
Masters Theses

Student Theses and Dissertations

Fall 2010

Evaluation of metal detection audio alert signals of AN/PSS-14 by means of real time visualization

Sandesh Srikantaiah Chandrashekar

Follow this and additional works at: https://scholarsmine.mst.edu/masters_theses



Part of the [Mechanical Engineering Commons](#)

Department:

Recommended Citation

Srikantaiah Chandrashekar, Sandesh, "Evaluation of metal detection audio alert signals of AN/PSS-14 by means of real time visualization" (2010). *Masters Theses*. 4806.

https://scholarsmine.mst.edu/masters_theses/4806

This thesis is brought to you by Scholars' Mine, a service of the Missouri S&T Library and Learning Resources. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

EVALUATION OF METAL DETECTION AUDIO ALERT SIGNALS OF AN/PSS-14
BY MEANS OF REAL TIME VISUALIZATION

by

SANDESH SRIKANT AIAH CHANDRASHEKAR

A THESIS

Presented to the Faculty of the Graduate School of the
MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree
MASTER OF SCIENCE IN MECHANICAL ENGINEERING

2010

Approved by

Virgil Flanigan, Advisor
K. Chandrashekhara
Richard Rechtein

ABSTRACT

The sweep arm of the AN/PSS-14 Landmine Detector attached to an independent visualization device will transform the AN/PSS-14 into a hand-held data acquisition system for conversion of real time MD and GPR audio alert signals into captured visual trace displays on an on-board PDA computer screen so that momentary sounds of millisecond durations can be captured and displayed for visual scrutiny and interpretation by analytical on-board data processing procedures. This is a part of a two-man team that is developing a visual data adapter for the AN/PSS-14 Landmine Detector where the current thesis is concentrating only on MD audio alerts.

The visualization device displays the amplitude-time plot and the instantaneous frequency-time plots of the MD audio alert signal for better understanding and for distinction of metallic firing pins from metallic clutter. This is achieved by the identification of the metal type, which would be common in any given landmine field and by observing the symmetric deviations of the amplitude envelope along multiple sweep directions over a buried target. The analysis of this research is constrained to only vertical firing pins.

Further, analyzing the frequencies of different types of firing pin (different metal types), it can be concluded that the frequency response of the AN/PSS-14 to metallic targets are specific to metals. This process is only applicable for single, isolated MD audio signals.

ACKNOWLEDGMENTS

I would like to thank all people who have helped and inspired me during my masters' study. I especially want to thank my advisor; Dr. Virgil Flanigan for his support, guidance, encouragement from the initial to the final level enabled me to develop an understanding of the subject and for providing financial support.

I am indebted to Dr. K. Chandrashekhara for recommending me to this opportunity in the first place, for being on my committee and for his constant support.

I would like to show my gratitude to my research guide Dr. Richard Rechtein for working with me on this project and for being in my committee. His experience in seismic and electromagnetic data acquisition, processing and mechanical systems is invaluable.

I am thankful to Department of Mechanical and Aerospace Engineering and the Center for Environmental Sciences and Technology faculty and staff. I would like extend my regards to Nitin Kolekar for being my research partner and for helping me in a number of ways to complete this project.

I would also like to thank all family members and friends for their continued support and for having the confidence in me and helping me reach my goal.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGMENTS.....	iv
LIST OF FIGURES.....	vii
LIST OF TABLES.....	ix
 SECTION	
1. INTRODUCTION.....	1
1.1. ELECTROMAGNETIC WAVE EQUATION.....	2
1.2. METAL DETECTION.....	5
1.3. GROUND PENETRATING RADAR.....	11
1.4. SKIN DEPTH.....	14
2. PROJECT DESCRIPTION.....	16
2.1. PROJECT OBJECTIVE.....	16
2.2. PROJECT BACKGROUND.....	17
2.3. LINEAR SWEEP FACILITY (LSF).....	19
3. DESIGN METHODOLOGY.....	22
3.1. DESIGN PROCESS.....	22
3.2. HAND-HELD VISUALIZATION INSTRUMENTATION.....	23
3.2.1. Hand-Held Computer.....	23
3.2.2. Hardware Requirement.....	23
3.2.3. Connection.....	24

3.2.4. Software.....	24
3.3. INSTRUMENTATION SELECTED.....	25
4. INSTANTANEOUS FREQUENCY PROGRAMMING.....	26
4.1. ALGORITHM	26
4.2. LABVIEW PROGRAM	28
5. INSTANTANEOUS FREQUENCY RESULTS.....	31
6. CONCLUSIONS AND FUTURE WORK.....	40
BIBLIOGRAPHY.....	42
VITA.....	43

LIST OF FIGURES

Figure	Page
1.1. AN/PSS-14.....	2
1.2. MD Coil Transmitting	6
1.3. MD Coil Receiving Metallic Returns.....	6
1.4. MD Audio Alert for a Standard, Non-Metallic, Anti-Personal (AP) Landmine Simulator with a Low-Metallic, Vertically Orientated Firing Pin.....	7
1.5. MD Radiation Field.....	10
1.6. MD Total Field Shape Co-relation.....	10
1.7. GPR Signal Transmitting.....	12
1.8. GPR Reflected Signal.....	13
1.9. Planar Logarithmic Spiral Antennas.....	13
1.10. Electromagnetic Dipole Showing Primary and Secondary Magnetic Fields.....	15
2.1. Linear Sweep Facility.....	20
4.1. Algorithms for Instantaneous Frequency and Instantaneous Amplitude.....	28
4.2. LabView Code.....	29
5.1. MD Audio Alert for Aluminum with Background Noise.....	31
5.2. Filtered MD Audio Alert for an Aluminum Firing Pin.....	32
5.3. MD Audio Alert Envelope for an Aluminum Firing Pin.....	33
5.4. Unwrapped Phase of the Analytical Signal for Aluminum Firing Pin.....	33
5.5. Instantaneous Frequency of the MD Audio Alert signal for Aluminum Firing Pin.....	34
5.6. Filtered MD Audio Alert.....	35
5.7. MD Audio Alert Envelope.....	36

5.8. Instantaneous Frequency Plot.....	36
5.9. Frequency Response to Five Conductors.....	37
5.10. Amplitude Response to Five Conductors.....	38

LIST OF TABLES

Table	Page
5.1. Metal Type and Instantaneous Frequency Values.....	38

1. INTRODUCTION

The AN/PSS-14 (formerly HSTAMIDS: Handheld Standoff Mine Detection System) Land mine Detector is an important tool used by the military for the detection of buried metallic and low metallic landmines. The system uses a combination of Metal Detection (MD) and Ground Penetrating Radar (GPR) technology for landmine detection. Both the MD and GPR are active search methods that transmit electronic signals into the ground and analyze that return. The presence of metal below the ground surface is sensed by the MD and the lateral dielectric variations of the subsurface are detected by the GPR, which are constantly activated during a sweep operation.

The advantage of using multiple detection technologies is that when used in combination, they provide a higher level of detection probability than if used separately. The combination of the two technologies reduces the false alarm rate. The GPR would return all the anomalies in the ground. To eliminate these signals, the software of the AN/PSS-14 suppresses the GPR alert signal from being processed until the MD detects the presence of metal. Thereby eliminating a large number of false alarm rates. When the MD detects the presence of the metal, the software releases the GPR signal so that the operator can hear both the signals. It is then up to the operator to localize the target and determine if the target is a mine or clutter. The audio alerts are often unheard and give no information about the metal type/clutter. This study has made an attempt in understanding, developing and production of a MD real-time visual display on a hand-held PDA based computer. Figure 1.1 shows the AN/PSS-14 [1].



Figure 1.1: AN/PSS-14

1.1. ELECTROMAGNETIC WAVE EQUATION

The principle of Electromagnetic Induction is used for landmine detection where the electromagnetic energy is generated within a host medium of air, by a simple antenna. The generated electromagnetic field radiates outward in all directions in accordance with Maxwell's Energy (Nabighian, 1988, p. 134). These equations combined with certain 'constitutive' relations (Nabighian, 1988, p. 135), result in the generation of the mathematical relationships which express relevant physical material properties, as well as the distribution of electromagnetic energy in homogeneous, isotropic media. In the frequency domain, the distributions of electromagnetic field quantities in a uniform, homogeneous medium are governed by the differential equations (Nabighian, 1988, p. 136,Eqs.131,132):

$$\nabla^2 E(r, \omega) = i2\pi f \mu \sigma E(r, \omega) - 4\pi^2 f^2 \varepsilon \mu E(r, \omega) \quad (1)$$

$$\nabla^2 H(r, \omega) = i2\pi f \mu \sigma H(r, \omega) - 4\pi^2 f^2 \varepsilon \mu H(r, \omega)$$

Where:

E is the electric field intensity,

H is the magnetic field intensity,

r is the position vector within the medium (meter),

μ is the magnetic permeability (henries per meter),

σ is the electrical conductivity (Siemens per meter, or $[\text{ohm-meter}]^{-1}$),

f is the frequency (hertz),

ε is the dielectric permeability.

In free space (air or vacuum),

$\sigma = 0.0$ Siemens per meter

$\mu = 8.85 \times 10^{-12}$ henries/meter

$\varepsilon = 12.56 \times 10^{-7}$ farads per meter

The first terms on the right-hand side of Equation (1) represents ‘diffusion’ components of the electric and magnetic fields, while the second terms represent the ‘wave’ components [2]. If the source frequency is low (in the kilo-Hertz range or below), the first terms are large as compared to the second and the field intensities are dominated by diffusion. These terms are mathematically ‘imaginary’, which simply means that the discrete frequency diffusion fields are phase shifted 90 degrees to the primary source field.

If the source frequency is high (I the mega-Hertz range or higher) the second terms of Equation (1) are large as compared to the first and the field intensities are dominated by ‘wave’ components. The crossover of energy dominance between on field type or the other occurs at the frequency,

$$f = \frac{\sigma}{2\pi\epsilon}$$

Below this frequency, the diffusion fields dominate. And above this frequency, the wave fields dominate.

At zero frequencies, all the terms on the right hand side of the Equations (1) are zero. The governing equations for the electric component then reduce to Laplace’s equation for direct current resistivity methods. Thus, the governing equations encompass three distinct electrical exploration regimes:

Resistivity	(f < 10 Hertz)
Electromagnetic Induction	(10 < f < 500 Hertz)
Electromagnetic Waves	(f > 500 Hertz)

The induction component (MD) is dependent upon the product of magnetic permeability and electrical conductivity whereas, the wave component (GPR) is dependent upon the product of magnetic permeability and dielectric permittivity. In the context of investigating typical below the surface earth materials for the presence of small metallic objects, conductivity alone is the significant electric material parameter. Relative to the host medium, within which a potential target may be hidden, conductivity, if it exists at all, is electrolytic. Relative to small targets within the host medium, target conductivity is electronic (movement of free electrons).

1.2. METAL DETECTION

Landmine's firing pins, shrapnel, or in portions of the casing are usually built using metal. The Metal Detection system is the heart of the AN/PSS-14 which detects metal if the mine has enough detectable metal. Without the MD system the GPR system will not be activated. The AN/PSS-14 is programmed to give out different types of audio alerts for different metals. The metal detector consists of an oscillator producing an alternating current that passes through a coil producing an alternating magnetic field. The MD coil is a cylindrically shaped coil covering the entire diameter of the sensor head of the AN/PSS-14. The MD coils consist of a low frequency transmission and receiver induction coils. The transmission coil continuously transmits magnetic pulses during operation. When a piece of electrically conductive metal is close to the coil, eddy currents will be induced by the pulses in the metal. The eddy currents in turn create an alternating secondary magnetic field. Depending on the composition and the quantity of the metal in the target, the secondary magnetic field may be strong enough to be detected by the system's MD receiver coil. When metal is detected in a buried object, an audio signal is provided to the operator through an earpiece.

The following figures illustrate how a metallic object is detected. Figure 1.2 shows the block diagram operation of an AN/PSS-14 MD transmitting coil continually transmitting magnetic pulses, while Figure 1.3 shows the block diagram operation of an AN/PSS-14 MD receiving coil receiving metallic returns [3].

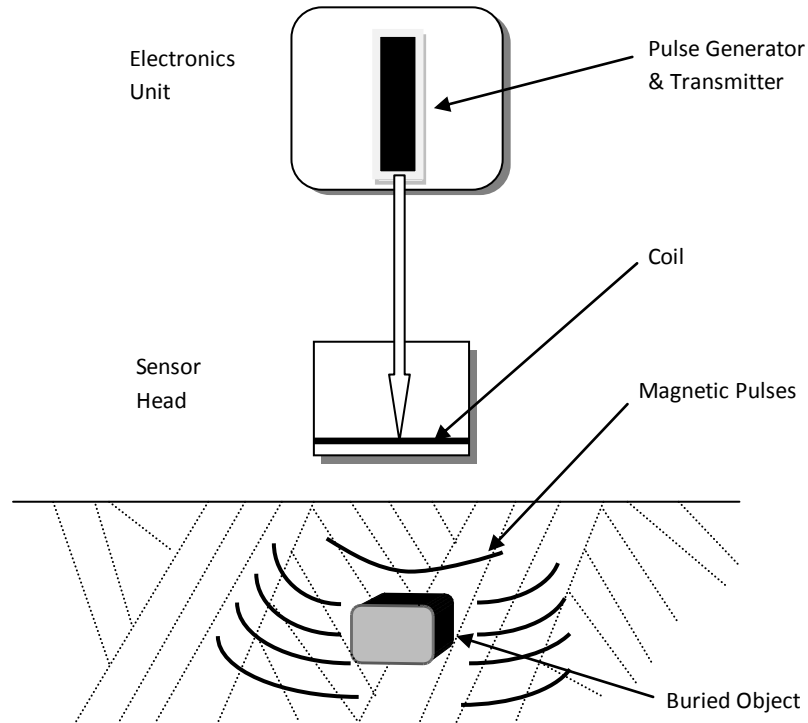


Figure 1.2: MD Coil Transmitting

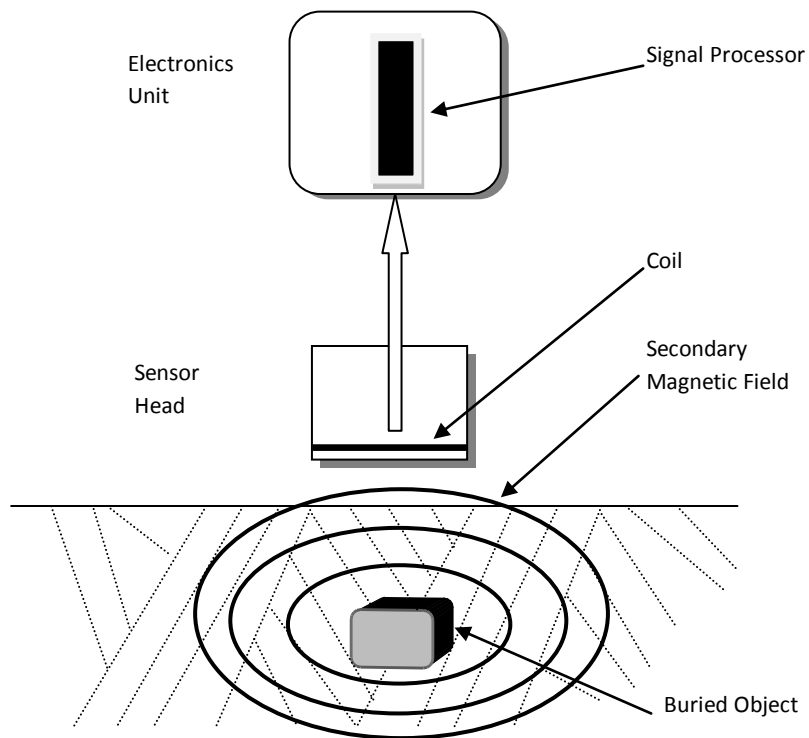


Figure 1.3: MD Coil Receiving Metallic Returns

While the MD transmitter coil is continuously transmitting magnetic pulses, the MD Audio alert can be heard at all times even in the absence of surface, subsurface or metal content due to electromagnetic background noise. The MD receiver starts picking up the low frequency induction signal as it comes in the vicinity of metallic objects and the MD audio alert increases in magnitude as the sensor head passes over the object. The audio alert signal will have the maximum amplitude when the transmitter-receiver is right over the head of a vertical firing pin along the sweep direction. This is illustrated in Figure 1.4 [4]. The MD alert curve should be a symmetrical for a vertical firing pin swept with a constant speed. The maximum amplitude of the MD audio alert envelope occurs right at that time of the sweep when the centre of the transmitter-receiver antenna is on top of a vertical firing pin.

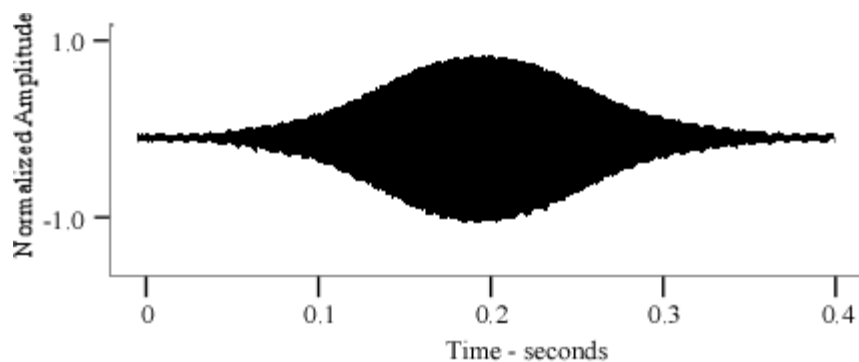


Figure 1.4: MD Audio Alert for a Standard, Non-Metallic, and Anti-Personal (AP) Landmine Simulator with a Low-Metallic, Vertically Orientated Firing Pin

The shape of the envelope of the illustrated example is dependent upon the lateral extent and geometry of the metallic object and the magnitude of the Total Illumination Field of the AN/PSS-14 Induction Coil. The AN/PSS-14 has a decision making algorithm that considers 100 distinct measured values associated with the transmitted and received

wave fields, two of which are associated with the MD measurement. The MD audio signal has been synthetically engineered to produce frequency modulated content which reveals information relative to the 'Metal Factor' or electrical conductivity of the metallic target. Thereby, the MD signal contains material information relative to the metal type of the firing pin.

The evident background noise that is seen in the above illustration is semi-deterministic which contains a dominant low-level sinusoidal in nature. Its frequency is determined to be in the neighborhood of 800 Hertz. The noise component is readily perceivable in an instantaneous frequency-time display and not so obvious in a spectral frequency-time display. The important addition of this noise to the audio alert is that it provides a frequency reference for the modulated frequency content associated with the Metal Factor of a given firing pin.

Most solid constituents (clay, sand, gravel, etc) of near surface materials, wherein land mines are to be found are essentially non-conductors of electric current. For a material in a surface to be conductive at all, electric conduction must be electrolytic; the conducting medium being an aqueous solution of common salts distributed in a complicated manner through the void structure of the material. The conductivity of such surface material will depend upon the porosity and permeability of the medium, the degree of saturation of pore spaces, the salinity of the water and the way in which the water is distributed.

Relative to electromagnetic fields, the substantive mineral property is the product of magnetic permeability and conductivity-as seen in the first (inductive) term on the right hand side of Equation (1). Magnetic permeability plays the role of magnification of

the inductive field, so that minerals with high electrical conductivity and low magnetic permeability have commensurate response to inductive magnetic fields as minerals with low electrical conductivity and high magnetic permeability.

The lateral extent of the MD alerts from a cylindrically shaped aluminum vertical pin simulators should be approximately 20 cm. The size is dependent on the diameter of the transmitter-receiver coil. In case of AN/PSS-14, the MD coil diameter is 19 cm. The figure below shows the AN/PSS-14 audio alerts, transmitter-receiver-landmine orientation and the field strength of the AN/PSS-14 MD emission field. The total MD emission field along with the vertical (red) and the radial (blue) components are also shown. MD audio alert amplitude envelope is a function of the distance along the sweep which mirrors the total field of the AN/PSS-14 MD emission field. The total MD emission field is the sum of the squares of the vertical and radial components. The temporal peak positions of the MD audio alert amplitude depends on the sweep speed: as the speed increases the two positions (onset and offset) of the maximum MD audio alert merge towards a single peak. At zero sweep speed the distance between MD peaks is approximately 16 cm determined by the diameter of the MD Induction Coil. When viewed in a time frame, the time interval from peak to peak decreases at a rate given by: speed x time. The sweep shown below is for a vertical aluminum firing pin simulator. Figure 1.5 shows the MD radiation field strength in a 3-D plot.

The MD audio alert at slow sweep speed is shown in Figure 1.6. When the onset edge of the MD transmission passes over the firing pin, the slope of the MD curve starts increasing and when the center the MD transmission coil passes over the firing pin, the

slope of the MD curve starts decreasing. The two peaks of the MD curve shown below converge as one peak as the sweep speed increases.

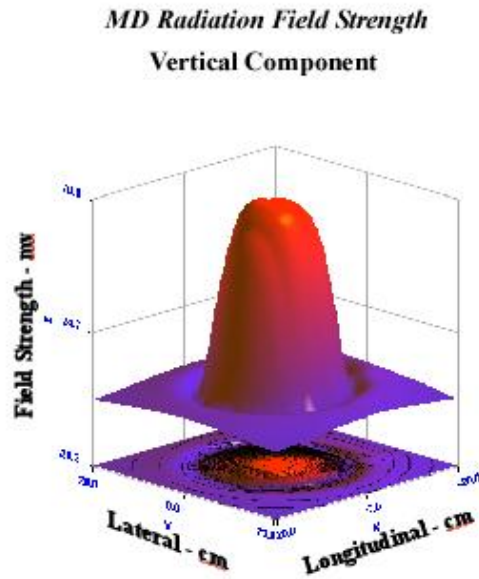


Figure 1.5: MD Radiation

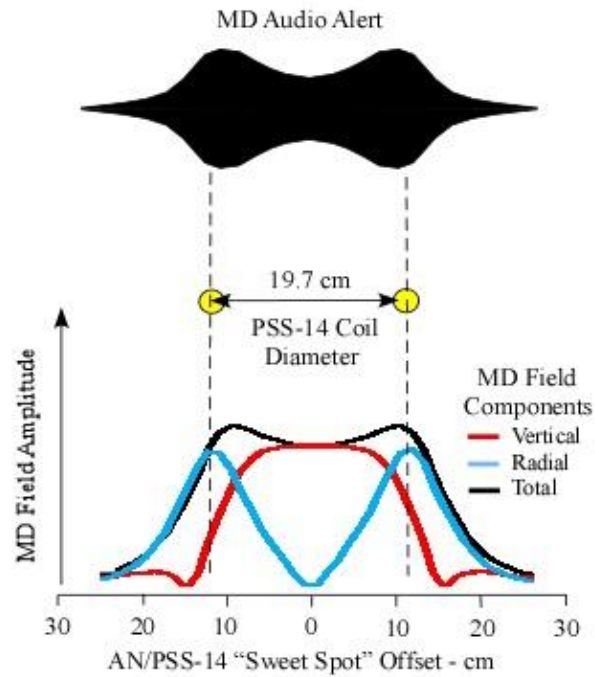


Figure 1.6: MD Total Field Shape Co-relation

1.3. GROUND PENETRATING RADAR

GPR is a geophysical method that uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band of the radio spectrum, and detects the reflected signals from the subsurface structures. GPR can be used in a variety of media, including rock, soil, ice, fresh water, pavements and structures. It can detect objects, changes in material, voids and cracks. Here, it is used in the detection of landmines.

GPR uses a stepped frequency, continuous wave radar to detect buried objects. The GPR antennas are located in the sensor head of the AN/PSS-14. The electronics unit contains both the radar generating and the processing electronics. GPR is capable of locating all mines buried at operational depth. The AN/PSS-14 continuously sends radar signals down into the ground and then receives and analyzes the reflected signals.

Radar waves travel down through the soil until they strike an irregularity, in this case a landmine. The part of the radar waves striking the object are reflected back to the receiving antennas.

During this process, the radar signal is stepped between a start frequency and a stop frequency in equal steps. For each frequency step, the signals are reflected back from the ground are received and digitized until all steps are completed. These signals are stored as data set called as a frequency packet. Each frequency packet is analyzed to determine if a buried object has been detected. The system is capable of handling 100 frequency packets per second. When a system determines that a buried object is detected, an audio signal is provided to the operator through the earpiece.

The AN/PSS-14 GPR uses three antennas mounted in a shape of a triangle in the sensor head. One antenna transmits radar signals into the ground and the other two antennas receive the reflected radar signals. Figure 1.7 and Figure 1.8 show the operation of GPR.

Figure 1.9 shows the planar logarithmic spiral antennas. The co-polarity and the quad-polarity of the receiver antennas relative to the transmission antenna are shown. Note that the co-receiver only senses reflections from the interfaces across which the dielectric constant decreases with depth. The converse is true for the quad-receiver. Transmission field components across any boundary layer always retain the polarity of the incident wave component.

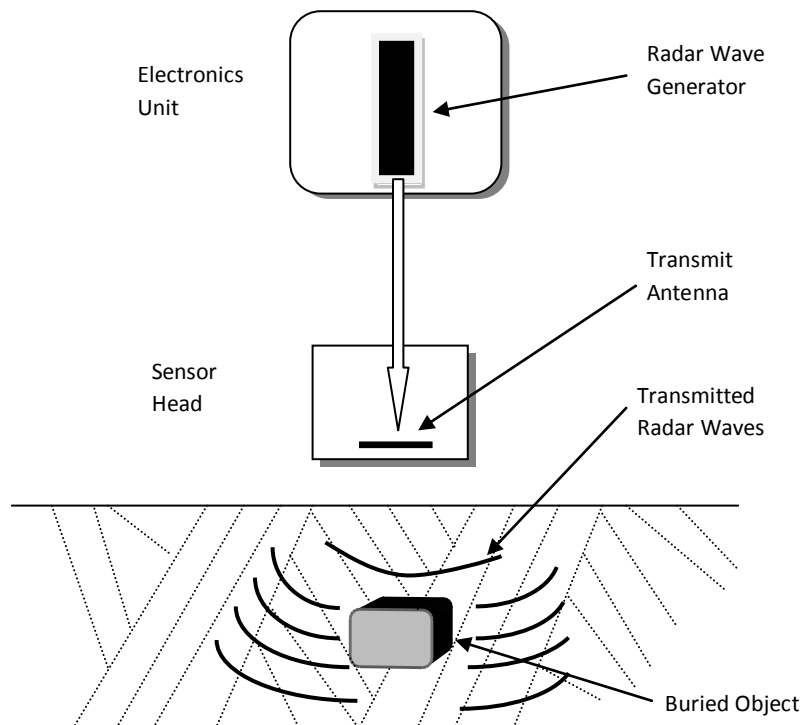


Figure 1.7: GPR Signal Transmitting

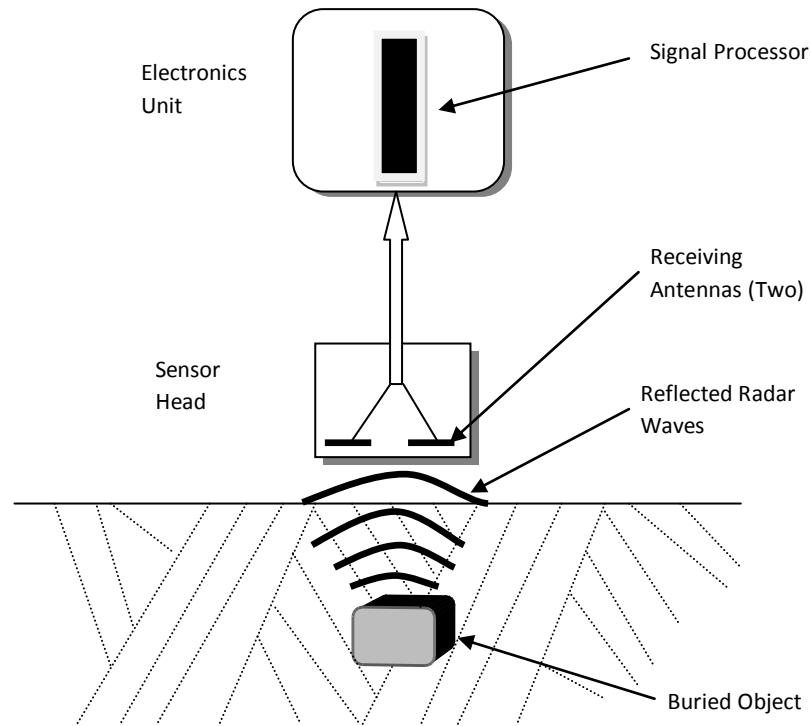


Figure 1.8: GPR Reflected Signal

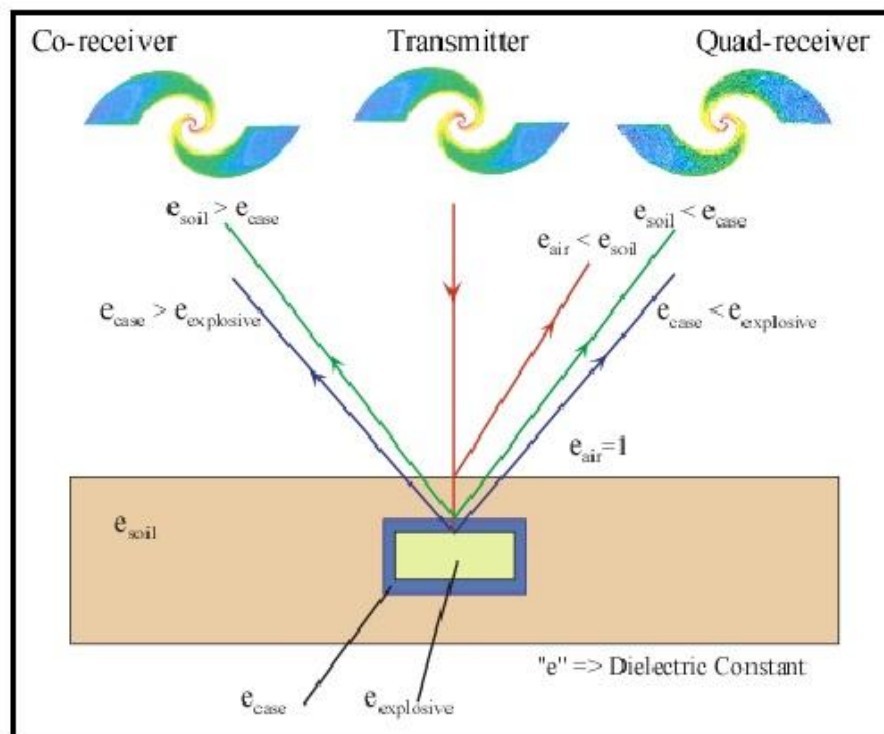


Figure 1.9: Planar Logarithmic Spiral Antennas

1.4. SKIN DEPTH

The metal detector can determine approximately how deep the object is buried based on the strength of the magnetic field it generates. The closer to the sensor head an object is, the stronger is the magnetic field picked up by the receiver coil and the stronger is the eddy currents generated. The farther below the sensor head, the weaker is the field. Beyond a certain depth, the object's field is so weak at the surface that it is undetectable by the receiver coil [5].

The near field and the far field are the boundary regions of the electromagnetic radiation that emanate from an antenna. In a homogenous electric medium: air, soil or rock, and at large distances from the transmitter coil (far field), the electromagnetic field geometry can accurately be described as that associated with an electromagnetic dipole with vertical orientation (the axis of symmetry of the co-planar coil geometry is vertical). Such dipole fields are easily understood and mathematically formulated. It is simply due to the field geometry of a dipole: the electromagnetic field strength diminishes rapidly in all directions with the distance from the center of the concentric, co-planar coil and the field is distorted by the presence of a conducting medium also. This distortion gives rise to the concept of skin effect or skin depth, which provides the definition of effective penetration of the electromagnetic field in electrical conducting media. In air, the electrical conductivity is zero and the magnetic permeability is 1. Thus there is no attenuation of the electromagnetic field apart from that due to the field geometry or the presence of a conducting medium.

The decline in current density versus depth is known as the skin effect and the skin depth is a measure of the distance over which the current falls to $1/e$ of its original

value. A gradual change in phase accompanies the change in magnitude, so that, at a given time and at appropriate depths, the current can be flowing in the opposite direction to that at the surface.

For distances from the center of the transmitter coil of the order of the coil diameter or less (near field), the electromagnetic field geometry is much more complicated. The near field dominates over the far field within this distance range and consequently geometric attenuation is significantly pronounced. Figure 1.10 shows the principle of electromagnetic dipole of a landmine detector. The secondary magnetic field is generated due to the induced eddy currents on the surface of a metallic conductor. The presence of a metal is indicated by a negative phase response between the primary and the secondary magnetic fields.

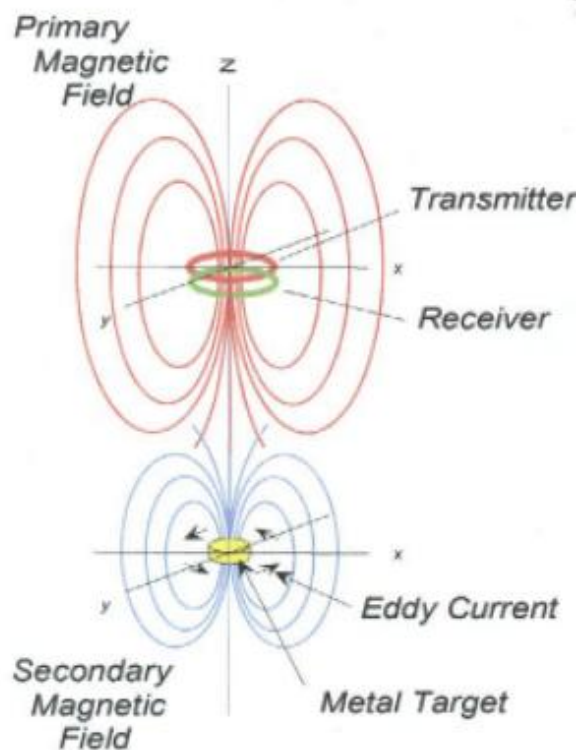


Figure 1.10: Electromagnetic Dipole Showing Primary and Secondary Magnetic Fields

2. PROJECT DESCRIPTION

2.1. PROJECT OBJECTIVE

The aim of this research project was to design and build a visual data adapter for the military AN/PSS-14 Landmine Detector that will allow real-time analysis of MD audio alert signal by using instrumentation and processing techniques in addition to the one already programmed in the AN/PSS-14. This visual clip-on data adaptor will transform the AN/PSS-14 into a hand-held data acquisition system for conversion of real time MD audio alert signal into captured visual traces on an on-board PDA computer screen so that the momentary sounds of millisecond durations can be captured and displayed for visual scrutiny and interpretation by on-board data processing procedures. This research is concurrent to the analysis of the GPR audio alert signal of the AN/PSS-14 given by Nitin Kolekar [6].

The main challenge was to study the field process of the AN/PSS-14 and using that to develop a visual data adaptor for the AN/PSS-14 without changing the current system followed by the military. This project expects to benefit the military in the reduction of complexity, confusion and the uncertainty in the use of this instrument. This project also has a commercial potential of the production of a ruggedized, low cost system that would be useful on any MD only, or MD plus GPR composite, landmine detector that has an audio output connector. The data collected for this thesis was obtained from a field test performed at Linear Sweep Facility. The MD and GPR audio alerts coming from the earphone jack of the AN/PSS-14 were recorded in wave format. This data is then analyzed using National Instruments' (NI) instrumentation and processing Virtual Instrument's (VI) on a handheld computer which will also display the

processed audio alert signal in envelope amplitude-time and instantaneous frequency-time formats.

This thesis is only valid only for non-metallic, vertically oriented low-metallic firing pin simulator. Basic knowledge of the working procedure of AN/PSS-14, metal detection principles and instrumentation techniques are essential to understand the scope of this project. This thesis will discuss all these with some detail.

2.2. PROJECT BACKGROUND

The users have faced a lot of trouble in understanding the audio alerts of this instrument (AN/PSS-14 Landmine Detector). There have been many cases of spurious and multiple issuances of audio alerts. The audio alerts from the landmines are often interpreted as clutter and the audio alerts from the clutter are often interpreted as landmines. These issues were studied and documented by Richard Rechtien. The study was carried out from the focal point of what interactions are, or are not, probable and when do the GPR audio alerts occur relative to the occurrence of the maximum intensity of the MD audio alert. It focused on source-target-receiver configuration geometry.

A GPR alert will only be released by the AN/PSS-14 detection software if and only if the MD sensor detects the presence of metal. Yet, GPR alerts commonly occur when there is no metal present in the vicinity of the sweep path. These spurious events and the equally spurious multiplicity of the events are consistently non repeatable, resulting in the inability of the user to trust the instrument. Thereby, this thesis was initiated where the MD audio alerts are studied and a companion thesis by Nitin Kolekar for the study of GPR alerts.

The findings of the Richard Rechten's study [2] are as follows:

MD Audio Alerts for Vertical Metallic Firing Pins

- MD audio alerts from the vertical firing pin simulators have a lateral extent of approximately 20 cm.
- MD audio alerts vary in both amplitude and frequency. Amplitude is a function of metallic volume and frequency is determined by the Metal Factor, resulting in an additional phase shift between the primary and the secondary electromagnetic field.
- MD audio alert is an engineered synthetic signal.
- The temporal form of the MD audio alert amplitude envelope at slow speed mirrors the spatial form of the Total MD Illumination field in space by the firing pin position and the diameter of the illumination coil of the AN/PSS-14.

Validation of GPR Events-

- GPR's should not occur in the absence of a MD audio alert.
- There should be at least one GPR event within the lateral extent of the MD envelope.
- The fundamental form of the GPR Event is a time-windowed, constant frequency of a discrete sine wave having a frequency of approximately 504 Hertz, with duration of approximately 93 milliseconds.
- All GPRs of greater duration are seamless superimpositions of multiply activated fundamental forms.

2.3. LINEAR SWEEP FACILITY (LSF)

A Linear Sweep Facility was constructed for the purpose of restraining the AN/PSS-14 to follow a reproducible path across a target to provide an investigative platform to evaluate the Land Mine Detector in a stand-alone scenario. This restraint eliminates any motion variations that might be induced by the operator. While this process cannot be duplicated in the field during search operations without a stable robotic platform, it can be used to evaluate the system alone with regard to the question of repeatability. Moreover, in a laboratory environment many observed response characteristics that have generally not been explained beyond speculation can be addressed quantitatively through experimentation.

Figure 2.1 shows the Linear Sweep Translation System. The AN/PSS-14 is strapped into a vertical cradle of a translation carriage. The carriage is mounted on parallel overhead transport rails and propelled by a belt-driven actuator at speeds up to 3 feet per second. The actuator has a length of 3 meters and is powered by a user programmable drive that allows for controlled acceleration, constant velocity over the target and deceleration to a stop position.

The drive also includes an on board encoder that allows for display of realized acceleration, velocity and deceleration. Programmable positions are accurate to within .0625 cm. The carriage is also connected to an external wire-line position and velocity transducer, which can be calibrated to all positions along the sweep traverse to within 0.625 cm. By this it means the position of the “sweet spot” of the PSS-14, at the time of reception of any reflected or diffracted event, is measurable to within 0.625 cm.



Figure 2.1: Linear Sweep Facility

The test bed is constructed from Styrofoam blocks and panels. The dielectric constant for Styrofoam is 1.03, as compared to 1.0 of vacuum. Thus, the test platform is, for all the practical purposes, transparent to electromagnetic waves and will not generate any diffractions, or reflections, except where the PSS-14 moves across the top surface contact between the Styrofoam with the earth medium. The surface contains a 4x24x48 inch well for the placement of an electromagnetic receiver beneath a soil cover. This receiver is used for in-site measurements of the dielectric constant of the material above it. The process of measurement yields depth-dependent dielectrically, moisture content, and electrical resistivity.

Measurable quantities are: MD, GPR, wire-line position, and velocity. Typically, combined MD and GPR are measured, along with wire-line position of the “sweet spot”, on a dual channel, 16-bit, 12 GHz PicoScope 9201 PC Oscilloscope. The scope provides real time observation of these measurements. A 24 bit, 96 KHz Edirol WAVE recorder is also used to measure MD and GPR data. This data must be transferred to the PC for visualization by means of a WAVE analyzer.

3. DESIGN METHODOLOGY

3.1. DESIGN PROCESS

The users of this instrument (AN/PSS-14) were not able to perceive the audio alerts at all times. In case of background noise or any other factors that may affect the attention of the user are dominant during a sweep of the landmine detector, the user may not pick up the audio alert if the instrument detects one. To assist the user in better understanding and validating the audio alert of the landmine detector, a visual data adaptor is necessary. This thesis is not about the detailed analysis of the data but it is about the design and the usefulness of the visual display to confirm the alert for the user. This is important as the visual display will give a better perspective of the target rather than the mere beep coming out of the earphone jack.

The instrument is synthetically engineered to give out different types of alert for different metallic objects. The intensity of the audio alert is dependent on the metal factor or electrical conductivity of the metallic target/object giving out the alert in different frequencies for different metal types. In plain words the intensity of the audio alert heard will be different for different kinds of metals. This requires the concentration of the user during the entire operation. At times, this may be confusing or induce uncertainty to the user. The visual device with a metal type indicator will give the user additional /specific details in better handling of the situation when a landmine is detected.

Since the AN/PSS-14 Landmine detector is currently the military instrument of choice for the detection of buried metallic and low metallic landmines and is in full operation, redesigning the instrument would incur huge losses to both the manufacture of the instrument and to the military to buy the new instrument. The addition of a clip-on to

the current instrument would take care of both the parties (manufacturer of the instrument and the military).

3.2. HAND-HELD VISUALIZATION INSTRUMENTATION

3.2.1 Hand-Held Computer. It is very important to use off the shelf (readily available) products from the market keeping in view of the time required to complete this project. A compact device yet powerful enough to analyze and process the data coming out from the instrument is required. It should have display capabilities for the user to interpret the results. A number of latest smart phones, hand-held computers (PDA/palmtop) or laptop computer will meet the requirements. A laptop is capable of doing all the required tasks by this project but it will not be handy to carry around in the field. It is not practical, space consuming, affects the weight of the total package (instrument plus add on device) and also not cost effective. The smart phones and hand-held computers are both powerful enough to do the processing. But hand-held computers are easier to program and add external programs which are required for acquiring, analyzing, processing and displaying results. Since hand-held computers are a miniature version of a laptop computer, it is easier to write/code programs to interlink the hardware devices to speak to each other.

3.2.2 Hardware Requirement. For a clip on device such as a hand-held computer to read the incoming data from the AN/PSS-14, some kind of hardware system is required. The hand held computer has restricted access to additional hardware. Keeping in view of this, a compatible memory card will be needed for acquiring the data and feeding the same to the analyzing program for processing.

There are a number of data acquisition hardware systems readily available in the market. For a mobile application such as this and for the hardware to be programmable by the software for analyzing and processing, National Instruments CF-6004 [7], Compact Flash Data Acquisition for PDAs was selected. The CF-6004 in a PDA is ideal for a number of applications where economy, small size and portability are essential for field monitoring/diagnostics and portable data logging and analysis. The features of the card are:

- Lightweight, ultraportable for mobile applications
- 4 analog inputs, 14-bit resolution, up to 200 kS/s single-channel sampling
- Programmable with LabView PDA Module for handheld measurements
- 3 connectivity options- base wires and shielded or unshielded connector blocks
- 4 LVTTTL/LVCMOS digital I/O lines

National Instruments hardware and software were chosen for this project as it reduces the customization of hardware and software. The hardware is compatible to the LabView software as it is from the same manufacturer.

3.2.3. Connection. A number of cables are required to hook the system together.

The AN/PSS-14 audio alert signal output, NI digitizing module and the PDA are all required to be connected to each other. The NI SH-15-15-B is readily available as an accessory for the NI CF-6004 to connect directly to the signals. In this case it is the audio alert signal of the AN/PSS-14.

3.2.4. Software. System programming constitutes the dominant work load of this project. The software should be able to take in the input (in this case the output of the AN/PSS-14), analyze and process the input and display the output. LabView, MATLAB

or any other computing/programming language can be used. The LabView software [8] was selected as it is a visual programming language which is mainly used for data acquisition, instrument control and automation which are the requirements of this project.

3.3. INSTRUMENTATION SELECTED

- HP iPAQ hx2000-PDA
- LabView PDA Module- Programming software
- NI CF-6004 Data Acquisition Card- Hardware
- Windows Mobile for Pocket PC- PDA operating system

4. INSTANTANEOUS FREQUENCY PROGRAMMING

To have a better understanding of the MD audio alerts, the output of the MD audio alerts of the AN/PSS-14 is fed to a hand-held PDA computer for analysis. The LabView program analyzes the incoming data and displays the Instantaneous Envelope Graph, Unwrapped Phase and the Instantaneous Frequency Graph of the MD signal through a series of mathematical manipulations. The visual data displayed on the PDA screen helps the user/soldier to discriminate between a valid and an invalid audio alert, thereby giving more clarity and information on the screen (in case the audio alert is not picked up by the user).

4.1 ALGORITHM

Hilbert transforms helps us to look at relationships between real and imaginary parts of a complex signal. Hilbert transform can be used to create an analytic signal which is very important in simulation. The analytical representation of a real-valued function or signal (in this case the MD audio alert) facilitates manipulation of the signal. The analytic signals help to represent bandpass signals as complex signals which have especially attractive properties for signal processing. An analytic signal [9] is a complex signal created by taking a signal and then adding in quadrature its Hilbert transform. An analytic signal is defined as follows:

$$g_+(t) = g(t) + j \tilde{g}(t)$$

Where,

$g_+(t)$ is the analytic signal

$g(t)$ is the MD audio alert

$\tilde{g}(t)$ is the Hilbert Transform of $g(t)$

The audio alerts recorded at the Linear Sweep Facility are inputted in to a measurement file which takes in point by point of the signal. Point by point analysis is ideally suited for real time data acquisition. With point by point analysis in LabView, data analysis also utilizes real time performance. The discrete stages of array based analysis such as buffer preparation, analysis and output, might be too slow for higher speed, deterministic, real time analysis. Real-time systems require continuous analysis, in which analysis occurs for each data point, point by point. The advantages of using LabView Point-By-Point VIs offer the following benefits:

- Track and respond to real-time events
- The analysis process connects directly to the signal for speed and minimal data loss
- Perform programming tasks more easily as allocating arrays and making adjustments to the sampling rates is not required.
- Analysis synchronizes automatically with data acquisition as a single signal is worked on instantaneously.

The raw input is passed through a Butterworth Bandpass Filter to minimize the noise which takes in data at a sampling rate of 44100 Hz. The Hilbert transform of the filtered signal $g(t)$ is added to the filtered signal to get a complex analytic signal $g_+(t)$. The Hilbert Transform of a function $x(t)$ is defined as

$$h(t) = H\{x(t)\} = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{t - \tau} d\tau$$

The rectangular components of the complex signal coming out from the Hilbert transform is converted into its polar components to find the amplitude envelope and

instantaneous frequency. The instantaneous frequency for a complex valued signal is given by the derivative of the instantaneous phase [10]. The algorithm developed to acquire field data and display its instantaneous frequency and envelope is shown in Figure 4.1.

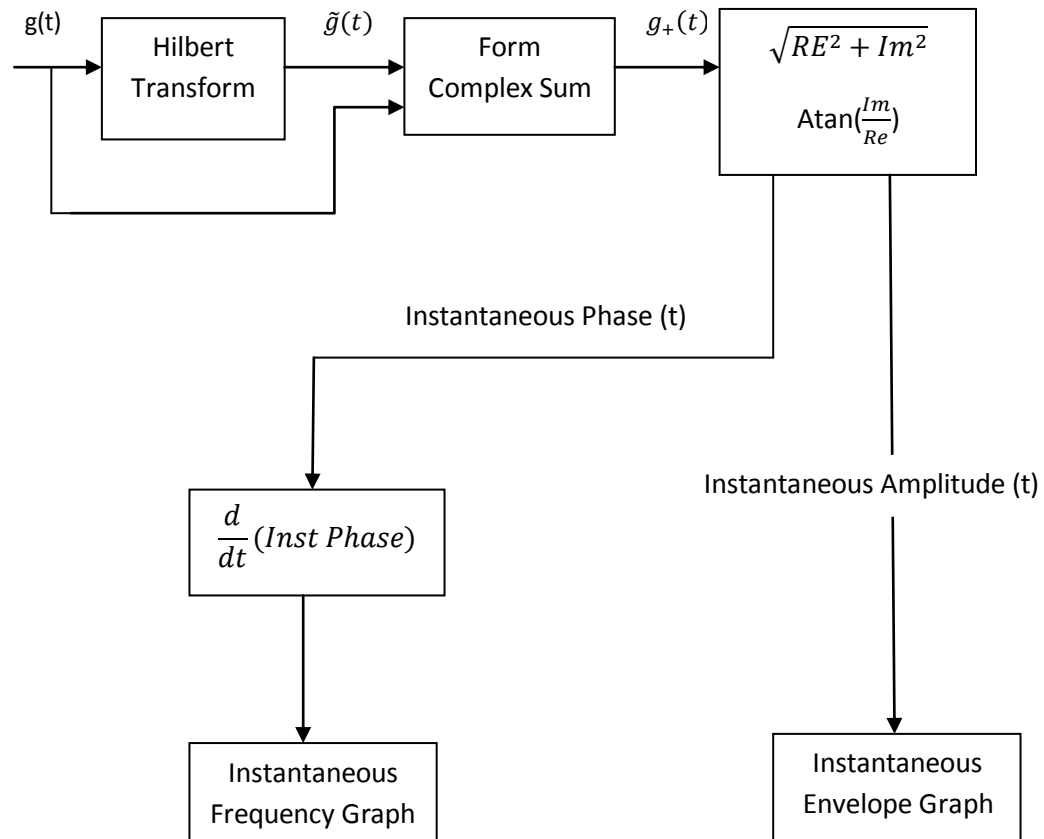


Figure 4.1: Algorithms for Instantaneous Frequency and Instantaneous Amplitude

4.2. LABVIEW PROGRAM

The LabView program to calculate the instantaneous phase and instantaneous amplitude is shown in Figure 4.2.

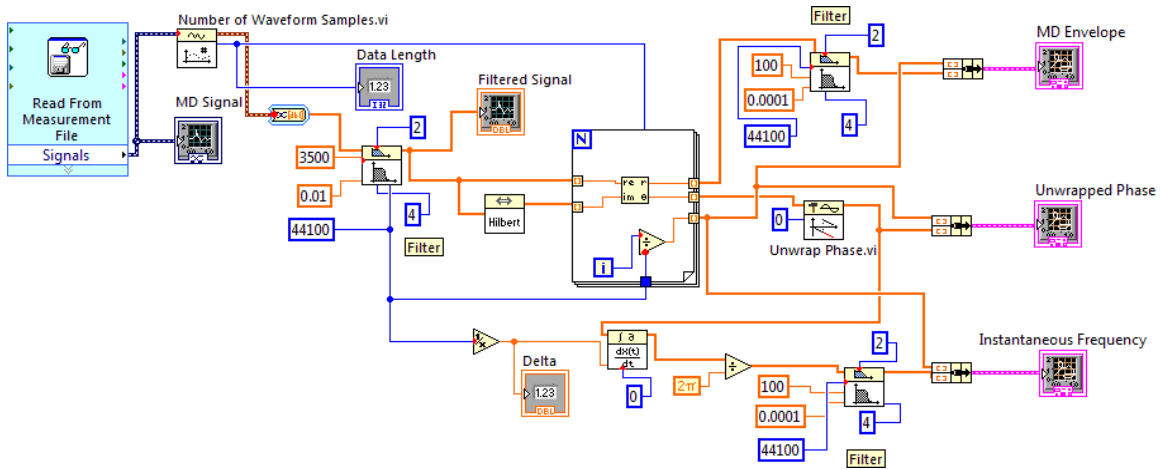


Figure 4.2: LabView Code

The AN/PSS-14's audio alerts are recorded at a sampling rate of 44100 Hz and are stored in wave format sound for use on a laptop for processing purposes. This is in turn converted to be read by the Read From Measurement File VI. The original MD audio alert is displayed in amplitude-time format as a reference to the manipulated signal. The original signal is also passed to Butterworth Filter VI to eliminate background noise and to also obtain a smooth curve whose lower cutoff frequency is set to 0.01 Hz and the upper cutoff frequency set to 3500 Hz. Once filtered, the signal is sent to Hilbert Transform VI which calculates the Hilbert transform of the signal required to form an analytical signal. The output of the Hilbert Transform VI is then added to the original signal to form a complex signal. This complex signal also called as an analytical signal is used to determine the instantaneous frequency and instantaneous amplitude envelope. The rectangular components of the complex number are converted into its polar components by the Re/Im To Polar Function VI. This inserted into a for loop for point by point analysis. The radial component r is then displayed in amplitude-time format as instantaneous amplitude. The phase of the polar angle aka theta is unwrapped by Unwrap

Phase VI and the time derivative of the unwrapped phase is calculated as the instantaneous frequency by Derivative $x(t)$ VI.

This research is limited to processing the data already stored in wave format. However, by connecting the output of the AN/PSS-14 directly to a PDA via cables, real time visualization of the MD audio alerts can be possible.

5. INSTANTANEOUS FREQUENCY RESULTS

Figure 5.1 shows the MD audio alert in an amplitude-time plot for standard, non-metallic, Aluminum, vertically orientated firing pin with background noise. The background noise is clearly visible in the below amplitude-time plot of the MD audio alert. The background noise is semi deterministic in the plot as it contains a dominant, low-level sinusoidal in the neighborhood of 800Hz. The noise is readily observable in the instantaneous frequency-time display and provides a frequency reference for the modulated frequency content associated with metal factor for a given firing pin.

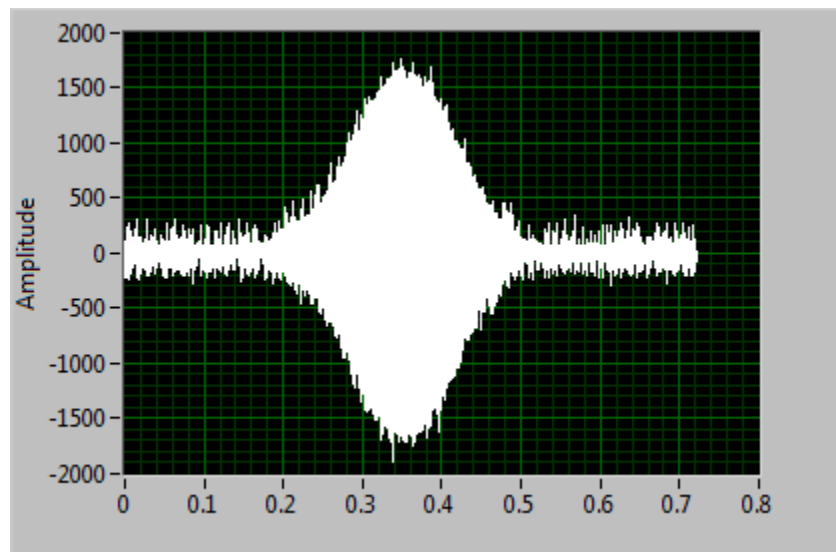


Figure 5.1: MD Audio Alert for Aluminum with Background Noise

Figure 5.2 shows the filtered MD audio alert in an amplitude-time plot for same audio alert described in Figure 5.1. The smoothness of the curve is because of the filtering of extraneous noise that is not required in the analysis. However there may be other noise present which is low-amplitude with high frequency. Both Figures 5.1 and 5.2

are formed by plotting point by point of the recorded oscillating signal of the MD audio alert of the vertical firing pin.

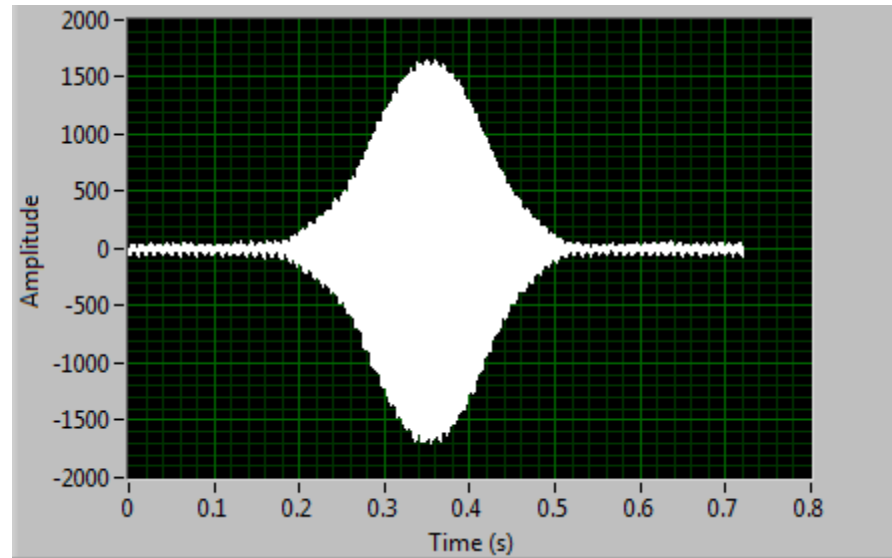


Figure 5.2: Filtered MD Audio Alert for an Aluminum Firing Pin

Figure 5.3 shows the Envelope of the MD audio alert in amplitude-time plot. This figure confirms that the program has not altered any characteristics of the original audio alert after mathematical manipulations as it is an exact replica of the original audio alert shown in Figure 5.2 before mathematical manipulations. This validates the logic of the program for determining the instantaneous frequency.

Figure 5.4 shows the Unwrapped Phase of the analytical signal created. The output phase of the analytic signal is returned in a form that suffers from 2π phase jumps due to the mathematical arctangent function, which produces an inherently wrapped output. Unwrapping the phase array eliminates the discontinuities whose absolute values

exceed π . The second figure below shows unwrapped phase in degrees. Linear curve of the unwrapped phase indicates that all appropriate multiples of 2π have been included.

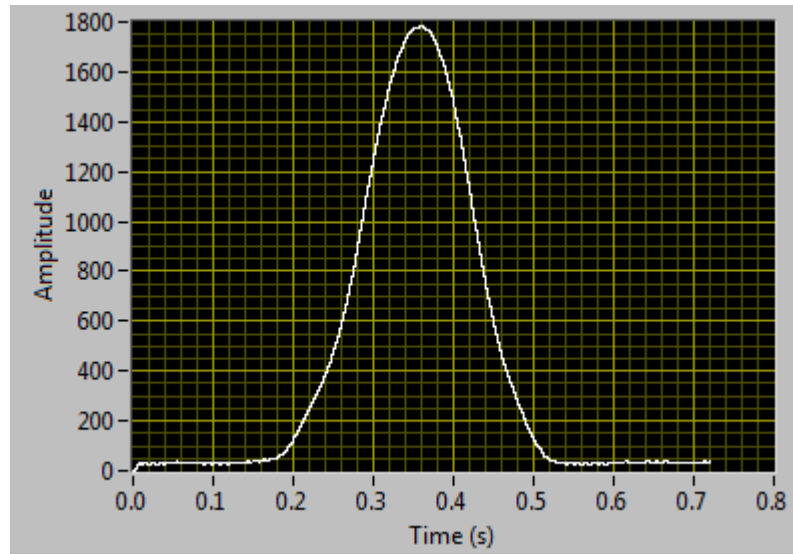


Figure 5.3: MD Audio Alert Envelope for an Aluminum Firing Pin

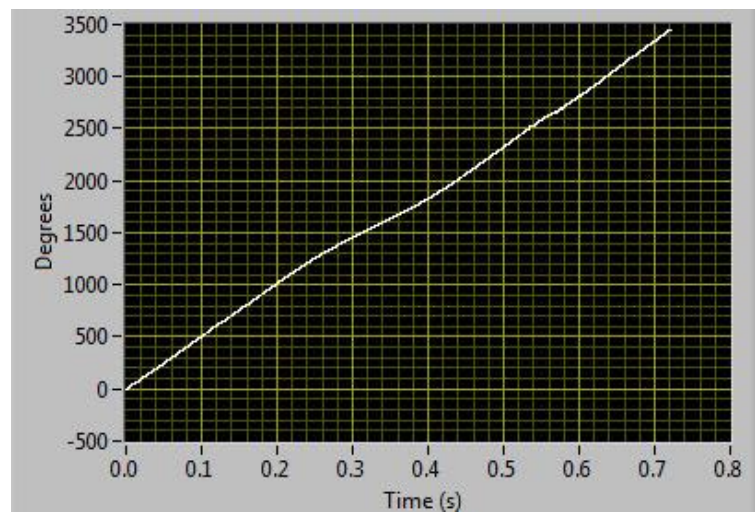


Figure 5.4: Unwrapped Phase of the Analytical Signal for Aluminum Firing Pin

Figure 5.5 shows the instantaneous frequency-time plot of the MD audio alert. The unwrapped phase can be represented in terms of an instantaneous frequency which is simply the time derivative of the instantaneous phase. Since the sampling rate of the MD audio alert is very high (44100 Hz), the phase between consecutive points in the for loop constructed will not be that great unless there is a major 2π shift between them. This can be eliminated by locally unwrapping the phase for all the points to guard against any 2π discontinuities present between them. The low-amplitude, high frequency which is not eliminated by the band pass filter is quite evident in this plot. As it is present in the base frequency range of 818 Hz and not when a metal is detected, it can be noted as background noise.

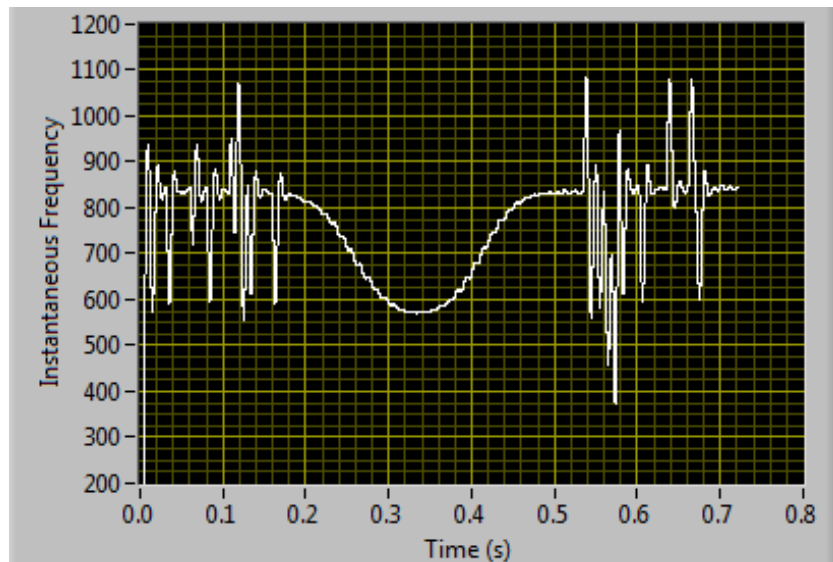


Figure 5.5: Instantaneous Frequency of the MD Audio Alert Signal for an Aluminum Firing Pin

The below figures show the results of another sweep of the MD audio alert for an aluminum firing pin. Figure 5.6 shows the filtered MD signal. Figure 5.7 shows the MD audio alert envelope for a second sample of the same aluminum firing pin. Figure 5.8 shows the instantaneous frequency of the second sample for the same aluminum firing pin. This is done to verify the repeatability and consistency of the program developed.

As seen from the below figures, the MD response for the same firing pin yielded the same results consistently, thereby, validating the program's logic in determining the instantaneous frequency and envelope for MD audio alerts of the AN/PSS-14. The sweep for the second sample was done the exact same way the first data was acquired. The sensitivity was set to 3 on the AN/PSS-14 where only the MD audio alert was recorded. This process is only applicable to a single, isolated MD audio signal only and does not apply to a sequence of MD plus GPR.

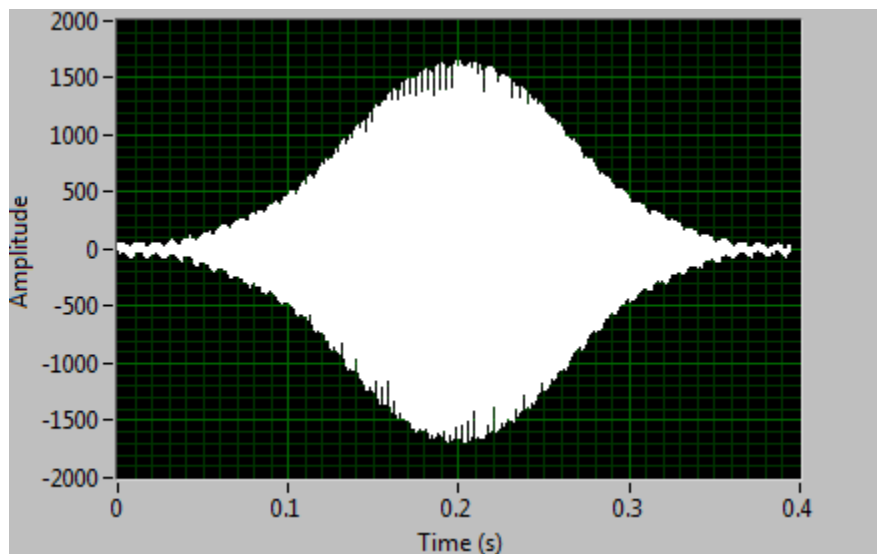


Figure 5.6: Filtered MD Audio Alert

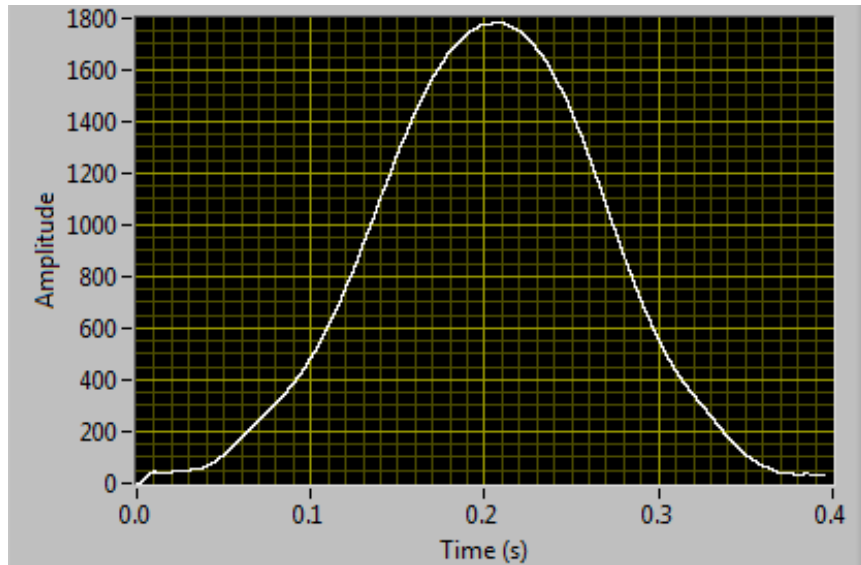


Figure 5.7: MD Audio Alert Envelope

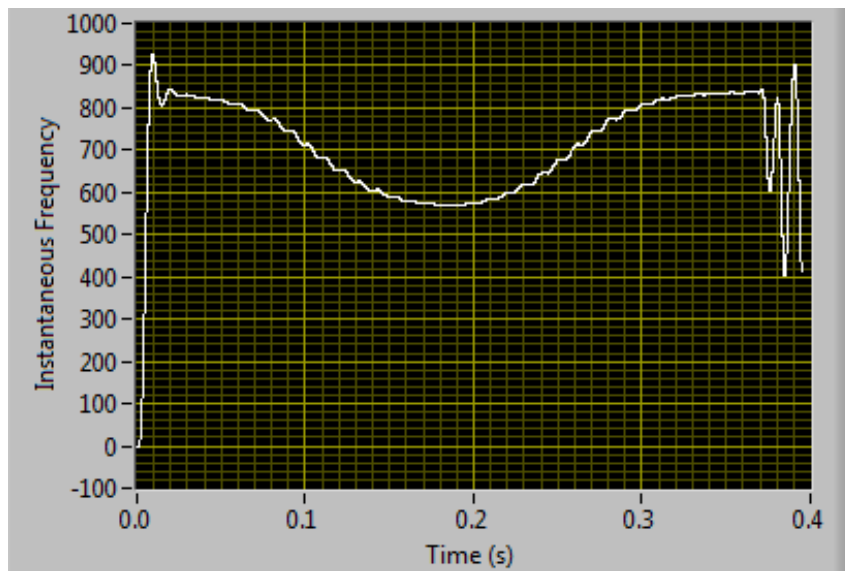


Figure 5.8: Instantaneous Frequency Plot

An attempt was made to understand the frequency and amplitude response of the MD audio alert signals for different metal types. The investigation involved five conductors: brass, aluminum, copper, steel and iron. All conductors were approximately

cylindrical. Brass, steel and iron were solid; aluminum target was a hollow cylinder; copper target was a stranded wire. All the targets were approximately of the same diameter.

Figure 5.9 shows the frequency response for MD audio alert signals for different metal types. The distance of the target was varied relative to MD detection coil. As seen in the graph below, it is evident that if the target is far away from the detection coil, i.e. farther than 7 inches, the target will not be detected and the output is the frequency modulated signal of 818 Hz. Ideal distance from the detention coil would be 3.5 inches from the target. The values for individual metals are tabulated in the following page.

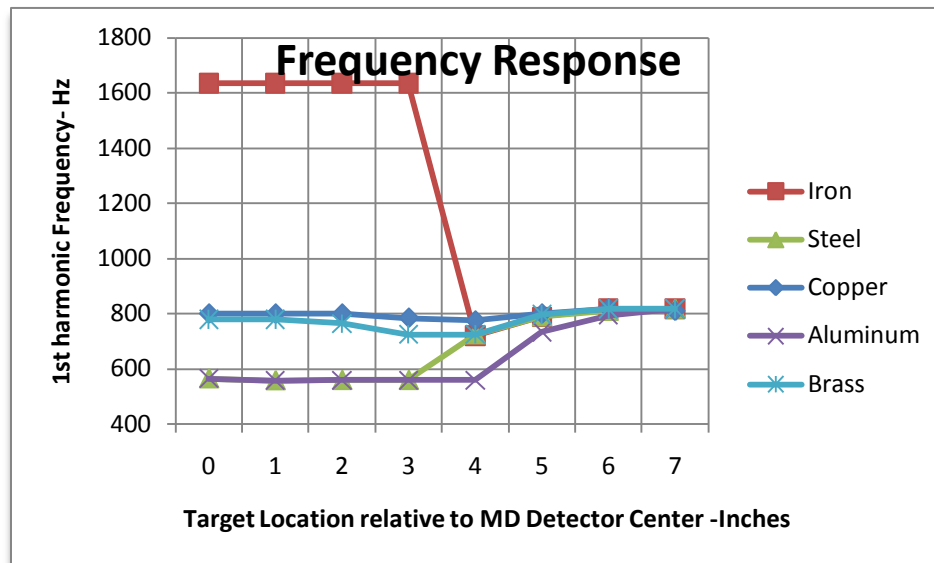


Figure 5.9: Frequency Response to Five Conductors

Figure 5.10 shows the amplitude response for MD audio alert signals for different metal types.

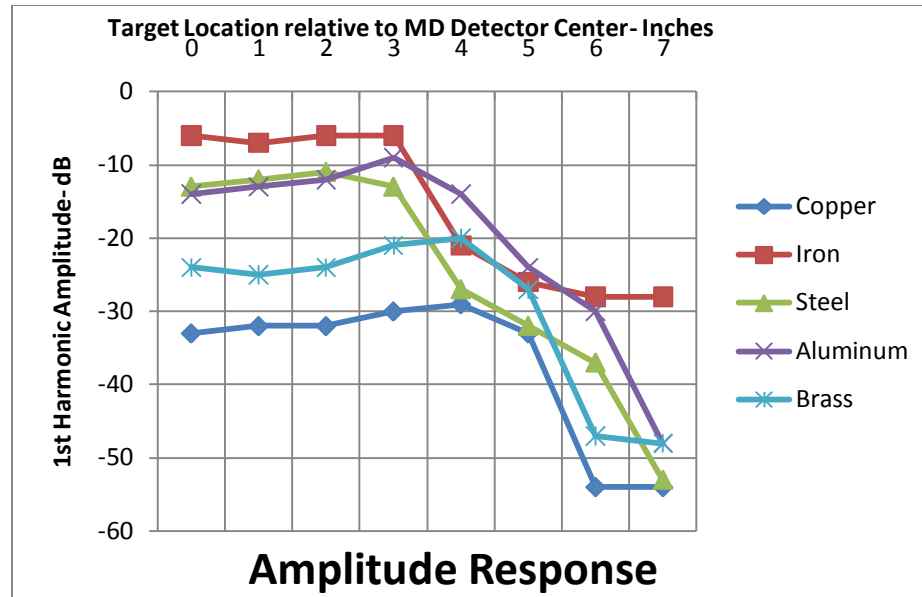


Figure 5.10: Amplitude Response to Five Conductors

Table 5.1 shows the instantaneous frequency response for different metal types.

Table 5.1: Metal Type and Instantaneous Frequency Values

Metal Type	Instantaneous Frequency (Hz)
Aluminum	559
Brass	712
Iron	1636
Copper	778
Steel	559

The instantaneous frequency for different metal types is different. This is evident in the frequency values obtained for different metals in the tests. Since MD audio alert is an engineered signal, specific metals give out specific frequency values. But the MD audio alerts were of same type and intensity, audibly.

Similar kind of metals or in other words low-metallic content metals give out the same frequency values. The first harmonic frequency for Aluminum is found to be 559 Hz, which of Brass is found to be 712 Hz, for Iron it is found to be 1636 Hz, for Copper it is found to be 778 Hz and for Steel it is found to be 559 Hz.

6. CONCLUSIONS AND FUTURE WORK

The visual data adaptor will transform the AN/PSS-14 into a hand-held data acquisition system for conversion of real time MD audio signals into captured visual trace displays on an on-board PDA computer screen so that momentary sounds of millisecond durations can be captured and displayed for visual scrutiny and interpretation by analytical on-board data processing procedures. The developed program executed on hand-held computer attached to the output of the AN/PSS-14 is reliable in analyzing and confirming the MD audio alert. The visual display of instantaneous frequency-time plot of the MD audio alert on the clip-on device helps the user with specifics of the target rather than a mere audio alert. The hand-held device is a feasible yet practical solution for better understanding of the audio alerts of the AN/PSS-14. This result can be extended to any metal detector systems available in the market.

This thesis is centered on low-metallic vertical firing pin simulators. Distinction of metallic firing pins from metallic clutter is achieved by the identification of the metal type and by symmetric deviations of the amplitude envelope along multiple sweep directions over a buried target. The frequency response of the MD audio alerts of the AN/PSS-14 for different metal types is different. The individual frequency responses for brass, aluminum, steel, copper and iron were studied and analyzed. The response to these metals is found in the results section. The ‘envelope and instantaneous frequency’ approach is only valid for a single, isolated MD audio signal only and does not apply to a sequence of MD plus GPR.

This thesis can be extended with little change in the logic of the program to account for firing pins that are not vertical and off-centric. The MD envelope for a non-vertical firing pin will not be symmetric in such cases.

A diameter variation of the firing pin does not have any effect to MD detection. If the metal content is more, the intensity of the alert may be stronger but has nothing to do with the frequency being affected.

Hollow and solid firing pins will also not have a great effect on the MD audio alert. However sweep speed plays a major role. If the sweep speed is slow, then the hollow and solid firing pins can be differentiated by the MD envelope. There will be two peaks for a hollow firing pin with a dip in between the peaks on the MD envelope. But for a solid firing pin, there will be one constant peak in the MD envelope.

Depth of the target plays a very important role in metal detection. If the target is far off from the magnetic field, there will be no metal detection.

A field test is required to study and validate the practicability of the hand-held device. The variations for the test would be firing pins that are not vertical, different diameters of the firing pin, different shapes of firing pins and with different target depths.

BIBLIOGRAPHY

- [1] <http://www.cytterra.com/products/handheld-cm.html>. “AN/PSS-14” January 2010.
- [2] Dr. Richard D Rechten, “White Paper, Sensitivity Issues of the AN/PSS-12 Mine Detection System,” 2007.
- [3] 20HS4310, “Operator’s Manual, HSTAMIDS,” 1st June 2004.
- [4] Dr. Virgil J Flanigan and Dr. Richard D Rechten, “Investigation of AN/PSS-14 (HSTAMIDS) GPR Wave Field Interactions with Buried Dielectric Targets,” Final Report, 31st March 2009.
- [5] Motoyuki Sato, Jun Fujiwara, Xuan Feng, Zheng-Shu Zhou and Yakao Kobayashi, “Evaluation of a Hand-Held GPR MD sensor system (ALIS),” December 2004.
- [6] Nitin S Kolekar, “Real-Time Visualization of AN/PSS-14 Audio Alert Signals for Landmine Detection Validation,” Thesis, Missouri University of Science and Technology, Rolla, MO-2010.
- [7] <http://www.ni.com/pdf/manuals/371399c.pdf>. “User Guide and Specifications, NI CF-6004,” December 2007.
- [8] <http://sine.ni.com/nips/cds/view/p/lang/en/nid/12222>. “National Instruments,” June 2010.
- [9] http://en.wikipedia.org/wiki/Analytic_signal. “Analytic Signal,” January 2010.
- [10] http://en.wikipedia.org/wiki/Instantaneous_phase. “Instantaneous Phase,” March 2010.

VITA

Sandesh Srikantiah Chandrashekar was born on August 8th, 1986 in Bangalore, India. He did his schooling in St. Paul's English School, Bangalore, India. He obtained his Bachelor's Degree in Mechanical Engineering in July 2008 from Visvesvaraya Technological University, Belgaum, India.

He enrolled at the Missouri University of Science and Technology to pursue a Master's Degree in the Department of Mechanical and Aerospace Engineering under the guidance of Dr. Virgil Flanigan in August 2008. He worked for seven months in Samtec Inc, New Albany, Indiana as an Engineering Intern. He received his Master of Science Degree in Mechanical Engineering in December 2010.