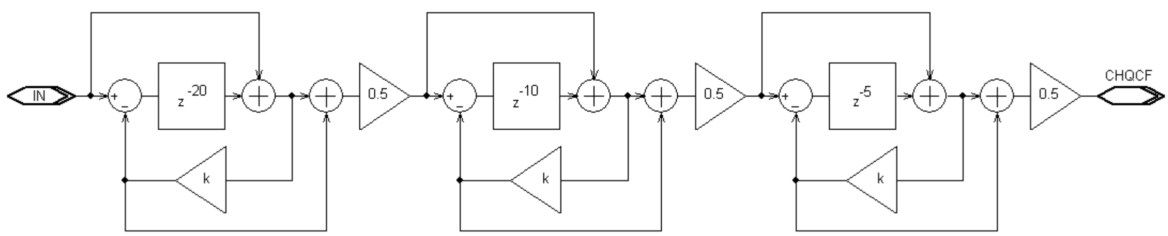

Fig. 5 Cascaded high-Q comb filter for PL interference rejection

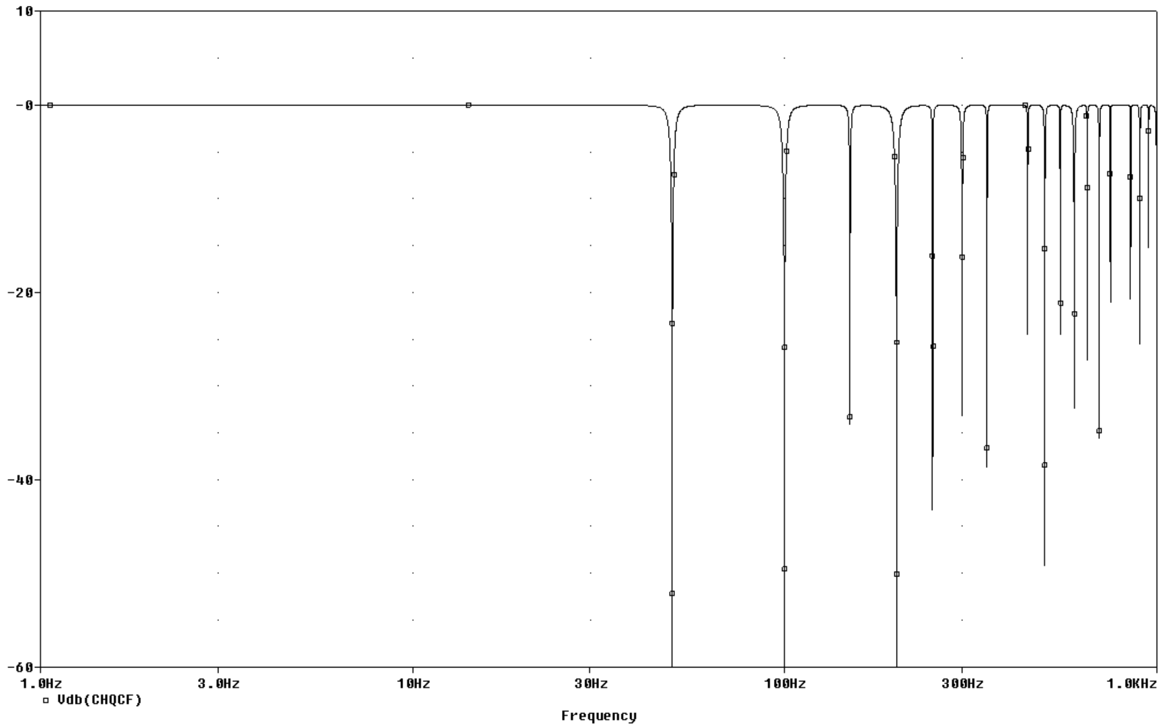

Fig. 6 Frequency response of cascaded high-Q comb filter from Fig. 5. Sampling frequency is 2 kHz. Coefficient k is set to 0.9375

3. SIMULATION RESULTS

The presented filter was tested by MATLAB simulations. A real, interference free ECG signal, sampled at 2kHz is used as an input. At the beginning of simulation, the amplitude of the PL interference is 0 LSBs. At 1.5s simulation time the PL amplitude is changed to 1000 LSBs.

Simulation results are shown in Fig. 7. The first and second traces are the original ECG signal, and the ECG signal with added PL interference. The third trace shows the original signal (from trace 1) after cascaded comb filter from Fig. 5. The value of k is 0.9375, and corresponds to $Q \approx 24$.

Note that for fast operation, with integer coefficient only, k should be selected to be proportional to some negative power of two. For example, in our case k is selected to be 0.9375, and is realized only with one 4 bit shift and one subtraction as:

$$0.9375 = 15/16 = 1 - 1/16.$$

A comparison with a simple one PL period (20 ms) moving-average filter is shown in the fourth trace. The error, i.e. the difference between trace 1 and trace 3, and trace 1 and trace 4 is shown on trace 5 and trace 6 respectively. 1 LSB corresponds to 1μV. It can be seen that the cascaded comb filter has minimal influence on processed signal. The implemented high Q factor ($Q \approx 24$) increases the filter adaptation time to about 0.5s.

Fig.7 Simulation results of cascaded comb filter compared with one PL period (20 ms) averager

4. CONCLUSION

The presented High-Q IIR comb filter provides a simple and powerful solution for rejecting the PL interference in almost all biosignal acquisition applications.

The main advantages of the presented filter could be summarized as:

- Simple solution for removal of fundamental frequency of the PL interference and its odd harmonics
- Can be cascaded for removal of the desired even PL harmonics
- Suitable for real-time operation with popular low-cost microcontrollers.

5. REFERENCES

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