SEISMIC, ACOUSTIC, AND MAGNETIC TEST RESULTS FROM US/GERMAN TESTING

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ABSTRACT

Seismic, acoustic, and magnetic (SAM) sensors are passive devices that play an important role in identifying vehicular features of military interest. This was the case during a recent joint (US/GERMAN) test at the Meppen Test Facility, Meppen, Germany. The test consisted of detonating a HARM missile warhead in close proximity to a SA-6 and other support vehicles. SAM sensors were deployed in the far field to simulate a probe that had penetrated to a depth of one meter below the ground surface. The discussion begins by describing the SAM sensors and their deployment in the field. A dialogue of signatures and their point of origin follows. SAM signature data will show the health of an operating SA-6 and its subsequent degradation, as monitored by the buried sensors, after detonation of the HARM warhead. Conclusions will depict how the correlation of SAM data can lead to a robust signature product for remote smart probes.

1.0 INTRODUCTION

In the spirit of joint international technical cooperation, the United States and Germany conducted live fire testing of the HARM with an improved warhead. This was accomplished under the United States/German data exchange agreement 7448. The test was conducted at the Meppen Test Range during the period of October 1997.

The CHICKEN LITTLE, Sensor/Seeker Seismic, Acoustic, and Magnetic (SAM) team traveled to the Meppen Test Range to collect SAM signatures from the live fire test.

The purpose of the test was to determine the effects that a HARM warhead would have against a SA-6 stationary vehicle configuration. Findings in this report only apply to the seismic, acoustic, and magnetic (SAM) signatures derived from the test. These signatures were collected to determine the health of the SA-6 Radar (operating engine, electrical system, radar, etc.) when a HARM warhead is detonated in the vicinity.

SAM sensors were located about the test site in the near and far field. The near field sensor consisted of a microphone placed inside the commanders compartment of an operating SA-6 Radar vehicle. Only one vehicle was operated with the engine at idle, the auxiliary power unit (APU) in the on condition, and the radar in the radiating mode. The radar was operated with a dummy load so that power output was limited to 1 Watt.

The SAM 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.

Ground truth in the form of background noise, sensor calibration, site survey, seismic shallow refraction, and meteorological data were documented.

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2.0 TEST SITE CONFIGURATION AND PROCEDURES

2.1 THE TEST SITE

The site consisted of a large open field with a bunker located along the northern perimeter. An improved road (asphalt) bordered the northern site perimeter. The site ground surface consisted of patches of exposed soil and some grasses indigenous to the area.

2.2 SENSOR DEPLOYMENT

The seismic, acoustic, and magnetic (SAM) sensor array is a low noise hardwired system used for the collection of data in the audio frequency range. Amplification of the sensor data was applied in the field prior to the signal entering the data lines. This technique eliminates amplifying any cable generated noise. The SAM array was deployed 150 meters northeast of the operational vehicle (SA-6 Radar).

2.2.1 Acoustic Sensor Deployment

MICROPHONE	GAIN	DEPLOYMENT
M-1	40dB	1 meter below the ground surface
M-2	40dB	1 meter below the ground surface
M-3	40dB	1 meter below the ground surface
M-4	N/A	None
M-5	20dB	Placed inside the operational vehicle.
M-6	40dB	Acoustic soaker hose. This device was placed directly on the ground surface.
M-7	40dB	Surface microphone and collocated with the soaker hose. Isolated from the ground surface to avoid seismic influences.
M-8	40dB	Surface microphone and collocated with M-1, M-2, M-3 and the 3-axis seismic sensor. This microphone was isolated from the ground surface to avoid seismic influences.

2.2.2 Seismic Sensor Deployment

SENSOR	GAIN	DEPLOYMENT
Seismic G-1 (Vertical axis)	40dB	Buried surface level.
Seismic G-2 (Longitudinal axis)	40dB	Buried surface level.
Seismic G-3 (Transverse axis)	40dB	Buried surface level.

Seismic G-4 (Vertical axis)	40dB	Surface placement.

The seismic array consisted of one 3-axis geophone (G-1, G-2, G-3) and a single axis sensor (G-4). The axes were oriented in the following manner. The vertical axis is self-understood. The transverse axis was aligned to the southwest or the operating vehicle (SA-6 Radar). Southeast-northwest to the operating vehicle was the placement of the longitudinal axis. The 3-axis geophone was collocated with M-1, M-2, M-3, and M-8. Seismic sensor, G-4, was collocated with M-6, and M-7.

2.2.3 Magnetic Sensor

The Magnetic sensor data was amplified 40dB. This device was buried and collocated with M-6 and M-7.

2.3 RECORDING EQUIPMENT

Data from the field sensors was fed directly via cables into two instrumentation 16-channel TEAC DAT tape recorders model RD145-T. Individual recorder channel gains were set so that the data would not saturate. One recorder was originally set to a gain of 0.5 volts and the other at 5.0 volts. Other gain changes were made to the recorder during the course of the test. These were noted on the voice channel. Voice was recorded on an individual channel for reference purposes. During the course of the experiment, the tape recorder operator would verbally log on the voice channel the events and activity as they took place on the pathway. This narration becomes very useful during tape playback and analysis of the data.

2.4 CALIBRATION

2.4.1 An acoustic calibrator was used to introduce a 94dB frequency tone into the acoustic sensors.

2.4.2 The acoustic calibrator and all other sensors and instrumentation had current calibration certification traceable to the National Institute of Standards and Technology, NIST.

2.4.3 A seismic shallow refraction test of the site was conducted.

2.5 VEHICLE OPERATION AND CONDUCT

The measurement of noise in the stationary mode was conducted. These measurements were made with the engine operating at idle. Idle is defined as the natural rpm generated by the engine without depressing the accelerator control. The SA-6 Radar was activated to radiate with the use of a dummy load. Power output was 1 watt. It must be noted, that all hatches to the SA-6 Radar were closed and locked.

2.6 METEOROLOGICAL DATA

Meteorological (MET) data was collected during the SAM data collection. The MET station was located at the northeast corner of the test site.

2.7 ELECTRICAL POWER

DC power was the source of electrical power for the operation of the sensors and instrumentation equipment. Deep cycle, 12-volt, lead-acid batteries were used. Use of batteries to power all the equipment improves the quality of the data product.

2.8 SAM CONTROL CENTER

Consisted of a concrete bunker located along the northern perimeter of the site. This structure was used for the protection of instrumentation equipment and personnel.

2.9 DATA PRODUCTS

Data products consisted of two DAT tapes, MET data, and a survey of the site.

3.0 SAM FINDINGS & ANALYSIS

3.1 Background Information

Seismic, acoustic, and magnetic (SAM) 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 SAM sensors were deployed above and below the ground surface in the far field.

Geographical placement between the SAM 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. Additionally, the radar emanations were directed away from the magnetic sensor. 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 SAM findings are very encouraging.

3.2 Acoustic Findings

Acoustic sensors were deployed primarily in the far field. One microphone, M-5, was placed in the near field inside the test vehicle. The narration that follows will compare acoustic data from the buried microphones (M-1, M-2, and M-3) against data from those collocated acoustic sensors placed on the ground surface.

3.2.1 Acoustic Background Noise Levels

These were found to be higher than expected. It is preferred to work with noise levels of 40dB or less. The background noise levels at the site averaged 50dB. 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 easily couples into the ground and can be sensed by microphones.

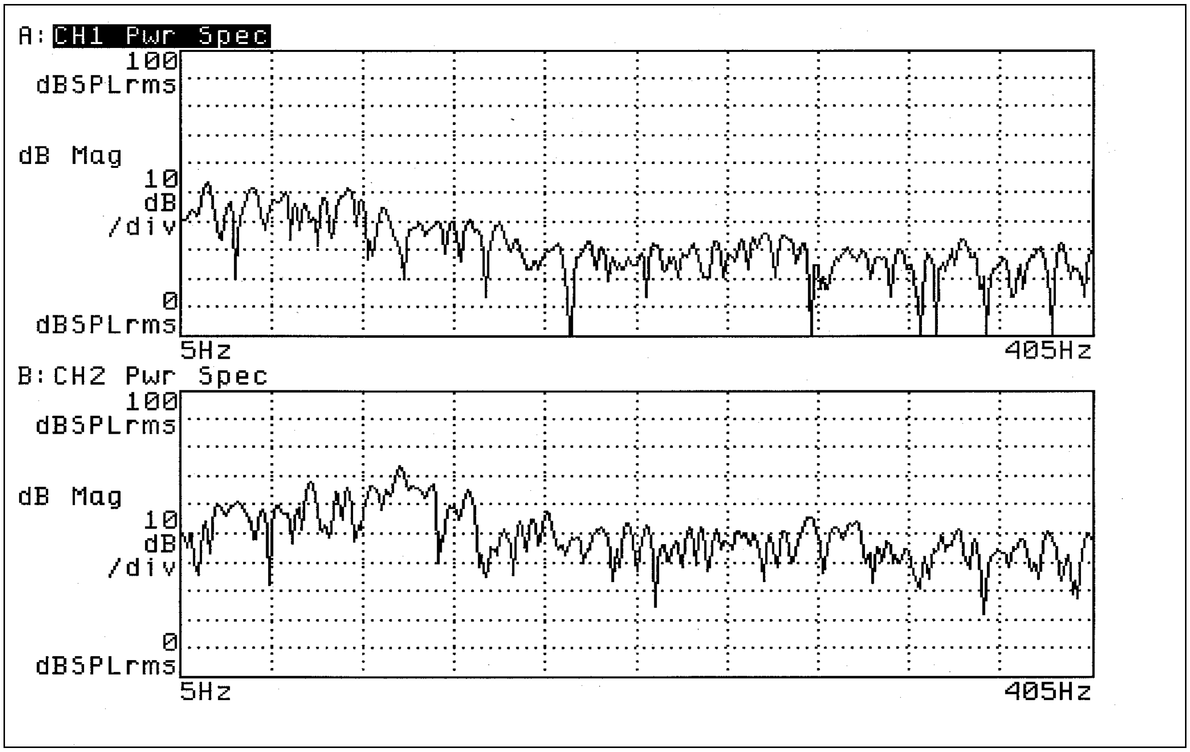

Figure 3-1 Acoustic Background Noise Sample from Microphones M-1 and M-8 Respectively

3.2.2 Acoustic Data Samples from the SA-6 Radar Prior to the Warhead Detonation

The SA-6 Radar was stationary with the engine operating at idle. A higher than usual engine rpm is attributed to other on-board operating systems. The auxiliary power unit was operational.

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 was used for this purpose.

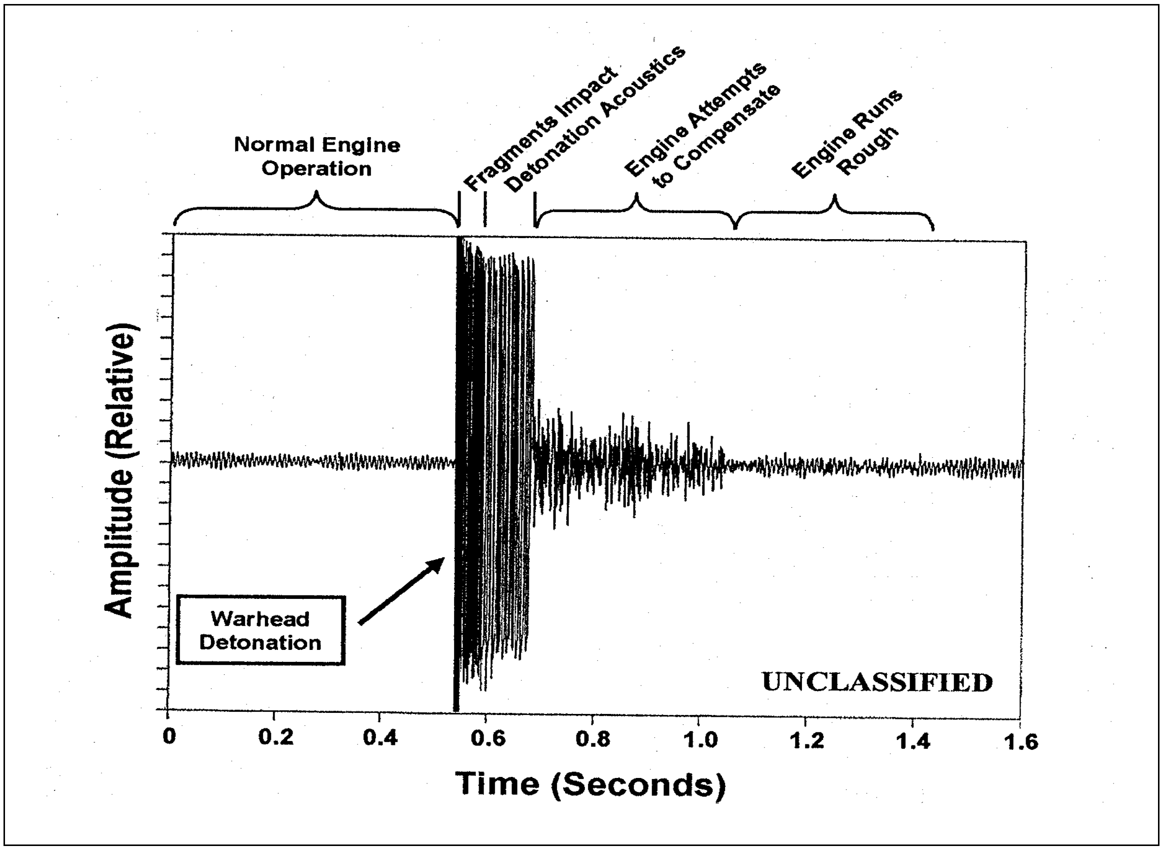

Figure 3-2 Acoustic Data from Microphone M-1 Shows Signal Time History

The dominant acoustic emanation from an operating engine is that which comes from the exhaust port. This acoustic product is composed of low frequencies, enabling it to propagate over long distances. This is the case of the SA-6 Radar vehicle that was used as a test item at the Meppen test facility. Although the APU was operational at the same time, its acoustic product is not capable of long distance propagation. This is due to the high frequency composition of the APU acoustic signature.

The engine exhaust acoustic product is a combination of harmonics. These harmonics are displayed when an FFT of the analog data is conducted. The dominant harmonic is known as the engine firing frequency. This is the result from the engine operating at a specific rpm value.

3.2.2.1 Acoustic Signatures from the Buried Microphones

Acoustic data from the SA-6 Radar vehicle shows that the engine firing frequency has an average value of 114.0 Hz and the sound pressure level for this point is 108.0dB. Sound pressure level values vary with the microphone sensitivity. These values were typical of the buried microphones M-1, M-2, and M-3. This is reflected in Figures 3-3,3-4, and3-5 respectively. The pyramid shaped harmonics result from wind noise and the soil inherent filter properties. These have an affect on the frequency components of the acoustic spectra.

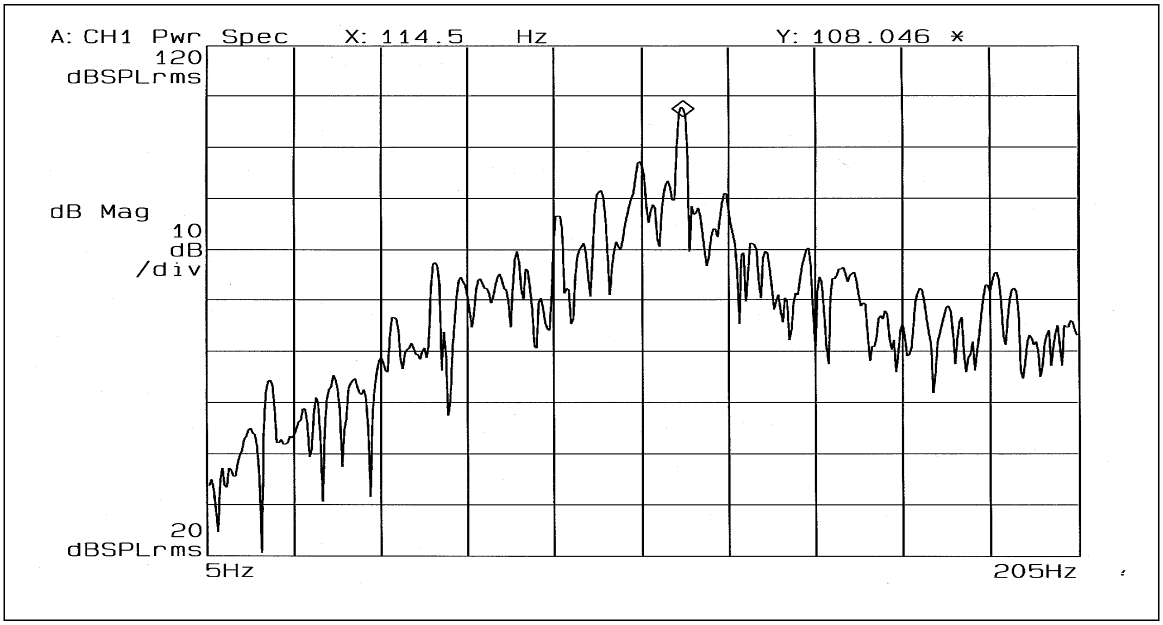

Figure 3-3 Acoustic Data Sample from Microphone M-1 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation.

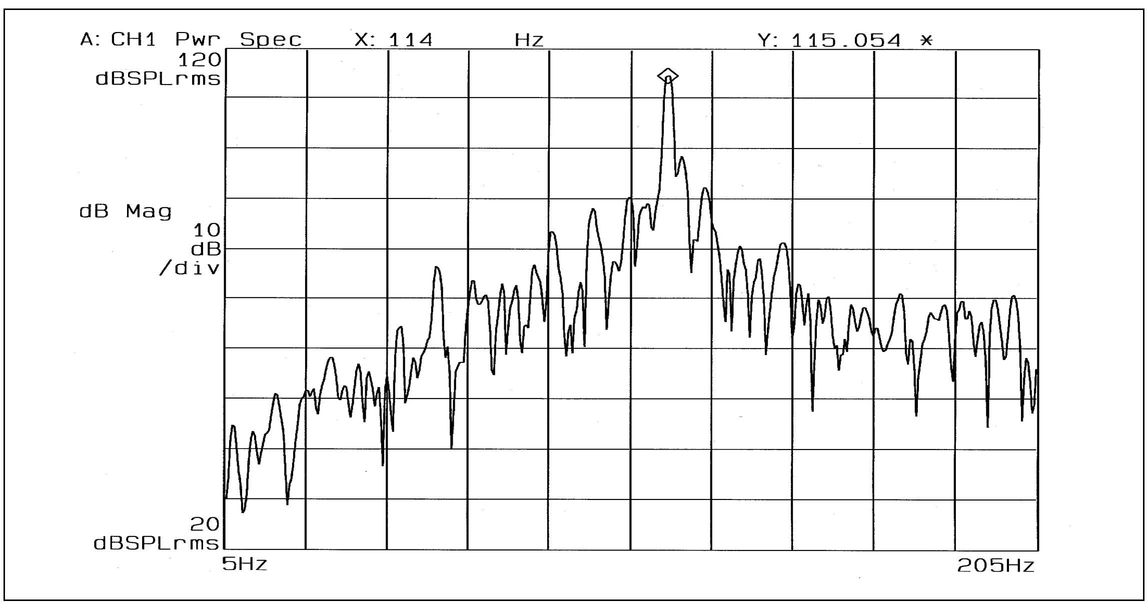

Figure 3-4 Acoustic Data Sample from Microphone M-2 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation.

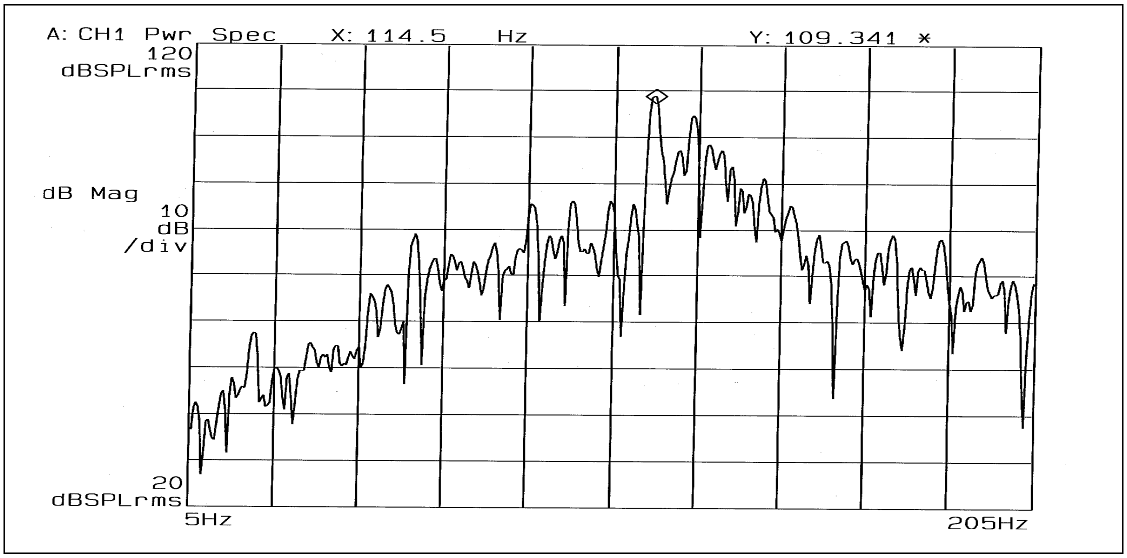

Figure 3-5 Acoustic Data Sample from Microphone M-3 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation.

3.2.2.2 Acoustic Signature from the Microphone Inside the Vehicle

Microphone M-5 was placed inside the vehicle for the purpose of monitoring compartment noise. Isolation techniques were employed so that the microphone would not come in contact with neighboring vibrating surfaces. The acoustic signature shows that it is similar in value to the data from the buried microphones. See Figure 3-6.

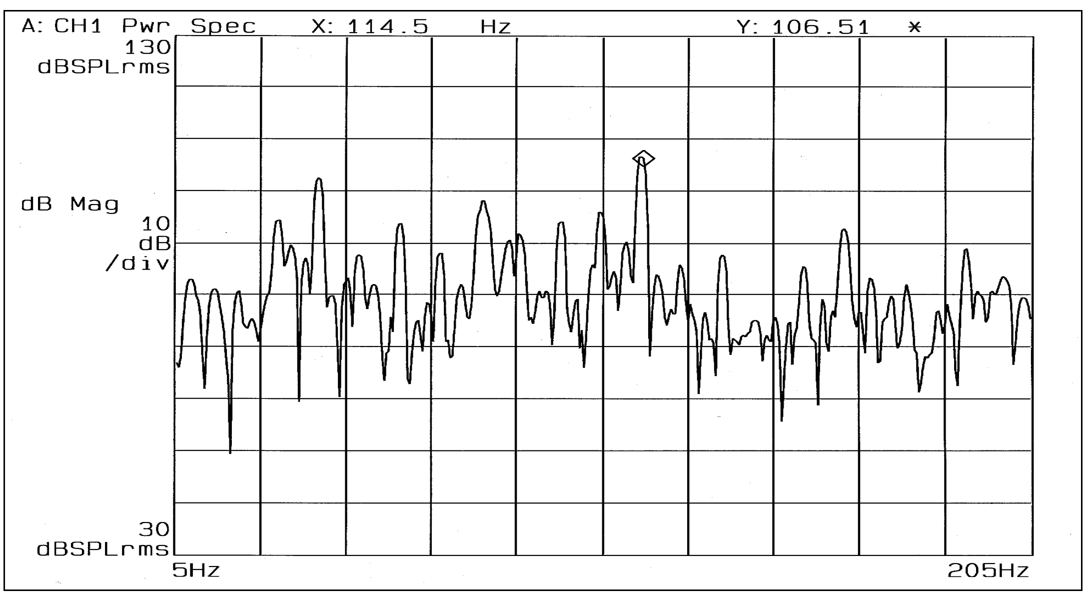

Figure 3-6. Acoustic Data Sample from Microphone M-5 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation.

3.2.2.3 Acoustic Signature from the Soaker Hose Microphone

Microphone M-6, was the soaker hose microphone. This device was placed directly on the ground surface. It operation is dependent on the length of a rubber hose that has random perforations. The soaker hose is used as a windscreen to minimize background noise. Figure 3-7 shows the SA-6 Radar acoustic signature. The engine firing frequency remains stable at 114.5 Hz. However, a decrease of sound pressure level is observed, 80.6dB. Two factors have contributed to the SPL attenuation. These are distance to the vehicle and the soaker hose windscreen.

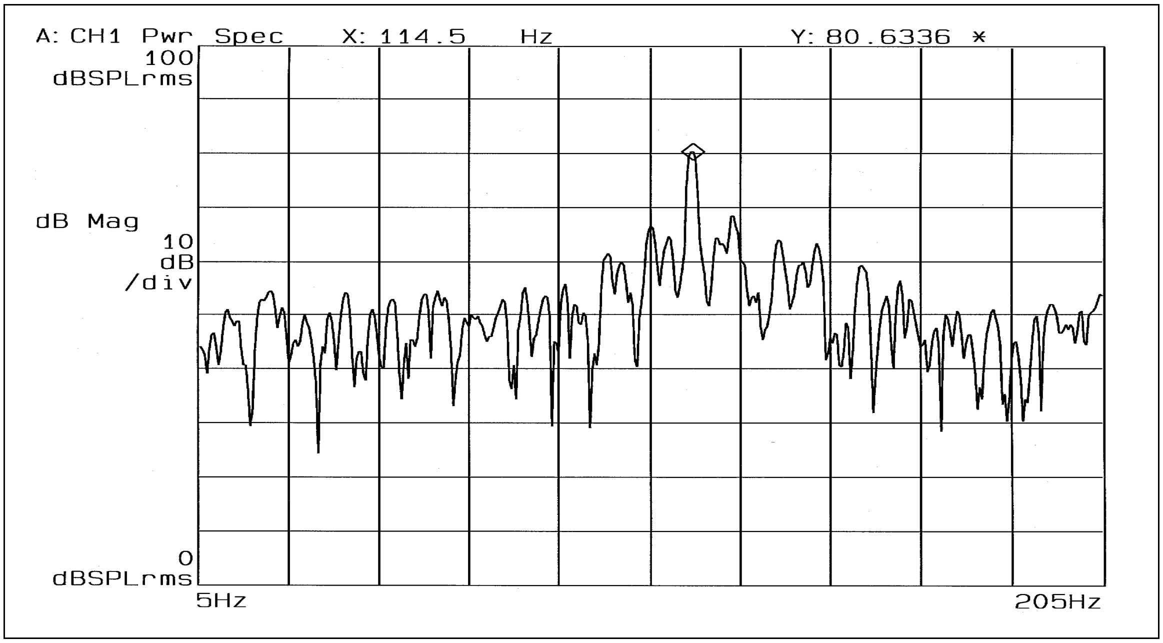

Figure 3-7 Acoustic Data Sample from Microphone M-6 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation.

3.2.2.4 Acoustic Signatures from the Surface Microphones

Microphones M-7 and M-8 were collocated with the soaker hose and the buried microphones respectively. The acoustic signatures of these are shown in Figures 3-8 and 3-9 respectively. No evident change is observed in the engine firing frequency. Average SPL is 87.0dB. Comparing the SPL level of these two microphones against the buried acoustic sensors M-1, M-2 and M-3 shows a SPL level difference of at least 20dB. The soil properties at the test site contributed little to none in the form of signal SPL attenuation.

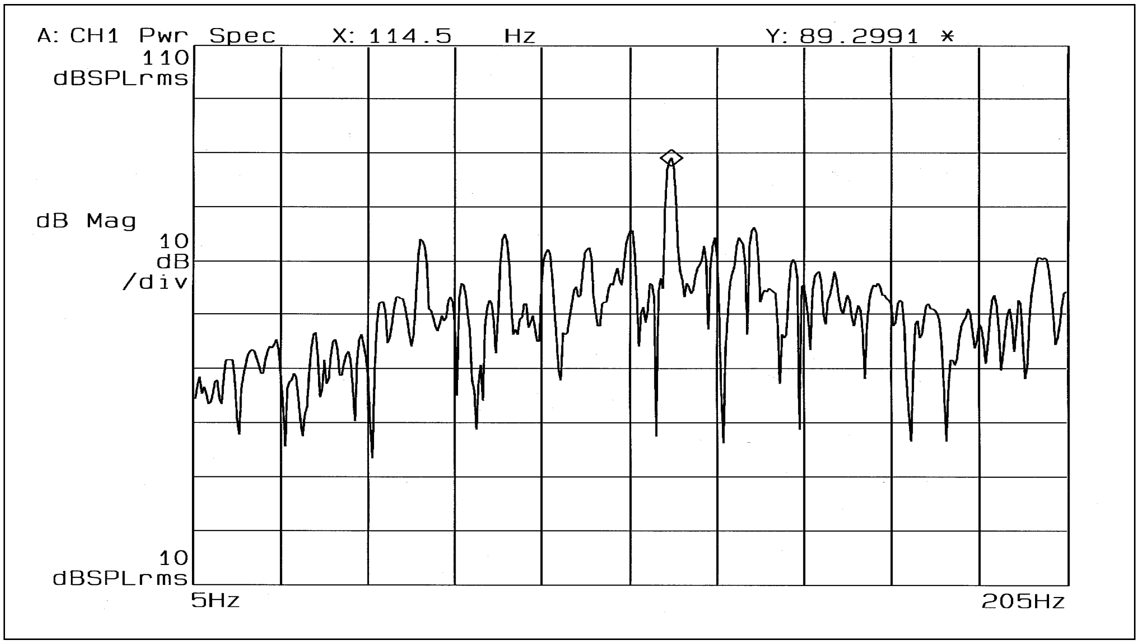

Figure 3-8 Acoustic Data Sample from Microphone M-7 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation

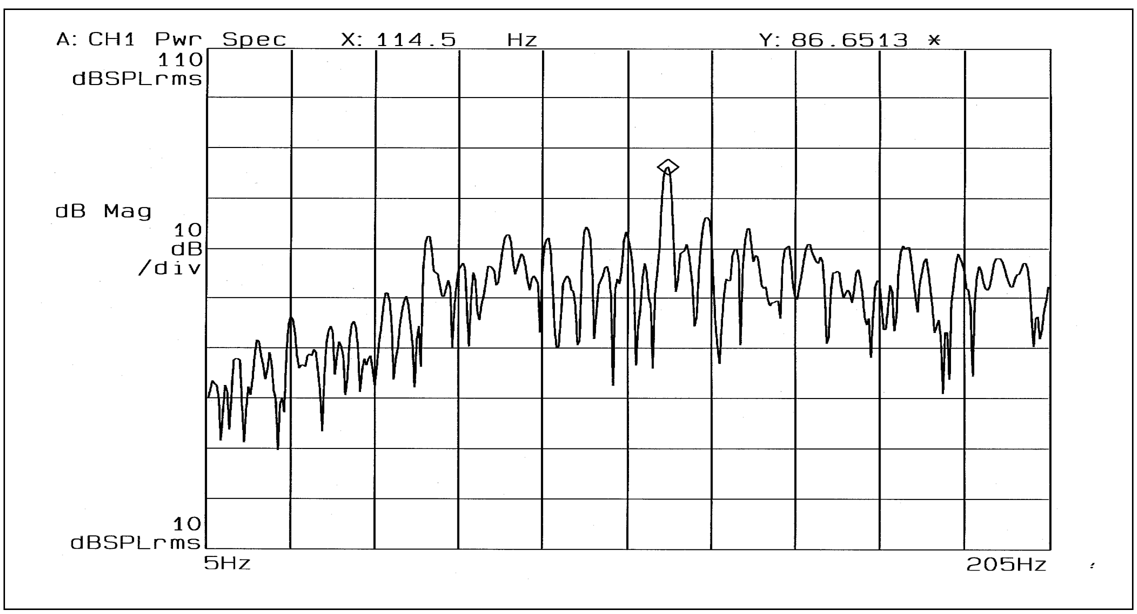

Figure 3-9 Acoustic Data Sample from Microphone M-8 Shows SA-6 Radar Vehicle Engine Signature Prior to Warhead Detonation

3.2.3 Acoustic Data Samples from the SA-6 Radar After Warhead Detonation

Detonation of the HARM warhead has taken place. The acoustic data that follows will relate the events that immediately followed the warhead detonation. Using the tape recorder time clock, it shows that the warhead detonated at 13:48:21. This time will be used as a reference to observe the condition of the engine and its affect on the acoustic signature.

3.2.3.1 Acoustic Signature Inside the Vehicle

The time is now 13:49:11. Acoustics (M-5) inside the vehicle compartment have changed. The engine firing frequency is now 117.00 Hz. This is an increase of 3.0 Hz over the former engine idle value of 114.00 Hz. Harmonic distortion is evident in the acoustic signature. Formerly clean peaks observed in Figure 3-6 now have side harmonics. See Figure 3-10.

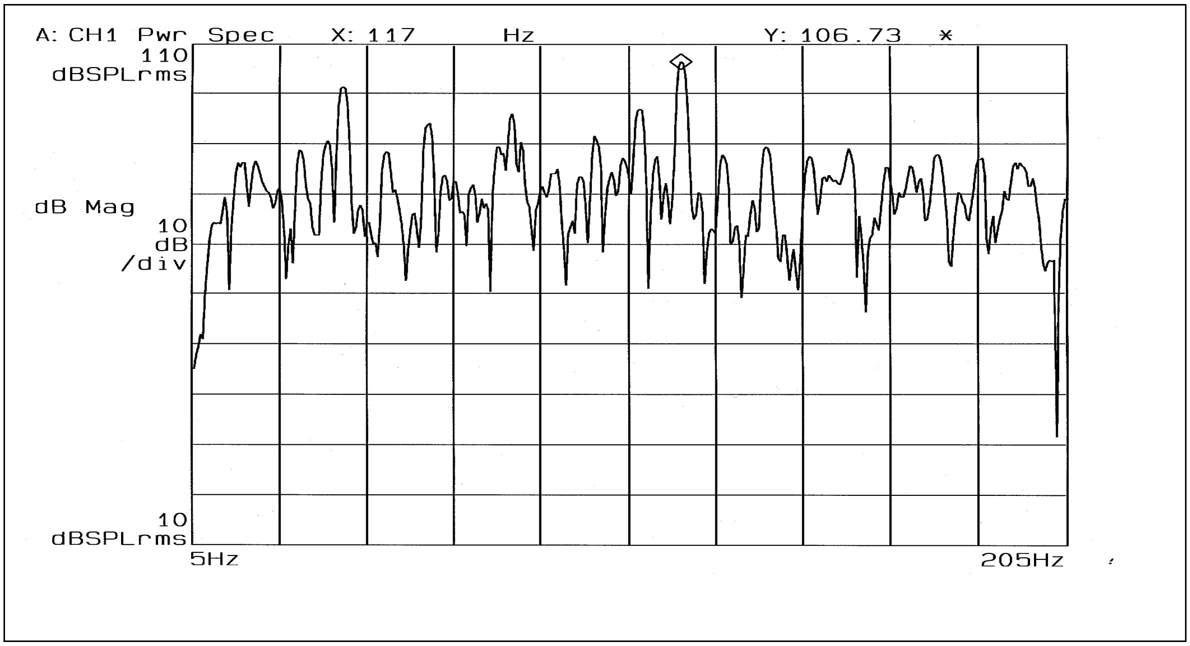

Figure 3-10 Acoustic Data Sample from Microphone M-5 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:49:11

The time is now 13:49:13. Acoustics (M-5) inside the vehicle compartment show that the engine firing frequency is 117.50 Hz. The harmonic distortion of the spectra has dropped to the floor noise area. See Figure 3-11.

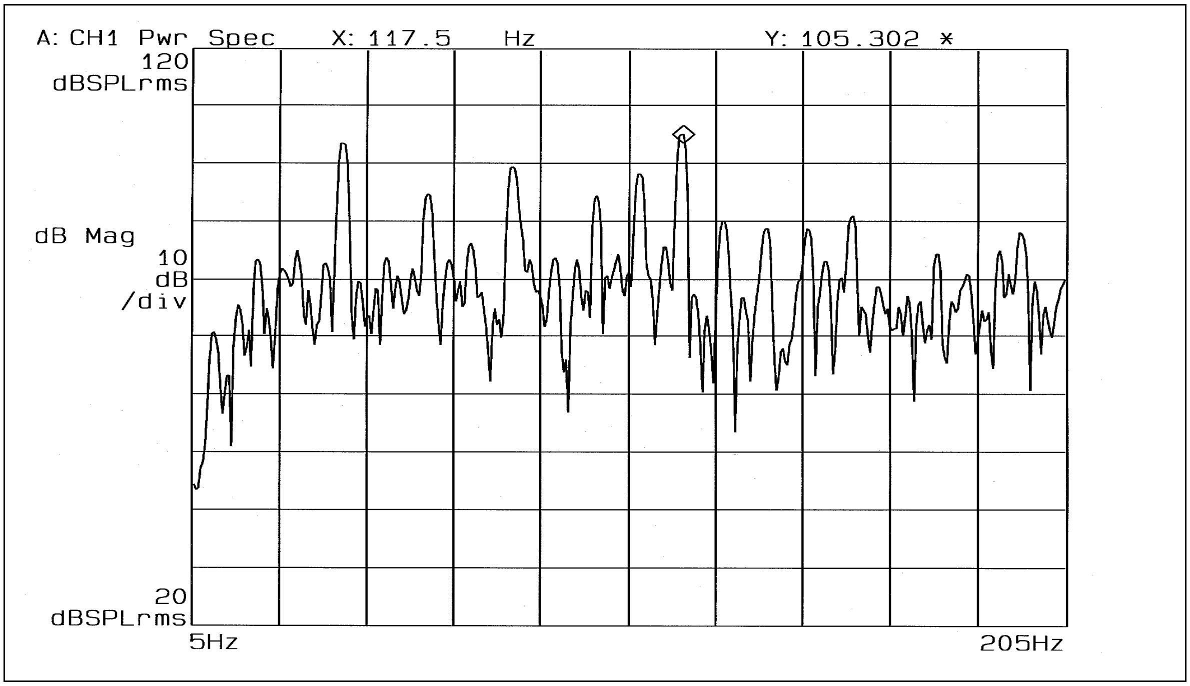

Figure 3-11 Acoustic Data Sample from Microphone M-5 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:49:13

The time is now 13:49:15. Acoustics (M-5) inside the vehicle compartment show that the engine firing frequency is 117.00 Hz. Harmonic content of the spectra has increased in value once more. See Figure 3-12.

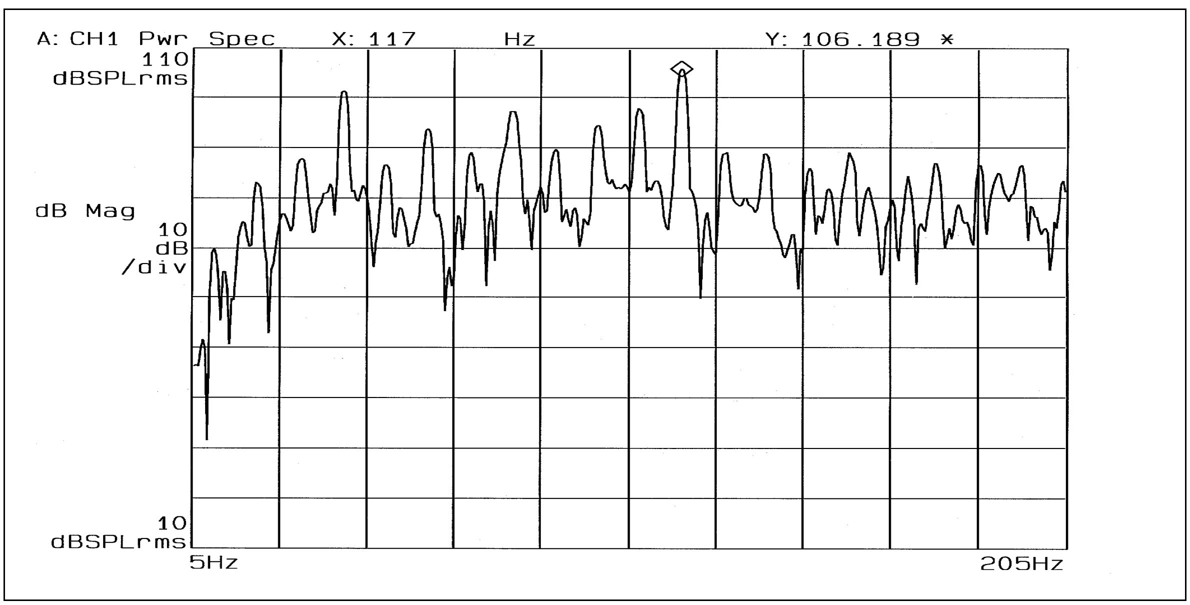

Figure 3-12 Acoustic Signature from Microphone M-5 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:49:15

During the period of 13:49:11 to 13:49:15, 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. 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 following the HARM warhead detonation.

3.2.3.2 Acoustic Signature from the Buried Microphones

The warhead detonation too place at 13:48:21. The acoustic data that follows is that from the acoustic sensors buried 1 meter below the ground surface. This acoustic array is located 150 meters away from the operational SA-6 Radar. These data samples were obtained at an earlier period of time than those discussed in 3.2.3.1 (vehicle interior acoustics).

The time is 13:48:38. Microphone M-1 data shows that the engine firing frequency is 117.00 Hz and SPL is 105.80dB. Distortion of the acoustic data sample is visible in Figure 3-13.

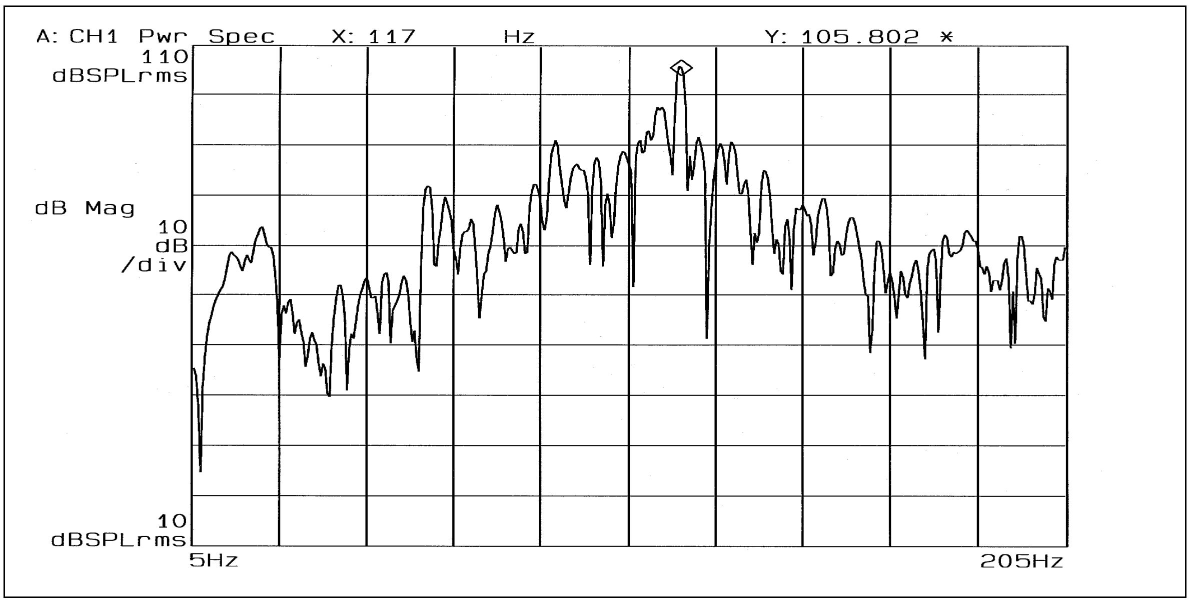

Figure 3-13 Acoustic Data Sample from Microphone M-1 Shows SA-6 Radar Vehicle Signature After Warhead Detonation. Time 13:48:38

3.2.3.3 Acoustic Signature from the Soaker Hose Microphone

The time is 13:48:41. The acoustic data sample from microphone M-6 shows that the engine firing frequency remains the same and SPL is 79.77dB. The SPL attenuation is due to the inherent characteristics of the soaker hose windscreen. Signal distortion remains evident. See Figure 3-14.

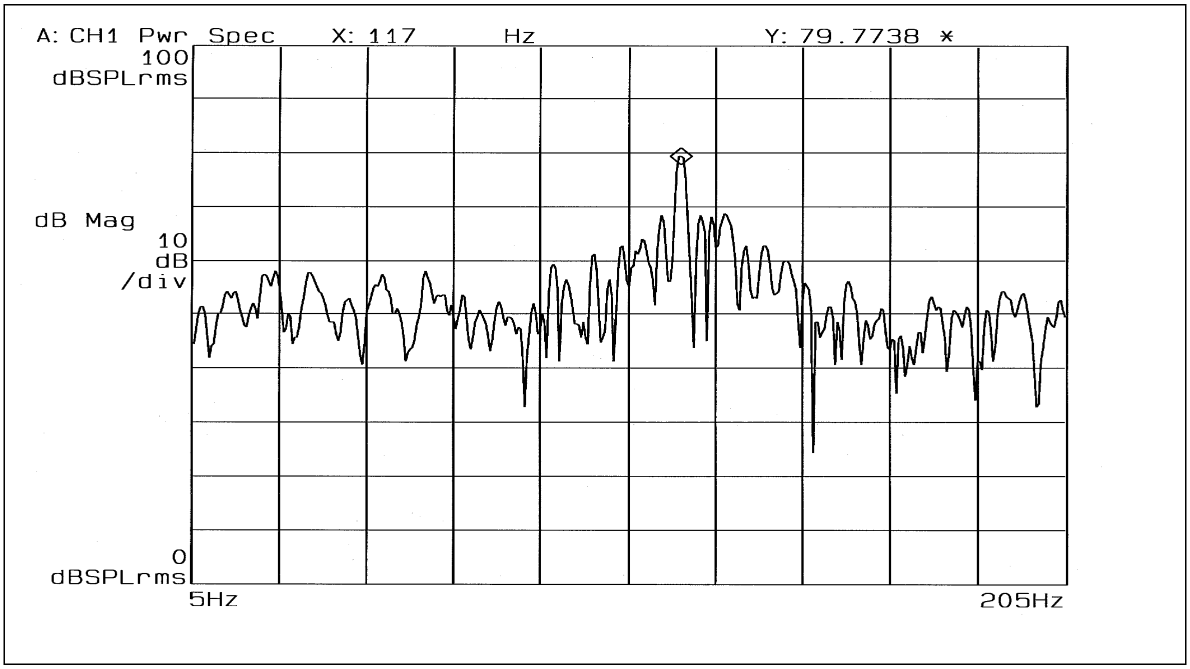

Figure 3-14 Acoustic Data Sample from Microphone M-6 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:48:41

3.2.3.4 Acoustic Signature from the Surface Microphones

The time is 13:48:42. This acoustic data sample is from microphone M-7. This device was collocated with the soaker hose. The engine firing frequency is 117.00 Hz and the SPL is 89.57dB. See Figure 3-15.

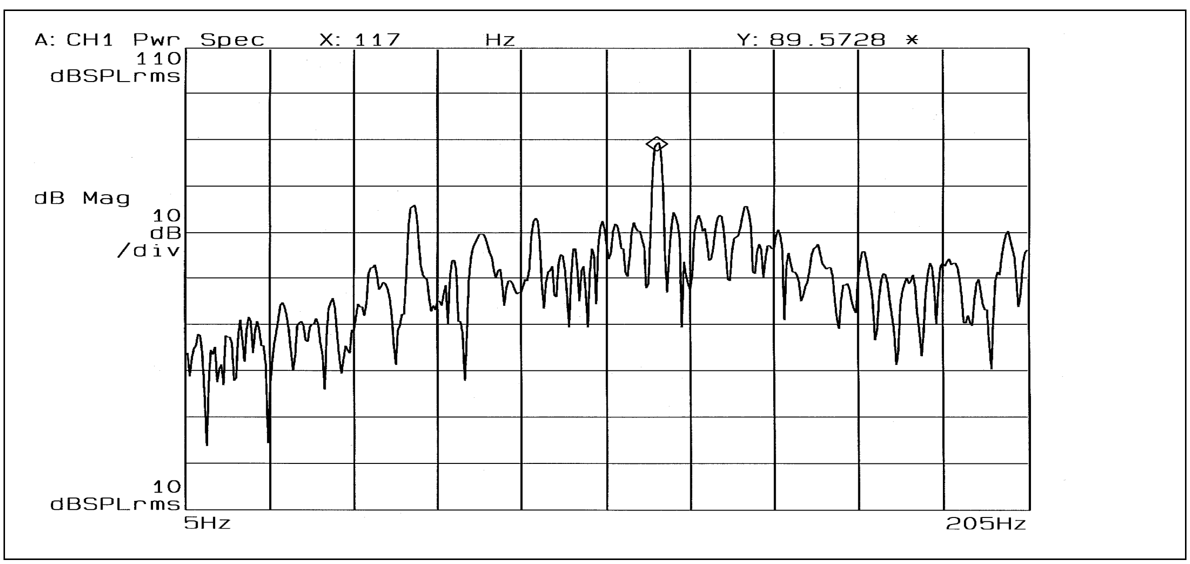

Figure 3-15 Acoustic Data Sample from Microphone M-7 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:48:42

Figure 3-16 shows the acoustic signature at 13:48:43. This sample was from microphone M-8. This device was collocated with the buried microphones. The data product is similar to that from microphone M-7.

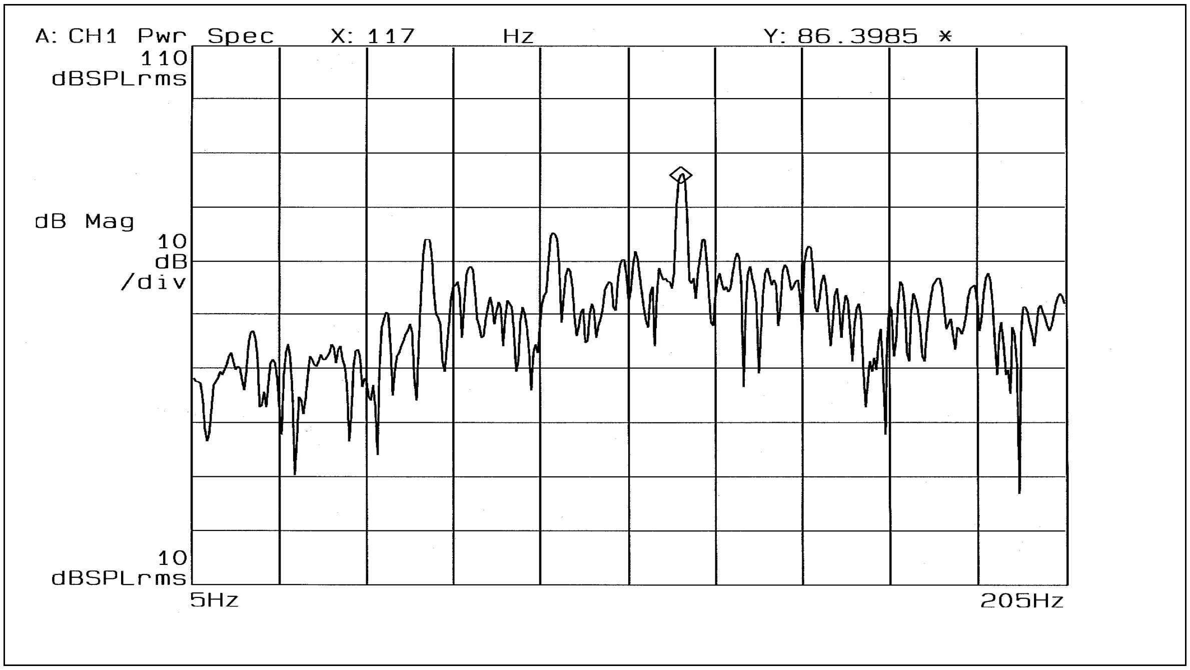

Figure 3-16 Acoustic Data Sample from Microphone M-8 Shows SA-6 Radar Vehicle Engine Signature After Warhead Detonation. Time 13:48:43

3.3 Seismic Findings

One three axis and a single axis geophone were deployed 150 meters away from the SA-6 Radar vehicle. Data from the seismic sensors show that the SA-6 Radar vehicle remained stationary during the test.

3.4 Magnetic Findings

A military vehicle such as the SA-6 Radar is a self-propelled ferromagnetic mass. It is therefore reasonable to expect that the detection and classification scheme based on a stationary magnetic sensor would prove useful in situations involving vehicles of military interest. The physical principal involved is that a ferromagnetic mass exhibits an induced magnetic moment when placed in the earth's magnetic field. The magnetic field of this induced dipole distorts the uniform geomagnetic field that can be detected by a magnetometer that produces a signature depicting the disturbance.

In addition to the induced moment, there exists a second magnetic moment, which contributes to a vehicle's magnetic signature. This moment, called the "on-board" moment, has for its origin electrical phenomena and mechanical motion created by the vehicle. A portion of the on-board moment is also due to the residual magnetic effects in the vehicle material due to long-term positioning in the geomagnetic field.

3.4.1 Magnetic Data Findings

The stationary SA-6 Radar vehicle was located 150 meters away from the magnetometer. In this configuration, the magnetometer has to rely on sampling "on-board" moment activity as it takes place aboard the SA-6 Radar. The primary source of on-board magnetic activity are the one (1) Watt magnetic emanations from the radar. Sampling of the induced moment at this distance is a problem because the data would be lost in the background noise. Thus, all efforts must be focused on the on-board moment activity.

The magnetometer was set up to sample emanations in a spectral region of less than (forty) 40 Hz. Magnetic data will now be presented showing two areas of interest. These were, magnetic samples before and after the warhead detonation. All magnetic data samples are presented in the time domain.

3.4.1.1 Magnetic Background Noise at the Meppen Site

A sampling of magnetic background noise was acquired to establish a baseline. This sample was collected with the SA-6 Radar vehicle stationary and all systems off. Figure 3-17 shows that the average background was 15.0 mGauss.

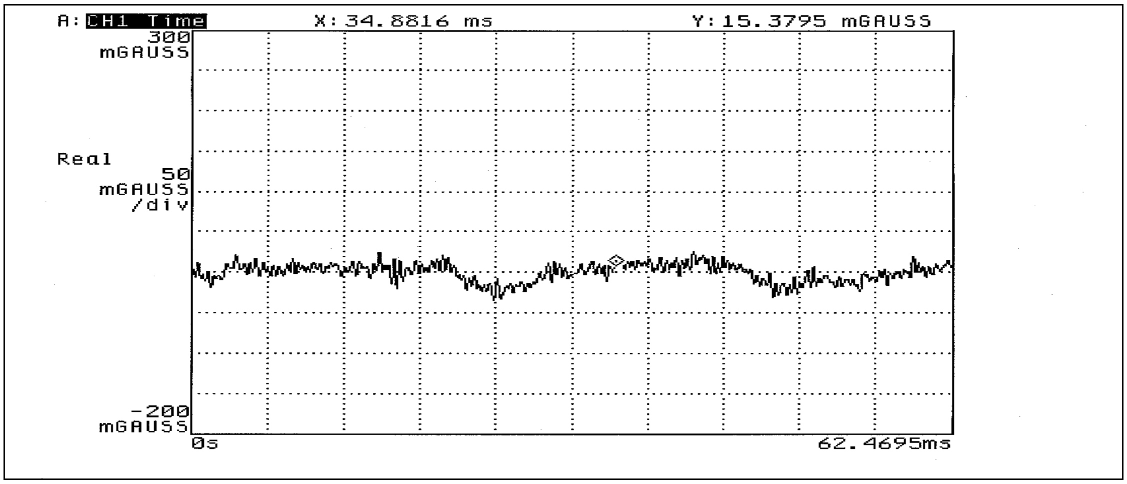

Figure 3-17 Sample of Magnetic Background Noise from the Meppen Test Site

3.4.1.2 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Before Warhead Detonation

The SA-6 Radar vehicle is now in operation and the radar is emanating 1 Watt of power. It must be noted that the magnetometer is sampling the backside of the SA-6 Radar dish. Figure 3-18 shows that the magnetic levels now average 130.0 mGauss.

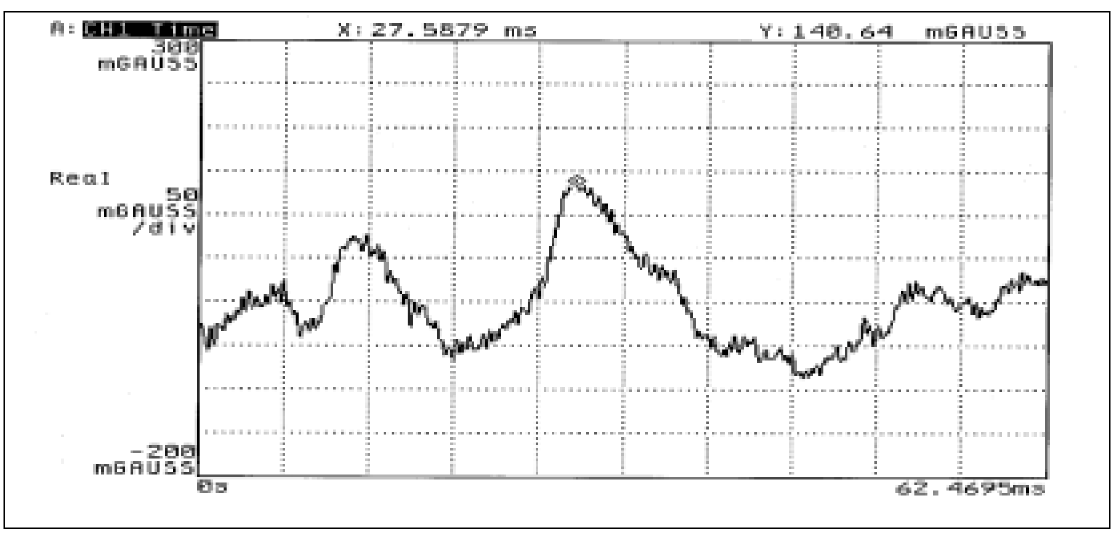

Figure 3-18 Magnetic Data Sample from the Backside of the SA-6 Radar Vehicle, Prior to the Warhead Detonation

3.4.1.3 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Five Seconds After Warhead Detonation

The HARM warhead detonation has taken place. Magnetic effects from the warhead detonation are added to the radar's magnetic field. Figure 3-19 shows the magnetic data sample immediately after the detonation.

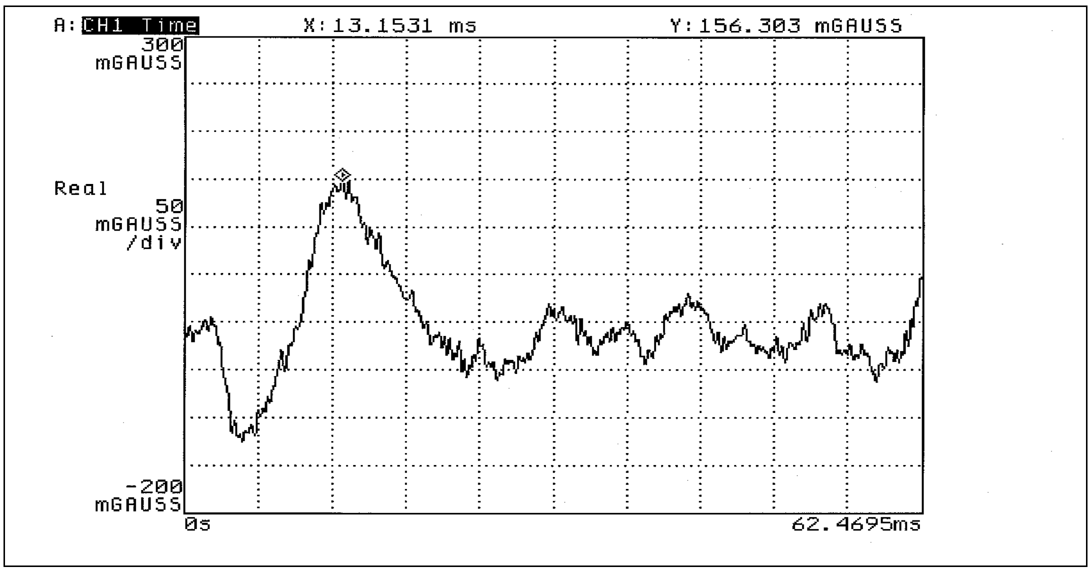

Figure 3-19 Magnetic Data Sample from the Backside of the SA-6 Radar Vehicle, Five Seconds after Warhead Detonation

3.4.1.4 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Seven Seconds After Warhead Detonation

The radar begins to show signs of magnetic decay. Emanations begin to decrease rapidly. The signature begins to show random attempts by the vehicle electrical systems to compensate. See Figure 3-20.

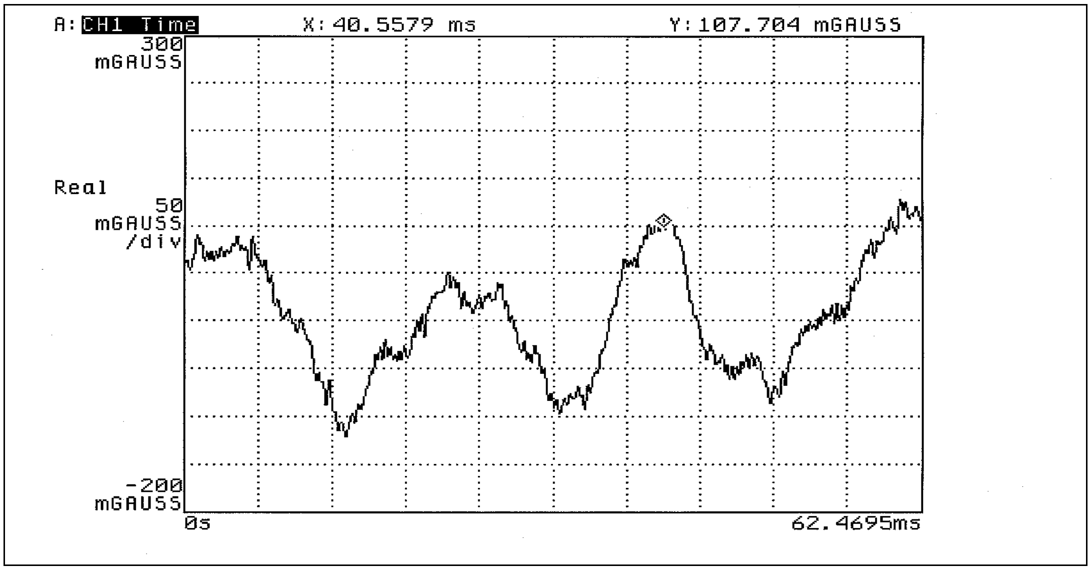

Figure 3-20 Magnetic Data Sample from the Backside of the SA-6 Radar Vehicle, Seven Seconds after Warhead Detonation

3.4.1.5 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Eleven Seconds After Warhead Detonation

The radar continues to show significant signs of magnetic decay. Emanations are now at a very low level. The signature continues to show a random effect. See Figure 3-21.

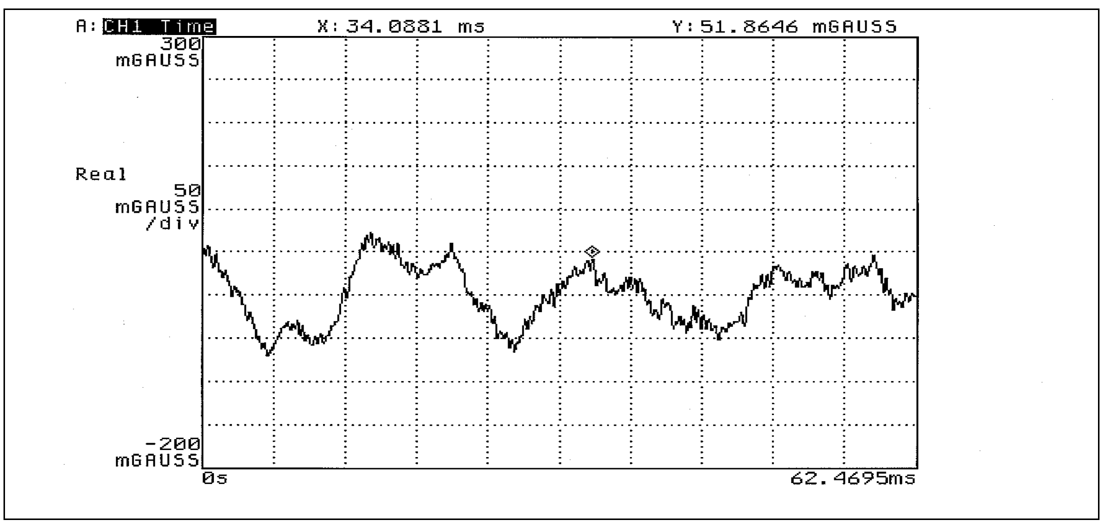

Figure 3-21 Magnetic Data Sample from the Backside of the SA-6 Radar Vehicle, Eleven Seconds after Warhead Detonation

3.4.1.6 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Thirty Seven Seconds After Warhead Detonation

The magnetic signature from the SA-6 Radar on-board moment is now approaching the background noise baseline value of 15.0 mGauss. See Figure 3-22.

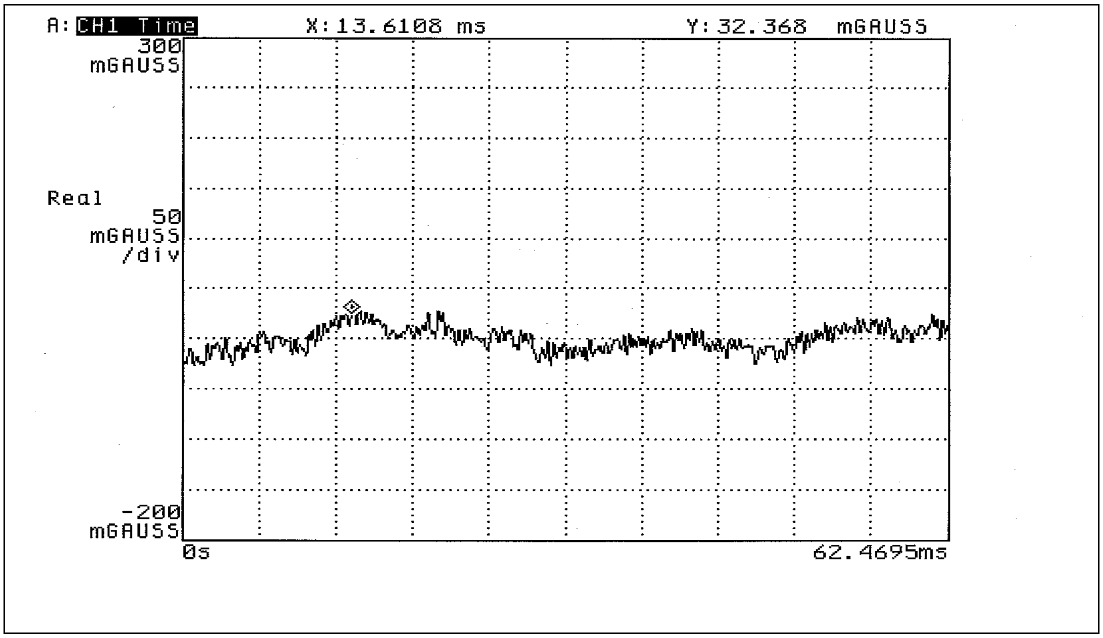

Figure 3-22 Magnetic Signature from the Backside of the SA-6 Radar Vehicle, Thirty Seven Seconds after Warhead Detonation

3.4.1.7 Magnetic Data Comments

It can be concluded that the magnetic sensors could be placed at a farther distance, if the SA-6 Radar Vehicle transmitter were to operate without a dummy load. The low frequency magnetic sampling of the on-board moment data from active radio frequency transmitters opens many areas of interest.

4.0 SUMMARY

Seismic, acoustic, and magnetic 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 SAM sensors at the Meppen facility yielded a wealth of information. SAM sensors were placed in the near and far field for the purpose of gathering vehicle information. The vehicle of interest was the SA-6 Radar. Geographical placement of the SA-6 Radar and the SAM sensors, placed the far field sensors at a disadvantage. Despite the impediments, the SAM findings were very encouraging.

The complete test lasted less than 20 minutes. However, much SAM data was acquired. Initial SAM findings include the following.

4.1 Acoustic Findings

4.1.1 Acoustic: Background noise levels at the site averaged 50dB. Despite these levels, good data samples were acquired.

4.1.2 Acoustic: SA-6 Radar acoustic data samples show that the engine firing frequency prior to the warhead detonation was 114.00 Hz and 117.00 Hz after the detonation.

4.1.3 Acoustic: Signature distortion was apparent in the SA-6 Radar engine acoustic data samples after the detonation.

4.1.4 Acoustic: Acoustic signatures show that the SA-6 Radar engine varied in rpm from 50 to 100 rpm immediately following the detonation.

4.1.5 Acoustic: The use of the soaker hose microphone for this type of work proved to be valuable in attenuating the pressure from the blast.

4.1.6 Acoustic: The use of buried microphones showed that detection and vehicle engine health monitoring was possible at extended underground distances.

4.1.7 Acoustic: Data shows that the engine tried to compensate as the transmitter became damaged.

4.2 Seismic Findings

4.2.1 Seismic: Seismic data shows that the SA-6 Radar vehicle remained stationary.

4.3 Magnetic Findings

4.3.1 Magnetic: Magnetic data samples show that the background noise at the Meppen site averaged 15.0 mGauss excluding the earth's magnetic field.

4.3.2 Magnetic: Magnetic data samples from the backside of the active SA-6 Radar transmitter, show an average value of 130.00 mGauss prior to the warhead detonation.

4.3.3 Magnetic: Magnetic data samples show the decay of the radar signal following the warhead detonation. This data can be correlated with the acoustic samples.

This report only addresses the SAM signatures from the SA-6 Radar vehicle. Detection and classification of the HARM warhead blast using SAM sensors is fertile ground that can be explored at another time.