Understanding & Setting STA/LTA Trigger Algorithm Parameters for the K2

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Introduction

The Kinemetrics K2 firmware (K2 DSP code 302242 Ver.8.10 and on and K2 MCU code 302241 Ver. 2.20 and on) includes, in addition to standard amplitude threshold trigger algorithm, a new algorithm: short-time average/long-time average (STA/LTA) trigger. This algorithm significantly increases the instrument's trigger sensitivity and makes it more robust to false triggers in many, particularly weak motion, seismological applications.

Successful capturing of seismic events depends on proper settings of the new trigger parameters. Setting of STA/LTA parameters is more demanding than setting of a simple amplitude threshold trigger which is traditionally built in strong motion seismic recorders. To help with this task, this Application note explains the K2's STA/LTA trigger functioning and gives general instructions on how to select its parameters. Technical instructions on how to set trigger parameters are not given here since the K2's QT communication program parameter windows are more or less self-explanatory. Refer to K2 and QuickTalk manuals for details.

Most of the discussion and examples in this document deal with weak motion seismological applications since these are the applications where the STA/LTA algorithm is most useful. Available K2 trigger parameter values and their default values are given in the Appendix.

Several specific improvements over the conventional STA/LTA trigger algorithms are built in the K2's algorithm. They are also discussed in this application note.

Purpose

The short-time average/long-time average (STA/LTA) trigger algorithm increases the sensitivity of the seismic recorder in comparison with amplitude threshold trigger algorithm used widely in the strong motion field. It improves the recording of weak earthquakes and decreases the number of false records triggered by seismic noise. To some extent it also allows discrimination among different types of earthquakes. A decreased number of false triggers and trigger's selectivity can minimize the work of analysts and allows more efficient use of a recorder's data memory.

The STA/LTA trigger is usually used in weak motion applications that try to record as many seismic events as possible and when not only the strongest events are of importance. However, it may also be useful in many strong motion applications, except when the interest is explicitly limited to the strongest earthquakes.

The STA/LTA trigger parameter settings are always a tradeoff among several seismological and instrumental considerations. The goal of searching for optimal parameter settings is the highest possible trigger sensitivity for a given type of earthquakes (which includes "all earthquakes" target as well) at a still tolerable number of false triggers.

The STA/LTA trigger is most beneficial at seismically quiet sites where natural seismic noise (marine noise) is the dominant type of seismic noise. It is also effective in case of changes of continuous man-made seismic noise. Such changes, for example, occur due to day/night variation of human activity in urban areas. The STA/LTA algorithm is less effective in the presence of irregular, high amplitude man-made seismic noise which is often of burst and/or spike type.

How it Works – Basics

The STA/LTA algorithm continuously keeps track of the changes in seismic noise amplitude at the station site and automatically adjusts the recorder's sensitivity to the actual seismic noise level. Calculations are repeatedly performed in real time. This process is taking place independently in all seismic channels of the K2. As a result, a significantly higher sensitivity of the instrument during seismically quiet periods is achieved and excessive numbers of falsely triggered records are prevented, or at least mitigated, during seismically noisy periods.

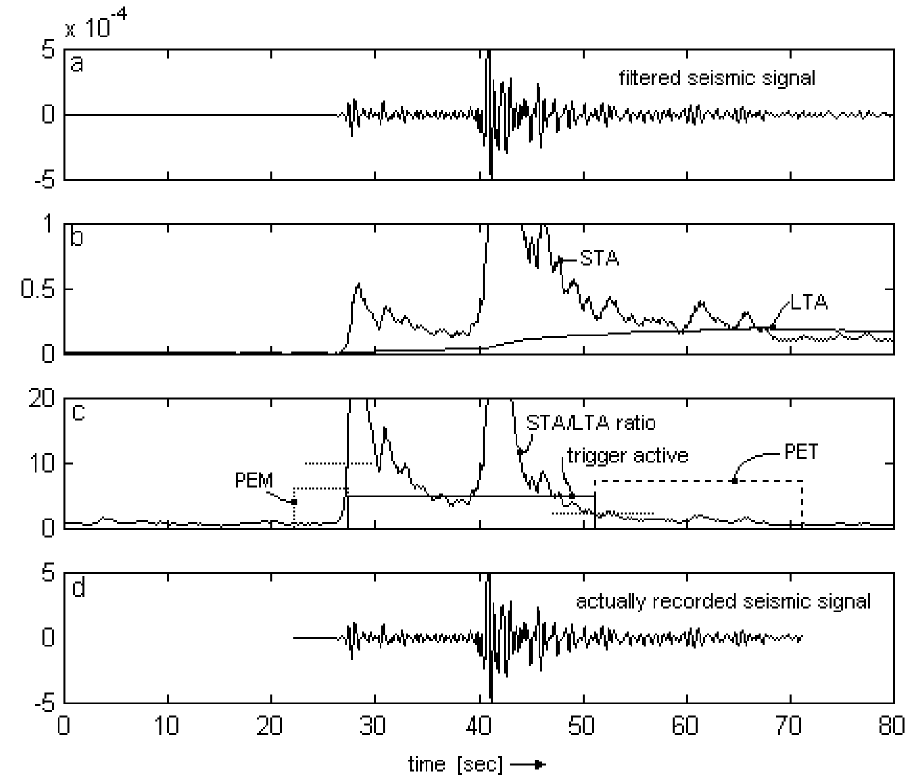
The STA/LTA algorithm processes filtered seismic signal (more in the section, "Selection of trigger filters", and page 14) in two moving time windows – a short time average window (STA) and a long time average window (LTA). The STA measures the "instant" amplitude of the seismic signal and is watching for earthquakes. The LTA takes care of average seismic noise. First, absolute amplitude of incoming signal is calculated. Next, average amplitudes in both windows are calculated. In the next step a ratio of both values — TA/LTA ratio—is a calculated.

This ratio is continuously compared to a user selected threshold value—STA/LTA trigger threshold level. If the ratio exceeds this threshold, a channel trigger is declared. A channel trigger does not necessarily mean that a multi-channel instrument actually starts to record seismic signals. Most seismic recorders, including the K2, have a "trigger voting" mechanism that defines how many and which channels have to be in a triggered state before the instrument actually starts to record data (more in the section, "Selection of voting scheme parameters," page 19). To simplify the explanation, we shall, for the moment, assume that there is only one channel in the recorder. A channel trigger is therefore equivalent to an instrument trigger.

After the earthquake signal gradually terminates, the channel detriggers. This happens when the STA/LTA ratio falls below another user selectable parameter—STA/LTA detrigger threshold level. Obviously, the STA/LTA detrigger threshold level must be lower (or rarely equal) than the STA/LTA trigger threshold level.

In addition to the data acquired during “trigger active” time, the K2 adds a certain amount of data to the event file before triggering – pre-event-time (PEM) data. After the trigger active state terminates, it also adds post-event-time (PET) data.

Figure 1. Function and variables of STA/LTA trigger calculations



For aid understanding, Fig.1 shows a typical local event and trigger variables (simplified) during STA/LTA triggering. Fig.1.a shows an incoming continuous seismic signal. Fig. 1.b shows an averaged absolute signal in the STA and LTA window respectively as they move in time toward the right side of the graph and Fig.1.c shows the ratio of both. In addition, the trigger active state (solid line), post-event time (PET), and pre-event time (PEM) are shown as “rectangles”. In this example, the trigger threshold level was set to 10 and detrigger threshold levels to 2 (horizontal dotted lines). One can see that the trigger became active when the STA/LTA ratio value exceeded 10. It was deactivated when the STA/LTA ratio value fell below 2. At the bottom on Fig.1.d the actually recorded data file is shown. It includes all event phases of significance and a portion of the seismic noise at the beginning.

In reality, the K2's STA/LTA trigger is slightly more complicated. The details are given in the section "How it works – advanced topics", page 23. However they are not essential for the understanding and proper setting of trigger parameters.

Setting Parameters for Proper Triggering & Data Recording

To set STA/LTA trigger algorithm you have to select following parameters:

- STA window duration in seconds
- LTA window duration in seconds
- STA/LTA trigger threshold level
- STA/LTA detrigger threshold level.

However, optimal recording of the K2 does not depend only on these trigger parameters. There are four additional associated parameters, which only if well tuned with the trigger parameters, guarantee proper data recording. These additional important parameters are:

- Trigger filters
- Pre-event time (PEM)
- Post-event time (PET)
- Trigger voting scheme.

Although not directly related to STA/LTA trigger algorithm, the additional parameters are also discussed in this application note in order to provide complete information.

How to Adjust STA/LTA Trigger Parameters

STA/LTA trigger parameter settings and associated parameters depend on the goal of the application, on the seismic noise condition, on the properties of earthquake signals at a given location and on the type of sensors connected to the K2. All these issues vary broadly among applications and among seismic sites. Obviously, there is no general, single rule on setting them. Each application and seismic site requires some study, since only practical experience enables the determination of really optimal trigger settings. Note that the K2's default trigger parameter values are strong-motion application oriented and therefore must be adjusted to become efficient for most weak motion applications. For best results, changing these parameters and gradually finding the best settings is a process , which requires a certain amount of time.

Selection of short time average window (STA) duration

Short time average window measures “instant” value of a seismic signal envelope. Generally, STA duration must be longer than a few periods of typically expected seismic signal. If the STA is too short, an averaging of the seismic signal will not function properly. The STA is no longer a measure of average signal (signal envelope) but becomes influenced by individual periods of seismic signal. For example, one should not select a very short STA with a long-period seismic sensor connected to the K2.

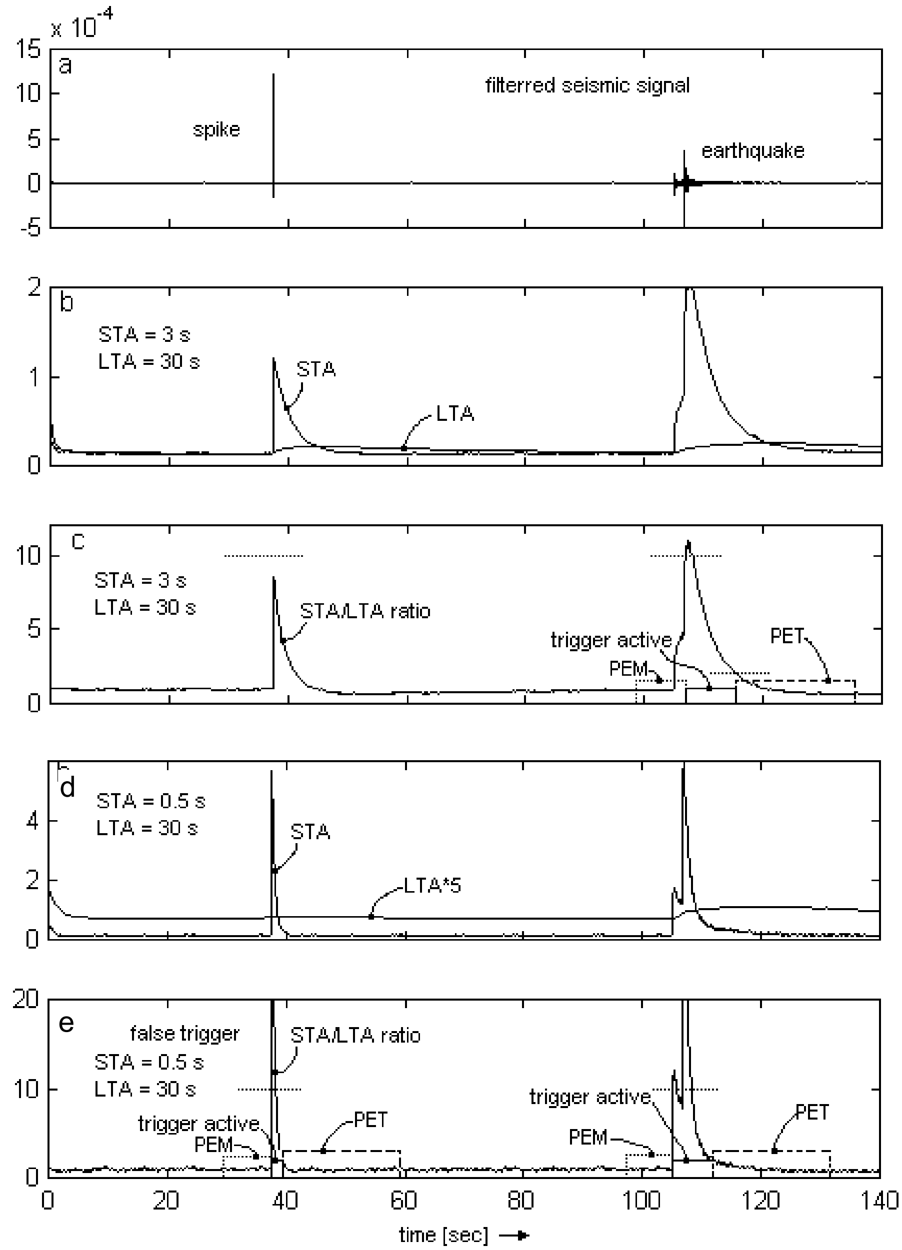
The STA functions as a signal filter. The shorter the duration selected, the higher the trigger’s sensitivity to short lasting local earthquakes compared to long lasting and lower frequency distant earthquakes. The longer the STA duration selected, the less sensitive it is for local earthquakes. By changing the STA duration you can, to some extent, prioritize distant or local events.

The STA duration is also important from the aspect of false triggers. By decreasing the duration of the STA window, for example, triggering becomes more sensitive to the spike-type of man-made noise, and vice versa. Although such noise is usually of an instrumental nature, it can also be seismic. At the sites highly polluted with spike-type man-made noise, you will be frequently forced to make the STA duration longer if false triggers are too numerous. Unfortunately, this will also decrease the sensitivity of the recorder to short very local events.

Fig.2 explains the effect of STA duration on local events and spike-type-noise. On graph a) a signal with an instrumental spike on the left and with a weak, very local earthquake on the right side is shown. Graphs b) and c) show STA, LTA, STA/LTA ratio, and trigger active states along with PEM and PET. The STA/LTA trigger threshold was set to 10 and detrigger threshold to 2. One can see that using a relatively long STA of 3 sec, the earthquake did triggered the system, but only barely. A much bigger amplitude (but shorter) spike did not trigger it. The STA/LTA ratio did not exceed the STA/LTA threshold and there was no falsely triggered record due to the spike. Graphs d) and e) show the same variables but for a shorter STA of 0.5 sec. The spike clearly triggered the system and caused a false record. Of course, the earthquake triggered the system as well.

For regional events, a typical value of STA duration is between 1 and 2 sec. For local earthquakes shorter values around 0.5 to 0.3 s are mostly used in practice.

Figure 2. Influence of STA duration on trigger sensitivity to short local events and “spiky” noise in seismic signals.

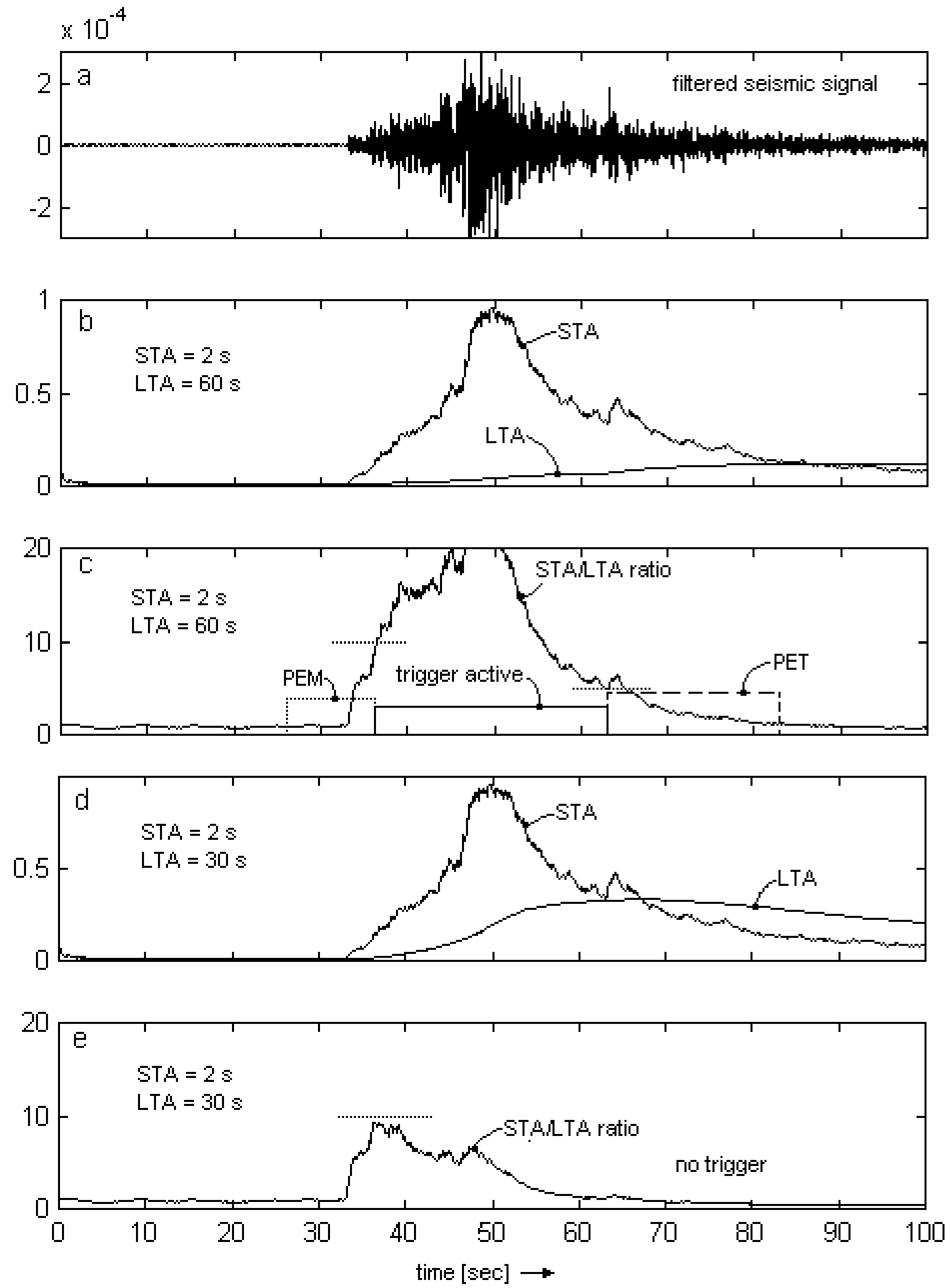


Selection of long time average window (LTA) duration

The LTA window measures average amplitude seismic noise. It should last longer than a few "periods" of typically irregular seismic noise fluctuations.

By changing the LTA window duration, you can make recording more or less sensitive to regional events in "Pn" range that are from 200 to 1500 km epicenter distances. These events typically show emergent Pn-onset waves.

Figure 3. Influence of LTA duration on trigger alogrithm sensitivity to earthquakes with emergent seismic signals.



A short LTA duration allows that LTA value to more or less adjusts to the slowly increasing amplitude of emergent seismic waves. Thus the STA/LTA ratio remains low in spite of increasing STA and LTA values. This effectively diminishes trigger sensitivity. In the opposite case, using a long LTA window duration, trigger sensitivity to emergent earthquakes is increased because the LTA value is not so rapidly influenced by the emergent seismic signal, allowing Sg/Lg waves to trigger.

Fig. 3 explains the described situation. In graph a) an event with emergent P waves is shown. Graphs b) and c) show the time course of trigger parameters for a relatively long LTA of 60 sec. The LTA does not change fast, allowing the STA/LTA ratio to exceed the STA/LTA trigger threshold (dotted line) and a normal record results. Graphs d) and e) show the same situation with a shorter LTA of 30 s. The LTA value increases much faster during the initial phase of the event, thus decreasing the STA/LTA ratio value which does not exceed the STA/LTA trigger threshold. No triggering occurs and the event is missed forever.

Similarly, event triggering with weak P waves compared to S waves requires a longer LTA for two reasons. First, if P waves do not trigger, they "contaminate" true information about seismic noise prior to the event. Since their amplitude exceeds the amplitude of seismic noise before the event, diminished trigger sensitivity to S waves results. This "contamination" is decreased if a longer LTA duration is selected. Second, longer LTA makes the trigger more sensitive to P waves as well.

Fig. 4 shows such a case. Graph a) shows a typical event with significantly bigger later phase waves than P waves. Graphs b) and c) show trigger parameters for a relatively long LTA of 100 s. P wave packet as well as S wave packet trigger the recorder. Appropriate PEM and PET assure that the event is recorded as a whole in a single file with all its phases and a small portion of seismic noise before them. Graphs d) and e) show the same situation but for a shorter LTA of 45 sec. One can see that the P waves did not trigger at all, while the S waves barely triggered. The STA/LTA ratio barely exceeds the STA/LTA trigger threshold. As the result, the recorded data file is much too short and contains only a portion of the event. P waves and information about seismic noise are missing in this record.

On the other hand, a short LTA will successfully accommodate recorder sensitivity to gradual changes of "continuous" man-made seismic noise. Such "transition" of man-made seismic noise from low to high is typical for night-to-day transition of human activity in urban areas. Also sometimes false triggers due to traffic can be mitigated by using a short LTA. Examples of such cases could be a single heavy vehicle approaching and passing close to the seismic station on a local road, or trains on a nearby railway. A short LTA can "accommodate" itself fast enough to such emerging disturbances and prevent false triggers.

Fig. 5 shows an example of the LTA response on increased seismic noise. Graph a) shows some seismic noise, which gradually increased in the middle of the record. Note that the change of amplitude is not sudden but lasts about 20 to 30 sec. Graphs b) and c) show the situation at a short LTA of 30 sec. One can see that the LTA value more or less keeps track of the increased noise amplitude. The STA/LTA ratio remains well below the STA/LTA trigger threshold and there is no false trigger in spite of significantly increased seismic noise at the site. Graphs d)

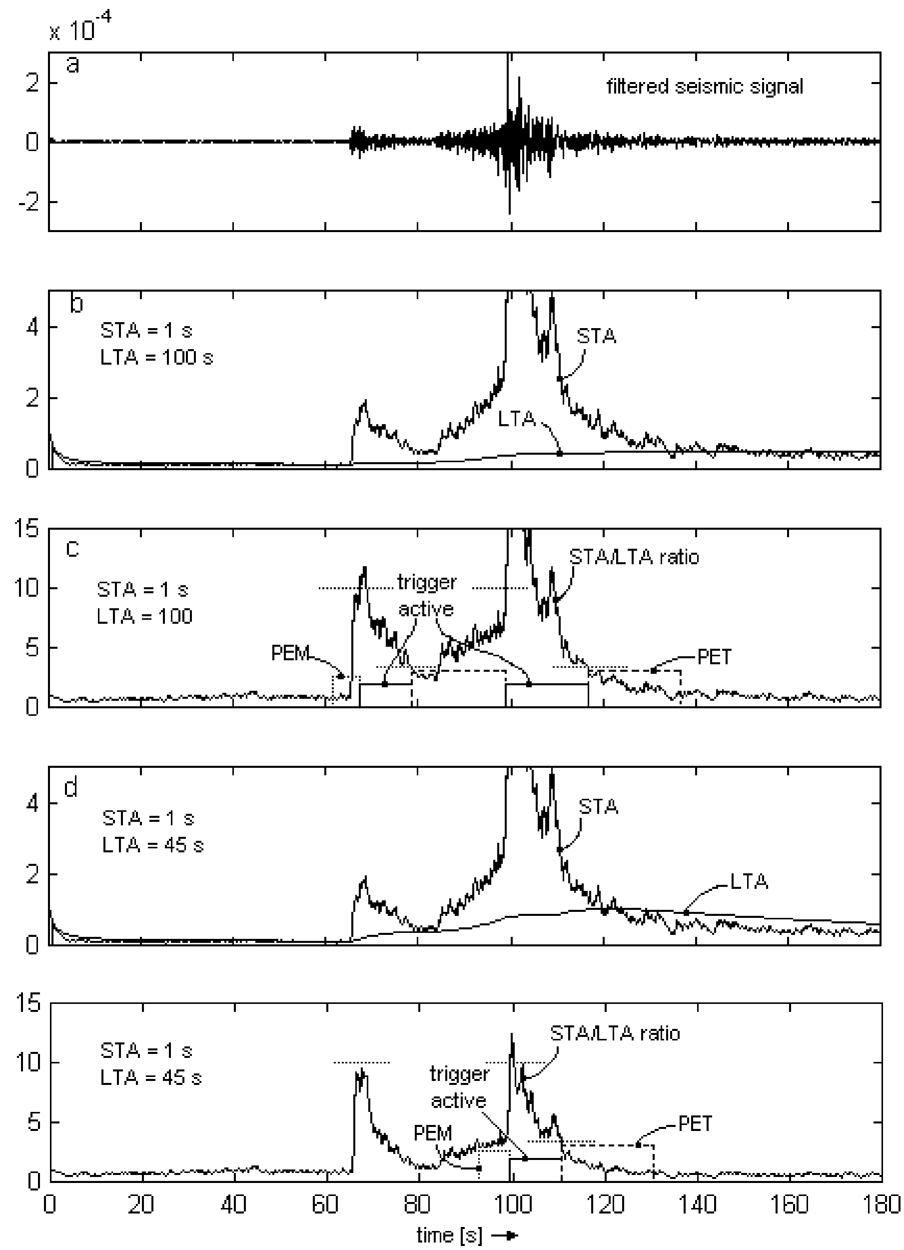
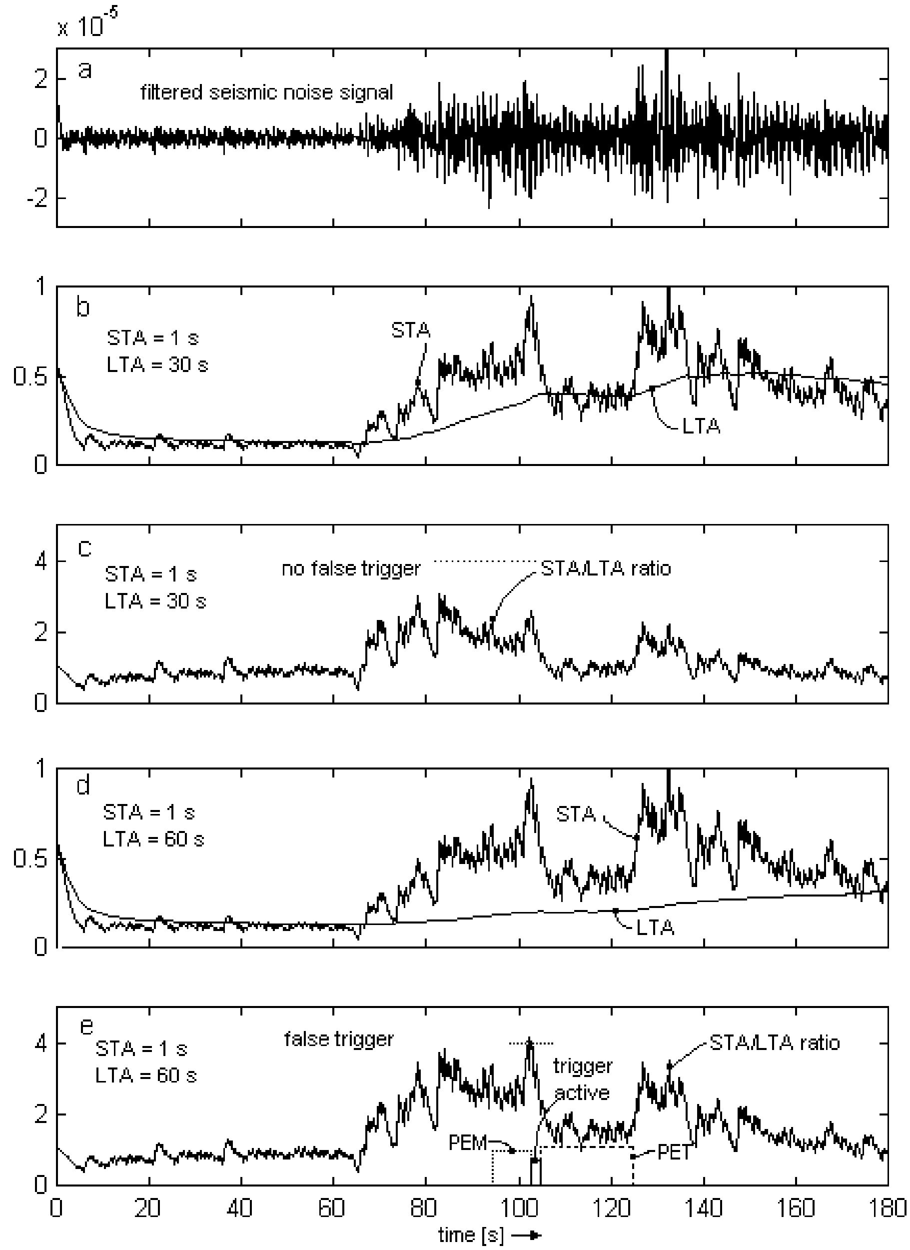


Figure 4. Influence of LTA duration on trigger algorithm sensitivity to earthquakes having weak P waves.

and e) show the situation with a longer LTA of 60 s. In this case, the LTA does not change so rapidly, allowing a higher STA/LTA ratio. As the result, a false trigger occurs and a false record unnecessarily occupying memory is generated.

Natural seismic noise (marine noise) can change its amplitude by a factor exceeding the value of twenty. However, these changes are slow. Significant changes can occur only during a few hours period, or at worst, in several tens of minutes. Therefore even the longest LTA duration is “short” enough to allow LTA to accommodate completely to marine noise amplitude variations.

Figure 5. Influence of LTA duration on false triggering when seismic noise conditions change



The LTA duration of 60 seconds is a common initial value. A shorter LTA duration is needed to exclude emergent regional events from triggering, if desired, or if quickly changing man-made noise is typical for the site. A longer LTA can be used for distant regional events with very long S-P times.

Frozen versus continuously updated LTA during events

Calculations of LTA value during an event, that is after a channel trigger is declared, can be performed in different ways.

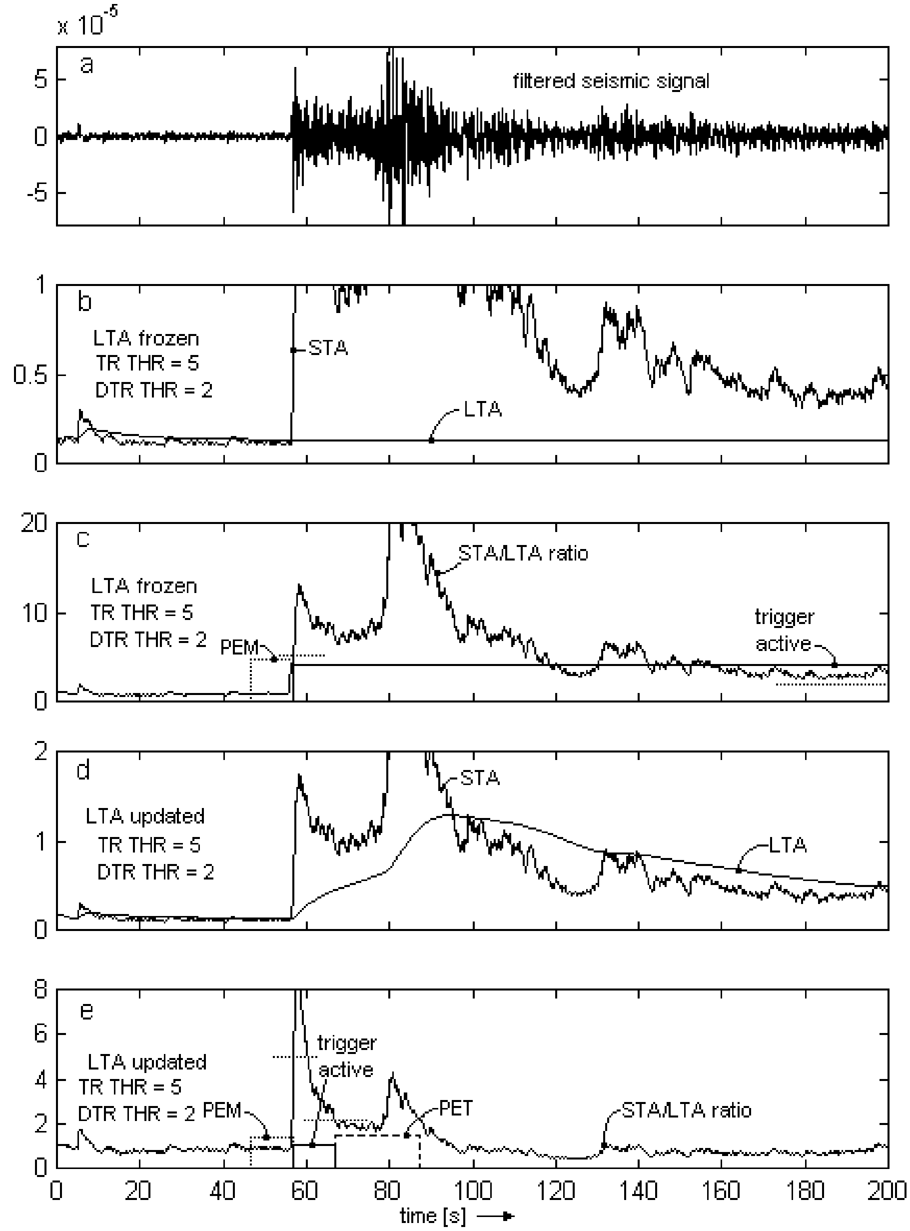
Either LTA value is continuously calculated during the event as usual, or LTA value is kept frozen at the moment when channel trigger is declared. It is not allowed to change (increase) during an event. Most seismic recorders available on the market have both or either frozen or continuously updated LTA user selectable options. However, each approach has its good and bad points.

“Frozen” LTA window (the word “clamped” is also used in literature) can force the unit into a permanently triggered state in case of a sudden increase of man-made seismic noise at the site. The situation is illustrated in Fig.6. Graph 6. a) shows an earthquake during which seismic noise increases and remains high even after the termination of the event. In such case a completely frozen LTA (graph b) would not allow STA/LTA ratio to fall below STA/LTA detrigger threshold level (graph c) and a continuous record would result. Such situation can, for example, happen if a machinery is switched on in the vicinity of the recorder. The recorder's memory soon gets full and blocks further data recording.

A continuously updated LTA (the word “unclamped” is also used in literature), on the other hand, easily terminates records too early. Graphs d) and e) of Fig. 6 explain the situation. Very often records with truncated coda waves result because LTA increases rapidly if a large earthquake signal is included in its calculation. Thus STA/LTA ratio decreases too rapidly and terminates recording prematurely. Coda waves of the event on Fig.6 a) are lost. This undesired result could be much more distracting for lasting regional events as it is shown in the Fig.6.

To keep the trigger parameter management as simple as possible, the K2 has a special version of LTA. The LTA value is, to the first approximation, “frozen” after a trigger. However, this “freezing” is not made complete. Therefore the K2 algorithm solves both problems. It does not cause endlessly triggered records in case of rapid permanent increase in seismic noise and, at the same time, does not cut coda waves too early. Refer to the section, “How it works - advanced topics” page 23, for more details about STA/LTA calculations.

Figure 6. Two conventional ways to calculate LTA – endless record with a completely frozen LTA and cut coda waves with fully updated LTA calculations.



Selection of STA/LTA trigger threshold level

The STA/LTA trigger threshold level to the greatest extent determines which events will be recorded. The higher value you set, the more earthquakes you will miss, but the fewer false-triggers will result. The lower the STA/LTA trigger threshold level is selected, the more sensitive the station will be and the more events will be recorded. However, also more frequent false triggers will occupy data memory and burden the analyst. Optimal STA/LTA trigger threshold level depends mostly on seismic noise conditions at the site. Amplitude and type of seismic noise influence optimal STA/LTA trigger threshold level setting. Statistically stationary seismic noise (with less irregular fluctuations) allows lower STA/LTA trigger threshold level, completely irregular behavior of seismic noise demands higher values.

Note that some false triggers and some missed earthquakes are an inevitable reality whenever recording seismic signals in an event triggered mode. Only a continuous seismic recording, if affordable, completely solves the problem of false triggers and incompleteness of data.

An initial setting for STA/LTA trigger threshold level of 4 is common for average quiet seismic sites. Lower values can only be used at the very best station sites. Higher values about 8 and above are required at less favorable sites with high man-made seismic noise. In strong motion applications higher values are more common due to the generally noisier seismic environments and generally smaller interest in weak events.

Selection of STA/LTA detrigger threshold level

The STA/LTA detrigger threshold level determines the termination of a recording (along with the PET parameter - more about it in the section “Selection of post-event time (PET) parameter”, page 19.).

The STA/LTA detrigger threshold level determines how well the coda waves of recorded earthquakes will be captured in data records. To include as much coda waves as possible, low value is required. On the other hand, if you are not interested in coda waves, a high value of STA/LTA detrigger threshold level enables significant savings in data memory. Note that coda waves of distant earthquakes can be very long.

STA/LTA detrigger threshold level is determined by a user-selectable STA/LTA detrigger threshold percentage parameter and current STA/LTA trigger threshold level. It is a product of STA/LTA detrigger threshold percentage divided by 100 and multiplied by STA/LTA trigger threshold level. A STA/LTA detrigger threshold percentage of 100% is the highest value possible. It makes STA/LTA trigger threshold level and STA/LTA detrigger threshold level equal. As an example, suppose that the desired STA/LTA detrigger threshold level is 4 and the selected STA/LTA trigger threshold level is 8. In the K2's parameter window the corresponding STA/LTA detrigger threshold percentage must be adjusted to 50%.

The K2 will always use a STA/LTA detrigger threshold level of at least 2. So, for example, if you select STA/LTA detrigger threshold percentage 10% with the STA/LTA trigger threshold level 4, your STA/LTA detrigger threshold level would theoretically be 10% of 4 or 0.4. In this case the unit would be continuously triggered. However, the K2 automatically overwrites this value and uses a STA/LTA detrigger threshold level 2 to prevent continuous triggering.

In general, the noisier the seismic site, the higher the value of the STA/LTA detrigger threshold level must be used to prevent continuous, repeated re-triggering. This danger is higher at the sites heavily polluted by man-made seismic noise.

A typical initial value of the STA/LTA detrigger threshold level is 2 to 3 for seismically quiet sites and weak motion applications. For noisier sites higher vales must be set. For strong motion applications, where coda waves are not of the highest importance, higher values can be used. The percentage set must be calculated taking into account the current STA/LTA trigger threshold level as explained above.

How to adjust associated parameters influencing triggering and data recording

Selection of trigger filters

There are three band-pass user selectable trigger filters IIR-A, B (Classic Strong Motion), and IIR-C available in the K2 recorder. They continuously filter incoming seismic signals prior to trigger algorithm calculations. Proper selection of this filter is important for STA/LTA trigger algorithm and also for amplitude threshold trigger algorithm. The purpose of these filters is three-fold.

- They remove DC component from incoming seismic signals. Namely, all active seismic sensors have some DC offset voltage at the output. This DC offset, if too high, deteriorates STA/LTA ratio calculation. Calculation of absolute value of the signal becomes meaningless if DC component is higher than seismic noise amplitude, which results in drastic reduction of trigger sensitivity for weak seismic events.
- Their frequency band-pass can prioritize frequencies, which correspond to the dominant frequencies of seismic events you want to record.
- Their stop-band can attenuate dominant frequencies of the most distracting seismic noise at a given site.

The trigger filter pass-band should accommodate to the frequencies of maximum energy of expected seismic events. It should at the same time have a band-pass that does not coincide with peak frequency components of seismic noise at the site. If this is possible, a significant improvement of even-trigger/false-trigger ratio results. Obviously, one can understand that if the peak amplitudes of seismic noise at the site and the dominant frequencies of earthquakes of interest coincide, the trigger filter becomes inefficient.

One should not forget that the frequency response function of the seismic sensor used with K2 also modifies frequency content of event and noise signals and therefore is an important factor in your choice of trigger filter. The type of sensor output - either ground velocity or acceleration proportional - has a similar effect. Accelerometers emphasizing high frequencies usually require filter protection against excessive high frequency man-made seismic noise. Seismometers with ground velocity proportional output and relatively low high-end corner frequency are less influenced by high frequency man-made seismic noise.

K2's A and C trigger filters are digital band-pass non-causal infinite impulse response (IIR) filters. As such they scale with the sampling frequency which is used in data acquisition. Their corner frequencies change according to sampling frequency selected. It must be taken into consideration that their effect on seismic signal changes if sampling frequency is changed.

The table below presents corner frequencies of the K2's trigger filters at different sampling frequencies. The numbers are approximations since these filters are simpler than K2's anti-aliasing filters. However, their accuracy, steepness, and stop-band attenuation is more than adequate for the purpose.

Trigger Type	100 SPS	200 SPS	250 SPS
IIR - A	~ 0.6 - 10 Hz	~ 1.2 - 20 Hz	~ 1.5 - 25 Hz
B Classic Strong Motion	~ 0.05 - 6.25 Hz	~ 0.1 - 12.5 Hz	~ 0.12 - 15 Hz
IIR - C	~ 1 - 20 Hz	~ 2 - 40 Hz	~ 2.5 - 50 Hz

Filter A prioritizes lower frequencies, the corner frequencies of the filter B are set according to standard “strong motion” trigger filter convention (at 200 Hz), and filter IIR-C prioritize higher frequencies. Some typical choices of trigger filters are given below.

- The IIR-A filter with a 100 Hz sampling rate can be used for recording of regional events with broadband or short period sensors. Its 0.6 Hz low-corner frequency protects against the dominant component of natural marine seismic noise. Its high-corner frequency at 10 Hz protects against excessive high-frequency man-made seismic noise. This setting would function well at an average quality station site with reasonably low urban seismic noise.
- The IIR-A filter with a sampling rate of 200 or 250 Hz can be used to monitor local earthquakes if broadband or short period seismometers are used. Low frequency corner of trigger filter at 1.2 Hz or 1.5 Hz respectively provides efficient protection against marine noise. However, there is little or no protection against high frequency man-made seismic noise. This selection would function well at a seismically quiet station with little or no man-made seismic noise.
- The Classic Strong Motion filter B at a sampling rate of 100 Hz and a broadband sensor can be used for distant-regional and tele-seismic applications. It does not attenuate long period signals but it efficiently protects against man-made seismic noise in urban areas. The unit can be

triggered by teleseismic body waves as well as some higher frequency surface waves (however a lower sampling rate would be more convenient for such applications). Note however that there is no protection against marine noise with this filter unless short-period seismometers are used.

This selection would also function (as much as circumstances allow) with a short period seismometer at seismologically inadequate sites polluted by man-made seismic noise.

- The Classic Strong Motion filter B at a sampling rate of 200 Hz or 250 Hz is traditionally used with accelerometers in typical strong motion applications.
- This selection of filter at a 250 Hz sampling rate and with short-period seismometers at the K2 input would also record local and near-regional earthquakes well. In this case, the sensor frequency response itself protects against marine seismic noise.
- The IIR-C filter with 100 Hz sampling rate is similar to the filter IIR-A at 200 Hz sampling rate. It thus allows use of a lower sampling rate with the same trigger properties.
- The IIR-C filter at 200 or 250 Hz sampling rate with short period seismometers or accelerometers would be an appropriate choice for local and very local earthquakes recording. There is no protection against high frequency noise, however. For very local events, such protection is impossible because frequency content of such events and man-made seismic noise approximately coincide. Therefore a site with low man-made seismic noise is a prerequisite for successful application.

Selection of pre-event time (PEM) parameter

Ideally, earthquake records should include all seismic phases of an event and in addition, include a portion of seismic noise signal prior to it. However, for some events, trigger algorithm doesn't trigger at the beginning of the event but somewhere during the event, most frequently when waves with maximum amplitude of ground motion reach the station. This happens very often with earthquakes that have emergent on-set waves, and with most weak local and regional events where the S phase can be much bigger than the P phase. In practice, triggering on S waves of weak local and regional earthquakes is far more frequent than triggering on P waves. Obviously, for seismological reasons, P on-set waves should be included in the record as well. Also, selection of an appropriate pre-event time (PEM) assures that earthquake records are complete in such cases.

In the K2 a portion of signal data prior to instrument trigger time is temporally stored in a pre-event buffer (abbreviation PEM denotes “pre-event-memory”) and prepend to the data recorded. PEM must surmount the following periods of time:

- time needed to calculate STA/LTA ratio, which, in the worst case, equals one STA duration,
- maximal expected S-P time of earthquake records, and
- desired record duration of seismic noise prior to the event.

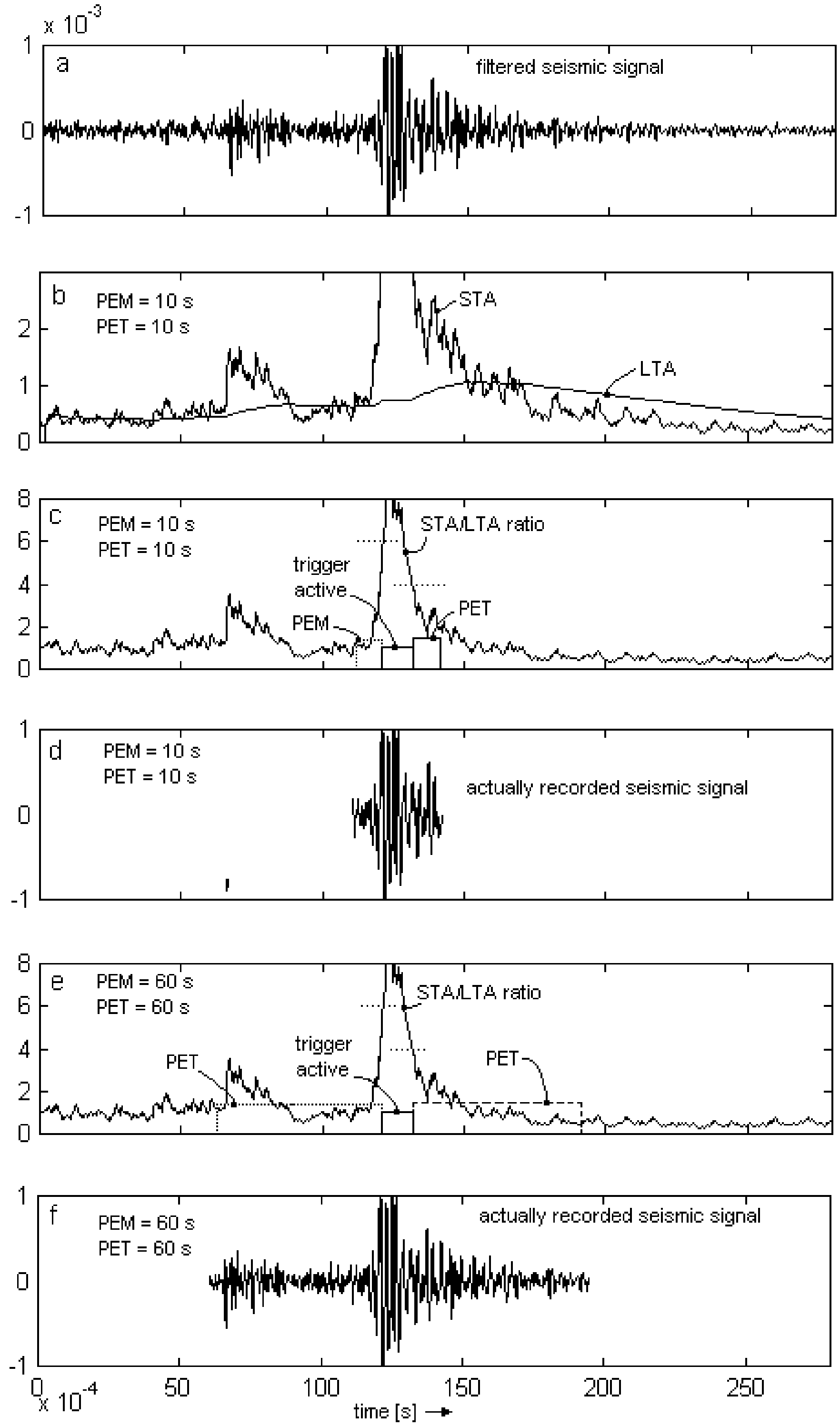
Add these three time periods and the result is the appropriate PEM value in seconds.

The effect of too short a PEM is shown in Fig.7. Graph a) shows an event approximately 400 km away from the station with weak P waves partly buried in the seismic noise. On graph b) STA and LTA values are shown. Graph c) shows STA/LTA ratio and trigger and detrigger thresholds (dotted lines). One can see that trigger threshold is set to 6. The channel triggers on S waves. A PEM of 10 seconds is much too short to catch P waves. Graph d) shows an actually "recorded" event, which starts much too late and which contains no seismic noise record. Graphs e) and f) show the same event but with a properly set PEM parameter. Seismic noise as well as P waves are properly recorded.

Maximal expected S-P time depends on maximal distance of relevant earthquakes from the station and on seismic wave velocity in the region. For practice and for local and regional events, accurate enough results can be gained by dividing maximum station-to-epicenter distance in miles by 5 (in km by 8) to get the required maximum S-P time in seconds.The application dictates the choice of the desired pre-event noise record duration. At least a few seconds are usually required. Note that if you want to study spectral properties of weak events, seismic noise spectra must also be taken into consideration. This, however, requires a significant length of noise records with every event record.

As an example, let us calculate a required PEM parameter value for a small local seismic network with 3 miles (5 km) aperture, where 0.5 sec is used for STA duration. The owner is interested in seismicity 60 miles (100 km) around the center of the network. He would also like to have a 10 sec long record of seismic noise before P waves. We need 0.5 sec for STA, 10 sec for seismic noise, and (60 miles + 3/2 miles)/5 ~ (100 km + 5/2km)/8 ~ 12.5 sec to cover maximal S-P time. Note that the most distant station from the epicenter in the network still has to record P waves — that is why we added 3/2 miles (5/2 km). One half of the network aperture must be added to the maximal distance of your interest. The PEM should therefore be set to 0.5 + 10 + 12.5 = 23 sec. Obviously, smaller networks and shorter ranges of interest require shorter PEM and vice versa.

Fig. 7. Proper and improper setting of pre-event time (PEM) and post-event time (PET).



Every physical pre-event buffer has its limitations. High sampling frequencies and many active channels may limit your choice of the longest PEM parameter in the K2. Note also that the K2's default value for PEM is appropriate for the strongest motion applications but much too short for the weak motion applications. Obviously you will have to select your own value in weak motion applications.

Selection of post-event time (PET) parameter

Post-event time parameter assures complete recording of seismic events after detrigger. The main purpose of PET is to catch the remaining earthquake coda waves that are lower than STA/LTA detrigger threshold level. Functionally it is simply a fixed recording time added to event file after instrument (not individual channels!) detriggers. It has a similar effect as STA/LTA detrigger threshold level parameter. However, its effect is event-size independent. This makes it a less effective coda wave “catcher” than a low STA/LTA detrigger threshold level. It is most suitable for local events. Practical values of PET for large distant earthquakes are usually too short to be of any help in this respect. Contrary to a very low STA/LTA detrigger threshold level that may cause re-triggering problems, a long PET generally eliminates repeated re-triggering (see chapter 4.1.5 “Selection of STA/LTA detrigger threshold level, page 13”).

Optimal PET duration depends mostly on your application. If coda waves are important to you, a long PET must be selected. If coda waves have no significance for your, use a short PET. Obviously, short local events require only a short PET, regional and teleseismic events, on the other hand, require much longer PET.

A reasonable value for local seismology would be 30 sec, and 60 sec for regional seismology, assuming we want coda waves well recorded. To find optimal value, observe coda waves of your records and adjust the PET accordingly.

There are no practical limitations on selection of the longest PET in K2. However, note that long PET use up the recorder's data memory. So, do not exaggerate, particularly in seismically very active areas. Note also that the K2's default value for PET is appropriate for the strong motion applications but too short for most weak motion applications.

Selection of voting scheme parameters

Voting scheme parameters are not directly related to STA/LTA trigger algorithm. The same principles are used with amplitude threshold trigger algorithm. However, inappropriate settings prohibit efficient functioning of STA/LTA trigger too. For that reason we also deal with voting scheme parameters in this section.

In the section “How to adjust STA/LTA Trigger Parameters,” on page 4 we described how each individual channel would trigger if it were the only one in an instrument. In the following section we describe how individual channel triggers are combined to cause the system to trigger in a multi-channel recorder. We call this "voting" as a number of votes or weights can be assigned to each seismic channel so that it may cast towards getting the system to trigger. Only if the total number of votes exceeds a given pre-set value, the instrument actually triggers, a new data file opens and data acquisition begins.

How this voting system is set up depends on the nature of signals that you are trying to record and on seismic noise conditions at sensor sites. The noisy channels, which will frequently falsely trigger, will obviously have less "votes" or assigned weights than the quiet channels. Obviously you will need some first-hand experience of the conditions at the site before you can optimize this voting scheme. There are five terms associated with voting scheme parameters

- Channel weights (votes).

  Select the number of votes the channel contributes to the total when it is triggered. If the channel has a good signal/noise ratio, you give it some positive number of votes. The more "reliable" the channel, the higher number is selected. If the channel is noisy and frequently falsely triggers, you give it lesser or even zero weight. In case you want a channel to inhibit triggering, you give it negative weights.

- Trigger weight

  This is the total number of weights required to get the seismic recorder to trigger.

- Detrigger weight

  The Detrigger Weight is a value below which the total trigger weights must fall in order to cause the recorder to detrigger. Only the channels which contribute to triggering process (channels with zero weights are excluded from triggering and detriggering process) count in this process. Detrigger Weight of 1 means that all voting channels must be detriggered before the recorder will detrigger.

- External channel trigger weight

  The value represents the number of weights you assign to the external trigger channel source. This parameter is most useful in networks of interconnected K2s. In this configuration every triggered K2 "informs" all other units in the network that it triggered. If you want to ensure that all units in the network trigger when one unit triggers, external trigger channel should have the same weight as the Trigger weight. If you want to use a combination of an external trigger with other internal criteria, you should set the weights appropriately.

- Keyboard Trigger Weight

  It is possible to trigger a K2 recorder or a network of interconnected K2s from the keyboard of a computer connected to the K2 for test purposes. It is also possible to acquire a seismic noise sample record. To install this option, give the keyboard trigger channel the same weight as the Trigger weight so it can trigger the recorder or the network of interconnected K2s without any other channels being triggered.

Understanding voting scheme parameters is best gained through examples. The following section gives a few examples of various voting schemes. The majority are more useful in strong motion than in weak motion applications, but the same principles apply in both fields.

- A classic strong motion free field site has no interconnected units and normally has a three channel internal FBA accelerometer. You would set all channel weights to 1 and also set Trigger weight to 1. Consequently any channel could trigger the system. At noisier sites a Trigger weight set to 2 would be appropriate. In the latter case, two channels must be in triggered mode simultaneously for the beginning of data recording.

- Let us suppose that an interconnected strong motion network of two K2s with internal FBA accelerometers is installed in a building, one in the basement and one on the roof. Initially you can set channel weights to 1 for each signal channel, as well as for the external trigger channel. You set Trigger weight to 1 as well. As a result each channel can trigger both units in the system.

  After a while you discover that the K2 on the roof triggers the system too frequently, due to the sway of the building in the wind. Changing the voting scheme of the roof unit so that its channels have 1 weight while the external trigger channel has 3 weights can compensate for this action. In this unit you set the Trigger weight to 3. Now, the K2 installed on the roof triggers only if all its three channels trigger simultaneously or if the recorder in the basement triggers. The number of false triggered records will be drastically reduced.

- A system on a bridge has a 12-channel K2. Sensors are installed on different vital parts of the bridge. You could start with all signal channels having channel weights 1 and requiring 1 weight to trigger by setting the trigger weight to 1. You may find that this system triggers far too often because of traffic vibrations or swaying of the bridge. You could then set the channel weights of several "quiet" sensors to 2 or 3 and channel weights of those sensors aligned with the direction of sway 1 or even 0. An appropriate Trigger weight with this setting would be 6. In extreme cases you can give negative weights to the channels aligned with the direction of sway, so before the system actually starts recording, several other channels must trigger to overcome their negative weights.

- A very small weak motion seismic network around a mine is designed for monitoring local micro-earthquakes. It consists of 5 surface sites with short period seismometers and one down-hole accelerometer. A 6-channel K2 is used as a data recorder. One of the surface stations is extremely noisy due to nearby construction works. You can temporally give a channel weight to 0 to this station to exclude its contribution to triggering and channel weights of 1 to all other stations. On the other hand, the down-hole accelerometer is very quiet. Select channel weight 3 for this particular channel. For this network a trigger weight of 4 would be adequate. Suppose also that there are frequent blasts in the mine. If you wish, you can use an external trigger channel weight set to -5 and therefore manually prevent seismic network recording of these blasts.

In conclusion, from these examples we learn about the flexibility of the triggering options and about some of the ways in which this flexibility can be used for particular installations.

Practical recommendations for finding optimal triggering parameters

A systematic approach is required for successful adjustment of optimal triggering and associated parameters. First, the goals of the instrument(s) installation must be carefully considered and apriori knowledge about seismic noise (if any) at the site(s) must be taken into account. Based on this information, initial parameters are set. The parameter set is up-loaded and parameter file saved for documentation purpose.

Then the instrument is left to operate for a given period of time. To gain useful information, the length of operation without changing recording parameters depends strongly on seismic activity in the region. At least several earthquakes and falsely triggered records must be recorded before the first readjustment of parameters. Judgements based on a single record rarely lead to improvements.

Afterwards, all records, including those falsely triggered, must be carefully inspected. Completeness (P arrivals, coda waves) of event records is searched for, and causes of false triggers are analyzed. The ratio of event records/false records is determined and compared to the acceptable level. If the number of false triggers does not reach the expected level, increase the trigger sensitivity. Lower STA/LTA trigger threshold level(s). Basically, you will acquire more seismic information for the same price and effort.

After the analysis is finished, the parameters are changed according to its findings, the parameter file is loaded up and archived for documentation purposes. Again the instrument is left active for a certain period of time, the new records are analyzed and other changes made. By repeating this process you will find the optimal parameter setting.

The K2 has a special mode of operation, which allows an advanced and extensive study of actual performing of STA/LTA algorithm. In this mode the seismic signal of a single channel, trigger-filtered signal, STA, and LTA signal are mapped to individual channels and recorded. By observing data files one can study the behavior of these signals during seismic events and false triggers under a particular parameter set of the K2. Refer to the Altus Terminal Mode Manual (in print) for details of how to use this special mode.

How it works - advanced topics

Several new features are built in the K2's STA/LTA trigger algorithm. They improve its performance with respect to other recorders on the market. The improvements are:

- Increased user friendliness and robustness to erroneous parameter adjustments
- Faster response of trigger algorithm
- Reduced initial "deaf" time period after recorder is switched on
- Better performance in caching late packets of seismic energy of events
- Minimized probability of continuous re-triggering

Increased user friendliness and robustness to erroneous parameter adjustments

Since experience shows that trigger algorithms that are too complex frequently result in an improper setting and consequently in "disappointments" about an instrument's performance, we kept the algorithm as simple as possible. To minimize the number of parameters, we made several of them transparent to the user or not used at all (like LTA "clamped"/"unclamped" parameter, LTA offset parameter, STA/LTA ratio versus STA/LTA difference parameter, known from older generation of seismic recorders). All parameter values are expressed in standard SI units.

Robustness to erroneous parameter setting was enhanced in two respects.

In an extremely noisy environment it would be very dangerous to set too high a STA/LTA trigger threshold level and too high a recorder's gain value. Due to many false triggers in such seismic noise conditions, the instrument is usually set to record only the strongest events. Suppose you have set a STA/LTA trigger threshold level to 20. Suppose also that you have about 150 mV average signal due to seismic noise at the input of the recorder. That represents 6% of the instrument's input range. Obviously, this would require 0.15 *20 = 3 V signal amplitude to trigger. Since K2 input amplitude range is limited to ± 2.5 V your K2 can never trigger, no matter how strong an earthquake occurs.

This potential danger of erroneously setting the K2, particularly because it is not easy to recognize, especially in low seismicity regions, is solved in the following way: Whenever you select the STA/LTA algorithm, the “old” amplitude threshold trigger algorithm remains active in the “background”. The K2 triggers whenever input amplitude exceeds 50% of input voltage range, in no relation to STA/LTA ratio and STA/LTA trigger threshold level. In this way the strongest, and therefore most important, events are still recorded, no matter how carelessly the STA/LTA trigger algorithm parameters are set.

A second potential mistake is to set STA/LTA detrigger threshold levels too low, which may result in occasional continuous re-triggering. Whenever the STA/LTA detrigger threshold level is set too low, the K2 automatically overwrites it with a higher value, which is safe in most cases. Details are explained in the section titled “Selection of STA/LTA detrigger threshold level” on page 13.

Faster response of trigger algorithm

Faster response is obtained by true real time calculations of all parameters, including comparison of the STA/LTA ratio with STA/LTA trigger threshold level. All calculations are made for every data sample in every channel of the recorder. A trigger can therefore happen any time, not only after each STA window completion. This process assures minimal average time delay between the seismic event and the triggering.

Actually, for computational reasons, an exponentially weighted STA calculation is used instead of a linear time window averaging. Similarly LTA is calculated from exponentially weighted STA values instead of LTA window data samples. This, however, has no practical influence on trigger operation.

Reduced initial “deaf” time period after recorder is switched on

After any digital recorder is switched on, or when it is set to acquisition mode from stand-by mode, several issues have to “settle” in the instrument, before it can start to operate in a normal mode. First, the system has to boot (cold start only), next anti-aliasing and trigger digital filters have to settle (cold start and setting to the acquisition mode). Since very powerful filters with hundreds of tabs are used in modern seismic recorders, this time may not be negligible. In addition, for STA/LTA trigger algorithm a realistic STA/LTA ratio must be calculated prior to any actual triggering. In the older versions of algorithm you had to wait until the first STA and LTA window elapsed. If a long LTA is selected, this may last quite a significant time. All these times add up and as a consequence the instrument is "deaf" for triggering for a significant time after manual start. Many inexperienced users are unaware of this fact and try to check the instrument operation by shaking it - but they shake it too early after switching it on. This leads to "disappointments", because the instrument apparently "does not want to trigger".

There is no cure regarding initialization of digital filters. However, the K2's initial STA/LTA ratio calculation differs from standard procedures.

The first STA values are not calculated by exponential weighting method (the result would be too inaccurate due to lack of knowledge about the signal before the start time) but by a variable length arithmetic average method. In this way, we get a realistic average of the signal already at the end of the first STA period.

At this moment the first LTA value is made equal to the current STA value. Therefore the initial STA/LTA ratio is always 1. After that, the LTA is calculated, using variable-length arithmetic average method with STA values as input values. However, what is important, triggering is already possible during this period. The calculated LTA may not be exactly what it is supposed to be, but triggering based on a "preliminary" STA/LTA ratio will function for most earthquakes.

So, the "deaf" period of K2 is shortened for one LTA window.

K2's trigger better catches late energy packets of events of seismic energy

An additional refinement is built into the K2's STA/LTA trigger algorithm. It helps to achieve better recording of some regional and many teleseismic events. In many of such events seismic energy arrives to the seismic station in several "packets" with little or no signal between them.

With standard STA/LTA trigger algorithm, such events are frequently dissected into several files, or sometimes some of the packets are not recorded at all.

In the K2's algorithm, once the STA/LTA ratio falls below the STA/LTA detrigger threshold level for the first time, the recorder switches to a state where it watches for consecutive exceeding of the STA/LTA detrigger threshold level. It does this rather then watch for exceedance of the STA/LTA trigger threshold level, which is usually much higher. This feature makes the instrument effectively more trigger-sensitive immediately after each detriggering for a certain percentage of PET and thus allows secondary packets to be recorded within the same data file.

Figure 8. Advantage of K2's alogrithm over conventional alogrithms related to recording of late energy "packets" in the seismic signal

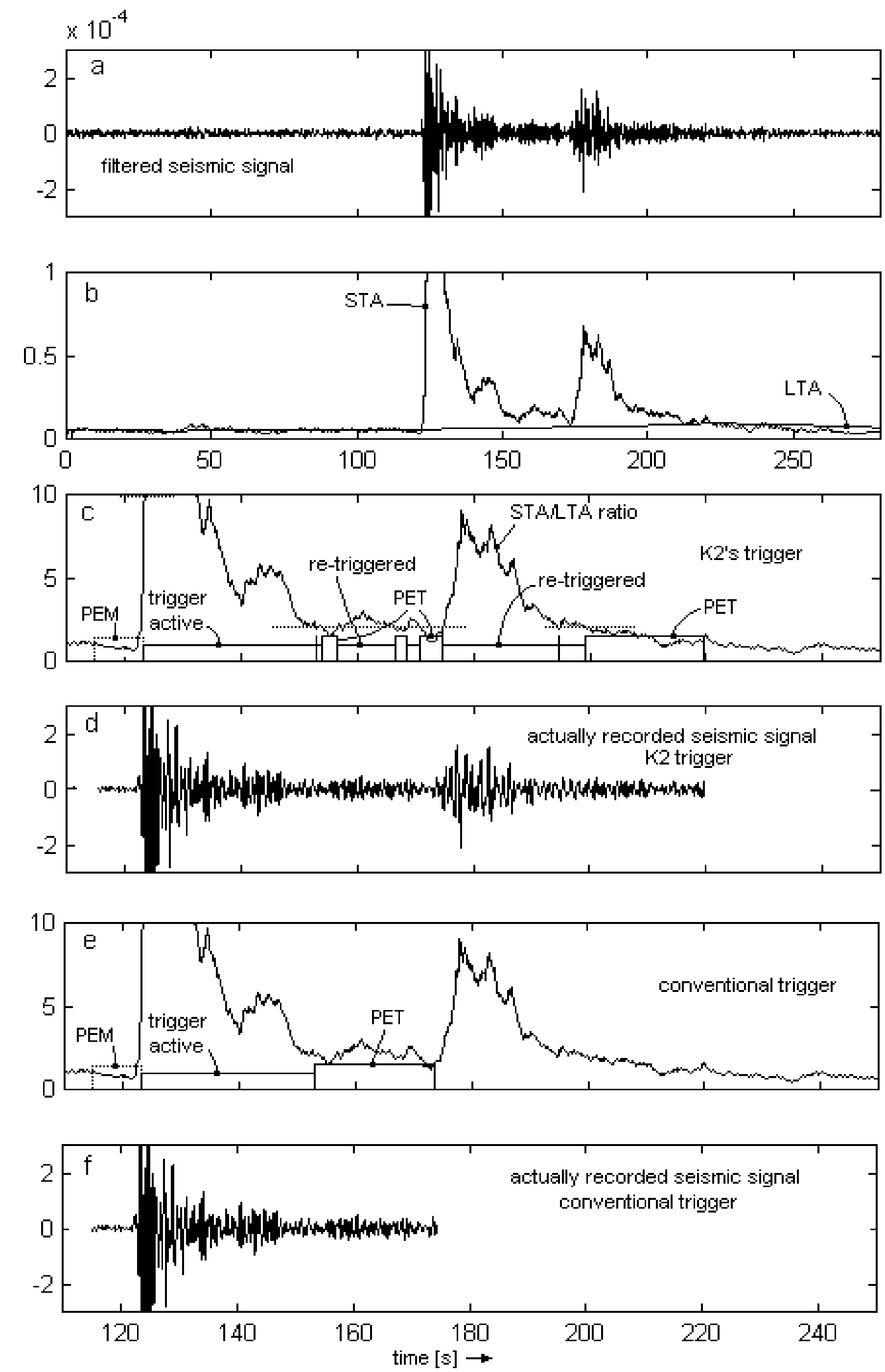


Fig. 8 a) shows an earthquake with seismic energy in two distinct “packets”. On graph b) STA and LTA time course is shown. Graphs c) and d) explain the K2's trigger algorithm functioning (note the changed time scale of the graphs). The instrument triggers on the first “packet”. The STA/LTA ratio exceeds the STA/LTA trigger threshold set to value 10 at time t = 124 sec. At time t = 153 sec the STA/LTA ratio, for the first time. becomes lower than the STA/LTA detrigger threshold set to 2. Immediately after that, the STA/LTA ratio again exceeds the STA/LTA detrigger threshold and the system activates again. This repeats three times all together. At time t = 195 sec the STA/LTA permanently decreases under the STA/LTA detrigger threshold. This marks the beginning of PET and after it terminates, the recording finishes. All seismic phases with the initial seismic noise record are stored in a single data file.

Graphs e) and f) show the performance of the conventional STA/LTA trigger. The system triggers and detriggers to the first time exactly as above. But since none of the following phases exceeds the STA/LTA trigger threshold, recording terminates well before the complete earthquake is recorded.

Minimized probability of a continuously re-triggered state

The K2 recorder uses an essentially “frozen” type of LTA. Note that this is in full accordance to its purpose: to “measure” the amplitude of seismic noise just before a seismic event occurs and to allow the STA/LTA ratio to reflect the ratio of the temporal earthquake signal envelope to the seismic noise level prior to the event. A much stronger signal during events would blur triggering and detriggering conditions if we allowed it to be included into LTA calculations. Therefore, once an event is declared, the LTA value is essentially frozen.

However, if man-made seismic noise would increase above the STA/LTA detrigger threshold level during the event recording and stayed at this level, the recording would never terminate. This could, for example, result from switching on some machinery close to the site. The same would happen if a strong permanent man-made noise would appear and exceed the STA/LTA trigger threshold level and remained at that level for a long time. In such cases, a completely frozen LTA would not allow the STA/LTA ratio to fall below the STA/LTA detrigger threshold level at all. The recording would continue until finally using up all available memory.

For this reason, a small leakage of energy of the seismic signal into the LTA after triggering is still allowed in the K2's algorithm. Therefore the LTA still increases slowly with time after the trigger, thus decreasing the STA/LTA ratio. Sooner or later, the STA/LTA ratio becomes lower than the STA/LTA detrigger threshold level and recording terminates in spite of newly appeared continuous noise at the site.

Technically this is achieved by keeping the calculation method for LTA unchanged during events, but replacing the current LTA window with a very long LTA window. Due to the exponential weighting nature of the calculations, the effect of the earthquake signal entering the calculations is highly reduced. This leakage causes a slow increase of the LTA value with time and assures detriggering of the recorder.

Appendix

List of available K2 parameter values pertaining to triggering as well as data recording and their default values

Valid for firmware version K2 DSP code 302242 Ver.8.10 and on, and K2 MCU code 302241 Ver. 2.20 and on. Default values are given in bold.

Short time average window (STA) duration in seconds:

0.1	0.2	0.3	0.4	0.5	0.6	0.8	**1.0**	1.2
1.4	1.6	1.8	2.0	2.5	3.0	5.0	10.0	

Long time average window (LTA) duration in seconds:

20	30	40	50	**60**	80	100	120

STA/LTA trigger threshold level:

1.5	2	3	**4**	6	8	10
15	20	30	40	60	100	

STA/LTA detrigger threshold percentage in % of STA/LTA trigger threshold level:

10	15	20	**40**	60	100

Trigger filter selection (for details see chapter "Selection of trigger filters", page 14):

IIR-A	**B Classic Strong Motion**	IIR-C

Pre-event time (PEM) in seconds:

Any number of seconds, up to the limit of the instrument, is allowed. The longest available PEM depends on the number of channels, the sampling rate, and the instrument. For standard three-channel K2 with 200 Hz sampling rate the maximal a PEM is 45 sec. If higher than the allowed PEM is entered, a warning message appears. Default value is 3 sec.

Post-event time (PET) in seconds:

Any number of seconds from 1 to 65,000 is allowed. Default values is 10 sec.

Channel Trigger Weight, Trigger Weight, Detrigger Weight, External Channel Weight, and Keyboard Channel Weight:

Any integer number from 0 to 10,000, positive or negative is allowed. Default values are 1.