# Validation of Pyroshock Data

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This article comprises a comprehensive description of pyroshock, the interpretation of pyroshock data, and the validation of pyroshock data. Recent events in the pyroshock testing community show that corrupted pyroshock data are still being taken at both government agencies and private companies. A large part of this article is devoted to the acquisition and analysis of pyroshock data because proper time-history data acquisition and, consequently, test specification development are common industry problems. To avoid corrupted pyroshock data and resulting corrupted pyroshock specifications, recommended practices for instrumentation and data acquisition systems as well as data analyses are given. Causes of corrupted pyroshock data are explored, and recommendations for avoiding corrupted pyroshock data are provided.

Pyroshock was once considered a relatively mild environment due to its low-velocity change and high-frequency content. Pyroshock rarely damages structural members, but can easily cause failures in electronic components that are sensitive to high-frequency pyroshock energy. In the near field, pyroshock acceleration is a high-frequency, high-amplitude shock wave that may have transients with a duration of microseconds.<sup>1,2,3,4,5</sup> In the *mid field* and the far field, the pyroshock acceleration time history approximates a combination of decayed sinusoids with one or more dominant frequencies.<sup>2,3,4,5</sup> Pyroshock or pyrotechnic shock originates from point sources (explosive nuts and bolts), line sources or flexible linear shaped charges (FLSC), mild detonating fuses (MDF), and combined sources (V-band/Marmon clamps). Types of failures caused by pyroshock commonly include relay chatter, separation of small-circuit test items, and dislodging of contaminants (e.g. solder balls) that cause short circuits.<sup>2,3,4,5</sup>

Definitions for pyroshock are now uniform in all major documents, as shown in Table 1; this was accomplished during the last four years.<sup>2,3,4,5</sup> These definitions are only guidelines. The most important aspect of these definitions is the frequency specification, because frequency content determines the pyroshock test or simulation. A near-field pyroshock test requires frequency control up to and above 10,000 Hz for amplitudes greater than 10,000 g. A pyrotechnically excited simulation technique is usually appropriate, although in some cases, a mechanically excited simulation technique may be used for small components.<sup>6</sup> A mid-field pyroshock test requires frequency control from 3,000 to 10,000 Hz for amplitudes less than 10,000 g. A mechanically excited simulation technique other that shaker shock is usually required. A far-field pyroshock test requires frequency control no higher than 3,000 Hz for amplitudes less than 1,000 g. A shaker shock or a mechanically excited simulation technique is appropriate.

Recent events show that sources of pyroshock data contamination appear to be the usual culprits that have been known for some time - electromagnetic noise (or other noise sources), digital aliasing and offsets in the data. Electromagnetic noise is always a potential problem with pyroshock testing, especially when explosives are detonated. The high frequency electromagnetic pulse can be eliminated in some cases, for example with a Faraday cage.But in many cases, the electromagnetic pulse produces an additional environment that creates invalid data contaminated by the inadequate response to the pulse by the signal conditioner and/or data acquisition system (DAS). The cause of digital data aliasing is, but not limited to, inadequate analog filtering prior to digitization and inadequate bandwidth of the DAS. Both electromagnetic (or other) noise and aliasing are "out-of-band" noise that can cause invalid data. Offsets in the acceleration data are generally caused by accelerometer malfunction<sup>7</sup> and, in some cases, DAS problems such as inadequate slew rate capability. The remedies for these problems are readily available, so why are corrupted pyroshock data still acquired? Examples of corrupted pyroshock data are provided, and recommendations for avoiding corrupted pyroshock data are given.

# **Choice of Accelerometer**

The first reason that corrupted pyroshock data are measured is that isolated piezoelectric (PE) accelerometers are used instead of piezoresistive (PR) accelerometers. There are two isolated PE accelerometers that are commercially available for purchase, and their constructions are similar. The isolated PE accelerometers were designed and manufactured because it was shown in the early 1970s that hard-mounted PE accelerometers zero-shift, a shockinduced damage (polarization switching) that occurs at less than 1% of mechanical energy present in typical accelerometer use.<sup>8</sup> A consequence of this study is that under no circumstances should a nonisolated PE accelerometer be used for pyroshock unless it is specifically designed for oscillatory shock; most are designed for positive shock only.

The discovery of PE polarization switching drove the development of isolated PE accelerometers<sup>7</sup> and high-g PR accelerometers. The isolated PE accelerometers are used with both success and failure and generally are more successful for mid-field and far-field pyroshock. One of these isolated PE accelerometers was used to take a set of the example data presented in this article. A linear analysis of this PE accelerometer based on the manufacturer's specifications shows that one isolated PE accelerometer has a peak response of 7-8% in the transfer function at around 8 kHz and attenuates above 8 kHz.<sup>9</sup> The other isolated, PE accelerometer has a resonance, as measured in a Hopkinson bar study, that is below 10,000 Hz and changes frequency and magnitude, with the magnitude and frequency content of applied shock.<sup>10</sup>

The change in resonant frequency and resonant frequency magnitude is a characteristic of both isolated piezoelectric shock accelerometers and indicates nonlinear response in the bandwidth of interest for pyroshock specifications, DC-10,000 Hz. The remedy is for the isolated accelerometer to have a resonance considerably higher than the frequency bandwidth of interest.<sup>10</sup> But this is not achieved with either of the isolated PE accelerometers, because their resonances are below 10 kHz. Additionally, another problem is that the pyroshock environment is highly variable, and whether or not the isolated PE accelerometers are stimulated to respond with high-amplitude, resonant behavior cannot be anticipated.

Table 1. Pyroshock definitions.			
Document	Region	Acceleration Amplitude, g	Frequency, Hz
IEST Pyroshock Testing RP (2009)	Near field	> 10,000	>10,000
Harris Shock and Vibration Handbook (2010)	Mid field	< 10,000	3000-10,000
MIL STD 810, Method 517 (2008) NASA STD 7003A (2011)	Far field	< 1000	< 3000
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 ${\it Table \ 2. \ Recommended \ pyroshock \ data \ acquisition \ system \ specifications.}$ 

Data Acquisition System Item	<b>Recommended Specification</b>
Bandwidth	DC to 100,000 Hz or wider15
Sampling Rate	10 times the desired data bandwidth or higher <sup>11,14</sup>
Analog Anti-Aliasing Filter Rolloff	$60 \text{ dB/octave or steeper}^{12,13,14}$
Analog Anti-Aliasing Filter Cutoff Frequency	One Octave below Nyquist Frequency or lower <sup>13,14</sup>
Slew Rate	Greater than 20 V/µs



Figure 1. Historical longitudinal gunfire shock.

In summary, the useable bandwidth of the isolated PE accelerometers is 4,000 Hz or less (5% deviation)<sup>9,10</sup> and is woefully inadequate for pyroshock measurements. In view of this analysis (analytical and experimental) of the isolated PE accelerometers, it is reasonable to question whether shock response spectrum peaks just below, at or just above 10,000 Hz are real or an artifact of the accelerometer resonant response.

The recommended practice is to always use PR accelerometers for pyroshock. Usually, a near-field pyroshock event using explosives is likely to excite the PR accelerometer's resonance(s), so an isolated PR accelerometer is recommended and is commercially available.<sup>10</sup> There is a continued resistance to the use of PR accelerometers because they are expensive, and the cost of the required signal conditioning is comparatively high. However, in comparison to the cost of the failed PE accelerometers and the time lost in the laboratory with a test configuration that cannot meet specification without adequate accelerometer measurements, the cost of PR accelerometers can be justified. In the long run, the PR accelerometers save time and money. New PR accelerometers that have resonances below 100,000 Hz are appearing on the market and require special consideration as "out-of-band" when limited bandwidth DAS with inadequate analog anti-aliasing protection (AAA) are used. It should be mentioned that a laser Doppler vibrometer is used occasionally as a laboratory instrument for pyroshock measurement but rarely as a field instrument due to difficulties in use.<sup>11,12</sup>

## **Data Acquisition System Characteristics**

The second cause of corrupted pyroshock data is that an adequate data acquisition system (DAS) is not purchased and used. A DAS adequate for long duration mechanical shock data, such as package testing or other impact testing, cannot be used for pyroshock measurements that require a wider bandwidth and a larger dynamic range as well as analog anti-aliasing (AAA) filters with very sharp roll-off prior to digitization. However, the converse is allowed. That is, a DAS that is adequate for pyroshock may be used for longer duration mechanical shock as long as the available sample rates and record lengths can record the entire event.

A note should be made here regarding calibration – pyroshock data should be accepted only if an end-to-end electrical calibration of the DAS is documented immediately prior to the pyroshock event or pyroshock simulation. Additionally, a yearly evaluation of all DAS channels is recommended with associated documentation. Finally, a DAS designed for vibration measurements should, under no circumstances, be used to record pyroshock data. A summary of recommended pyroshock DAS specifications is given in Table 2. Additionally, a noise channel, or inert accelerometer (also called a placebo), is highly recommended and may be purchased from most accelerometer manufacturers at low cost.<sup>3,14</sup>

The DAS items in Table 2 are familiar to those recording shock data. In some cases, the recommended specifications have been recorded for years,<sup>13,14</sup> while others are more recent develop-

ments.<sup>3,12,15</sup> Many of the recommended specifications may be met with a sigma-delta or delta-sigma (SD) DAS architecture. However, SD DAS architecture is not the complete solution in itself because limited bandwidth SD DAS are commercially available that have limited slew rate, as an example below shows and are unacceptable for pyroshock measurements. Recent discussions at the 2011 Shock and Vibration Symposium have resulted in a restating of the 60-dB/octave AAA filter rolloff as: an AAA filter with an attenuation of 60 dB or greater for 12-bit systems; 80 dB or greater for higher resolution systems, at the Nyquist frequency (sample frequency divided by two).

Slew rate specification is often overlooked as a DAS item, but is very important for pyroshock. To understand slew rate, the characteristics of voltage signal conditioners (including amplifiers) must be considered. The output of a voltage signal conditioner,  $V_{\rm out}$ , for a sinusoidal input with frequency  $\omega$  and magnitude V may be defined as:

$$V_{\rm out} = V \sin \omega t \tag{1}$$

Slew rate is defined as the change in  $V_{\rm out}$  with time or:

$$\frac{dV_{\text{out}}}{dt} = V\omega\cos\omega t = \text{Slew Rate}$$
(2)

The product  $V\omega$  is a characteristic value for an amplifier and:

$$V\omega = \text{Gain} \times \text{Frequency}$$
 (3)

The gain/frequency product (often called gain/bandwidth)is a constant for a particular signal conditioner design, so Equation 3 says that as the input frequency to the amplifier increases, the available gain decreases. Consequently, when an amplifier is subjected to high-frequency, high-magnitude input at its upper bandwidth limit, the amplifier saturates. The amplifier saturation is evidenced by an offset or a low-frequency sinusoid in the time domain.<sup>14</sup> The shock response spectrum (SRS) and the discrete Fourier transform (DFT) will have additional frequency content not in the original input. The signal conditioner slew rate on most systems is specified to 10  $V/\mu s$ , a level that can easily be exceeded in pyroshock tests that have significant content above 10,000 Hz. Pyroshock data may be contaminated at slew rates as high as 28 V/µs. In general, most DAS manufacturers do not advertise slew rates, and the user must either request slew rate information from the manufacturer or perform their own detailed experimental evaluation of the DAS.<sup>16</sup> In many respects, the description of slew rate above is simplistic; a more detailed description<sup>17</sup> may be found in many other references.

### **Data Analyses**

The third cause for corrupted pyroshock data is that the data are not adequately examined when acquired. The recommended practice is to calculate four quantities for every data channel: a wideband, acceleration time history with the offsets prior to the event removed; the integral of the acceleration time history; the discrete or finite Fourier transform of the acceleration time history (DFT); and finally the shock response spectrum (SRS) of the acceleration time history. Offsets prior to the event are generally caused by amplifier drift, will result in an erroneous velocity time history, and should be eliminated by averaging the pre-shock data and subtracting the mean from the entire acceleration time history. Some prefer to calculate a mean for the entire record and subtract the mean from the entire acceleration time history. The results should be the same. The integral of the acceleration time history or velocity time history shows any offsets that occur after the pyroshock event or simulation is initiated.

The velocity time history is the single best indicator of data quality and has been recommended for decades.<sup>3,14</sup> The DFT is calculated for the full DAS bandwidth and *may* show that the analog, anti-aliasing filter is adequate and that the data are or are not aliased. However, severe aliasing is often undetected, because in most cases, once the data are digitized, aliasing is not apparent.<sup>3,11,14,15</sup> Finally, the SRS is calculated and examined for the correct low-frequency asymptote (9 to 12 dB/octave)<sup>2,3</sup> and the expected structural resonances. The SRS should be calculated to

a high enough frequency so that it is evident that all frequency content has been captured; the shock response spectrum reaches a constant value. An SRS calculated for frequencies starting at 10 Hz generally reveals low-frequency problems.

Additionally, the use of positive and negative SRS (as shown below) will reveal if the pyroshock test or simulation creates a realistic pyroshock; the positive and negative SRS should be similar but not the same. If all four quantities are thoroughly examined, generally problems with the DAS and instrumentation are apparent although the cause of the problems may be hard to identify after the test without examining each item in the measurement process separately. The noise channel should also be analyzed with the four quantities above and may provide insight of the cause of accelerometer anomalies as discussed below.

### Aliased Pyroshock Data

This example is based on a set of near-field data recorded at a government contractor facility that routinely conducts pyroshock testing. One type of gunfire data is shown in Figure 1.<sup>17</sup> These data are pyroshock data even though there are three events, because the explosive event occurs first and is the most severe. The data were measured with a PR accelerometer and a signal conditioner manufactured by one company and DAS manufactured by another company. The DAS has conventional architecture. The signal conditioner has a four-pole, Butterworth, low-pass, analog, antialiasing (AAA) filter with a 20-kHz cutoff frequency (or bandwidth of DC-20 kHz). Consequently, the AAA filter rolloff or attenuation slope is 80 dB/decade or 24 dB/octave. The data were sampled at 25 kHz, so the Nyquist frequency is 12.5 kHz. This combination of hardware would give correct amplitude (5% accuracy) for measuring signals where the bandwidth of interest is no more than 2.5 kHz if it had an effective AAA.<sup>17</sup> The recommended practice is to sample at least 10 times higher than the desired bandwidth of the measurement to minimize amplitude error.<sup>14</sup>

A comparison of these gunfire data parameters and the recommended pyroshock DAS specifications in Table 2 reveals that the DAS parameters are woefully inadequate for pyroshock measurements because the signal conditioner's AAA filter specification means that the filter attenuation is only 80 dB down in a decade (200,000 Hz) and has not reached the noise floor of 96 dB for a 16 bit DAS. Since the Nyquist frequency for these data is 12.5 kHz, there is no aliasing protection at all between 12.5 kHz and the 20 kHz cutoff frequency of the AAA filter. All of the frequency content between 12.5 kHz and the 20 kHz cutoff frequency will fold back (alias) without attenuation between 12.5 kHz down to 5 kHz. The recommended practice for pyroshock data is an anti-aliasing filter that has a 60-dB/octave rolloff, and the cutoff frequency should be placed at least one octave below the Nyquist frequency.<sup>13,14</sup> The PR accelerometers used to acquire these test data have a resonance that is at about 60 kHz and has 10 times the magnitude of the signal of interest. Consequently, the PR accelerometers' resonance will also alias into the data bandwidth of interest. The severe aliasing of these data is evident simply by examining the parameters of the gunfire data<sup>17</sup> and comparing these parameters to those in Table 2.

This gunfire acceleration time history in Figure 1 looks plausible. However, the velocity time history in Figure 2 clearly does not represent gunfire data taken with a stand that holds the rifle stationary. The velocity should oscillate about zero according to the test configuration. With the recent advances in data analysis and our knowledge of the data parameters per the evaluation above, the velocity data exhibit the now well-known evidence of aliasing.<sup>11</sup>

Figure 3 shows the shock response spectrum (SRS) for the data in Figure 1 that is calculated over a wider range (10 to 100,000 Hz) than conventionally shown (100 to 10,000 Hz). The SRS is plausible: it has the correct low-frequency slope for pyroshock that is, in this case, about 9 dB/octave or +1.5 decades in amplitude for one decade of frequency and the SRS magnitude and settles out to a constant value by 30,000 Hz. However, the absence of the accelerometer resonance at 60 kHz clearly indicates that the data are aliased. The resonance should be visible because the attenuation of the analog AAA filter is not sufficient to prevent the resonance appearance in the SRS.



Figure 2. Velocity for longitudinal gunfire shock (integral of acceleration in Figure 1).



Figure 3. Shock response spectra for longitudinal gunfire shock in Figure 1.

Aliasing cannot be detected by an SRS, so if the acceleration time history and the SRS are all that is examined, then the data appear plausible. However, the examination of the DAS specifications, data parameters, and the velocity time history reveals that these data are severely flawed by aliasing and should be discarded because there is no way to correct aliased data.<sup>11,14</sup>

# Slew Rate Limited Pyroshock Data

The data analysis in this section illuminates the slew rate characteristics of the signal conditioner and DAS used to acquire these data. This example is based on a set of near-field data recorded at a government contractor facility that routinely conducts pyroshock testing. Triaxial accelerometer data were recorded during the firing of explosives located on a 20-by-20-inch steel plate, but only the in-axis accelerometer data (data sensing the strongest response) are discussed and analyzed. The data were taken with hardware frequently used for pyroshock - a piezoelectric (PE) accelerometer with an internal mechanical low-pass filter and an internal electrical low-pass filter, a signal conditioner with an AAA filter that is a 4-pole Butterworth, low-pass filter with a 20-kHz cutoff frequency, and a DAS with sigma-delta architecture. Consequently, the AAA filter rolloff or attenuation slope is 80 dB/decade or 24 dB/octave. Both the accelerometer and the signal conditioner are manufactured by the same company, and the DAS is manufactured by a second company.

The raw in-axis accelerometer data are shown in Figure 4 and appear to have the general characteristics of near-field pyroshock data: the pyroshock acceleration time history is a high-frequency, high-amplitude shock that has transients with durations of mi-



Figure 4. Typical near-field pyroshock acceleration time history.



Figure 5. Integral of the acceleration time history in Figure 4.



Figure 6. Wideband discrete Fourier transform for Figure 4, acceleration time history.

croseconds. The data are very symmetrical visually. The integral of the accelerometer data is shown in Figure 5 and indicates a velocity change that is inconsistent (and therefore erroneous) with a pyrotechnic test that has a zero velocity change. Further analysis is required to discover the source of the erroneous velocity time history.

A comparison of these pyroshock data parameters and the recommended pyroshock DAS specifications in Table 2 reveals the AAA does not have adequate low-pass filter specifications as evidenced by the manufacturer's specifications and the DFT in Figure 6. In Table 2, the recommended slope for the AAA filter is 60 dB/octave (or 200 dB/decade), and this DFT clearly does not have this slope.



Figure 7. Shock response spectrum of acceleration time history Figure 4 (Q=10).

The sigma-delta DAS architecture ideally provides additional aliasing protection by initially sampling at a much higher sample rate than the final sample rate (as well as other features), but this is an issue that must be explored with each DAS manufacturer. The sample rate for these data is 100 kHz, so the Nyquist frequency is 50 kHz and is the upper limit of the DFT. The upper limit of 50 kHz also allows examination of the frequency content at and above 20 kHz.

This DFT has the classical characteristics of pyroshock – an initial pulse-like DFT that has decreasing magnitude until about 800 Hz, where the DFT starts to increase with structural response. However, a low structural frequency of 800 Hz is usually not excited by near-field pyroshock that has significant frequency content above 10,000 Hz. Generally, structural frequencies above 1000 Hz are excited by near-field pyroshock. The structural response still has a high magnitude at the 20 kHz cutoff frequency of the signal conditioner/DAS low-pass filter. A bandwidth wider than 20 kHz is recommended for these data so that the natural pyroshock magnitude decrease with frequency is observed; Table 2 recommends 100 kHz minimum.

The DFT also shows that mild aliasing of the data did not occur because the magnitude decreases uniformly above 20 kHz. If mild aliasing had occurred, then the DFT magnitude would show an increasing magnitude near the cutoff frequency. Other frequency distortions may occur as the result of aliasing and may not be detectable at all.<sup>11</sup> To prevent undetectable aliasing, one requirement, in addition to the AAA filter rolloff, is a sample rate of 1 MHz or higher.<sup>3,11,14</sup> Clearly, the low-frequency asymptote of the SRS in Figure 7 is contaminated below about 800 Hz and does not have the correct slope.

So what is the cause of the erroneous velocity change in the accelerometer data shown in Figure 5 (and also the contaminated low frequency in the Figure 7 SRS)? The answer is found by examining the noise channel shown in Figure 8 as well as the effect of this noise on the other channels that are responding to the high-magnitude, high-frequency pyroshock environment.

Figure 8 shows an electromagnetic, noise spike from the pyrotechnic detonation with a magnitude of ~120 g. Since the noisegage channel magnitude is very low level compared to maximum level set up for all channels to measure 20,000 g pyroshock, the noise level of  $\pm 10$  g is evident. The corresponding DFT in Figure 9 is typical of a short-duration spike or pulse. But what does this noise do to the other channels that are responding to the highmagnitude, high-frequency pyroshock environment combined with the electromagnetic noise?

A wavelet analysis<sup>18</sup> was performed on the data in Figure 4 to correct the erroneous velocity change. Figure 10 is the acceleration data corrected with wavelets,<sup>19</sup> and the corresponding velocity change and SRS are in Figures 11 and Figure 12, respectively. There is no discernible difference between the original accelera-



Figure 8. Accelerometer time history of the noise gage.



Figure 9. Wideband discrete Fourier transform of noise gage acceleration time history in Figure 8.



Figure 10. Near-field pyroshock acceleration time history corrected with wavelets.

tion time history in Figure 4 and the corrected acceleration time history in Figure 10. The integral of the acceleration time history in Figure 10 yields an oscillatory velocity time history in Figure 11 that agrees with the physics of the test configuration, a zero-mean velocity. In both Figures 7 and 12, the SRS approaches a constant value of 20,000 g above 20 kHz that is a direct result of the analog anti-aliasing filter cutoff frequency of 20 kHz. With the wavelet correction, the SRS in Figure 12 has the correct low-frequency slope.

The wavelet analysis not only produces a corrected acceleration



Figure 11. Integral of acceleration time history in Figure 10.



Figure 12. Shock response spectrum of acceleration time history in Figure 10 (Q=10).



Figure 13. Time history of wavelet correction removed from acceleration time history in Figure 4.

time history but also the time history that was removed from the original data as shown in Figure 13 with its corresponding SRS in Figure 14. So, Figure 10 plus Figure 13 equals the original, corrupted acceleration time history in Figure 4. The data removed from Figure 4 with wavelet analysis has a magnitude of +800/–500 g, or ~4% of the amplitude in Figure 4 and has a highly oscillatory time history that is the response to the combined environment of pyroshock acceleration and noise by either the signal conditioner, the associated DAS, or both.

The two characteristics of slew-rate problems are present in Figure 13 - low-frequency modulation (800 Hz, as shown in the SRS)



Figure 14. Shock response spectrum of acceleration time history in Figure 13 (Q=10).



Figure 15. Shock response spectrum comparison for corrupted acceleration (Figure 4) and removed wavelet correction (Figure 13) (Q=10).

and an offset. Although the slew rate for this signal conditioner and DAS combination was not provided, it is assumed to be 0.2  $V/\mu s$  based on the parameters that were provided. A comparison of this slew rate with that in Table 2 indicates this slew rate is two orders of magnitude less than it should be. A direct comparison of the two SRSs from Figures 7 and 14 is made in Figure 15, and the curves directly overlay each other up to a frequency of 800 Hz, depicting the low-frequency contamination.

Also, Figure 14 shows that the upper-frequency limit of the wavelet correction is 800 Hz and does not change the high-frequency content above 800 Hz that is crucial to creating an accurate pyroshock specification from the SRS. What was initially assumed to be a structural frequency at 800 Hz is now shown to be erroneous, and the results are consistent with near-field pyroshock. The SRS in Figure 12 can now be used to create a specification with a high degree of confidence, because the low-frequency asymptote is correct and the high-frequency content has been preserved. However, the peak acceleration at 10 kHz may be an artifact of the isolated PE accelerometer.

Even though the time history correction (Figure 10) is ~4% of the original acceleration time history, it causes both an erroneous velocity change and an erroneous SRS low-frequency slope. Detonation noise (or other noise) contamination of the pyroshock accelerometer data is a common problem and *may* be prevented with a battery-operated device for pyrotechnic detonation or special facilities constructed to eliminate electromagnetic noise (i.e., Faraday cage or similar device). In any case, it is the data analyses of the original acceleration data, the noise channel data, and the wavelet analysis that reveal the source of contamination of the acceleration time history in Figure 4.

#### Conclusions

The data presented here were measured and acquired using equipment that is very popular for pyroshock measurements. However, in comparison to the recommended pyroshock DAS specifications in Table 2, it is clear why the data are corrupted, in one case by aliasing and in the second case by slew rate limitations. If only the acceleration time history pyroshock and the SRS (plotted over the conventional frequency range of 100 Hz to 10,000 Hz) are examined, both sets of data are plausible. It is the integral of acceleration time history or the velocity time history that reveals the corruption of the data.

Both data sets were measured with a four-pole Butterworth, low-pass AAA filter (24 dB/octave rolloff slope and 20,000 Hz cutoff frequency). Measurement of pyroshock data requires a much sharper AAA rolloff of 60 dB/octave; and the bandwidth of 20,000 Hz results in limited slew-rate capability that invalidates the data.

Additionally, the sigma-delta DAS architecture used to measure the slew rate limited data shows clearly that the sigma-delta architecture by itself does not guarantee valid data. Even more importantly, these two examples are for illustration purposes only and in no way imply that data correction should be routinely employed to make up for inadequate measurements. Since these corrupted data were acquired during the last two years, it is probable that a large quantity of pyroshock data that have been collected are corrupted in some way.

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