

AN ACCELEROMETER WITH INTERNAL SELF-TEST
AND IDENTIFICATION

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An Accelerometer with Internal Self-Test
and Identification

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Abstract—An accelerometer has been developed which on command generates a self-test signal immediately followed by a unique identification number. The self-test and ID signals are transmitted serially over the same wire that conducts the acceleration signal and input supply current during normal operation, so only standard two-wire cables and connectors are required. Self-test and ID are initiated by reducing the supply current below a specified threshold. The self-test and ID signals are generated by a digital CMOS ASIC, while signal conditioning, supply current detection, and voltage regulation for the digital ASIC are provided by a low-noise analog bipolar ASIC. The accelerometer itself is a doubly shielded, piezoelectric, annular shear type.

I. INTRODUCTION

Piezoelectric accelerometers are widely used to measure shock and vibration. They are very simple and reliable devices. Perhaps their largest drawback is their high impedance. Electrically they are equivalent to a small capacitor, typically a few hundred picofarads, in series with a voltage generator, or, alternatively, in parallel with a charge generator. This high impedance necessitates the use of well shielded cable with special construction to avoid tribo-electric noise arising from movement of the cable.

When environmental conditions allow, high output impedance problems may be avoided by building simple signal conditioning circuitry into the accelerometer. Accelerometers with internal electronics are widely used and are available from many manufacturers. Most accelerometers with internal electronics are limited to temperatures from -55 to $+125$ °C whereas some bare piezoelectric accelerometers can be used from -423 to $+750$ °C. However, in most applications, the -55 to 125 °C range is quite adequate.

To avoid extra cabling, accelerometers with in-

ternal electronics usually are designed as two-wire systems with power supplied by a constant current and the signal returned as an analog voltage on the same wire. Occasionally the power and signal roles are reversed: power is supplied by a constant voltage and the signal is returned as an analog current. Block diagrams of typical accelerometers are shown in figure 1.

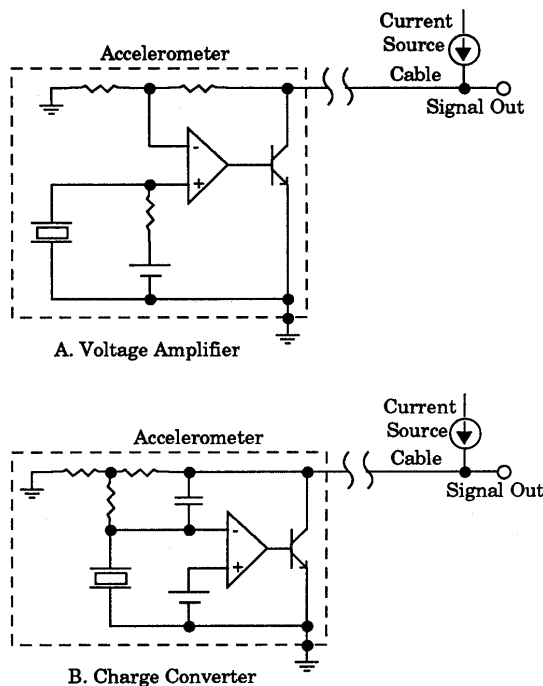


Fig. 1. Block diagrams of accelerometers with internal signal conditioning. A. Voltage amplifier. B. Charge converter.

The internal signal conditioner may be either a voltage amplifier as shown in in fig. 1 A or a charge converter, as shown in fig. 1 B. Internal circuitry is usually implemented as a hybrid microcircuit with discrete components. Great ingen-

uity has been exhibited in reducing these circuit to their bare essentials and jamming them into oddly shaped spaces to keep the accelerometers as small and light as possible.

While internal signal conditioning solves the problems associated with high output impedance, there still is room for improvement in over-all system reliability. Sometimes shock and vibration measurements require monitoring the acceleration at dozens of points scattered about a very large structure. Some of these points may be virtually inaccessible, and thousands of feet of cable may be re-

quired to connect the accelerometers to the central data collector. These circumstances might arise when measuring vibration in aircraft or naval vessels, in modal analysis of large structures, etc.

on a square-wave generator for a fixed number of cycles. The square-wave signal voltage is injected in series with the piezoelectric acceleration sensing element so that the entire signal processing and transmitting chain is exercised. This includes the PE element itself, so there are few if any failure modes that are not detected. At the end of the self-test, the accelerometer transmits a unique identification number by the same mechanism. The ID number is six octal digits; each digit is transmitted with an odd-parity bit. Figure 2 shows the waveforms of the test and ID signals.

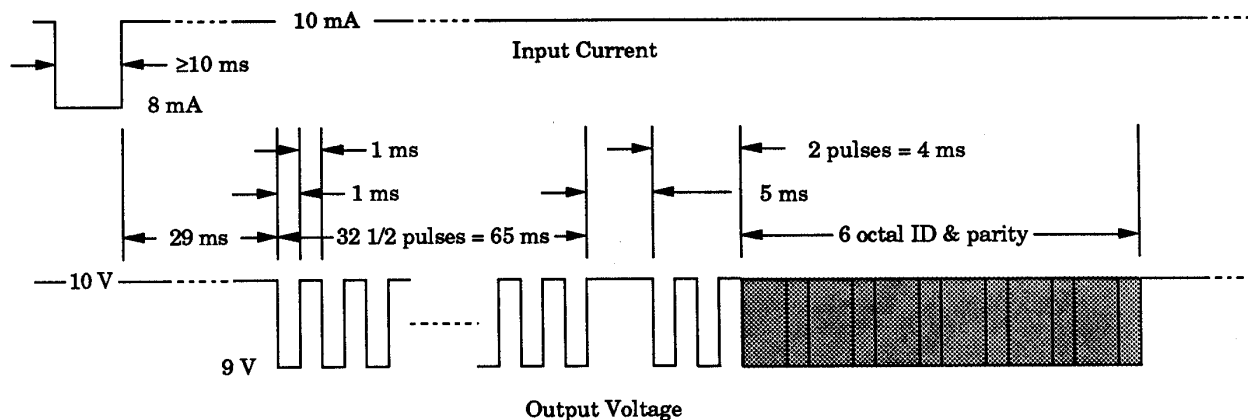


Fig. 2. Waveforms and timing of the self-test/ID signal. The start signal is generated by the analog ASIC when the supply current drops below a pre-defined threshold. It must persist for at least 5 ms or the self-test/ID signal will not appear.

quired to connect the accelerometers to the central data collector. These circumstances might arise when measuring vibration in aircraft or naval vessels, in modal analysis of large structures, etc.

In order to make accurate, reliable measurements with a large number of widely scattered accelerometers, it is essential to know with certainty which accelerometer is connected to a particular cable, that the cable is indeed connected, free of short or open circuits, and that the accelerometer and cable are functioning correctly together. Often this has required a lot of climbing around and banging on things, yelling back and forth, etc.

The Endevco 35427F accelerometer was designed to eliminate this unseemly behavior. It does so by generating a test signal and unique identification code upon command.

II. THE ACCELEROMETER

A request for self-test/identification is made by reducing the supply current to the 35427F accelerometer below a specified threshold. The accelerometer circuit recognizes this condition and turns

The 35427F was specifically designed for submarine vibration monitoring, though it has obvious application in other areas. A submarine must run quietly in order to hide effectively. Quiet running requires identifying and reducing internal noise sources. The noise sources may be identified by correlating hull vibration with the vibration of the various pumps, motors, etc. in the submarine that are potential sources of noise. Inasmuch as the ultimate goal is to reduce the hull vibration to the barest minimum, the accelerometer itself must have the lowest possible noise floor. Therefore the 35427F was constrained to have high sensitivity with low noise. The test and identification circuitry could not be allowed to increase the noise. Furthermore, many of the accelerometers must be incorporated into the submarine structure as it is built, and are essentially inaccessible thereafter. Because of this, the accelerometers had to be extremely reliable.

The Endevco 35427F accelerometer is a doubly-shielded annular shear type. All the circuitry is incorporated in a single hybrid microcircuit on an annular substrate mounted on the accelerometer's seismic mass. A schematic cross-section of the ac-

celerometer is shown in figure 3. The annular shear design provides low pyroelectric and base strain sensitivities.

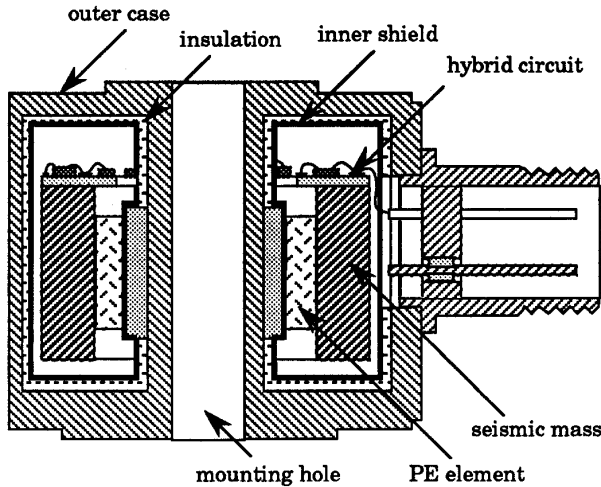


Fig. 3. Simplified cross-section of the Endevco 35427F accelerometer. The inner shield is insulated from the

Furthermore, the annular design allows for a mounting hole through the accelerometer so that it may be attached with a single screw with the side connector oriented in any direction. Double shielding provides low susceptibility to electro-magnetic interference. The inner shield of the accelerometer

is connected to the inner shield of the tri-axial cable, which serves as the ground return for the circuit. The accelerometer case provides the outer shield.

Figure 4 below is a block diagram of the circuitry. It shows how the circuit is partitioned between two application specific integrated circuits (ASICs). The analog functions are handled by a bipolar ASIC while the digital functions are handled by a CMOS ASIC.

The analog ASIC incorporates a charge converter (except for the first stage), a band-gap voltage reference, a voltage regulator to provide power to the digital chip, and a comparator to detect a request for self-test/ID as indicated by reduced supply current. To provide the lowest possible noise, the first stage of the charge converter uses an external, discrete, low-noise, dual JFET. The current source and load resistors for the JFET stage are on the ASIC chip.

The digital ASIC incorporates power-on-reset, clock oscillator and divider chain, timer, and ID encoder. The clock oscillator is shut off completely when the accelerometer is operating in its normal mode; this ensures that digital switching noise will not corrupt the acceleration signal. The timer holds off the self-test/ID signal until a request has been sustained for at least 10 milliseconds. This prevents temporary glitches from starting a self-test/ID cycle. The ID number of an accelerometer is incorporated into the hybrid microcircuit by dis-

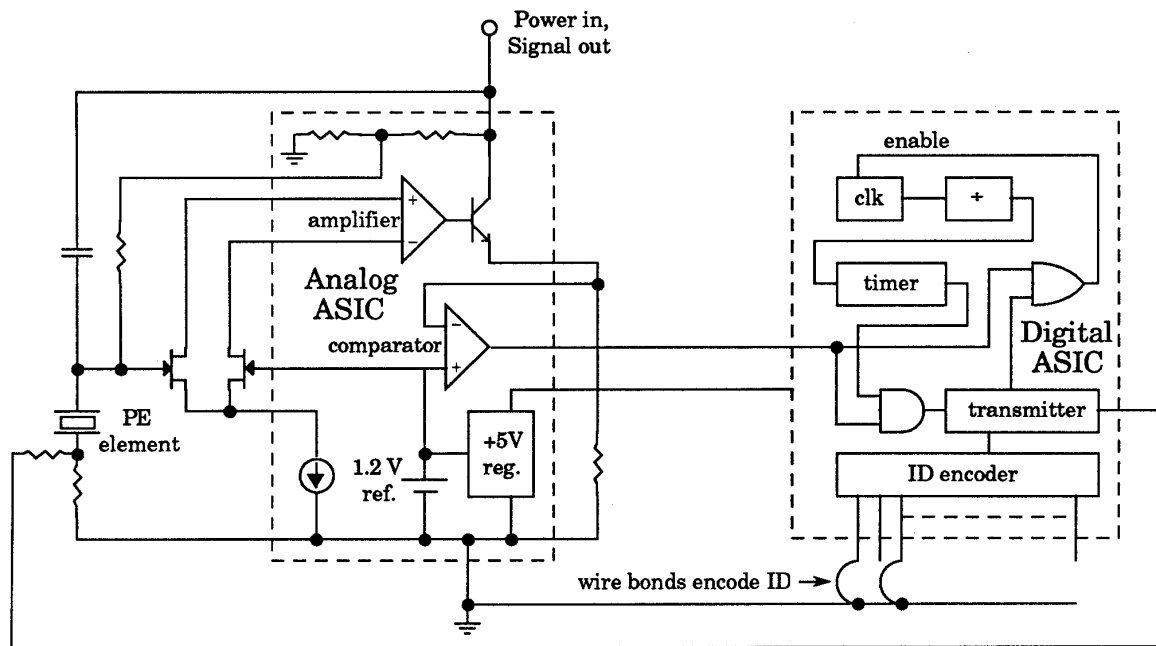


Fig. 4. Simplified block diagram of the Endevco 35427F accelerometer. An external dual JFET is used for the first stage of the signal conditioner to provide low noise. The self-test/ID signal is injected in series with the PE element so the entire signal chain will be checked.

cretionary wire bonds; each microcircuit is built with a different pattern of bonds.

In normal operation, the 35427F accelerometer operates just like other accelerometers with internal signal conditioning. Indeed, it may be used as an ordinary, dumb accelerometer. However, on command it enters this self-test/ID cycle: the analog ASIC detects reduced supply current and signals the digital ASIC. The digital ASIC clock and timer are started. If the reduced supply current signal persists until the timer times out, a test signal is generated followed by the ID signal specified by its internal wiring. At the end of the cycle, the clock is turned off. If the reduced supply current signal does not persist until the timer times out, the timer is reset, and the clock is turned off.

The specifications of the Endevco 35427F accelerometer are summarized in table 1.

TABLE 1

Endevco 35427F Summary Specifications

Linear range	±10 g minimum
Dynamic range	>100 dB
Sensitivity	100 mV/g ±5%
Frequency response	±10% from 5 Hz to 10 kHz
Resonant frequency	25 kHz minimum
Amplitude linearity	within ±1% of reading to ±10 g
Phase dispersion	±1.5° of specified curve from 5 Hz to 2 kHz
Transverse sensitivity	<3% in any transverse direction
Temperature response	±3% from 5 to 55° C
Self-test/ID	per fig. 2
Power requirement	10 mA constant current, 7 mA to request self-test/ID
Output impedance	<25 Ω
Noise	<167 μg, 5 Hz to 10 kHz, <33 μg in any 1/3 octave band
Diameter	.98" exclusive of cable
Height	.86" exclusive of mounting screw

III. DISCUSSION AND CONCLUSIONS

Test engineers increasingly are concerned that much of the test data that has been collected over the years at enormous expense is of dubious quality. This concern comes from the possibility that the accelerometers were not working properly or were not properly connected. Self-test/ID circuitry built into accelerometers can eliminate these doubts.

The Endevco 35427F accelerometer was designed specifically to measure vibration in submarines, but clearly would be useful in numerous applications, wherever large numbers of accelerometers are involved. The circuitry required to provide self-test and ID can be incorporated in an accelerometer at modest cost.

There are, of course, limitations on what should be expected from a self-test signal. It does not constitute a true calibration. That would require the whole accelerometer to be vibrated at a known acceleration. Nevertheless, the appearance of a self-test signal of the correct frequency and amplitude provides very high assurance that the accelerometer and its cabling are operating correctly.

The term "smart sensor" is rather vague. Some regard any sensor with internal signal conditioning as smart. Others regard only sensors with internal microprocessors as smart. Still, whether or not an accelerometer with self-test/ID capability is regarded as smart, it can serve to greatly increase the assurance that vibration data are in fact correct and accurate.

