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High-Q Bandpass Comb Filter for Mains Interference Extraction

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Summary: This paper presents a simple digital high-Q bandpass comb filter for power-line (PL) or other periodical interference extraction. The filter concept relies on a correlated signal average resulting in alternating constructive and destructive spectrum interference i.e. the so-called comb frequency response. The presented filter is evaluated by Matlab simulations with real ECG signal contaminated with low amplitude PL interference. The made simulations show that this filter accurately extract the PL interference. It has high-Q notches only at PL odd harmonics and is appropriate for extraction of any kind of odd harmonic interference including rectangular shape. The filter is suitable for real-time operation with popular low-cost microcontrollers.

Keywords: Power-line interference, Comb 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 traverse the electrodes and produce a common mode voltage over the 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 [8], 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 [2, 3] or post-analog filtering.

A modern approach to interference removal is based on its extraction or synthesis, and on usage of the extracted or synthesized values for subsequent subtraction from the incoming data stream [7, 1]. Similar

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approach is used for reducing 16.7 Hz railway interference in public access defibrillation [5, 6]. A better solution of software frequency measuring, internal irregular re-sampling according to the interference frequency, and moving averaging over constant sample number followed by regular back re-sampling is described in [4]. So, if there is a simple way for accurate interference extraction, it will lead to great benefit in many biosignal processing applications.

This paper presents a simple digital high-Q bandpass comb filter for PL or other periodical interference extraction. 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 extracts only odd harmonics of PL interference. For additional increase in its Q-factor and stopband suppression or for extraction of PL even harmonics more stages can be cascaded or paralleled.

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 (colour) signals from composite video signal [9].

Recently a simple IIR notch comb filter for PL odd harmonics rejection was described [2]. Its structure is redrawn in Fig. 1. By varying a coefficient *k*, the filter Q factor can be significantly improved and set to this value which is needed.

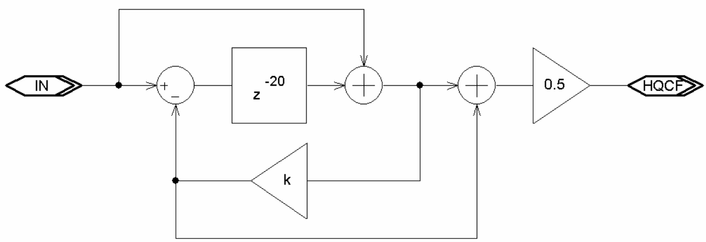

Fig. 1 High-Q notch comb filter. Sampling frequency is 2 kHz, i.e. z^{-20} corresponds to frequency independent delay of 10 ms

The simplest conversion from notch to bandpass response or vice versa is achieved when the filtered output is subtracted from the input. Thus, a filter structure shown in Fig. 2 is easily obtained. Note that difference-summing-summing node sequence in Fig. 1 is changed to summing-difference-difference sequence in Fig. 2.

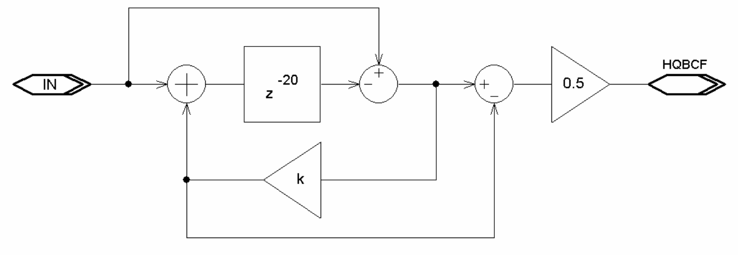

Fig. 2 High-Q bandpass comb filter. Sampling frequency is 2 kHz

The filter is stable for $0 \leq k < 1$. We note that when $k = 0$ the structure is converted to a simple FIR first difference comb filter. The filter has the following transfer function for sampling frequency 2 kHz:

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

The frequency response is shown in Fig. 3

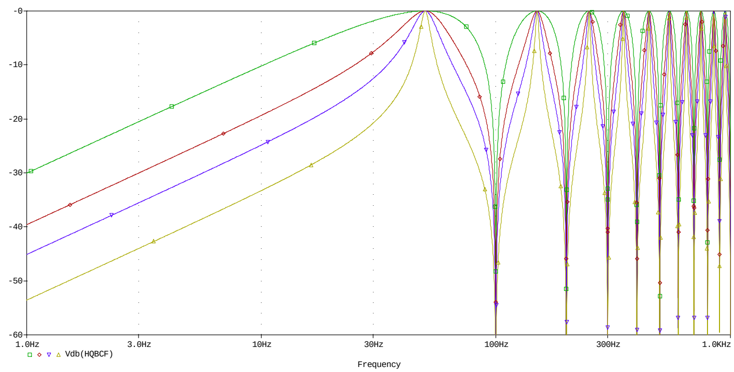

Fig. 3 Frequency response of high-Q comb filter from Fig. 2. Coefficient *k* is varied: 0, 0.5, 0.7 and 0.875

As seen from Fig. 3, the filter bandpasses only odd harmonic of PL interference. Because of its high-Q factor, for bandpassing of even PL harmonics more stages could be paralleled. Also for increase in its Q-factor or stopband attenuation, i.e. for more accurate PL interference extraction more stages could be cascaded. A frequency response of two cascaded stages from Fig. 2 is shown in Fig. 4. It can be seen that the stopband attenuation is increased two times (in dB), for example the suppression of 30Hz when *k* = 0.875 is a little more than 20dB in Fig. 3, while in Fig. 4 it is more than 40dB.

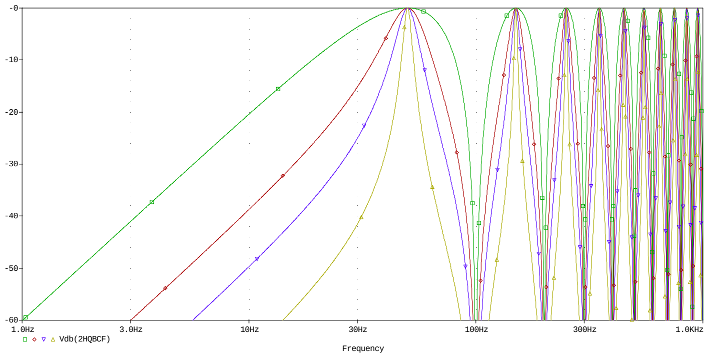

Fig. 4 Frequency response of two cascaded stages from Fig. 2.
Coefficient *k* is varied: 0, 0.5, 0.7 and 0.875

3. SIMULATION RESULTS

The presented filter was tested by Matlab simulations. A real ECG signal, contaminated with low level PL interference, sampled at 2 kHz is used as an input. The amplitude of PL interference is set to 10 LSBs. One LSB corresponds to 1μV. Simulation results are shown in Fig. 5. The first trace is the ECG signal with added PL interference. The second trace is the signal used as PL interference. The third trace shows the extracted PL interference from trace 1 after a presented comb filter from Fig. 2, with *k* = 0.875. The forth trace shows the extracted PL interference from trace 1 after cascaded two filter stages from Fig. 2, with *k* = 0.875. The fifth trace is the error in trace 4, i.e. it is the difference between trace 4 and trace 2. The error is independent from the PL interference amplitude, for example if PL interference amplitude is changed to 1000 LSBs, the steady state error remains the same. It can be seen that the error is appeared mainly as a response due to QRS complexes and baseline drift, so additional input QRS elimination algorithms and/or high-pass filtering could be implemented.

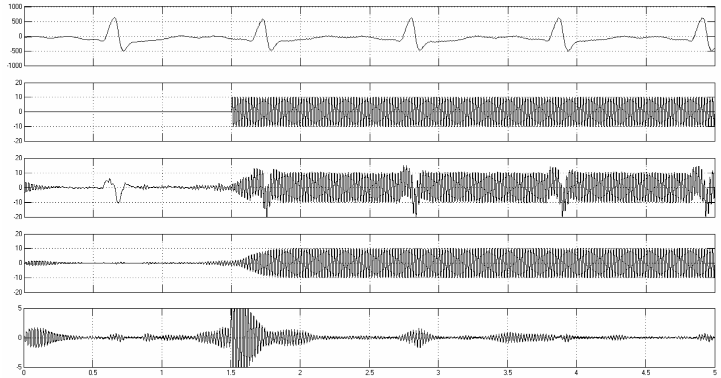

Fig. 5 Simulation results

We should note that for fast operation with integer coefficient only, *k* should be selected to be a common multiple of some negative power of 2. For example, in our case *k* is selected to be 0.875 and is realized as: 0.875 = 1 - 1/8.

It can be seen that two cascaded stages of the presented comb filter accurately extract PL frequency. The PL period or PL frequency can be calculated if they are averaged for a large period of time, e.g. 1s.

4. CONCLUSIONS

The presented high-Q IIR bandpass comb filter provides a powerful solution for PL interference or other periodical interference extraction in all biosignal acquisition applications.

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

- simple solution for extraction of fundamental frequency of the PL interference as well as its odd harmonics
- could be cascaded or paralleled for increased stopband attenuation or for extraction of eventual even PL harmonics
- suitable for real-time operation with popular low-cost microcontrollers.

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