Investigation of the FIR Filters in the Subtraction Method for Filtration of Power-line Interference in Case of Even Sampling

Georgy S. Mihov[1] and Ventsislav D. Manoev[2]

Abstract – **In the paper are investigated fifteen non-recursive filters for application in the subtraction method for removing power-line interference from ECG in case of multiple even sampling. The filters have been tested in the same conditions with a real ECG signal. An analysis of their impulse, frequency and phase responses have been done. The evaluation of the FIR filters suitability is performed on the base of the calculated error as a difference between the original and the filtered signal.**

Keywords – **ECG, power-line interference removal, subtraction method.**

I. INTRODUCTION

The subtraction method for removing the power-line (PL) interference from electrocardiographs (ECG) signals [1, 2, 3] is established in 1980 by Bulgarian scientists and shows high efficiency when the sampling rate Φ and the PL frequency F are synchronized, i.e. when $\Phi/F = n$ is an integer. The basic structure of the subtraction method is shown in Fig. 1. The sequence of application of the method includes the following stages:

– *Linear segment detection*. Every ECG signal sample X_i is tested whether it belongs to linear segment. A criterion for linearity is developed which is insensitive to the PLI.

– *Interference extracting.* If the linearity criterion is fulfilled a filter (denoted K-filter) is performed in these segments to remove the PLI. The PLI sample B_i is obtained by subtracting filtered samples Y_i from the original signal samples X_i.

– *Interference restoring.* The PLI samples B_i are stored in an *Interference temporal buffer* of FIFO type. They are updated every time when a linear segment is found. These samples are used later on, to subtract the PLI from ECG signal.

– *Interference subtracting.* In the non-linear segments where the linearity criteria is not fulfilled the PLI is removed by subtracting the phase locked interference sample B_{i-n} in FIFO buffer from the original signal sample X_i. The subtraction procedure is done in the module *Subtractor*. To clarify the method in the basic structure, it is shown that for the linear segments the PLI is canceled by subtracting the computed sample B_i from the ECG sample X_i in the module *Subtractor* as well. In fact, its equivalent is performed by the K-filter in stage *Interference extracting*.

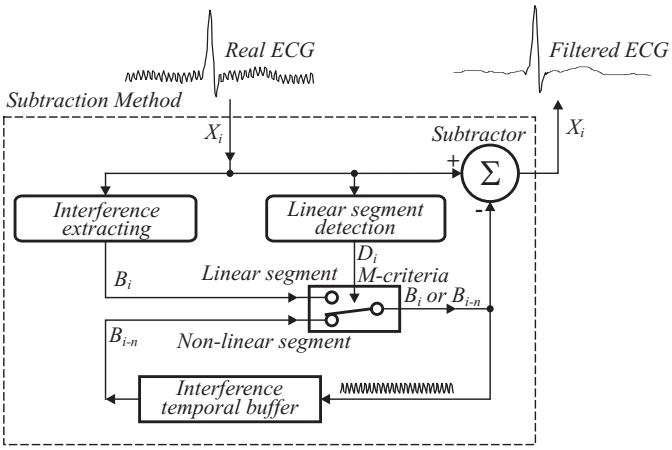

Fig. 1. Basic structure of the subtraction method

II. INVESTIGATION

The aim of this investigation is to test some non-recursive digital filters (with Finite Impulse Response – FIR) for its applicability in the subtraction method in case of even multiplicity, i.e. when $n = 2m$ is even number. The case in point K-filter, which is applied in the stage *Interference extracting*. Such test at odd multiplicity is carried out in [4].

In [2] are defined main features of the K-filters: frequency response with zero in $f = F$, unity gain in $f = 0$ and a linear phase response. Fifteen filters are investigated (below they are signed with numbers from 1 to 15), which are exercised in the same conditions at even multiplicity $n = 8$:

1. The K-filters are tested with an episode from a signal of AHA database AHA_1001d1, which is considered as a conditionally clean from PL frequency (*Original signal*) The testing episode have got a duration of 4 *s* and sampling rate $\Phi = 400$ *Hz*.

2. A synthesized PL interference with frequency $F = 50$ *Hz* and amplitude $p = 0{,}2$ *mV* is added to the *Original signal* (*Contaminated signal*).

3. The *Contaminated signal* is treated by the subtraction method and the filtered signal is signed as a *Clean signal*. The used criterion of linearity is $Cr < M$, where the threshold $M = 80\ \mu V$ is chosen empirically. The complex criterion $Cr = |D_i| \vee |D_{i-1}|$ corresponds to the second difference (acceleration) of the signal $D_i = X_{i-n} - 2X_i + X_{i+n}$.

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4. An *Error* is calculated as an absolute difference between the filtered *Clean signal* and the incoming *Original signal*.

The sequence of the testing is shown in Fig. 3.

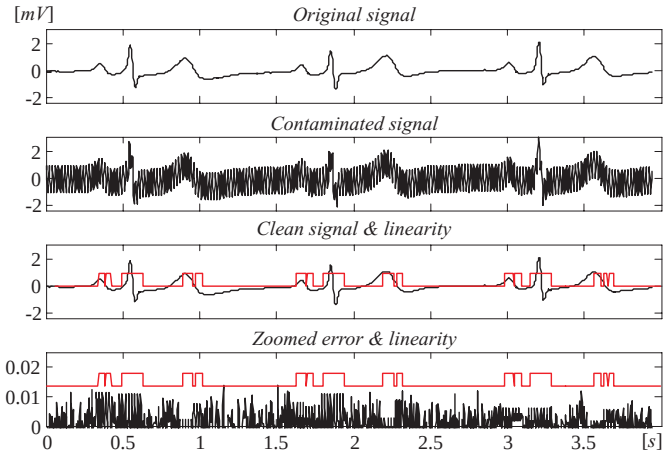

Fig. 3. Experimental sequence of the testing

The evaluation of the K-filters is performed on the base of the calculated *Error*, which is used for the following parameters estimating: Err_all – mean error for the whole tested episode; Err_m0 – mean error for linear segments; Err_m1 – mean error for non-linear segments; Err_max – maximal error in the whole tested episode; Err_ms – mean square deviation of the error within the whole tested episode.

The investigation is done in the Matlab environment. All used filters are presented with their impulse, frequency and phase responses that are shown in Figs. 4 – 18.

Filters 1, 2 and 3 are simple moving averaging even filters within the interval [-*m* … +*m*]. Filter 2 is with reduction by two [2]. Filter 3 is with reduction by four and was called 'three point' filter [5], because it consists of just three terms. Filters from 4 [6] till 12 are asymmetrical filters with a different steepness of asymmetrically *a*. They are produced by Filter 1, 2 and 3 adding a weight of +a/*N* and –a/*N* to the terms, spaced on *n* samples (*N* is the scaling factor, which is a sum of all filter terms). Except the Filter 11, which is called 'two point' filter [2], they have non-linear phase responses. Filters 13, 14 and 15 are first derivate of the Filters 1, 2 and 3 [7]. Second derivate filters are not tested.

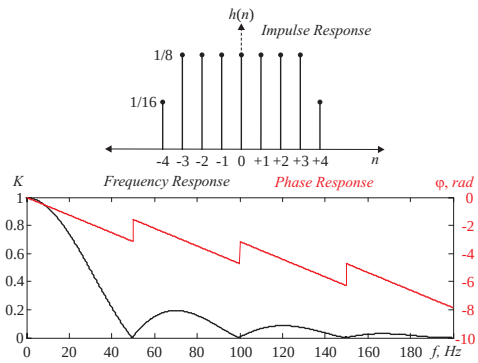

Fig. 4. Filter 1: even moving averaging filter;
K = [0 0 0 0,5 1 1 1 1 1 1 1 0,5 0 0 0]/8

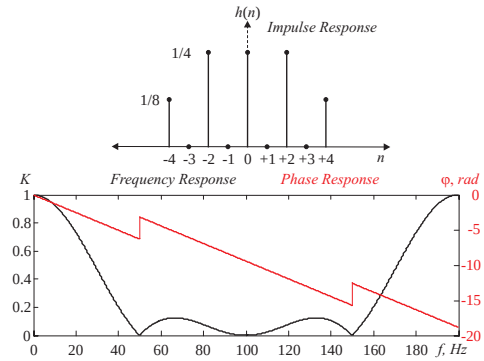

Fig. 5. Filter 2: moving averaging with reduction by two;
K = [0 0 0 0 0,5 0 1 0 1 0 1 0 0,5 0 0 0 0]/4

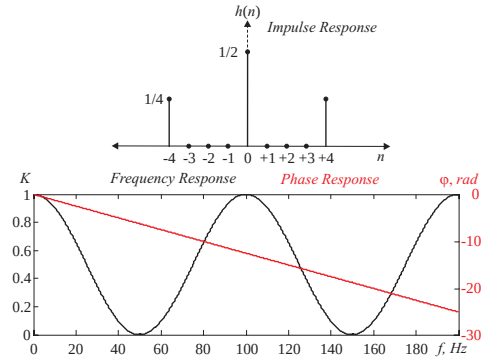

Fig. 6. Filter 3: reduction by four ('three point' even filter);
K = [0 0 0 0 0,5 0 0 0 1 0 0 0 0,5 0 0 0 0]/2

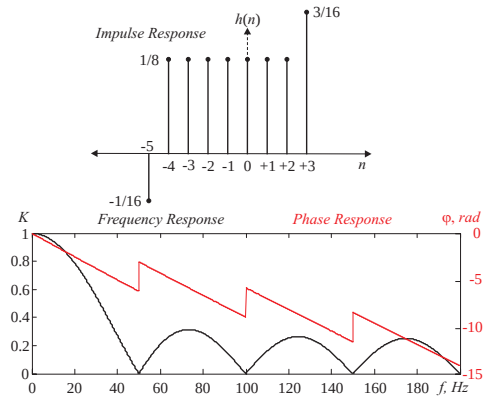

Fig. 7. Filter 4: asymmetrical by one averaging filter;
K = [0 0 0 -0,5 1 1 1 1 1 1 1 1,5 0 0 0 0 0]/8

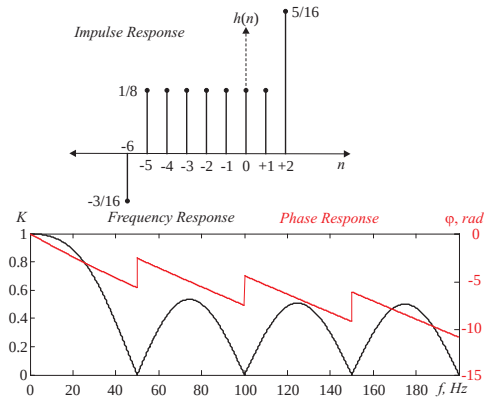

Fig. 8. Filter 5: asymmetrical by two non-causal filter;
K = [0 0 -1,5 1 1 1 1 1 1 1 2,5 0 0 0 0 0 0]/8

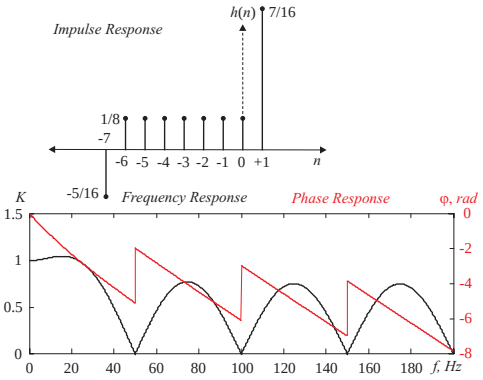

Fig. 9. Filter 6: asymmetrical by three non-causal filter;
K = [0 -2,5 1 1 1 1 1 1 1 3,5 0 0 0 0 0 0 0]/8

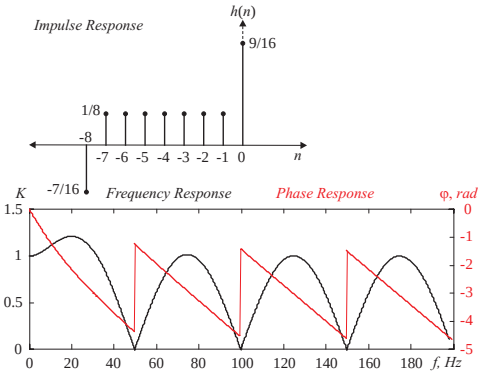

Fig. 10. Filter 7: asymmetrical by four causal filter;
K = [-3,5 1 1 1 1 1 1 1 4,5 0 0 0 0 0 0 0 0]/8

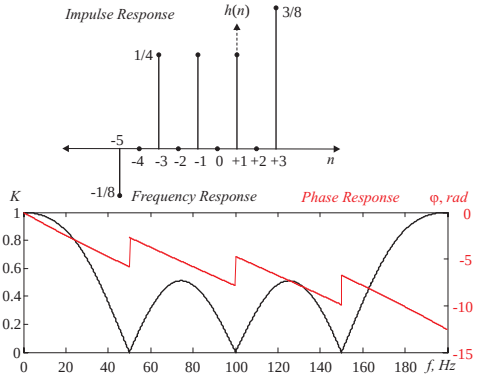

Fig. 11. Filter 8: reduced by two asymmetrical by two filter;
K = [0 0 -0,5 0 1 0 1 0 1 0 1,5 0 0 0 0 0 0 0]/4

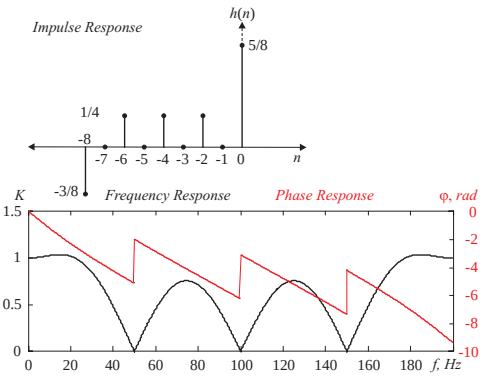

Fig. 12. Filter 9: reduced by two asymmetrical by four casual filter;
K = [-1,5 0 1 0 1 0 1 0 2,5 0 0 0 0 0 0 0 0]/4

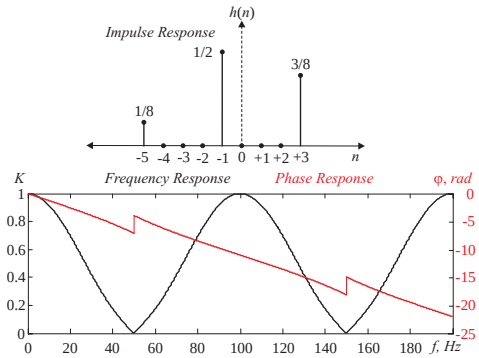

Fig. 13. Filter 10: asymmetrical by one 'three point' filter;
K = [0 0 0 0,25 0 0 0 1 0 0 0 0,75 0 0 0 0 0]/2

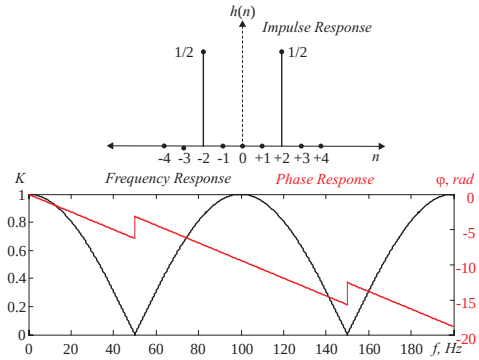

Fig. 14. Filter 11: reduction by four ('two point' odd filter);
K = [0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0]/2

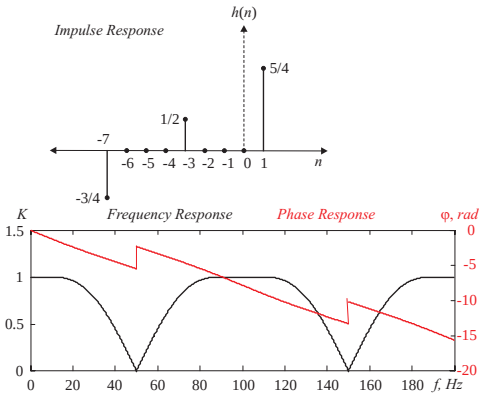

Fig. 15. Filter 12: asymmetrical by three 'thee point' filter;
K = [0 -1,5 0 0 0 1 0 0 0 2,5 0 0 0 0 0 0 0]/2

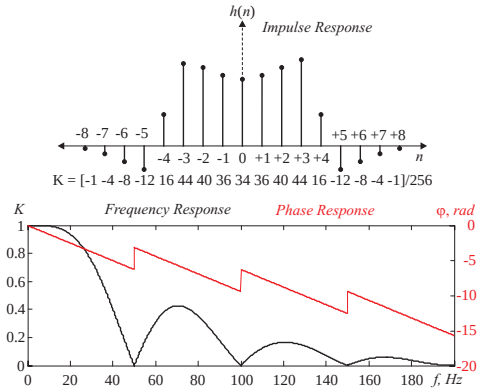

Fig. 16. Filter 13: first derivate of the averaging Filter 1;
K = [-1 -4 -8 -12 16 44 40 36 34 36 40 44 16 -12 -8 -4 -1]/256

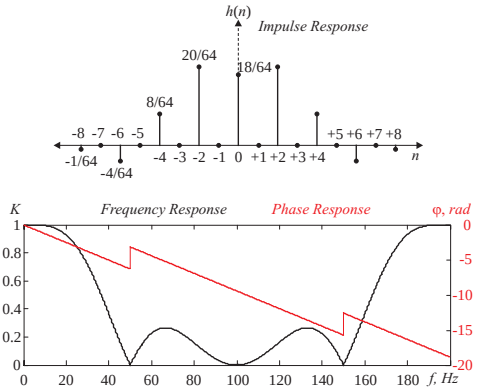

Fig. 17. Filter 14: first derivate of the reduced by two Filter 2;
K = [-1 0 -4 0 8 0 20 0 18 0 20 0 8 0 -4 0 -1]/64

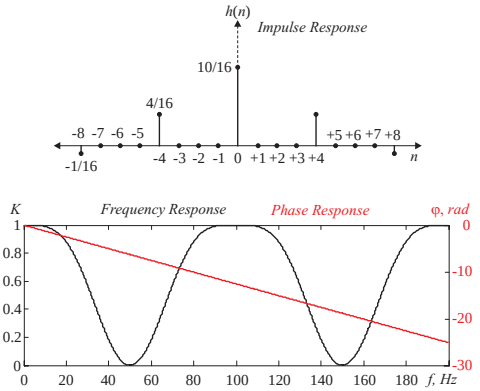

Fig. 18. Filter 15: first derivate of the 'three point' Filter 3;
K = [-1 0 0 0 4 0 0 0 10 0 0 0 4 0 0 0 -1]/16

TABLE I
ERRORS WITH DIFFERENT FILTERS APPLYING

	Err_all	Err_m0	Err_m1	Err_max	Err_ms
Filter 1	3,34	3,27	3,53	13,76	4,27
Filter 2	3,38	3,30	3,62	13,76	4,32
Filter 3	3,51	3,29	4,12	12,91	4,38
Filter 4	3,33	3,29	3,42	13,57	4,20
Filter 5	3,17	3,18	3,14	14,31	4,03
Filter 6	3,01	2,95	3,16	12,24	3,69
Filter 7	3,84	3,79	4,00	21,48	4,73
Filter 8	3,24	3,24	3,24	14,31	4,07
Filter 9	3,07	3,02	3,21	12,66	3,75
Filter 10	3,57	3,48	3,84	14,28	4,59
Filter 11	3,73	3,72	3,77	16,75	4,75
Filter 12	3,46	3,44	3,54	13,48	4,16
Filter 13	3,25	3,22	3,32	14,84	3,99
Filter 14	3,01	2,96	3,14	14,87	3,78
Filter 15	1,97	1,76	2,24	9,63	2,52

Table I contains the calculated errors as results of the Filters applying in the subtraction method with the testing signal. The diagrams obtained using the software product Excel can be seen in the Fig. 19.

One may see that the filters that have lower suppression of the spectral components, different from the power-line frequency, are more accurate in interference extraction.

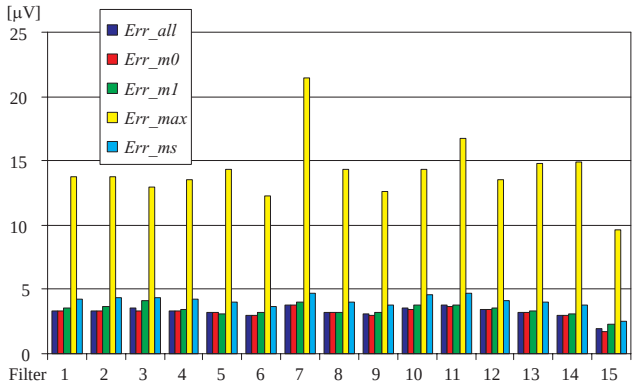

Fig. 19. Comparison between experimented K-filters

III. CONCLUSION

In the paper are investigated fifteen non-recursive filters for their applicability in the subtraction method for removing PL interference from ECG. Non-recursive K-filters have been chosen because their impulse responses are finite and could be locked in a linear area [-*n*…+*n*] defined by the linearity criterion. The results lead to the followed conclusions:

1. All K-filters that perform the condition to have a transfer coefficient $K(f) = 1$ for $f = 0$ and $K(f) = 0$ for $f = F$ are suitable for using in the subtraction method.
2. Unsymmetrical K-filters, which have *non-linear phase response* are also suitable for using in the subtraction method (see experiments with Filters 8 and 9).
3. Filters with less suppression of the frequency components different from F produced a smaller error.
4. Lower value of the errors are obtained using K-filters, which have higher steepness of the tangent in $f = 0$.

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