Understanding ECG Filtering

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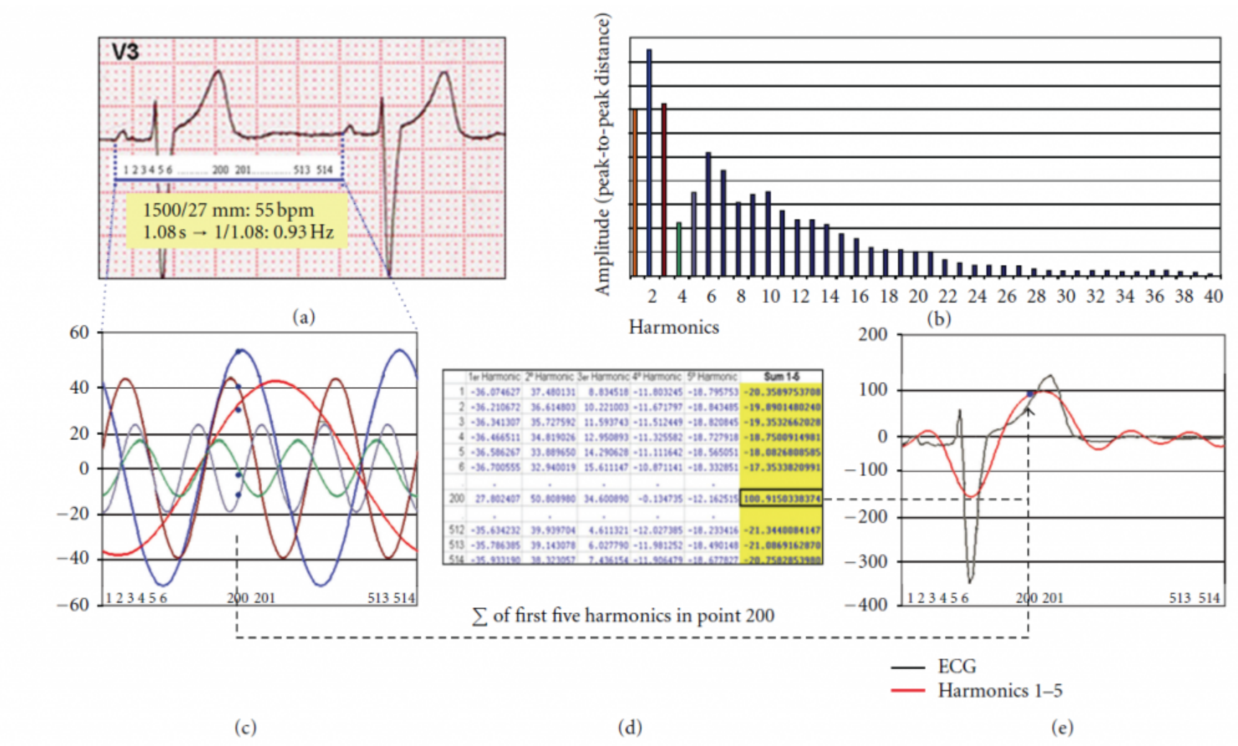
A common problem in ECG interpretation is the removal of unwanted artifact and noise. To help with this our cardiac monitors provide a means to **filter** the ECG recording. Most cardiac monitors will choose the appropriate filter based on the situation. When performing routine monitoring, where only the cardiac rhythm is important, the filters applied are known as **monitor mode** filters. When performing a 12-Lead, which requires a high fidelity tracing, the filters applied are known as **diagnostic mode** filters. Beyond this, little emphasis is placed on understanding ECG filtering. This gap in education leads to problems for both experienced and inexperienced interpreters.

Signal Processing Basics

The **frequency** of a signal measures the **cyclic rate** or **repetition**, and is measured in **Hertz (Hz).** A frequency of 1 Hz means a signal repeats itself every one second. Our hearts produce electrical activity recorded by electrodes as a **signal**. The sinoatrial node fires at roughly 50 to 90 beats per minute, and for the sake of this post we will say **60 beats per minute** is the happy median. This means the heart has a fundamental frequency of **1 Hz** at this heart rate. Therefore, all of the ECG components (P, QRS, and T) will occur at or above this frequency.

Because the ECG signal repeats itself, each time the heart cycles through systole and diastole, we can break it down into individual waves or **harmonics**. This process of breaking down a signal into a series of *sine waves* is known as **Fourier Analysis**. Using the property of **superposition**, if you add together enough of these harmonics you can recreate the original signal.



Each of the harmonics (sine waves) have a certain **amplitude**, **frequency**, and **phase**. Amplitude is the magnitude of the signal, measured on the ECG in millivolts (mV). Frequency was discussed previously, and is the rate of repetition of the signal. Lower frequency harmonics have higher amplitudes, and higher frequency harmonics will have lower amplitudes. Therefore, the low frequency ECG components play the largest role in observed amplitude on the ECG.

Phase can be thought of as the delay before the signal begins. Think of a group singing Row Your Boat, where each person starts after the previous. We can say that if two singers match that they are *in phase*, and two who are at different parts of the song are *out of phase:*

What electrical signals are recorded by the ECG?

Like we said, the ECG signal is comprised of multiple sources. The recording is made through electrodes on the skin, which capture more than just the electrical activity of the heart. The primary electrical components captured are the myocardium, muscle, skin-electrode interface, and external interference.

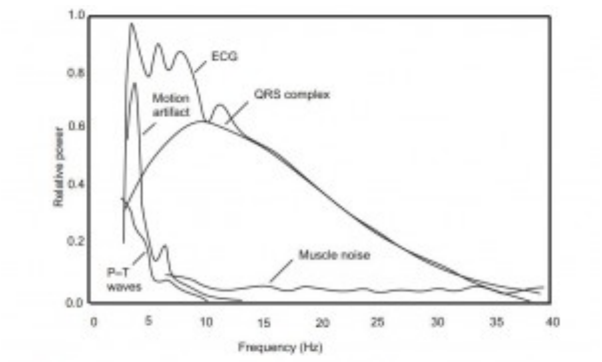


Figure 12.1 Relative power spectra of QRS complex, P and T waves, muscle noise and motion artifacts based on an average of 150 beats.

The common frequencies of the important components on the ECG:

- Heart rate: 0.67 – 5 Hz (i.e. 40 – 300 bpm)
- P-wave: 0.67 – 5 Hz
- QRS: 10 – 50 Hz
- T-wave: 1 – 7 Hz
- High frequency potentials: 100 – 500 Hz

The common frequencies of the artifact and noise on the ECG:

- Muscle: 5 – 50 Hz
- Respiratory: 0.12 – 0.5 Hz (e.g. 8 – 30 bpm)
- External electrical: 50 or 60 Hz (A/C mains or line frequency)
- Other electrical: typically >10 Hz (muscle stimulators, strong magnetic fields, pacemakers with impedance monitoring)

The skin-electrode interface requires special note, as it is the largest source of interference, producing a DC component of 200-300 mV. Compare this to the electrical activity of your heart, which is in the range of 0.1 to 2 mV! The interference seen from this component is magnified by motion, either patient movement, or respiratory variation.

How does Fourier Analysis relate to ECG filtering?

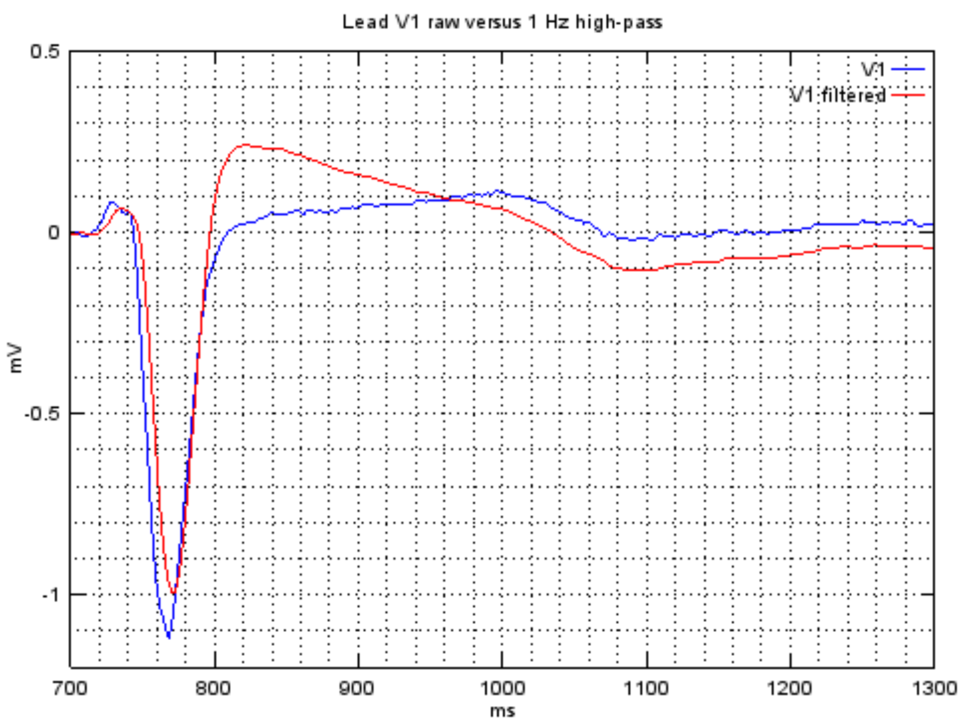
Filtering on an ECG is done four fold: high-pass, low-pass, notch, and common mode filtering. **High-pass filters** remove low frequency signals (i.e. only higher frequencies may pass), and**low-pass filters** remove high frequency signals. The high-pass and low-pass filters together are known as a **bandpass filter**, literally allowing only a certain frequency band to pass through. The **notch filter** is used to eliminate the line frequency and is usually printed on the ECG (e.g. ~60 Hz). **Common mode rejection** is often done via right-leg drive, where an inverse signal of the three limb electrodes are sent back through the right leg electrode.

All filters introduce distortion in the resulting output signal. This distortion can be in amplitude or phase. Filters found in cardiac monitors need to be **real time** and thus cannot tolerate delays. Because of this, the filter output exhibits **non-linear characteristics** due to their required shorter delays.

Basically, they distort different frequencies differently causing **phase distortion**. If the filters were applied during post-processing, where real-time output of the signal is unnecessary, the design of these filters can be linear which minimizes phase distortion.

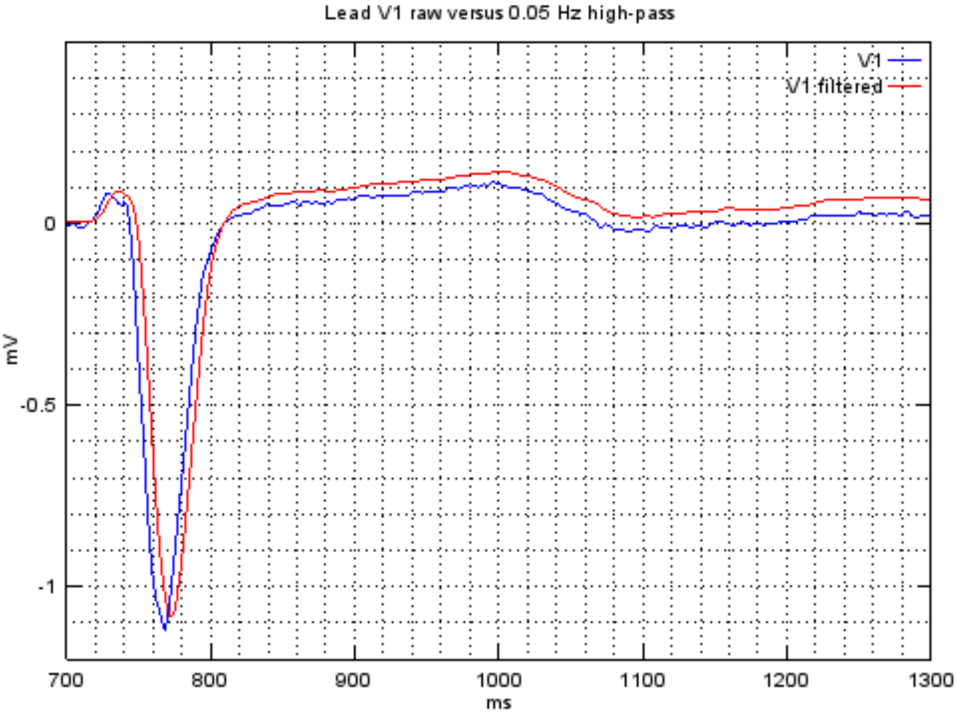
Low-pass filters on the ECG are used to remove high frequency muscle artifact and external interference. They typically attenuate only the amplitude of higher frequency ECG components. Analog low-pass filtering has a noticeable affect on the QRS complex, epsilon, and J-waves but do not alter repolarization signals.

High-pass filters remove low-frequency components such as motion artifact, respiratory variation, and baseline wander. Unlike low-pass filters, analog high-pass filters do not attenuate much of the signal. However, analog ***high-pass filters suffer from phase shift*** affecting the first 5 to 10 harmonics of the signal. This means that a 0.5 Hz high pass filter, which is a lower frequency than the myocardium produces, still can affect frequencies up to 5 Hz!



Compare the ST/T-waves between the raw V1 (blue) and filtered V1 (red). Common monitor mode 1 Hz analog high-pass filter was simulated using GNU Octave 3.6 and a 4th order Butterworth filter.

Remember that *lower* harmonics are of a *larger* amplitude than the higher harmonics, so any *distortion to their phase is magnified* on a real-time ECG. Studies have found that ECG’s with baseline alterations to the normal vectors of depolarization and repolarization feature greater distortion with high-pass filtering.



If a linear-phase high-pass filter is used, such as on a post-processed ECG, the frequency cutoff can be as high as 0.67 Hz without affecting ventricular repolarization at normal heart rates. However, because this filter design requires delays which do not permit real time display of the ECG signal, they are not commonly used in cardiac monitors. If a non-linear high-pass filter is used, the cutoff should be set to 0.05 Hz in order to minimize distortion to the ST-segment (10 times 0.05 Hz is 0.5 Hz, which is below physiological heart rates).

Putting it All Together

1. Use a frequency setting appropriate for your equipment and clinical setting. Most 12-Lead ECG's should be acquired at 0.05 – 150 Hz for full fidelity ST-segments and late potentials (such as epsilon or J-waves). A decent compromise with 0.05 – 40 Hz or 0.05 – 100 Hz can be used if muscle artifact is severe, provided you're aware of the amplitude distortions which will occur.

2. Always read the frequency settings and calibration pulse when interpreting an ECG. These provide valuable information in order to accurately interpret the ECG!

References

- Buenda-Fuentes, F., Arnau-Vives, M., & Arnau-Vives, A (2012). High-Bandpass Filters in Electrocardiography: Source of Error in the Interpretation of the ST Segment. ISRN Cardiology.
- Venkatachalam, K. L., Herbr, J. E., Herbrandson, J. E., son, & Asirvatham, S. J (2011). Signals and signal processing for the electrophysiologist: part I: electrogram acquisition Circulation. Arrhythmia And Electrophysiology, 4(6), 965-73. doi:10.1161/CIRCEP.111.964304

- Venkatachalam, K. L., Herbr, J. E., Herbrandson, J. E., son, & Asirvatham, S. J (2011). Signals and signal processing for the electrophysiologist: part II: signal processing and artifact Circulation. Arrhythmia And Electrophysiology, 4(6), 974-81. doi:10.1161/CIRCEP.111.964973

See also: Guide to Understanding ECG Artifact at ACLSMedicalTraining.com.
