G.R.A.S.
SOUND & VIBRATION

Application Note

Measurement of Impulsive Noise

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Measurement of short impulsive noise signals with broad frequency spectra in a free field requires the use of small transducers. The transducer may either be a free field type microphone used in a 0 deg incidence configuration or a pressure type transducer used in a 90 degree incidence configuration. The resulting measured peak value will depend on the frequency range of the transducer and the size of the transducer together with the diffraction caused by the transducer. Further more the phase response of the transducer together with the phase response of subsequent amplifiers and anti-aliasing filters will influence the results.

Introduction

Result of measurements of short impulses is often reported as the Peak Value of the impulse as a measure of the magnitude of the signal. The value of the Peak Value depends however on a number of factors such as type of transducer used for the measurements, bandwidth of the transducer, anti-aliasing filter and sampling rate in the A/D-conversion.

Ideally the transducer or microphone should be infinitely small so as not to disturb the sound field to be measured. In practice the transducer has however to have a certain size in order to obtain sufficient sensitivity to measure the impulse. The transducer converts the acoustical pressure signal to an electrical signal and this has to be handled by the preamplifier. In many cases with very high impulses as near explosions etc. the limitation to the dynamic range of the system is not determined by the microphone, but by the associated preamplifier's capability to handle the signals. If the preamplifier furthermore has to drive a long cable between the preamplifier and the data acquisition equipment, slew rate limitations may easily limit the systems capability to handle high level, short impulses.

The data acquisition system will also affect the measured peak level. Anti-aliasing filters before the A/D converter will influence the peak by changing the bandwidth of the signal and the phase characteristic of the filter will change the shape of the impulse. Finally the sampling rate will influence the ability of the system to handle very sharp impulses.

The measurements have been performed with a National Instruments PXI-6120 simultaneous sampling data acquisition

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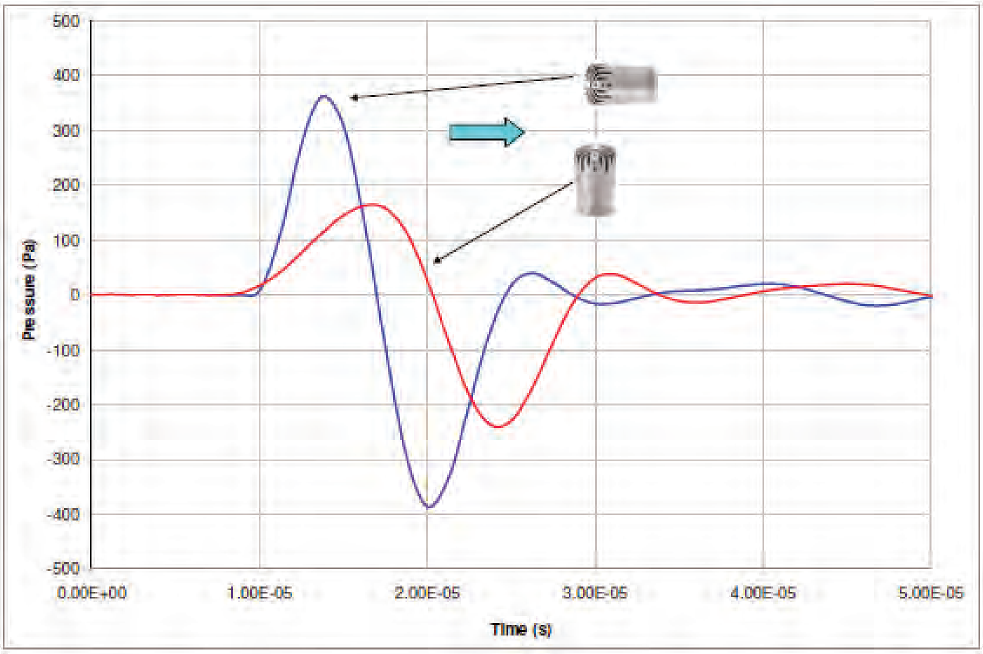

Fig. 1. *Impulse measurement with two microphones.*
Red curve: ¼" pressure microphone perpendicular to the wave propagation
Blue curve: ¼" free field microphone pointing towards the wave propagation

board mounted in a 4-slot PXI chassis. This board allowed four data channels to be recorded with sampling rates up to 800 kHz with an analog trigger facility. The data was stored in a 64 M Sample on-board data buffer, and was set up to record 50 ms of data before the trigger with a total data length of 0.5 s. The data were sampled with 16 bit resolution giving a 90 dB dynamic range. The data acquisition was controlled by a custom LabView program with integrated calibration routines and trigger control and the data were afterwards post-processed with National Instruments Diadem.

Type of Transducer

There are basically two types of microphones relevant for impulsive measurement: free field microphones or pressure microphones. Free field microphones are designed to measure the sound pressure in a free field as it was before the microphone was introduced in the sound field. At high frequencies, where the size of the microphone is comparable to the wavelength, diffraction around the microphone body will change the sound field locally. The free field microphone is designed to compensate for the "disturbance" of the sound field, if the microphone is pointed towards the sound source. Pressure microphones are on the other hand designed to measure the sound pressure as it is on the diaphragm of the microphone, including the diffraction effects caused by the microphone's presence in the sound field. By pointing the microphone perpendicular to the direction of the sound field propagation direction, this influence can be minimized.

The influence of the choice of transducer can be illustrated with the graphs in Fig. 1, which show measurements of an impulse generated by an electrical spark generator.

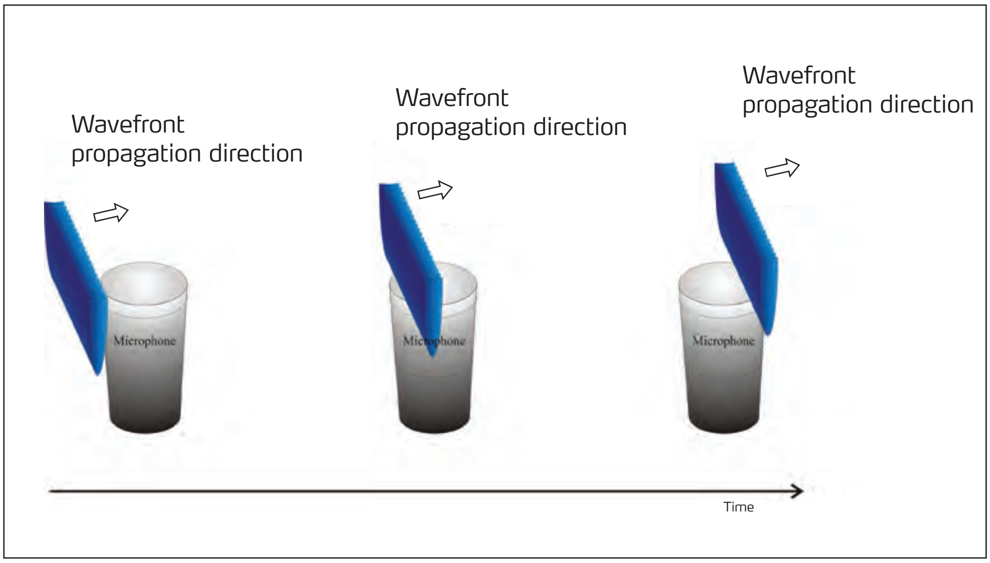

Fig. 2. *Impulse travelling perpendicular to the diaphragm*

The impulse was measured with a G.R.A.S. 40BP ¼″ pressure microphone and a G.R.A.S. 40BF ¼″ free field microphone. It can be seen that the pressure microphone perpendicular to the wave propagation both under-estimate the peak value and distorts the time signal. This is because the size of the ¼″ microphone is large compared to the extension of the impulse wave front.

If the duration of the initial positive pressure pulse is estimate to be 7 μs and with a propagation speed of 340 m/s, the pulse width will be approximately 2.4 mm. This is relatively small compared to the size of the microphone diaphragms, which for the ¼″ microphone is approximately 4 mm. As illustrated in Fig. 2 the short impulse will travel over the diaphragm area and excite only part of the sensitive diaphragm. This will distort the wave form and reduce the measured peak value. This can be verified be repeating the same experiment using a ⅛″ microphone (G.R.A.S. 40DP ⅛″ pressure microphone) with half the diameter and a ½″ microphone (G.R.A.S. 40AC ½″ pressure microphone) with the double diameter both perpendicular to the propagation direction instead of the ¼″ microphone as shown in Fig. 3 on page 5. This illustrates that for a certain size of microphone, for example ¼″ microphone, the free field type microphone should be preferred.

Microphone Size

As indicated in Fig. 3 on page 5, the microphone is influencing the measured impulse. For the pressure microphone used perpendicular to the propagation direction, this influence is in part caused by the size of the diaphragm area compared to the duration of the impulse as shown in figure 2. For free field microphones pointed towards the sound source, the size of the microphone will also influence the result as the frequency range for the microphone normally depends on the microphone size.

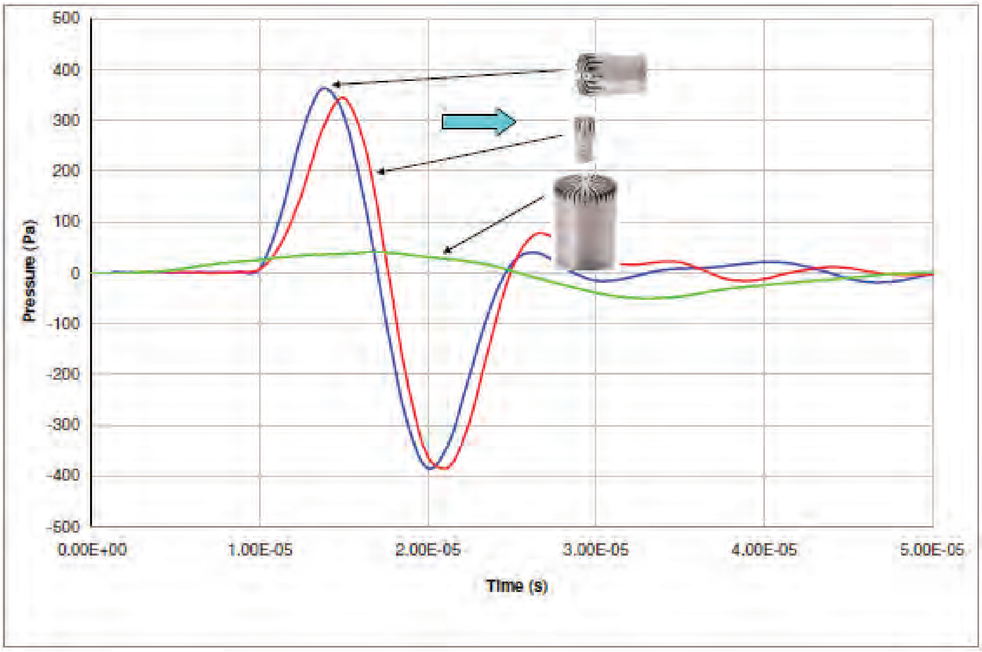

Fig. 3. *Impulse measurement with three different microphones.*
Blue curve: ¼" free field microphone pointing towards the wave propagation
Red curve: ⅛" pressure microphone perpendicular to the wave propagation
Green curve: ½" pressure microphone perpendicular to the wave propagation

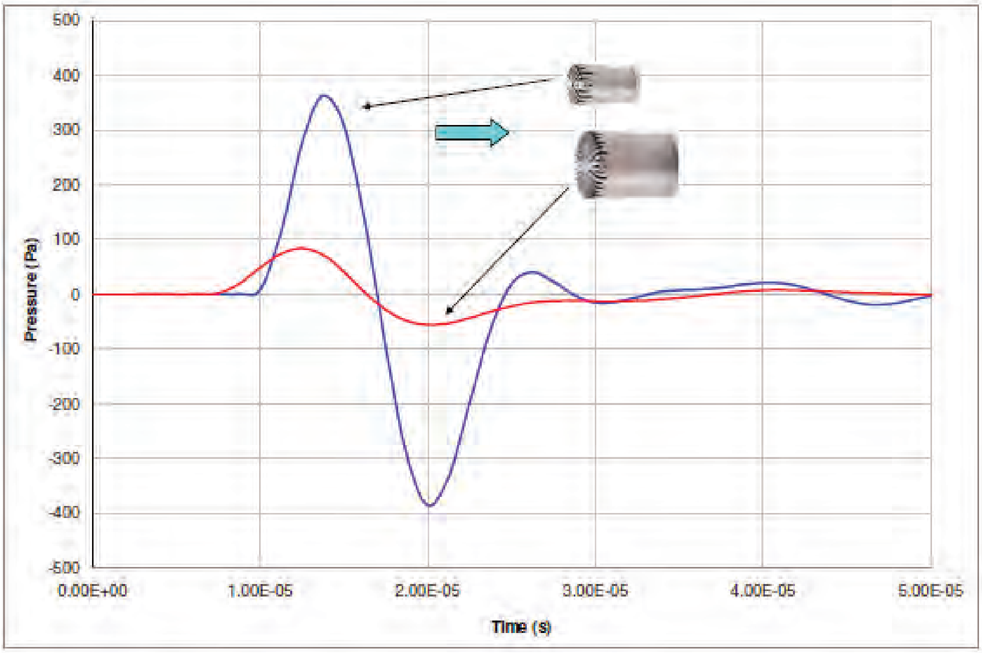

Fig. 4. *Impulse measurement with two different microphones.*
Blue curve: ¼" free field microphone pointing towards the wave propagation
Red curve: ½" free field microphone pointing towards the wave propagation

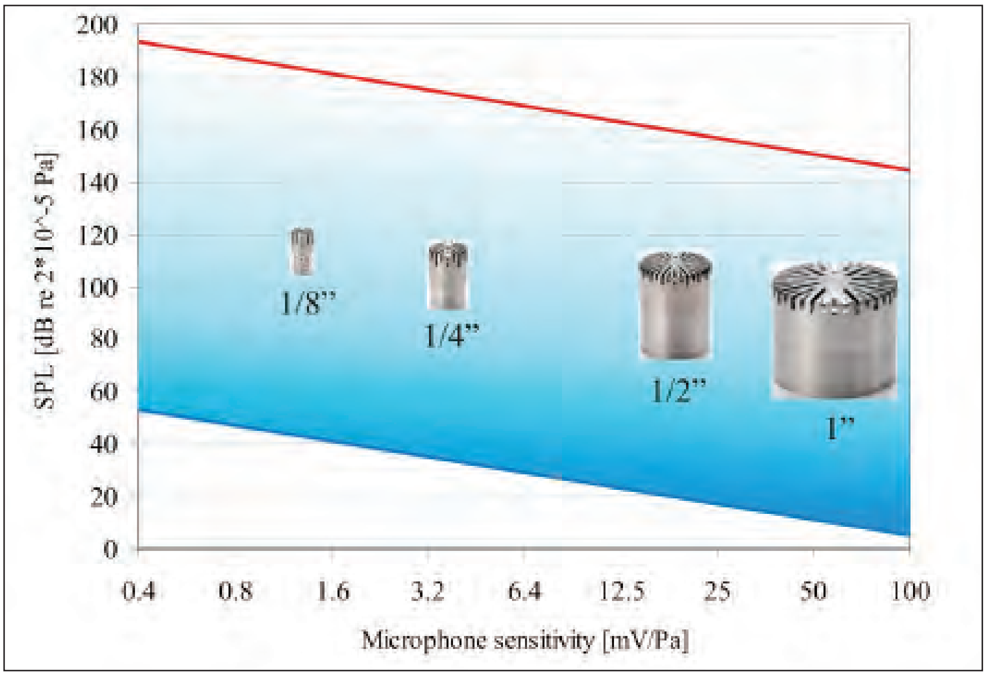

Fig. 5. *Microphone dynamic range as function of microphone sensitivity and typical microphone dimensions.*

Typically a ½" microphone can cover the frequency range up to 20 or 40 kHz, while a ¼" microphone can cover the frequency range up to approximately 100 kHz.

The difference in the recorded impulse caused by the difference in bandwidth can be seen in Fig. 4 on page 5, which shows the response of a ½" free field microphone type G.R.A.S. 40AC and a ¼" free field microphone type G.R.A.S. 40BF. It can be seen that the impulse peak value as measured with the ¼" microphone is around 360 Pa, but only around 80 Pa for the ½" microphone.

Besides the consideration related to the frequency range for the microphone, the dynamic range of the microphone needs also to be considered when choosing microphone size. In general, the size of the microphone is related to the sensitivity of the microphone and thereby the upper and lower limits of signal that can be measured. In order to measure very high level impulses it is thus necessary to use small microphone with very low sensitivity and for low level impulse a large, high sensitive microphone.

Anti-aliasing filter

The type of anti-aliasing filter and the cut-off frequency will influence the measured peak value. This can be demonstrated by analyzing the same signal with different filters. The simulations were performed with Labview on a signal measured with a 1/8" microphone on a pressure impulse generated by a blast tube. The original signal was measured with sampling rate of 800 kHz, which was assumed to be high enough compared to the frequency range of the microphone. The original signal is seen in Fig. 6 on page 7. This signal was then processed with three different types of filters, all with 48 kHz cut-off frequency.

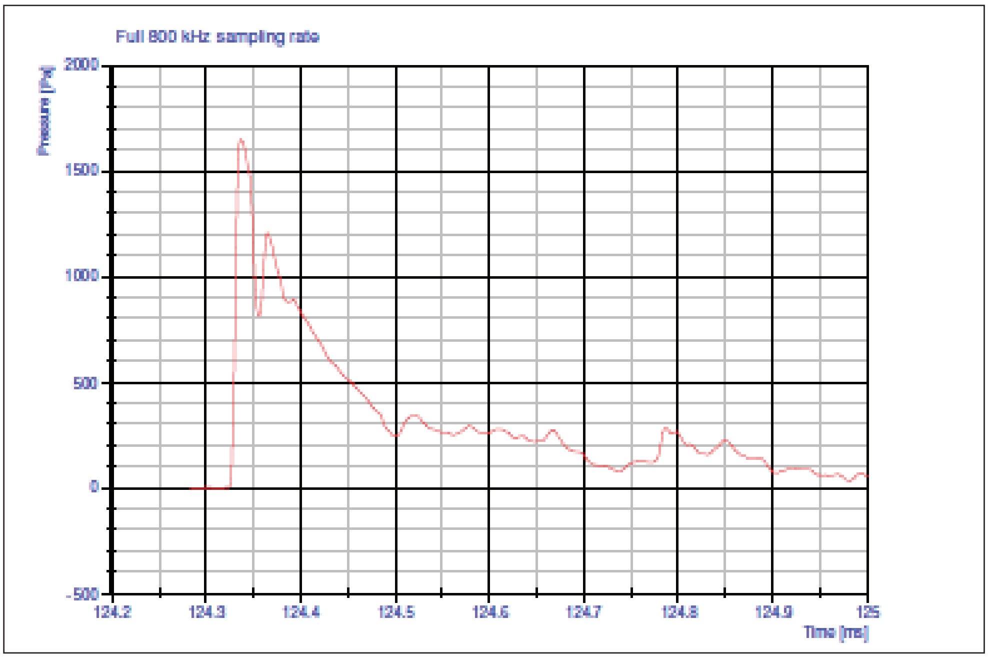

Fig. 6. *Raw signal from blast tube*

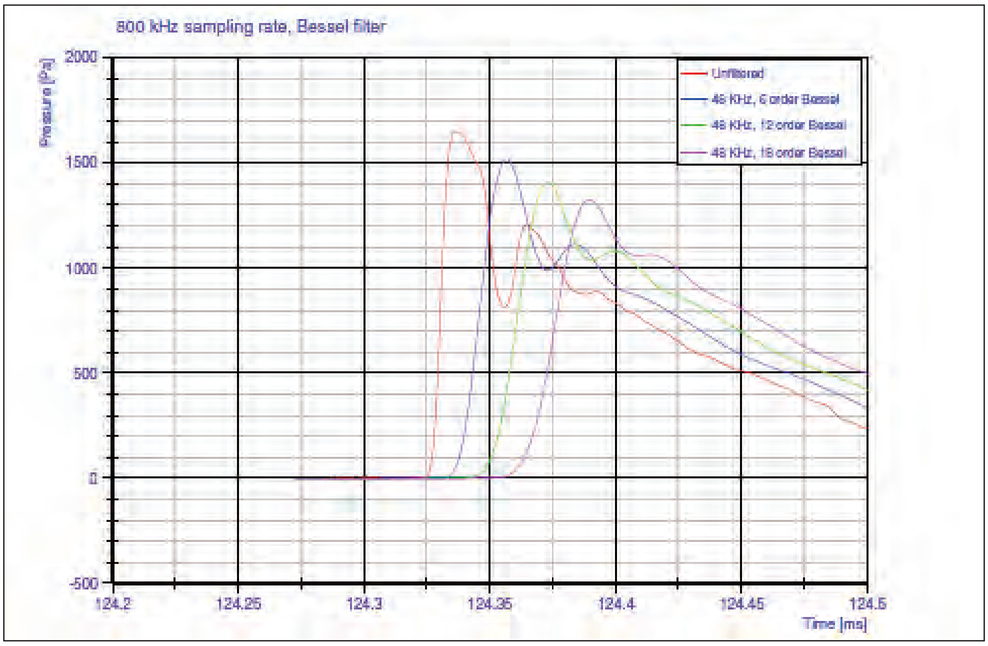

Fig. 7. *Signal from blast tube unfiltered and filtered with 48 kHz Bessel filter*
Red Curve: unfiltered
Blue Curve: 6 order Bessel
Green Curve: 12 order Bessel
Purple Curve: 18 order Bessel

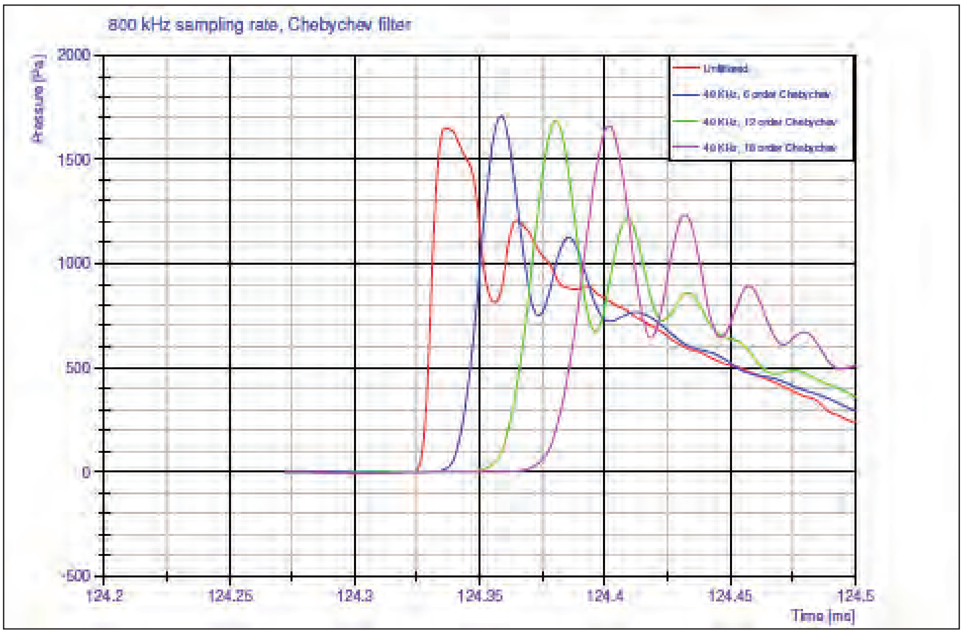

Fig. 8. *Signal from blast tube unfiltered and filtered with 48 kHz Chebychev filter*
Red Curve: unfiltered
Blue Curve: 6 order Chebychev
Green Curve: 12 order Chebychev
Purple Curve: 18 order Chebychev

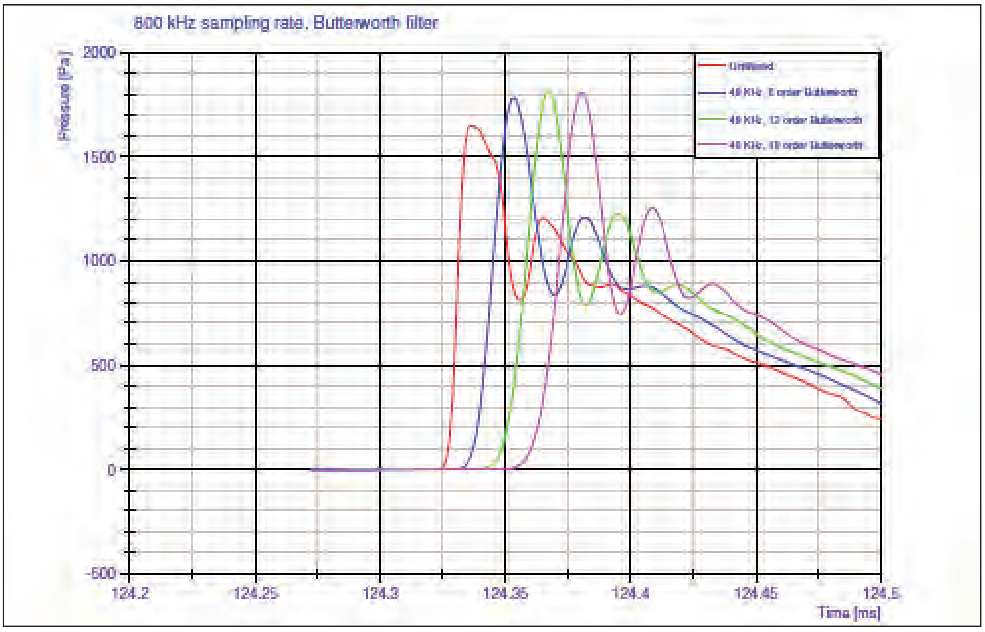

Fig. 9. *Signal from blast tube unfiltered and filtered with 48 kHz Butterworth filter*
Red Curve: unfiltered
Blue Curve: 6 order Butterworth
Green Curve: 12 order Butterworth
Purple Curve: 18 order Butterworth

For each type of filter the signal was processed with three different filter settings corresponding to different filter cut-off slopes. It can be seen that the Bessel filter will reduce the peak value. The actual reduction will depend on the specific input signal. The Butterworth filter will slightly over-estimate the impulse, while the Chebychev filter gives the best reproduction of the peak, but with more ringing after the filtering.

Conclusion

When stating peak values as a measure of the magnitude of an impulse it is important to consider the bandwidth of the transducer and subsequent analysis system. Also when comparing reported values for peak level of impulses it is important that these have been measured with comparable instrumentation.

Acknowledgment

The data used for the simulation of the influence of anti-aliasing were obtained with the blast tube at NIOSH Cincinatti thanks to Dr. William J.Murphy.