Applications of Piezo Cable

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Introduction

Piezoelectric polymer film is well known for its very high sensitivity, broad bandwidth and wide dynamic range. Applications range from sub-audio to high ultrasonic frequencies. Since the late 1980's, the Sensor Products Division (formerly AMP Sensors, Atochem Sensors) have produced and supplied a cable form also, which uses piezopolymer extruded directly onto a stranded core wire, with conventional braid and jacket giving a final product very similar in appearance to a small coaxial signal cable.

Linearity and Dynamic Range

One of the inherent advantages of piezo cable over other forms of sensor is the ability of the cable to detect impacts or vibration ranging from very weak pressure signals caused by ground-borne vibration, through to impacts from heavy vehicle axles at high speed. The linear dynamic range exceeds 80 dB, as can be seen from Figures 1 and 2. One shows the stability of cable sensitivity over a 4 decade range of applied force, the other shows actual charge output for the same data set. In this test, force was applied using an electromagnetic vibration exciter.

Testing has been extended up to a level of 50 N/mm (using dropping mass impacts). At this level, the cable does not fail, but shows inelastic deformation of the core and braid. This result indicates a total working dynamic range of around 130 dB - quite an exceptional figure for such a simple sensor construction.

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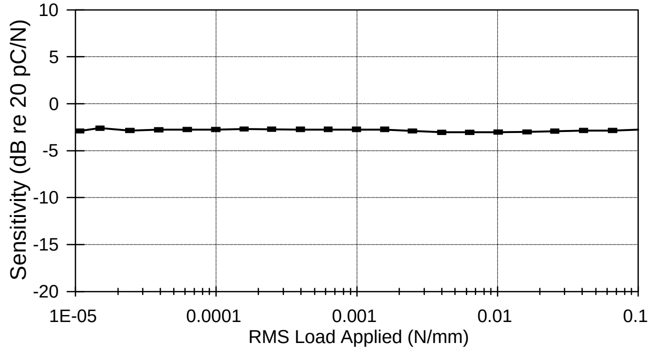

Figure 1: Sensitivity of piezo cable vs applied load, for continuous sine excitation at 120 Hz

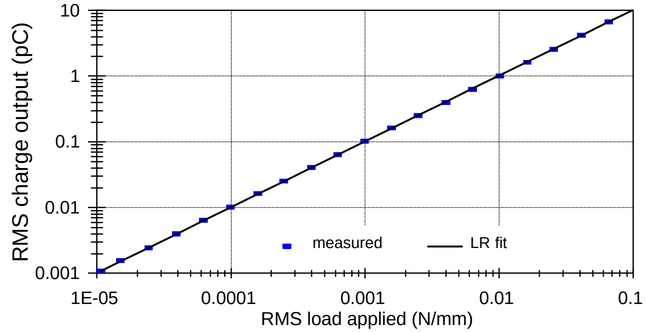

Figure 2: Charge output of piezo cable vs applied load, for the data set shown in Figure 1

Traffic Sensors

An initial target application for piezo cable was to form the sensor element for axle detectors, where a length of cable (typically 2 to 4 m) is protected by an extruded or moulded channel, and then embedded into the road surface. Use of two such sensors allows vehicle speed to be determined (although three sensors are often employed for higher confidence, especially for enforcement purposes). With the addition of an inductive loop, vehicles can be classified into the many categories required for long term statistical analysis of road usage.

Several generations of product have seen the development of a custom cable with solid brass outer electrode (in place of conventional braid and jacket), as a more rugged specific form for traffic applications. Typical output voltage waveforms are shown in Figure 3, representing a saloon car travelling at 75 kph passing over two sensors spaced 1 m apart.

Consistent waveform amplitude is of great importance for weighing-in-motion (WIM), where an algorithm calculates axle weight on the basis of the integral of charge output, scaled by vehicle speed. An example of a raw signal from a 5-axle heavy goods vehicle is shown in Figure 4. WIM information is of particular interest in the assessment of damage to road surface (pavement), as damage increases exponentially with axle load. Bridges, flyovers, and similar structures are also frequently monitored using WIM systems. As with speed detection, both statistical data gathering and enforcement are areas of interest. In general, the overall accuracy of piezo-based WIM systems is perhaps +/- 10% at best: even so, the convenience of such low-cost installations makes even “weight indicative” information highly desirable.

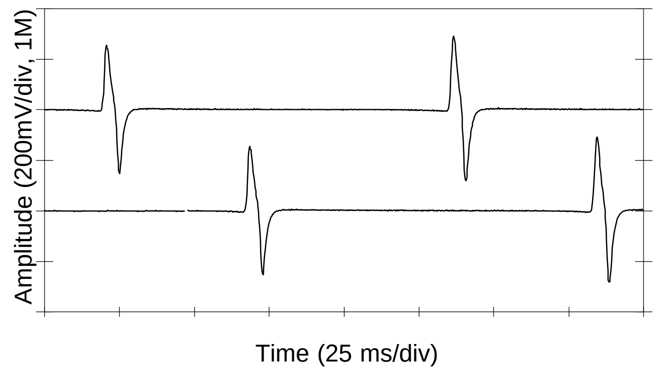

Figure 3: Output voltage recorded from two traffic sensors spaced 1 m apart, for passenger car travelling at 75 kph

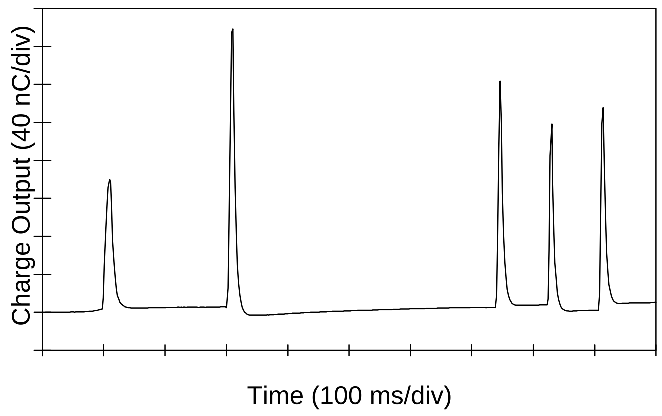

Figure 4: Charge output from transit of heavy goods vehicle, showing distribution of load over 5 axles

Presence / Occupancy sensing

The high sensitivity of piezo cable allows very low vibration levels to be detected with ease. In particular, the quasi-random signals generated by the human body (from blood circulation, muscle tremor, and micro-movement) can be transferred through the feet onto a "mat" containing piezo cable. When a person steps onto such a mat, an initial transient signal is generated which may be several volts in amplitude, followed by a continuous signal with strong components in the 1 to 100 Hz band - see Figure 5.

In exactly the same way, the presence of a person in a car seat may be detected by a piezo cable mat introduced into the structure of the seat. The upper plot in Figure 6 shows traces from a reference accelerometer (picking up the vibration signal from the floor pan of the vehicle), while the lower plot shows the charge output from a piezo cable mat with young child as occupant. The two signals are substantially uncorrelated, and the mat signal shows significantly stronger low-frequency components. Clearly, signals of human origin will show varying characteristics depending upon the physiology and temperament of the individual, and can be expected to change significantly if, for example, the occupant falls asleep. In such a case, discrimination between animate and inanimate loads may not be possible under all circumstances, but the presence or absence of a load can still be determined confidently.

A commercial application based on the same principle has been developed to detect presence of waiting pedestrians ("demand") at a controlled road crossing. Piezo cable, formed into a large mat, is laid underneath conventional paving slabs. Despite the presence of an additional static load, the vibration signals from even a young child can be detected, while vibration generated by the passage of road traffic very close to the sensor is rejected. Detection of demand for the crossing prevents the traffic from being stopped in the case where pedestrians have already crossed against the signal. Overhead detectors (microwave or infrared) are effective in "seeing" pedestrians while in motion (crossing the road), but are less able to discriminate waiting pedestrians against a complex dynamic background.

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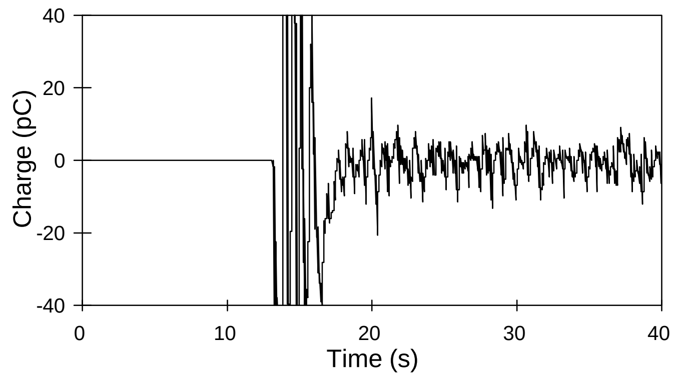

Figure 5: Piezo cable "mat", showing charge output as person walks onto the mat and remains standing still

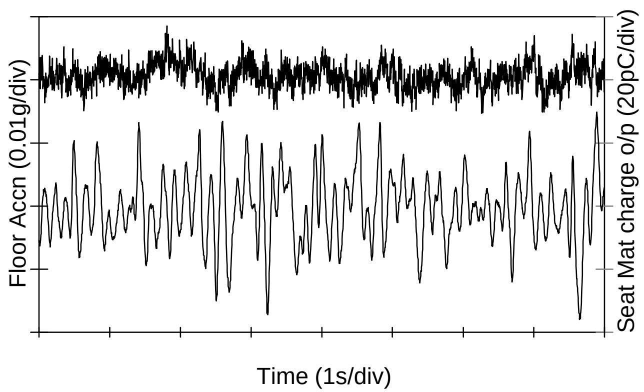

Figure 6: Cable mat installed in passenger seat of an automobile (lower trace), showing high amplitude, low frequency signals compared with chassis acceleration (upper trace)

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Vital Signs Monitoring

Carrying the principles described under "Presence/Occupancy sensing" to a logical conclusion, it has been shown that a mat comprising piezo cable embedded in a compliant urethane encapsulant may be placed in, on, or under a mattress, to detect pulse, respiration and gross bodily movement.

Satisfactory detection of breathing requires a preamplifier or monitoring circuit which has sufficiently long time constant (or equivalent low frequency response). Inhalation may take place over a period of more than one second, and therefore the electronics should have a significantly longer time constant. In practice, however, there are disadvantages in using very long time constants: the system may take a very long time to "settle" after switch-on, or after any significant high amplitude transients. Thermal effects due to slow heating or cooling of the piezo cable are not generally seen, but the open-circuit sensitivity to temperature changes is extremely high, and extended measurement time constants will reveal this.

The following plots (Figures 7 and 8) show results from a mat placed first on top of a foam mattress (approximately 90 mm thick), then when the mat was placed between the mattress and a carpeted, concrete floor. The mat comprised a 1 m length of piezo cable, supported in a "W" shape within a moulded urethane sheet 5 mm thick, nominally 300 mm square. A charge amplifier with lower limiting frequency of 0.2 Hz (to -10% of nominal gain) was found sufficient to detect breathing signals. Subject was a 70 kg adult male.

Comparison of the two traces shows that the relative balance between breathing and pulse signals was altered by the placement of the mat, with the breathing signal showing less relative amplitude with the mat placed underneath the mattress. But in both cases, respiration and pulse rate can clearly be seen.

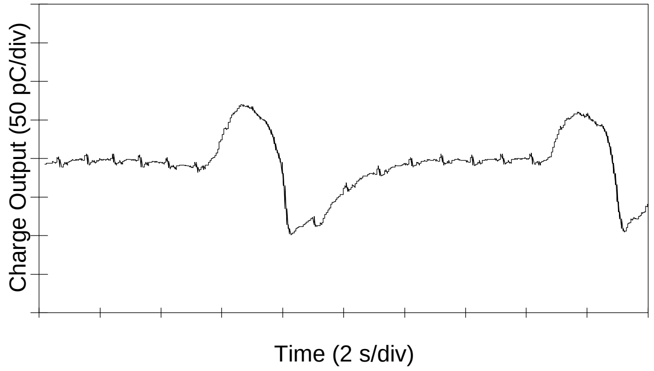

Figure 7: Response of cable mat, when placed on top of foam mattress

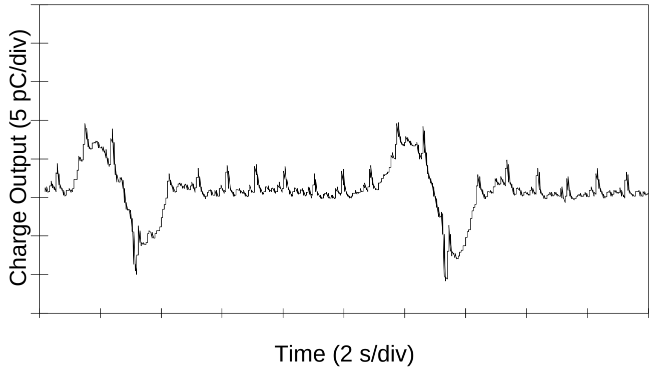

Figure 8: Response of cable mat, when placed between mattress and carpeted floor

Buried Cable for Perimeter Security

Long continuous lengths of piezo cable can be buried at a shallow depth in soil or sand to act as a distributed ground microphone or geophone. Depending on local soil conditions, a range of up to 50 m can be achieved for detection of a person walking normally. Wheeled or tracked vehicles can also be identified by advanced signal processing. Individual lengths of between 25 m and 1000 m of cable are deployed for each required detection zone. Use of a charge pre-amplifier allows unlimited , varying cable lengths to demonstrate identical sensitivity (use of a voltage-mode amplifier would result in long cable runs giving lower open-circuit sensitivity compared with short runs). Typically, an interface and RF transmitter is buried along with the sensor cable, so that information from the sensor may be covertly reported to a base station.

The cable is buried directly in the ground, just a few cm below the surface. The need for rapid deployment under difficult conditions often precludes the possibility if mounting within a prepared channel or conduit. System performance is obviously dependent on the sound transmission characteristics below the surface, but even dry sand has been found to give satisfactory detection range. Figure 9 shows an example of a commercial detector/transmitter designed for direct burial.

To illustrate graphically the sensitivity of such a system is difficult. Purely by way of example, a plot is shown in Figure 10, from a piezo cable buried at the edge of a domestic lawn, while a child walks from a location very close to the sensor to a few metres away, closes a wooden gate, and starts walking back. The footsteps at start and end of this time excerpt can be clearly seen. The ground reverberation from the gate closing (near centre of trace) can be seen to contain much higher frequency components than the footsteps.

A further plot (Figure 11) shows the "sound" of waves breaking on a stony beach, as detected by a 25 m length of piezo cable buried some distance up from high water line. The "rumble" of the shingle creates a high spectral energy in the 0 to 20 Hz region. Despite this continuous low frequency "background", a single footstep remains clearly detectable by its relative amplitude and frequency characteristics (see Figure 12, noting different x and y scaling from Fig 11).

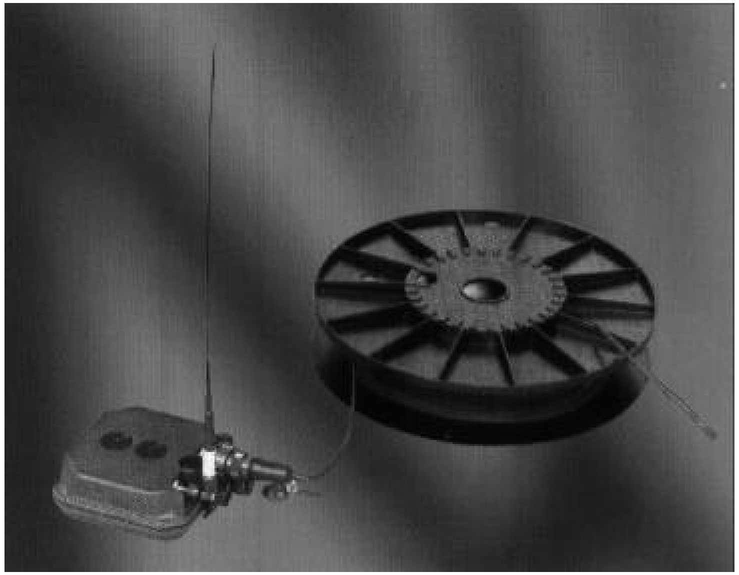

Figure 9: Piezo cable as a buried perimeter security sensor, together with detection and RF transmission module

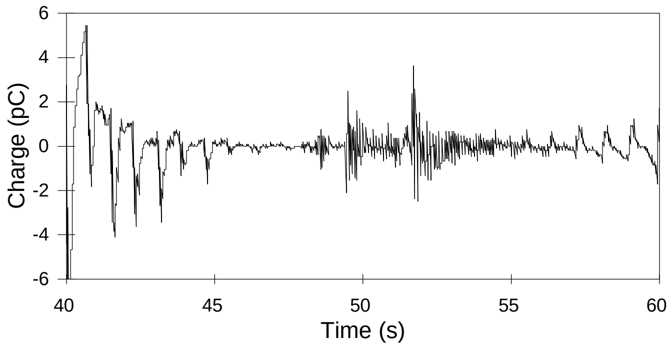

Figure 10: Buried piezo cable, detecting footsteps and gate closing

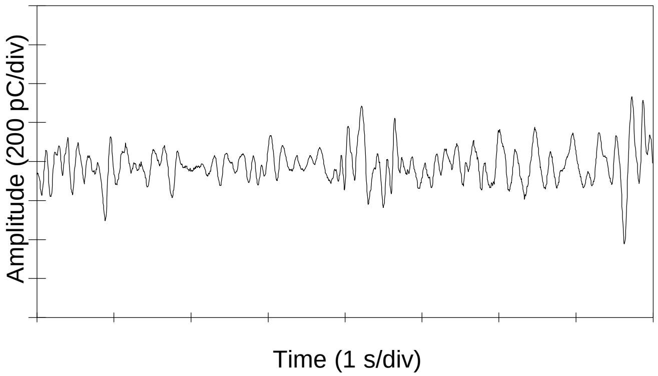

Figure 11: Waves breaking on shingle beach, detected by 25 m length of buried cable

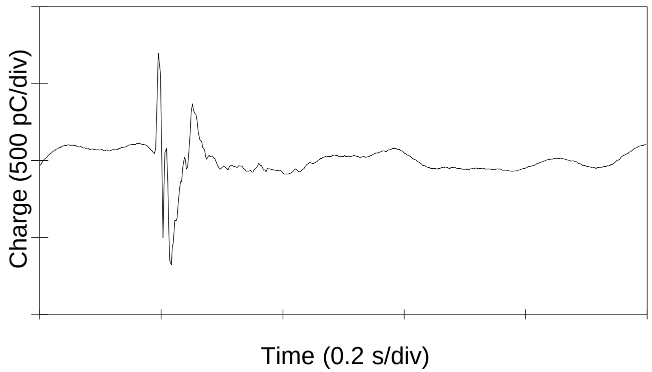

Figure 12: Footstep on beach, same installation as Fig 11

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Fence-mounted Cable for Perimeter Security

Piezo cable may be fastened to a variety of fence types, and used as a distributed contact microphone to listen to events such as climbing or cutting. An example of an installation is shown in Figure 13.

A typical signal from an impact to a rigid fence is shown in Figure 14. The cable was fixed to the fence using cable ties at 0.3 m intervals. Frequency domain analysis of this signal reveals several resonances at low frequencies (below 2 kHz), but also significant energy extending up to 10 kHz, as shown in Figure 15.

Fence-mounted microphonic sensor systems, as with buried systems, are sensitive to a range of natural "environmental" stimuli, in addition to the particular signals of interest. For this reason, high sensitivity, good linearity, and wide dynamic range are strong advantages, so that the maximum amount of useful information may be extracted from the incoming raw signal.

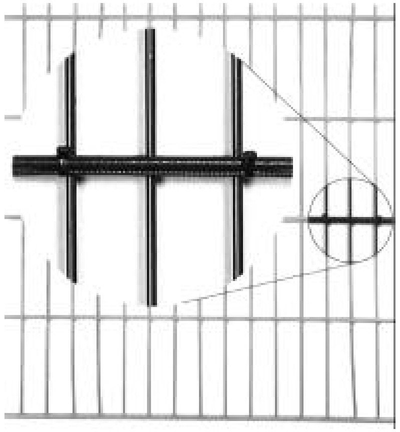

Figure 13: Example of mounting arrangement for microphonic piezo cable on rigid fence

Acknowledgements:

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Figure 13: reproduced by kind permission of Sysco Sicherheitssysteme GmbH

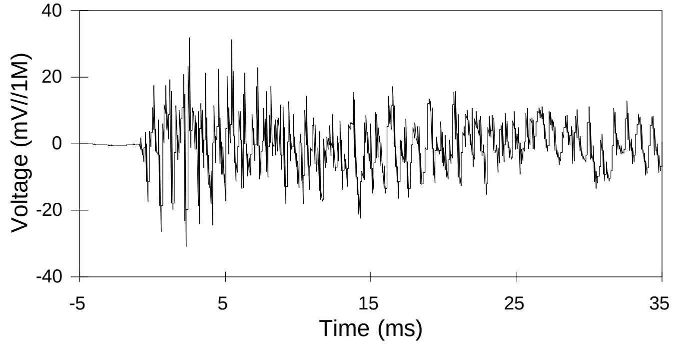

Figure 14: Voltage output from impact to rigid fence, using piezo cable as contact microphone

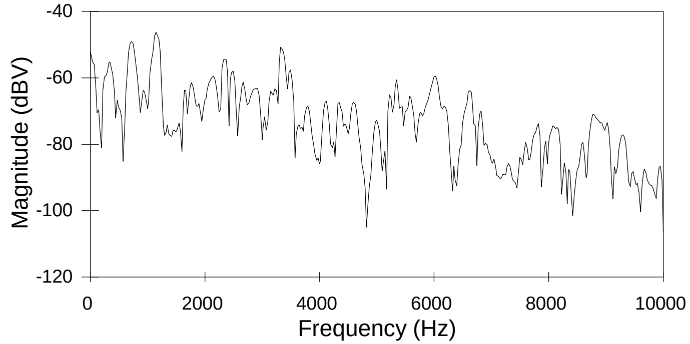

Figure 15: FFT analysis of time signal from Figure 12, showing energy distribution over wide frequency range