



Endevco

**Practical considerations of accelerometer noise**

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**Practical considerations of accelerometer noise**

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This paper is written as an overview on low-noise piezoelectric accelerometers and will review when and where low-noise devices are needed as well as the engineering tradeoffs made during the design of the device.

**I. When is low-noise a factor?**

Noise can be defined as any undesired signal. This paper will limit the discussion to noise generated by the electrical and mechanical components of the accelerometer, the amplifier and cables.

Figure 1 below shows examples of Endevco accelerometers and their relative noise spectra. The model 86 is an ultra low-noise device used in very low noise applications. The model 5220 is an industrial accelerometer used where frequency response is of interest and low-noise is secondary.

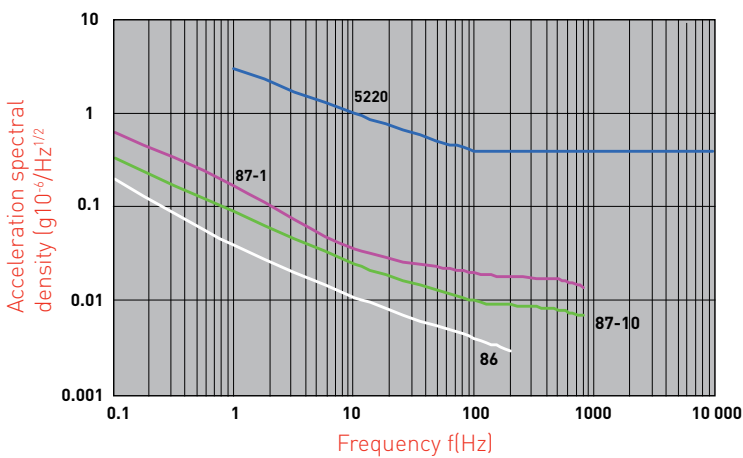
**Here are some examples of where low-noise accelerometers and electronics are required**

**Seismic applications**

This is an area that has two basic requirements including low level-low frequency signals often in the presence of larger signals. This requires both a wide dynamic range and very low-noise. For example, an event that has a displacement amplitude of +/- 1" (25.4 mm) peak to peak will produce only 0.5 mg (0.0035 m/sec<sup>2</sup>) of acceleration. To measure these levels with any reasonable amount of accuracy, a very low-noise measurement system is required such as the Endevco 86 or 87 accelerometer. More details will be covered in the next section of this paper.

**Wide dynamic range**

This might be an application where a single accelerometer may have to be used to measure both a high shock response and then is called upon to measure low levels of vibration. This application would call for the use of a relatively insensitive accelerometer with a low noise floor. In general terms, this is a device with a wide dynamic measuring range.



**Figure 1** A comparison showing the acceleration spectral density of a typical industrial accelerometer vs. two Endevco low noise accelerometers, the model 86 and 87.

This type of measurement problem is often encountered in rocket and missile testing thus small lightweight devices are required. Depending on the requirements, the engineer needs to make a choice between using an IEPE (Isotron) or a piezoelectric charge-mode accelerometer.

### Other low-noise applications

Some industrial applications require the use of low-noise accelerometers when observing low frequency, low level events. Many of these applications call for a threshold of 10  $\mu\text{g}$  for a signal-to-noise level of 10 (20 dB).

Very low-level signals are often encountered in medical applications requiring low-noise sensors.

### Low levels

When making low level measurements it is important to consider both the noise floor and the sensitivity of the accelerometer (see equation below). The noise specifications can be found on IEPE (Isotron) data sheets and are generally given in "equivalent "g", referred to as the threshold, where:

$$\text{Threshold (in g rms)} = \frac{\text{Noise in mV (over a specified frequency range)}}{\text{Sensitivity in mV/g}}$$

As an example, the Endevco model 86 has a threshold of 0.1 ng rms based on a bandwidth of approximately 1 kHz.

There are instances where noise is of minimum interest (note; this is minimum interest, not NO interest)? Generally speaking, low-noise devices are not required when measuring very high shock signals since maximum amplitude of the signal is of major importance. Also, when measuring high levels of vibration such as imbalance on a large rotating machine, no special consideration as to accelerometer noise is generally required.

## II. Noise considerations in accelerometer design

Since there is no one accelerometer that "does all" there are trade-offs that the designer must consider during the development of the device. For example, when making a subminiature device, small size and lightweight must give way to very low noise and high output, which will be explained within this section. There are several noise sources within the acceleration

measurement chain. These consist of noise that originates from the transducer element's electrical and mechanical properties. Other factors include the electronics, be they internal electronics (IEPE, Isotron, etc.) or external charge amplifiers. Over the years, piezoelectric material sciences, including single crystal technology, have advanced to the point where the noise generated by the crystals is so low that, if implemented and installed correctly, presents a very minimal amount of noise to the measuring chain. Crystal systems with higher charge sensitivity require less gain within the electronic system thus resulting in lower total system noise.

The following sections are brief reviews of three major noise sources within the acceleration measurement system.

### Sources of Accelerometer Noise

Noise sources are broken down in terms of mechanical-thermal noise and electrical thermal noise. The noise power spectral density of the sensor is:

$$P_{sd} = \sqrt{a_{nm}^2 + a_{ne}^2}$$

Where:  $a_{nm}^2$  = mechanical noise  
 $a_{ne}^2$  = electrical noise

Mechanical noise can be related to the mass and spring constant and mechanical resistance of the sensor's seismic system. Mechanical noise can be reduced by increasing the mass and quality factor (Q) or by decreasing the resonance frequency. One can easily see that these factors represent tradeoffs in terms of frequency response. Mechanical-thermal noise is dominant over electrical-thermal noise above 10 kHz.

Electrical-thermal noise is the second source of sensor noise. This noise source is in addition to noise contributed by any internal or external electronics used in the measurement system. Electrical noise is a function of the sensing materials loss factor which is the inverse of the materials quality factor. When

selecting and processing material for low-noise applications, materials with few defects and impurities are selected. Losses are increased by the addition of capacitance and thus an increase in the electrical noise. This noise source is generally dominant at frequencies below 10 kHz.

The internal electronics of Isotron (IEPE) type accelerometers represent an additional noise source. FET's have been used at the input stage of the internal electronics due to their high input impedance. JFET's are generally the transistor of choice, but the semiconductor manufacturers are reluctant to publish noise specifications thus sensor designers must use their experience to choose the best components. Many low-noise accelerometers include internal electronics. This design approach improves signal to noise ratios since the extremely short distance between the sensor and charge amplifier reduces the capacitance thus eliminating a source of noise.

As a user, one can generally expect to find that lower noise devices are larger in size and mass than accelerometers with higher residual noise specifications. As discussed above, the larger size is the result of a higher mass and as a size comparison, Figure 2 shows two low-noise accelerometers and their relative size difference. The crystal sensor assemblies can be larger in order to produce a higher output level. Also keep in mind that as the mass is increased, the resonance frequency is reduced thus lowering the accelerometer's frequency response.

### III. User actions

Up to this point, we have covered what the manufacturer does to decrease the noise level of accelerometers. There are many actions that the user can do, and in some cases must do, to ensure a clean noise free sensor output. This section will cover charge mode accelerometers than voltage mode sensors. Most of the emphasis will be on charge mode accelerometers since they are the most susceptible to noise.



**Figure 2** Showing the Endeveco models 86 and 87 low-noise accelerometers. Note the large size of the model 86, which is the ultra low-noise unit.

### Cable problems

Cables should be as short as possible. Short cable lengths are especially important when used with charge mode accelerometers.

As discussed in section II, capacitance (when using a charge-mode accelerometer) will add to the noise floor of the accelerometer's output signal. A cable looks like a capacitor and a typical cable has a capacitance of approximately 30 pF/foot. It is easy to see that the longer the cable, the more the capacitance, thus more noise. In addition, a long cable acts as an antenna and will pick-up electromagnetic signals.

Only cables with low-noise treatment should be used with charge mode accelerometers. Cable motion will cause the self generation of electrical noise from within the cable. This self-generated noise is referred to as the Triboelectric effect. The low-noise treatment is the solution to minimizing this effect. It is still necessary to limit the motion of cables to further reduce noise.

Voltage mode accelerometers can use ordinary coaxial cable and are less susceptible to noise pickup due to their low impedance characteristics. Again, long cables act like antennas thus length should be limited. It is

often necessary to increase the excitation current as cables length is increased which will result in increased noise generation.

### Charge converters and amplifiers

A technique to reduce cable noise is the use of an in-line charge converter (Figure 3). In-line charge converters are joined to a charge mode accelerometer with a short length of low-noise cable. The charge converter provides a low impedance voltage output, which is most desirable for long cable runs. Charge converters are powered by conventional IEPE current sources and look like an IEPE accelerometer to the measurement electronics. The short cable between the accelerometer and charge converter provides for a low capacitance load resulting in a lower noise acceleration signal.

Care must be taken in making sure that all cable connections are as clean and dry as possible. This is of paramount importance on charge-mode piezoelectric accelerometers. Connectors must be cleaned with alcohol and then dried with a lint-free wipe. While cleaning is not as critical on IEPE devices, it is still a good practice to ensure precision measurements.

With the introduction of the Endevco 2771C charge converter, the signal to noise ratio has been improved up to a factor of five times that of most other charge converters.



**Figure 3** Endevco 2771C low-noise charge converter with 10-32 Accelerometer connector and BNC for the conventional two wire IEPE output/power

Lastly, the user should be aware of the noise characteristics of subsequent voltage amplifiers in the measurement chain.

IEPE current sources are found in many data acquisition systems and FFT analyzers. These built-in sources of power are convenient and work well in most applications. When making low-noise measurements, it is advisable to know the noise characteristics of the internal power source. Many internal current sources use voltage converters that produce noise that can be introduced into the accelerometer's output signal. If the built-in current source noise is a problem, use an external power supply such as the Endevco model 133.

### Selecting the right accelerometer

Last and most important; select the right accelerometer by reviewing the noise specifications. Data sheets provide a noise threshold in equivalent g's. Noise spectral density figures are also provided and should be observed, especially when making low-noise measurements at low frequencies. The noise spectral density information provides noise information as a function of frequency. A quick way to determine if the accelerometer selected has a low enough noise floor, use the rule-of-thumb: the lowest g level to be measured should be 10 times the threshold level.

There are other noise sources the user should be aware of such as ground loops, etc. These topics are covered in other Endevco papers.

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