

Application Note 142: *AcqKnowledge* and BSL PRO Find Rate Detector

This application note is concerned with the Find Rate Detector, which is critical to *AcqKnowledge* and BSL PRO software's ability to extract information from physiological data which has a degree of periodicity. Physiological data which can be investigated using Find Rate include:

Waveform	Metrics	Waveform Profile ¹
Airflow	Respiration Rate	smooth
Blood Flow	Flow Peak, Flow Min, Flow Mean	smooth
Blood Pressure	Systolic, Diastolic, Mean, dP/dt Max, dP/dt Min	smooth
ECG	Heart Rate or Inter-Beat-Interval recording	spikey (high slew rate or sharp amplitude transitions)
EKG (Electrogastrogram)	Peristolic contractions	smooth
EMG	Zero Crossing or Mean Frequency analysis	spikey
Goniometer (joint angle)	Repetitive motion/exercise	smooth
Nerve	Spike counting, Frequency	spikey
Pulse plethysmogram	Pulse Rate, Inter-Beat Interval, Volume	smooth
Respiration	Respiration Rate	smooth

¹Most physiological data which is periodic in nature is smoothly varying. However, important data types that are "spikey" include ECG and EMG.

The Find Rate Detector incorporates a significant amount of flexibility to optimize performance when extracting data from periodic physiological waveforms. There are three basic modes of operation for the Find Rate Detector:

1. Fixed threshold mode
2. Auto threshold detect mode (enables Noise rejection)
3. Remove baseline and Auto threshold detect mode

The Find Rate Detector will eliminate certain options when selecting different modes of operation. For example, the Remove Baseline function always uses the Auto-threshold detect mode. Furthermore, any cyclic measurement relating to amplitude (e.g. Peak-Peak, Maximum, Minimum, Area, Mean) automatically turns off the Remove Baseline function. If the measurement pertains directly to time, (e.g. Hz, BPM, Interval, Peak Time, Count Peaks), the Remove baseline and Auto-threshold detect modes are enabled for optional use, if needed.

Generally, it's best to use the simplest Find Rate Detector mode which is suitable for the application. If the simplest mode doesn't work add layers of sophistication, one at a time. For example, if the Fixed Threshold mode can't or will not work, use the Auto Threshold detect mode. If the Auto Threshold detect mode is similarly impaired, try adjusting the Noise rejection or try adding the Remove Baseline option (if enabled).

The Find Rate Detector Algorithm is a procedure whereby some special cyclic property of a waveform is determined by a search for waveform peaks or valleys. This note will attempt to explain the major component functionality of the Find Rate Detector algorithm that facilitates the search for these peaks. Thereafter, a discussion will focus on signal conditioning methods that will help render optimal results when the Find Rate Detector tool is applied.

1 Mode Overview

For a discussion of the options **Output reset events** and **Peak Interval window**, please refer to the *AcqKnowledge* or BSL PRO software manual.

1.1 Operate in fixed threshold mode

Fixed threshold detect mode is the simplest mode of operation for the Find Rate Detector. In Figure 1a, the threshold has been set to 0.00 volts. If the waveform crosses 0 volts, the Detector will begin to look for positive or negative peaks.

Note that noise rejection and rate windowing options are not available in this mode.

1.2 Operate in Auto-threshold detect mode

Auto-threshold detect mode is a more advanced and flexible mode of operation for rate detection. In this case, the Find Rate Detector will create a variable threshold and noise hysteresis to facilitate peak detection in noisy environment. Further, the detector can recover from a momentary loss of threshold triggering events. Figure 1b shows the dialog for this mode.

1.3 Operate in Remove Baseline and Auto-threshold detect mode

Remove Baseline operates in concert with the Auto-threshold detect mode. Primarily, the Remove Baseline option performs an automatic (and hidden) difference on the waveform data. This has the effect of removing low frequency signal components associated with baseline drift. Figure 1c shows the dialog for this mode.

2 Discussions of the Major Algorithm Components

The major algorithm components of Find Rate Detector are listed in Table 1 and depending on the Find Rate user interface options, as selected by the user (see Figure 1), any four of the five components can be invoked.

Option	Action	Dialog option
Fixed threshold	User specifies a fixed threshold whether searching for positive or negative peaks.	☐ Auto threshold detect Threshold level: 0.0000 Volts
Auto-threshold detect	Typically subject to the structure of the waveform and associated user preference, detect positive or negative peaks.	☒ Auto threshold detect
Noise Rejection through hysteresis	Mitigate the influence of noise on threshold detection.	Noise rejection: 5.0000 % of peak
Baseline Removal	Remove low frequency signal baseline drifts in the waveform.	☒ Remove baseline
Peak Detection	Algorithm used to identify positive or negative peaks and to calculate rate values	None

Table 1 Some of the algorithm component functions that are available through the Find Rate dialog. The search algorithm (shaded) is internal to the code and not user accessible.

2.1 Auto-Threshold Detection

The Find Rate Detector has been designed to process signal types such as ECG waveforms, as shown in Figure 2. These waveforms possess the property that they contain spike-like positive/negative excursions that are cyclic in time, i.e. sharp-sloped waves, with narrow peaks.

During the course of stepping through the waveform to find peaks in an impending cycle, thresholds are defined and determined from peaks of previous cycles. Figures 3a,b delineate how a threshold is defined.

The threshold definitions for either positive or negative signal peak are **referenced** to the negative signal peak in the defining cycle. The threshold equations are as follows:

Signal excursion

Equation

Positive $threshold - (OldMax - OldMin) \cdot 0.75 + OldMin$

Negative $threshold - (OldMax - OldMin) \cdot 0.25 + OldMin$

From these definitions the software can calculate rate or other cyclic parameters on a cycle by cycle basis.

2.2 Noise Threshold

Noise that is embedded within a signal can unduly influence the detection of signal peaks within the Auto-Threshold detection scheme. Mitigation in the form of hysteresis can be used as shown in Figure 4 (see also Figure 7a). The hysteresis value, h , is defined as a certain percentage of the previous cycle minimum/maximum signal values:

$$h = (OldMax - OldMin) \cdot NoisePercent / 100$$

This parameter is dynamically updated on a cycle by cycle basis.

2.3 Baseline Removal

Baseline removal allows the software to remove low frequency signal baseline drifts in the waveform. This process aids the peak detection by providing a level waveform.

To accomplish baseline drift removal, a **simple differencing scheme** is employed. The waveform is first offset by a set number of samples then differenced with itself. *Offsets greater than 1 sample are used to ease the load on the processor during the differencing calculation when high sample rates are used.* The number of samples used in the offset is determined by a ratio:

$$nDifSamples = \frac{25 \text{ msec}}{SampleTime(\text{msec})}$$

Referring to Figure 5, parameter $nDifSamples$ is the offset variable used in the code.

The first 25 samples (if the sample time is 1 msec) of the waveform is adjusted in amplitude to the first sample point within the waveform selection span. Thereafter, the waveform experiences a transformation analogous to being shifted 25 samples then differenced with itself. Figure 5 details the procedure on a simple ramp waveform. Note that the baseline drift is eliminated.

When applied to an ECG signal with drift, the “shift” **preserves** some part of the peaks of the waveform while eliminating the baseline drift. Figures 6a, b are simply two identical ECG signals, one is delayed 25 samples relative to the other then the two are differenced.

The third waveform (difference) is devoid of baseline drift.

Baseline removal is akin to taking a derivative. Any signal with a baseline drift component will have that component reduced to lesser amplitude over time.

Or, equivalently, drift removal is akin to using a high pass filter. Applying a digital FIR high-pass filter to the upper waveform of Figure 6a with a frequency cutoff of 0.1 Hz (Blackman – 61dB window) renders the same result – drift elimination and thus “leveling” of the ECG waveform.

2.4 Algorithm for peak detection

The detection scheme is somewhat straightforward. Table 1 shows the flow of the logic. Refer to Figure 7a while reading the contents of Table 1. Figure 7b shows the situation (for positive peak detection) where the hysteresis range is **greater** than the noise amplitude impressed on a signal. Note that there may be multiple low-to-high crossings of the “t+h” threshold, denoted by “A”, but no spurious crossings of the “t-h” threshold due to noise, which means no false peak detection.

Figure 7c shows the same situation where the hysteresis range is **less** than the noise amplitude. Not only are there multiple crossings of the “t+h” threshold, but there are multiple high-to-low crossings of the “t-h” threshold, denoted by “B”. This situation triggers false peak detection.

No.	Logic Element	Description
1	Positive or Negative Peaks	The user selects, through the dialog radio buttons, what type of peak to search for: positive or negative, but not both.
2	Thresholds	The threshold placement is determined by the type of peak. Section 2.1 lists the threshold definitions for positive or negative peaks. Hypothetical threshold placement, relative to the waveform, is shown in Figure 7a.

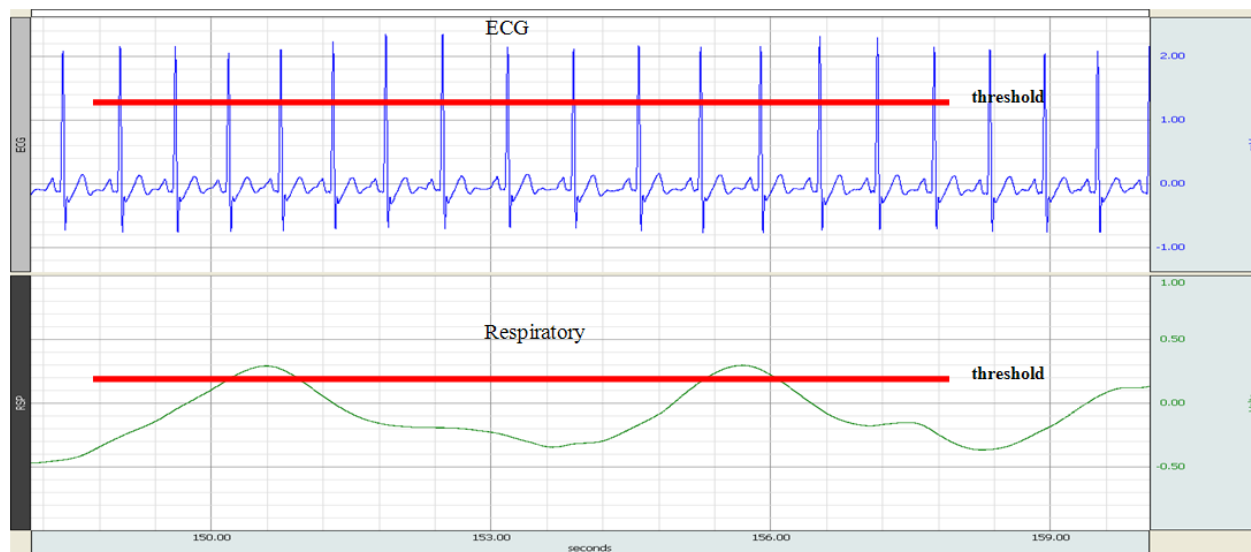
3	State	This binary state flag denotes whether the search has entered an area that is below the hysteresis threshold (0) or above it (1). The State values, along with the thresholds, define the boundaries of positive or negative peaks.
4	The search routine	As illustrated in Figure 7a, the search routine for peaks is constrained to two states: - whether one is below the threshold (State 0) - whether one is above the threshold (State 1) This is the routine to search for positive peaks; the logic for negative peaks is similar. As the arrow in the figure indicates: - The search is ready to transition from State 0 to State 1, denoted by A on the diagram. - Once within State 1, the routine performs a sequential search for the peak value. - Once found, it is stored for later processing and threshold updating. - Upon transitioning from State 1 to State 0, denoted by B on the diagram, this flags the condition that a peak has been found - The appropriate storage parameters are updated and a rate calculation (in concert with the previous peak value) is performed.

Table 1 Search algorithm

3 Signal Conditioning Prior to Application of the Find Rate Tool

Signals that are optimal for use with the Find Rate Detector tool include those with the following properties:

Periodic Well-defined Minimal noise Reasonably stable baseline



The figure above shows two types of signals, with the desired properties, that work well with the Find Rate Detector.

3.1 Signal Conditioning for Noise Mitigation

Even though the Find Rate Detector routine contains a noise threshold feature, too much noise can overwhelm the algorithm. Filtering can help.

In Figure 8a, the top waveform shows an ECG waveform with a strong noise component. Applying an FIR filter (one of many filter techniques available within AcqKnowledge or BSL PRO renders the lower waveform. Figure 8b shows the filter dialog and pertinent parameters. Figure 8c is an overlay of the peak waveforms for both the unfiltered and filtered signals. As seen from the figure, filtering accomplishes two goals:

- suppression of spurious threshold crossings by smoothing the waveform

- preservation of peak/valley locations and amplitude values.

4 Operational Suggestions

- If the waveform has clearly defined positive or negative peaks (like ECG or respiratory, or air flow data), which are consistently higher (in magnitude) than the rest of the waveform, use the Fixed Threshold option.
- If the waveform data has clearly defined zero-crossings (like EMG), the Fixed threshold option can be used to determine the rate of these crossings.
- If the waveform data has a moving baseline, but the peaks are otherwise larger in magnitude than other parts of the waveform (blood pressure), the Auto-threshold detect option can be used—adjust the noise rejection (hysteresis) as necessary to optimize performance.

Figure 1a Fixed threshold mode

Figure 1b Auto-threshold detect mode

Figure 1c Remove baseline + Auto-threshold

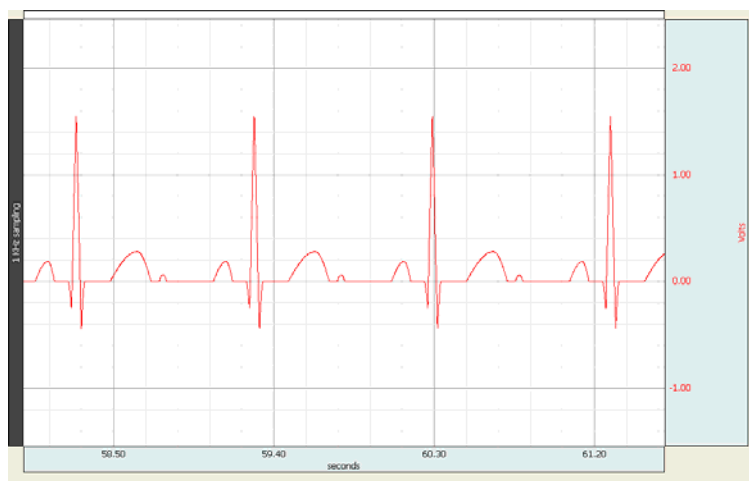


Figure 2 sample ECG waveform to illustrate the Find Rate Detector Algorithm.

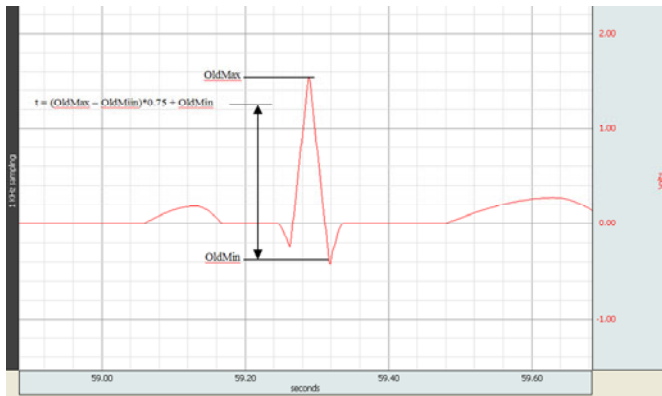


Figure 3a Threshold Definition for positive peaks

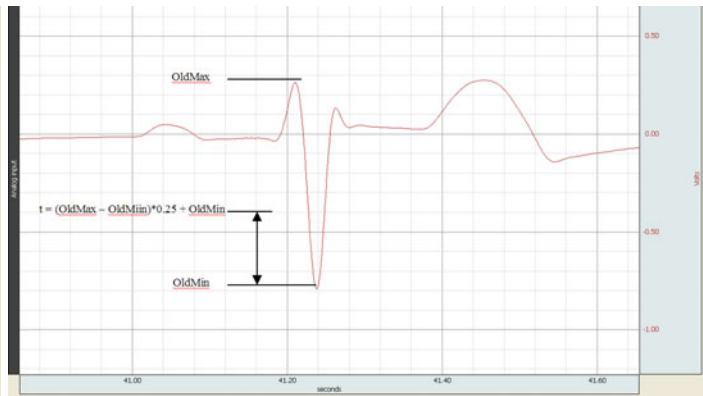


Figure 3b Threshold Definition for negative peaks

“t” will define threshold for next cycle peak

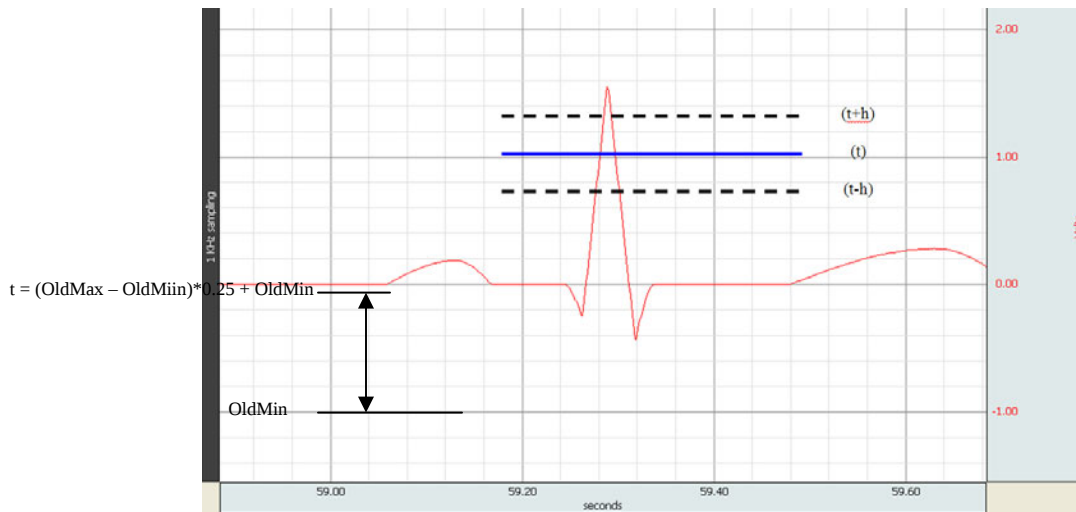


Figure 4 Threshold and Hysteresis Definition. Hysteresis is incorporated into the threshold setting to mitigate transient noise spikes. “t” is defined from previous cycle peak. Critical threshold crossings are at (t+h) and (t-h). “h” is the noise threshold as defined in Section 2.2.

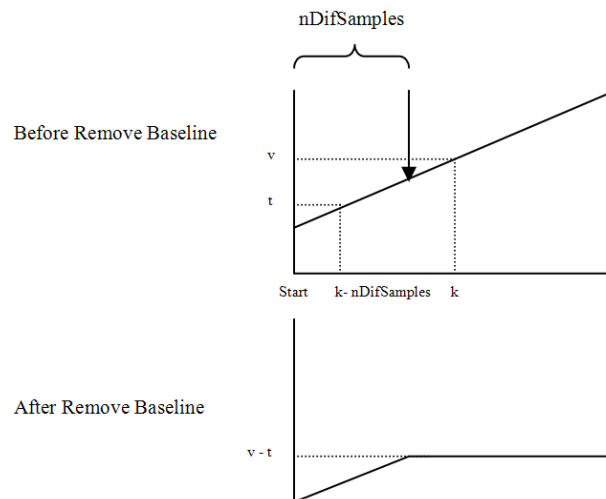


Figure 5 A linear drift applied to the ECG signal and the effect of Remove Baseline option on the drift. Here nDifSamples represents the offset in samples. After the application of Remove Baseline option, the superimposed baseline drift on an ECG signal is mitigated. “Start” represents the starting sample; k is the index for the next sample. For samples > (Start + nDifSamples), the drift curve sample values are adjusted by value “v – t” where “t” is the sample value at the index (k – nDifSamples) and “v” is the sample value at index (k). nDifSamples = 25/SampleTime. SampleTime is in msec.

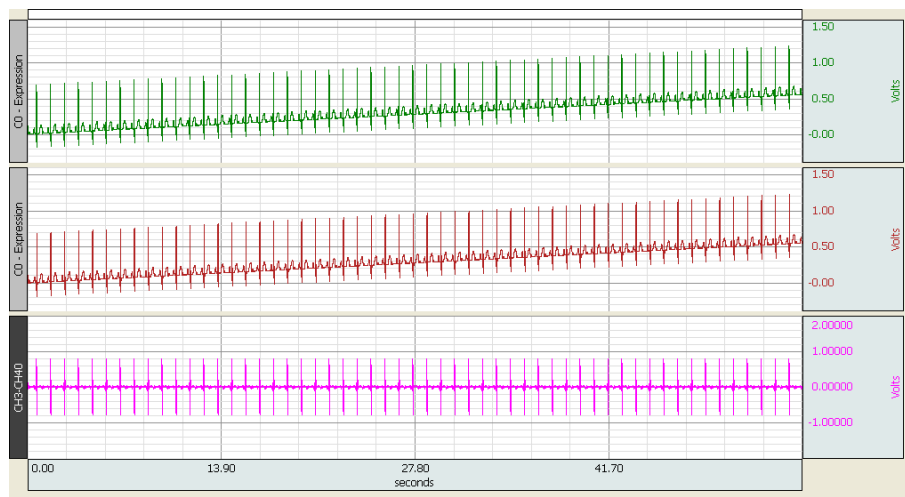


Figure 6a ECG signals: top waveform has linear drift, middle waveform has drift and a 25 sample delay, bottom waveform is the difference between the top and middle waveforms.

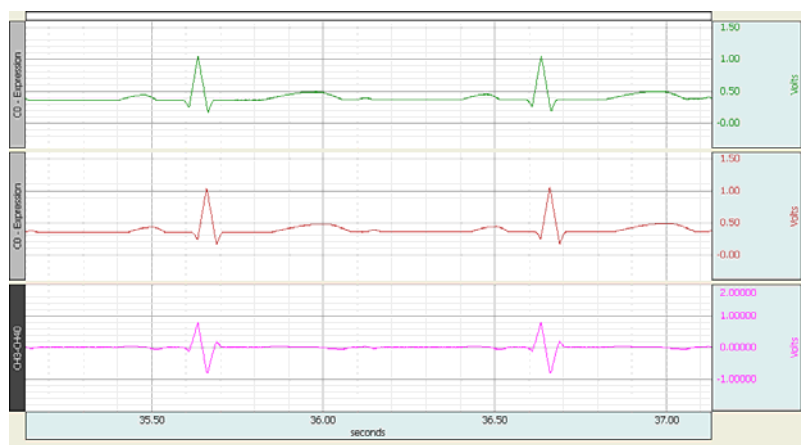


Figure 6b Expanded view: Top waveform contains baseline drift; second waveform is the first with a 25 sample delay; bottom waveform represents: (first wave – second wave). Note the baseline drift is gone and a “derivative” waveform is created.

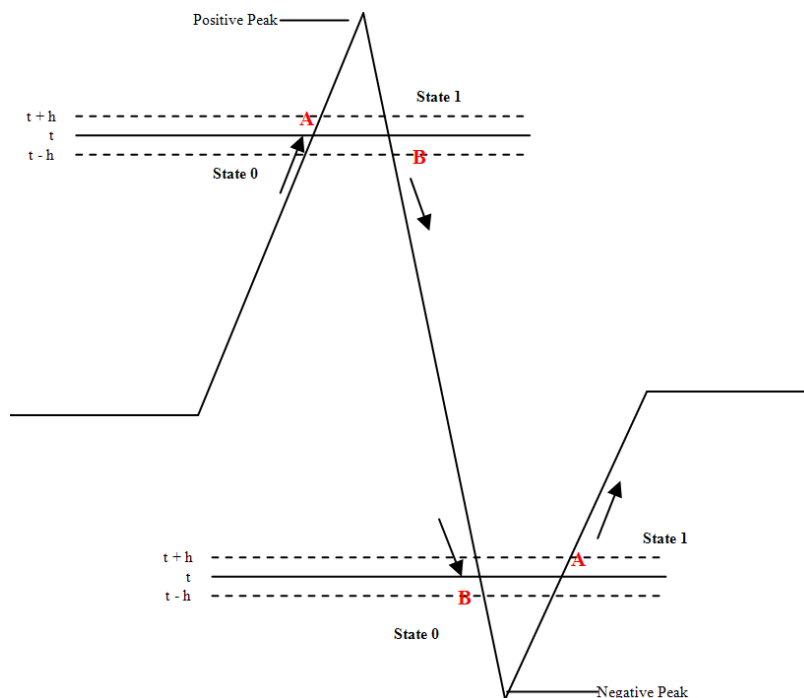


Figure 7a Diagram of the find peak algorithm. The user selects a preference of keying on positive or negative peaks but not both. Refer to Section 2.4 in the document for a description of the algorithm.

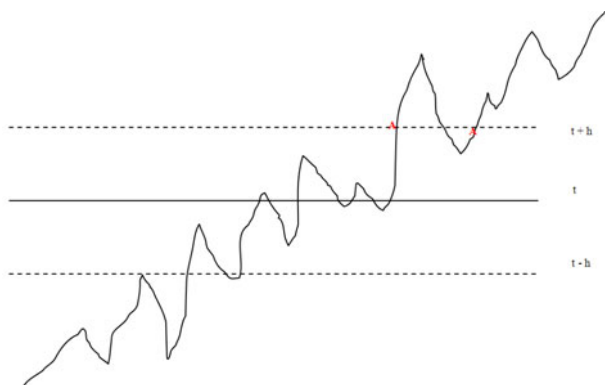


Figure 7b Threshold span is **greater** than the noise amplitude on a signal; searching for positive peaks.

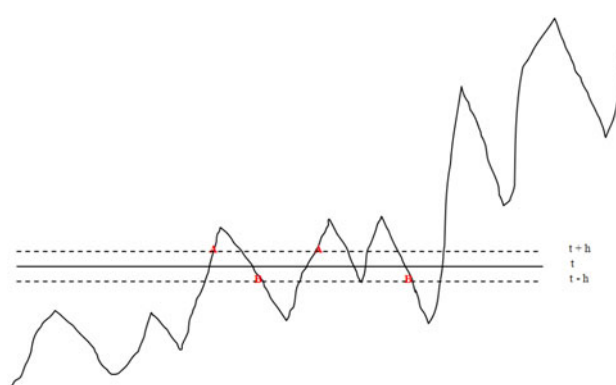


Figure 7c Threshold span is **less** than the noise amplitude on a signal; searching for positive peaks.

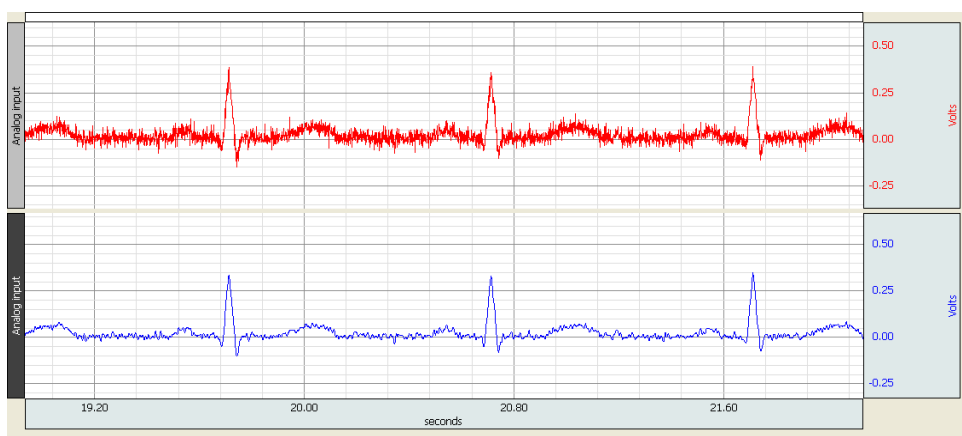


Figure 8a Top waveform is a noise laden ECG signal. Lower waveform represents the same ECG signal after passing the signal through a Low Pass FIR filter. See Figure 8b for details of the filter parameters.

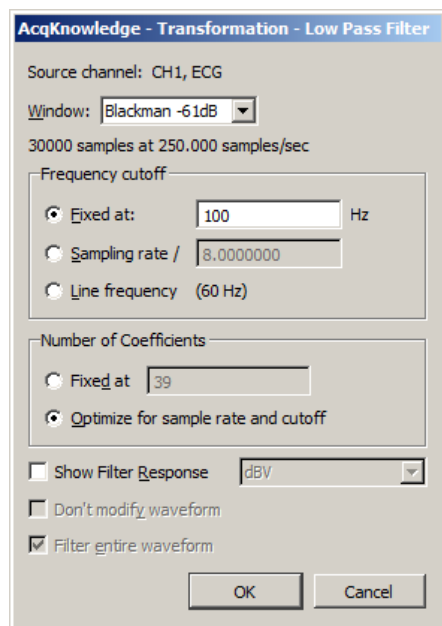


Figure 8b Filter parameters

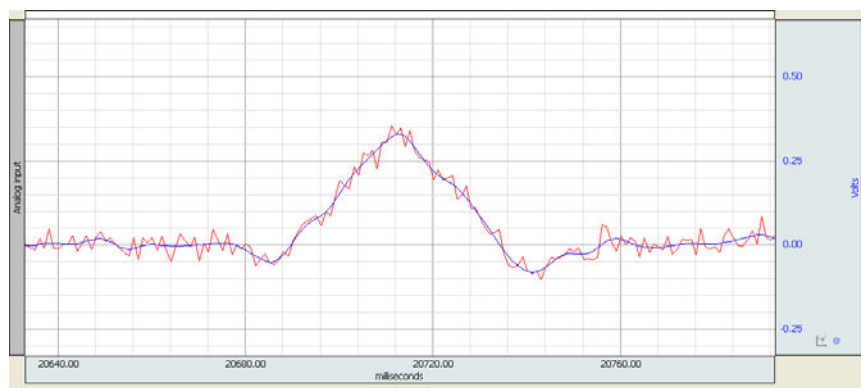


Figure 8c (Transform > Digital Filters > FIR > Low Pass)
Overlay view of the original, noisy ECG signal and the filtered signal.