SUBSURFACE ACOUSTIC SENSOR

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ABSTRACT

The need for acoustic instrumentation to gather signatures under prohibited weather conditions or hostile natural and man-made barriers led to the placement of microphones below the ground surface. This paper will show how the idea was conceived and its initial implementation. Testing of the device at various sites will show its performance as an acoustic signature-gathering sensor. Equations will be presented to describe its performance. Further evolution of the sub-surface microphone will be discussed and some applications for the device will be shown.

SECTION I

INTRODUCTION

The subsurface microphone resulted from a need to collect acoustic signatures in environments where ambient noise levels negated the use of surface acoustic sensors. Four years ago I began using an earlier design of the subsurface sensor. Collocating the device with other seismic, acoustic, and magnetic sensors was a good way to compare data and check its performance.

The initial intent was for detecting an acoustic signal and determine if signal-processing techniques could be used. Initially, the microphones were attached to a piece of plastic pipe and placed in the upright position. Gradually, the idea evolved to point the microphone downward; provided an acoustic product that was of good quality. Some limitations were immediately observed. The most significant observation was dependency of the soil filter characteristics. The fact that the neighboring soil behaves as a low pass filter was not a problem since most vehicular traffic of interest operates in that frequency range. Numerous acoustic data samples have been collected using these underground devices with good results. Now the technical presentation of the subsurface microphone follows.

SECTION II

DESIGN OF THE SUBSURFACE MICROPHONE AND ITS USE

The subsurface microphone consists of microphone mounted inside a PVC (plastic) piece of pipe one-meter long. The diameter of the plastic pipe is 1.25”. A perforated plastic cap covers the end that points downward. Near the perforated cap, on the inside, a microphone is mounted in a windscreen. The windscreen is designed to protect the microphone. The amplifier electronics are located in the upper part of the pipe. This area is outside and near the ground surface where access can be gained for attaching cables, changing batteries, etc. Figure 1 shows the sub-surface microphone and the various parts.

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Figure 2-1. Subsurface Microphone, Complete System

2-1 PREPARING THE SITE AND INSERTING THE MICROPHONE INTO THE CAVITY

A cavity a meter deep and ten inches in diameter is adequate to accommodate the sensor. The subsurface microphone is inserted and an inner tube used to isolate the device from the surrounding ground surface. The sensor can be used as a single unit or in multiples of three to determine bearing. Figure 2 shows the subsurface microphone being placed in the data gathering position. In this pictorial the subsurface microphone is being inserted into the cavity. See Figure 2-2.

Figure 2-2. The Subsurface Microphone About to be Inserted in the Cavity for Acoustic Data Gathering Purposes

2-2 THEORY OF OPERATION

The Subsurface microphone takes advantage of its immediate environment to operate. It uses a vertical cavity (hole) in the ground to collect acoustic data. Once the device is inserted into the ground, it is isolated from all the surrounded soil surfaces. An approach that has been suggested to describe its performance is its similarity to a Helmholtz Resonator. The following equation is now presented in Figure 2-3.

Given a cylinder where,
Radius = a
Depth = d

$f_O = Co/2\Pi\ (S/L'V)^{1/2}$

$Q = 2\Pi[V(L'/S)^3]^{1/2}$

For an open hole,

$S = \Pi a^2$
$L' = 1.7a$

$V = \Pi a^2 d$

For resonance,

$f_0 = Co/2\Pi\ (S/L'V)^{1/2}$

$f_0 = Co/2\Pi\ (\Pi a^2/1.7a\ \Pi a^2 d)^{1/2} = Co/2\Pi\ (1/1.7ad)^{1/2}$

$f_0 \cong 0.1221\ Co/\Pi ad$

$f_0 \cong (1/8.2)(Co/\Pi ad)$

$\therefore$ let a = ½ meter

d = 1 meter

$f_0 \cong 58.7$ Hertz

Figure 2-3. Helmholtz Resonator Equation Used to Typify Subsurface Microphone Cavity, Calculation for Resonance

SECTION III

SIGNATURES FROM THE SUBSURFACE MICROPHONE

Up until now the subsurface microphone has been used in numerous tests. Among these are military vehicle detection, helicopters, bombing raids, sniper tests, fixed wing military jet aircraft, location of bunkers and shelters, Howitzer fire, subsurface location of UXO, range scoring systems, explosions, etc. These have been accomplished with good results in various types of terrain. The terrain ranged from sand, clay soils, frozen soils, and solid rock. Despite the variations of soils, the subsurface microphone continued to provide good quality signature data. Samples of these data are now presented.

3-1 MEPPEN TEST FACILITY ACOUSTIC TESTS

The purpose of the test was to determine the effects that a warhead would have against a SA-6 stationary vehicle configuration. These signatures were collected to determine the health of the SA-6 Radar (operating engine, electrical system, radar, etc.) when a warhead is detonated in the vicinity.

The subsurface microphone had its first test in the international arena. It was at the Meppen Test Facility, Meppen, Germany where the sensor proved itself. An initial survey of the test range showed that background noise levels were higher than expected. Thus an acoustic device that would negate background noise and collect the necessary acoustic data was needed.

Acoustic signatures were collected from a stationary SA-6 Radar test vehicle at the Meppen Test Facility, Meppen, Germany. The test vehicle was operated with the engine in the idle mode, the auxiliary power unit (APU) running, and the radar emanating one Watt of power. A dummy load was used on the radar to decrease the output power. The acoustic sensors were deployed above and below the ground surface in the far field.

Geographical placement between the subsurface sensors and the SA-6 Radar test vehicle, placed these passive sensors at a disadvantage. For example, the vehicle exhaust and APU ports faced away from the acoustic sensor array. Furthermore, the body of the vehicle behaved as an acoustic shield between the vehicle and the engine exhaust. It was noted that acoustic background noise levels were higher than expected. This was attributed to aircraft, a nearby rail system and time of the day. Despite these impediments, the subsurface microphone findings are very encouraging.

The acoustic sensors in the far field were placed 150 meters from the vehicle. Some of these devices were buried one meter deep and the other sensors were placed on the ground surface. Thus, the sensors were collocated. The technique later allows analysts to correlate buried and surface data to determine signature attenuation factors.

3-2 ACOUSTIC BACKGROUND NOISE LEVELS

These were found to be higher than expected. It is preferred to work with noise levels of 40dB re 20uPa or less. The background noise levels at the site averaged 50dB re 20uPa. Figure 3-1 shows the background noise levels from microphones M-1 (buried) and M-8 (surface). Noise created by the wind, natural phenomena, and man made objects easily couples into the ground and can be sensed by microphones.

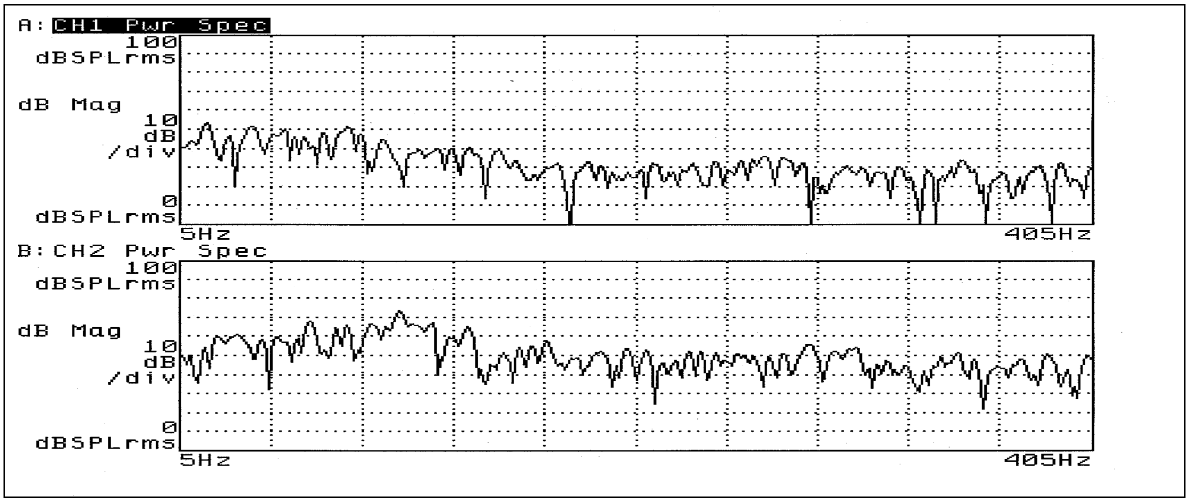

Figure 3-1. Acoustic Background Noise Sample from Microphones M-1 Subsurface and M-8 Subsurface Respectively

3-3 SUBSURFACE ACOUSTIC SAMPLES FROM THE WARHEAD DETONATION AND THE SA-6 VEHICLE

Prior to doing any data analysis it is advisable to look at the analog data stream in the time domain. This is necessary so that a time history of the events can be placed in perspective. Figure 3-2 shows this. The data from microphone M-1 subsurface microphone was used for this purpose.

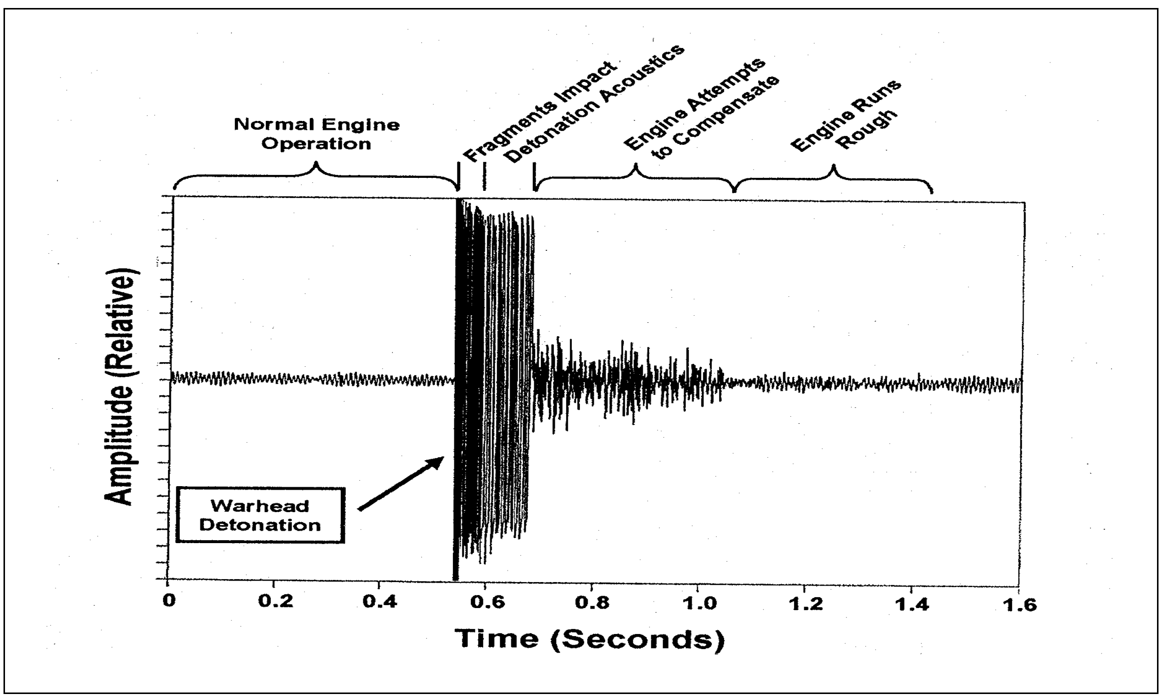

Figure 3-2. Acoustic Data from Microphone M-1 Subsurface Microphone Shows Signal Time History

Figure 3-3 shows the pictorial of the warhead detonation depicted in the acoustic time line history in Figure 3-2.

Figure 3-3 Detonation of Warhead

Four seconds following the warhead detonation, the engine firing frequency fluctuated between 117.00 Hz and 117.50 Hz. Periods of distortion were evident in the acoustic spectra. This caused the engine revolutions per minute (rpm) to increase in value and vary from 50 to 100 rpm. Some of the electrical systems in the SA-6 Radar are shared systems. Thus it was necessary for the engine to try to compensate as fuses were blowing and breakers popping. This accounts for the engine acoustic variations that took place thus affecting the acoustic spectra shown in Figure 3-4.

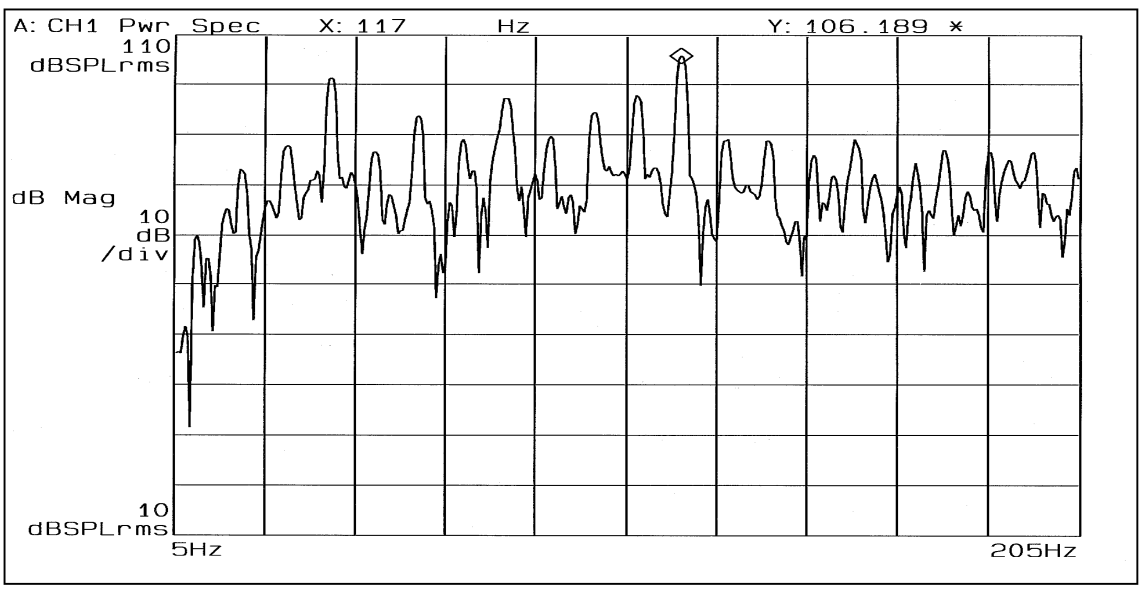

Figure 3-4. Acoustic Signature from the Subsurface Microphone Following Warhead Detonation

SECTION IV

ACOUSTIC DATA FROM A GERMAN UNDERGROUND SHELTER

Subsurface microphone background measurements showed that the electrical activity from the nearby German shelter had been collected. These samples consisted of 50-hertz data common in European electrical systems. Figure 4-1 shows the acoustic data from the subsurface microphone. Figure 4-2 depicts the shelter.

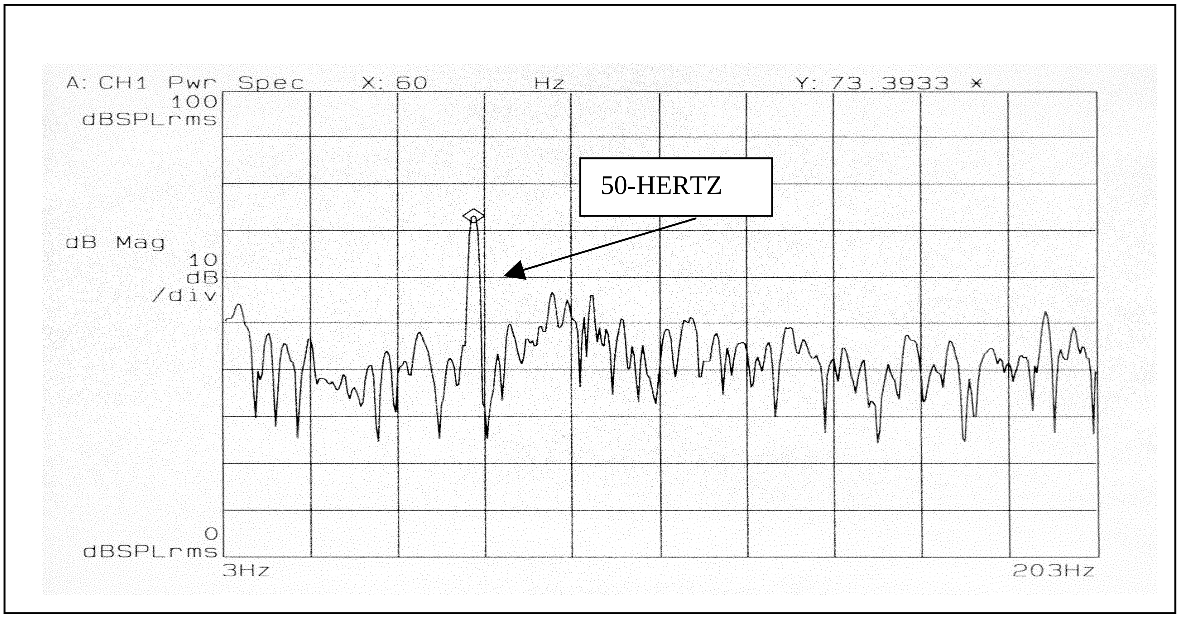

Figure 4-1. German Underground Shelter Electrical System Acoustic Sample

Figure 4-2. German Underground Shelter at the Meppen Test Facility

SECTION V

AIRCRAFT ACOUSTIC SIGNATURES FROM THE SUBSURFACE MICROPHONE

The detection of airborne aircraft is an area where the subsurface microphone excels. Noise from airborne platforms couples into the ground and is easily detected by the subsurface microphone. Single engine airborne acoustic sources, which fly near the ground surface (8000 feet) are typical. The subsurface microphone is dependent on the filter characteristics of the soil to eliminate and minimize background noise levels. The same soil characteristics that minimize acoustic background noise aid as a filter in allowing frequencies of 1000 hertz or less to be detected. Figure 5-1 shows the acoustic signature from an airborne platform.

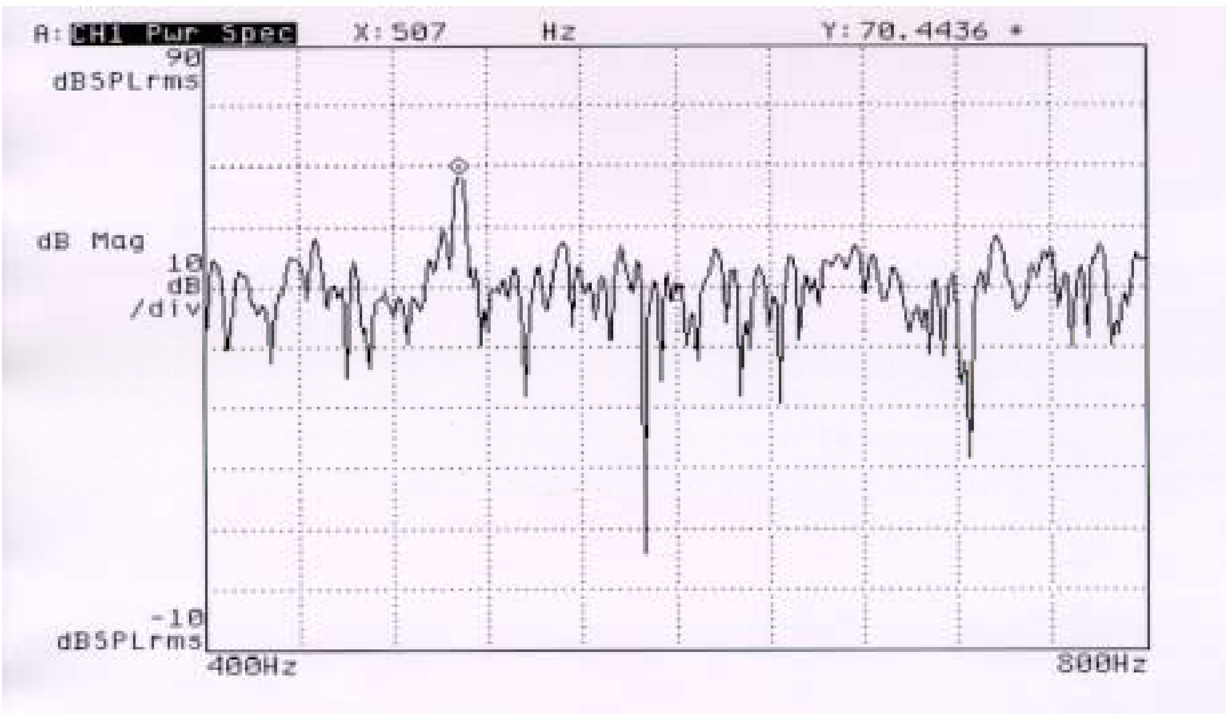

Figure 5-1. Detection of Acoustic Airborne Source Using the Subsurface Microphone

The acoustic sample in Figure 5-1 was filtered using a band pass filter from 400 to 800 hertz to achieve the desired result. This was done to capture the area of interest. The airborne platform was a single engine aircraft flying at 9,000 feet.

SECTION VI

SUBSURFACE ACOUSTIC SIGNATURE FROM A MILITARY VEHICLE

The Subsurface microphone has been used to collect acoustic signatures from vehicles of military interest at distances of two to three kilometers. Acoustic spectral findings show substantial harmonic detail in the analysis product. Figure 6-1 shows the acoustic product from a 12-cylinder diesel engine at one kilometer from the subsurface acoustic sensor.

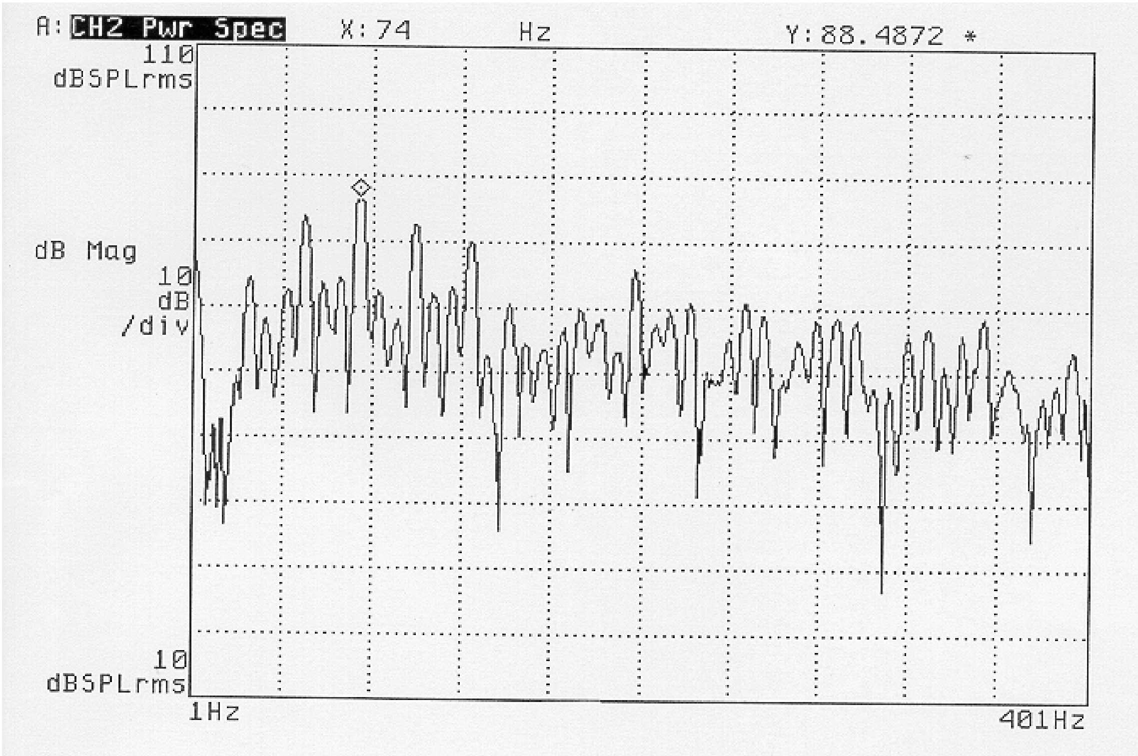

Figure 6-1. Acoustic Data Sample from the Subsurface Microphone. Data Sample shows Engine Harmonics from 12-Cylinder Diesel Engine.

A study of Figure 6-1 shows the definition of the harmonic content in the data sample. The influence from the soil filter characteristics is shown.

SECTION VII

SUMMARY

Acoustic sensors are passive, non-line of site devices that have a place in the detection and classification of military vehicles. The use of new signal processing methods with the SAM data have proved that these low cost devices have a place in the battlefield. SAM sensors are frequently used to monitor front line activity and gather intelligence regarding a threat.

The use of the acoustic subsurface sensors at the Meppen facility yielded a wealth of information. Noises occurring at the site were detected by the sensors. These included the warhead detonation, SA-6 vehicle engine activity, and the electrical noise from the shelter.

Data from the subsurface microphone included that from a single engine airborne platform and that of a military track vehicle powered by a 12-cylinder diesel engine.

The subsurface microphone has potential use in the detection of remote detonations and those sounds produced by single engine airborne platforms such as cruise missiles and UAV’s.

Additionally, this device plays a significant role in the location of unexpended ordnance (UXO) during sustainment range clean up activities. This technique is accomplished with the use of low frequency sonic instrumentation.

SECTION VIII

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