Random-Source Surveying Operations Manual

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Random-Source Seismic Surveying

Background

Note: *This discussion assumes that the reader is familiar with the concepts underlying swept-source surveys. See the recommended reading at the end of this document for more in-depth discussion.*

The Geometrics Random-Source package allows acquisition and processing of seismic data (usually reflection data) with a construction tamper (hereafter referred to generically as a “Wacker”, after the German company that manufactures the one shown below) or other repetitive impact source. This technique was first developed in France in the 1970s and has been known ever since as the “mini-Sosie” technique (Barbier and Viallix, 1974). Essentially, the Wacker is used as an inexpensive vibrator, and the method follows the same general principals as those of vibrator surveys: Energy is introduced into the ground over a finite period of time (commonly 30 to 60 seconds). A reference trace (hereafter referred to as the “pilot”) is recorded, which represents the signal that was introduced into the ground, and then the pilot trace is cross-correlated with the raw data, trace by trace, to decode the record and collapse it to what would have been yielded by a single impulse.

The most commonly-used source in this type of survey is a Wacker like that shown in Figure 1.

Figure 1. *“Wacker” Construction Tamper (courtesy Wacker Corporation).*

Surveying with a Vibrator

A quick review of vibrator surveying is instructive. When using a vibrator like the one shown in Figure 2, a programmed input sweep, generally ranging from low frequency

Figure 2. *Buggy-mounted vibrator (courtesy Industrial Vehicles International).*

to high frequency, is introduced into the ground over a period of time, generally between 8 and 30 seconds. This sweep is highly repeatable and controlled by the control electronics of the vibrator itself. A portion of a typical 10-100-Hz vibrator sweep is shown in Figure 3:

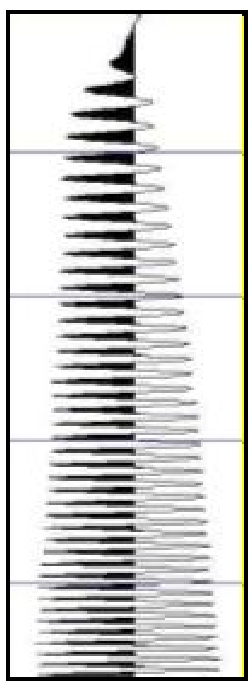


Figure 3. *Raw vibrator pilot.*

This is recorded by a sensor mounted on the base plate of the vibrator and fed into an auxiliary channel on the seismograph. The resultant raw record is the result of refractions and reflections of the input sweep; hence it is unintelligible – it does not look like a record you would expect to get from an impulsive source like dynamite. A typical raw vibrator record is shown in Figure 4:

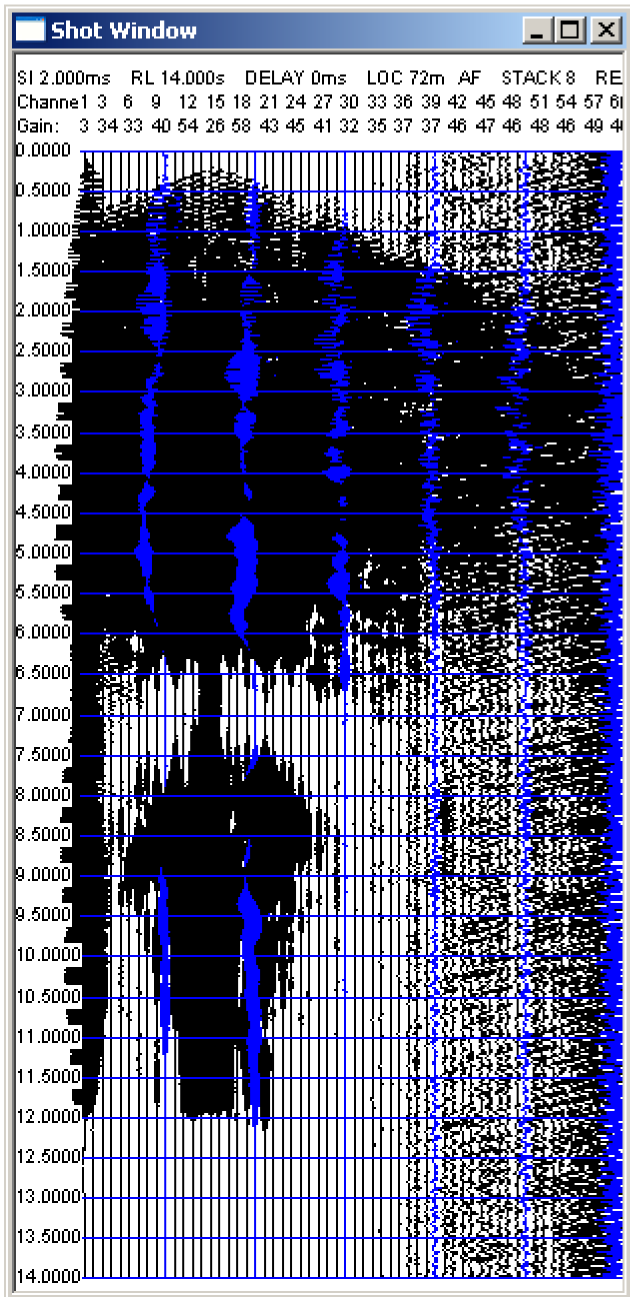


Figure 4. *Uncorrelated vibrator record.*

To decode the record, we simply cross-correlate the raw data with the pilot signal. The resultant decoded (correlated) record now resembles a typical impulse-type record:

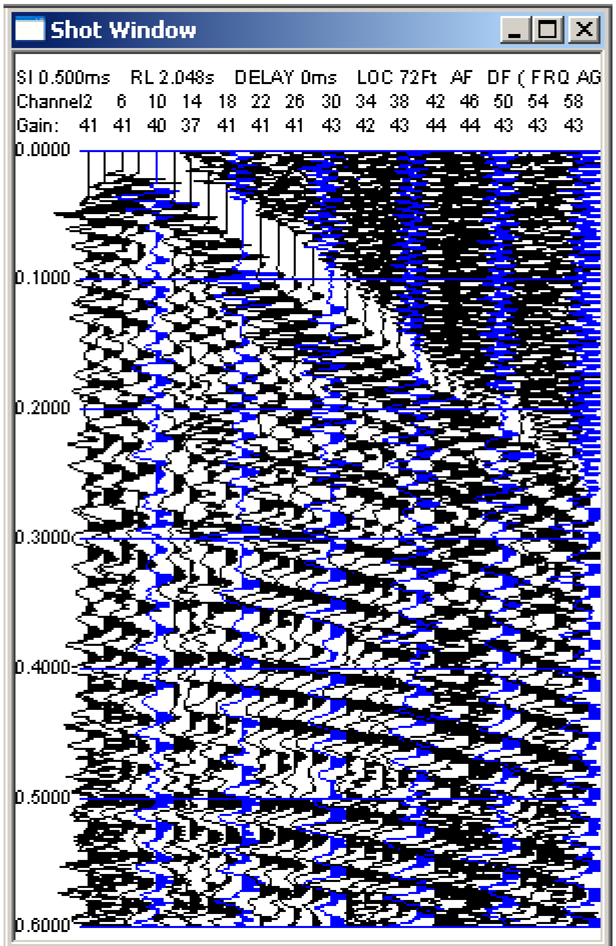


Figure 5. *Correlated version of vibrator record shown in Figure 4 .*

The process is summarized in Figure 6. Good discussions can be found in Yilmaz (1994), Sheriff and Geldart (1995), and Reynolds (1998).

Vibrator Pilot QC

The most common method of monitoring the quality of a vibrator pilot is to view its autocorrelation (the result of correlating the pilot with itself), because the shape of the autocorrelation greatly influences the shape of reflected events on the final record. The fewer side lobes on the autocorrelation – the more rapidly the energy decreases to some background level as you move away from zero lag – the less “ringy” individual events on the record will be. Also, the greater the overall frequency range of the pilot, the narrower the autocorrelation “pulse” at zero lag will be. This is best illustrated by example.

Figure 7 shows a typical autocorrelation trace from a vibrator (it is the result of the sweep of Figure 3 correlated against itself). Note that the pulse at zero lag is very narrow, and that the amplitude decreases rapidly with increasing lag.

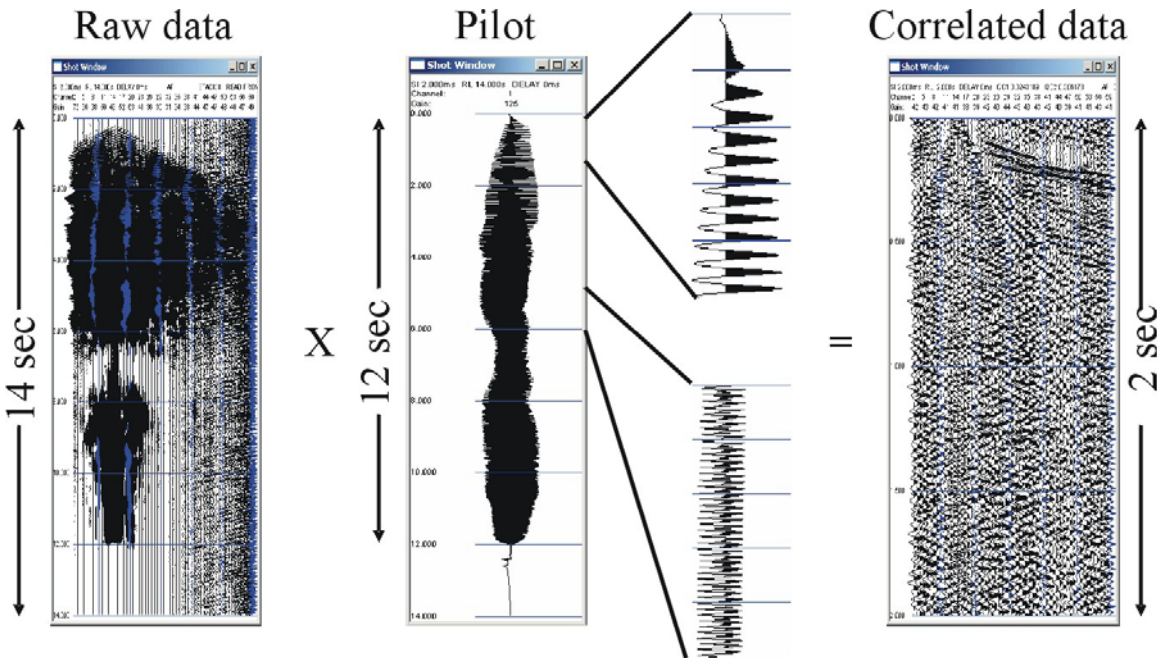


Figure 6. *Decoding a vibrator record through cross-correlation with the pilot trace.*

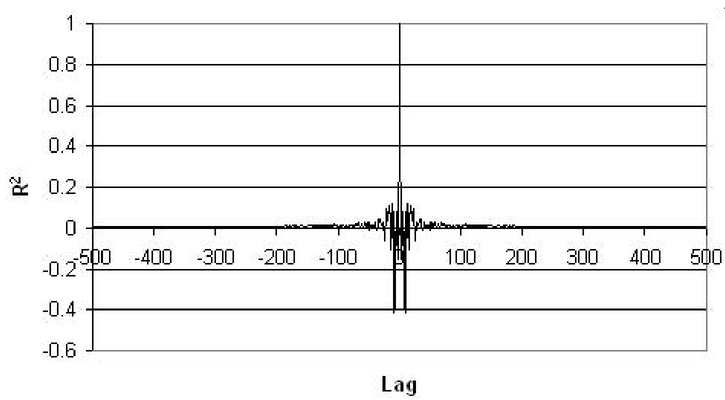


Figure 7. *Autocorrelation of 3.3-octave vibrator pilot.*

The frequency range of the sweep was 10-100-Hz, or about 3.3 octaves. By contrast, Figure 8 shows the autocorrelation pulse of a sweep ranging only 1 octave. To take it to the extreme, the autocorrelation of a sine wave (zero octaves) is just a sine wave. The greater the frequency range of the sweep, the poorer the correlation at lags beyond zero lag, and the more quickly the correlation coefficient (R^2) decays with increasing lag. Most vibrator surveys use sweeps of at least 3 octaves.

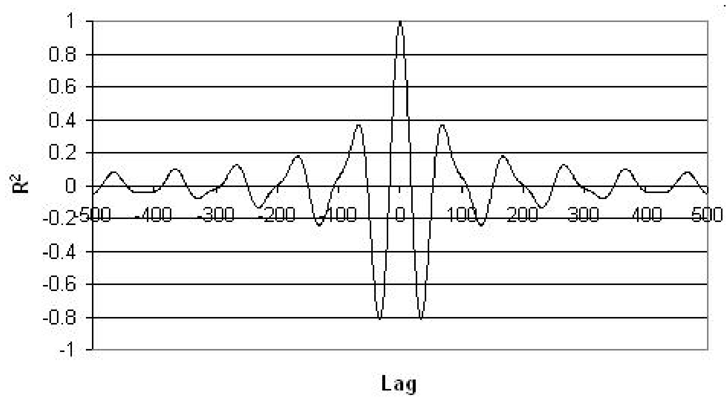


Figure 8. *Autocorrelation of 1.0-octave vibrator pilot.*

Generally, the sweep and resultant autocorrelation trace from an electronically-controlled vibrator are quite stable – vigilant pilot QC is generally not necessary. This marks the *fundamental difference* between surveying with a vibrator and surveying with a Wacker, which will be discussed presently.

One characteristic of a vibrator sweep is that no one frequency is repeated – it sweeps through a range of frequencies continuously and in a single direction. That is why there is only a single peak in the autocorrelation – there is only one point (at zero lag) at which the correlation is perfect ($R^2 = 1$). If any frequency were repeated, the autocorrelation would have multiple peaks, and these would contaminate the correlated shot record.

Wackers like the one pictured in Figure 1 were designed to operate in a periodic fashion. When operated as intended (by holding the throttle constant), it will impact the ground at a relatively constant rate. The autocorrelation pulse of such a periodic input signal will *not* be a single peak at zero lag. In order to achieve a pilot with an autocorrelation similar to the one shown for the 3.3-octave vibrator above, the operator must "randomize" the impact sequence, so that the time between impacts is never (or rarely) repeated during the sequence. This is accomplished by varying the throttle in as random a fashion as possible (the use of multiple Wackers also helps in this regard). This takes some practice, but with adequate feedback, an operator can hone his technique fairly quickly.

To get an idea of what this looks like, click on the picture below to watch a short video clip:

MOV00565.MPG

As you can see, everybody has their own style.

Because a certain amount of skill is required to generate a good random-source pilot, one of the most important features of the Geometrics Random-Source package is the pilot quality control parameter, or “randomness coefficient”. This will be discussed in detail in a later section. First we will discuss random-source pilots in more general terms.

Random-Source Pilot Quality – the Good, the Bad, and the Ugly

What does a “bad” pilot look like, and what does this do to the final record? First, let’s examine a good random-source pilot. Figure 9 shows a section of a randomized pilot recorded by a damped 40-Hz geophone from two Wackers located immediately adjacent to it. The geophone was connected to the wacker channel through the Pilot Processing Module (PPM), which is discussed in a later section.

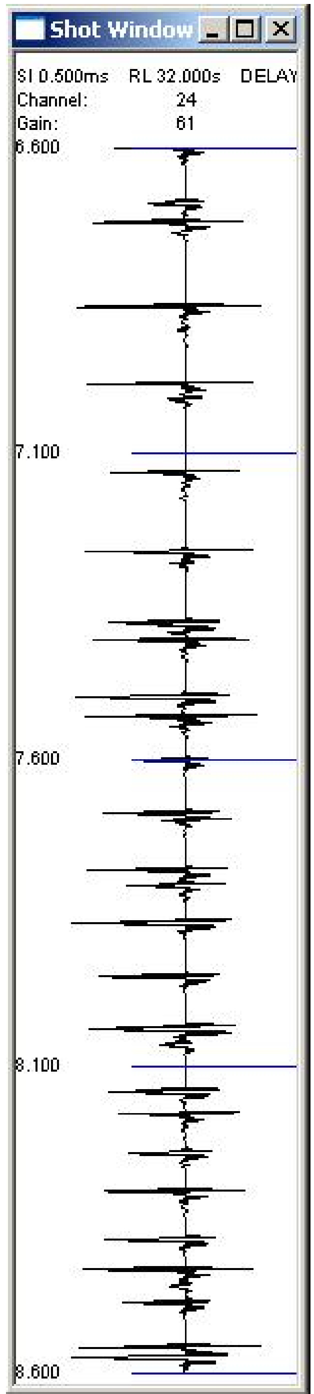


Figure 9. *Section of randomized Wacker pilot (two Wackers, 6" from 40-Hz geophone).*

Figure 10 shows the autocorrelation of this pilot:

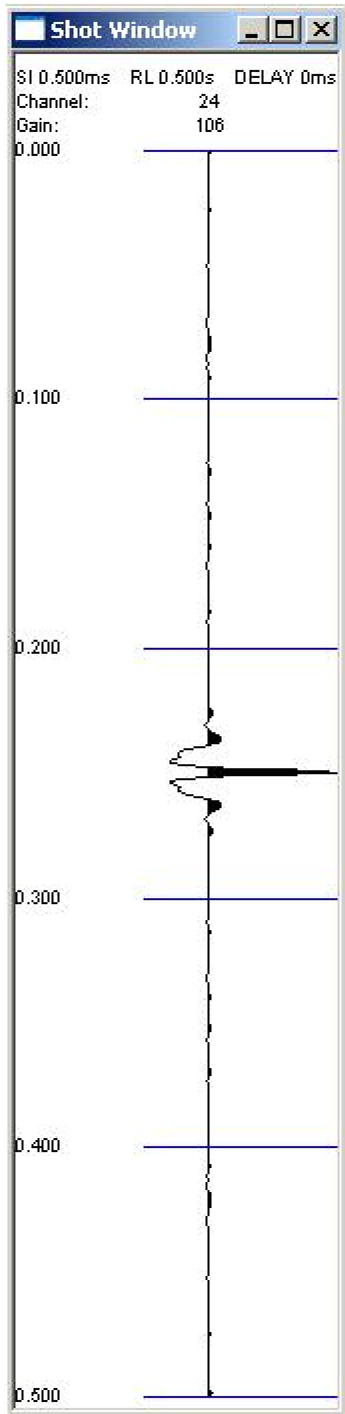


Figure 10. *Autocorrelation of randomized Wacker pilot.*

Note the absence of secondary peaks beyond the central autocorrelation pulse. By contrast, Figure 11 shows a portion of a non-randomized pilot generated using a single Wacker running at full throttle:

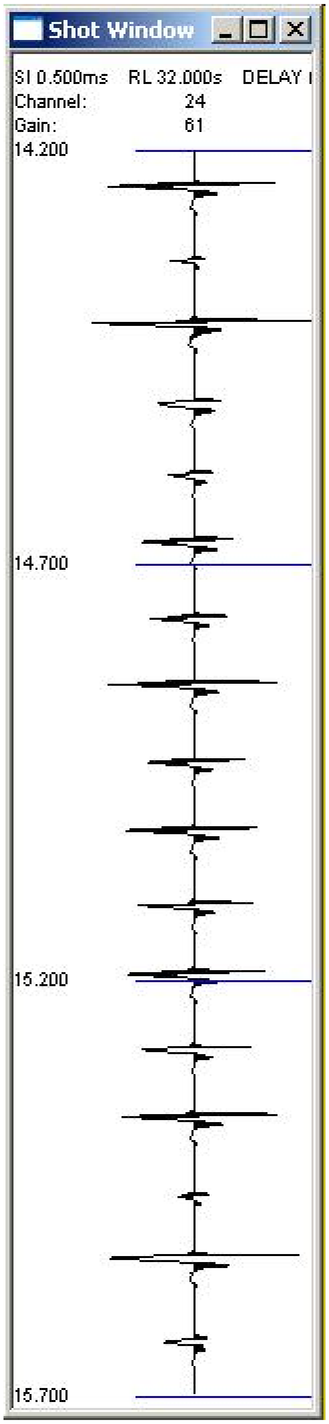


Figure 11. *Non-randomized Wacker pilot.*

Compare Figures 9 and 11; note the relatively periodic nature of the pilot in Figure 11. This gives rise to the autocorrelation in shown in Figure 12:

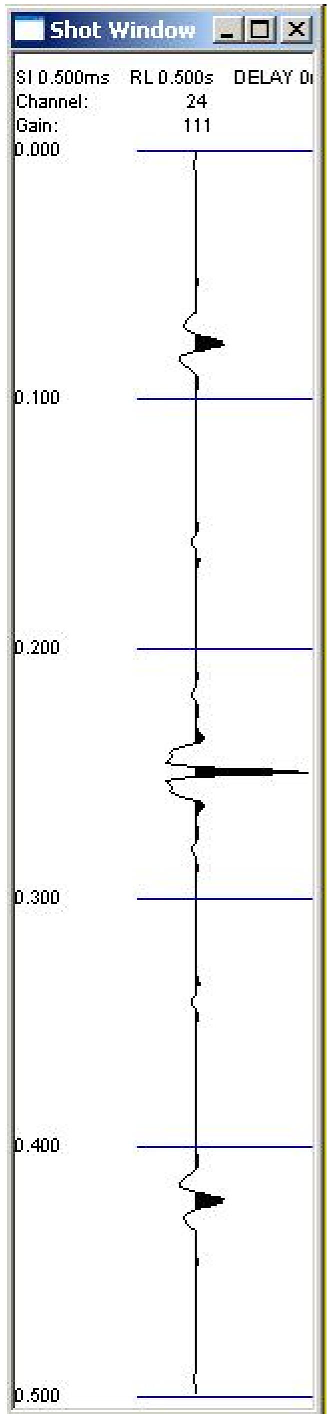


Figure 12. *Autocorrelation of non-randomized Wacker pilot.*

Notice the strong secondary peaks on either side of the main peak at zero lag. This is due to the periodic nature of the non-randomized pilot. This is a problem that is unique to random-source surveying, and it is the reason that pilot QC is so important in this type of survey. See the section on Pilot Quality Control for an in-depth discussion.

Figure 13 shows the effect of these secondary peaks on the correlated record. The correlated record can be thought of as the result of convolving the autocorrelation trace at the left with the reflection coefficient series. The autocorrelation trace is superimposed on and scaled to each reflection coefficient in the series, with the central peak centered on the reflection coefficient in question. Any secondary peaks then show up as lower-amplitude “ghosts” above and below the true reflection, at a time-distance t equal to that on the autocorrelation trace. Eliminating ghost events on the final record is the main purpose of randomizing the pilot to the greatest degree possible.

Figure 14 shows a comparison of two records from the same location obtained with a randomized and non-randomized pilot. Notice the ghosting in the record on the right, particularly the relatively high-move out “reflectors” about half-way down. These are actually ghosts of shallower reflectors – look up a time-distance of t to find them.

You will find the QC feedback mechanism quite valuable in eliminating this source of noise.

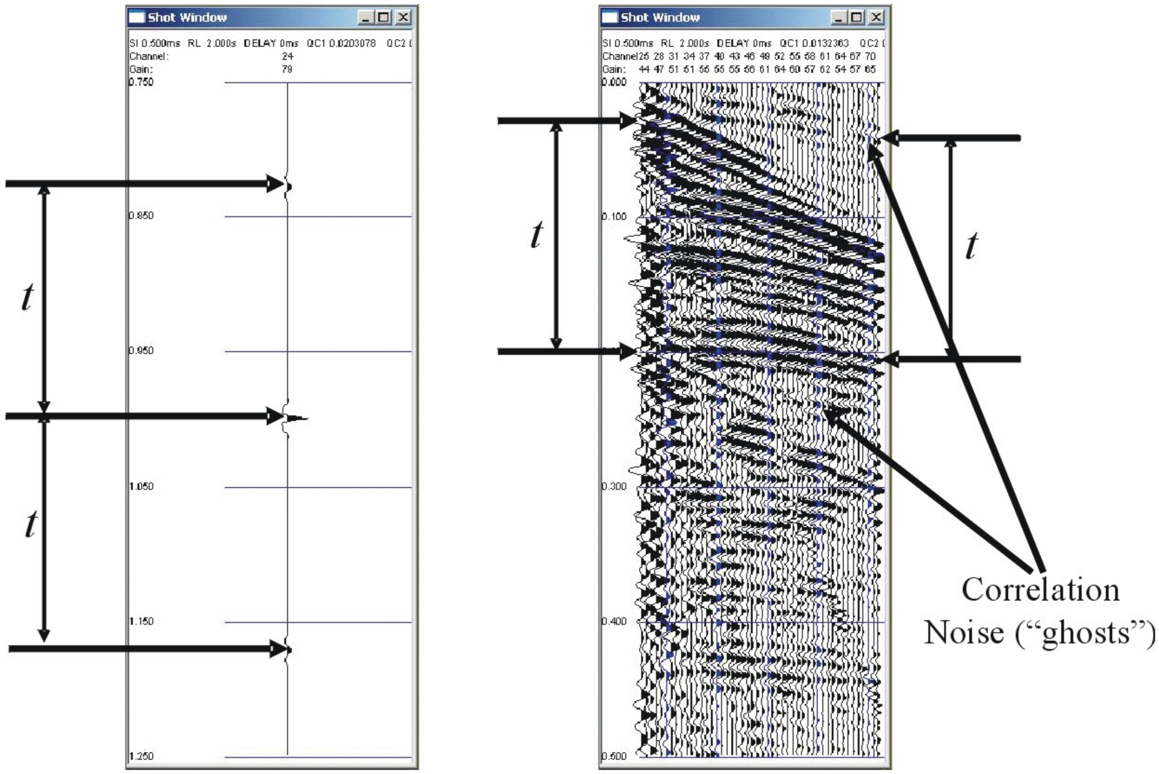


Figure 13. *Ghosting in final record caused by secondary peaks in autocorrelation.*

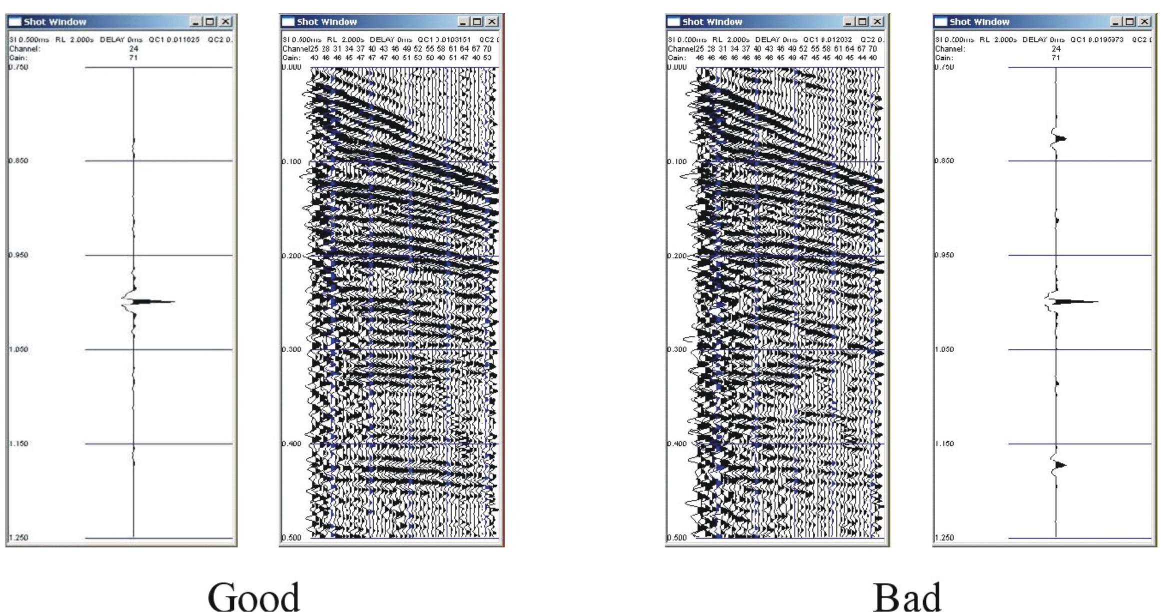


Figure 14. *Comparison of records obtained with randomized and non-randomized pilot.*

The Geometrics Random-Source Package

Hardware

The Geometrics Random-Source package consists mainly of software, but does include a Pilot Processing Module (PPM) and associated cables, pictured in Figure 15. A 100-Hz geophone is also included.

Note: *The optional trigger extension cable (orange spool) is not included in the Random-Source package but is shown here to illustrate the assembly if you need greater offset or do not want to accomplish your offset by disabling channels. The adaptors required to use the trigger extension cable are included.*

Figure 15. *Random-Source Pilot Processing Module (PPM)*

The PPM module is designed to allow the use of a standard 40-Hz geophone as the Wacker/Wacker geophone when conducting CDP surveys. You simply move the Wacker to the shot station, unplug the geophone present there, plug the module into the geophone cable, and plug the geophone into the module. It conditions the output of the geophone and prevents clipping of the pilot channel.

Alternatively, if you find that you get better results using the supplied 100-Hz geophone to record the pilot, you can use simply replace the existing geophone with the 100-Hz phone.

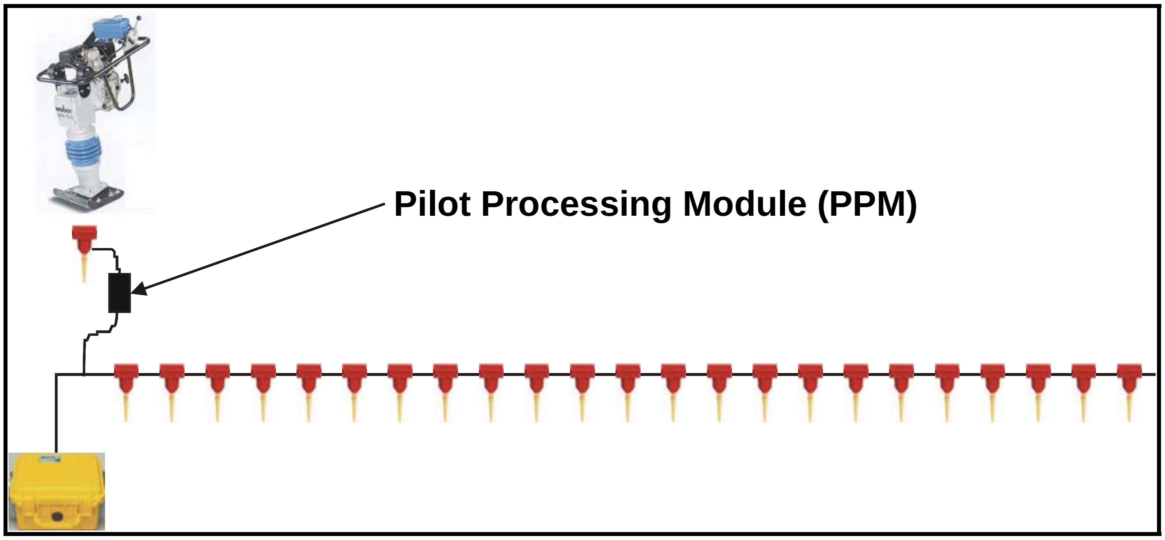


Figure 16. *Typical layout showing connection of PPM. In this example, the extension cable is not used and offset is achieved by disabling the near channels.*

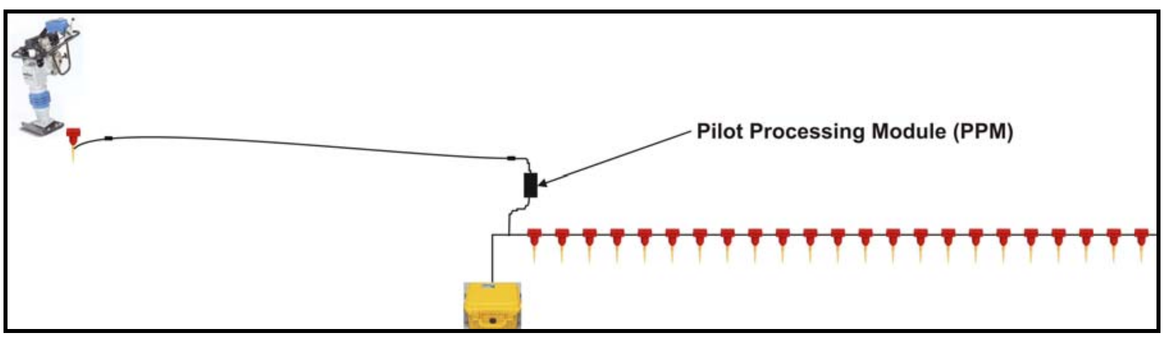


Figure 17. *Layout using trigger extension cable for larger offsets*

Software Overview

There are several software tools that comprise the Random-Source package. We will discuss the function of each in turn, and then put their function in context by way of a few examples.

Definitions

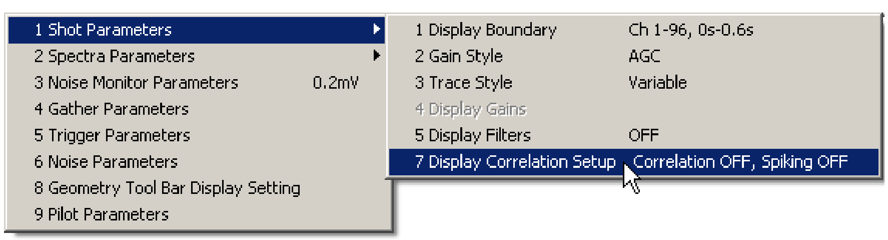
Wacker channel(s) – records impacts of a Wacker via 40-Hz geophone and Pilot Processing Module (PPM). Up to four channels can be designated as Wacker channels.

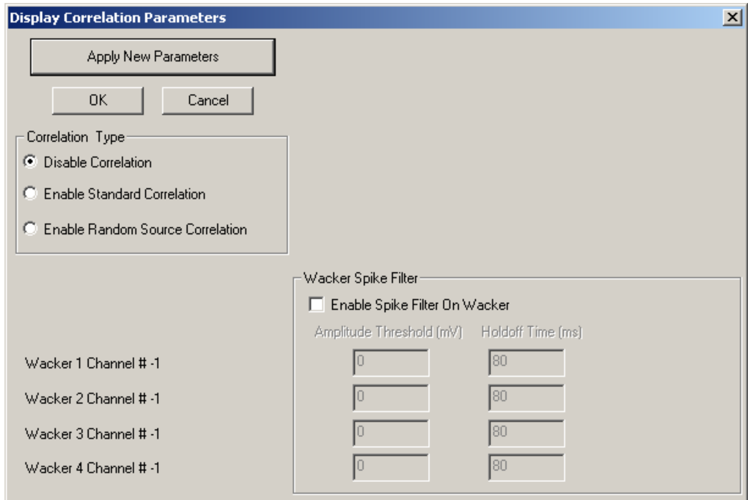
Pilot channel – the sum of all Wacker channels; is cross-correlated with the raw data. If only one Wacker channel is used, the data in the Wacker channel and the Pilot channel are identical. There is never more than one pilot channel.

Display Correlation Setup

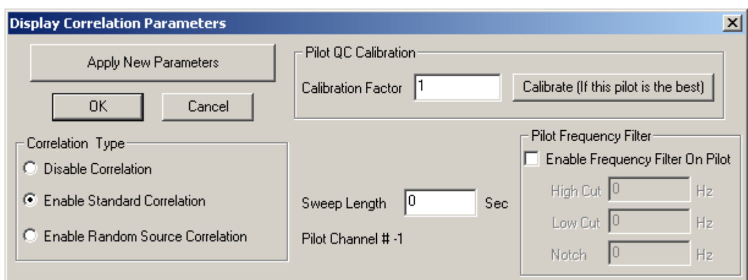
One of the most important steps in a random-source survey is setting up the acquisition parameters. This often requires some trial and error. For this reason, the software provides the ability to acquire a raw, unadulterated seismic record and then try different parameters in *display mode only*, allowing you to try different settings until you achieve the desired result. Once you have settled on your settings in the display menu, you can copy them over to the acquisition menu and begin acquiring correlated random-source data.

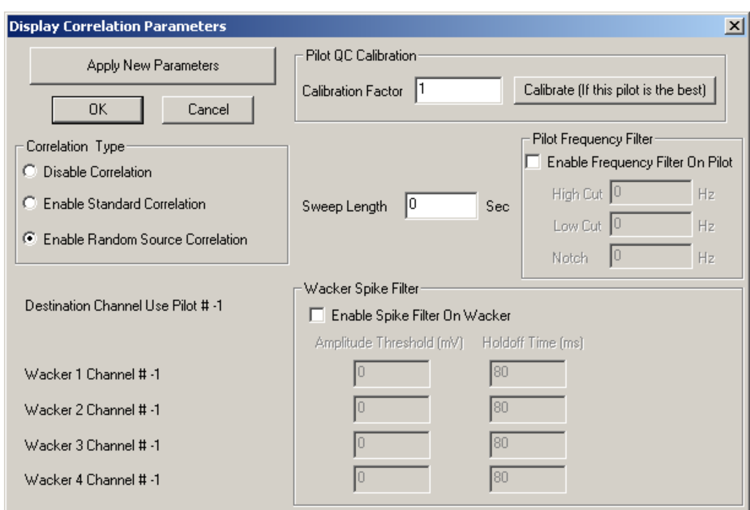
Click on **Display**>*Shot Parameters>Display Correlation Setup* to reveal the *Display Correlation* submenu:





The makeup of this menu depends on which correlation option you have enabled – none, standard, or random-source correlation.





Standard correlation is dealt with in the main MGOS manual. We will discuss only random-source correlation here.

Wacker Channels

It is generally easier to achieve a random input by using more than one Wacker (although a practiced operator can usually achieve sufficient randomness with only one). Multiple Wackers also put more energy into the ground over a given length of time. The software can support up to four Wacker channels, as indicated in the lower-left portion of the menu. This means that you can have a Wacker at each of four Wacker geophone locations, and record a unique pilot from each. The software will then sum the multiple pilots into a user-selected destination channel and the data will be correlated with the composite pilot.

Pilot QC Calibration

Quality control of the pilot is based on a “gold standard” pilot that was acquired with two Wackers, as shown in Figure 17 (also see Figures 9 and 10). This auto-correlated pilot represents what our experience has demonstrated to be the “best credible” pilot that can be expected with two Wackers. As such, in our proprietary pilot-grading algorithm, it has

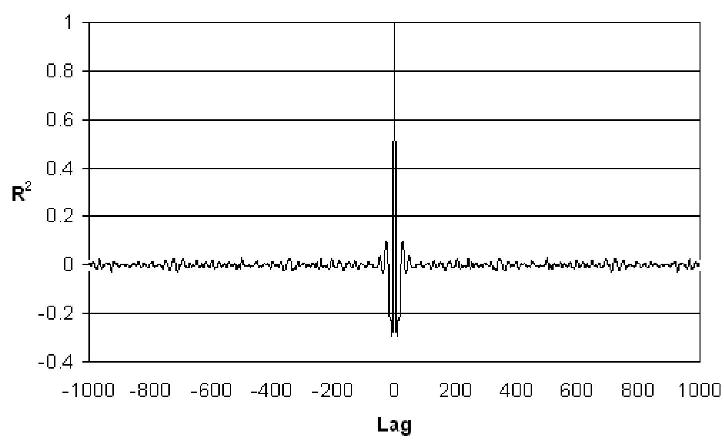


Figure 18. *"Gold Standard" Wacker pilot, obtained with two randomized Wackers. Randomness coefficient = 10.*

been assigned a “randomness coefficient” of 10. At the other end of the spectrum, the pilot of Figures 11 and 12 is considered to be the “worst credible” pilot, having been generated by a single Wacker running at full throttle. Normalized to the ideal pilot in Figure 17, it scores a randomness coefficient of about 1.0.   Each time you correlate a record, the randomness coefficient will be scored on this scale of 1-10, giving instant feedback that can be relayed to the operator, and allowing the observer the option of selective stacking and recording. The randomness coefficient is displayed in the top line of the shot window, as shown below:

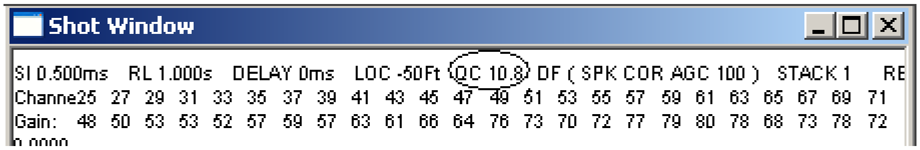


Figure 19. *Randomness Coefficient, displayed at top of Shot Window.*

Note that pilot quality is somewhat influenced by site conditions and other factors. For this reason, we provide the option for you to determine your own site-specific "gold standard". To recalibrate to the present pilot, simply press the **Calibrate** button in the **Display Correlation** submenu. Now, this new pilot will be assigned a randomness coefficient of 10. To reset to the default pilot, set the **Calibration Factor** back to 1.

In the above case, the randomness coefficient is 10.8, indicating that, by our criteria, it is even better than the "gold standard". Pressing the **Calibrate** button would make this pilot the new "gold standard" (for this software session) and all subsequent randomness coefficients will be normalize accordingly.

Note: *It is not necessary to calibrate your pilot. This function is for your convenience only, as it allows you to rate each pilot on a scale of 1 to 10.*

Sweep Length

This parameter is the same as in standard correlation. It represents the length of time the Wackers are active. The total record length less the sweep length equals the final correlated record length, also known as the "listen time". Since we are in display mode, the data in memory are raw and uncorrelated, so we can choose whatever sweep length/listen time combination we wish. For instance, if we have a 32-second record, we can choose a sweep length of 31.5 seconds, press the **Apply New Parameters** or **OK** button, and end up with a 0.5-second correlated record. If we were to choose a 30-second sweep, the final record would be two seconds long.

Note: *In swept-source surveys, it is not necessary to synchronize the trigger with the very beginning of the sweep. Random-source surveys are especially forgiving in this regard. What matters is that the Wacker/pilot channel(s) and data channels all begin recording data simultaneously, and this is assured by the seismograph itself. Likewise, it is not necessary for the length of the actual impact sequence to be exactly identical to the sweep length entered in the dialog box. The usual modus-operandi is to start the Wackers, manually trigger the seismograph, and then signal the Wacker operators to stop once the seismograph indicates that it has finished acquiring data.*

Wacker Spike Filter

Our experience has been that an acceptable pilot signal is usually gained with a standard 40-Hz geophone in combination with the PPM of Figure 15. A close-up of a typical single impact is shown in Figure 19.

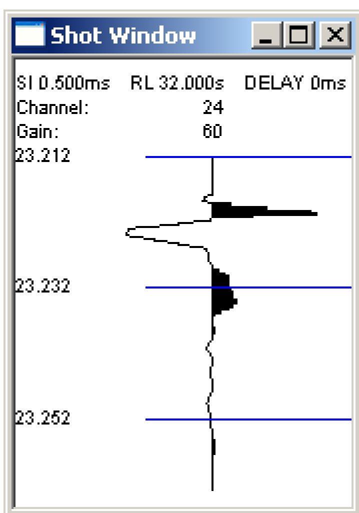


Figure 20. *Single Wacker impact recorded with 40-Hz geophone and PPM.*

Note that the pulse is relatively discrete – it displays minimal "ringyness", and can be safely said to have a duration of about 20 milliseconds. By contrast, Figure 20 shows a

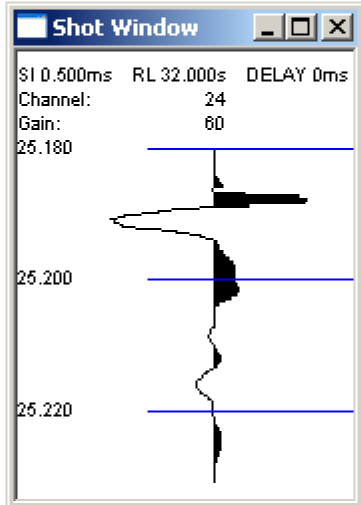


Figure 21. *Single Wacker impact recorded with 40-Hz geophone and PPM. Note" ringy" character compared to that shown in Figure 19.*

single impact recorded with the same geophone at a different location. As evidenced in the above two figures, site response can vary. A sequence of ringy pulses can result in a ringy central autocorrelation pulse, further resulting in a ringy correlated record, no matter how random the input.

For this reason, (and others discussed later), it is often desirable to further condition the pilot prior to correlation. The spiking filter allows you to collapse each impact into a single sample spike. This is actually the way the original mini-Sosie technique worked. The pilot channel was a simple series of delta functions representing the impact sequence. A "shifting and adding" algorithm, guided by the pilot, was employed to decode the composite record (see Park et al., 1996 for an excellent graphic of this process).

Note: *"Shifting and adding" is mathematically identical to cross-correlation, but before the days of fast computers, it was a much more expedient way of arriving at the same result, as it ignored all of the inter-impact zeros in the pilot.*

Spiking a Wacker trace requires setting two parameters. The most critical is the amplitude threshold. This tells the algorithm the minimum amplitude to be considered to be "real" – anything smaller will be ignored and zeroed out. The second parameter is the hold-off time – this is the minimum allowable time between successive events. After spiking a pulse, the algorithm will ignore all events coming afterwards for a period equal to the hold-off time. Any events occurring within the hold-off time will be zeroed out.

Note: *The default hold-off time is 70 milliseconds, and can generally be left alone if using a standard Wacker. Experimentation has shown that the maximum impact rate of these machines is about 1 impact every 75 milliseconds. If there is any doubt, or if you are using some other type of impact device, it would be advisable to do a test and adjust the hold-off time if necessary.*

The effect of the spiking filter is illustrated in Figure 21.

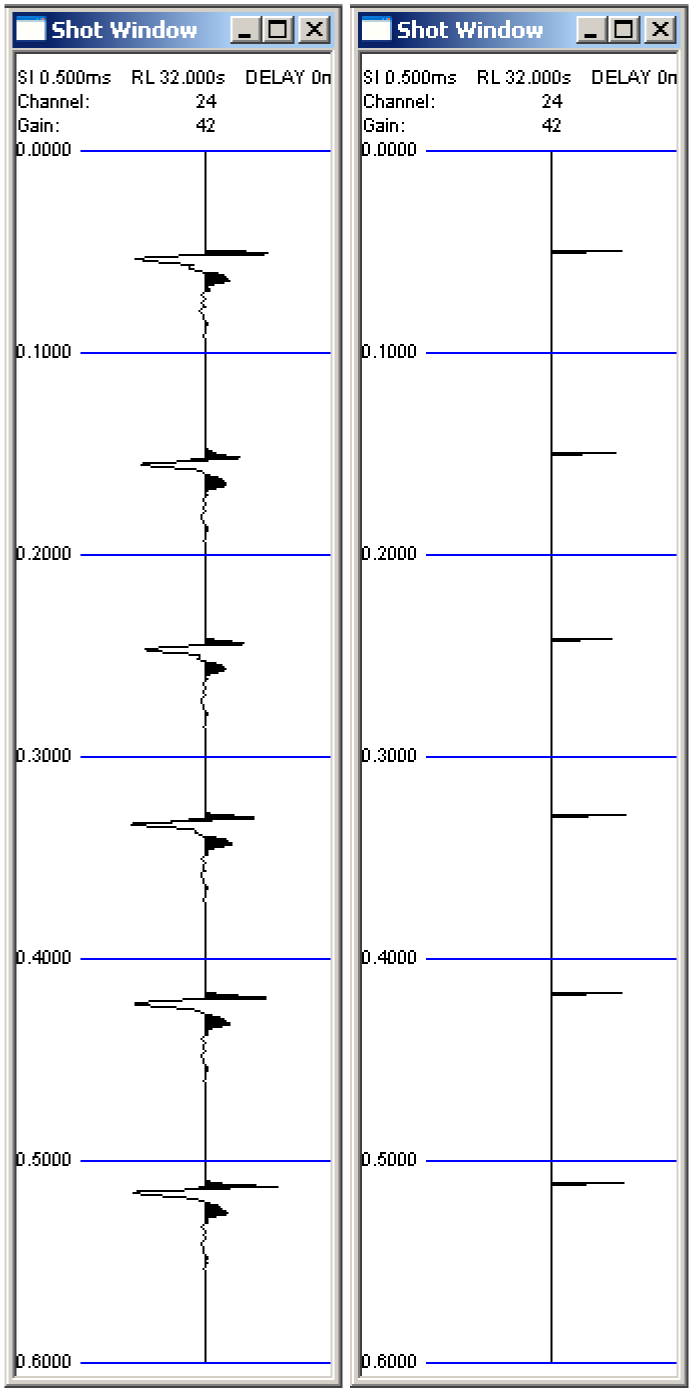


Figure 22. *Raw impact sequence (left, as recorded with 40-Hz geophone) along with spiked version.*

Setting Your Survey Parameters

Setting up the survey parameters is a critical step when using a random source. There are varying degrees of complexity, depending on how many Wackers you are using, whether or not you are spiking the pilot, and other considerations. We facilitate this process by allowing you to set up everything in display mode, and then to copy all of those display parameters over to the acquisition parameters with a touch of a button. This is best illustrated by example. We will start with the simplest of setups – a single Wacker with an unspiked geophone pilot – and work from there into more complex setups.

Example 1 – Single Wacker Channel, Unspiked Geophone Pilot

The first step in any setup is to take a raw record. In this first example, we will use a single pilot channel, and an unspiked geophone pilot (spiking is disabled).

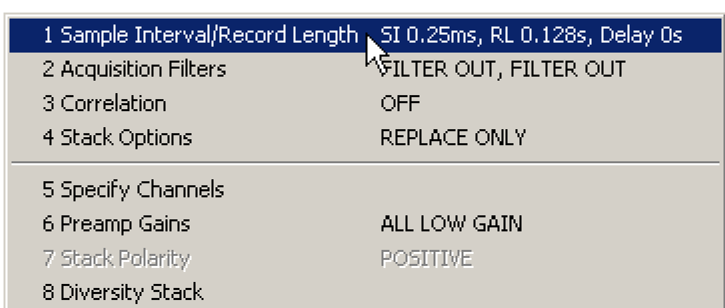
Note: *When collecting a random-source record, the Wacker should be no more than 1 foot from the Wacker geophone.*

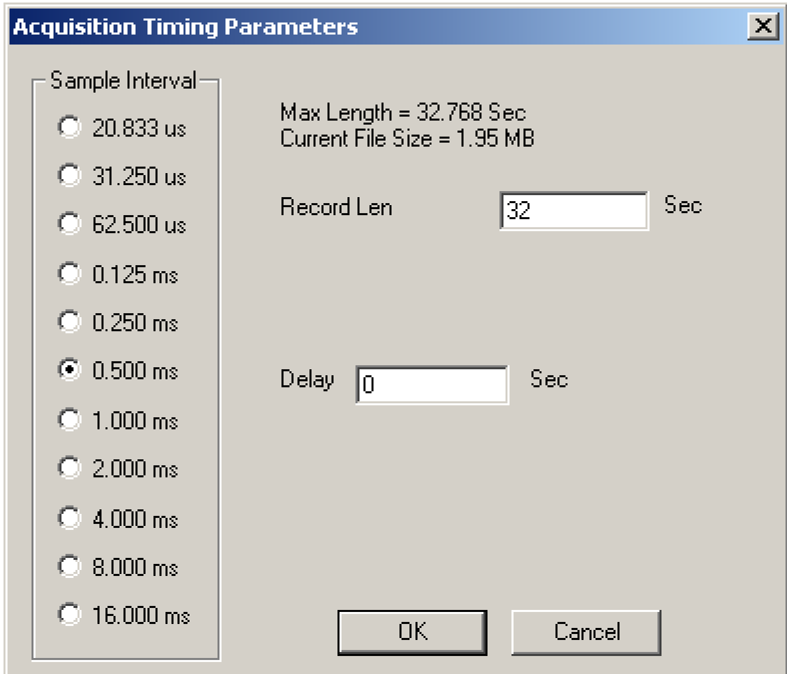
Note: *Using a single pilot channel does not mean you can only use a single source. Up to three Wackers can be practically used with a single Wacker geophone, with the three operators facing each other in an equilateral triangle.*

Note: *If* ***multiple*** *sources are used with a* ***single*** *Wacker geophone,* ***pilot spiking is not applicable****, because there will be overlap in the Wacker impacts and they will not be separable. Only use multiple Wackers with a single pilot channel when an unspiked geophone pilot will suffice. This is the recommended methodology whenever possible.*

This is the simplest case, and the parameter setup is essentially identical to that used with a conventional vibrator. The only difference is that the Random-Source correlation option does not allow stacking before correlation (stacking before correlation only makes sense when every sweep is identical, which is never the case with a random source).

We set up the system as if we are going to take a hammer record – we turn off all filters, correlation, etc. and take a single 32-second record at ½ msec sample interval:

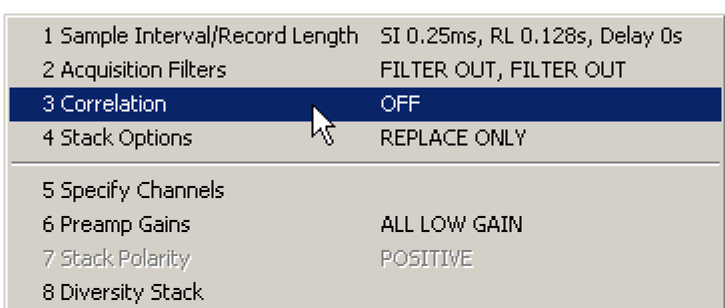


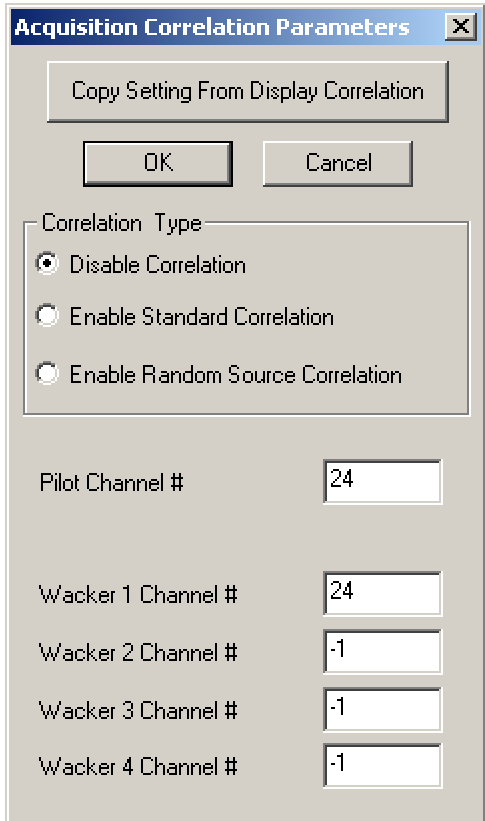


Note: *It is recommended that you use the longest record length possible. The longer the record length, the higher degree of randomness you can achieve with each sweep. The system allows up to 64,000 samples per trace, so at ½ msec, the maximum uncorrelated record length is 32 seconds. A 1-second sample interval would allow a 64-second record length. In any case, this is not the final record length. The final record length will be the uncorrelated record length minus the sweep length.*

Next, we must designate the pilot channel in the **Acquisition>***Correlation* submenu. This is the channel that the Wacker geophone (the geophone used to record the input of the Wacker[s]) is connected to, and it is the channel that the raw data will be cross-correlated against.

Clicking on **Acquisition**>*Correlation* opens the Correlation menu:





For now, we'll leave acquisition correlation disabled, but set the **Pilot Channel #** to 24. Also, we'll set **Wacker 1 Channel #** to 24.

Note: *In the case of a single Wacker channel, the **Pilot Channel** and the **Wacker Channel** are one in the same. When using multiple Wackers, the Wacker channels will be summed into a single Pilot channel.*

Note: *When in Random-Source mode, the Pilot **channel** only has meaning when acquisition correlation is disabled and you are correlating only the displayed data. Once you have decided on your parameters, and enable Random-Source Correlation, there is no pilot channel – the Wacker channels are summed and correlated against the raw data, and the resultant correlated pilot is displayed in the pilot window – but the correlated pilot is not stored anywhere.*

To take a record, the Wacker operator positions the Wacker(s) close the geophone connected to the Wacker channel(s) (in this case, channel 24). When he begins running the Wacker, the seismograph observer manually triggers the seismograph by pressing the "t" key (alternatively, if you have purchased the Self-trigger software option, you can program one of the Wacker channels to be a trigger channel). The operator runs the Wacker as randomly as possible for ~32 seconds.

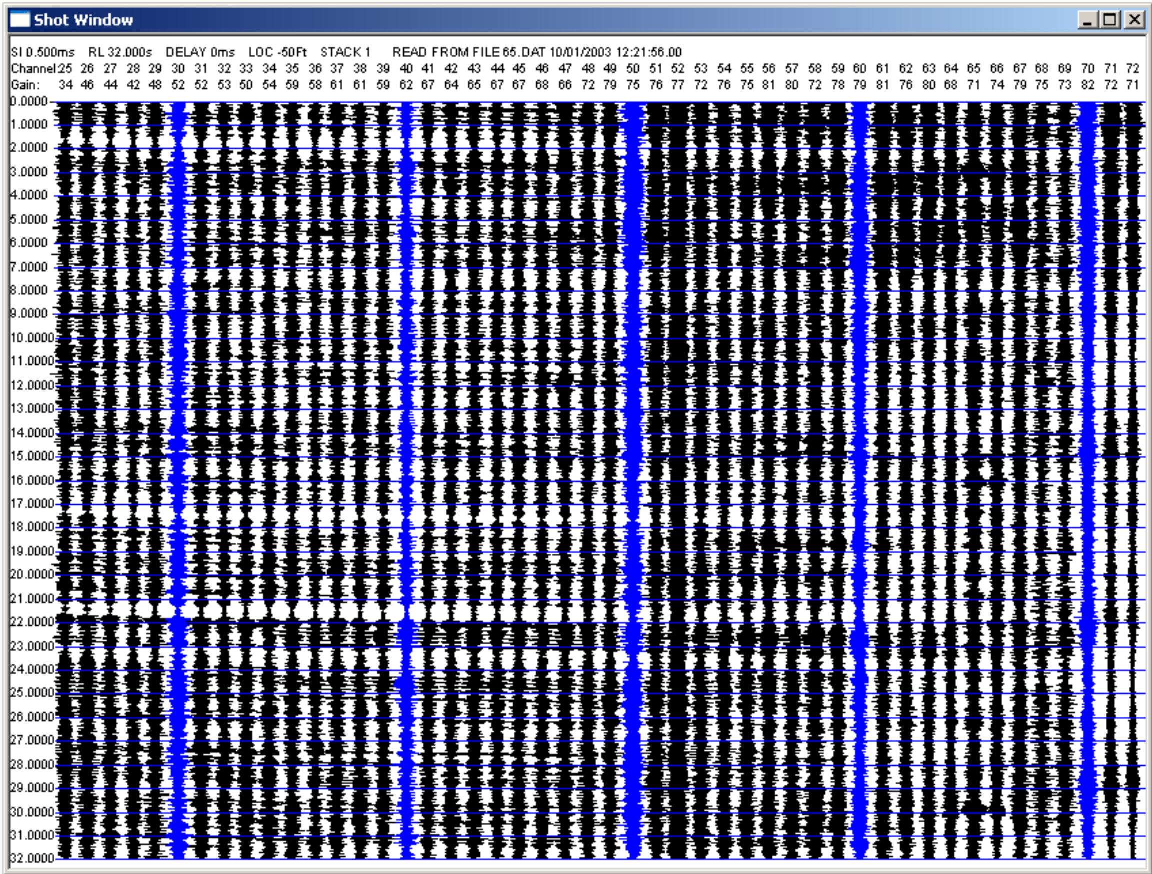


Figure 23. *Raw, uncorrelated shot record, 32 sec @ 1/2 msec.*

The resulting raw data are displayed in **Fixed Gain** mode (above, Figure 22.). In this particular data set, channels 25-72 are the active data channels. Channel 24 (not included in the shot record) is the wacker/pilot channel. Two views of a portion of the pilot channel are shown in Figure 23. In this case, two Wackers were used, so some events are the result of the interference between the two, resulting in a more complicated signature. This is OK – it is a representation of what actually went into the ground – but it illustrates why pilot spiking should not be used when using multiple Wackers on a single pilot channel.

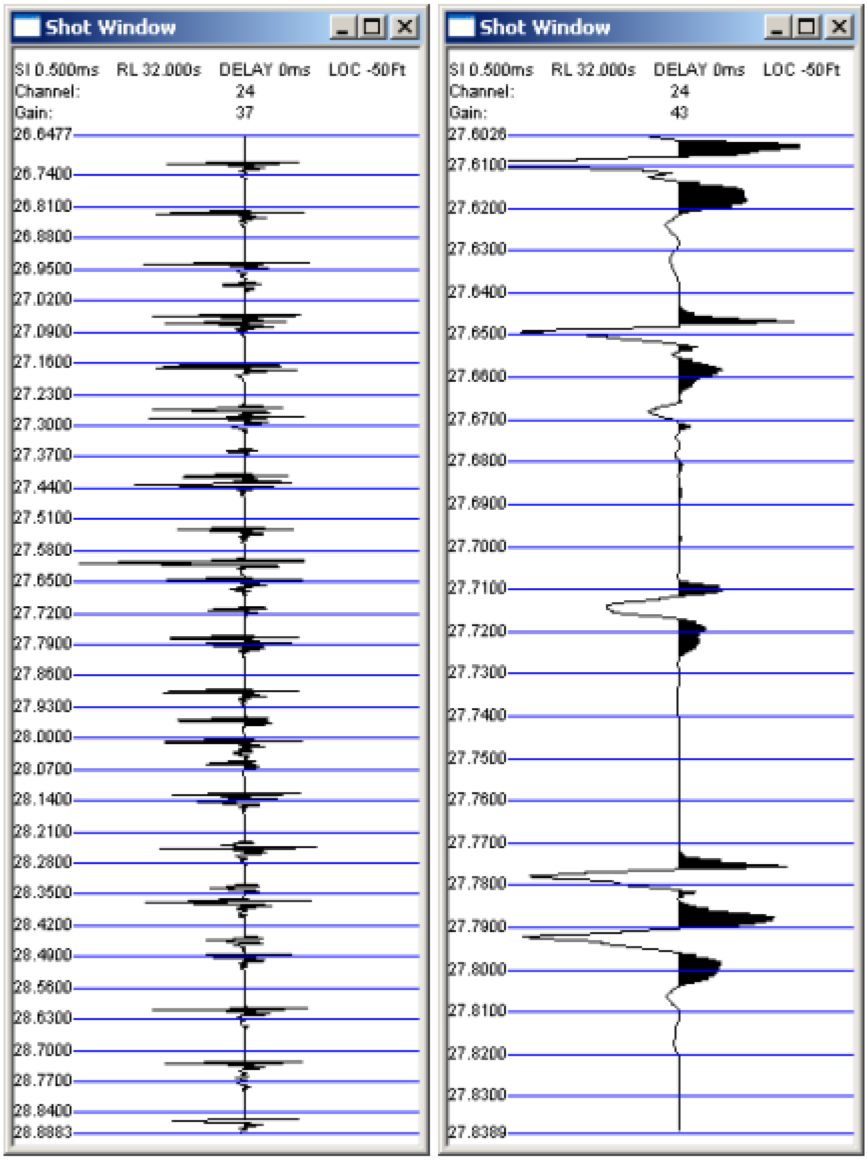
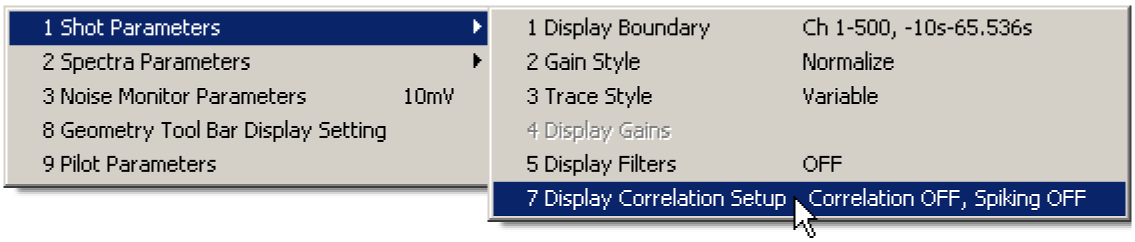
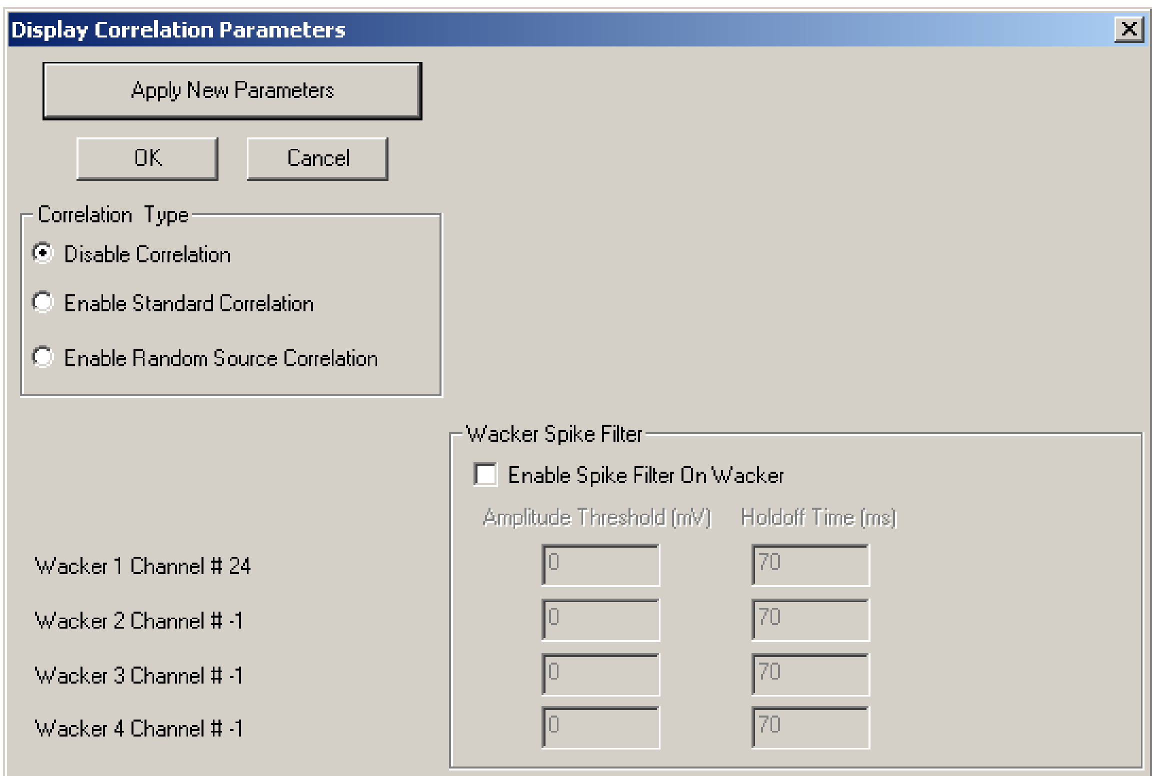


Figure 24. *Two views of raw geophone pilot generated by two Wackers.*

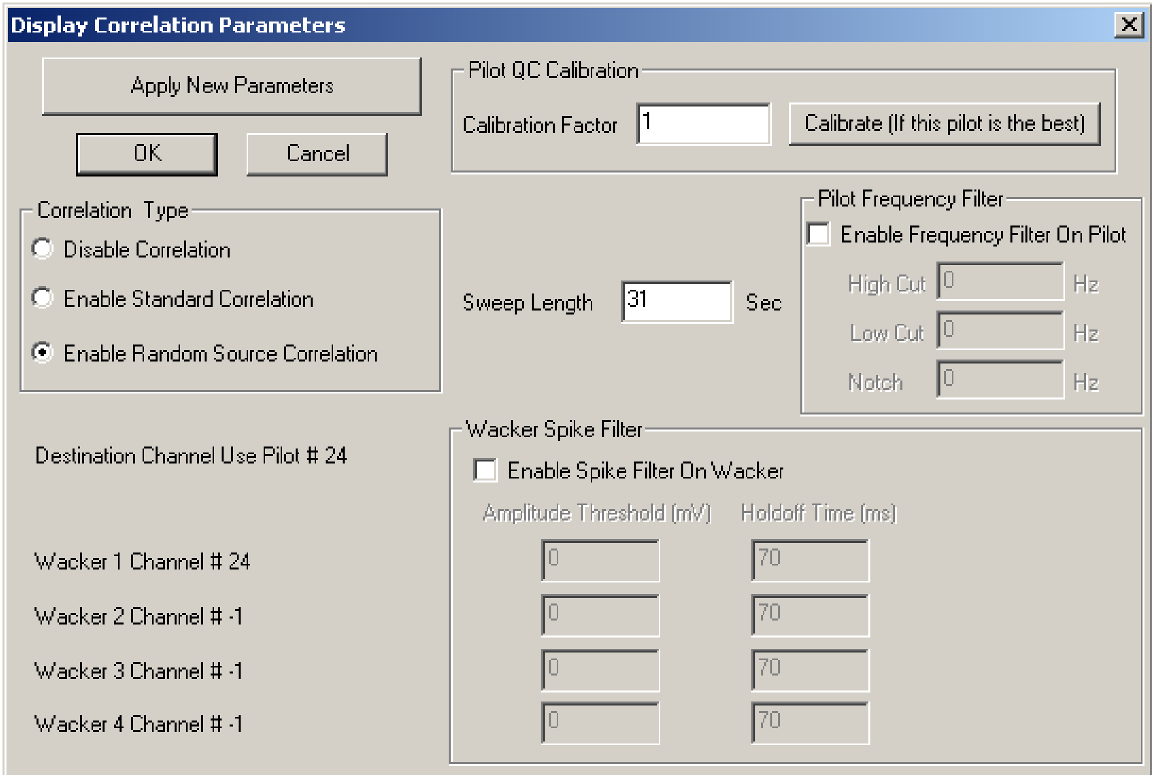
Now we want to correlate these data and see that we are getting a reasonable-looking shot record.

Clicking on **Display**>*Shot Parameters*>*Display Correlation Setup* reveals the **Display Correlation** menu:





Clicking on the **Enable Random-Source Correlation** radio button enables the correlation parameters portion of the menu:



We want a *listen time* (final record length) of one second. Recall that the listen time is the total raw record length minus the sweep length. So in this case, setting a *Sweep Length* of 31 seconds will yield a final record length of one second.

For now, let's ignore all of the other parameters in the menu. Pressing the **Apply New Parameters** or **OK** button will cause the data to be correlated. If everything is set properly, we should see something that resembles an impulsive record:

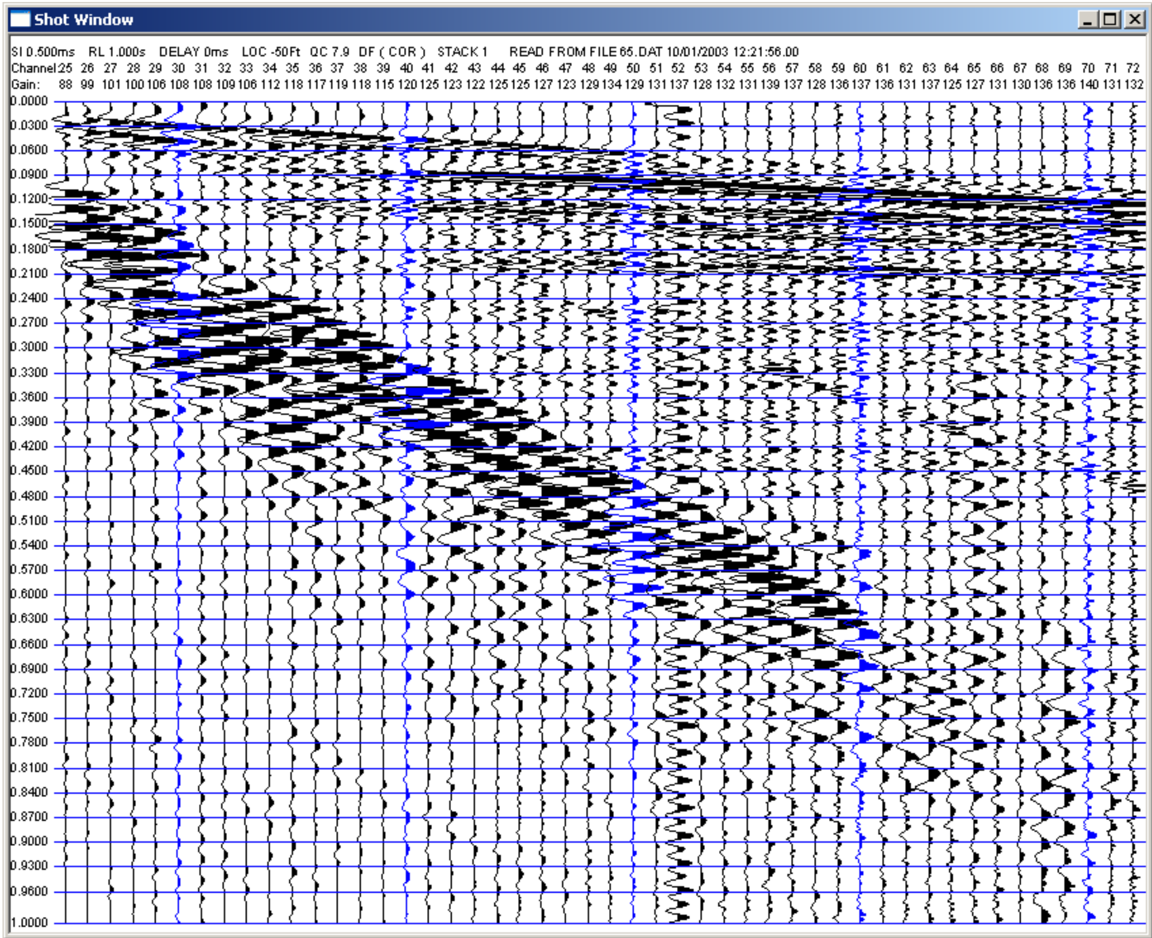


Figure 25. *Correlated shot record showing refracted and reflected arrivals, surface waves, and air wave.*

The correlated record in Figure 24 has now been "decoded" – you can see the hallmarks of a typical shot record, including refracted and reflected energy, surface waves, and air wave. Enabling AGC and display filters and changing the horizontal scale to optimize for seismic reflections, we get the following record:

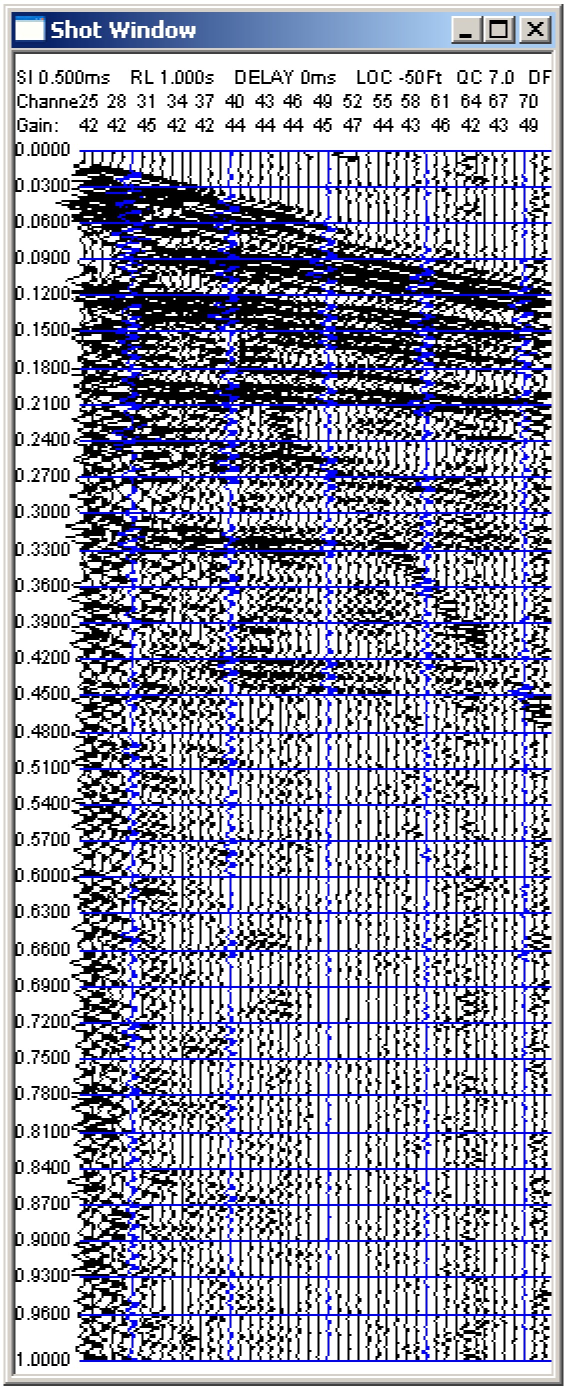


Figure 26. *Correlated shot record, optimized for seismic reflections. AGC Window = 200 samples, trace overlap = 5, filter = 85-Hz low cut.*

The correlated record shown in Figure 25 indicates that we have the pilot channel set correctly and that our parameters are reasonable. Before we settle on these parameters, let's have a look at the pilot trace:

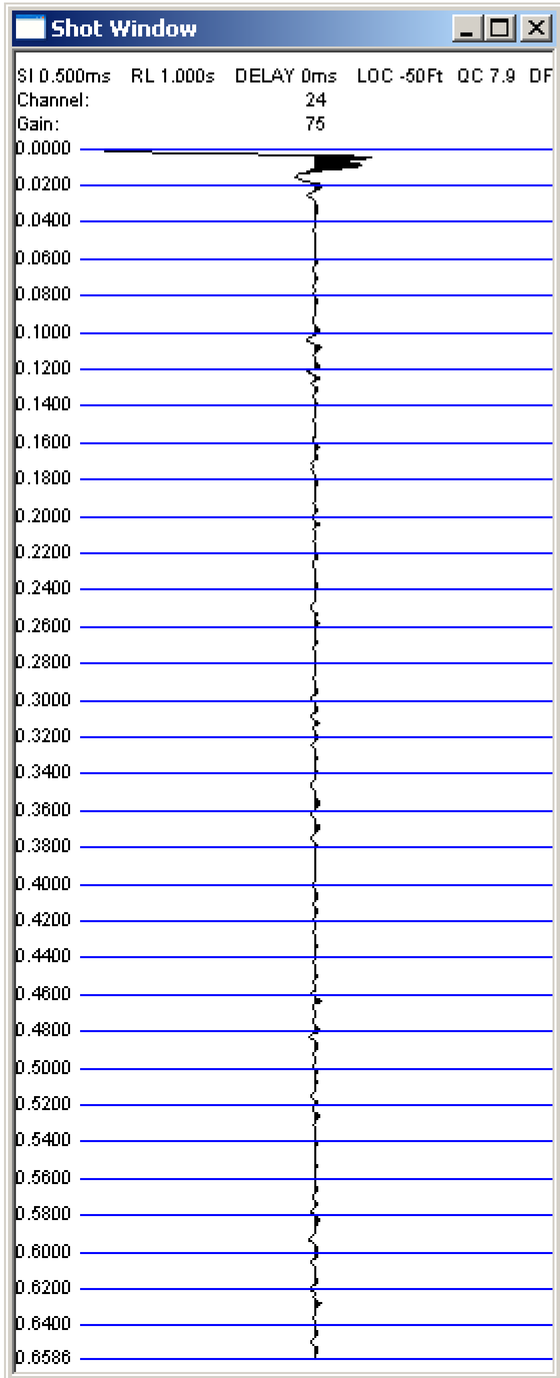


Figure 27. *Auto-correlated pilot trace, shown in fixed gain mode, no filters.*

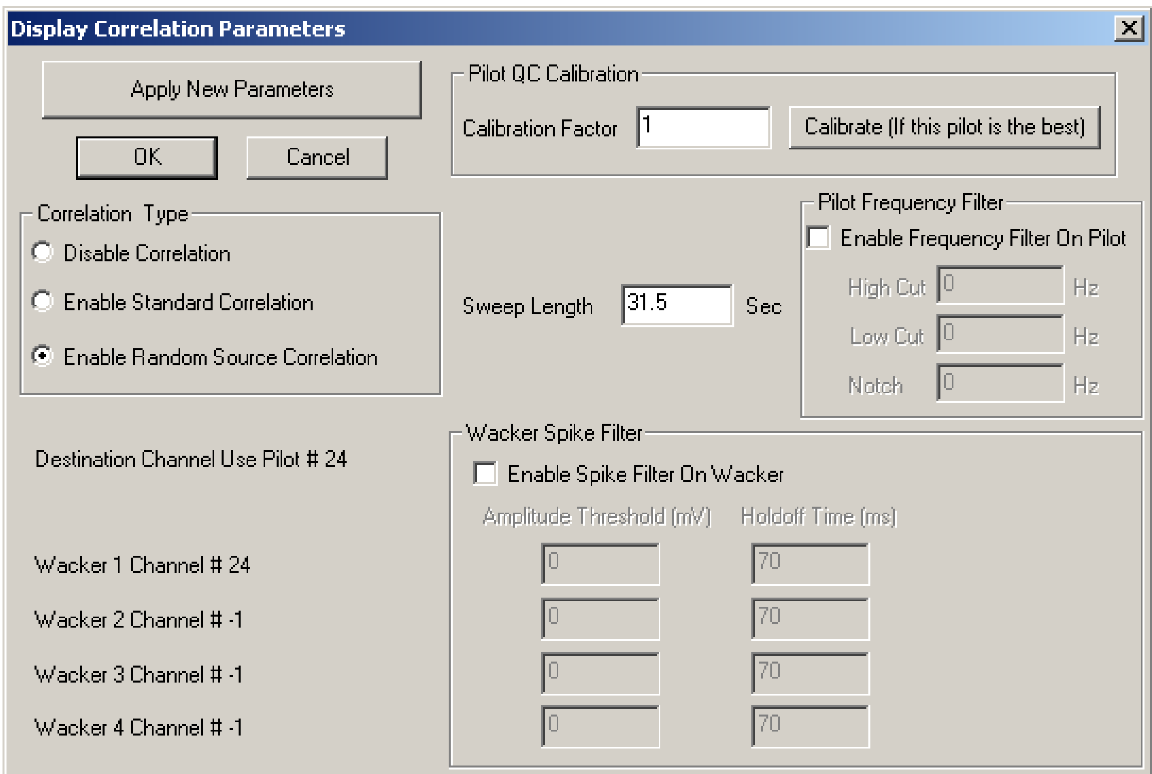
Note: *When displaying and analyzing the Pilot Channel, you should use Fixed Gain mode, and all filters should be disabled. Otherwise the pilot's shape will be distorted and you may draw the wrong conclusions about its quality.*

What we want to see is a large peak at zero time (this is zero lag), and no significant secondary peaks away from zero time. This looks like a good pilot. Also note the

Randomness Coefficient of 7.9/10 displayed at the top of the record (QC 7.9). For now we'll consider this to be an acceptable pilot – we'll discuss pilots in more detail later.

Note: *In the setup mode, no pilot is displayed in the Pilot window (discussed later). To view the pilot trace, correlated or uncorrelated, you must do so in the Shot window. In this mode, only the portion of the autocorrelation trace corresponding to lags ≥ 0 will be displayed. When we get to production mode, the Pilot trace will be displayed on its own in the Pilot window, and it will be shifted so that zero lag is at ½ the listen time.*

Look back at the shot record displayed in Figure 25. Note that there do not appear to be any reflectors beyond about 0.5 seconds. For this reason, let's say we decide that a ½-second record is all we really need to record – the rest is just wasted hard drive space. To test this, we can go back to the **Display Correlation** menu and change the **Sweep Length** to 31.5 seconds:



Since the total record length is 32 seconds, this will leave us with a ½-second record after correlation:

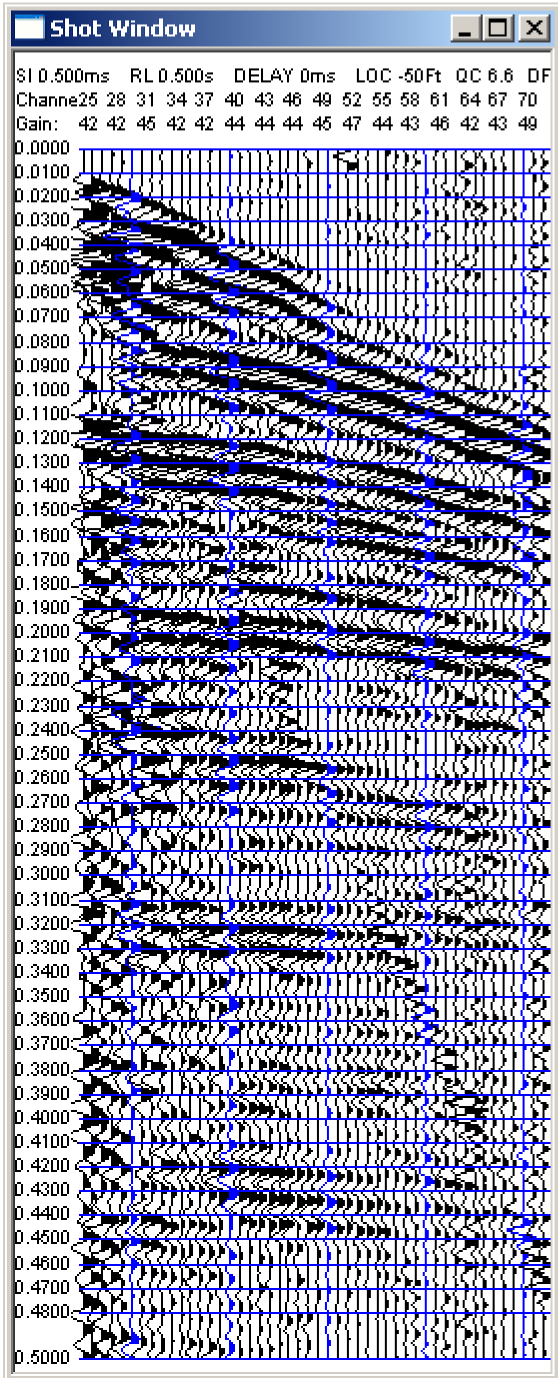


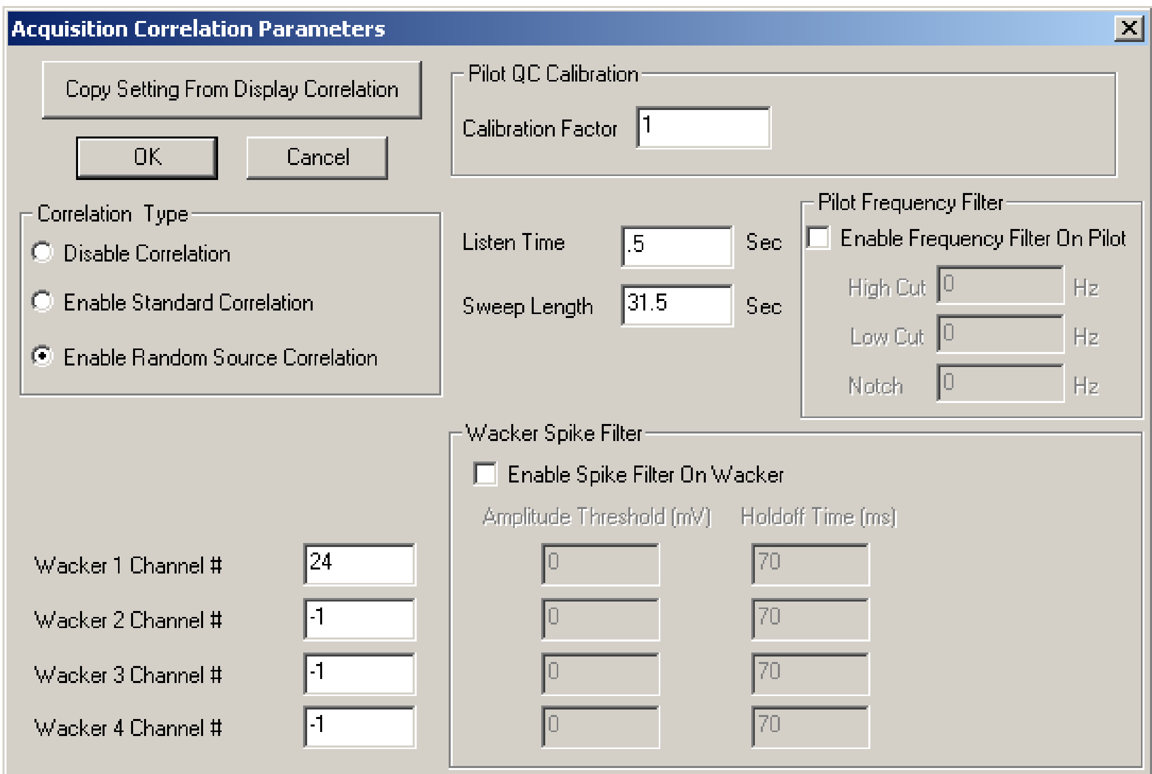
Figure 28. *Shot record of Figure 25 truncated to 1/2 second by increasing sweep length to 31.5 seconds.*

Once were are satisfied that our parameters are what we want, can copy them over to the acquisition menu so that we actually record and save correlated data.

Note: *Some practitioners prefer to record raw, uncorrelated data while viewing correlated data in the field. This is useful when it is desirable to pre-process the pilot prior to correlation (spectral whitening is one of the more common pre-processing steps).*

*This can be done by **not** copying the display parameters over to the acquisition menu, thereby correlating only the displayed data. This allows you to have control over the correlation step during the processing. The disadvantage is that, since **acquisition** correlation occurs in real-time in the Geode modules, a much larger data file must be transferred over the network, and data acquisition rates will be impaired. It takes significantly longer to transfer a raw, uncorrelated record than it does to correlate and transfer the much shorter correlated record.*

To do this, open the **Acquisition Correlation** menu and press the **Copy Settings From Display Correlation** button. The sweep length will be copied over, and the listen time will be computed on the basis of the sweep length and the record length of 32 seconds (set earlier in the **Acquisition Timing** menu):



***Note:** You are not bound to a listen time of 0.5 seconds at this point. If you decide that you want a 0.3-second listen time, you can simply type it in. The only rule is that the listen time plus the sweep length cannot exceed the total record length; in this case, 32 seconds.*

You are now ready to acquire data. Data will be correlated in real-time against channel 24 (the correlation step takes place in the Geode modules), and correlated data will be stored to disk.

Let's move on to another example.

Example 2 – Two Wacker Channels, Unspiked Geophone Pilot

In this example, we will use two Wacker channels rather than one.

Note: *When using more than one Wacker channel, the distance between Wacker geophones should be* ***at least 10 times the distance between any Wacker and its respective geophone****, as shown below. This assures that the seismic crosswalk between pilots will be at least 100 times below the signal level, enough to be considered to be negligible. The nearest a Wacker can realistically be to a geophone is about 8 inches, so the closest two Wacker channels should be to each other is 80 inches or about 7 feet (green squares are Wackers; red circles are Wacker geophones).*

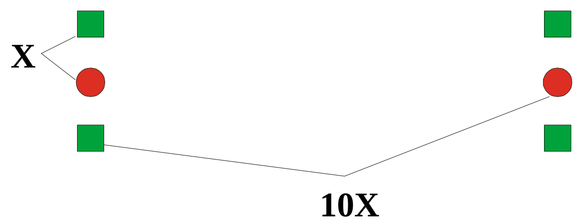
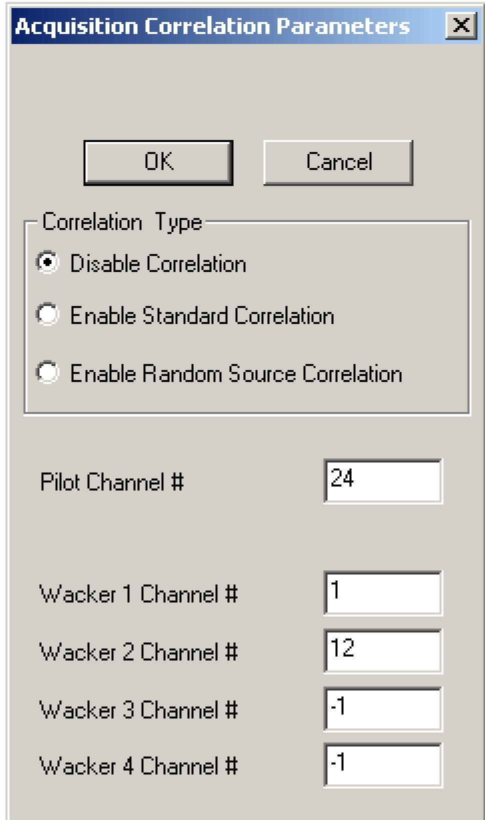


Figure 29. *Wacker/geophone layout when using more than one Wacker channel. Distance between Wacker channels should be at least 10 times the distance between a Wacker(s) and its respective geophone.*

Following Example 1, we start by designating the pilot and Wacker channels. In this case, the Wacker channels are 1 and 12. They will be combined and stored in channel 24. Channel 24 will be the pilot channel that the raw data are correlated against. As before, we will leave acquisition correlation disabled for now.



Next, we take a raw record:

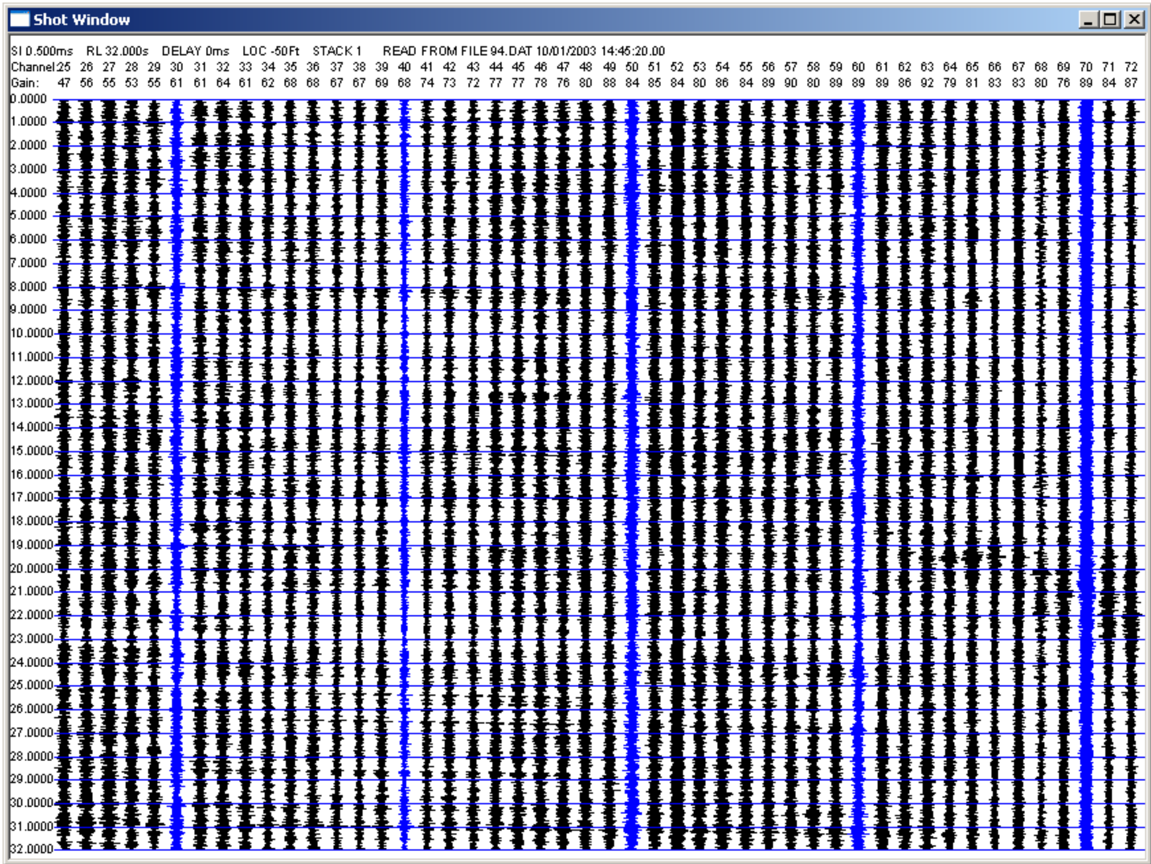
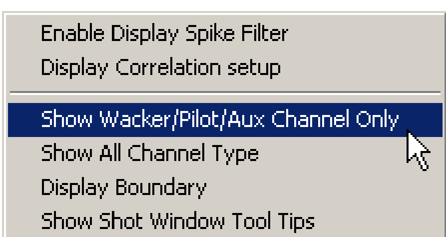


Figure 30. *Raw, uncorrelated shot record, 32 sec @ 1/2 msec.*

Only data channels 25-72 are shown in the shot record.

Note: *As before, since we are not spiking the pilot, more than one Wacker can be used at each of the two Wacker channels. In this particular case, only one Wacker was used at each Wacker channel.*

Now let's have a look at the two Wacker channels and the resultant pilot. Right-clicking in the shot window will reveal the following menu:



Click on **Show Wacker/Pilot/Aux Channel Only:**

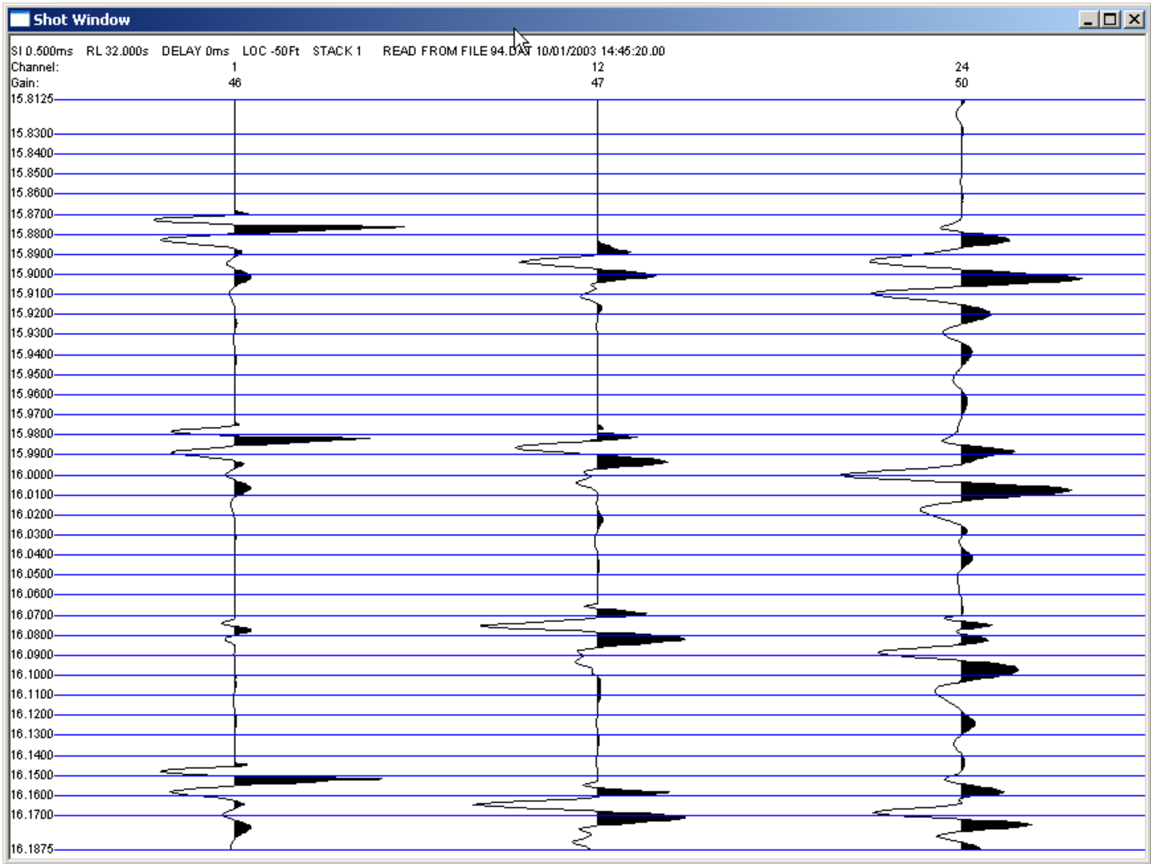
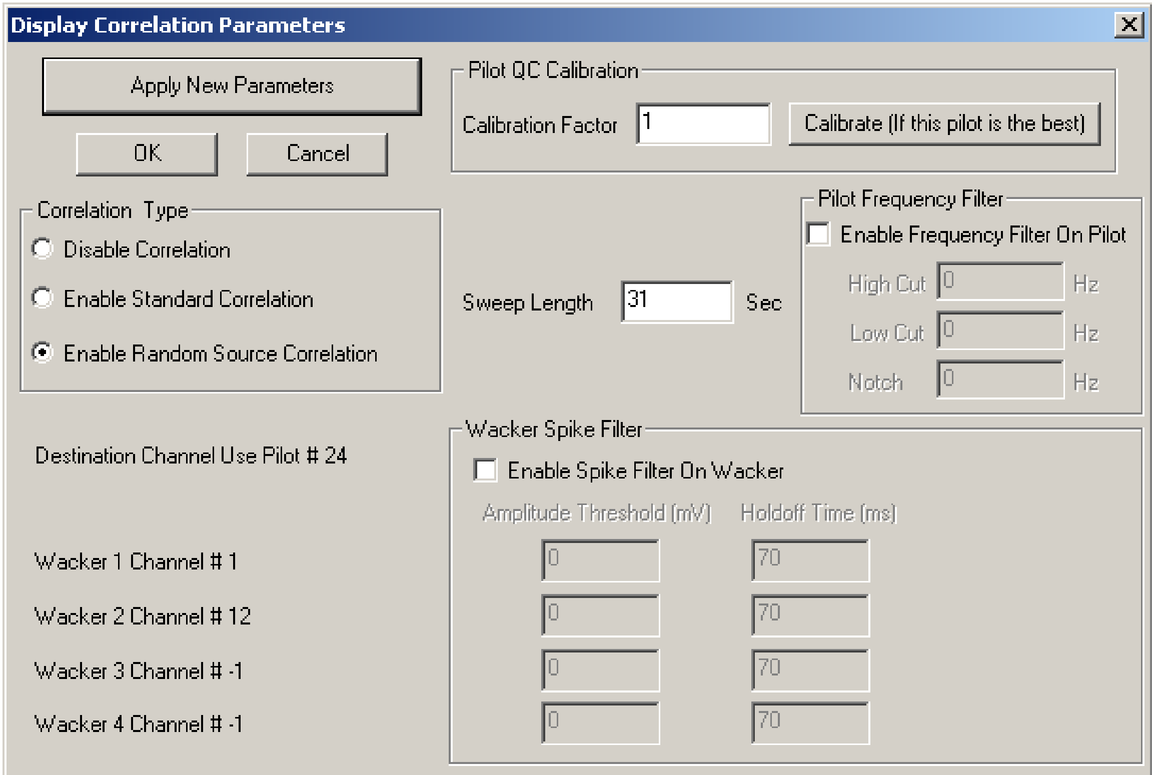


Figure 31. *Segment of Wacker channels (1 and 12) and pilot channel (24). Pilot channel is the sum of all Wacker channels.*

Now only channels 1, 12 (Wacker channels), and 24 (pilot; sum of Wacker channels) are displayed.

Let's correlate the data and see what it looks like. We bring up the **Display**>*Correlation* menu and set a sweep length of 31 seconds:



Again, we'll ignore all of the other parameters in the menu for the time being.

Next, we press the **Apply New Parameters** or the **OK** button and correlate the data:

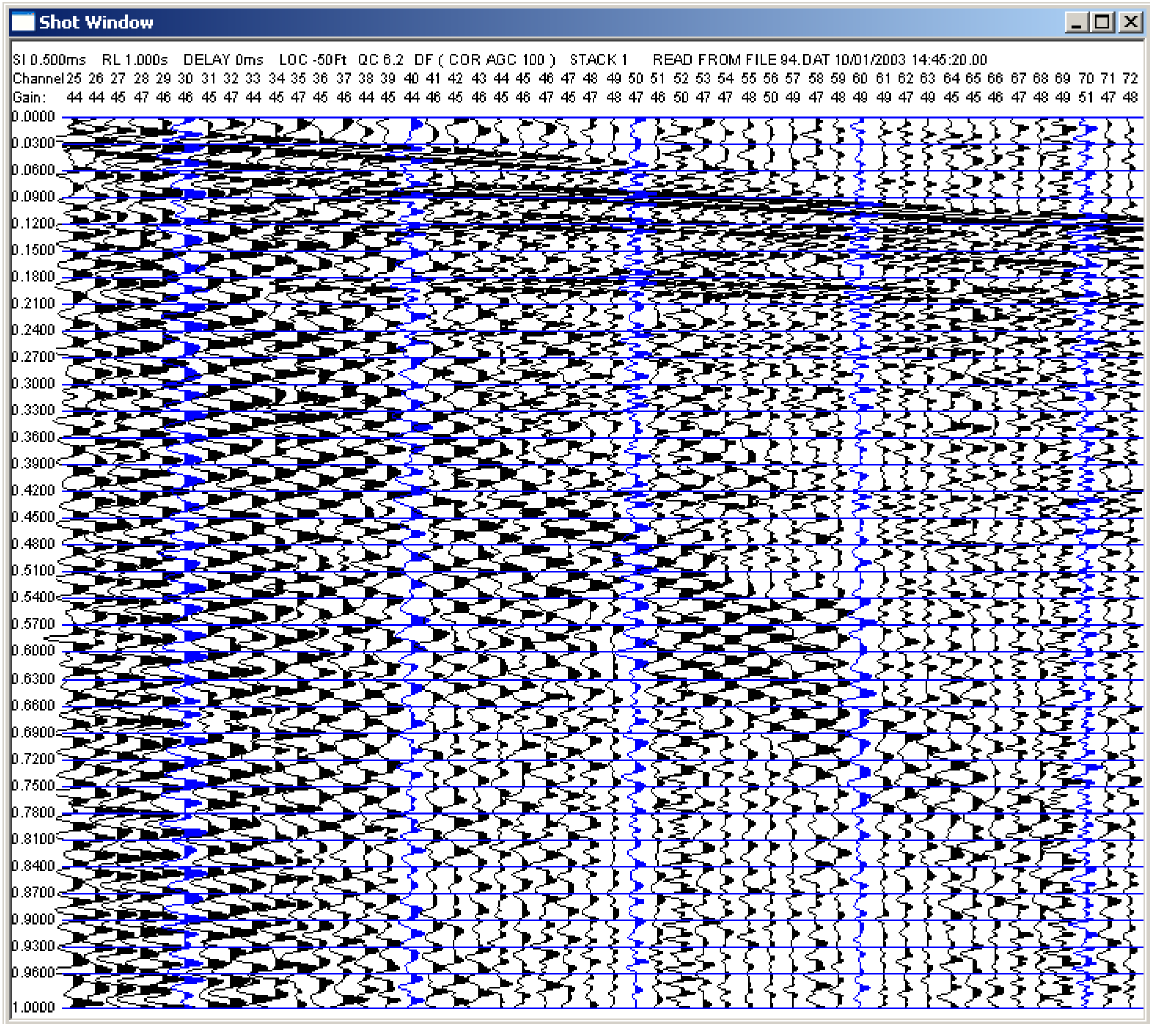


Figure 32. *Correlated shot record showing refracted and reflected arrivals, surface waves, and air wave.*

We get a 1-second correlated record similar to that shown in Figure 24. The difference is that the pilot trace in this case was created by summing two separate Wacker channels.

The autocorrelation trace of the pilot (channel 24) is shown below:

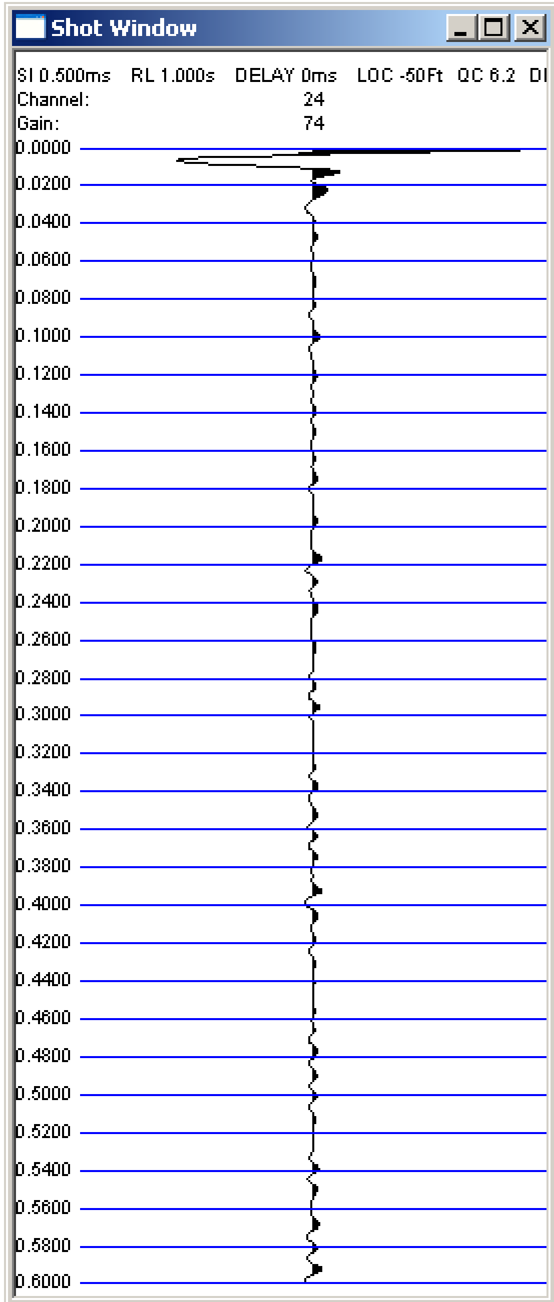


Figure 33. *Auto-correlated pilot trace, shown in fixed gain mode, no filters.*

If were are satisfied with these setup parameters, we can copy them to the **Acquisition Correlation** menu by pressing the **Copy Settings From Display Correlation** button.

We are now ready to acquire and save correlated data using channels 1 and 12 as Wacker channels.

Example 3 – Two Wacker Channels, Spiked Geophone Pilot

In some situations, as discussed earlier, it is desirable to "spike" the pilot signal before correlation. Many people prefer to operate this way, as it is similar to the original "mini-Sosie" technique of "shifting and adding" according to a pilot trace consisting of a series of delta functions corresponding to individual impacts (see Park, Miller et al., 1996). In this case, the pilot trace carries only timing information – it records when the Wacker impacts the ground, but says nothing about the actual ground motion. We have found that using the raw geophone/PPM output works best in most situations, but in areas where the ground surface tends to "ring", resulting in a more complex geophone signal, spiking the pilot is often useful.

The spiking filter can be thought of as a sort of repeating first break picker. The user must set two parameters – the **Hold-off Time**, and the **Amplitude Threshold**. The hold-off time determines the minimum allowable time between spikes. A hold-off time of 70 milliseconds means that all events within 70 milliseconds of the previously spiked event will be ignored.

The amplitude threshold is the minimum geophone output amplitude that will be considered for spiking. If an amplitude threshold of 10 mV is selected, all events below 10 mV on the Wacker trace will be ignored by the spiking filter.

Setting Your Spiking Parameters

A typical Wacker like the one shown in Figure 1 can run at a maximum rate of about 1 impact every 75 milliseconds. The default hold-off time of 70 milliseconds can therefore generally be left as is. The more important parameter is the amplitude threshold. Determination and setting of the amplitude threshold is best illustrated by example.

Let's go back to our previous case of two Wacker channels. A portion of the two Wacker channels and the resultant pilot channel are shown below:

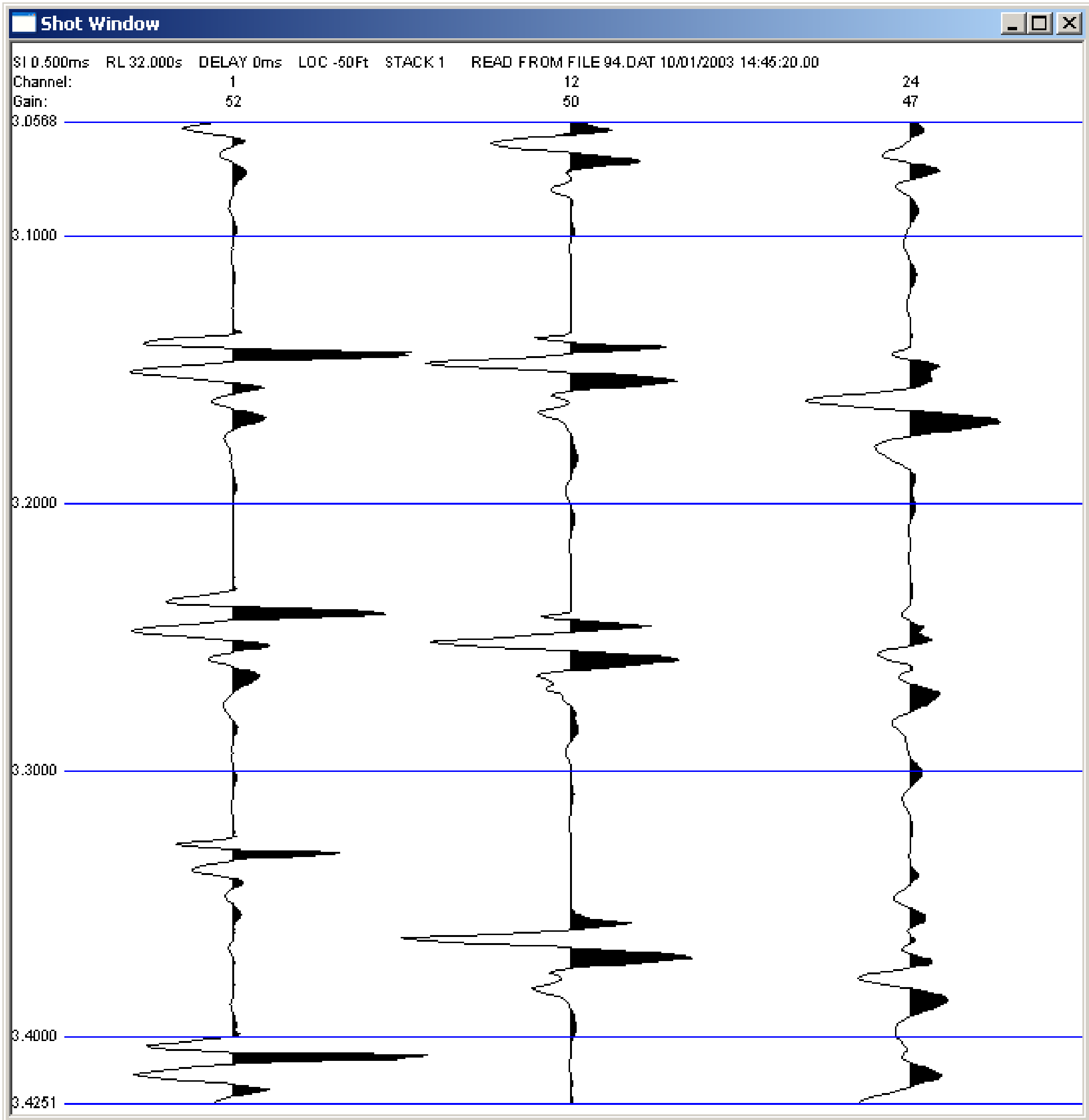
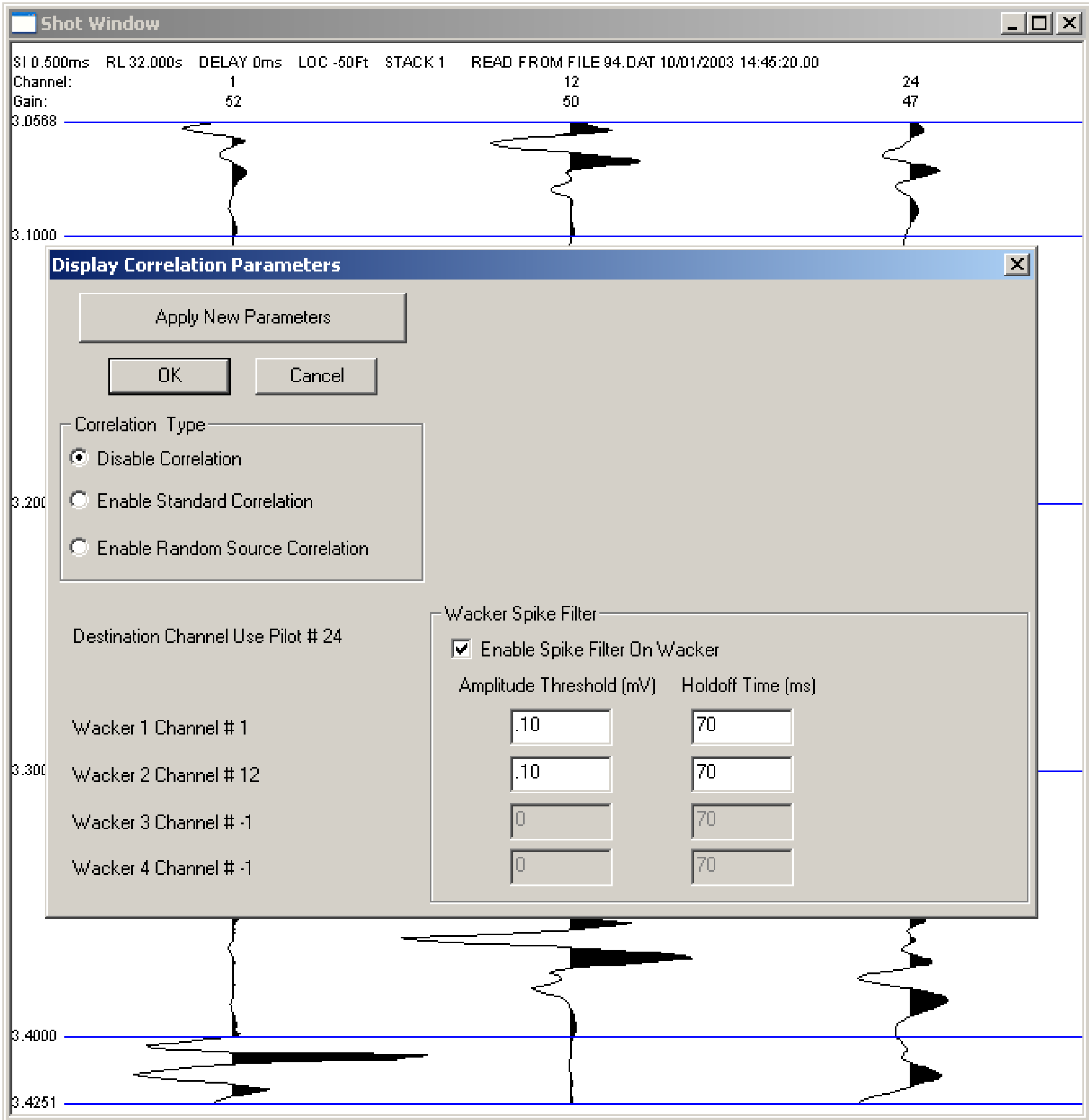


Figure 34. *Raw Wacker channels and resultant pilot channel.*

If we already know what we want our amplitude thresholds to be (which may be the case if we have lots of experience with these particular geophones and Wackers), we can simply open the **Acquisition Correlation** menu and type them in:



Pressing the **Apply New Parameters** or the **OK** button will spike the Wacker channels and sum them into the pilot channel.

The other option is to use the interactive approach. After scrolling through the Wacker traces and locating a few representative impact events, we can set the amplitude threshold graphically. Pointing the cursor at a trace will reveal the time and amplitude:

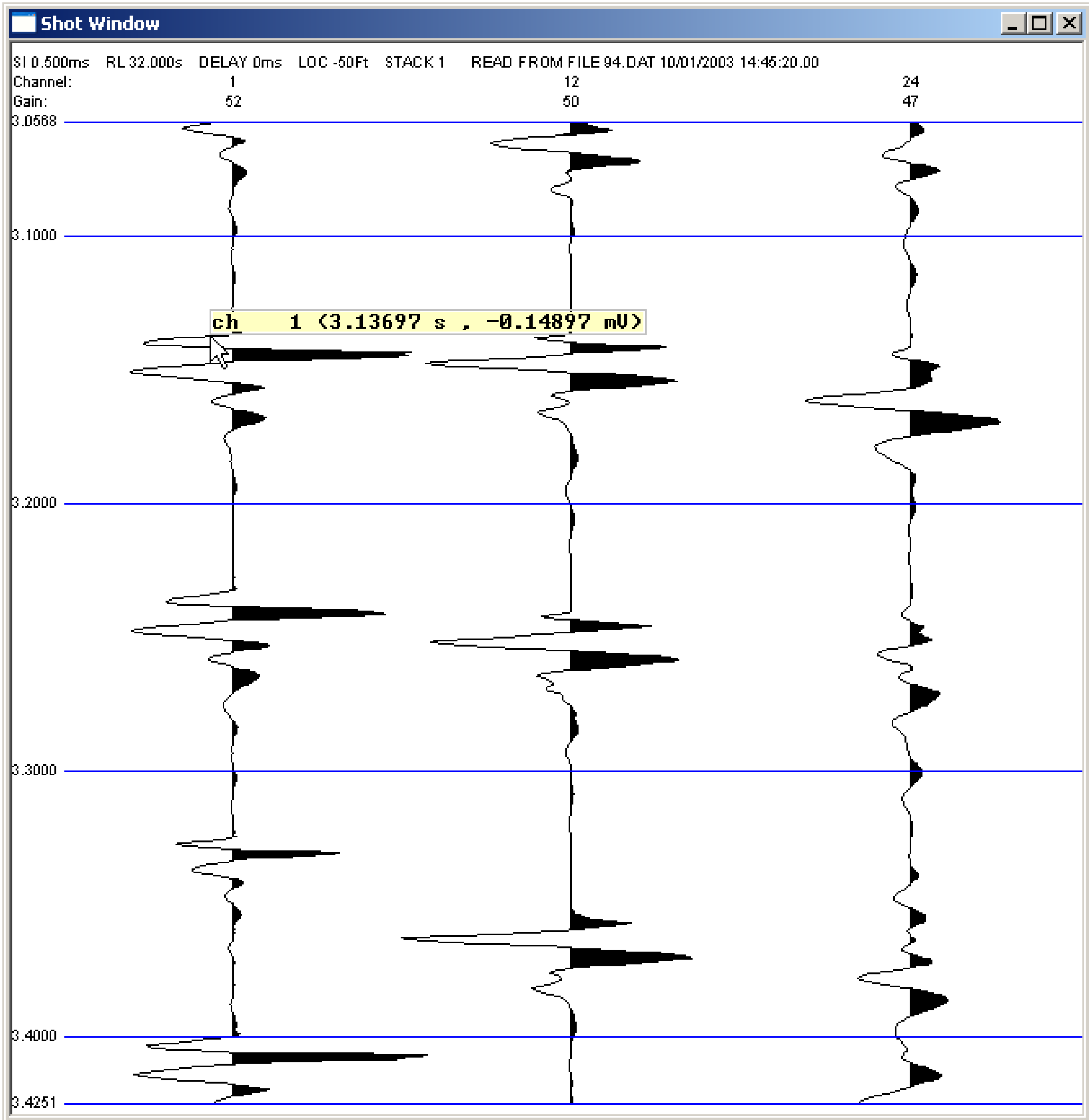
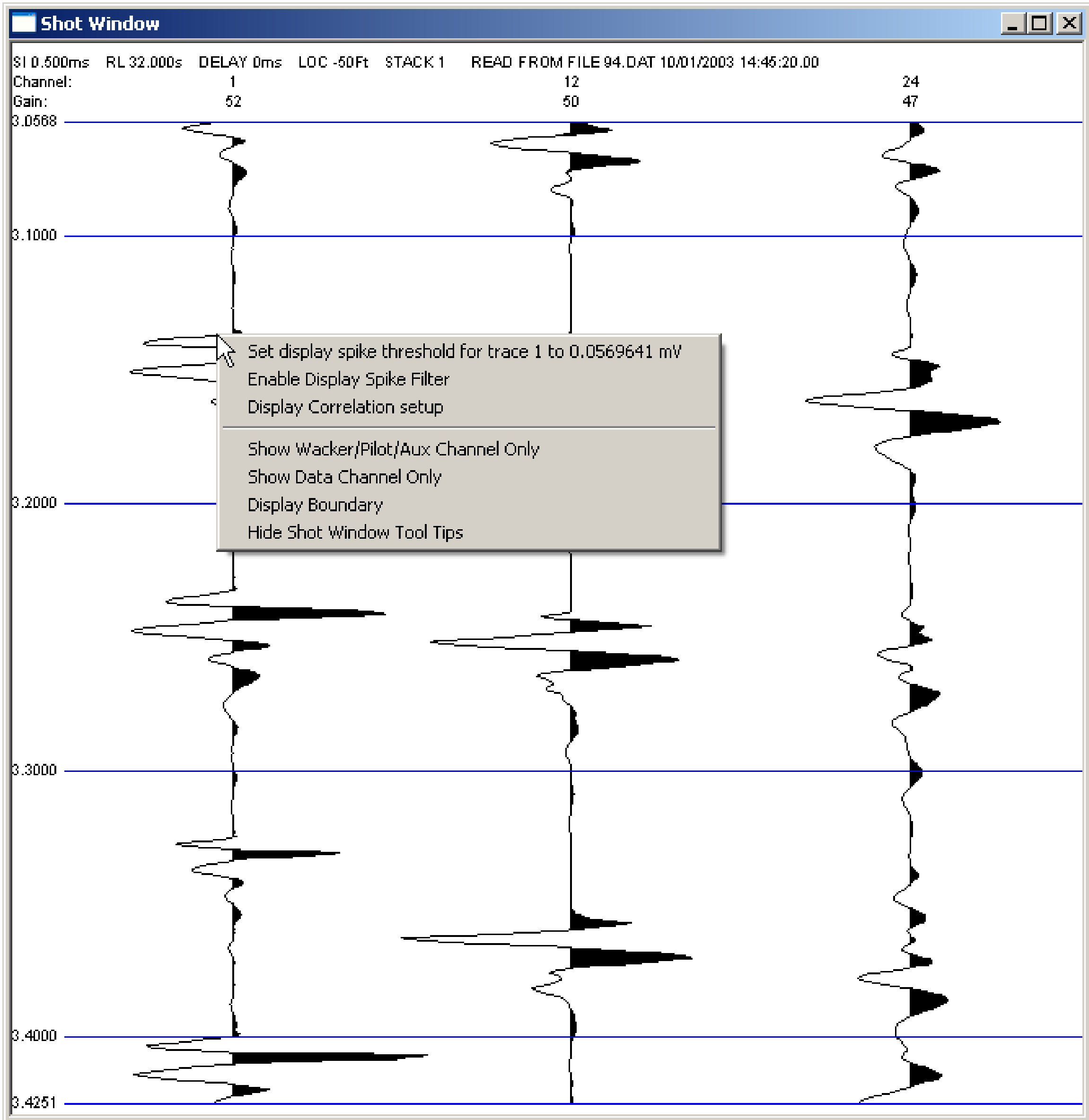


Figure 35. *Time and amplitude of cursor location.*

Note: *The time/amplitude display shown above can be disabled by right-clicking and choosing* ***Hide Shot Window Tool Tips****.*

If we point the cursor at the part of the event we wish the spike to be placed (generally the earliest onset), and then right click, we will see the following menu:



To set the amplitude threshold where the cursor is pointed, we click on **Set display spike threshold for trace 1 to x.xxxxxxxx mV**. We then repeat for all other Wacker channels (in this case, channel 12). After setting the amplitude thresholds on all Wacker channels, we right-click and chose **Enable Display Spike Filter**. The Wacker channels will be spiked according to your parameters, and summed into the pilot channel (in this case, channel 24):

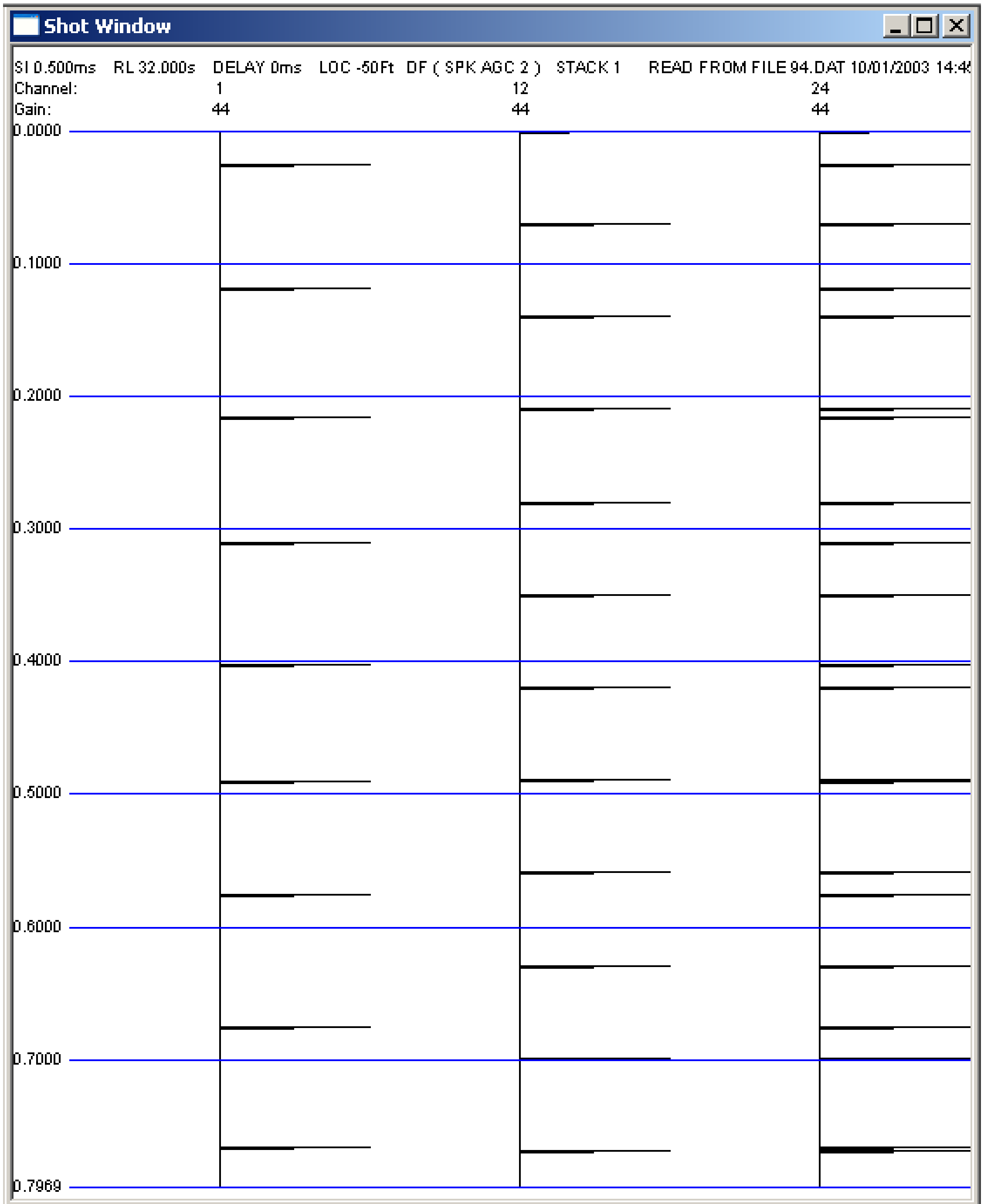


Figure 36. *Spiked Wacker channels (1 and 12) and resultant spiked pilot (24).*

If necessary, we can scroll through the data and toggle back and forth between spiked and unspiked data to satisfy ourselves that our spiking parameters are acceptable. We want to make sure that our threshold was not too high so as to miss spiking some events. The time between events, while “random”, should not vary so much as to leave large gaps (although it is perfectly acceptable to stop a Wacker for a second or two during a sweep to increase the randomness). Compressing the time scale is useful in locating gaps in the spiked Wacker channels that may be due to setting the amplitude threshold too high:

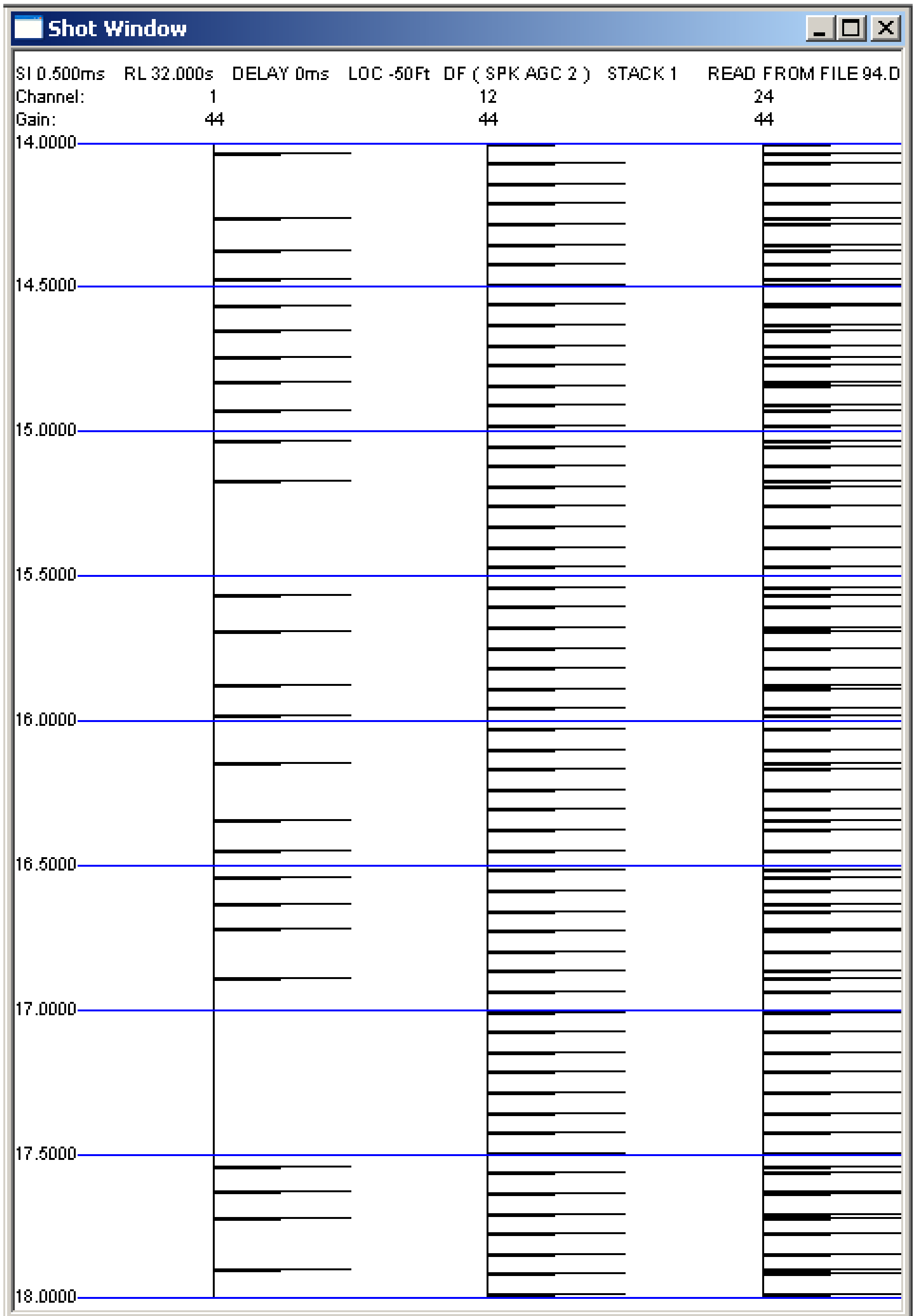


Figure 37. *Spiked Wacker channels and resultant spiked pilot. Scale compressed to reveal gaps that might result from setting the amplitude threshold too high.*

Note the apparent gaps in spikes on channel 1. Is this the result of setting the amplitude threshold too high, or is this a real gap in the impacts? We can find out by simply disabling spiking. We right click and choose **Disable Display Spike Filter**. The spiked and unspiked versions are shown below.

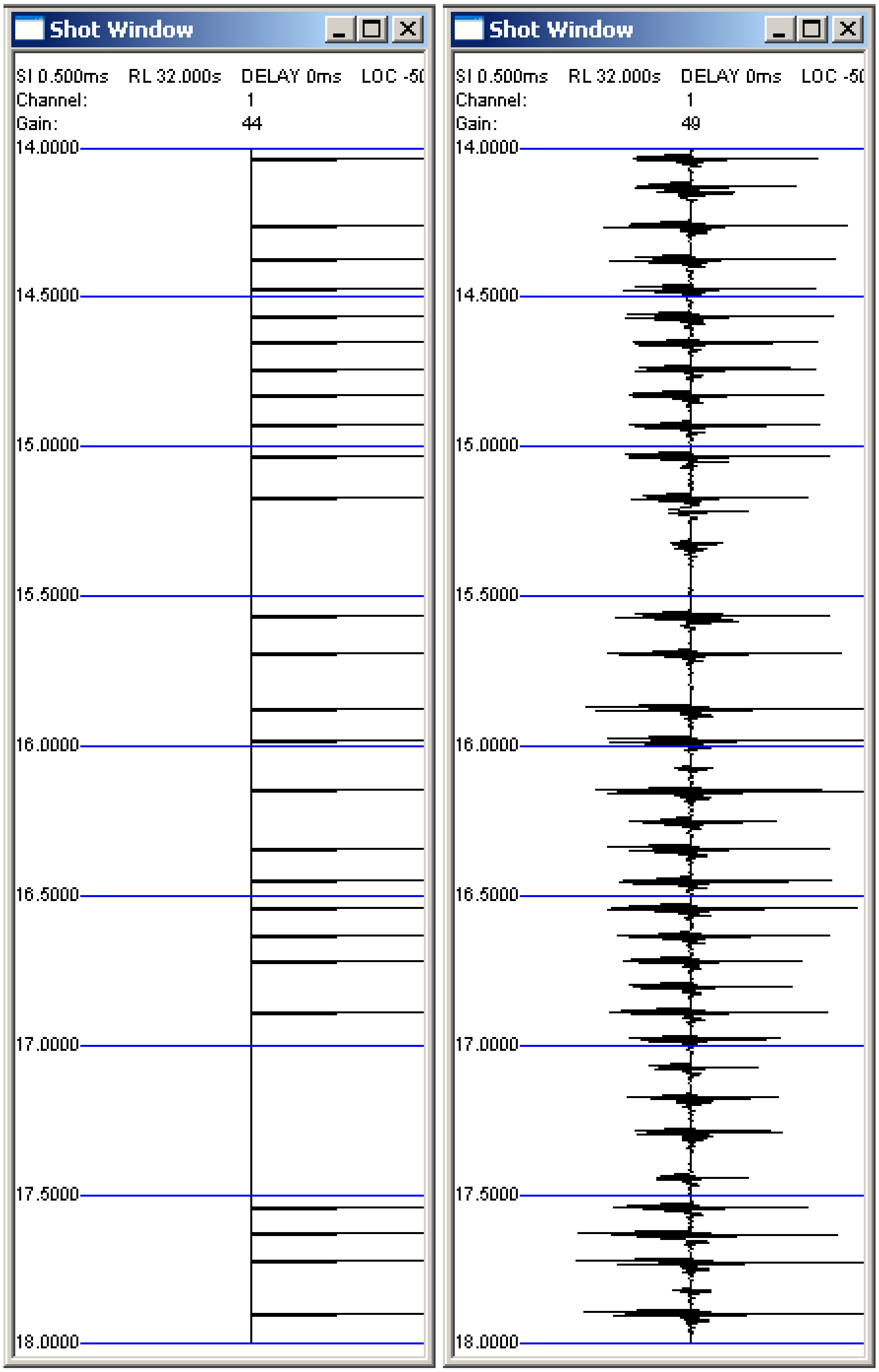


Figure 38. *Spiked and unspiked versions of Wacker channel 1.*

Comparing the two, it appears that the amplitude threshold was too high to spike some the events. By repeating the above step, this time pointing our cursor at a lower amplitude, we can fine-tune the amplitude threshold:

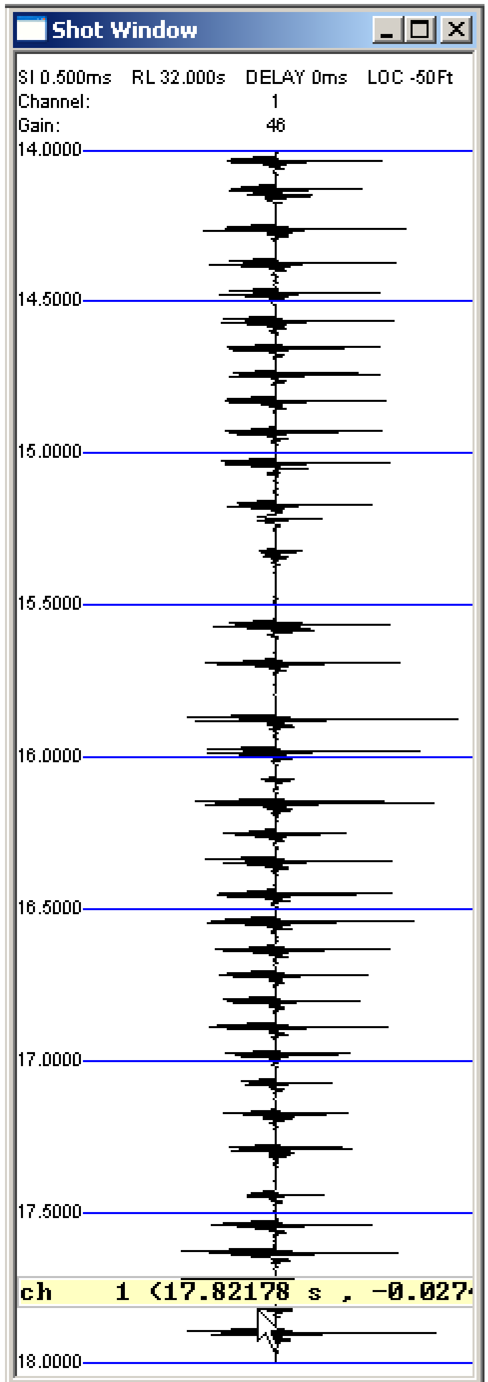


Figure 39. *Fine-tuning the amplitude threshold to include smaller events.*

Lowering the threshold to –0.27 mV (only the absolute value is used) eliminates the gaps:

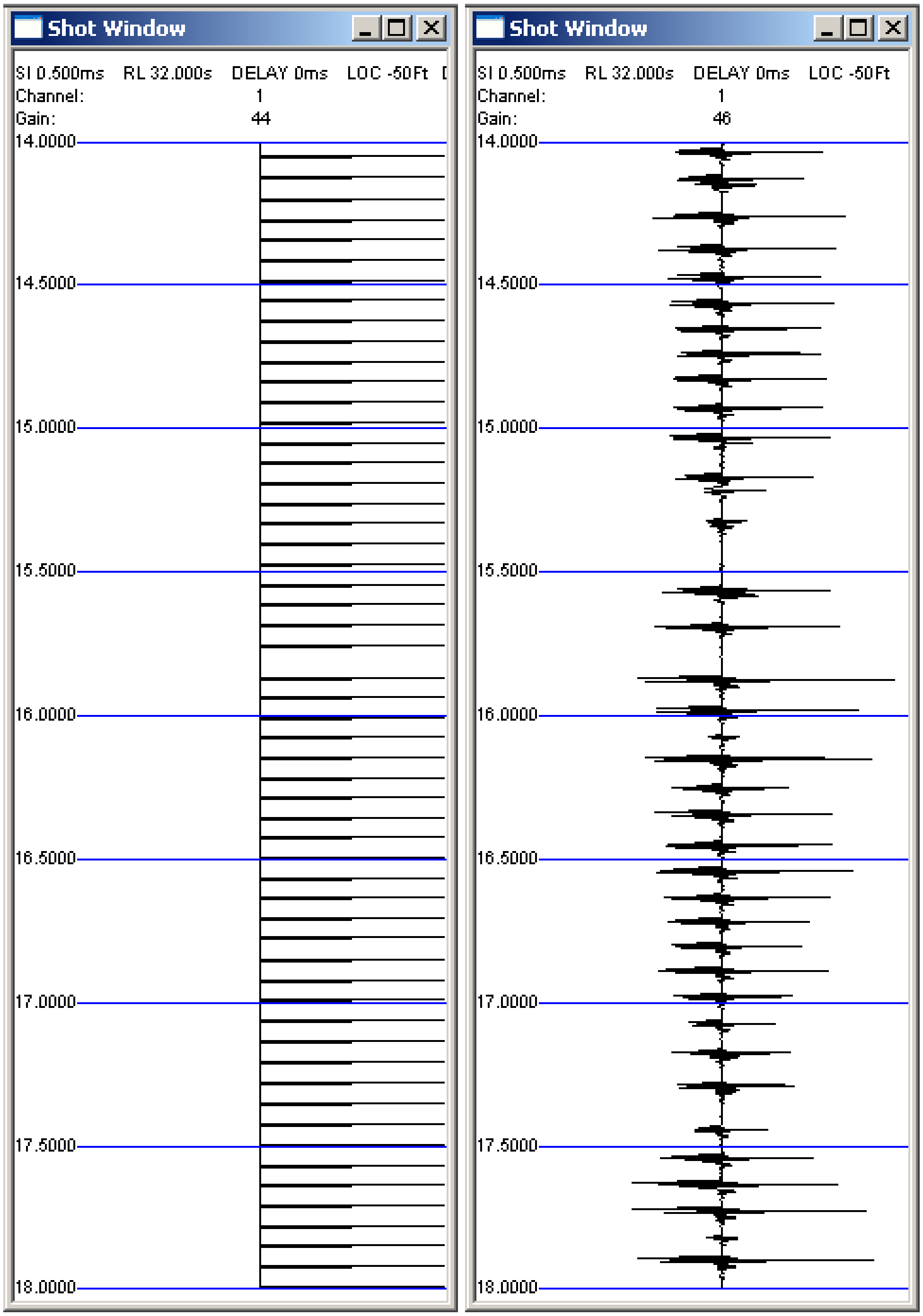


Figure 40. *New spiked Wacker channel with lower amplitude threshold.*

Note: *The amplitude threshold is indifferent to polarity – only absolute values are considered. For instance, setting a threshold of –0.2 is the same as setting a threshold of +0.2. Any event outside of the hold-off time having an absolute value greater than 0.2 will be spiked. Remember, the spiked pilot is nothing more than a time-series indicating the timing of events.*

Once we are satisfied that all or the vast majority of impacts are being spiked, we can correlate the data. Right-clicking on the shot window, we choose **Show Data Channels Only**:

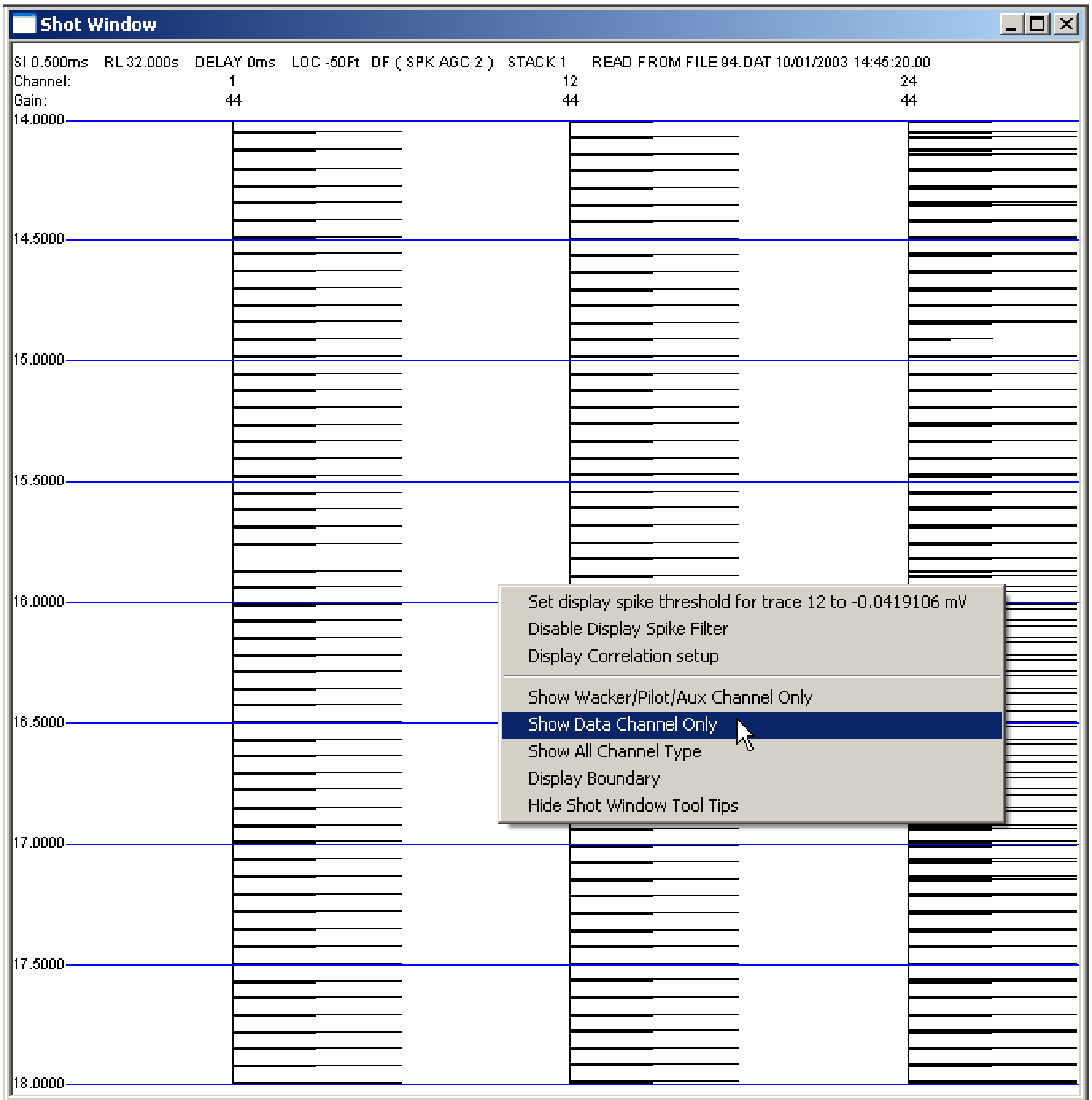


Figure 41. *Toggling from Wacker/pilot channels to data channels.*

Right-clicking again and choosing **Display Correlation Setup** brings up the **Display Correlation** menu:

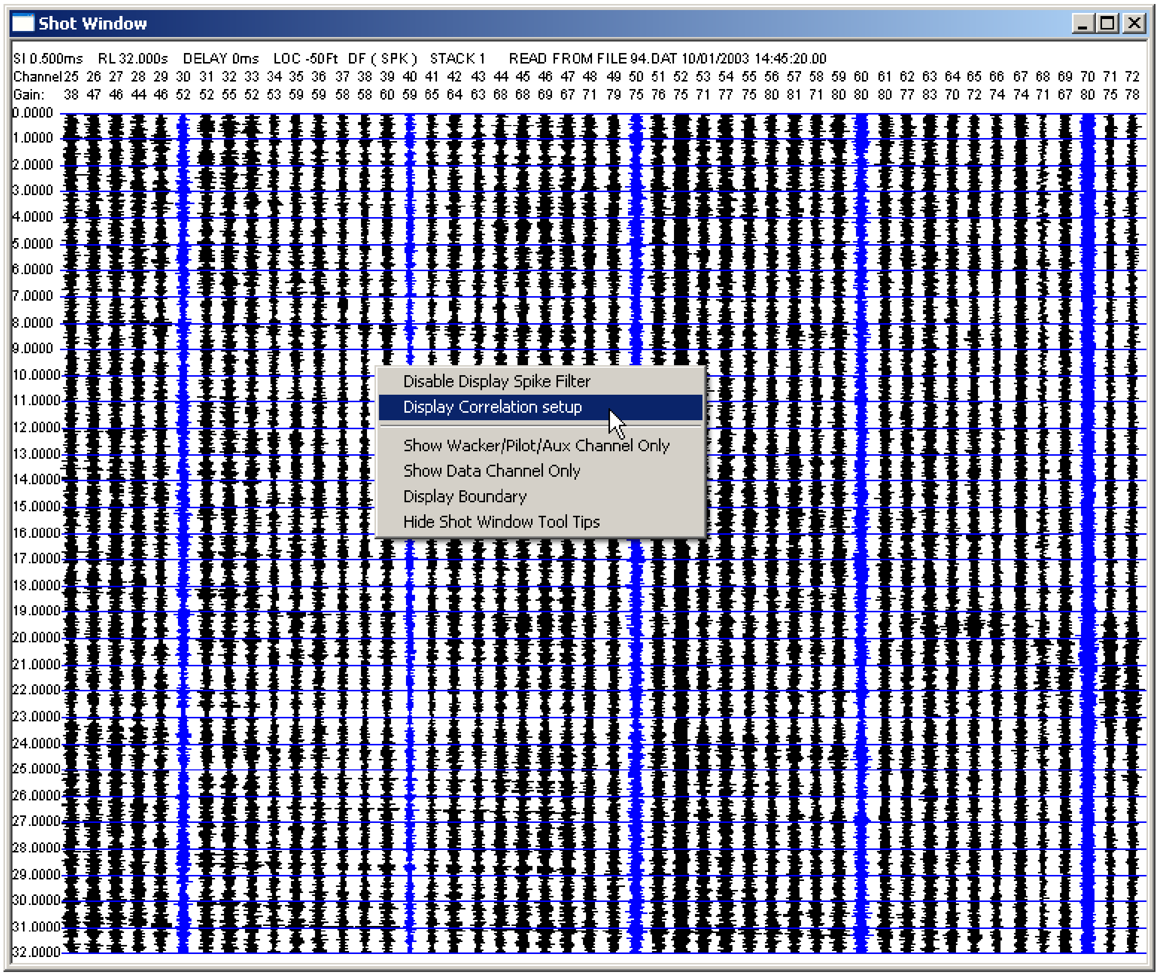
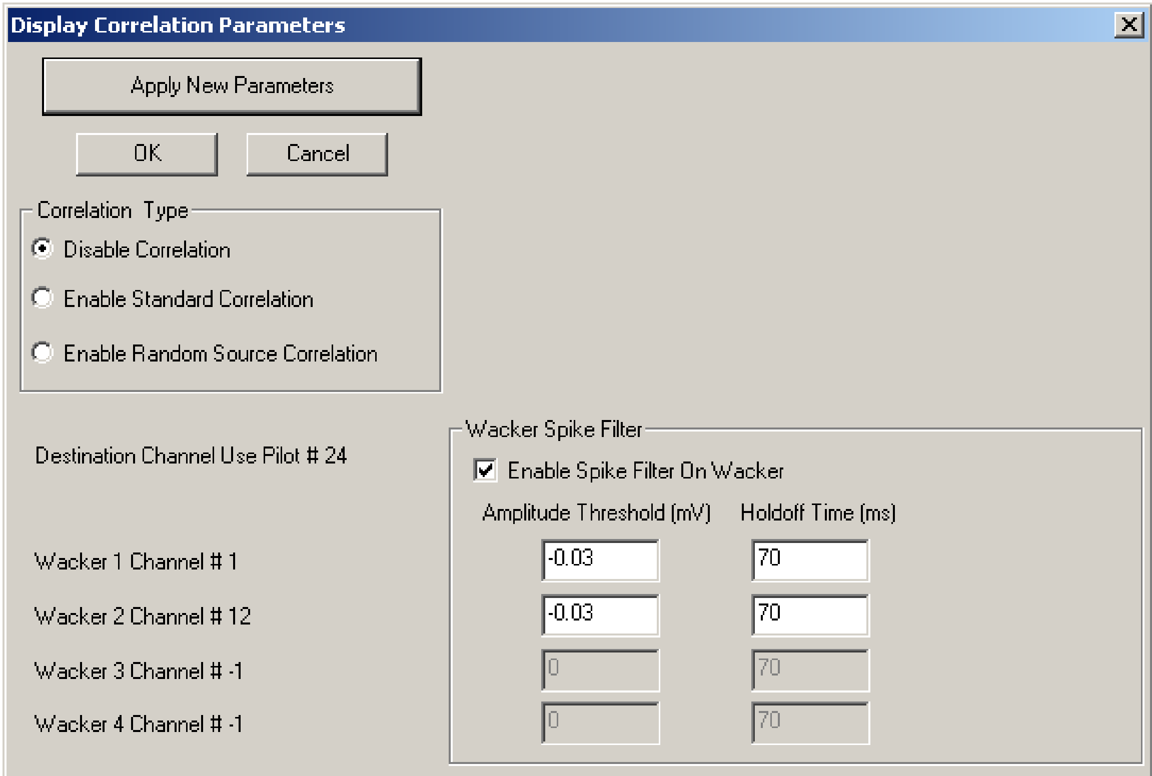
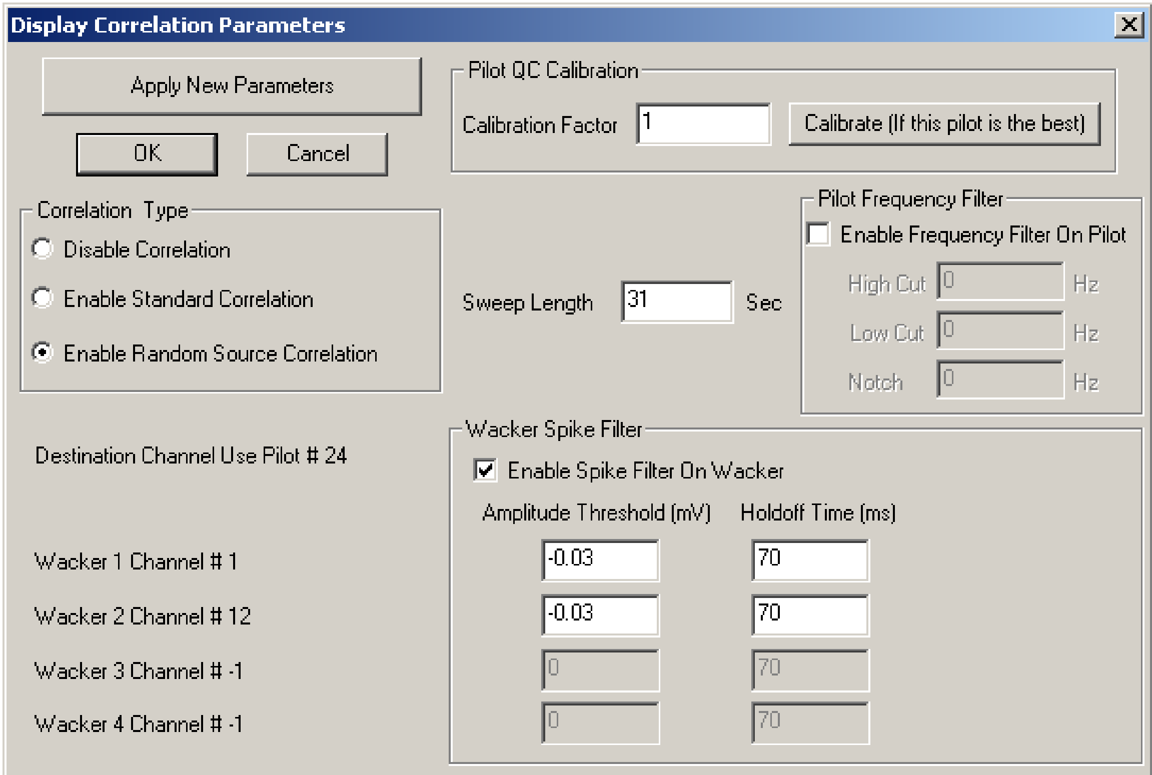


Figure 42. *Raw, uncorrelated shot record, 32 sec @ 1/2 msec.*



.

Clicking the **Enable Random-Source Correlation** radio button displays the correlation parameters dialog box:



As before, we set the **Sweep Length** to 31 seconds, and press **OK**:

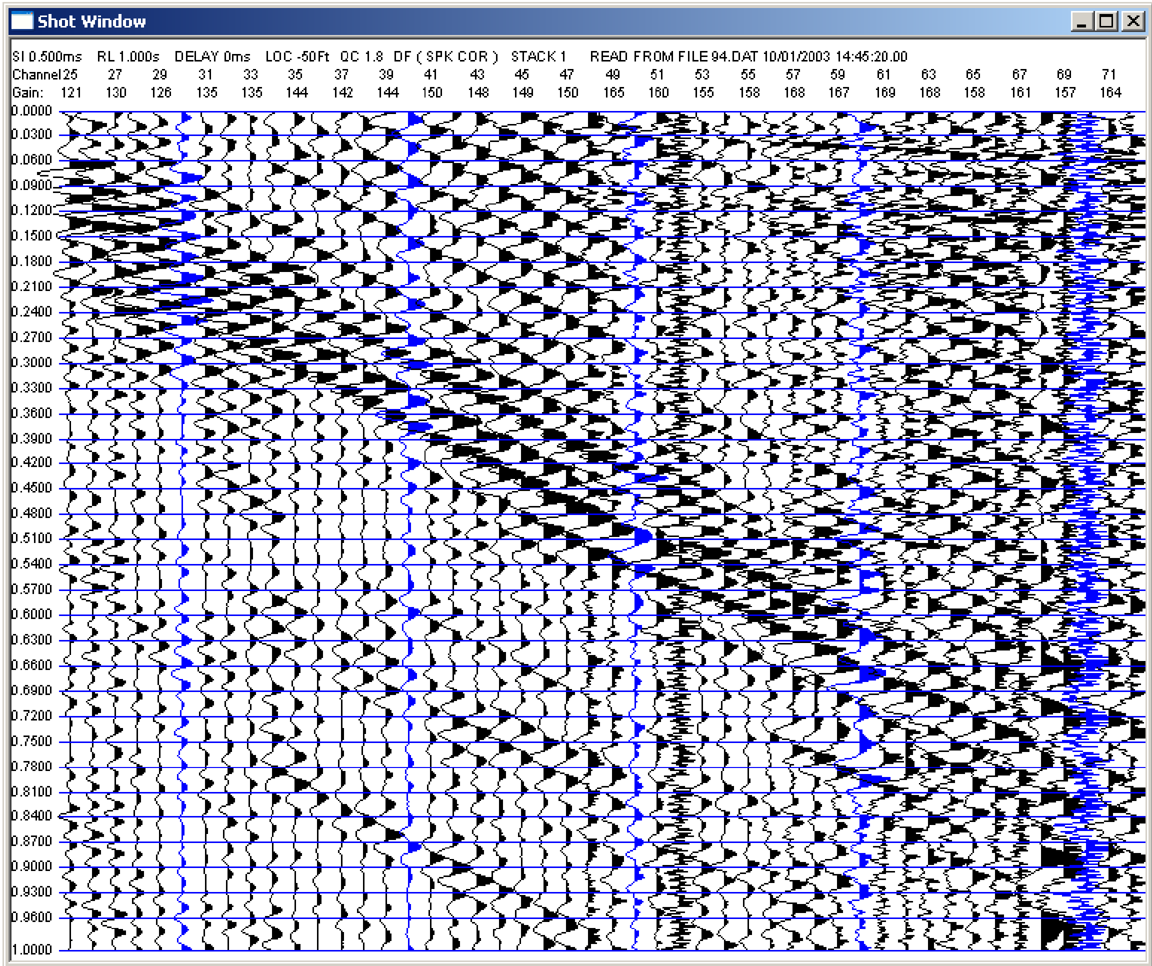


Figure 43. *Correlated data (compare to Figure 24).*

We have now correlated our data using a spiked version of the pilot. If we wish to use these parameters, we can press the **Copy Settings From Display Correlation** button in the **Acquisition**>*Correlation* submenu, and we are ready to conduct our survey.

The first thing to notice is the marked difference between data correlated with an unspiked raw pilot (Figure 24) and that correlated with a spiked pilot (Figure 40). The answer is found in the natural filtering effect of using a raw, band-limited geophone output in the former. This is best illustrated by a more direct comparison.

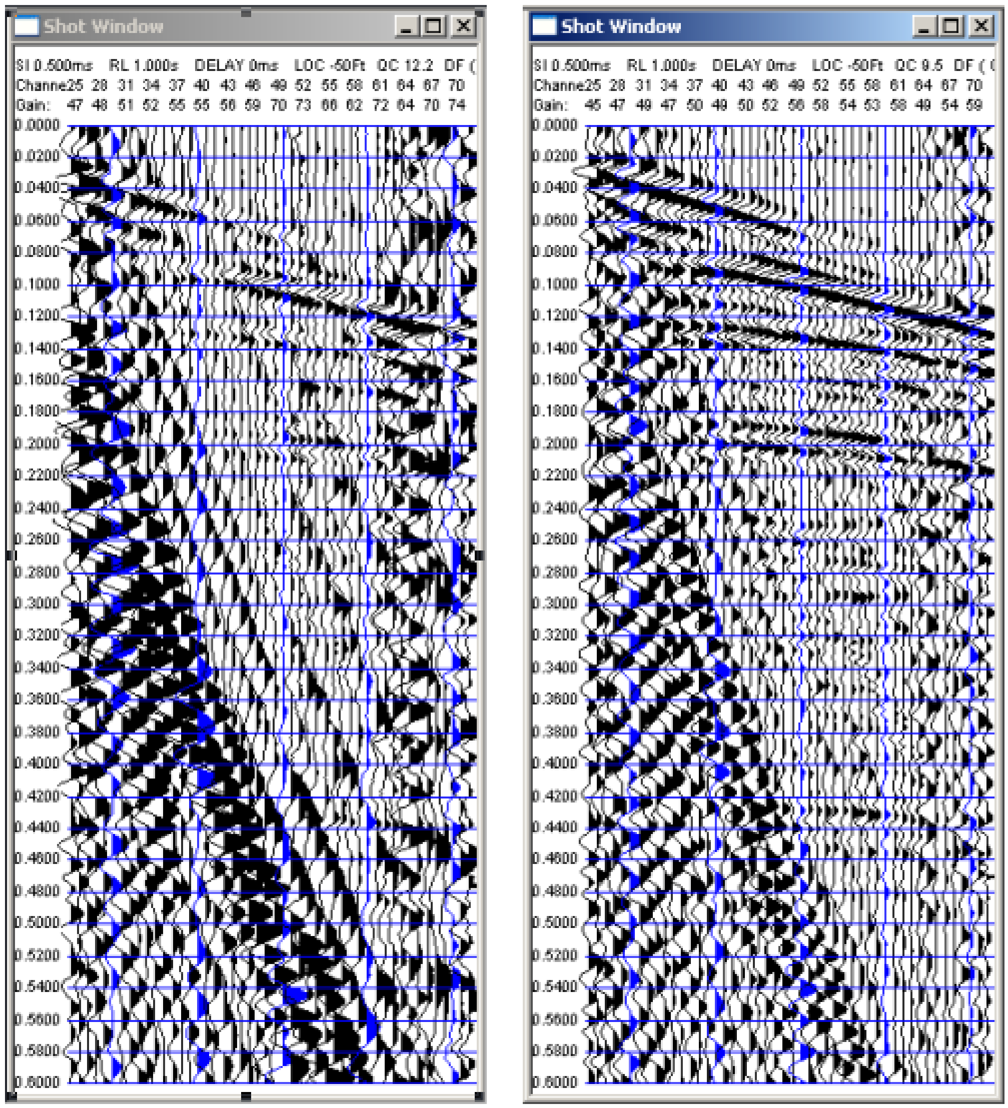


Figure 44. *Spiked pilot (left) vs. unspiked (right). AGC enabled, no filtering applied.*

The two shot records shown above are of the same data. A single Wacker and Wacker channel were used. The pilot for the record on the left was spiked before correlation, while that on the right was not. The data on the left are broader band – the range of frequencies is greater. This is because each event on the pilot is a delta function of infinite frequency. Correlation against a spiked pilot tends to "correlate in" all frequencies present in the raw shot record. By contrast, the bandwidth of the 40-Hz geophone is approximately 40-250-Hz, and correlating against this band-limited pilot results in a final record having frequencies roughly limited to this range.

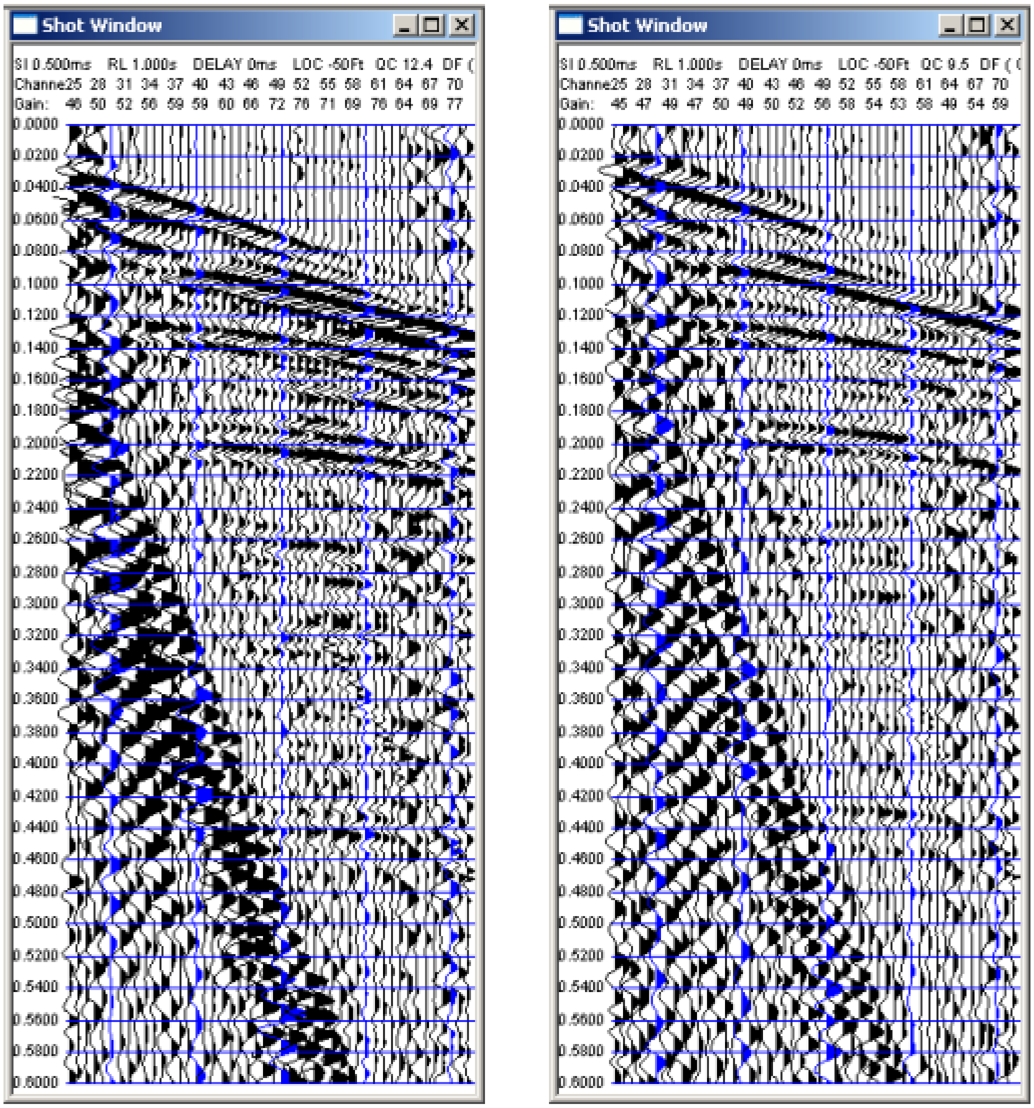


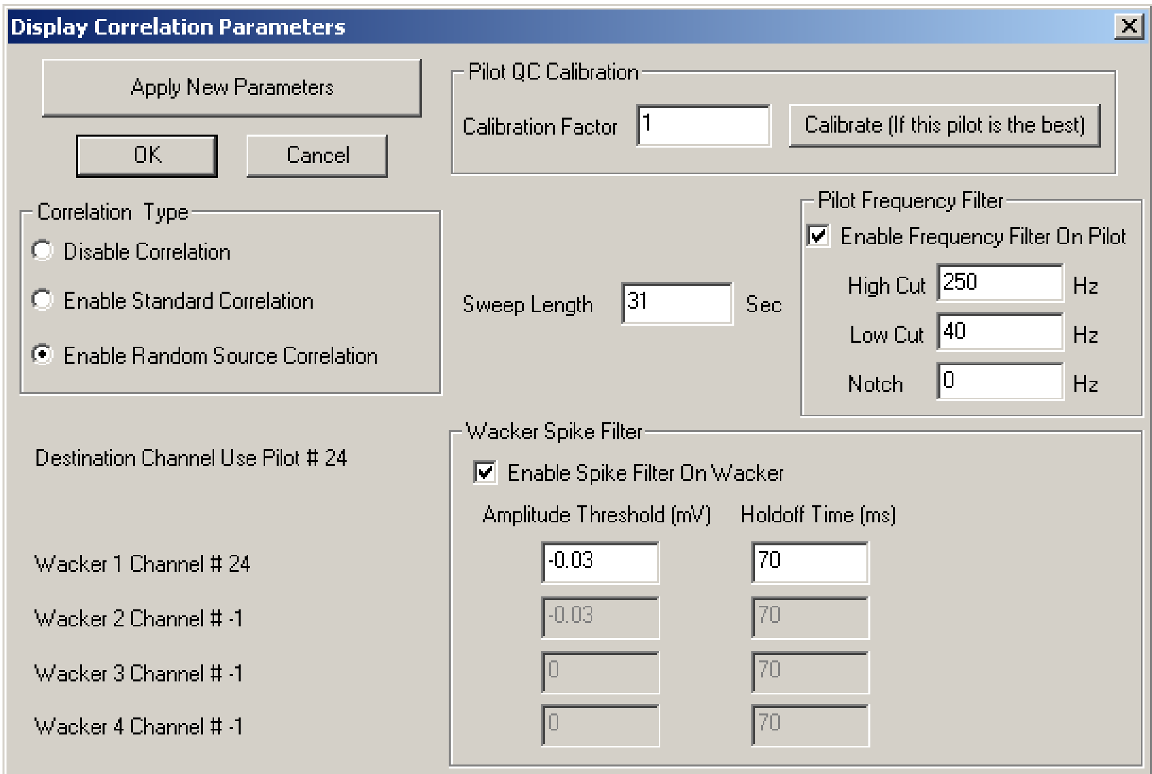
Figure 45. *Same data as shown if Figure 43, but with a 40-250Hz band pass filter applied to the record correlated with spiked pilot (left).*

In Figure 44 above, the data correlated against the spiked pilot (left) have been filtered with a 40-250-Hz band pass filter, the approximate bandwidth of the 40-Hz geophone used as the Wacker geophone. No filters have been applied to the record correlated against the unspiked pilot (right). Both records now have similar frequency content and look much more like each other than before.

One difference between the records is the +10 msec shift in events in the spiked-pilot record. This will be discussed in the section entitled Spiked vs. Raw Pilot (coming in next edition of this manual).

Filtering the Pilot

In the above comparison, we in effect compared the difference between filtering the pilot *before* correlation (the filter being the geophone) and digitally filtering the resultant data *after* correlation. Some argue that it is better to filter a spiked pilot before correlation. Without getting into the argument itself, suffice to say that you can operate this way if you prefer to. In the **Display Correlation Parameters** menu, check the **Pilot Frequency Filter** checkbox and set the filters as desired:



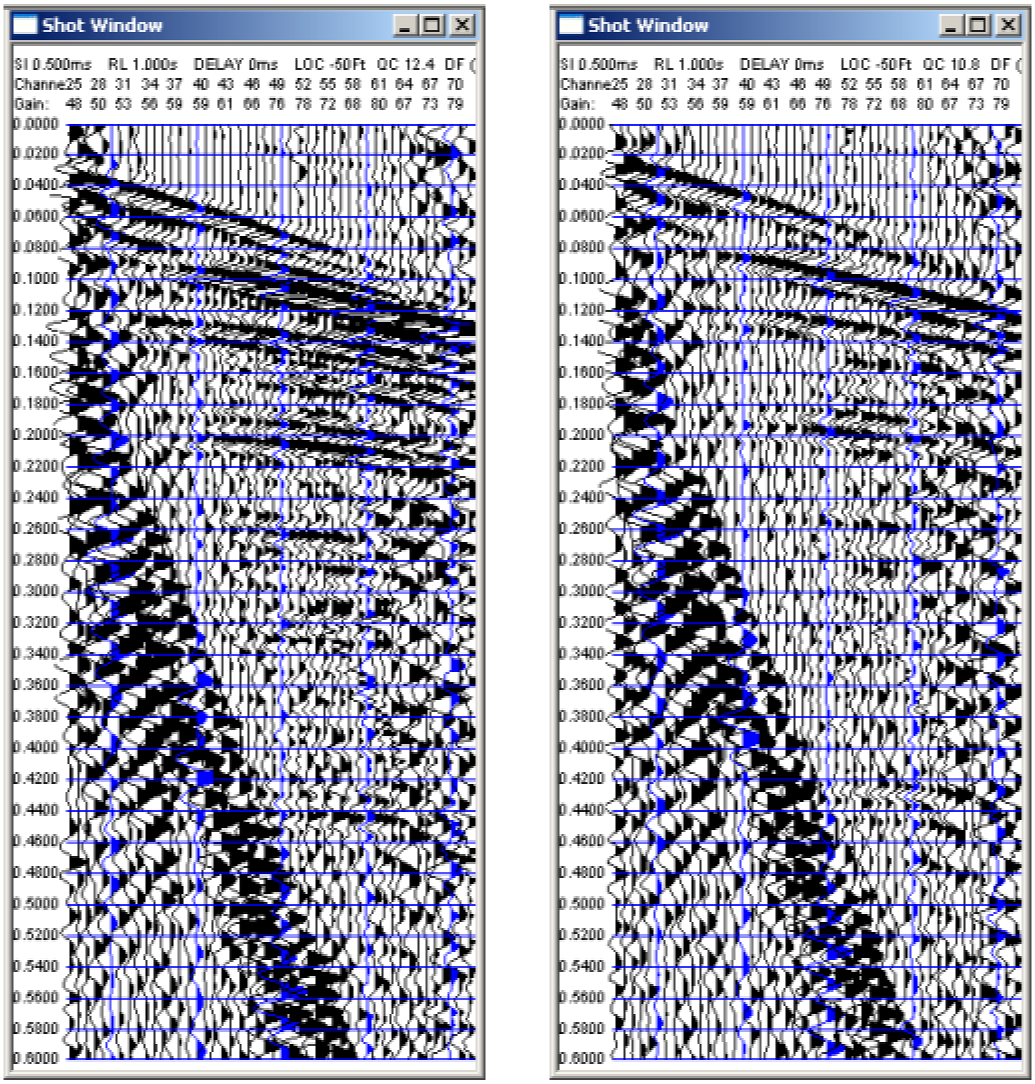


Figure 46. *Data correlated with spiked pilot and filtered after correlation (left) vs. spiked pilot filtered prior to correlation (right). Filter was 40-250-Hz band pass in both cases.*

Figure 45 compares the results of the two methods. The pilots of both records were spiked. The record on the left was correlated with the spiked pilot, and then the correlated data were filtered with a 40-250-Hz band pass filter. In the record on the right, the spiked pilot was filtered with a 40-250-Hz band pass filter, and then correlated with the data -- no filters were applied after correlation.

Note: *In general, when using a spiked pilot, our experience has been that it is best to correlate against the spiked pilot and then filter the resultant data. In other words, do not filter the pilot. Not only does this seem to yield the best-looking shot records, but it is also safer – once you have correlated the data, you can not go back.*

Pilot Window

Once you copy all of your parameters to the acquisition window and begin acquiring correlated data, the correlated pilot trace (autocorrelation trace) will be displayed in the Pilot window, as shown below.

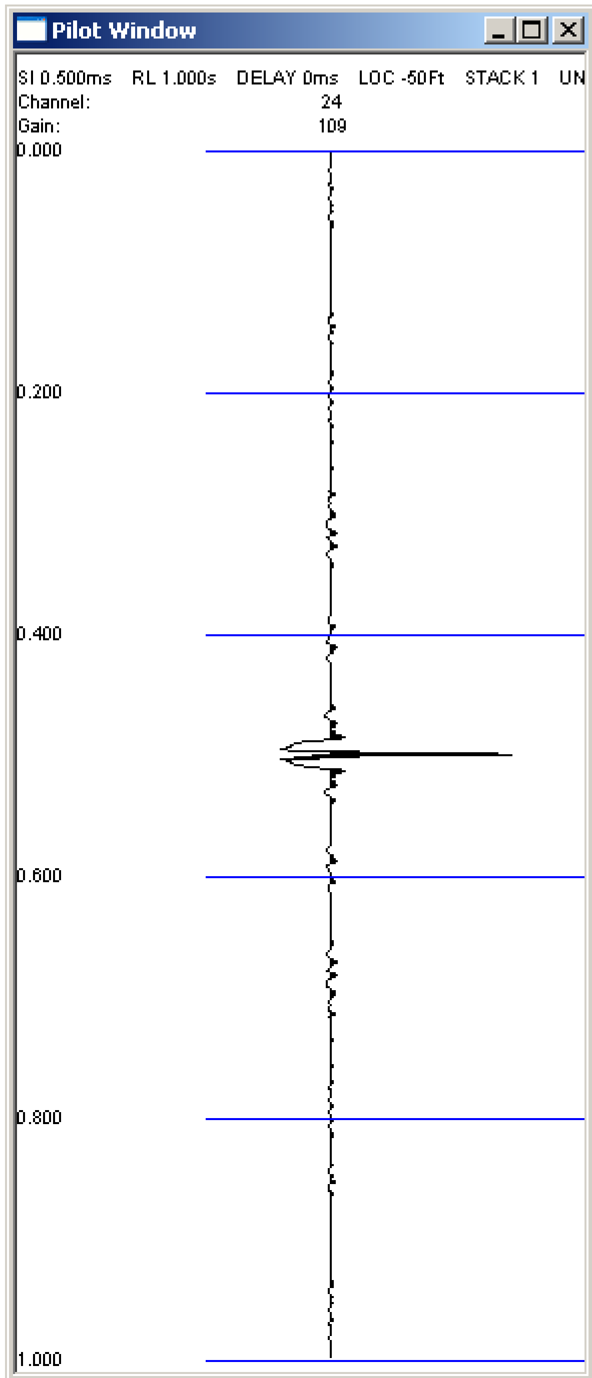
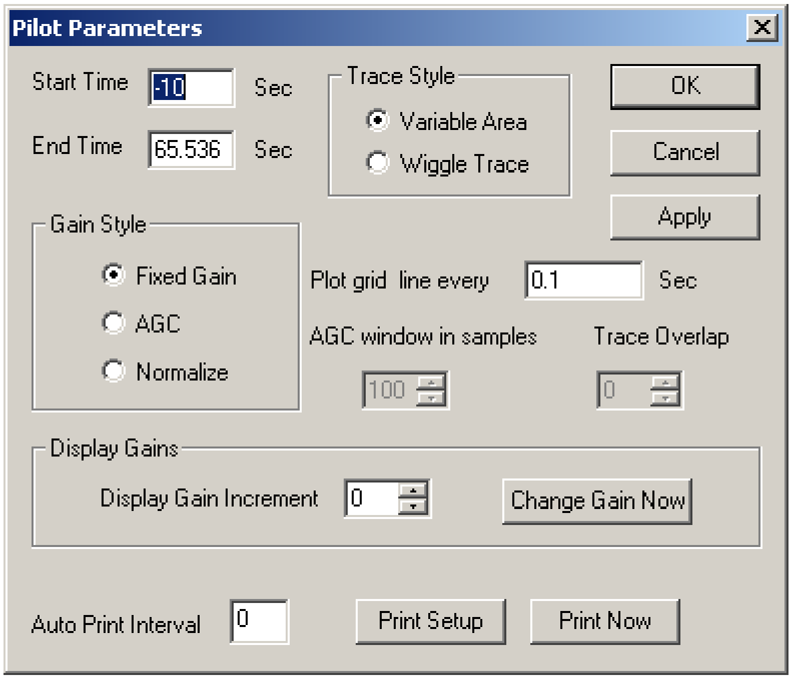


Figure 47. *Pilot Window showing autocorrelation trace.*

You can control the display parameters of the Pilot Window from the **Pilot Parameters** menu:



Note: *It is generally advisable to display the correlated pilot in **Fixed Gain** mode. Display filters, if enabled, are not applied to the autocorrelation trace.*

The Pilot Window, along with the randomness coefficient, is useful for monitoring pilot quality, and should always be displayed in a swept-source survey.

Conducting a CDP Survey – Rolling the Spread

Thus far, we have discussed how to get to the point where you are ready to acquire and save a correlated record. But in order to actually do a reflection survey, you must also set up the rolling parameters. This is discussed in detail in the main Seismic Control Software manual (it is recommended that you read the main manual first). However, when in Random-Source mode, there are some additional parameters and functions to be aware of.

The Geometrics Random-Source package is designed to allow you to use, in conjunction with the Pilot Processing Module, the geophone that is present at the current shot location. By using the regular data geophones already in the ground, as opposed to a dedicated sensor mounted on the Wacker itself, we avoid the problem of transmitting the pilot signal via long cables or radio.

Briefly reviewing, CDP surveys are predicated on having more geophones than live channels. This allows you to "roll" through the spread, moving the shot and associated live geophone spread in lock-step. In older systems, this was accomplished through a mechanical roll switch. Although the StrataVisor NZ/Geode can be used with a roll switch, it is much better, especially with the Geode, to roll electronically by turning on and off the appropriate channels. In the case of random-source surveying, you use the geophone at the current source location as your Wacker geophone. The source, and hence the Wacker0 geophone, moves with each shot. So not only must you roll the live portion of the spread, you must also roll the pilot channel. Unlike typical swept-source surveys, the pilot channel is not static. This is the point of departure between a random-source survey and a typical vibrator survey. This is best illustrated by example (for more in-depth discussion of rolling with the SCS software, see the main User's Manual).

Note: *The following discussion on rolling is best viewed on a PC at 200% zoom.*

Let's say we want to conduct a 6-fold reflection survey with a 48-channel Geode system. Assuming we intend to shoot at every geophone station, we must have 12 live channels for each shot. Further assume that our geophone spacing is 5 meters, and that the first geophone is at zero meters in our local coordinate system. After doing our walk away tests, we determine that the optimum shot offset is 40 meters or 8 stations. Normally, we would activate channels 1-12 (stations 0-55) and put the shot at –40 meters. This is illustrated in the figure below (active channels shown in green).

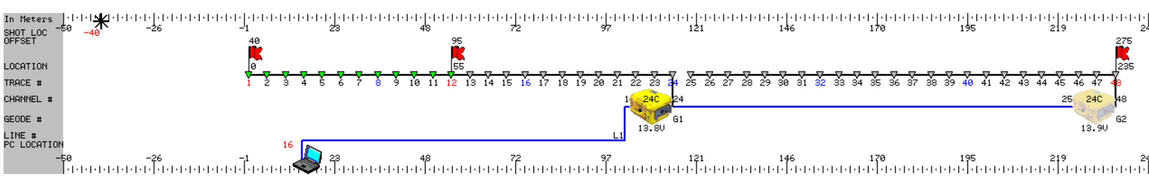


Figure 48. *Typical "first shot" CDP layout. Active channels 1-12, shown in green.*

However, unlike a normal vibrator survey, the Wacker geophone is not attached to the source – we take advantage of the geophones already in the ground. The tradeoff is that we must start with the source at the location of the first geophone (channel 1). To achieve our 40 meters of shot offset, we must disable the first eight channels. Now the shot is at zero meters (channel 1), and the first *active* channel is at 40 meters (channel 9). Next, via the **Acquisition**>*Correlation menu*, we designate channel 1 as the Wacker channel (shown in dark gray). This is illustrated in the figure below.

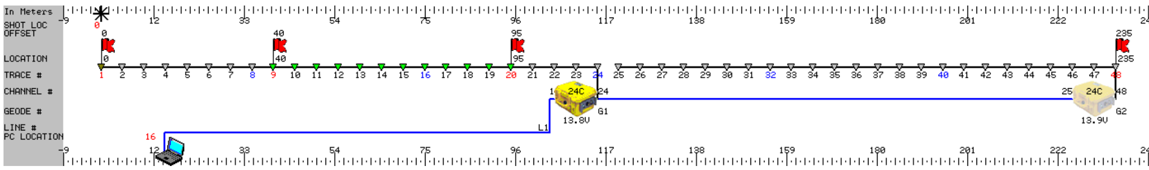
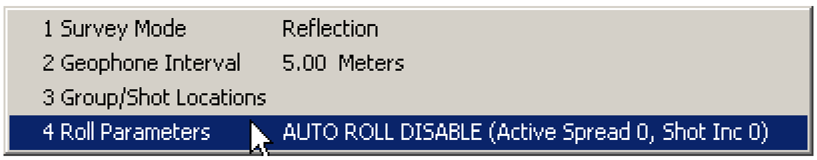
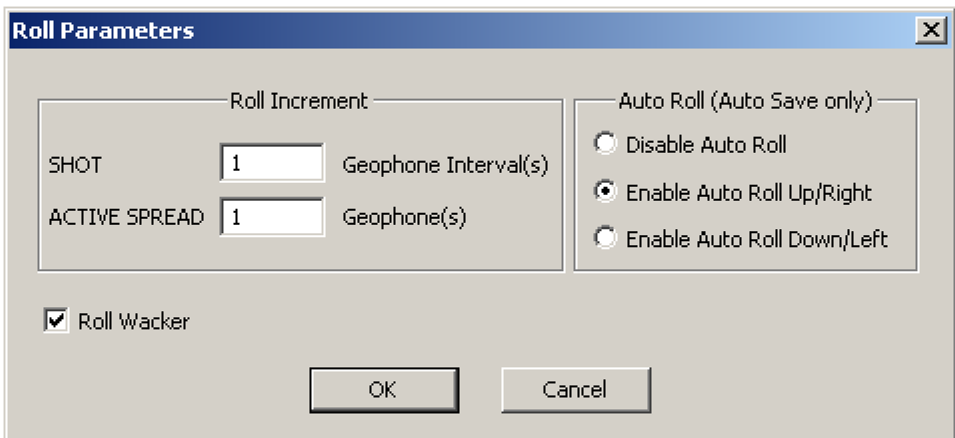


Figure 49. *"First-shot" CDP layout with source at first geophone station. Active channels 9-20, shown in green. Wacker channel 1, shown in dark grey.*

After taking our first record, we will need to roll, either manually or automatically upon saving the data. To set up the rolling parameters, we click on **Geometry**>*Roll Parameters*:





We want both the shot and active spread to move 1 station (1 geophone interval, or 5 meters). In addition, *we want the source to roll as well.* We must check the **Roll Wacker** checkbox. This will increment the Wacker channel number(s), so that the source geophone always moves with the Wacker. Rolling one station moves the shot location to channel 2 (at 5 meters), disables channel 1 and enables channel 2 as the new Wacker channel, disables channel 9, and enables channel 21. Now our active spread is from channel 10 to channel 21 (from channel 9-20). This is shown in below.

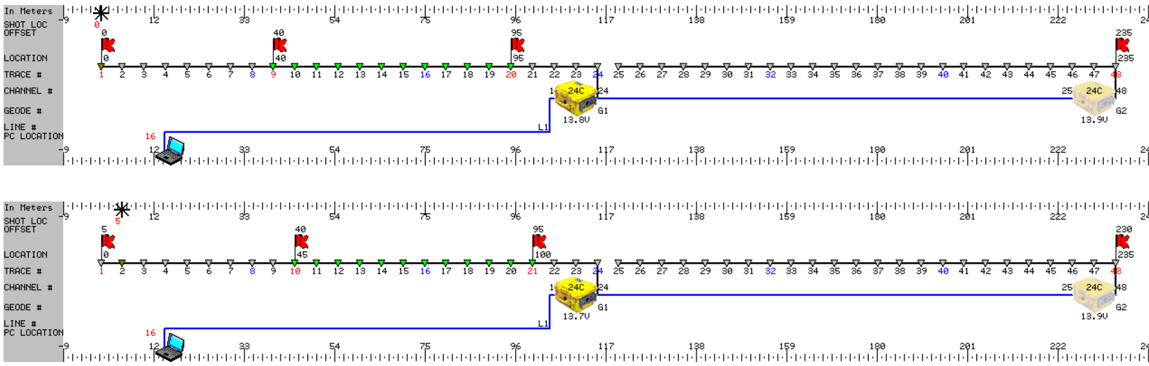


Figure 50. *Second shot. Shot at 5 meters, Wacker channel 2, active channels 10-21 (Figure 48 included [top] for comparison).*

Surveying is continued in this manner like any other CDP survey until it is necessary to move cable.

The above applies regardless of the number of Wacker channels/Wackers. In the case of multiple Wacker channels, the shot location should be set in the middle of the source array. For instance, with four Wackers, your geometry plot might look like the following:

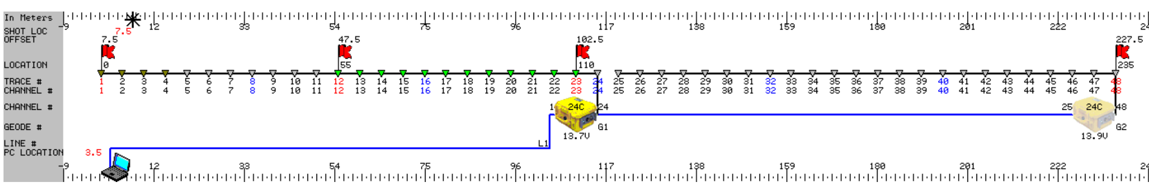


Figure 51. *"First-shot" CDP layout with sources at first* ***four*** *geophone stations. Active channels 12-23, shown in green. Wacker channels 1,2, 3 and 4, shown in dark gray. Shot location is 7.5 meters, half-way between channels 2 and 3.*

The shot is located in the middle of the source array. After rolling one station, your geometry would look like the bottom layout below:

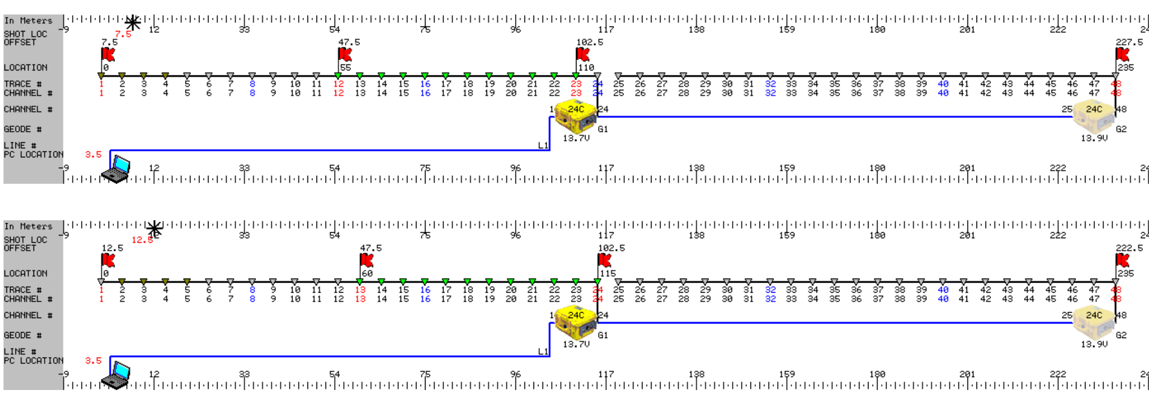


Figure 52. *Second shot. Shot at 12.5 meters, Wacker channels 2, 3, 4, and 5, active channels 13-24 (Figure 50 included [top] for comparison).*

Real-time Noise Suppression

When conducting non-impulsive surveys, which entail introducing the energy into the ground over a relatively long period of time, it is generally futile to try to time your shots with quiet periods if you are working in a non-rural environment. The longer the sweep+listen time, the more difficult this is. Random-source surveys, with their long (30+ seconds) sweeps, make it nearly impossible. While it might be quiet at the beginning of a sweep, anyone who has done seismic surveys in non-rural environments knows that 30-60 seconds is an eternity – something *will* happen to inject noise into your record.

In addition, unlike in an impulsive survey, it is usually impractical to ask for "quiet on the line" while actively recording in non-impulsive surveys, since recording is almost continuous. Not only does each sweep last a long time, but multiple sweeps (stacks) are often taken at each shot point. Nobody would get anything done. The survey crew needs to be able to flip cable and geophones and conduct other routine work while data is being acquired.

For the reasons stated above, non-impulsive surveys often employ real-time noise-suppression to edit out noise prior to stacking and correlation. This is often known as "diversity" stacking. Most diversity stacking algorithms analyze individual traces for noise (based on user-set criteria) and then scale them accordingly prior to stacking and correlation. A noisy trace will be scaled down or eliminated completely so as to contribute less to the overall stack. It is essentially a weighting system, with noisy traces being weighted less than non-noisy traces.

To put this in less abstract terms, if an ATV goes past channels 33, 34, and 35 during a sweep, those three traces will be scaled down or zeroed out prior to stacking and correlation. Presumably, the ATV will have moved on to other channels by the time the next stack commences, so the next stack and subsequent stacks will have a full contribution from channels 33-35, while channels further down the spread will be suppressed similarly. This allows activity on the line during acquisition without producing unacceptable degradation of the overall signal-to-noise ratio.

For random-source surveys, Geometrics has developed a proprietary real-time noise suppression algorithm that works somewhat differently than traditional diversity stack routines. Because random-source surveys generally have longer sweeps than traditional vibrator surveys, the length of the noise event (say, from a passing vehicle), is often much shorter than the 30+ second sweep. When it is, it is overkill to scale down an entire trace when only a small portion of it was affected by the noise source. If you have a 60-second record with 8 seconds of noise, it makes more sense to mute only the noisy portion of the trace, rather than the entire trace.

Figure 52 below shows a random-source record that was taken as a car passed by parallel to the spread. The relative duration of the influence of the car on any one trace depends on the speed of the car and the overall record length. Note that in this case, the "noise burst" on each trace affected is roughly 2.5 seconds in duration. This is about 15% of the total trace length, meaning that 85% of the data in the affected traces is useable. Note also that this is a short record, at only 16 seconds – had it been a 30-second record (the minimum recommended for random-source surveying), the percentage of useable trace would be well over 90%.

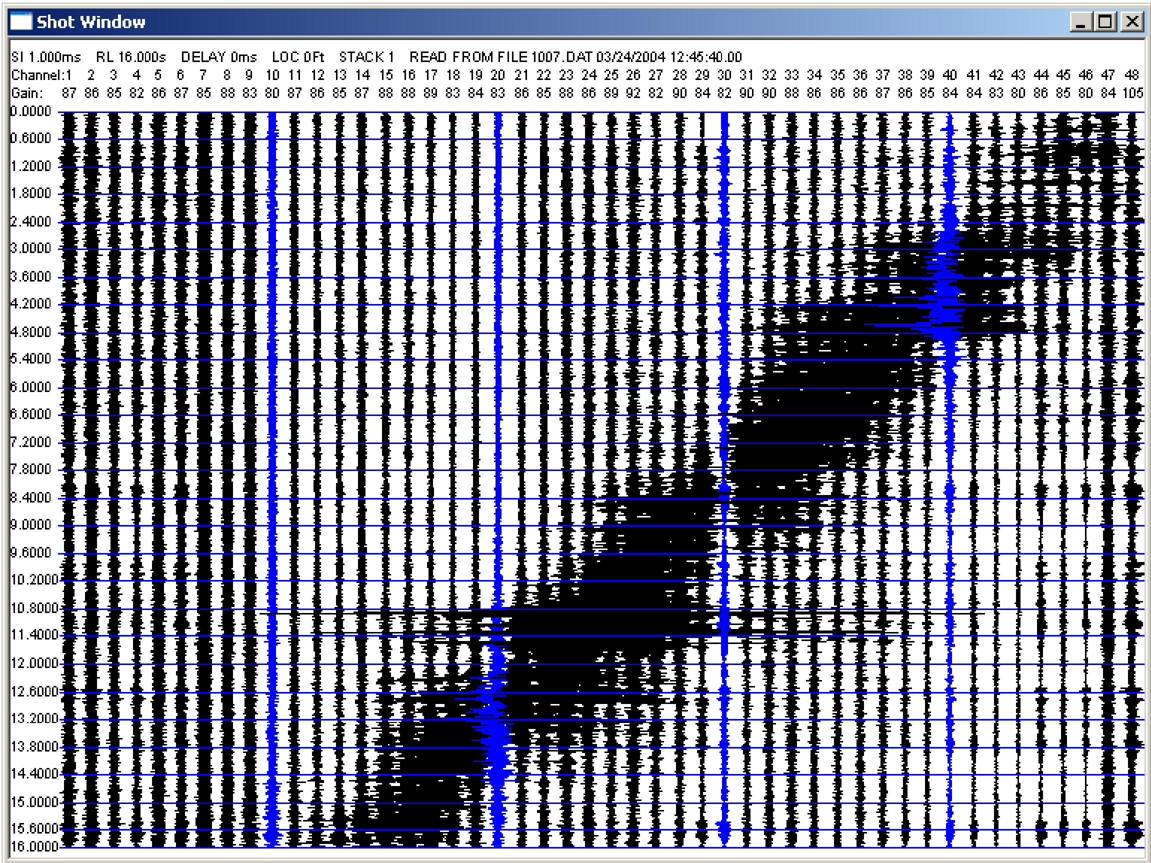


Figure 53. *Random-Source record showing effect of passing vehicle.*

Next we examine the effect of the Geometrics noise suppression feature.

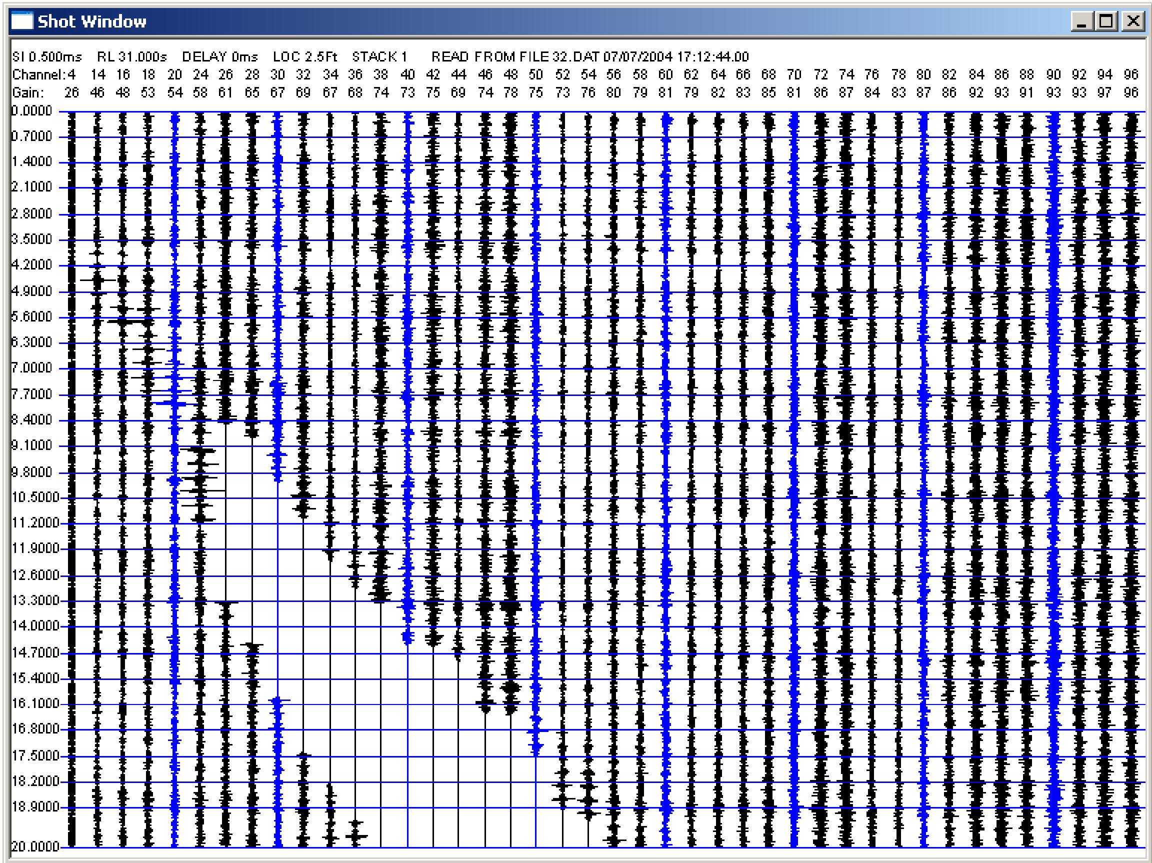


Figure 54. *Effect of real-time noise suppression on a record acquired while a vehicle passed by parallel to the spread.*

In Figure 53 above, noise suppression was enabled as a vehicle passed by the spread. Traces 26 through 52 recorded noise levels that exceeded the user-selected rejection criteria, and were muted accordingly. These data are then correlated and stacked. While the partially-muted traces contribute less signal to the final stack, more importantly, they do *not* contribute degrading high-amplitude noise.

Note: *If this method were used with a standard vibrator, whose pilot frequency increases monotonically over time, it would tend to entail some frequency bias – the frequency content of the final record would depend on when the muting occurred in any given trace. But a random source is fundamentally different – frequencies are distributed evenly throughout time – so muting any one portion of the pre-correlated record does not tend to focus on any finite frequency range.*

What does this do for us? We can see the overall result in Figure 54 below.

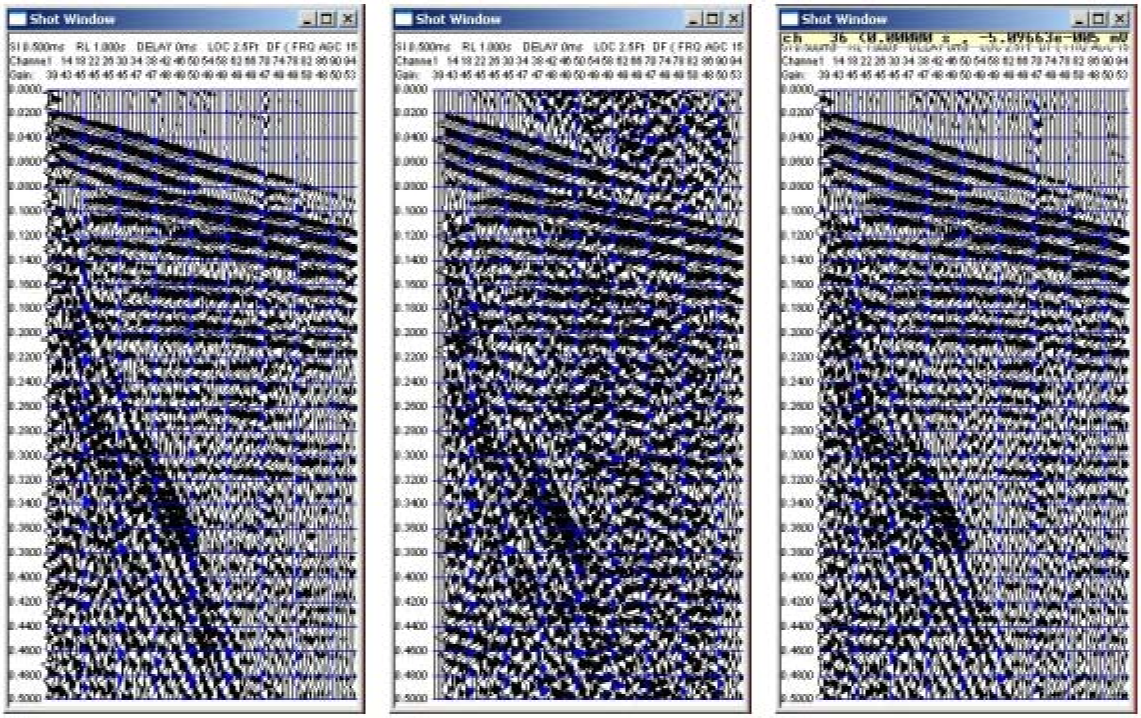


Figure 55. *Effect of noise suppression. Left -- data acquired under ideal conditions with no noise source. Middle -- data acquired while vehicles passed the spread, with noise suppression disabled. Right -- data acquired while vehicles passed the spread, noise suppression enabled.*

The record on the left consists of four stacks taken during a quiet period with no noise sources passing by the spread – i.e., ideal conditions. In the middle record, a vehicle passed by the spread during each of the four stacks, but noise suppression was not enabled. Finally, the record on the right was taken under identical conditions as the one in the middle, but this time noise suppression was enabled. The effects of the noise suppression feature are self-evident.

Setting Noise Suppression Parameters

Note: *If you intend to use noise suppression in your random-source survey, you will want to set the noise suppression parameters prior to enabling correlation. See the Summary for the suggested steps to follow when preparing to conduct a random-source survey with real-time noise suppression enabled.*

The first step in setting up the noise suppression parameters is to determine what your signal level is going to be. To do this, we must take a raw, uncorrelated record during a quiet period. We turn off all correlation and filters, and set the record length equal to the sweep length you plan to use. Next, we place the Wacker at the planned offset, and make sure the geometry is set up correctly in the **Geometry** menu.

Now, we take a record, running the Wacker for the full record length.

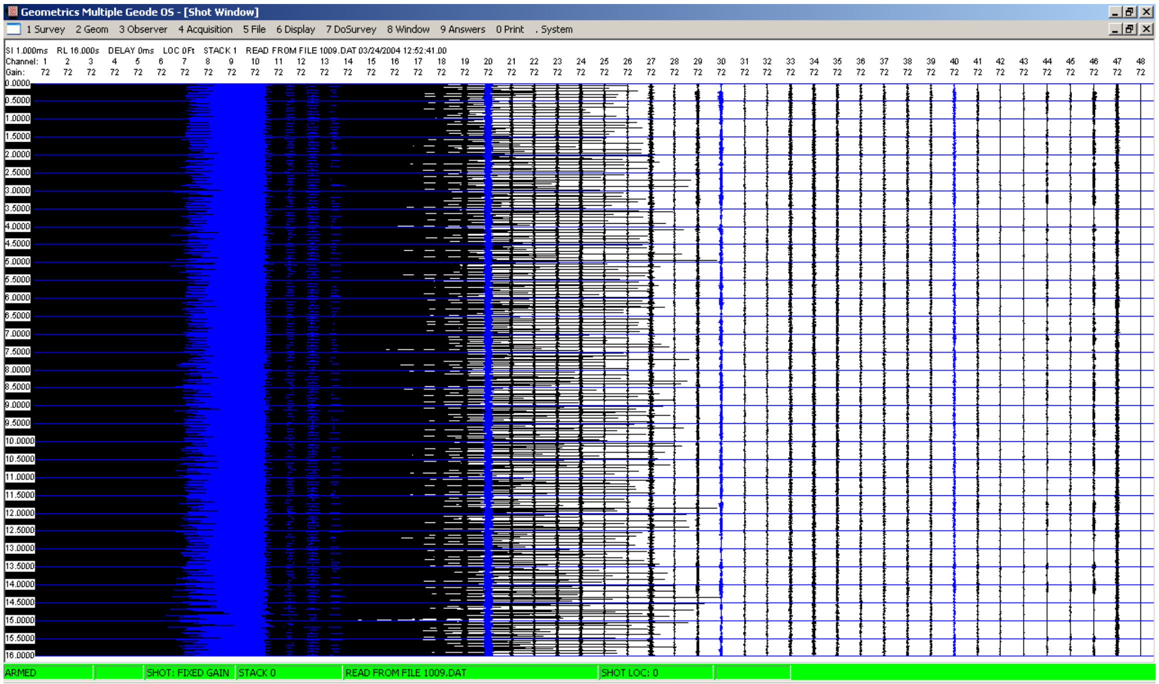


Figure 56. *Raw, uncorrelated record taken during quiet period to calibrate noise suppression settings.*

For the test record shown in Figure 55, the source was about 5 stations away from the first geophone. Display gains are the same for all traces. As you would expect, the greatest amount of signal amplitude is on the traces closer to the source, trailing off exponentially.

Now, from the **Window** menu, we enable the **Geometry Toolbar** (if not already enabled):

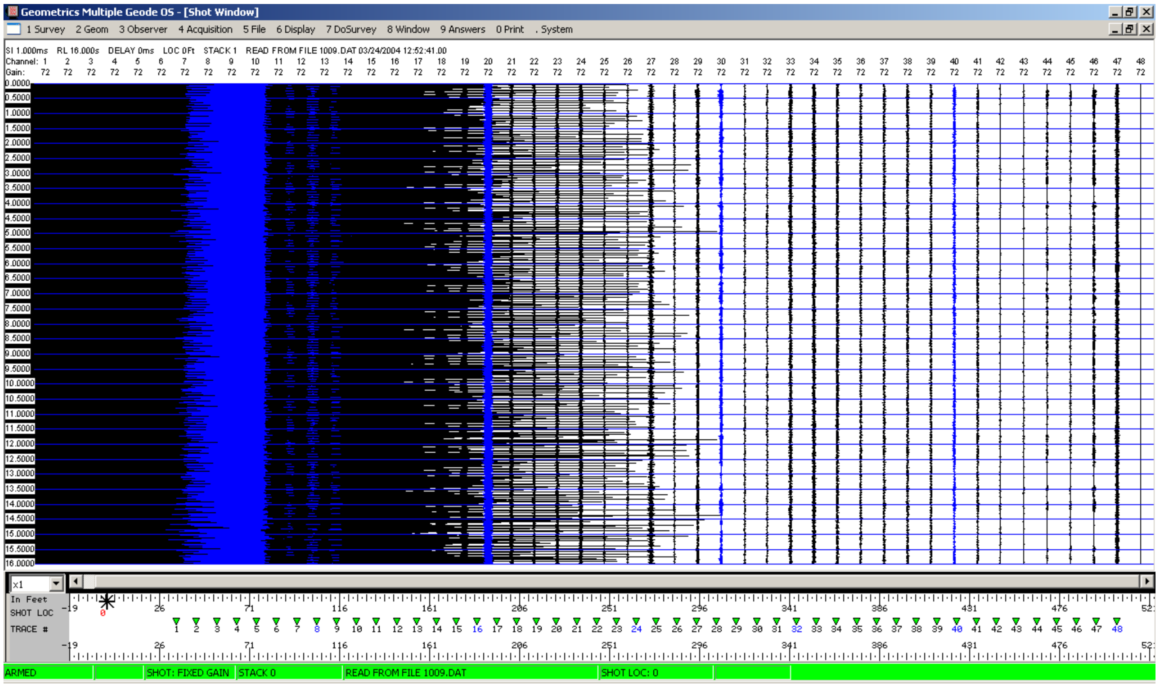
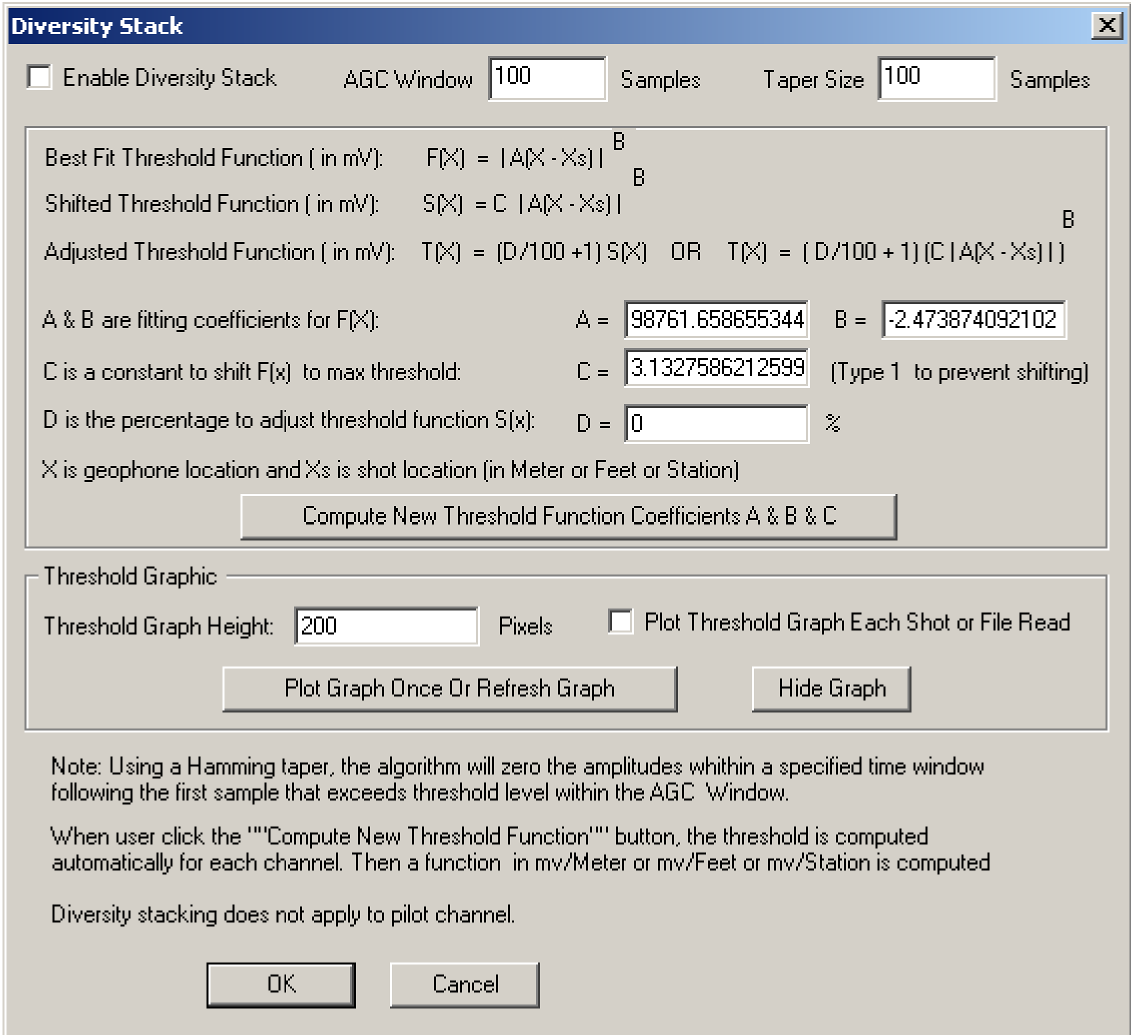


Figure 57. *Test record along with Geometry toolbar.*

Now we are ready to set up our noise suppression parameters. We open the **Acquisition**>*Noise Suppression* dialog box:



Pressing the **Plot Graph Once or Refresh Graph** button displays a bar graph of the data amplitude:

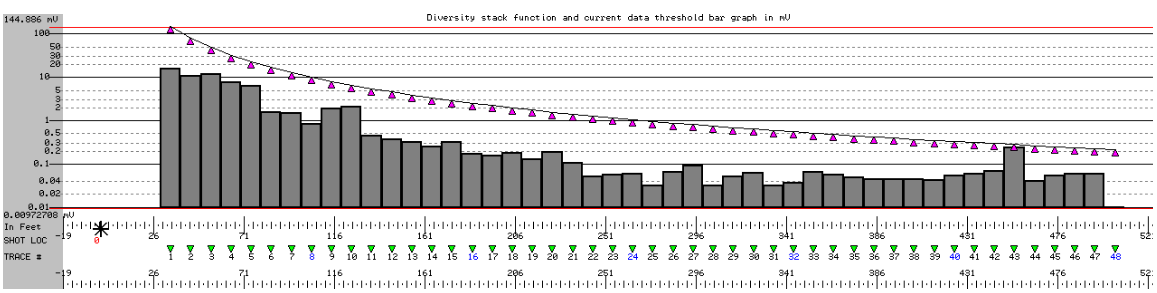


Figure 58. *Bar graph of amplitude with computed noise suppression function.*

An exponential function (described in the upper part of the dialog box) is automatically fit to the amplitude plot. This is your rejection or mute threshold function, and where you set it determines the difference between what will be considered signal (and accepted) and what will be considered noise (and rejected). Wherever the amplitude exceeds the mute threshold for any given channel, the trace will be muted.

Note: *The best-fit algorithm uses as input the shot offset and geophone spacing, so it is imperative that these are set correctly in the* ***Geometry*** *menu. If they aren't, you will be less likely to get a good fit.*

Let's discuss this dialog box in detail before going too much further. We will skip the **Mute Window** and **Taper Size** for the moment, but we will return to them later.

The basic form of the fitting algorithm is

$$f(x) = [A(x-x_S)]^B$$

where x is the geophone location, x_S is the shot location, and A and B are constants computed via the least-squares technique.

After the function is computed, it is DC-shifted by an amount C such that at no channel is it below the signal level (see Figure 57 above). If C is set to 1, this shift will not occur (see Figure 58 below).

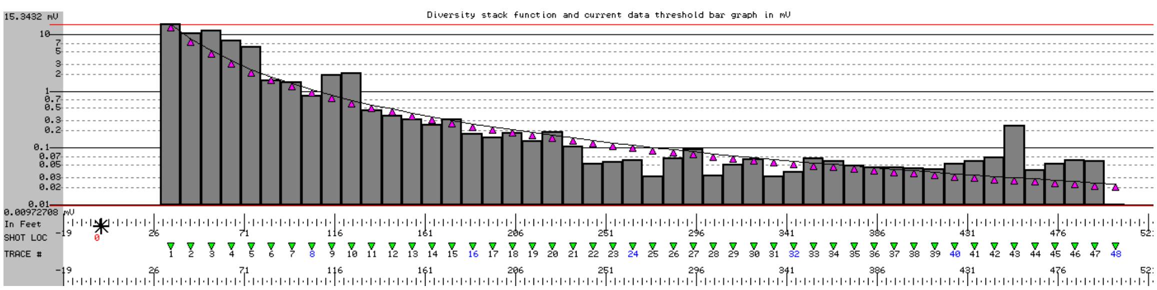


Figure 59. *Unshifted mute threshold function; C = 1.*

The constant D is not computed, but is set by the user and represents the percentage DC shift to apply after the mute threshold function has been computed (regardless of the value of C). For instance, applying +100% to the above will result in shifting the threshold function up:

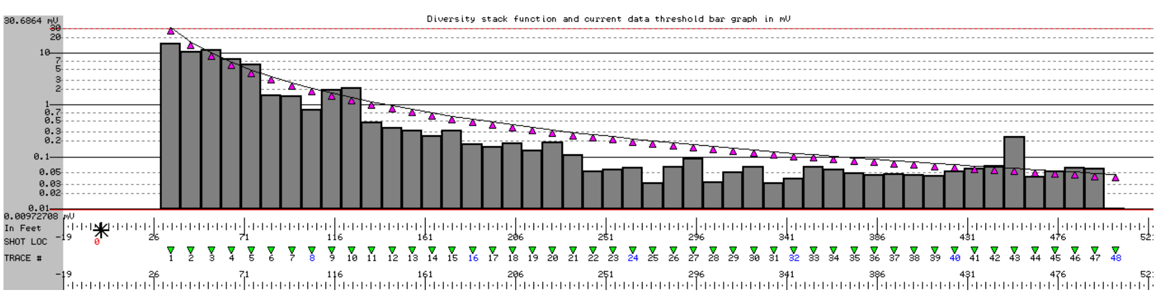


Figure 60. *Shifted mute threshold function; C=1, D=100%. Compare to Figure 58.*

Note that all of the constants, including *A* and *B*, can be modified by the user if the automatically-computed values give an unsatisfactory fit. A larger negative number for *B* will increase the fall-off rate; a smaller negative *B* will flatten the curve. In most instances, the automatically-computed values will suffice; however, in the event that the shot offset is large, you might find it helpful to set *B* experimentally. If the shot offset is large enough, there may be no perceptible fall-off in energy along the spread. In this case, you can set all the mute thresholds equal (a flat threshold function) by setting *B* to zero.

Note: *Whenever you set any of the coefficients A, B, or C manually, press the* ***OK*** *button to compute the new mute threshold function with these values. Pressing the* ***Compute New Threshold Function Coefficients A & B & C*** *button will revert to the automatically-computed coefficients.*

You can set the **Threshold Graph Height** to whatever you wish. The default is 200 pixels. Checking the **Plot Threshold Graph Each Shot or File Read** button will refresh the graph each time you take a new record or read in a file. To do this manually on a shot-by-shot basis, simply press the **Plot Graph Once or Refresh Graph** button.

Getting back to setting our parameters -- once we have taken the record and the mute threshold function has been computed, we need to do three things: adjust the mute threshold, set the **Mute Window** size, and set the **Taper Size**.

Adjusting the Mute Threshold

Once we are happy with the shape of the threshold function (again, the automatically-computed coefficients *A* and *B* will suffice 99% of the time), we fine-tune the DC level by grabbing the curve with our mouse and dragging it up or down. This is just a graphical way of adjusting the constant *D*, discussed above. We want to set it such

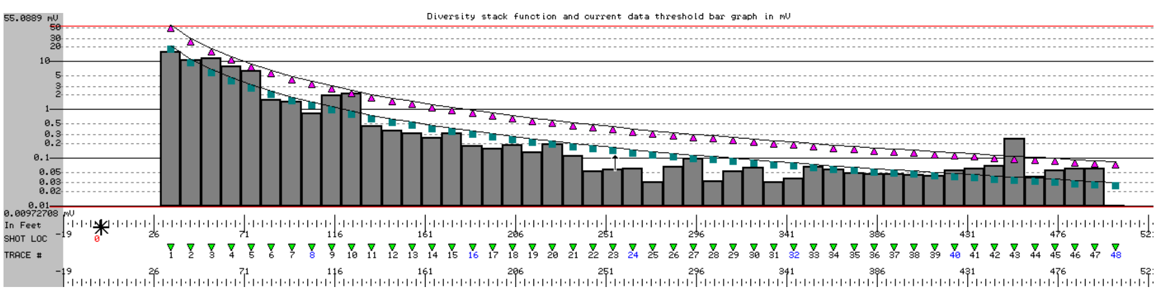


Figure 61. *Adjusting Mute Threshold graphically using mouse.*

that it just skims the tops of the bars in the bar graph. The higher we set it, the more noise will get through. If we set it too low, we will be cutting into our data too much. A typical threshold setting is shown below.

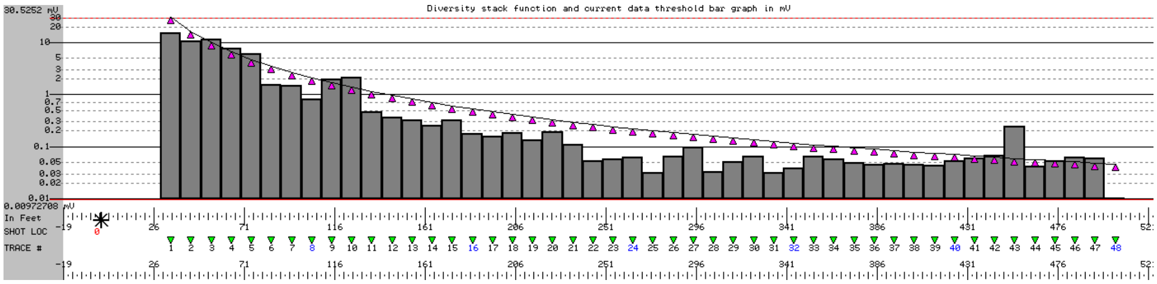


Figure 62. *Typical mute threshold setting.*

Setting the Mute Window and Taper Size

The Geometrics'-proprietary noise suppression algorithm windows the data as it comes in, analyses the data in that window, and determines what and what not to mute within that window, based on the mute threshold. Experimentation has shown that the optimal width of the **Mute Window** is about ½ the width of the "noise burst" we wish to eliminate. For instance, in the trace below, we see the effect of a passing car:

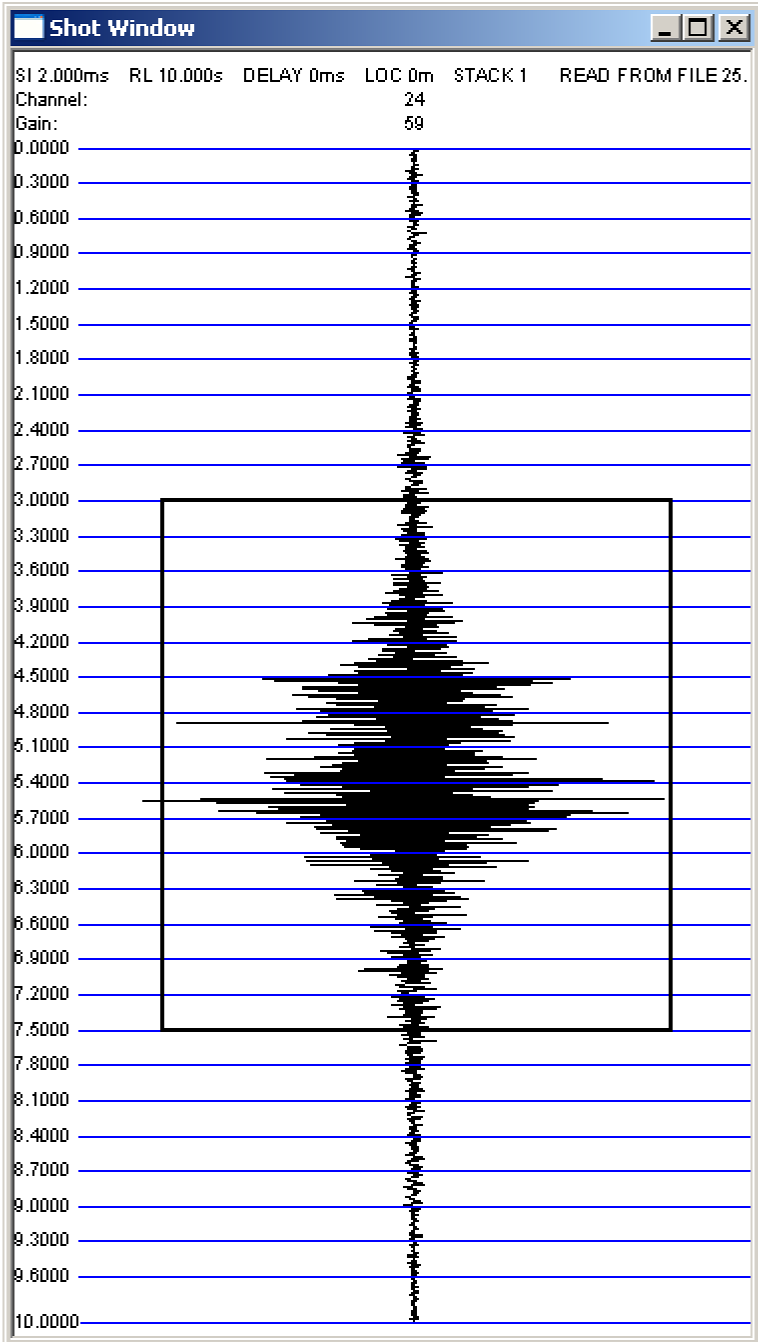


Figure 63. *Signature of passing car. Time-width of "noise burst" indicated by rectangle.*

The time-width of the noise burst from the car is about 4.5 seconds (this is subjective – you might choose different limits). The sample interval, in this case, is 2 msec, so the width in samples is 4.5 sec x 500 samples/sec, or 2250. We would therefore set our mute window to 2250/2 or 1125 samples.

Like any filter, a rectangular mute window would tend to introduce spurious frequencies into our record. This is avoided by sloping the cutoff, and the **Taper Size** determines the slope. In general, setting the taper size to ¼ the width of the mute window is a good rule of thumb.

Testing Our Noise Suppression Parameters

Once we have set all of our parameters, we should run a test, if feasible. For instance, if we are working along a road with intermittent traffic, it would be useful to take a few records while a car is passing by, trying different parameters and noting the effect.

While running the Wacker, we take a full-length record, while a typical noise source is active.   For simplicity, let's focus on a single trace. The signature of a passing car might look like the following:

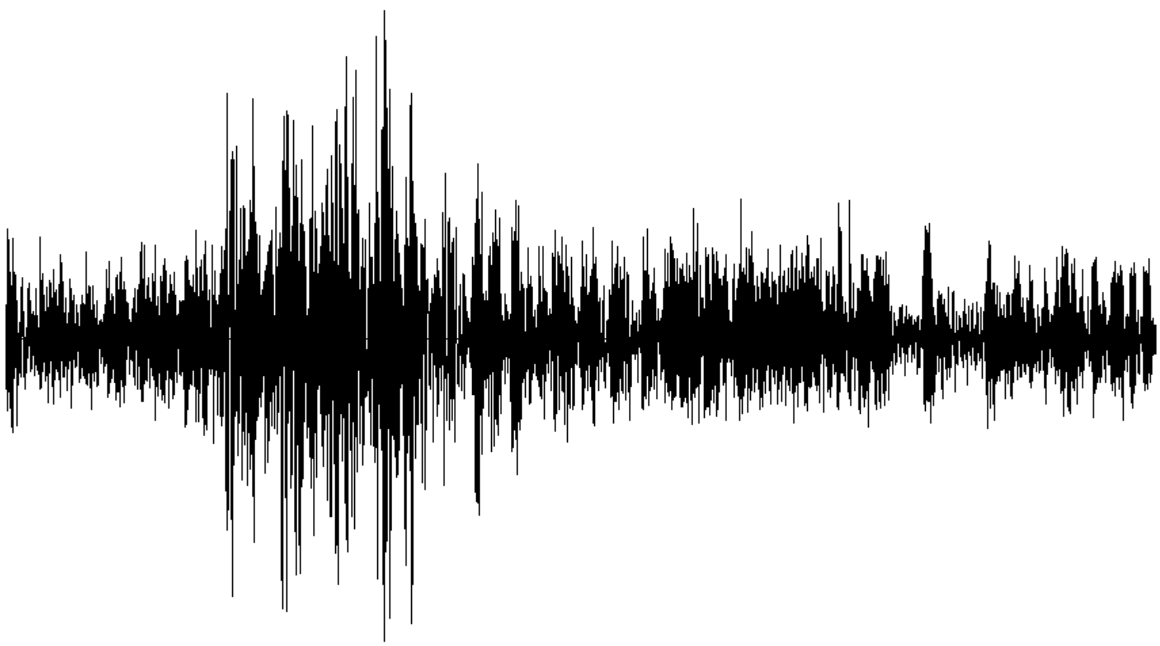


Figure 64. *Signature of passing car; noise suppression disabled.*

We open the **Acquisition**>*Noise Suppression* menu and enable noise suppression by clicking in the **Enable Noise Suppression** checkbox.   We wait for another car to pass. If we have our parameters set optimally, we should see something like the following:

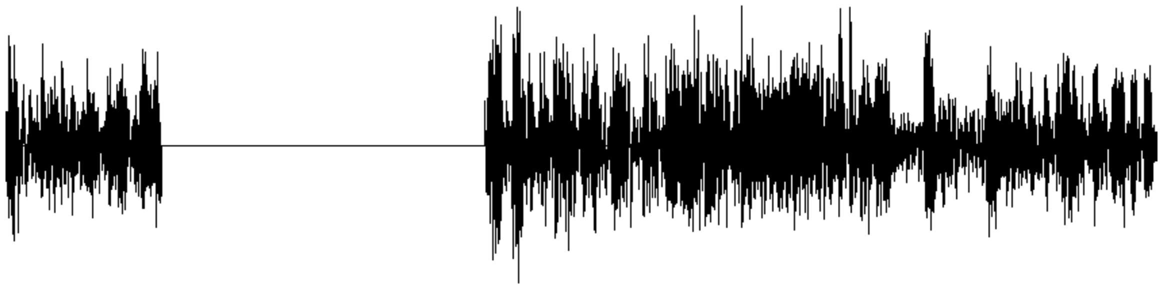


Figure 65. *Noise suppression enabled, Mute Threshold = 1000 mV, Mute Window = 2000 samples*

If we set our mute threshold too high (or the mute window too narrow), we might see something like that shown below. Some of the noise burst has been eliminated, but we could probably do better.

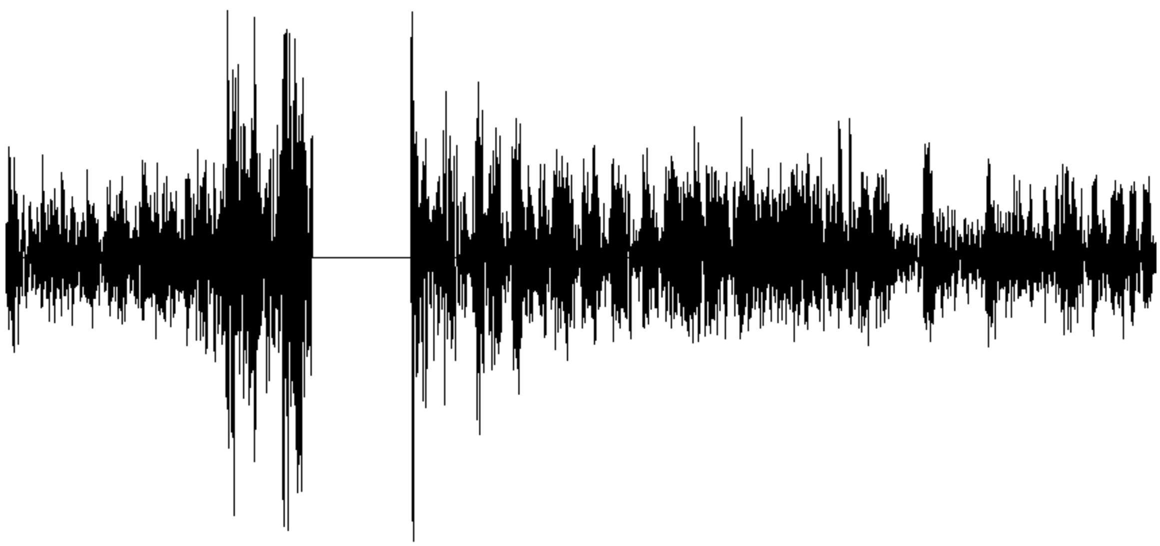


Figure 66. *Noise suppression enabled, Mute Threshold = 1500 mV, Mute Window = 2000 samples.*

Conversely, if we set the mute threshold too low (or the mute window too wide), we will mute more of the record than necessary:

Figure 67. *Noise suppression enabled, Mute Threshold = 500 mV, Mute Window = 2000 samples.*

It takes some practice, but in conditions with intermittent noise, any noise suppression is often better than none, and as long as you are not muting out too much of your data, you should see better results with noise suppression on than with it off.

Acquiring Data

Once we are happy with our parameters, we are ready to acquire data. We disable noise suppression, set all of our other acquisition parameters, and then enable noise suppression again and begin our survey. After taking our first record, we open the **Acquisition**>*Noise Suppression* dialog box and de-select **Plot Threshold Graph Each Shot or File Read** to save space on the monitor.

The total amount of data muted in each stack will be displayed in the status bar at the bottom of the screen. This allows us to keep an eye on how much data is being muted prior to correlation of each stack.

Figure 68. *Task bar, showing amount of data muted by noise suppression.*

Final Notes on Real-time Noise Suppression

The Geometrics noise suppression algorithm was designed specifically for situations marked by intermittent noise of relatively short duration relative to the overall record length. It is most useful in non-impulsive surveys requiring correlation and long record times, most especially random-source surveys. It is not recommended for impulsive surveys, and is not helpful in areas of constant noise levels.

The most common situation in which this feature is useful is when working along roads with intermittent (not constant) traffic. When doing 30 or 60-second sweeps, it can be difficult to impossible to time your records to be between passing cars. Without some sort of noise suppression, if a car goes by during active acquisition, you generally have to throw that record out. Judicious use of the noise suppression feature will enable you to largely ignore intermittent traffic, and preclude the necessity of "throwing the baby out with the bathwater". The net affect of this is to greatly increase production rates in high-noise areas.

Of course, not all noise sources are equal, and with respect to passing vehicles, varying size and speed will result in different signatures. Faster moving cars, for instance, will have a shorter duration effect on individual traces than slower moving cars. You will likely have to experiment in order to come up with noise suppression parameters, particularly the mute window, that will be the best compromise.

Summary

Clearly, there are numerous ways to conduct random-source surveys, and the software was designed to be flexible enough to accommodate the main ones. The purpose of the preceding discussion was to give the reader a general understanding of the method and the software – there are more possible variations that can possibly be covered. The flexibility of the software should facilitate individual creativity.

The foregoing discussion is complicated, so a summary is beneficial.

Basic Methods

There are two basic ways of doing a random-source survey with the StrataVisor NZ/Geode system – with an unspiked pilot and a spiked pilot. Different rules apply in each, and this is summarized below.

1) **Correlating against the raw, unspiked output of the geophone/Pilot Processing Module.**

    a) Up to three Wackers per Wacker channel.

        i. Wackers should be in an equilateral triangle as close together as possible, so as to be as close as possible to the Wacker geophone.

    b) Up to four Wacker channels.

        i. Distance between Wacker channels should be at least 10 times the Wacker/Wacker geophone distance.

2) **Correlating against a spiked version of the output of the geophone/Pilot Processing Module.**

    a) Maximum of one Wacker per Wacker channel.

    b) Up to four Wacker channels.

i. Distance between Wacker channels should be at least 10 times the Wacker/Wacker geophone distance.

General Steps to Follow in Setting up Random-Source Recording Parameters

1) Go to the **Acquisition**>*Correlation* menu – Disable correlation, set Wacker channel(s) and Pilot channel. The Pilot channel can be any non-data channel.
2) Take a raw, uncorrelated record. If you are using noise suppression, time the record with a typical noise event. If not using noise suppression, skip to step 6.
3) Go to the **Acquisition**>*Noise Suppression* menu and set the Mute **Threshold**, **Mute Window**, and **Taper Size**.
4) Enable **Noise Suppression** and test. Adjust muting parameters if necessary.
5) Disable **Noise Suppression**.
6) Go to the **Display**>*Shot Parameters>Display Correlation Setup* menu – enable **Random-Source Correlation**, set **Sweep Length**, **Pilot Frequency Filter** (optional), and **Wacker Spike Filter** thresholds (optional).
7) Inspect correlated record; adjust parameters as necessary.
8) Go back to the **Acquisition**>*Correlation* menu – press **Copy Settings From Display Correlation** button.
9) Go to the **Acquisition**>*Specify Channels* menu – enable/disable appropriate channels.
10) Go to **Acquisition**>*Stack Options* menu – enter a non-zero **Unstack Delay** to allow selective stacking (if you want to be able to do selective stacking).
11) Go to **File**>*Storage Parameters* menu – enable **Autosave**.
12) Go to **Geometry**>*Geophone Interval* menu – set **Geophone Interval**.
13) Go to **Geometry>***Group/Shot Locations* menu – set location of first shot and locations of all geophones (active and inactive).
14) Go to **Geometry>***Roll Parameters* menu – set **Roll Increments** (usually 1), click **Roll Wacker** checkbox, and enable **Auto Rolling** (if desired).
15) **Acquisition**>*Noise Suppression* menu and enable Noise Suppression.
16) Begin acquiring data.

Recommended Reading

Park, Choon B., Miller, Richard D., Steeples, Don W., and Ross A. Black, 1996, *Swept Impact Seismic Technique (SIST),* Geophysics, Vol. 61, No. 6, pp 1789-1803.

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Sheriff, R.E., and L.P. Geldart, *Exploration Seismology*, ©1995, Press Syndicate of the University of Cambridge, 591 pages.

Geyer, Robert L., and Franklyn K. Levin (eds.), *Vibroseis*, ©1990, Society of Exploration Geophysicists, 830 pages.

Yilmaz, Ozdogan, *Seismic Data Processing*, ©1994, Society of Exploration Geophysicists, 526 pages.