SEISMIC-ACOUSTIC HYBRID SENSOR & ITS APPLICATIONS

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ABSTRACT

The need for instrumentation to gather seismic-acoustic signatures under unusual conditions requires the use of low cost, simple design, and robust sensors. In some instances, the sensors must adapt and mold to the environmental medium to provide proper coupling for data collection purposes. This paper explains how the idea of a hybrid seismic-acoustic sensor originated and initially implemented. Testing shows the device performs as a seismic and acoustic signature-gathering sensor. The data product from the hybrid sensor is similar to those sensors available through commercial sources. Further evolution of the hybrid sensor and additional commercial applications for the device are discussed.

SECTION I

INTRODUCTION

The seismic-acoustic hybrid sensor addressed the need of a low-cost, simple design and robust capability. The sensor was considered hybrid because it reacted to seismic and seismic phenomena. The sensor was deployed in the field in one of two ways. One method crested the sensor on top of the ground. The second method required burying the sensor in the soil. Once deployed, the hybrid sensor operated for long periods of time, nominally for months.

Earlier designs of the hybrid sensor appeared in the mid-1970s. The basic design consisted of 20 AWG Teflon insulated wire placed inside a copper tube. Variations of design included different lengths, and diameters of copper tubing to capitalize on signal detection. Coupled with detection was analyzing the data. Preliminary findings, striking a plate with a sledgehammer and generating sound from speakers, showed detection possible and conventional signal processing techniques useful.

Follow-on testing involved sensor detection of different vehicles. One significant observation regarding soil characteristics was noted. Neighboring soil behaved similar to a low-pass filter. Since most vehicular traffic of interest operated in the same frequency range, the observation did not affect the collected data. Signatures from people walking or running also fall within the same bandwidth making the device useful for perimeter security purposes.

SECTION II

DESIGN AND OPERATION OF THE SEISMIC-ACOUSTIC HYBRID SENSOR

The mechanically flexible hybrid sensor easily adapts to various environments. The device has inherent high noise characteristics similar to those found in noise coaxial cables. Triboelectricity, current generated by friction, is the chief cause of electrical noise in coaxial cables. Using a standard length of RG-58 coaxial cable produces erratic bursts of noise when acted upon by an external force. These bursts of erratic noise are unmanageable and non-reproducible using basic signal processing techniques.

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Abstract

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A single wire in a tube verified earlier experiments. Findings confirm that the sensor was too large and cumbersome and produced an excessive number of harmonics. To minimize size and obtain a manageable signal output a new design was necessary. Looping the wire added more wire to the interior of the copper tube while minimizing the length of the tube. The problem of a long and cumbersome copper tube still existed. (Figure 2-1) Coiling the tube compacted the sensor. (Figure 2-2) Tests compared other types of wires to find insulating materials, which exhibited better capacitive charges than those observed in Teflon. Through empirical experiments, Kynar displayed better capacitive and dielectric properties than Teflon. Kynar insulated wire is used for wire-wrap applications and it was easily available on the market. The size of Kynar wire used in wire-wrap applications is typically 26 AWG.

Figure 2-1 Earlier Design of a Single Wire in a Straight Tube Terminated with a BNC Connector

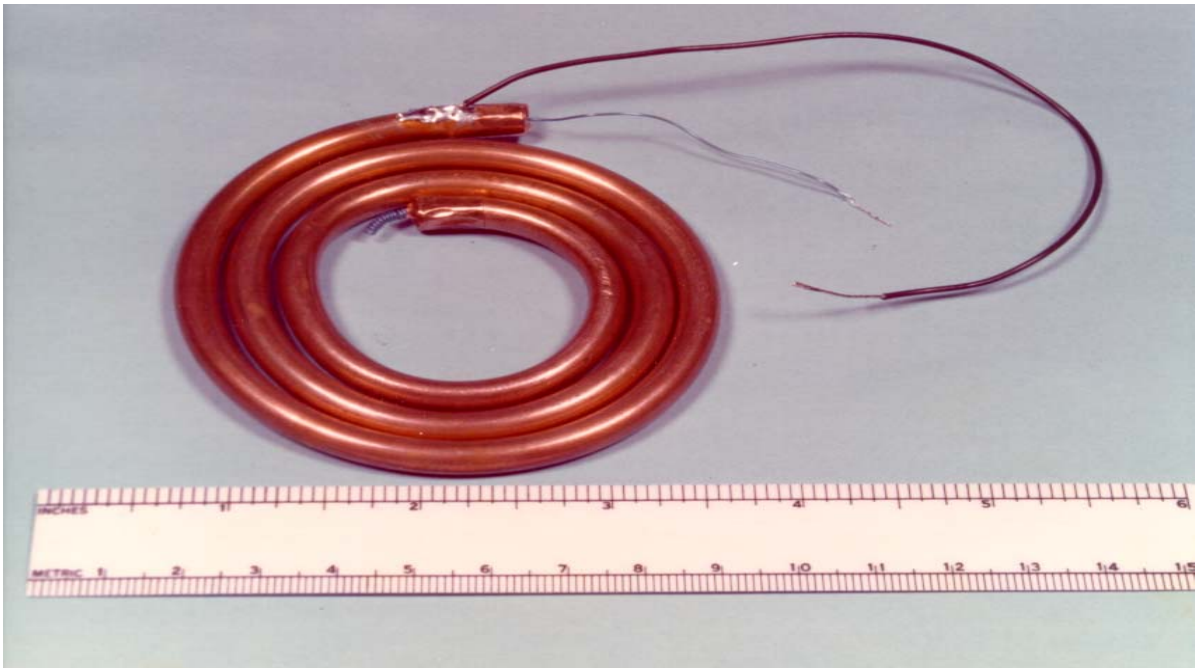

Figure 2-2. Hybrid Sensor Shows Ground Cable Attached to the Skin of the Copper Tubing

2-2 THEORY OF OPERATION

The seismic-acoustic hybrid sensor consists of Kynar coated tightly looped, laid inside a coiled piece of copper tubing. (Figure 2-2)It acts as a distributed line capacitor in which the relative movements of the looped wire and its points of contact with respect to the interior side of the tube cause proportional changes in capacitance. These capacitance changes are converted into voltage changes by means of the electret action of the Kynar insulation.

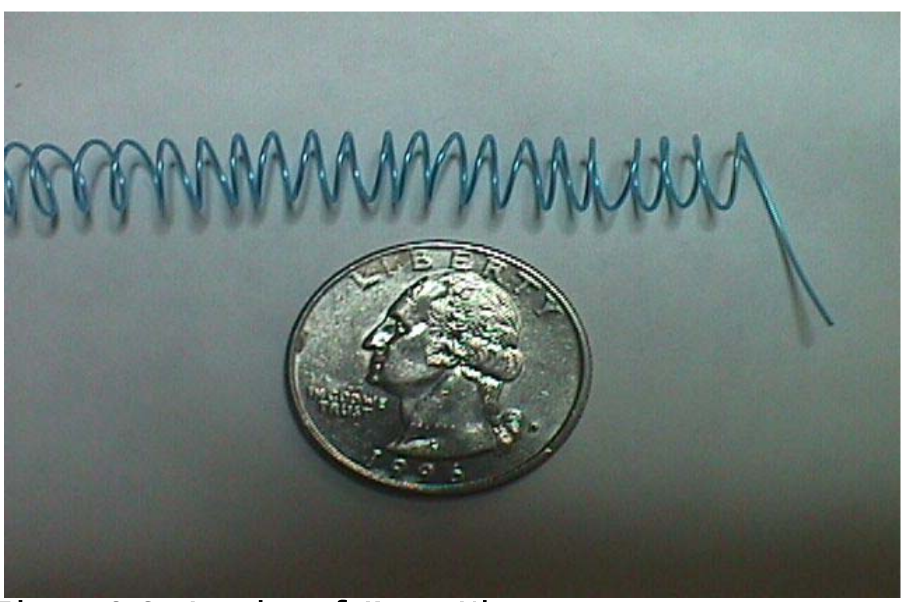

Figure 2-3. Looping of Kynar Wire

The hybrid sensor requires a special amplifier because of its low voltage output (millivolts) and its infinite impedance characteristics. A P-Channel field effect transistor is recommended for the initial amplification stage. Figure 2-4 shows the circuit for the Hybrid Sensor.

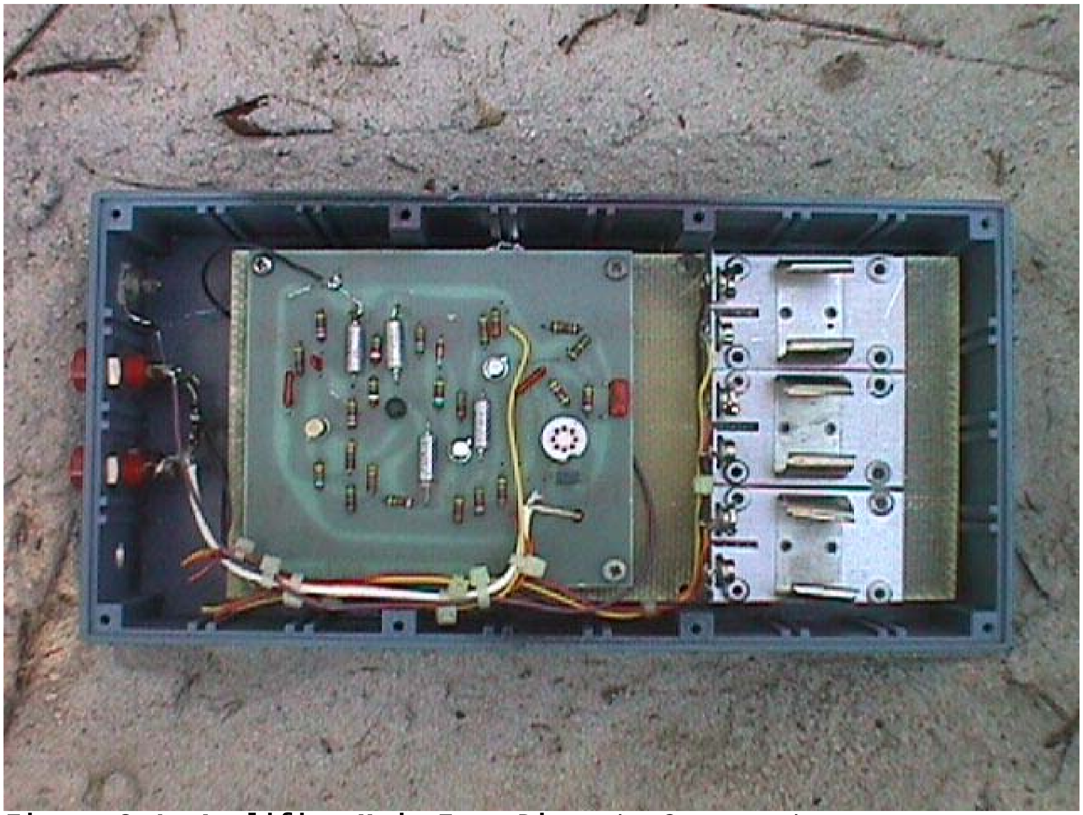

Figure 2-4. Amplifier Made From Discrete Components

2-3 HYBRID SENSOR - SITE PREPARATION AND PLACEMENT

Ground Surface Placement. A relatively flat area on the ground surface, enough to accommodate the sensor is needed. Remove any intrusive vegetation to insure better coupling with the soil. The sensor is placed flat on the ground and slightly below the ground surface. The device is buried two inches below the surface to afford good coupling with the neighboring area. Figure 2-5 shows the device placed on the ground surface.

Subsurface Placement. Burial below the surface is considered to be six inches or more. The device is typically placed in a similar manner as discussed above. Burial of the amplifier is recommended to minimize the connection between the amplifier and the sensor.

Figure 2-5. Sensor Placement on the Ground Surface for Seismic-Acoustic Data Gathering Purposes

SECTION III

SIGNATURES COLLECTED USING THE SEISMIC-ACOUSTIC HYBRID SENSOR

Up until now the sensor has been used in numerous tests. Among these are military vehicle detection. Vehicle detection was accomplished with good results in various types of terrain. Despite soil variations, the hybrid sensor provided good quality signature data. Samples of these data are now presented.

3-1 Seismic Activity Detected by the Seismic-Acoustic Hybrid Sensor

All military vehicle track systems closely resemble a chain driven by a sprocket and running over idler wheels. The pitch of the chain or track is equal to the length of each chain link or track block. This length is also the distance between the sprocket tooth centers measured at the sprocket pitch diameter. As the vehicle travels over the ground, each track block passes over the sprocket and is laid on the ground with a frequency determined by vehicular speed. Seismic track frequencies vary with vehicular speed resulting in signatures that occur in the 10 Hz to 100 Hz range. Higher frequencies are produced in the form of squeaks when the track passes over the drive sprockets and wheels. These squeaks occur in a range centered at 2000 hertz. The higher frequencies produced by the track are acoustic in nature and are easily detected by microphones at nominal distances. Figure 3-1 shows the track of a military vehicle powered by a 12-cylinder diesel engine.

Figure 3-1 Typical Military Vehicle Track

The hybrid sensor detected seismic signatures from vehicles of military interest at varying distances, 0.5 to 1.0 kilometer. Seismic spectral products show substantial harmonic detail in the data. Figure 3-2 is an example of the track seismic data.

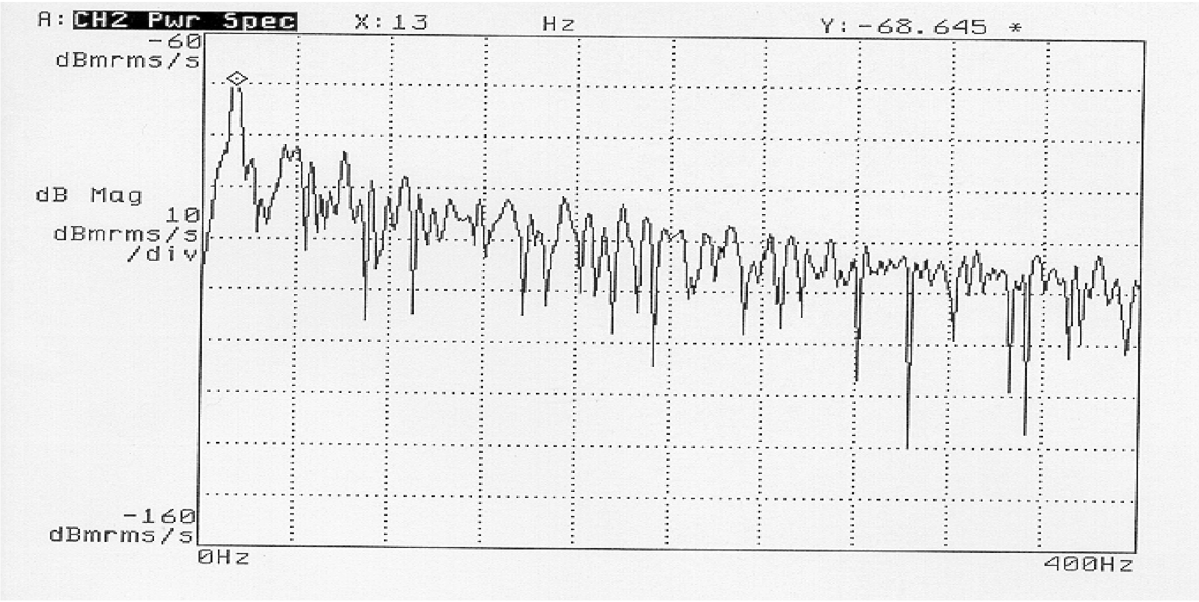

Figure 3-2. Seismic Data Sample From the Hybrid Sensor. Data Sample Shows Track Frequency of the Vehicle Moving at 7 Kilometers Per Hour

A study of Figure 3-2 shows the track frequency to have a value of 13 hertz. This is generated as a result of the repetitive ground slapping by the vehicle track. Thus, if the track vehicle increases speed, it can be expected that the track slapping frequency will increase in value. Figure 3-3 shows the seismic spectral product as vehicular speed increases.

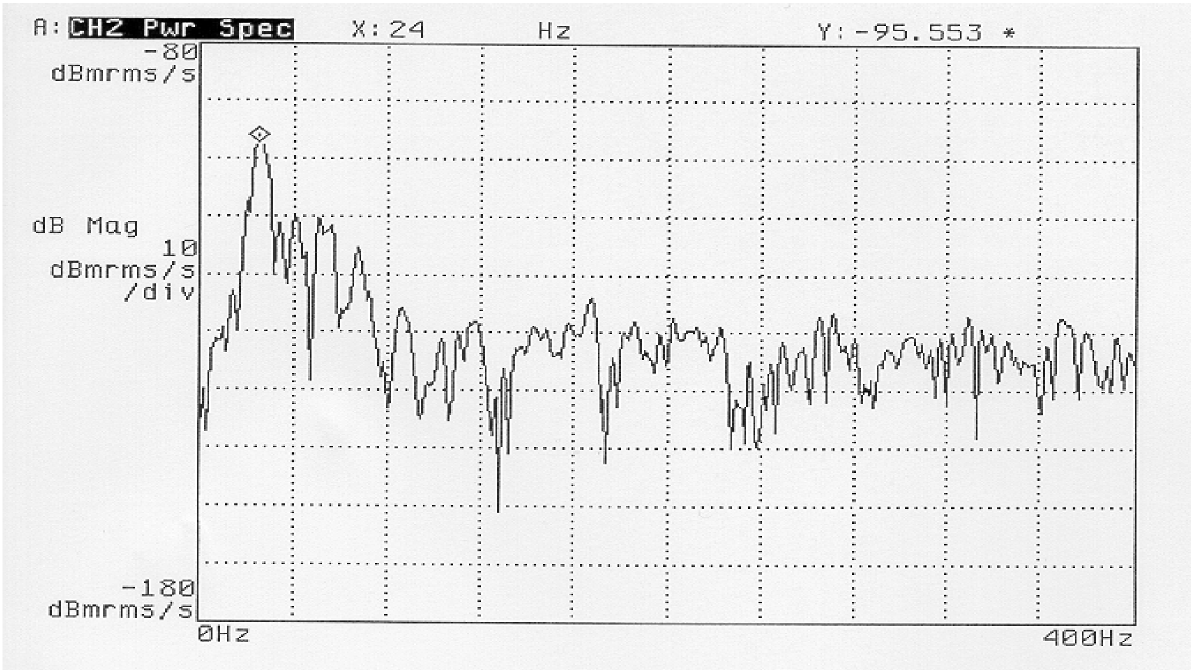

Figure 3-3. Seismic Data Sample From the Hybrid Sensor. Data Sample Shows Track Frequency of the Vehicle Moving at 12 Kilometers Per Hour

Given the size and weight (40 tons) of a military track vehicle it is understandable that the signatures were of good quality. Under the same circumstances, a laboratory grade geophone would generate second and third harmonics of the fundamental track frequency. Typically, second and third harmonics can be associated with vehicular proximity to the sensor.

3-2 Application of the Distance Formula to the Seismic Data

The most prominent seismic feature from a track vehicle is the pad slapping frequency. The following equation, a variation of the distance formula, is used to determine the size of the pad of a track vehicle in motion. Use of the seismic data in Figure 3-2, the following equation is derived to verify the distance between the track pads.

$\boldsymbol{S}$ = vehicular speed (7 km/hr or 4.35 miles/hour)
$\boldsymbol{P}$ = size of the pad or distance between track pins
$\boldsymbol{F_t}$ = track frequency in hertz (13 hertz)

$$\boldsymbol{F_t} = \frac{(12\ \text{in/ft})\ (\boldsymbol{S}\ \text{miles/hr})\ (5280\ \text{ft/mile})}{(\boldsymbol{P}\ \text{in})\ (60^2\ \text{sec/hr})}$$

Solve for $\boldsymbol{P}$ in inches and centimeters

$$\boldsymbol{P}\ \text{in} = \frac{(12\ \text{in/ft})\ (5280\ \text{ft/mile})\ (\boldsymbol{S}\ \text{mile/hr})}{(\boldsymbol{F_t}\ \text{Hz/sec})\ (60^2\ \text{sec/hr})}$$

$$P \text{ in} = \frac{(12)\ (5280)\ (4.35)}{(13)\ (60)^2}$$

P = 5.89″ or 14.6 cm

The measured value for the track is 5.7″ or 14.2 cm.

3-3 Comparisons of Acoustic Data Samples between the Hybrid Sensor and Commercial Microphones

The combustion of the fuel/air mixture in the engine cylinders is the greatest source vehicle sound emission. Vehicular engine noise, which is periodic in nature, is emitted chiefly from the walls of the engine block, pan, head, engine surfaces, and exits through the exhaust system with the combustion gases.

A sample of acoustic background noise is depicted in Figure 3-4. The acoustic sample is used to determine the presence of those sound sources, which may conflict with the data. Typically a value of 40 dB SPL is the maximum background noise is recommended when collecting acoustic measurements. Figure 3-4 shows 35.16 dB to be the value of the background noise.

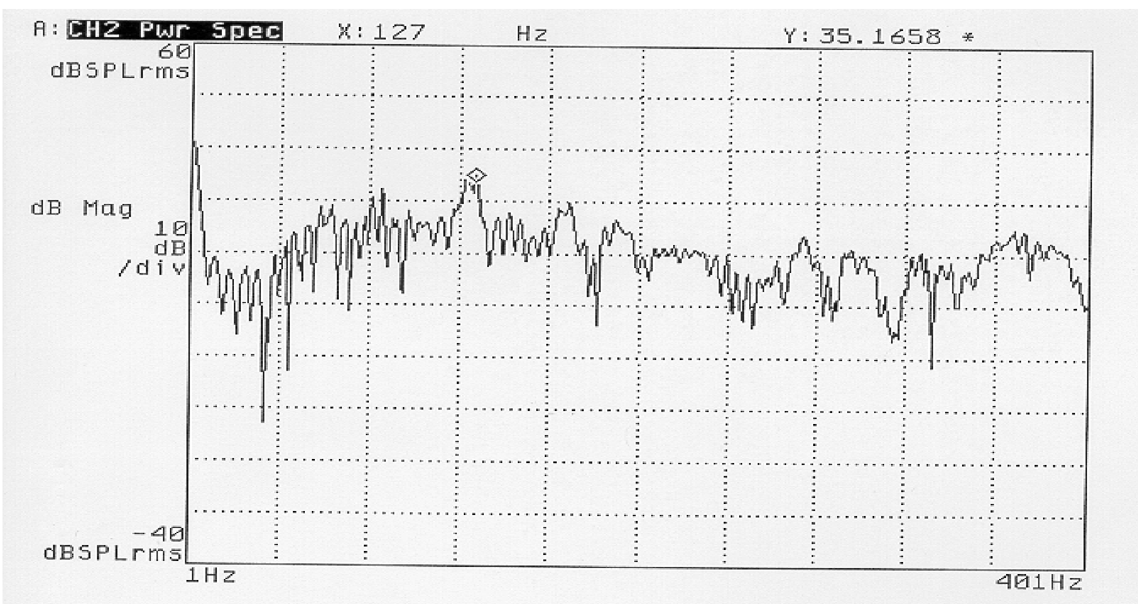

Figure 3-4 (U) Acoustic Background Noise at the Test Site

3-3-1 Acoustic Data Samples from the Engine Exhaust

The stationary mode of vehicular operation the engine is operated without the load of the vehicle. Acoustic harmonics generated under this condition have values that are lower in frequency than those collected when the vehicle becomes mobile. The engine firing frequency is the largest spectral peak in the spectra. During the engine idle condition this is shown to be the 9th harmonic with a 71.00-hertz frequency and its amplitude was 77.79 dB. The engine rpm was calculated from these values and found to be 946.66 revolutions per second. See Figure 3-5.

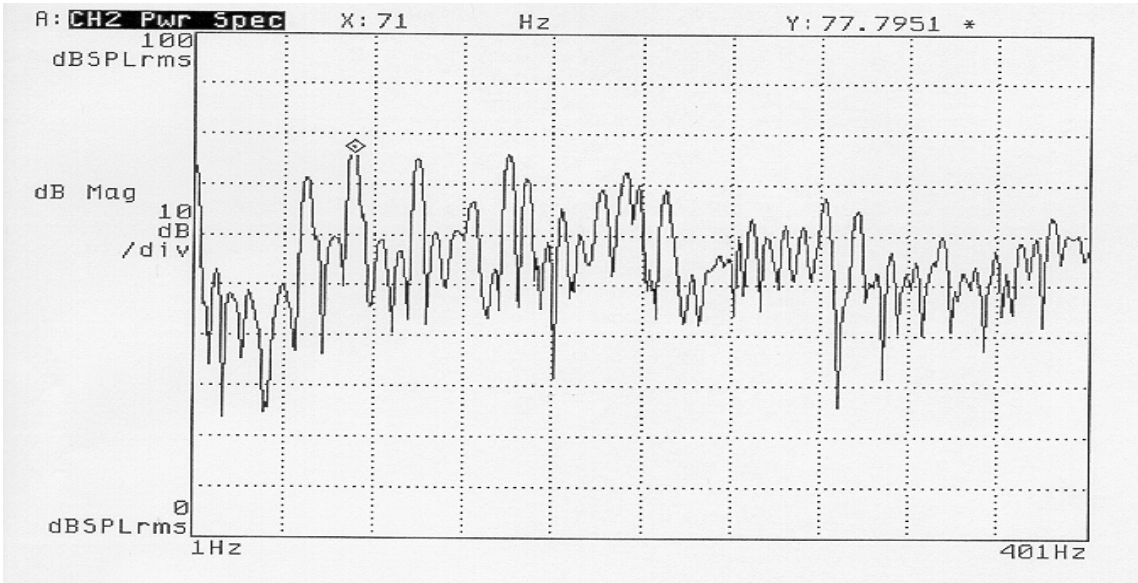

Figure 3-5 (U) Acoustic Signature Collected Using the Hybrid Sensor

A look at the acoustic spectra from the sensor shows a crowded spectral window. Several prominent harmonics share a bandwidth from 40 to 124 hertz. These are directly attributed to the engine. Using the same rpm value from before it is calculated that the five dominant harmonics are the 3rd, 6th, 9th, 12th, 14th, 15th. These are shown in Figure 3-5.

3-3-2 Acoustic Data Sample from a Commercial Microphone Collocated with the Hybrid Sensor

The collocated commercial microphone gathers acoustic signatures from the ground slightly below the ground surface. Vehicular emitted engine sound propagates upward, laterally, and it couples into the soil. The commercial microphone data is of good quality and easily depicts the engine harmonics. The 9th harmonic is shown to have a value of 74 hertz. Very little calculating is needed to determine the placement of the harmonics. These can be easily identified in the spectra. The dominant harmonics are the 3rd, 6th, 9th, 12th, 15th. This is shown in Figure 3-6.

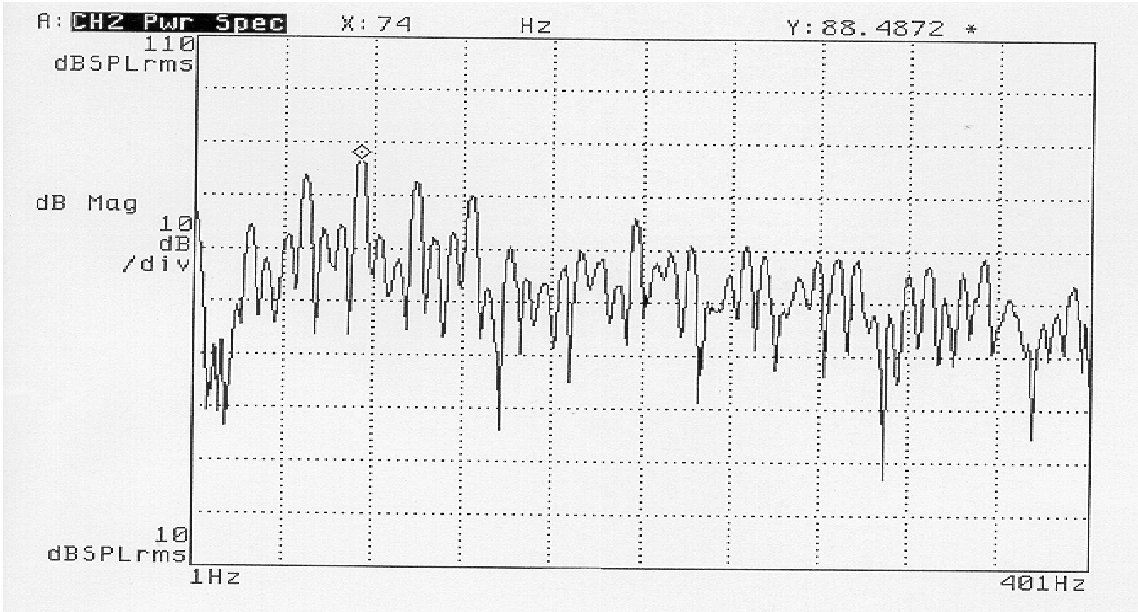

Figure 3-6. (U) Acoustic Signature Collected Using a Microphone from the Stationary vehicle at the CPA

SECTION IV

RECOMMENDATIONS

Military applications have monopolized the content of this paper. Many other hybrid sensor applications, which come to mind, are an intrusion device, a range scoring system, wildlife and insect monitoring, etc. Insect monitoring is a subject worthy of discussion.

Insect monitoring offers many possibilities for the hybrid sensor. The idea of using the seismic-acoustic hybrid sensor for insect detection resulted from a lab experiment. An aquarium was filled halfway with play sand and the hybrid sensor buried to a depth of two inches. Instrumentation was attached to the sensor to monitor sensor activity. To induce signals, small objects were dropped inside of the aquarium. Sensor sensitivity proved to be better than expected due to the coupling between the sand and the sensor. An insect was placed on the surface of the sand and made to walk. The insect footsteps were easily monitored and detected by the hybrid sensor.

4-1 Instrumenting the Wall Plate with the Hybrid Sensor

The seismic-acoustic sensor is designed to play a role in the housing industry as a termite detector. Taking advantage of the sensor's flexibility to mold to its environment, the device is used in its extended mode for termite detection. Which means that the copper tubing is built into the part of the wall known as the plate. The plate is the bottom end of the wall that comes into contact with a concrete pad, blocks, etc. Using the extended mode, the sensor is built into the perimeter of the house. The instrumented plate is the first line of defense when termites invade a structure from their commute between the neighboring soil and their next meal. Figure 4-1 shows the sensor placement in the board known as the plate.

Figure 4-1 Sensor Placement in the Plate, Tube Terminated With a BNC Connector

4-2 Termite Noise

Most evidence shows that termites communicate primarily by secreting chemicals called pheromones. Each colony develops its own characteristic odor. Odor recognition is primarily used for intruder detection and establishing trails to food sources. Since the seismic-acoustic sensor cannot exploit odor-emitting communications a source of generated termite sound looks more promising.

The US Department of Agriculture found that, under ideal conditions, a termite colony of 60,000 workers might consume a one-foot length of 2" X 4" pine in 118 to 157 days. Although termites are soft-bodied insects, their hard, saw-toothed jaws work like shears and are able to bite off small fragments of wood a piece at a time. Another form of sound communications takes place when the soldiers and workers bang their heads against the tunnels creating vibrations to mobilize the colony. These later forms of termite noise are fertile areas to exploit using the hybrid sensor.

SECTION V

SUMMARY

Commercial seismic and acoustic sensors are frequently used for the detection of military vehicles. Advances of new signal processing methods with the data product have proved that these low cost devices have a place in the battlefield. These passive sensors are frequently used to monitor front line activity and gather intelligence regarding a vehicular threat.

The seismic-acoustic hybrid sensor was not designed to replace present commercial seismic and acoustic sensors. The hybrid sensor was developed for those instances where commonly used devices cannot be deployed. New advances in insulating materials like Kynar significantly contribute to the new design and improve sensitivity of the hybrid sensor. Miniaturizing electronic components allow for the sensor and electronics to be packaged as one device.

Collected seismic and acoustic data samples show much promise for this device in some military applications. Other applications use the hybrid sensor for insect monitoring. However, its most important feature is its flexible resiliency to mold to various shapes for the purpose of data collection. More testing is required to enhance calibration of the device. Collocation with calibrated seismic and acoustic sensors is recommended.

SECTION VI

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