Technical Notes on Filtering Techniques and Standards for Diagnostic and Monitoring ECGs

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Abstract

ECG signal processing techniques and standards differ depending on the purpose of the ECG. Diagnostic ECG's require preservation of very low frequencies to preserve ST-Segment fidelity. Monitoring ECG's are more permissive, and allow the use of efficient recursive high pass filters for on-line processing, but these may not preserve ST-Segment fidelity. We note specific applicable medical device standards.

Filtering ECG signals will inevitably change some aspects of the raw signal, or we would not have recourse to filters in the first place. Generally, we want to attenuate noise with as little effect on the signal as possible. Though filtering is necessarily obtrusive, it is required for some applications, particularly those involving mobile subjects engaged in walking or running during the collection of theECG.

Some relevant standards include:

- **IEC 60601-2-25** Medical electrical equipment - Part 2-25: Particular requirements for the basic safety and essential performance of electrocardiographs
- **IEC 60601-2-27** Medical electrical equipment - Part 2-27: Particular requirements for the basic safety and essential performance of electrocardiographic monitoring equipment
- **IEC 60601-2-47** Medical electrical equipment - Part 2-47: Particular requirements for the basic safety and essential performance of ambulatory electrocardiographic systems
- **ANSI/AAMI EC11-1991/(R)2001**: Diagnostic Electrocardiographic Devices, 2ed

The ST-Segment contains low frequency components which must be preserved for ST-Segment diagnostics. Monitoring applications such as rhythm strips are not as stringent in their requirements for low frequencies. Thus frequency bandwidth requirements vary with the application:

- **Heart Rate/HRV**: Bandwidth is unspecified: There are no particular requirements for signal bandwidth preservation in this application, since HR/HRV is derived from QRS complex fiducial points only.

- **Ambulatory, and Monitoring**: 1Hz to 40Hz bandwidth is suitable for heart rate estimation and on-line monitoring displays.

- **Diagnostic**: 0.05Hz to 150Hz frequency band supports ST segment measurements. Moreover, diagnostic ECG's are taken from clinically placed 12-lead ECG's, so sensor placement may be critical to obtain diagnostic fidelity. 0.05 Hz seems very low, relative to a 1 Hz. heart rate, but the non-linear smearing of the QRS complex by realtime monitoring filters causes clinically significant ST-Segment changes if the recursive high pass filter is set higher than 0.05 Hz.

Buenda-Funetes et al. describe the clinically significant alterations to the ST segments made by by applying various filters at monitoring and diagnostic bandwidths[1].The following filter configurations: 0.05–40 Hz, 0.5–40 Hz, 0.05–100 Hz, 0.5–100 Hz, 0.05–150 Hz, and 0.5– 150Hz were used in the work. In order to obtain diagnostic bandwidth, the sampling rate was set to 400 Hz, which offers a theoretical maximum Nyqvist frequency capture of 200 Hz., but since this is an upper bound, we actually obtain an effective maximum frequency which is lower, so a guard band of 50 Hz. used by Buenda-Funetes is good engineering practice. Figure 1 shows the original ECG and application causal filter, e.g. a Butterworth Filter, and its effect on the ST-Segment.

High pass filters of the type shown in Figure 1 are generally applied to attenuate baseline drift that is common in electrocardiograms taken while the subject is mobile. But we see that they can introduce significant artifacts and must be used carefully.

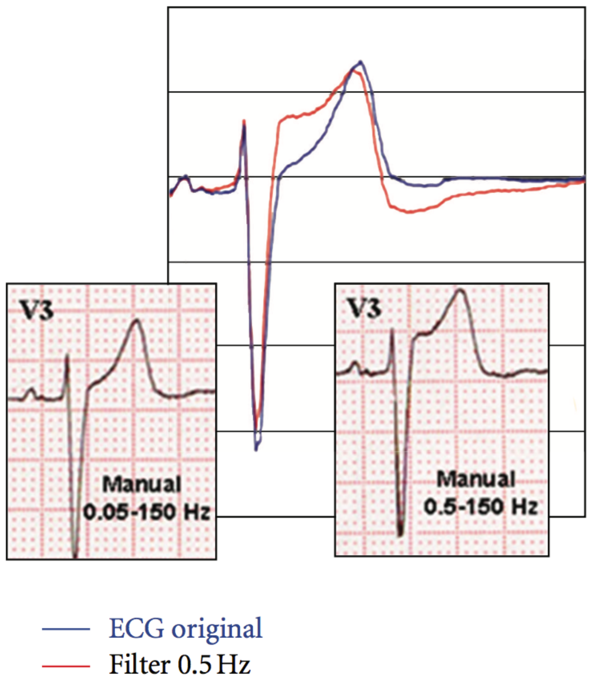
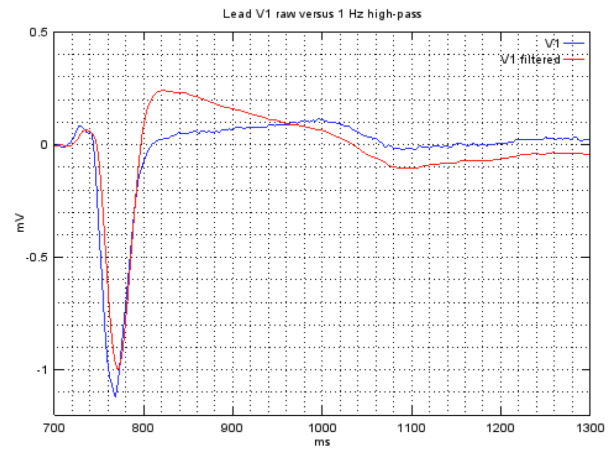


Figure 1: ECG filtered using a causal recursive filter (after Buenîa-Funetes et al.) showing ST-Segment artifacts. The V3 lead is shown in the Manual diagnostic bandwidth recording (lower left) and the the V3 Lead after filtering with a highpass causal recursive filter with a cut frequency of 0.5 Hz (lower right). Upper center shows the pre-filtered ECG and the filtered ECG superimposed. Note the pronounced ST segment elevation introduced as a filtering artifact. These artifacts are potentiated by the nonlinear phase response of the causal recursive filters used for monitoring because of the need for realtime display generation. Causal filters introduce a frequency dependent phase delay into the filtered signal, i.e. different signal frequencies are delayed by different amounts of time, which can smear the signal in the time domain, which can alter clinical measurements significantly.



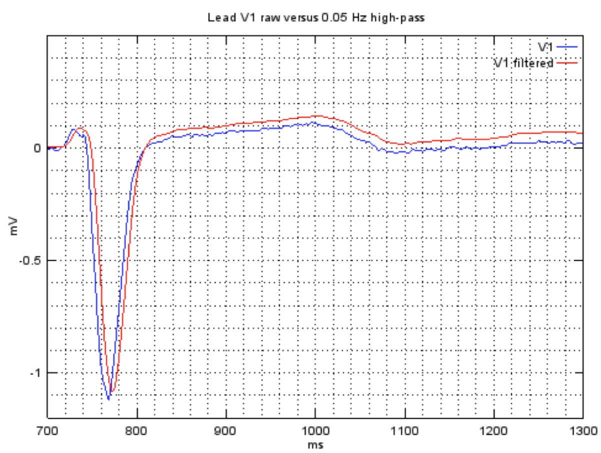


Figure 2: Filtered V1 lead with recursive non-linear filter (top) and linear non-recursive filter (bottom).The non-linear recursive 1 Hz. highpass filter introduces non-linear phase distortions that elevate the ST-Segment. In contrast, the 0.67 Hz. non-recursive linear phase high pass filter does not distort the ST-Segment as much, though it does show a slight diminution the amplitude of the R-Wave. (After Watford).

In figure 2 we see that linear phase (non-causal) filters can attenuate baseline drift frequencies up to around 0.67 Hz without extensive of damage to the ST-Segment in the illustration. In general, the types of filtering applied to clinical electrocardiograms include:

- **Highpass**: These can remove motion artifact, respiratory variation, and baseline wander. High-pass filters do not necessarily attenuate much of the signal. However, realtime causal highpass filters cause phase shifts affecting 5 to 10 harmonics of the signal. This means that a 0.5 Hz recursive causal high pass filter, can affect frequencies up to 5 Hz!.

- **Lowpass**: Used to remove high frequency muscle artifact and external interference. They often attenuate the amplitude of higher frequency ECG components. Analog low-pass filtering has a noticeable effect on the QRS complex, epsilon, and J-waves, but not re-polarization signals.

- **Notch**: These narrowband filters are used to remove 50/60 Hz. mains frequencies and their harmonics. Improperly designed notch filters can introduce visible ringing in the neighborhood of the QRS complexes, and so require caution.

Watford provides some helpful illustrations of the functioning of the recursive non-linear phase, and non-recursive linear phase filters on the ST-Segment[2]. Most cardiac monitor technology developers will choose the appropriate filters based on the situation. When performing routine monitoring, where only the cardiac rhythm is important, the filters applied are known as monitor mode filters. When performing a 12-Lead clinical ECG for reading, which requires a high fidelity recording, the filters applied are known as diagnostic mode filters. Typically, the resting heart rate will be in the neighborhood of 1 to 1.5 Hz, or 60 to 90 beats per minute.

References

[1] F. Buendîa-Fuentes. High-bandpass filters in electrocardiography: Source of error in the interpretation of the st segment. *ISRN Cardiology*, 2012(706217):1–10, April 2012.

[2] Christopher Watford. Understanding ecg filtering, March 2014. http://www.ems12lead.com/2014/03/10/understanding-ecg-filtering/.