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A Note on Filtering Electrocardiograms

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In developing computer programs for analysis of the electrocardiogram, concern for noise superimposed on the signal is essential. The two major sources of noise are 60 cycle pickup and random myoelectric noise. A large portion of this noise can be suppressed by low pass filtering of the signal. Design of digital low pass filters has received considerable attention during the past few years (*1*, *2*). A common practice is to truncate an appropriate $\sin(X)/X$ function and use those values as the set of weights for the transfer function of the filter. These weights are the A_k's in the convolution Eq. (1) and the output Y_i is the digitally filtered signal.

$$Y_i = \sum_{k=0}^{n-1} A_k X_{j-k}. \tag{1}$$

Since truncation of the function causes distortion of the filter in the frequency domain, a *window function* is usually applied to minimize this distortion. For a filter designed in this manner to have a frequency response which closely approximates that of an ideal low pass filter a large number of terms should be used. However, high speed techniques have been developed in recent years which reduce significantly the time to filter a signal with such precise filters (*1*). Thus, filters of this design could conceivably be practical for use by a computerized on-line ECG analysis program.

Using the truncation design, various low pass filters were studied for possible use by our on-line ECG rhythm analysis program. The rhythm program samples 16 consecutive heart beats to determine the basic rhythm of the patient and counts the number of premature complexes detected during the analysis. For this program to be of practical use, it is necessary that the analysis time be in the order of 5–10 sec. Two filters were compared. The first (Filter 1) consisted of 17 weights, and the second (Filter 2), 255 weights. These filters were formed by truncating the $\sin(X)/X$ function calculated from an ideal low pass filter with a cut off at 30 cycles per second and a sampling rate of 200 samples per second. Figure 1 shows the frequency response of the

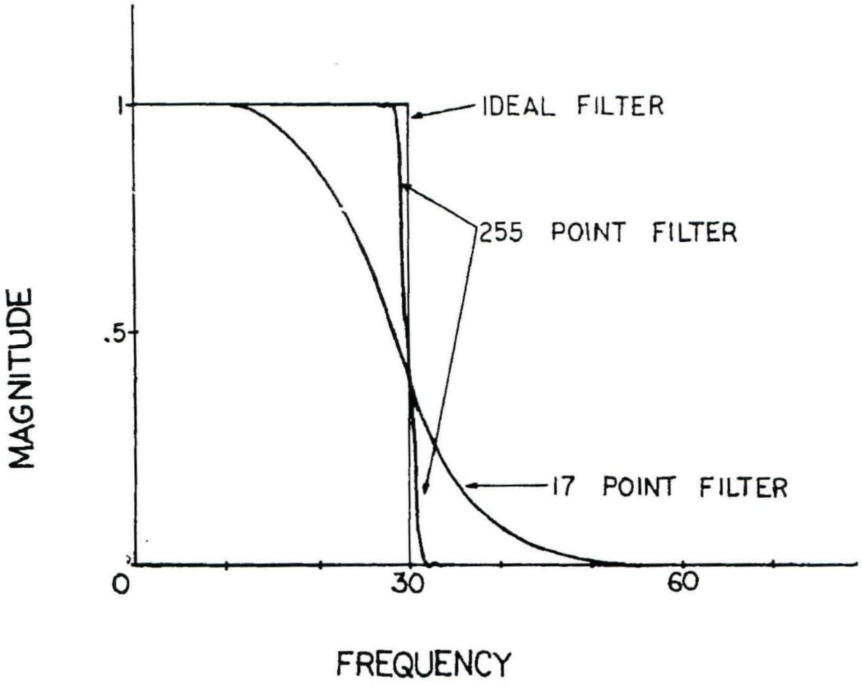

FIG. 1. Frequency characteristics of ideal low pass filter, 17 point filter and 255 point filter.

ideal low pass 30 cycle filter and the frequency responses for the two filters under consideration. The weights were smoothed using the *hanning* smoothing function

$$W_k = A_k\left(\tfrac{1}{2} + \tfrac{1}{2}\cos\frac{2\pi k}{n}\right). \tag{2}$$

At 60 cycles Filter 2 attenuates the signal 160 db and Filter 1 is down 80 db. With this degree of attenuation at 60 cycles the two filters need only be compared on

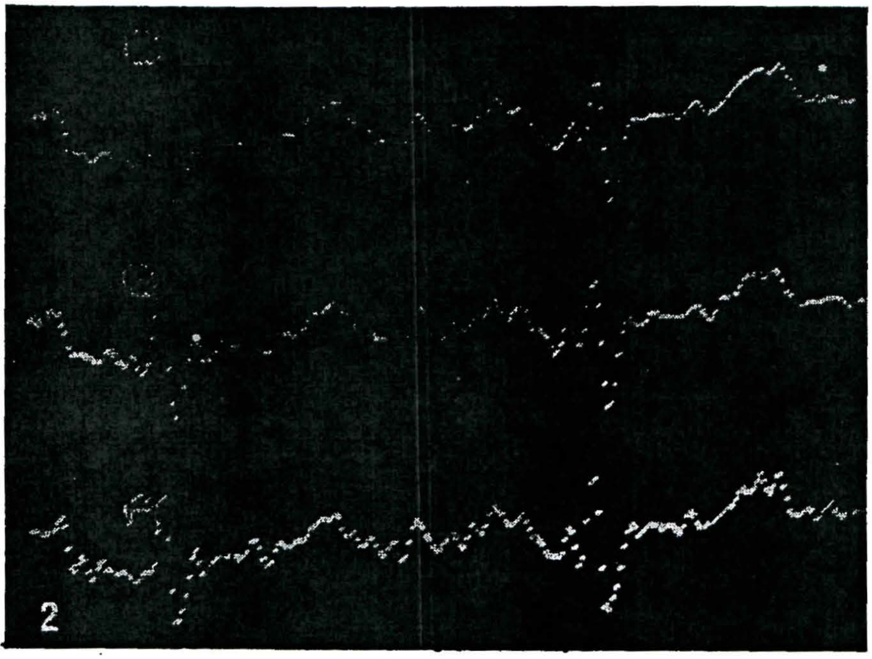

FIG. 2. Electrocardiogram containing myo-electric noise.

myoelectric noise attenuation and signal distortion in the pass band. Because of the large number of weights Filter 2 was implemented using high speed convolution techniques involving Fast Fourier transforms. All 16 beats were sampled at 200/sec and stored on computer disc memory before filtering. The time required to filter the data on a CDC 3300 was approximately 10 sec. Since the amount of time to filter the data was much greater than the subsequent analysis time (less than 1 sec), the total time required was essentially the time to filter the signal. Floating point hardware and sectioning of the data was necessary for the high speed convolution. Filter 1, however, was implemented using the conventional convolution Eq. (1). The filtering was performed on-line between beats since the amount of time to filter one beat was only 120 msec. Hence, the analysis was completed in less than 1 sec following the sampling of the 16 heart beats. This filter also had the advantage that analysis could be performed using fixed-point techniques which reduced further the amount of computer time required (e.g., no transformation from fixed to floating point number was required).

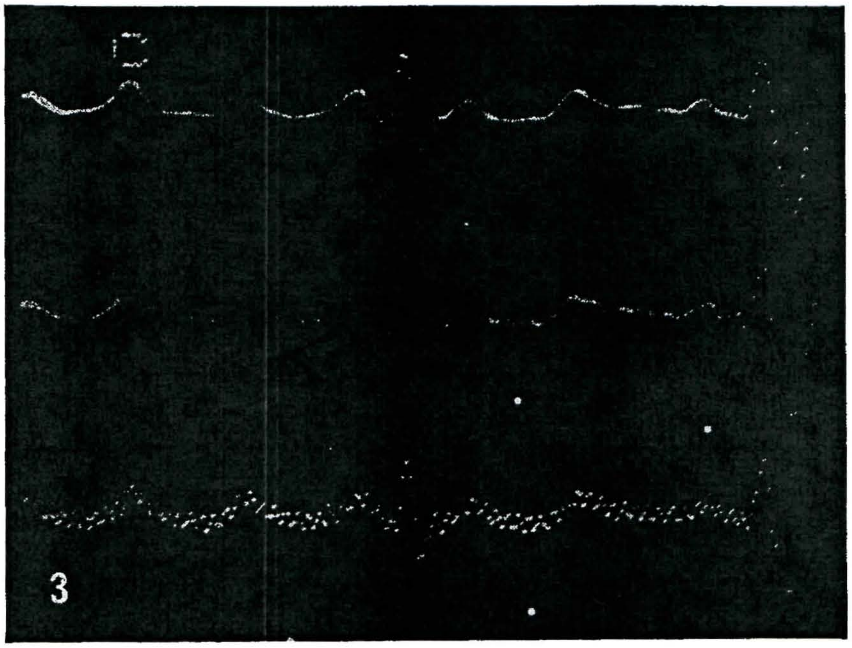

FIG. 3. Electrocardiogram containing 60 cycle noise.

Figures 2–4 give examples of the effectiveness of the two filters. In each case, Graph A is the unfiltered data, B the output of Filter 2, and C the output of Filter 1. Figure 2 shows an ECG which is contaminated with myoelectric noise. Figure 3 shows an example with considerable 60 cycle noise. Figure 4 is an electrocardiogram which is essentially noise free. As can be seen from these figures, there is no appreciable improvement in the signal when filtered with the 255 point filter (B) over the 17 point filter (C). Not only does Filter 1 eliminate most of the noise which might

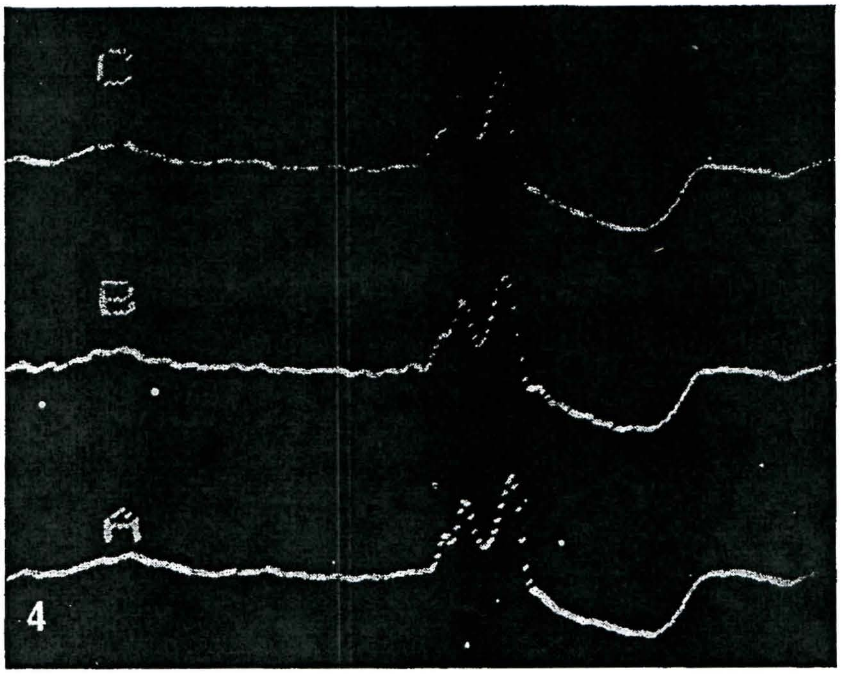

FIG. 4. Noise free electrocardiogram.

interfere with *P* wave recognition, but the more *expensive* filter (*2*) seems to *generate* noise as seen in the area just preceeding the onset of the QRS.

The roll off of Filter 1 starts at approximately 10 cycles per second. This results in distortion in the QRS configuration of the waveform. For the examples shown in Fig. 4, Table 1 gives the QRS duration as measured by the rhythm program using each of these filters, as well as the difference between maximum and minimum of the QRS. The fourth row represents those measurements on the same example after processing through a filter whose design was 17 weights with a cutoff frequency at 40 cycles per second (Filter 3). There is indeed some distortion of the QRS by Filter 1, as seen by the lengthening and attenuating of the QRS, but this is minimized using Filter 3. Note also the notch in the unfiltered QRS in Fig. 4 which is smoothed using

TABLE 1

QRS DURATION AND MAXIMUM–MINIMUM QRS VALES FOR ELECTROCARDIOGRAMS IN FIG. 3 AND 4

	QRS duration	Max–min
Unfiltered	27	87
Filter 1	31	85
Filter 2	28	86
Filter 3	28	87

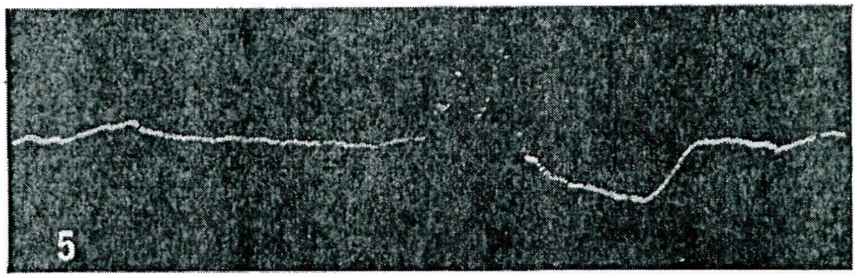

FIG. 5. Noise free electrocardiogram filtered by 40 cycle, 17 point filter.

the Filter 1, but is again present using Filter 3 as seen in Fig. 5. Table 2 gives the 17 weights of both the 30 cycles and 40 cycle cutoff filters. These weights have been scaled up by 1 000 000.

TABLE 2

WEIGHTS FOR 17 POINT, 30 CYCLE FILTER AND 17 POINT, 40 CYCLE FILTER

30 Cycle filter	40 Cycle filter
1141	−705
1644	3127
−7796	12614
−26304	0
−27448	−44413
24591	−46794
133659	82606
249753	293602
300000	400000
249753	293602
133659	82606
24591	−46774
−27448	−44413
−26304	0
−7796	12614
1644	3127
1141	−705

[a] Filter weights for sampling rate of 200 samples/second.

As a result of these studies, two filters are presently used in our ECG analysis program. Filter 1 is used for smoothing in the rhythm analysis, and Filter 3 for the morphological analysis. These filters not only preserve those components of the ECG signal required for pattern recognition and analysis and minimize noise encountered in routine recording of these signals but also minimize computer requirements for accomplishing this.

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2. SU, K. S. AND CHENG, P. C. Design of Digital Low-Pass and Band-Pass Filter for Biomedical Data Series. Proceedings of San Diego Biomedical Symposium, San Diego, Calif.