

Innovative and Effective Techniques for Locating Underground Conduits

FINAL REPORT

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<p>16. Abstract</p> <p>The New Jersey Department of Transportation (NJDOT) operates and maintains a network of thousands of miles of conduits, many carrying fiber optic cables, that is vital to the State's communication system. These conduits frequently must be located and marked to avoid damage from construction. These conduits were to be located using a system of trace wires (TW) and radio frequency detection. However, for various reasons the TW are missing and this system is not functioning over a significant portion of the network.</p> <p>The purpose of this research was to find an effective means for locating these conduits. The solution must meet requirements for accuracy and depth sensitivity, be practical to implement, cost effective, work with both metallic and plastic conduits, and be reliable. Innovative means for locating underground conduits were investigated, evaluated and compared. Possible solutions are identified and documented and the most effective discussed in detail. Approaches include enhancements to current TW methods, Acoustic Transmission (AT), Ground Penetrating Radar (GPR), Ground Penetrating Sonar (GPSon), and the Measurement of Electro-Magnetic Impedance (EMI).</p> <p>The benefits include: reduced cost and time from more expedient systems for locating conduits, less accidental damage to conduits, the avoidance of connectivity problems and loss of crucial communications, and the preservation of the fiber optic network.</p>			
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EXECUTIVE SUMMARY

The New Jersey Department of Transportation (NJDOT) operates and maintains a network of thousands of miles of conduits, many carrying fiber optic cables, that is vital to the State of New Jersey's communication system. These conduits frequently must be located and marked to avoid damage from construction. These conduits were to be located using a system of trace wires (TW) and radio frequency detection. However, for various reasons the TW are missing and this system is not functioning over a significant portion of the network.

The purpose of this research project was to find an effective means for locating these conduits. Any solution must not only meet requirements for accuracy and depth sensitivity, it must also be practical to implement, cost effective, work with both underground metallic and plastic conduits, and be reliable. The research on in this report investigated innovative means for locating NJDOT's underground conduits, and evaluated and compared alternative solutions. These solutions are identified and documented and the most effective discussed in detail.

Approaches researched include Acoustic Transmission (AT), Ground Penetrating Radar (GPR), Ground Penetrating Sonar (GPSon), and the Measurement of Electro-Magnetic Impedance (EMI). No one approach applies to all situations. Both AT and GPR were found useful when non metallic conduit without TW are present. Based on project and vendor testing, GPR seemed to work best in certain suitable soils and within an allowable range of conduit depth to diameter ratio. AT seemed to work best under unpaved surfaces. Means of improving the present TW system were also identified, and ways to alleviate problems resulting from difficulty in gaining access to junction boxes were found.

A better inventory of the network and the condition of its components is needed. As part of this work, a computerized data base (DB) of the network was begun. This DB includes information to the section level of much of the network, and to the segment level (Junction Box to Junction Box) for the missing trace wire portions of the network. However to be most useful, it should be expanded to identify conditions at individual junction boxes across the whole network, in order to have segment-level information at any location in the network. Given the size of the network, and the need to locate many conduits with missing or incomplete information, the portfolio of solutions would likely include a GPR unit, preferably with a GPS capability, as well as a further developed AT configuration/unit currently being upgraded as a result of this effort.

The benefits of this project will include: reduced cost and time resulting from the application of more expedient systems for locating conduits, an improved facilities (conduits and junction boxes) database allowing for the inclusion of data from field investigations, less accidental damage to conduits carrying fiber, the avoidance of connectivity problems with related loss of crucial communications, and the preservation of the State's fiber optic communications network.

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1. BACKGROUND

The New Jersey Department of Transportation (NJDOT) operates and maintains a network of thousands of miles of conduits, approximately close to 600 miles of it carries fiber optic cables that are vital to the State of New Jersey communication system. These conduits have to be located and marked prior to construction activities to avoid potential damages. Currently, NJDOT locates conduits using trace wires (TW) and radio frequency (RF) detection methods. However, a portion of the network has missing or damaged trace wires, which pose a significant problem. To understand the scope of the location problems being encountered by NJDOT, an initial meeting between the research team and members of the NJDOT was held on January 7, 2010. Minutes of this meeting and subsequent NJDOT meetings are shown in Appendix A.

Based on this meeting and a literature search, four alternative detection techniques: acoustic transmission (AT), ground penetrating radar (GPR), ground penetrating sonar (GPSon), and the measurement of electro-magnetic impedance (EMI) were selected for investigation. Enhancements to TW based on radio frequency identification (RFID) technology operating at low frequencies was also conceived and evaluated.

2. PROJECT OBJECTIVES

The overall objective of this project was to investigate NJDOT's fiber optic network to find 1) where problems exist in locating conduits, 2) the limitations of currently used TW and RF detection location tools, and 3) possible solutions. Specific objectives were:

1. Examine and understand NJDOT's fiber optic network and related conduit system with regard to the requirements for identifying conduit locations.
2. Investigate possible technologies for locating buried conduits including TW (and its related embodiments such as Mule Tape), AT, GPR, GPSon, EMI and other methods that may be discovered.
3. Determine the preferred method for locating the conduits based on the required accuracy and performance, ease to implement, effort to apply, cost effectiveness and reliability.
4. Develop a systematic plan for the implementation of the preferred conduit location system.

This project aims at identifying technologies capable of identifying the location of fiber optic conduits with missing trace wires, with enough accuracy for actionable response. This response might involve digging for possible repairs, or simple mark-out for other utilities to perform maintenance work of their own. Based on the type of requirement and the location of other contiguous utilities, the requirement for accuracy may be more or less demanding.

For it to be relevant to the study, the review of the capabilities of candidate technologies ranging from Ground Penetrating Radar to Acoustic Testing and Variations on the Trace Wire Technology, had to be made within the context of the fiber optic cable conduit and the missing trace wire problem. To that effect, a better understanding of the problem, including variations related to various locations impacting the location problem, is a key objective of the study.

Key criteria for success of this study include:

- 1- TECHNOLOGY SELECTION: the ability to recommend and rank appropriate cable location technologies for a given conduit segment or address within the NJDOT ITS Fiber Optic Cable Conduit Network.
- 2- ADDED TECHNOLOGY IMPROVEMENTS: the ability to identify technologies or added new features that would not necessitate, at least in the long run, the removal of the manhole cover, which is usually required to ascertain the presence or absence of a trace wire.
- 3- INVENTORY KNOWLEDGE BASE: the ability to improve the information base about the location of the entire network and its facilities, both as a concerted database effort, and as a result of future field investigations.

3. THE STATE OF DEVELOPMENT OF TECHNOLOGY FOR LOCATING BURIED CONDUIT

A comprehensive search of the technical literature was conducted to determine the state of the art in detecting and locating underground objects as conduits and pipes. Items of interest included proof of capability and cross verification of the performance and technical capabilities of the various systems for locating buried conduits. A bibliography generated during this search is contained in Appendix B of this report. Based on this work (and meeting with NJDOT) four detection schemes (AT, GPR, GPSON and EMI) were selected for investigation. Enhancements to TW based on radio frequency identification (RFID) technology operating at low frequencies was also conceived and evaluated.

4. UNDERSTANDING OF THE CONDUIT LOCATION PROBLEM

Inclusion of trace wire is currently a standard specification in new fiber optic/communication conduit systems installed by NJDOT. This has not always been the case in New Jersey, and many miles of conduit exist that were installed prior to this standardization. Additionally, many segments exist that may have damaged or removed trace wire due to contractor oversight when removing or replacing fiber optic cables. In the absence of other solutions researched during this project, these trace wires are crucial for locating and marking conduits on a roadway prior to digging or road maintenance. By creating an inventory of state-owned conduit, as

well as adapting and testing various locating technologies, this TCNJ/NJIT research supports safe and effective digging on cluttered roadway sections.

NJDOT conduit related records were reviewed and NJDOT personnel interviewed to gain a better understanding of NJDOT's fiber optic network/conduit system, and to quantify the requirements for locating buried conduits. The focus was on understanding the conduit location problem with statistics such as percent of network without trace wire, percent with clutter, percent with various surrounding soils, material types, ease/difficulty of removal of junction box covers, etc. Among those contacted were Keith Kirby and Mark Renner regarding the inventory analysis problem for all or a large sample of fiber cables. A Word document listing the locations of sections with missing trace wires was obtained from Mark Renner from ITS Operations South, and was the key base information for the development of the inventory of segments with missing trace wires.

Master Inventory Database Clean-Up, Development and Analysis

As a preliminary objective, the team sought out the complete inventory of NJDOT-owned conduit as well as began the creation of a sub-inventory of conduit missing trace wire. This inventory will support the future testing of location technologies, as well as enhance the existing NJDOT reference database.

After phone conferences and meetings with the NJDOT ITS, Susan Catlett and Jerry Keegan, NJDOT ITS Engineering, provided the team at NJIT with a master electronic inventory comprised of 582 miles of fiber optic and communications conduit owned by NJDOT, as well as access to plans and drawings related to the sections listed by Mark Renner's team as sections with missing trace wire.

The master baseline inventory was exported from a database by request and included particular fields of interest, including roadway locations, relative position, mile-post start, mile-post end, and conduit diameter. The mile-post start and end were of particular interest initially, because they enabled the team in most cases to determine the total length of conduits in the system. The database required clean-up and adjustment, and was then used to apply simple statistical analysis to attempt to understand the inventory of fiber optic conduits, and its various disaggregation by material, diameter, etc.

The inventory provided enabled the team to disaggregate the total system by fields, including diameter and material type (*Table 1, Figures 1 and 2*). While the analysis clearly shows the predominance of non-metallic pipes, both rigid (RNMC) and flexible (FNMC), with the percentage of non-metallic pipes at 63%, 175.9 miles out of 581.7 miles of network, or 30% of the network have unknown material type and would benefit from a review of information at hand in order to identify the materials for all sections in the database.

Sum of Length (mi)	Type				
Size	FNMC	RMC	RNMC	Unknown	Grand Total
1"		0.23		5.48	5.71
1.25"	3.30		20.62		23.92
1.5"		0.15		0.00	0.15
2"	6.94	21.94	232.61	3.15	264.63
2.5"		0.57	0.23		0.80
3"		17.34	4.78	4.00	26.13
3.07"		0.01			0.01
4"		1.18	57.03	92.58	150.78
4.8"				4.12	4.12
6"		0.05			0.05
Unknown		1.82	37.03	66.58	105.43
Grand Total	10.24	43.28	352.30	175.90	581.72

Table 1 – NJDOT network disaggregated by conduit material and diameter

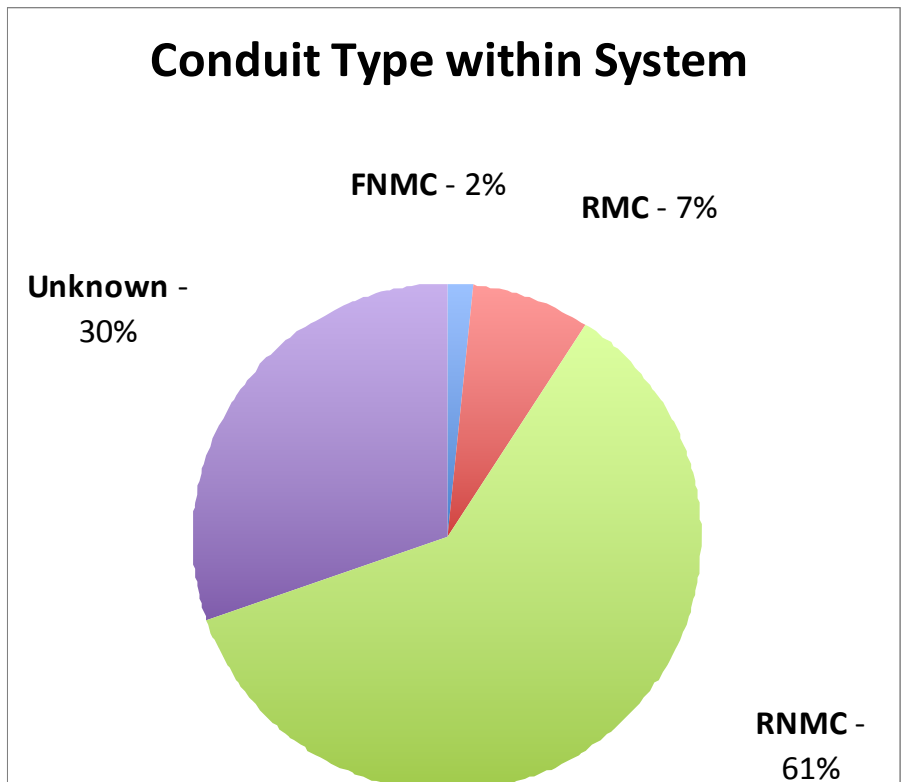


Figure 1 – NJDOT network distribution by conduit material

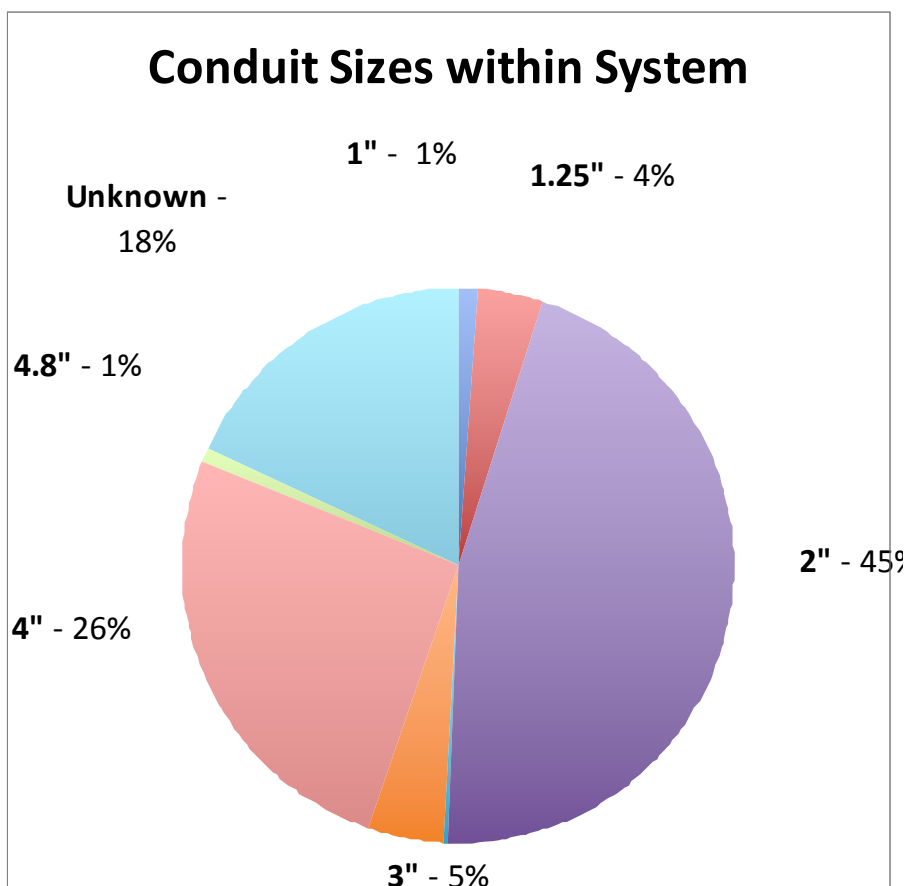


Figure 2 – NJDOT network distribution by conduit diameter size

It is useful to note that the master inventory contains records consisting of sections with multiple junction boxes. The development of a junction box (JB) inventory and a disaggregation of the master database by segments (JB to JB), could prove to be a valuable task for not only selection of the best locating technology, but also for improving the throughput from operations, as the segment length and other useful data would likely prove to be important reference information to operators in the field.

Using the Natural Resources Conservation Service (NRCS) Soil Survey and a geographical cross-referencing of the inventory database, the team established soil profiles and predominant soil types for all conduit segments within the network, information valuable to future field-testing (*Figure 3*). The enhanced master database with soils information (soils distribution within a section and pre-dominant soil type) is an output of this project that can help in any decision support related to locating fiber optic conduits or other nearby utilities. This enhanced database is provided as a separate file on the disk with the final report.

The soils distribution analysis shows a pre-dominance of soils that are conducive to successful location using ground penetrating radar, as New Jersey soils in the southern and central parts of the State are considered GPR-friendly. However, 23% of the

inventory seems to be in pre-dominantly difficult soils that were specifically evaluated in GPR tests in representative sections of the Northern part of the ITS network.

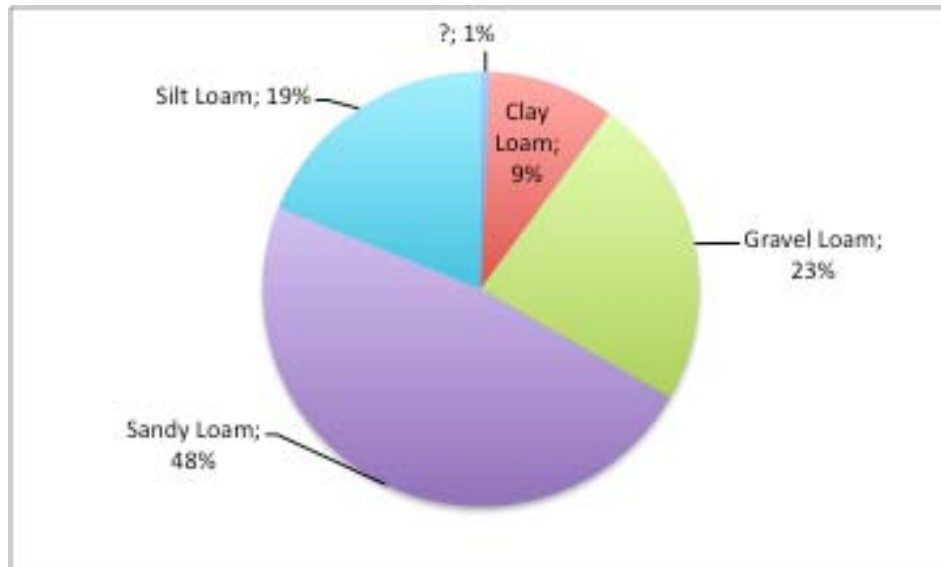


Figure 3 – Predominant soil types within NJDOT conduit network

Missing Trace Wire Inventory Database Development and Analysis

Certain fields included in the exported data were inconsistent or only applicable to portions of the total system, including the relative location of conduits on roadways and their position, as well as the location of contiguous utilities and the degree of clutter. This data, while not critical for basic analysis, is necessary for the effective and safe location/maintenance of conduit segments. What remained unknown was which portions within the total inventory had missing/damaged trace wire. Once the sub-inventory of conduit missing trace wire was completed, it could then be cross-referenced back to the master inventory and added as an additional reference field.

Although the master inventory was developed at the section level, it was decided that the sections of missing trace wires would be inventoried at the detailed segment level, which included the identification of all segments (JB to JB) in the missing trace wire sections.

To determine the location and lengths of conduits with missing/damaged trace wires, the research team reached out to NJDOT Operations Divisions with the objective of developing a comprehensive State-wide sub-inventory. NJDOT Southern Operations provided electronic and paper drawings corresponding to the missing trace wire list of sections. This list generally included a variety of descriptions, including mileposts or roadway landmarks and a short description for easy location on roadway construction plans. With this preliminary inventory, the team obtained and analyzed as-built construction plans from NJDOT ITS Engineering to determine necessary data, including

conduit segment length, junction box count, diameter, and relative location on respective roadways. Analysis of this data enabled the team to make general assumptions valuable to future field-testing; including average length between segments, conduit material type, and implications regarding predominant soil types (*Table 2 and Figure 4*). As in the rest of the master inventory, the pre-dominant material in the missing trace wire inventory is the RNMC, non-metallic type.

Total Length of Conduit	26.2 mi.
RMC	2.3 mi.
RNMC	20.8 mi.
Unknown material	3.1 mi.
Average Segment Length	643.9 ft.
Median Segment Length	490.0 ft.

Table 2 – Missing trace sub-network – NJDOT Southern Operations

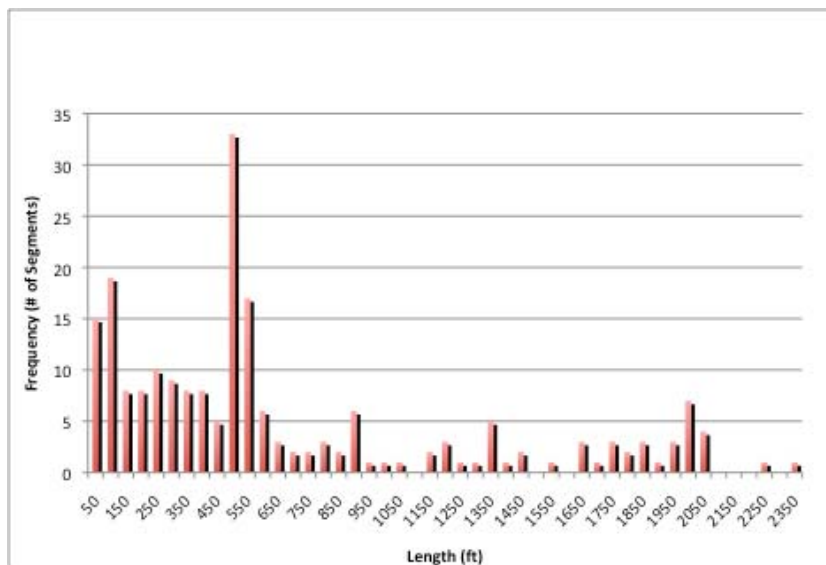


Figure 4 – Frequency of segment lengths in missing trace sub-network

The 26.2-mile sub-inventory provided by NJDOT Southern Operations represents only a small portion of the 582-mile conduit inventory, and is assumed to be incomplete. This database is also provided as a separate file on the disk accompanying this report.

For analysis to be statistically significant, the inventory needs to be expanded to include additional areas in Southern New Jersey, as well as all areas covered by NJDOT Northern Operations. Additionally, depth data for conduit sections or junction boxes would be helpful in determining overall effectiveness of various location technologies, particularly in areas of variable soil profiles. To the extent possible as part of this effort

the TCNJ/NJIT research team has investigated the availability of this data, and means to provide solutions to the data issues related to inventory and condition of underground fiber optic conduit. The sub-inventory developed as part of this study allows cross reference of segments to the total inventory.

5. TRACE WIRE (TW)

An evaluation of the performance of the existing TW method of determining the location of conduits was begun during a site visit. Details of this visit are documented in a report in Appendix C. Based on this visit, interviews and subsequent site testing, this technology appears to work well at many locations. However, even when TWs are in place and access to the wires is possible, there can still be limitations to the application of this technology. Difficulties occur principally due to the presence of noise, often from nearby power lines and other co-located TWs. Many of these problems can be eliminated through the use of newer TW systems that employ sharper filters and coding to minimize interference. Examples of some of the new TW detectors are illustrated in Figure 5. These new detectors can include GPS and GIS, and offer better estimates of conduit depth.



Figure 5 – Examples of newer, more effective TW detectors made by Radiodetection and 3M Dynatel.

When TW is missing, but when metal conduit is in place, it is possible to use TW techniques by connecting the transmitter directly to the metallic conduits. When TW is missing and the conduit is non metallic, it is possible to insert a *snake* like device into

the conduit, which acts as a TW. This device works equivalently to TW and is applicable for runs up to about 500' provided there are not many sharp bends.

When TW is present, but the JB cannot be accessed, (difficulty in opening the JB, manhole cover), it may be possible to indirectly couple enough radio energy into the TW (or even the metallic conduit when present with no TW) for detection. A better solution is to provide a connection to the TW that does not require removal of the manhole cover. A prototype device was constructed as part of this research to perform for this function and tested as shown in Figure 6. It is comprised of an existing trace wire connected to a strip of copper, which is connected to a short length of wire. This short length of wire protrudes from a hole in the manhole cover and is secured. In this test, it was secured with a tie wrap. The protruding wire can be connected to a trace wire transmitter and thus used to locate a conduit. The results of the testing conducted at Milepost 43 of I-295 are discussed in Appendix G. In all ways, the test functioned as if the trace wire transmitter was connected in the normal way, when the manhole cover is removed.

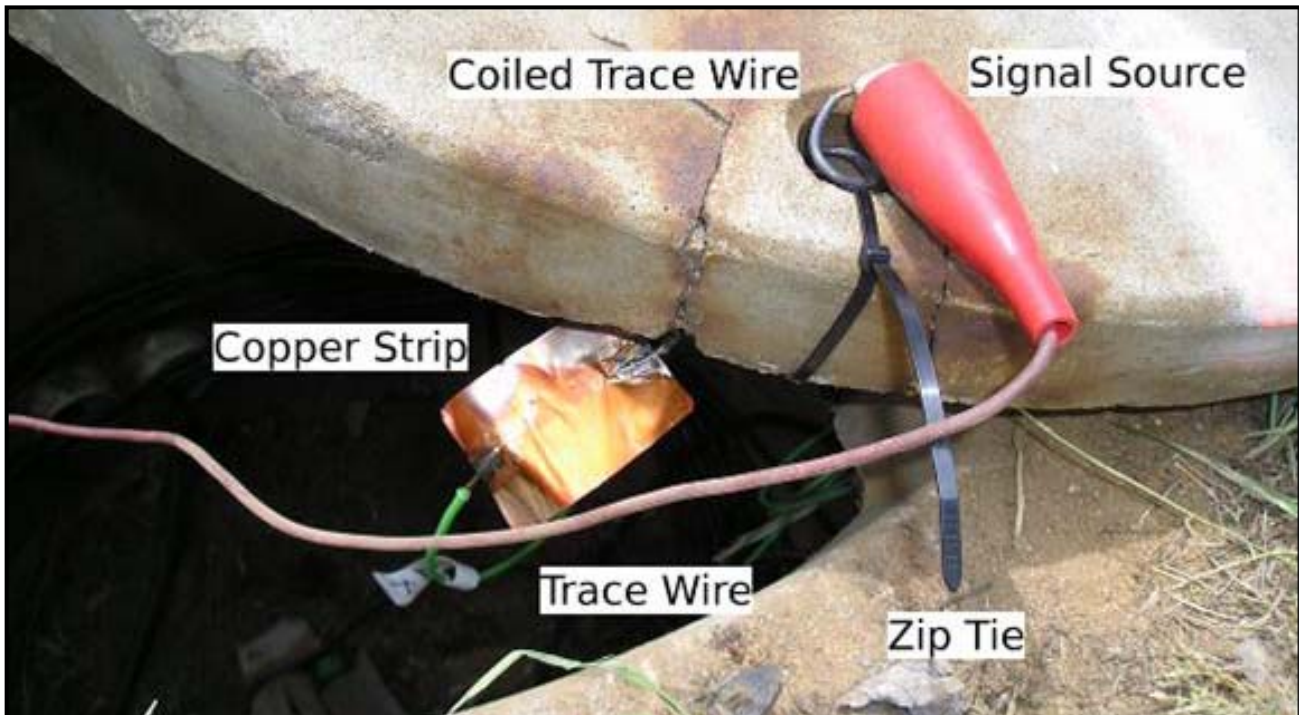


Figure 6 – Prototype device for connecting to TW with removal of a manhole cover.

A more detailed drawing of the device is shown in Figure 7. This version also uses a copper strap of about an inch in width, but with a conductive threaded rod soldered to one end. The other end of the copper strap is attached to the trace wire (could be soldered). The rod fits through an existing hole (about ½ inch in diameter) in the manhole cover. A washer and nut are used to hold the rod and thus the device in place.

Many manhole covers are concrete and act as an insulator. If a manhole cover is metallic, the copper strip and rod as well as the washer can be insulated with tape or another non-conductive material. When ready to use, the trace wire transmitter (signal generator unit) can be attached to the conductive rod at the top of the cover. The trace wire receiver (cable locator unit) can then be used as normal without the need to open the manhole.

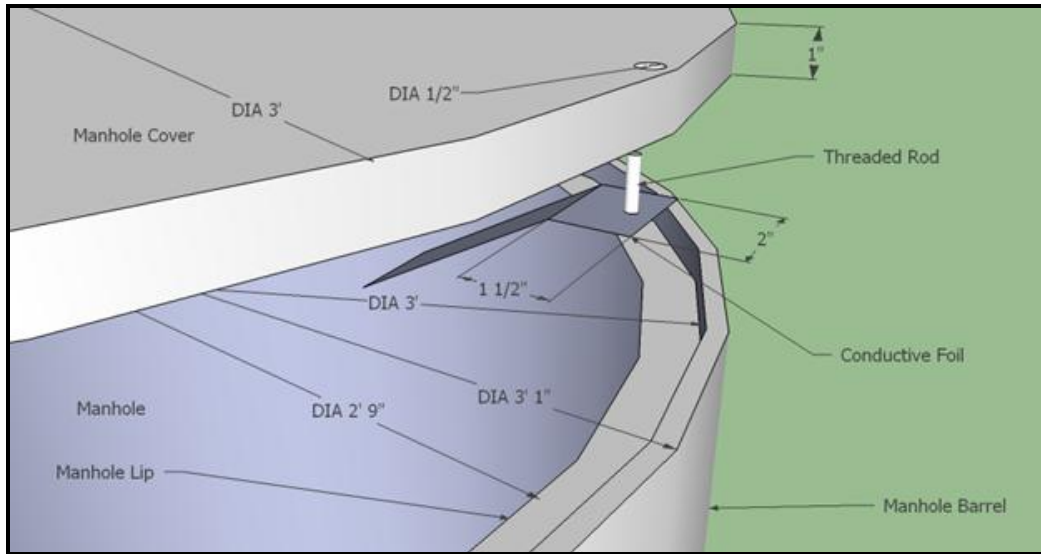


Figure 7 – Details of a device to eliminate removal of a manhole cover to access TW.

An even more flexible solution that may work even when the location of the JB is not known involves the application of another new TW technology conceived as part of this research. The concept is to apply Radio Frequency Identification (RFID) techniques to TW. RFID systems have a long history since its early inception of its predecessors as Identification of Friend or Foe (IFF) systems in 1939 in England. Today, modern RFID systems can be classified as passive or active depending on whether the tags contain a battery or not. Furthermore they can be grouped as low/mid/high frequency systems based on their operational frequency. Systems that could be used in identification of buried conduits will be preferably operating at low frequencies due to high attenuation of electromagnetic signals through soil. Such systems usually operate based on inductive coupling between the tag reader antenna and the tag, as shown in Figure 8, and must include the path length inside the ground at which the tag can be placed in near proximity of the utility.

Commercially available systems have a typical range in the vicinity of 6 feet in free space and available tags are well encapsulated to weather adverse conditions within the ground and consist of coils coupled to the chip as shown in Figure 8. Typically, ferrite rods are associated with the coils to increase inductance values for tuning to the appropriate frequency as shown in Figure 9.

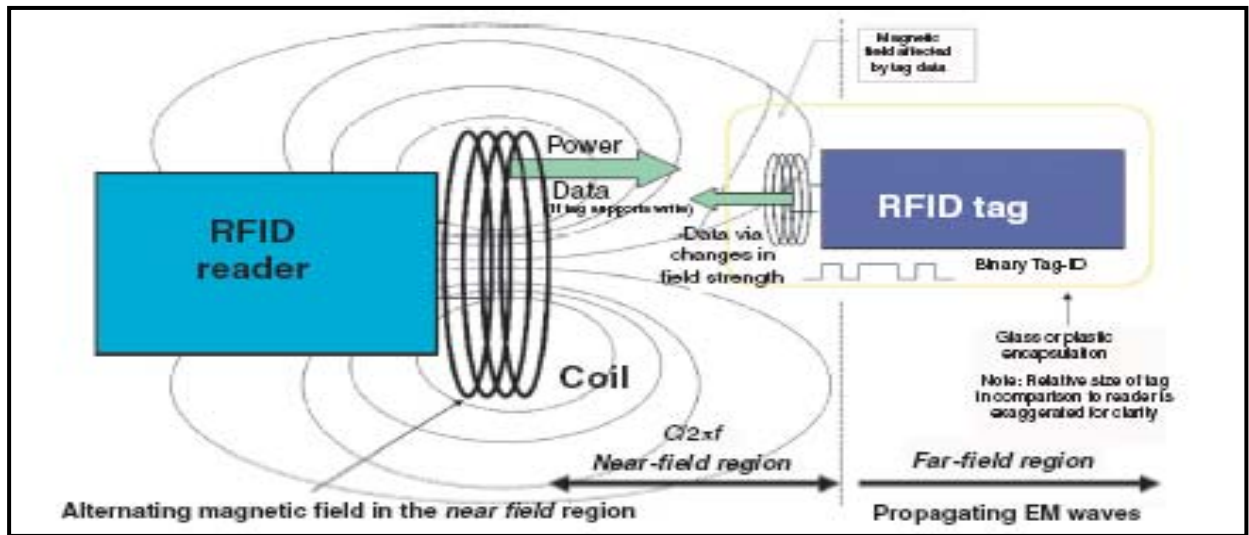


Figure 8 - Near-field power/coupling mechanism for RFID systems operating at less than 100 MHz. [R.Want, "RFID Explained: A Primer on Radio Frequency Identification Technologies," Morgan & Claypool Publishers, 2006].



Figure 9 - Typical RFID tag based on near field coupling at 128 kHz, 1 cm in length. [Trovan RFID, "Method and apparatus for modulating and detecting a sub-carrier signal for an inductively coupled transponder," www.trovan.com, US patent # 5,095,309].

The idea is to use tapes with RFID components attached at periodic intervals in lieu of trace wires – see Figure 10.

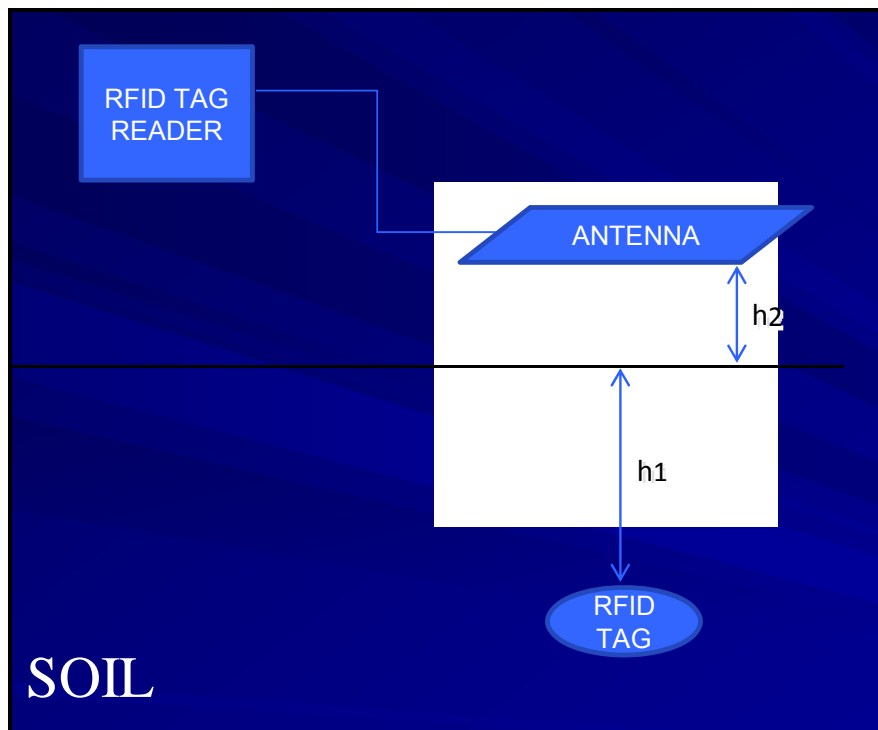


Figure 10 – Schematic diagram of the experimental RFID system to probe buried tags.

An RFID source above ground can then emit a signal and activate the sensors on the tape; thus removing the problems encountered with trace wires, such as the identification of multiple conduits, and the need to power the trace wire. RFID units operating at low frequency (132 kHz) with minimal attenuation by soil were obtained to verify that this technology can achieve sufficient penetration of the signal to be workable. A tag was buried in about 18” of soil in the lab, and tested successfully – see Figure 11. A range of about 18” was the maximum range of the RFID components tested in air as well. Improvements in the tag itself should allow further depths to be achieved. A patent disclosure for this technology was written and submitted for processing by NJIT. A copy of the disclosure and additional details on the use of RFID principles for the location of conduits are included in the Appendix K.



Figure 11 – Test of RFID TAG system (134.2 kHz) when buried in the ground

Another promising embodiment uses diodes inserted in series with the trace wire at periodic intervals to produce an *RFID like signal*. A radio frequency (RF) source above ground is used to emit a signal that is converted to its harmonic frequencies by the diodes and can be detected by a trace wire detector (receiver) as illustrated in Figure 12. This solution, as the RFID chip concept, allows trace wires to be detected without the need to be directly connected to a transmitter at a JB (manhole does not need to be opened). It does not add significant cost to the trace wire (less expensive than conventional RFID) and can be implemented in a form that will allow multiple conduits to be uniquely identified even when in close proximity to each other. It also eliminates the need to power the trace wire.

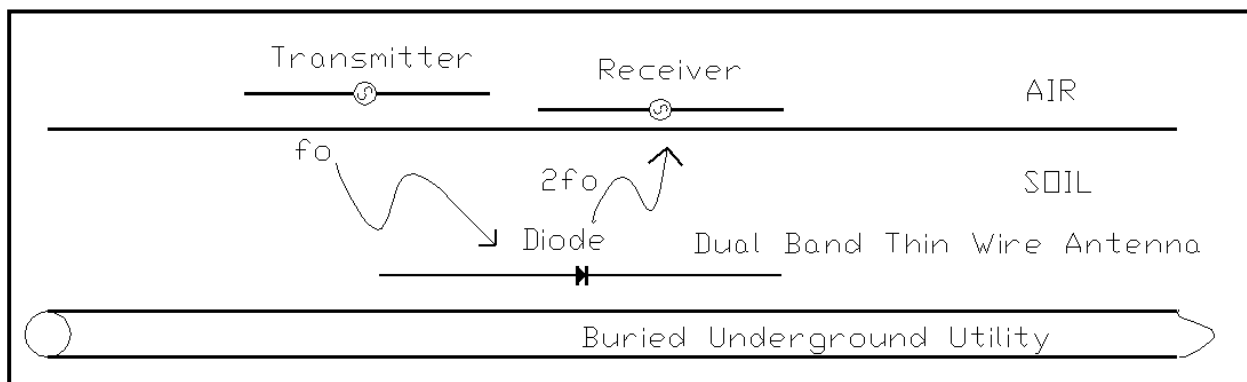


Figure 12 - Simplified tag comprising of a diode and a thin wire dual band antenna.

This concept was tested in the laboratory, but was not tested in the field by actually inserting a diode loaded trace wire into a conduit – see Figure 13. This concept was also included to the RFID patent disclosure.



Figure 13 – Test of diode based RFID system for improved TW.

There is also a commercial RFID system made by 3M that is designed to be buried. These devices are not designed for TW application, but consist of 4” diameter spheres containing passive RFID tags that can be buried in the proximity of utilities to identify their locations. Their penetration depth is about 5 feet and they are commercially available as the 1407-XR product. The details are discussed in Appendix L.

6. ACOUSTIC TRANSMISSION (AT)

When TW (of any embodiment) are not present and non-metallic conduit is not in use (the most common case - more than 63% of the network is non-metallic), TW methods are not usable. One solution to this problem is to use AT. This approach applies acoustic vibrations either directly to the end of a conduit in a JB or alternately to the manhole cover over a JB, and detects the resulting acoustical emissions at the surface above the conduit. In the case of the AT system, the sound level relative intensity is used to locate the conduit. Since the conduit is used to carry the acoustic signal, no trace wires are required. A block diagram illustrating a basic AT system is shown in Figure 14.

To test this concept a prototype AT system was assembled. The initial transmission system consisted of an audio signal generator, audio power amplifier, subwoofer, subwoofer enclosure, PVC connector, and brackets for attachment to the conduit as illustrated in Figure 15. (A commercially available subwoofer speaker was selected for use as the transmit transducer when a study of available components showed that very

similar technology was being used for industrial applications). We planned on directly connecting the acoustic sending transducer (subwoofer assembly) to the conduit itself. In doing so, the vibrating sound from the back panel of the subwoofer enclosure would directly vibrate the conduit. A frequency in the range of 10 to 300 Hz was selected for testing as it is known that the attenuation of soil to sound waves is low in this frequency range, and components were also readily available for this range. The specific acoustic frequency used for transmission was determined experimentally.

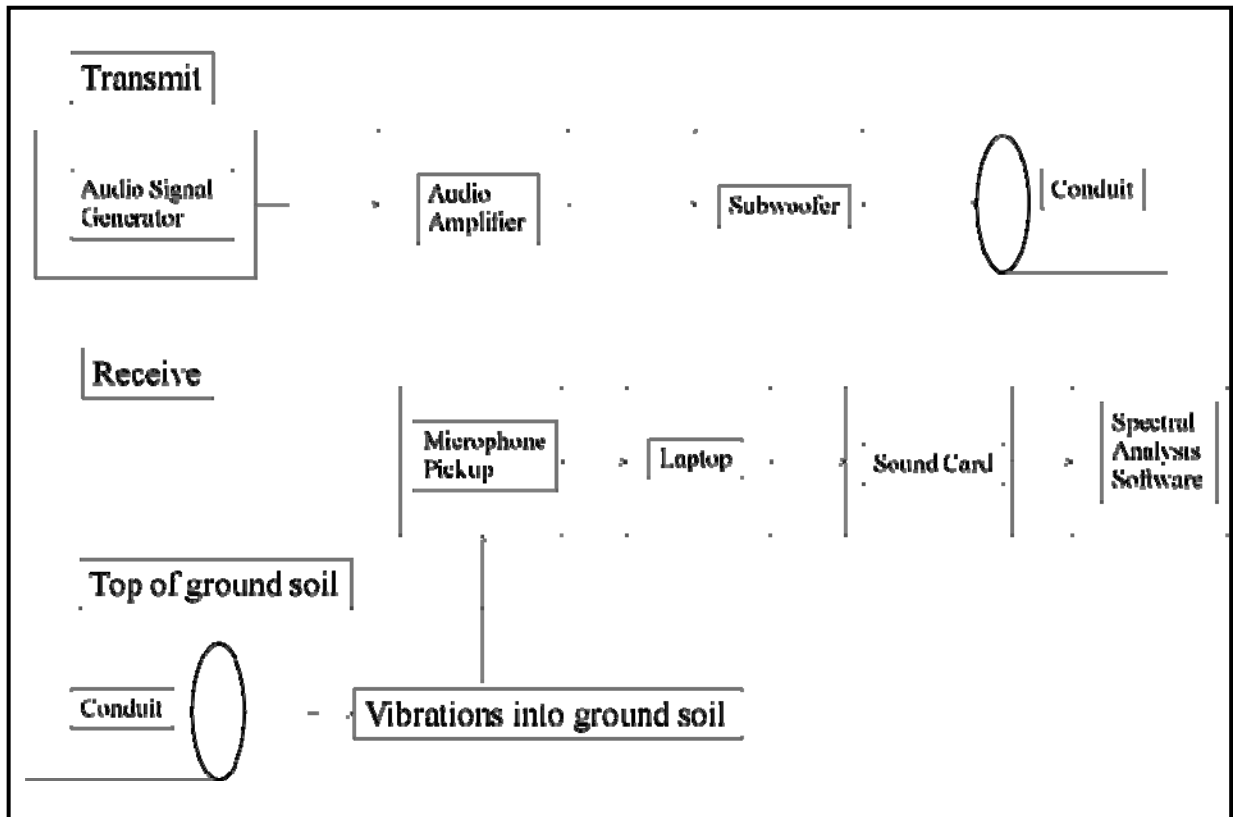


Figure 14 - Block diagram of AT system. The top of the diagram shows how the acoustic signal is generated and applied to the conduit. In the bottom half of the diagram, the conduit is shown underground and the system for detecting the acoustic signal emanating from the conduit is illustrated.

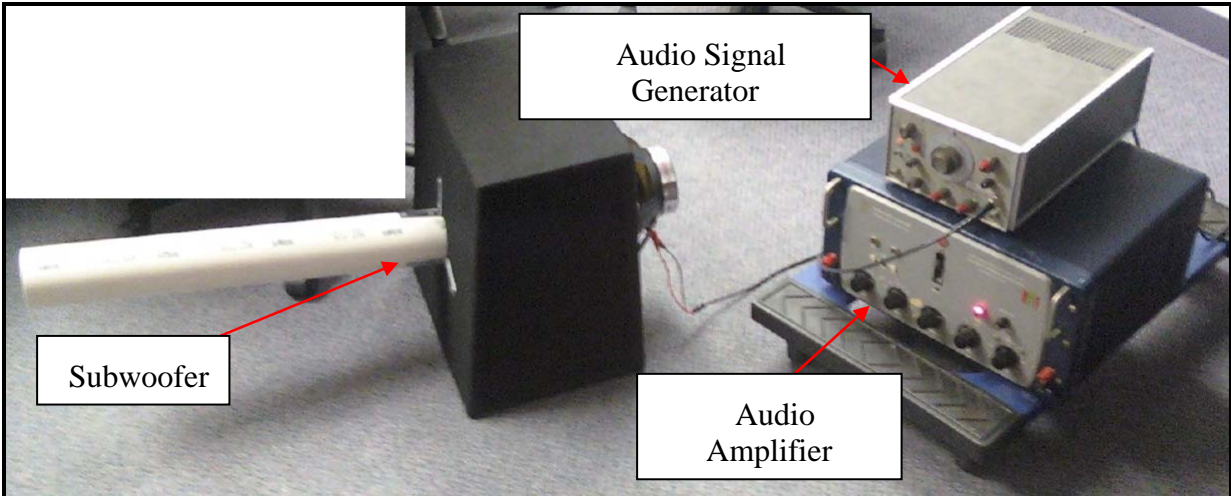


Figure 15 - Audio signal generator, audio power amplifier, subwoofer and subwoofer enclosure used to acoustically excite the conduit.

A microphone attached to a rod was used to pick up the acoustic signals. The rod was inserted into the earth to achieve better detection of the soil borne vibrations. The microphone was also insulated to isolate it from air borne noise. The microphone was connected to the input of a sound card in a laptop computer and the signals processed and analyzed with spectrum analysis software. The receiver system with a shielded microphone is shown in Figure 16 and a screen display in Figure 17. A list of equipment is given in Table 3.



Figure 16 - Microphone and receiver (laptop/sound card with spectrum analyzer software)



Figure 17 – AT system spectral display

Description	Make/Model
Amplifier	Krohn-Hite/UF101A
Frequency Generator	Krohn-Hite/5200
12 inch Subwoofer	Scosche
12 inch Subwoofer box	Scosche
Shelving Brackets (3)	N/A
3 inch PVC T-connector	N/A
10 feet of speaker wire	N/A
Laptop computer	Dell
Portable microphone	Gigaware/33-119
Spectrum Analysis	Spectrian

Table 3 - Basic AT System List of Equipment/Materials

This basic system was tested at multiple locations and was successfully able to locate conduits at distances of over 1,500', and with indirect stimulation (to manhole cover) over shorter distances. It was shown effective at locating the position of a conduit within several inches when buried in soil. A frequency in the range from 50 to 150 Hz was found most effective depending on the soil type. An example of results taken in the center island of I-295 near Milepost 43 is shown in Figure 18a. The measurements were made at 150 Hz at 600' from the JB with two parallel conduits coming from the same JB. One of the conduits was directly stimulated. Figure 18b shows similar measurements at 1200' where only one conduit was present.

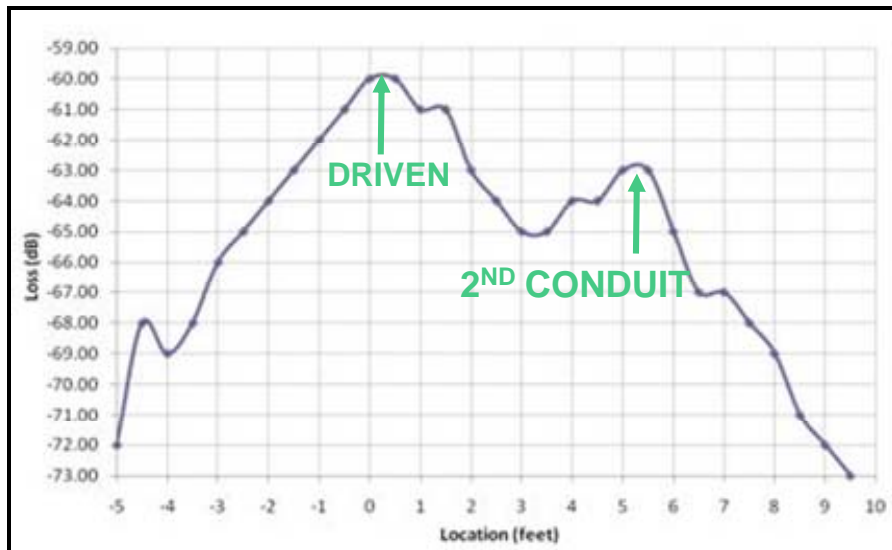


Figure 18a - Response vs. location for two parallel conduits (one directly excited) at 600 feet from the manhole (130 Hz).

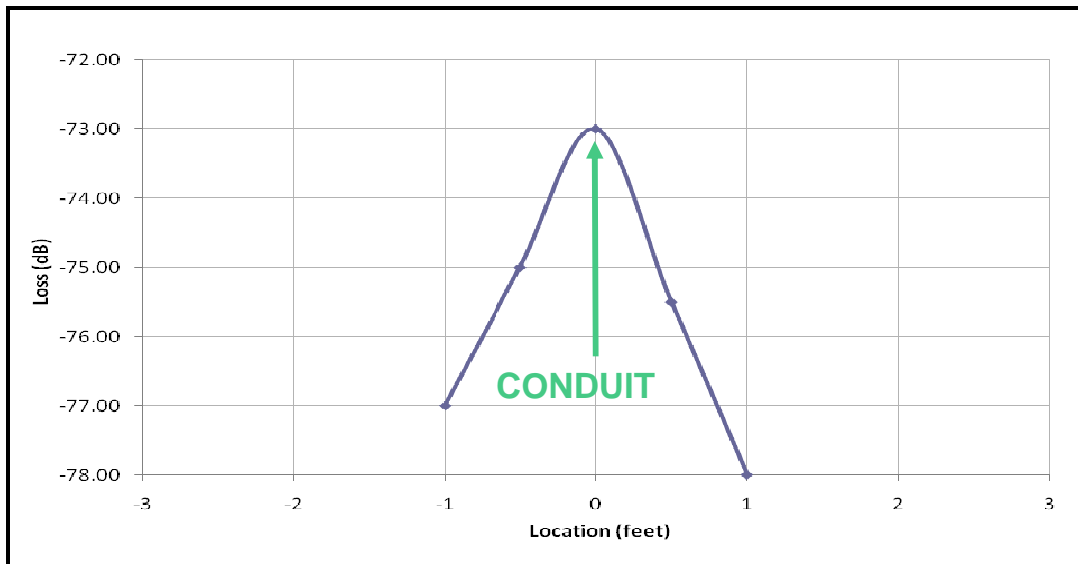


Figure 18b - Response vs. location for conduit (directly excited) at 1200 feet from the manhole (130 Hz).

The AT system worked well except under paving where resolution was limited by the acoustic conductivity of the surface material. Data taken for a conduit under an asphalt surface is shown in Figure 19.

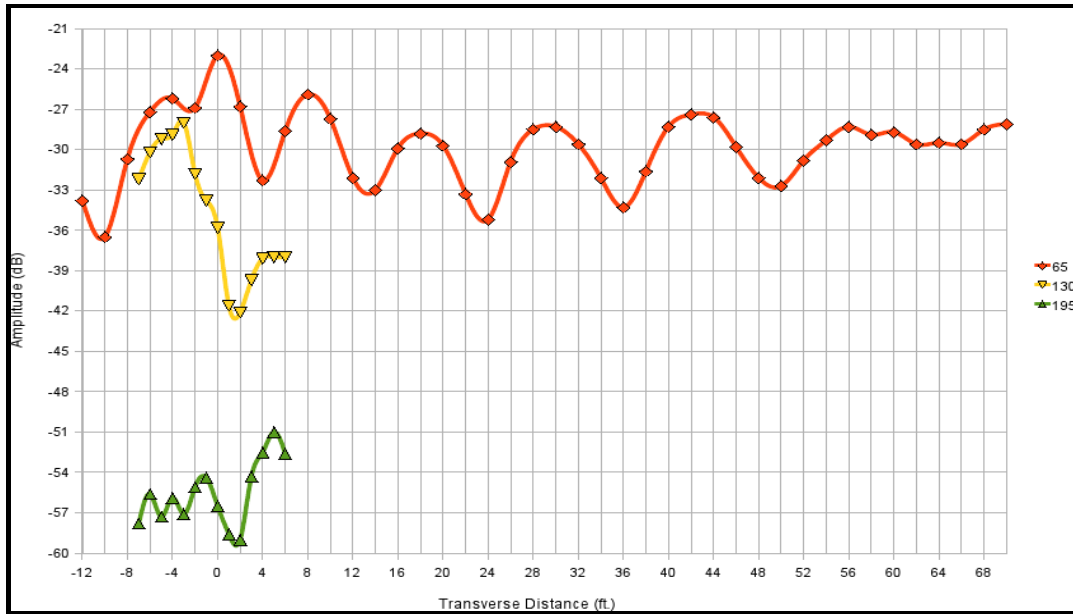


Figure 19 – Under asphalt AT system resolution can be degraded

Ways to better isolate the driver (woofer) and microphone from sending/receiving signals through the air were investigated. Tests of shielding the microphone and woofer using cardboard boxes insulated with foam were tried. These boxes were positioned over the microphone, speaker, or both. The microphone was placed in the ground at an arbitrary point about 100 feet from the speaker. Tests were done using both 65 and 130 Hz signals, and the background noise level and the signal level measured. It was found that the signal to noise ratios was greatest when just the microphone was covered for both the 65 and 130 Hz signals. These results are illustrated in Figure 20. It was concluded to use no shielding of the speaker, while shielding of the microphone made a significant improvement and was used in following tests.

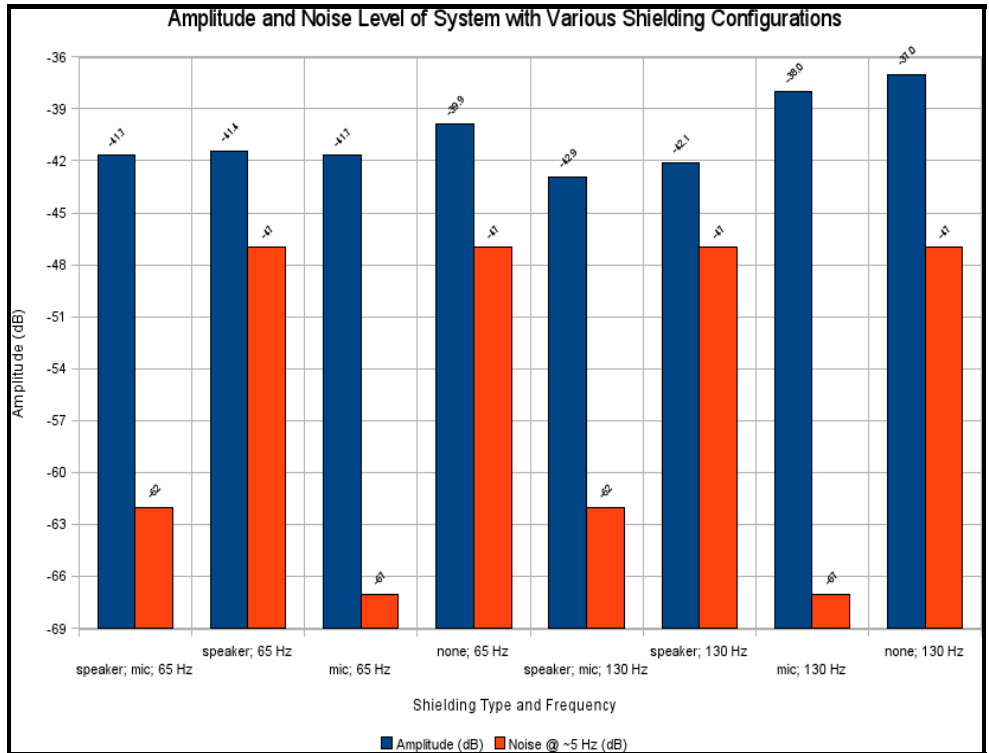


Figure 20 - Signal and noise levels of AT system using various shielding combinations of speaker and microphone.

Figure 21 shows how signal level varied with distance at 130 Hz when directly driving the conduit. Figure 22 shows how signal level varied with distance at 65 and 130 Hz when driving a manhole cover. Both sets of data show a linear increase in attenuation over distance. Directly driving the conduit shows an attenuation of approximately 0.02 dB per foot, while driving the manhole cover shows an attenuation of approximately 0.066 dB per foot. This indicates that driving the manhole cover leads to more than triple the attenuation over distance as does directly driving the conduit.

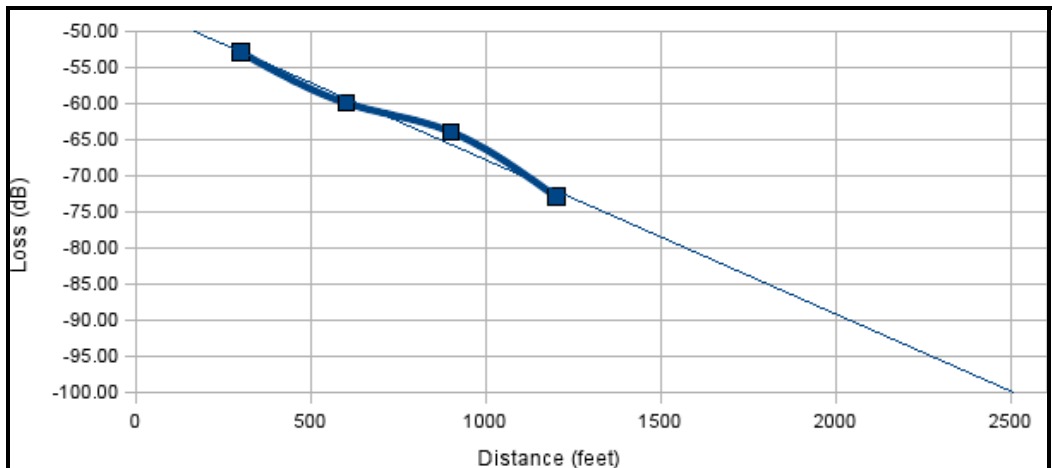


Figure 21 - Loss vs. distance from the manhole at 130 Hz when directly driving the conduit.

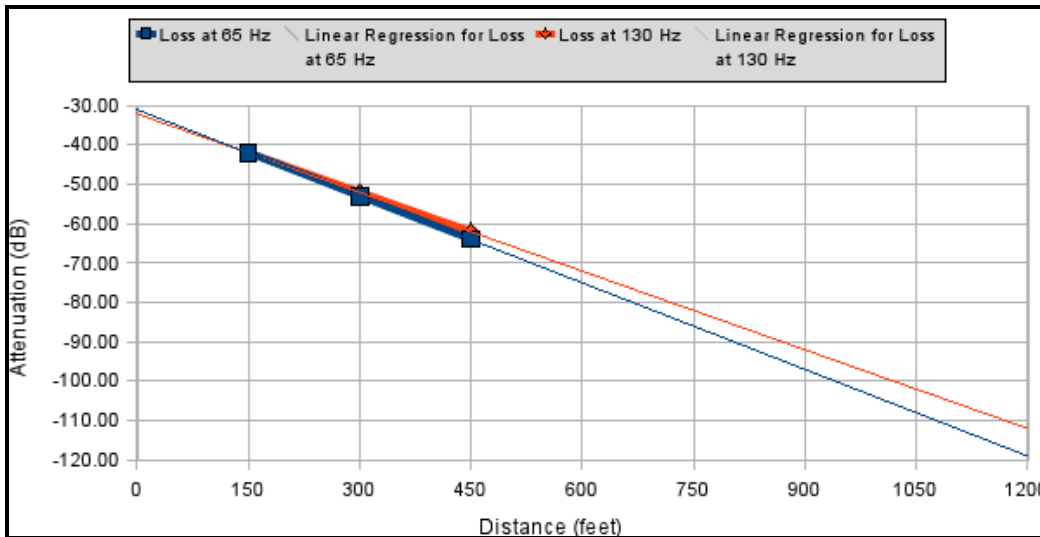


Figure 22 - Loss vs. distance from the manhole at 65 Hz and 130 Hz, driving the manhole cover.

Tests of the AT system were conducted at three different locations at different times. The results of these tests are documented in Appendices E through H and provide additional incite in to this technology's performance.

7. GROUND PENETRATING RADAR (GPR)

Because the GPR seemed the most likely solution to the conduit location problem, considerable time was allocated to understanding the fundamentals of these systems and to their evaluation. A GPR uses a transmitting antenna to emit pulses of high-frequency RF waves into the ground. A separated antenna is normally used to receive the signals reflected off of discontinuities (objects) in the subsurface, as illustrated in Figure 23.

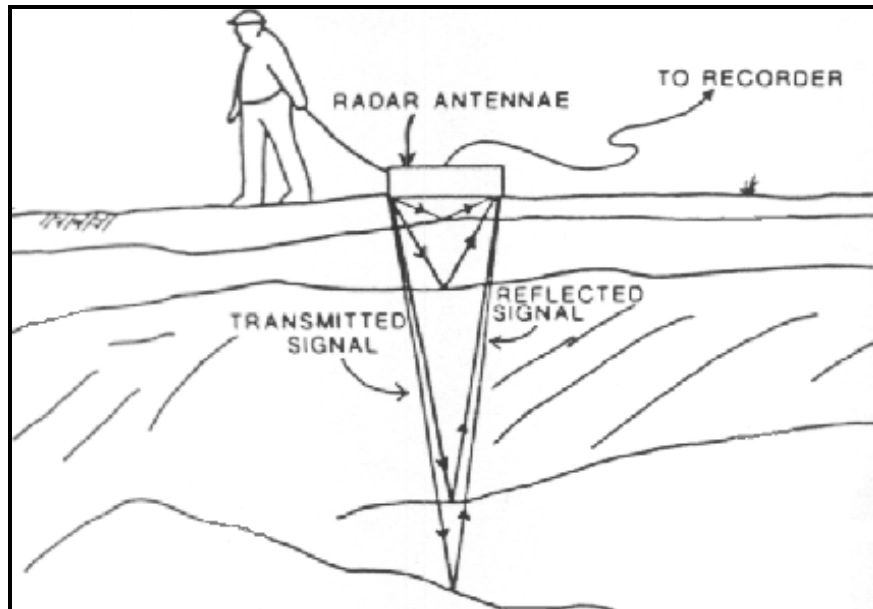


Figure 23 – A GPR receives signals reflected off of subsurface discontinuities. It is normally moved across the ground with the signals recorded as a function of time.

One of the questions in the selection of a GPR is the frequency of operation. Ground attenuation of the signal is a function of frequency - the lower the frequency, the lower the loss. However, because of the relatively small distances involved in many GPR applications, the signal (pulse) must be sent over a very short time period. RF signals travel at a velocity (V) of 1.22×10^{10} inches/sec times a propagation factor (PF) depending on the dielectric properties of the medium the wave is traveling through, in this case soil.

$$V = 1.22 \times 10^{10} \text{ PF}$$

PF is always less than 1 and typically for soil < 0.5 . This means to detect a reflection from an object one inch away, a pulse must be less than about 0.4 nsec long. This short period is necessary in order for the pulse to be received after its transmission has stopped. (The transmission must have stopped to avoid interference with the received signal). The pulse width also sets the depth resolution (DR) of the GPR, because a time separation is needed between reception of a signal from an object at one level and that at another to differentiate between the two objects.

$$DR \approx 2 / (1.22 \times 10^{10} \text{ PF})$$

To maintain its spectral characteristics, a pulse must be at least one cycle in length (and preferably several cycles); this means the lowest frequency that can be used to obtain a resolution of 1 inch is about 1.25 GHz. The attenuation at this frequency is normally too high for most soils and typically a lower frequency is used with consequently less DR.

The GPR tests conducted during this project were all at around 400 MHz, giving a DR of greater than about 3.25”.

The transmitter and receiver apparatus is normally moved across the ground and the reflected signals recorded as a function of time to determine where objects are located with respect to surface coordinates, as illustrated in Figure 24. (One of the wheels is normally used as the position readout).

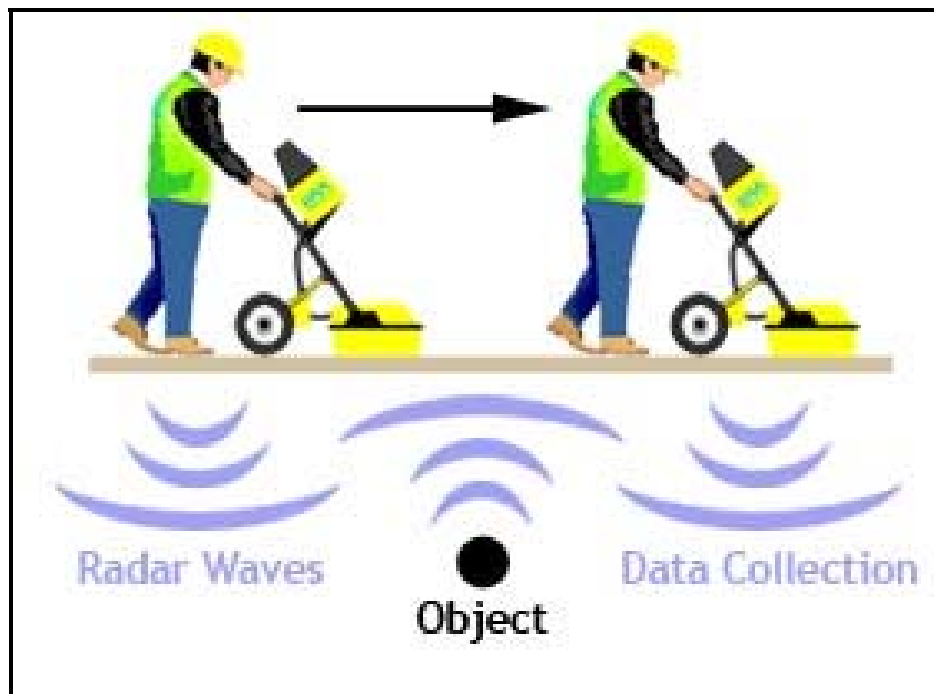


Figure 24 – The GPR is moved over the ground to determine where objects are located below the surface.

The GPR’s resolution in position (horizontally) along the surface is determined by the beamwidth of the transmit and receive antennas, and the soil characteristics, which tend to spread out the beam beyond its free space pattern. The GPR keeps track of its position relative to a reference point that can be set by the operator. The GPR unit is often installed on a pushed *lawnmower* style cart. A typical GPR is shown in Figure 25. The units tested, two different types were evaluated as part of this project, appeared relatively easy to use, and both in favorable conditions were specified to locate conduits buried up to 12’ deep.



Figure 25 – A typical GPR looks and is pushed similar to a lawnmower.

The signal received is displayed as a function of distance along a line (relative to the reference) and depth. The depth is calculated from the time delay of the pulse reception for each position along the line and the assumed PF of the soil. (PF can be changed, and ideally if an object of known depth is available for test, its depth can be used to set the value of PF). A typical GPR display is shown in Figure 26. Objects are indicated by *cone shapes* with a rounded top, also referred to as hyperbolas. The width of the cone is a function of the width of the object and the beam pattern of the antennas as already discussed. Before the GPR is above the object, some of the RF energy from the transmitter hits the object because of the antenna's finite beam pattern and is reflected back and received. This energy travels further because of the slant angle and thus appears to be from a deeper point producing the hyperbolic shape. A possible conduit is indicated by the white arrow. The distance along the surface is indicated by the horizontal scale at the top of the screen. From this scale it can be estimated that the horizontal resolution is about 2.5' ~ 3'. The depth is about 2.5' as indicated by the vertical scale on the left side of the screen. This distance is a bit shallow for a conduit, which is expected to be at about a meter in depth. This difference may be a result of an error in the assumed value for the PF.

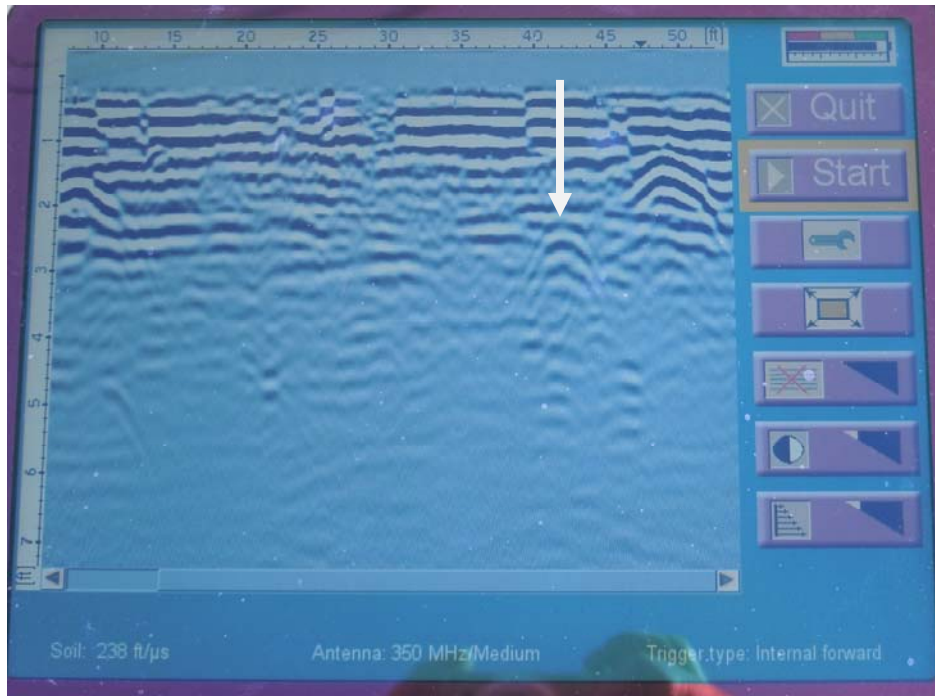


Figure 26 – Typical GPR display showing an indication of a possible NJDOT conduit.

An example of another GPR display where multiple objects were present is shown in Figure 27. The key question is whether GPR can provide sufficient information (signature) to clearly differentiate NJDOT’s conduits from other buried objects in New Jersey’s varied soils/terrain.

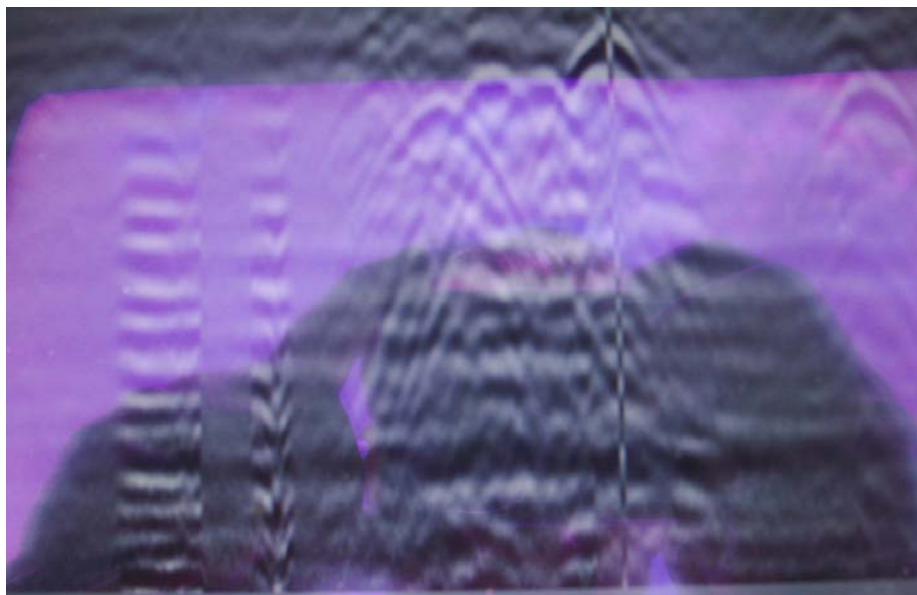


Figure 27 – GPR display with multiple buried objects shown.

During this research, multiple GPR manufacturers were contacted and arrangements made for testing. GPR systems made by Geo Physics and Mala were tested at three sites. One location was in south central New Jersey (RT. 295 north at milepost 43) and another at NJDOT headquarters in Ewing. The third location where GPR testing was conducted was in a more north part of the state under less favorable soil conditions. The GPR tests conducted showed GPR's ability to locate multiple buried objects, and that results are dependent on soil conditions and knowledge of the underground utilities general locations. At all locations the information provided by the GPR was useful, i.e., at no location were the soil conditions bad enough to make the GPR inoperative. The answer to the question on identification is dependent on the available information at a site. First, as is shown in Appendix M, some soils are more suitable for GPR detection. This GPR-suitability map for the state of New Jersey, provides a color-coded rating of suitability based on soil types. By using this type of geographic cross-referencing, a soil suitability field was added to the inventory DB of cable conduits. Although some sections in that DB stretch over a number of segments of conduit, the soil suitability field is a first indicator for that geographic location of the applicability of GPR for the location of underground conduits.

A rule of thumb provided by many vendors based on large amounts of test data, is that GPR units can detect pipes made of all commonly used materials. However, a pipe diameter to depth ratio is used as a guideline for how deep users can expect to see. *This ratio is roughly one inch in diameter for every foot deep a pipe is buried, i.e., 2 inch pipe at two feet, four inch pipe at four feet and so on.* Since many pipes in the NJDOT system are in the 2" diameter range and are about 3' deep, the usability of GPR for such cases has to be considered marginal. (All GPR tests conducted as part of this study were at sites with 3" or larger diameter conduits).

This type of rule used in GPR suitability screening, further confirms the importance of a detailed computerized inventory of all pipe segments, including information about individual pipe diameter, and material. For example, if a 1" diameter pipe is buried at 3 feet depth, GPR may not be able to detect the pipe, particularly if the soil is not highly suitable. Since many segments may be missing conduit diameter information, it is often not possible to ascertain if the GPR technology is suitable. Completing the diameter, depth, and material fields will help in deciding on the suitability of GPR in a certain area, but it also helps validate the location based on the review of the "signature" of the pipe. The signature of a metallic pipe is much more accentuated than of a plastic pipe, as can be seen from information by Sensor and Software, Inc. at http://www.sensoft.ca/applications/buried/casestudy/cs_plasticmetalpipes.html).

Clutter also makes it often impossible to distinguish various pipe signatures, if the relative location information on the fiber optic conduit and its contiguous utilities is not available a priori. If there is no clutter and the diameter to depth ratio rule applies along with other supporting information (e.g. soil suitability) is available, then a conduit can be identified with high certainty with GPR.

This research stimulated interest in ways that current GPR technology can be improved. Most recent GPR development efforts have focused on the processes of the signals received from the GPR's RF components to produce improved displays of the information. Such displays make the GPR easier to use and more *user friendly*, but do not solve the *signature* problem – how to uniquely identify specific buried objects. Two properties of RF radiated signals that do not seem to have been considered are: 1) polarization – signals reflected from an object often have a unique polarization; by measuring the depolarization of the reflected signal it may be possible to find unique characteristics associated with particular classes of objects; and 2) nonlinearity – often objects have nonlinear properties that will cause new frequencies (harmonics) to be radiated along with the original signal reflection; it may be possible to associate these new frequencies with particular classes of objects. Although not in the scope of this effort, the authors hope to investigate this avenue for improved GPR performance in the future.

8. GROUND PENETRATING SONAR (GPSon)

GPSon is of interest for areas where soil conditions make GPR techniques of little or no value. Although the soil conditions in NJ vary, there does not appear to be any part of the State where GPR could not be used. Nevertheless, GPSon was investigated to determine if there might be situations where it could be applied as an alternate to GPR. The major problem with GPSon is obtaining sufficient resolution. The speed of sound in soil varies greatly depending on conditions and is often more than ten times that of the speed of sound in air. If a velocity of 10,000 ft/sec is assumed for comparison purposes, then a signal reflected from a conduit 1 meter below the surface will be delayed by about 0.6 ms. A signal must thus be shorter than 0.6 ms in duration to avoid having the transmitted signal interfering with the reflected signal – the same problem as discussed for GPR. The shortest duration sinusoidal signal is generally considered to be one period, or the lowest frequency that could be used is $1/(0.6 \text{ ms})$ or about 16.6 kHz. Similar to GPR, the attenuation of acoustic signals is lowest at low frequencies, but in many ways more severe than for RF. Our AT testing was conducted at under 300 Hz because of the low signal loss at these frequencies. Detection sensitivity is further degraded, when the signal (pulse) of one cycle duration is used, since the energy is spread over a spectral band approximately equal to signal frequency – this is why several cycles are preferred as discussed for GPR, and why commercial GPR equipment is available but not GPSon equipment. GPSon is used for geological measurements where the distances of concern are thousands of feet, not inches.

Nevertheless, GPSon tests were attempted using the AT system components with ceramic ultra sound transducers designed for operation at 30 kHz. Tests at 30 kHz using the ultra sound transducers were not possible due to limitations with the available equipment. Our receiver/spectrum analysis only works to 20 kHz, and the power amplifier used with the AT systems did not functional properly at 30 kHz.

Attempts were tried at just below 20 kHz, but were unsuccessful because the response of the transducers had fallen off significantly and the soil had very high attenuation. We then tried at AT frequencies (using the woofer transducer), but as expected due to interference from the transmitted signal (pulse), detection of reflections at conduit distances were impossible. We were able to detect reflection from objects at much greater distances in air. Reflections from a truck at several hundred feet separation are illustrated in Figure 28.

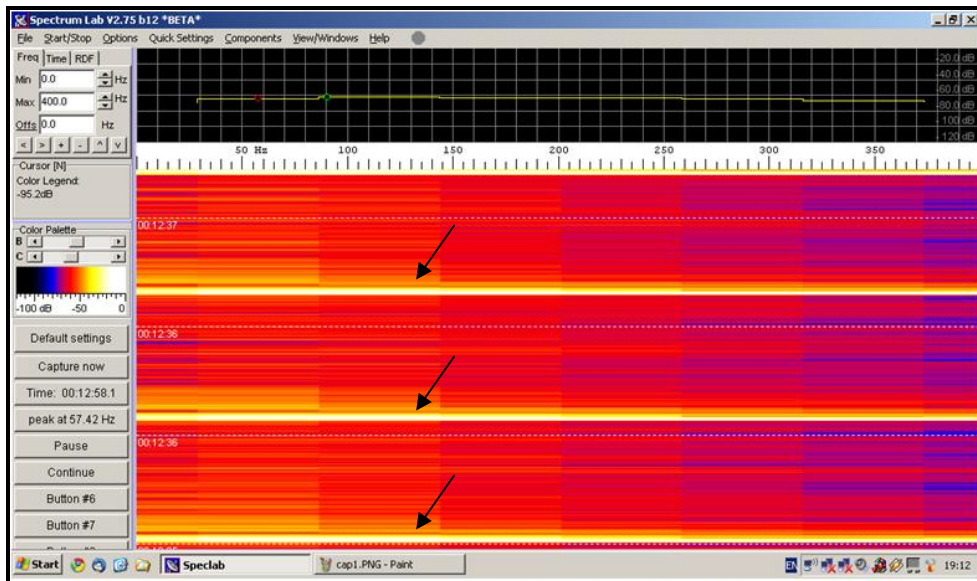


Figure 28 – Reflections from the truck across the street. There are 3 pulses and their corresponding reflections are shown (arrows).

We also investigated using nonlinear acoustics. As proposed in the RF case, when an object is excited by a sinusoidal signal, it can also produce new frequencies (harmonics). As in the RF case, one of the issues is to have a signal source that is low in distortion, so that it does not produce its own harmonics that will mask those produced by the object under test. We tried exciting a length of conduit in air. We found experimentally that the conduit was most nonlinear at 312 Hz. Figure 29 shows the response of the conduit. Since we did not have a perfectly linear source, we looked for an increase in the level of the second harmonic, when the conduit was present and not present. The figure shows a 2 dB increase in level (arrow) when the conduit is present. This level is not a huge increase, but is encouraging enough to warrant further investigation.

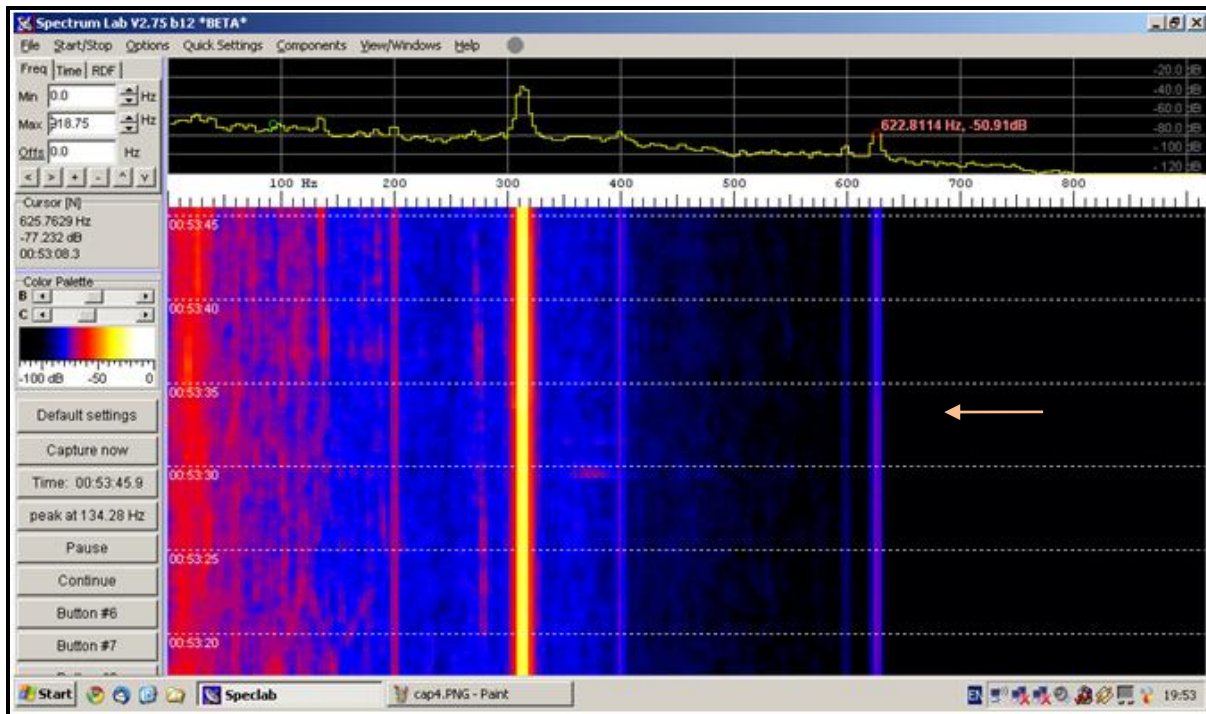


Figure 29 – The change in color of the 2nd harmonic represents a 2 dB increase when the conduit was present.

9. ELECTRO-MAGNETIC IMPEDANCE (EMI)

The fundamentals of EMI systems have been studied and the availability of commercial systems researched. The most common systems are known as *metal detectors* and are quite effective at detecting metal objects near the surface. It appeared that these systems would have insufficient sensitivity (and resolution) to be useful for the detection of non metallic objects as NJDOT's fiber conduit; however, recent research indicates that electro-magnetic methods may be effective for locating the plastic pipe used in the transport of gas. (These pipes are larger than those used by NJDOT). These results seemed promising enough for us to attempt to see if we could achieve similar results with the conduit used by NJDOT. Several special antennas were designed, fabricated and connected to a very sensitive impedance measurement instrument. This analyzer could see differences in impedance of the order of a tenth of an ohm. A picture of one of these antennas being tested with a length of conduit in air is shown in Figure 30. In all cases a negligible change in impedance was detected. Further effort on this detection approach does not seem justified as the sensitivity should be even less when the conduit is buried.



Figure 30 – Electro-magnetic impedance measurement techniques were found ineffective with fiber conduit.

A variation on EMI, sometimes called passive EMI involves the reception of signals coupled into buried metallic conductors (TW and metal conduit) from external sources as local radio transmitters or signal sources set up just for this purpose. This technique is illustrated in Figure 31. This location approach has already been discussed as an aspect of TW techniques, but is included here for completeness.

present, but cannot be readily accessed, can sometimes be overcome by use of passive receivers (picks up signals from other sources; not always effective).

- When TW is not present and the conduit is non-metallic, if access to the conduit can be achieved and the distance is not far (< 500 feet), a flexible stiff wire (*snake*) can be inserted into the conduit and used as a temporary TW. If use of a *snake* is not possible, an AT system can be used and has been shown effective for both metallic and non-metallic conduits up to half a mile. AT usually gives a clear indication of location. It works well in most NJ soils, but has less resolution with asphalt, and can be used when a manhole is difficult to open, but over shorter distances. Alternately GPR can be used. GPR is most effective with metallic conduits, but is also useful with non-metallic conduits. It works in most NJ soil and with asphalt. There is no need to open or even find the junction box. However, it can be difficult to interpret and give a false indication when multiple utilities are present. Other methods seem to be of minimal value.

A flow chart for selecting/implementing the preferred conduit location system is illustrated in the following diagram, Figure 32.

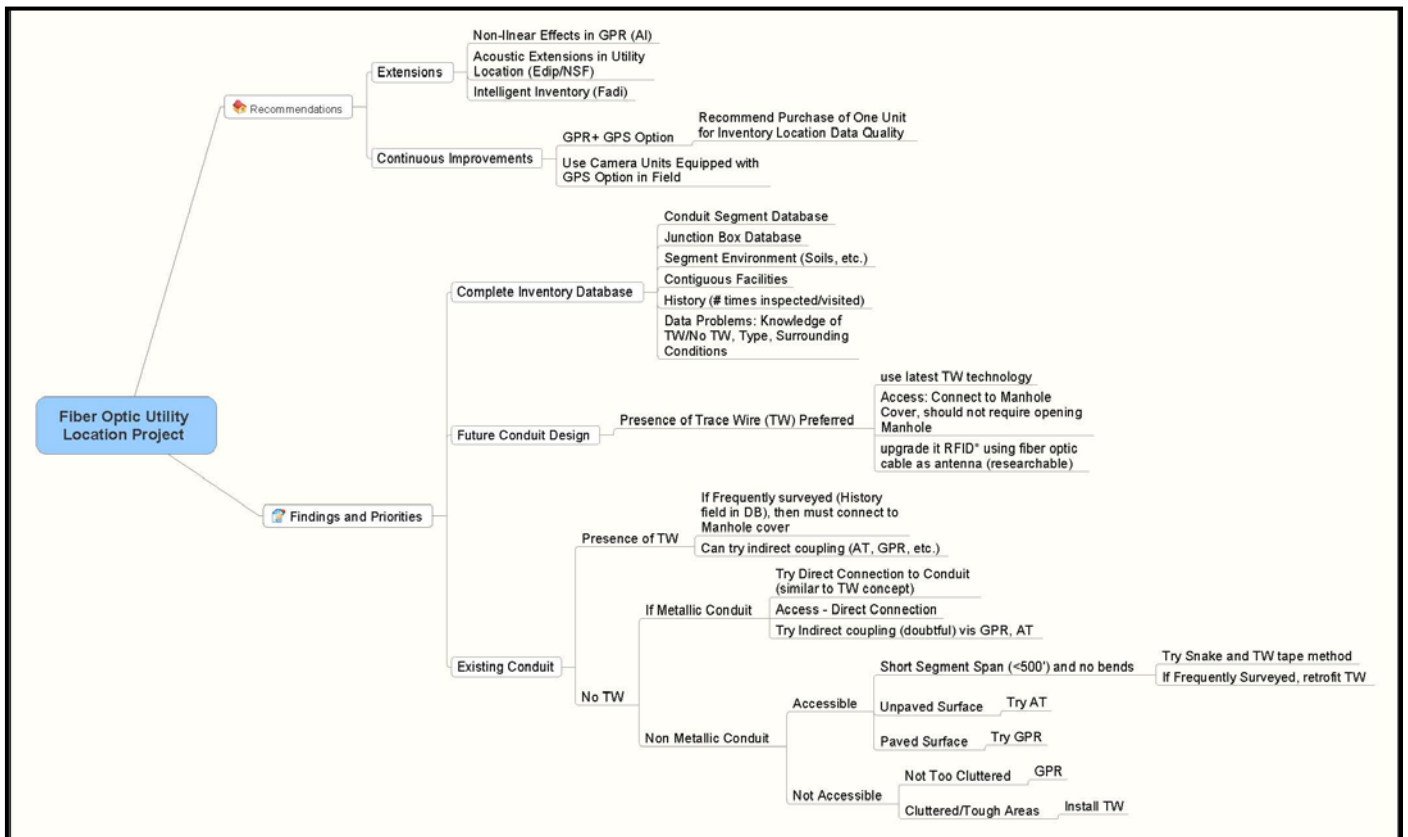


Figure 32 – Plan for locating conduit considering different conditions and level of complication.

11. TRAINING PLAN

A proposed training plan is presented below, which includes a module for the inventory database and missing trace wires, and the use of the information for the purpose of location. Under the assumption of a continued role of GPR and AT, these technologies are also featured in a training module that could be developed in the summer, after a GPR unit with a GPS capability has been acquired, and access to AT equipment is provided at the end of spring 2011. A training seminar is proposed for the end of July 2011 after possible completion of the training modules in July 2011.

Training Plan and Implementation Options Work Breakdown and Schedule	Start Time	End Time	Latest Start
Training Plan and Implementation Options	7/1/2011 8:00	7/29/2011 17:00	7/1/2011 8:00
Module I: Updated Inventory Database of Fiber Optic Conduit Sections	7/1/2011 8:00	7/21/2011 17:00	7/4/2011 8:00
Understanding the Trace Wire Location Problem - Missing Trace Wire Segments	7/1/2011 8:00	7/1/2011 17:00	7/22/2011 8:00
Definition of Data Fields re: Geographic Location and Impact on Technology Choice	7/1/2011 8:00	7/14/2011 17:00	7/4/2011 8:00
Upgrading of Central Database at Engineering and records	7/8/2011 8:00	7/21/2011 17:00	7/11/2011 8:00
Development of Inventory User's Manual	7/15/2011 8:00	7/21/2011 17:00	7/18/2011 8:00
Development of Saved Queries for Technology Selection	7/15/2011 8:00	7/21/2011 17:00	7/18/2011 8:00
Technology Choices and Basic Parameters	7/1/2011 8:00	7/22/2011 17:00	7/1/2011 8:00
The GPR Solution	7/1/2011 8:00	7/12/2011 17:00	7/1/2011 8:00
Technology Basics and Mode of Use	7/1/2011 8:00	7/7/2011 17:00	7/1/2011 8:00
Applicability to Fiber Optic Conduits, Limitations, and Usage Rules	7/8/2011 8:00	7/12/2011 17:00	7/8/2011 8:00
The AT Solution	7/13/2011 8:00	7/22/2011 17:00	7/13/2011 8:00
Configuration of the AT Custom Configuration and Mode of Use	7/13/2011 8:00	7/19/2011 17:00	7/13/2011 8:00
Applicability to Fiber Optic Conduits, Limitations, and Usage Rules	7/20/2011 8:00	7/22/2011 17:00	7/20/2011 8:00
Selection of Preferred Method and Data Collection	7/25/2011 8:00	7/28/2011 17:00	7/25/2011 8:00
Selection Approaches	7/25/2011 8:00	7/26/2011 17:00	7/25/2011 8:00
Documenting field investigations	7/27/2011 8:00	7/28/2011 17:00	7/27/2011 8:00
Delivery of Training Session - Train the Trainer	7/29/2011 8:00	7/29/2011 17:00	7/29/2011 8:00

12. CONCLUSIONS

Based on these general guidelines for the usability and conditions of use of various technologies, some key conclusions can be made with regard to an implementation plan that would improve the ability of NJDOT to locate in a cost-effective and accurate manner, fiber optic (FOC) conduits:

- 1) **Computerized Segment-Level Database of All Facilities (Cables, Junction Boxes, Cameras, Connections, etc.):** The development of a detailed dynamically updated inventory of all conduit segments (Junction Box to Junction Box) and the Junction Boxes themselves is a high priority pre-requisite for the implementation of a rational FOC and other cable location program. The ability to identify, for every location, fields such as physical characteristics (diameter, length, material, depth of cover, start, end), and location characteristics (soil type/suitability for GPR, under asphalt/concrete/grass, contiguity to other utilities/clutter), as well as frequency of inspection is essential to the choice of method or accessories needed.

- 2) **The Standardization of (Improved) TW for All Future Conduit Designs:**
As shown in most of our tests, the most reliable method of locating conduits remains the TW Method. However, in order to use the method in the most effective manner, the latest approach to TW should be implemented, including some of the promising techniques identified in this study such as diodes (RFID-like operation) placed on the trace wire at regular intervals, which would remove the requirement for a direct connection. Also, if the traditional TW is used, the requirement for a connection of the TW through the manhole cover should be a standard part of contract specifications in order to facilitate access to the trace wire by removing the necessity to open the manhole cover.

- 3) **The Purchase of a GPR Uunit with a GPS capability:** GPR seems to be a part of the FOC location solution, given the large soil suitability percentage coverage in the state of New Jersey and the acceptability of the diameter to depth ratio for a significant percentage of the 580+ miles of conduits. Nevertheless, the availability of a quality database as described in 1) will help avoid false starts and GPR operator/unit visits where they are not warranted, and will “target” areas most suitable for GPR use. The GPS capability would help complete location coordinates, and improve the accuracy of the database.
Also, *the purchase of cameras with a GPS capability* for operators to capture the location and inner structure of a JB, after opening a manhole cover, including the presence or absence of TW, is recommended for field use.

- 4) **The Inclusion of Acoustic Testing (AT) in the Technology Portfolio:** AT has performed very well in the testing presented in this work, particularly under grassy or unpaved surfaces. Its accuracy makes it a solid candidate for future use, particularly when GPR is not suitable (diameter to depth ratio, soil or clutter causes), and TW is missing.

- 5) **The Retrofitting of Trace Wires Using Snakes:** Although 26+ miles of conduits with missing trace wires were inventoried, it is expected that many more segments do not have functioning trace wires. For short span non-metallic segments in cluttered areas, the use of snakes accompanied by a trace wire tape would be justified for conduits with a high inspection frequency..

APPENDIX A: Minutes of Meeting NJDOT Jan. 7, 2010 (Initial Meeting)

Present: Bob Sasor, Al Katz, Edip Niver, Fadi Karaa, Mark Renner, William Brantley and Marc Smith

Location: NJ DOT Offices in Cherry Hill, NJ (Traffic Operations South).

1. Members of project team and NJDOT group needing solution were introduced.
2. Objectives of the project were reviewed:
 - a. Examine and understand the NJDOT's fiber optic network and related conduit system with regard to the requirements for indentifying conduit locations.
 - b. Investigate possible technologies for locating buried conduits including Trace Wires (TW and its related embodiments such as Mule Tape), AT, GPR, GPSON, EMI and other methods that may be discovered.
 - c. Determine the preferred method for locating the conduits based on the required accuracy and performance, ease to implement, effort to apply, cost effectiveness and reliability.
 - d. Develop a systematic plan for the implementation of the preferred conduit location system.
3. Planned tasks were discussed:

TASK	MONTHS											
	1	2	3	4	5	6	7	8	9	10	11	12
Phase I Literature Search												
1. Initial Meeting and Presentation		X										
2. Study Conduit Location Problem												
3. The Trace Wire Evaluation												
4. Acoustic Transmission Evaluation												
5. Ground Penetrating Radar Evaluation												
6. Ground Penetrating Sonar Evaluation												
7. Electro-Magnetic Impedance Evaluation												
8. Determine Preferred Method												
9. Plan for Implementation												
10. Documentation and Final Report	M	M	Q	M	M	Q	M	M	D/F			
11. Training												

4. Issues associated with Task 2 and the present trace wire system were discussed. Among these were the access to manholes/cabin, lack of availability of electric power in manholes, manholes are often filled with water.

5. Physical constraints were discussed. The spacing between junction boxes is 200 to 2500 feet with ducts typically of 4" diameter plastic (PVC) or 3" diameter metallic.
6. The present trace wire system transmits at 8 MHz or 33 MHz and typically has an output power of 8 watts, but is not permanently connected.
7. Possible solutions were discussed that might circumvent the power problem. The use of remotely activated trace wire transmitters that could be turned on only when needed was suggested. The possible use of buried "balls" containing battery power transmitters with limited life was also suggested.
8. The problem of missing or broken trace wires was discussed. Acoustic alternatives to radio frequency trace wires were discussed. Techniques for detecting breaks in trace wires using a TDR scope were discussed.
9. Ground penetrating radar was introduced as a possible solution for identifying conduits. The problem of clutter, multiple conduits and piping in the same area was also noted.
10. It was agreed that the team would send representatives to evaluate typical conduit sites and the present trace wire system. NJDOT agreed to identify appropriate locations for visits.

APPENDIX B: Bibliography - Literature Search

This literature search was undertaken along many dimensions, including the range of problems and solutions for the location of utilities, as well as the success/applicability and limitations of various technologies (Ground Penetrating Radar, Acoustic Transmission, etc.) that are under study. Our preliminary findings are that the most generally accepted non-invasive technology to tackle the missing trace-wire fiber-optic conduit problem is the Ground Penetrating Radar (GPR). The validation of the usefulness of the technology was demonstrated in some of the early references listed below. A pre-cursor of the current GPR technologies that we plan to investigate and test was described at length in (GPR Theory and Applications, Michiguchi et al. [8]), on the development of a “subsurface radar system for imaging buried pipes” capable of reconstructing clear pipe images under unfavorable conditions such as large attenuation rate of the radio waves propagating in soil. The system was successfully applied to imaging of buried metallic and plastic pipes, such as a steel pipe buried at a depth of 2.5 m and a plastic pipe at 1 m, both 6.5 cm in diameter, which were clearly reconstructed as color images. GPR was further investigated: 1) as a standalone technology, by evaluating means to improve GPR accuracy via image reconstruction techniques such as tomographic reconstruction applied to environments with multiple buried conduits and pipes, where GPR was successfully used to identify multiple conduit locations (GPR Theory and Applications, Pettinelli, et al [5]). The applicability of GPR technology in various soils and under various conditions was further discussed in (GPR Theory and Applications, Bernhold et al [71]). 2) in conjunction with another support technology (Location of Utilities, Young [2]). Although limitations of the technology are mentioned, the use of combined technologies can in some cases be the right approach to detection of buried conduits in difficult cluttered environments.

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APPENDIX C: Report on visit to communication hub on RT. 295 north at Milepost 43, February 24, 2010

Present: NJIT: Fadi Karaa, Edip Niver and Magee Hanna, TCNJ: Allen Katz and Tom DeVito, NJDOT: Louis Ranson and Keith Kirby.

The purpose of the visit was to 1) view and investigate conduits containing and carrying fiber optic cables and 2) view and evaluate the trace wire system that was operational at this site. The following figures document the visit.



Figure 1: View of site and manhole that provides access to fiber optic conduits. Orange lines indicate the path of two conduits entering and exiting the manhole.



Figure 2: View of manhole with cover removed. Three of the four PVC conduits entering the hole can be seen.



Figure 3: Closer view of conduits on one side. White wire entering one of the conduits is a trace wire. A small transmitter was connected to this wire to generate a signal that could be detected through the earth.

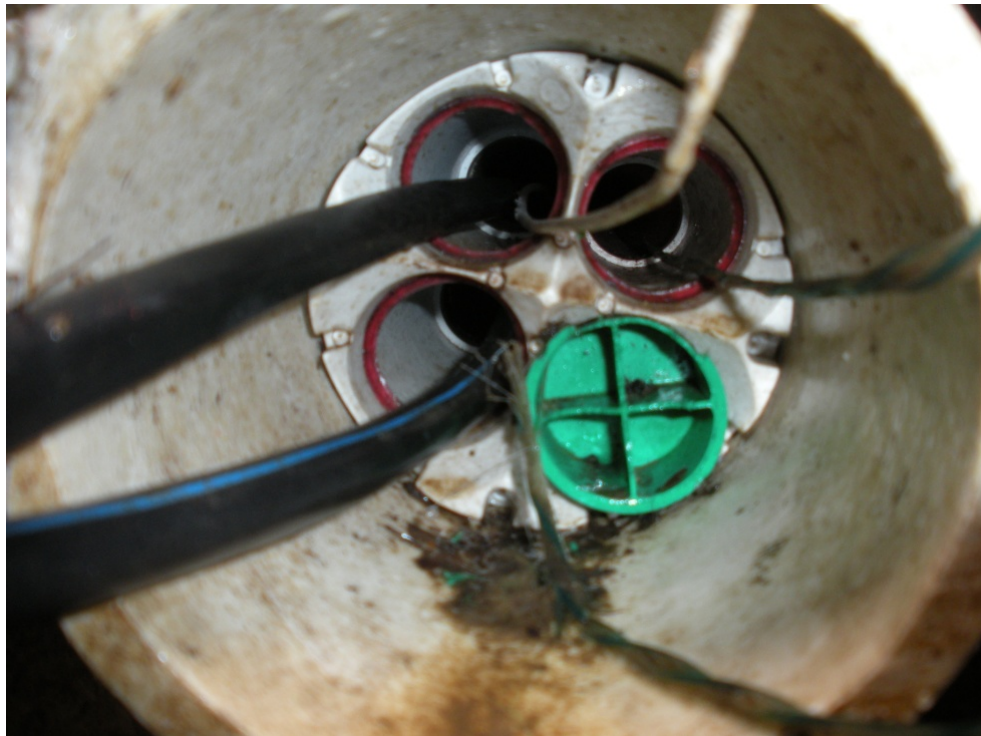


Figure 4: View looking into a conduit, showing sub-conduits each carrying a fiber optic cable. The trace wire enters one of these sub-conduits.



Figure 5: Trace wire receiver being used to detect conduit. The trace wire's signal could be clearly detected.



Figure 6: Trace wire receiver display shows an indication of signal level and wire location.

APPENDIX D: Report on visit to communication hub on RT. 295 North at Milepost 43 on April 20, 2010

RE: GPR Fiber-Optic Conduit Detection Demonstration

Present: TCNJ: Allen Katz and Tom DeVito, NJIT: Fadi Karaa, and GSSI: Peter Masters.

A demonstration of the [Geophysical Survey Systems, Inc. \(GSSI\) Utility Scan Ground Penetrating Radar \(GPR\)](#) took place at the same site where the Trace Wire technology was previously tested. The demonstration was conducted by Peter Masters, GSSI's technical representative.

The GPR product is a unit installed on a pushed *lawnmower* style cart – see Figure 1. It appeared relatively easy to use, and for the test was operated at a base frequency near 400 MHz. In favorable conditions it can locate conduits buried up to 12' deep. Given assumptions of soil type and condition, a calibration of the unit can be performed at a location of known conduit depth (e.g. junction box location), by making sure the depth of the conduit as “read” on the GPR screen matches the known depth.



Figure 1: The GSSI GPR is pushed similar to a lawnmowers

The operation of the GPR unit is as follows:

1) Starting at or near a known point (for example a junction box), the identification of the conduit can take place by driving forward and backward (pushing and pulling) the equipment in a direction perpendicular to the expected path of the conduit. The location of the conduit is derived when a cursor, which moves as the equipment moves, is exactly positioned at the highest point of a cone-shaped curve reproduced by the GPR response – see Figure 2. (During the demonstration, this identification point matched within an inch of a marker previously identified by the trace wire-based surface detector).

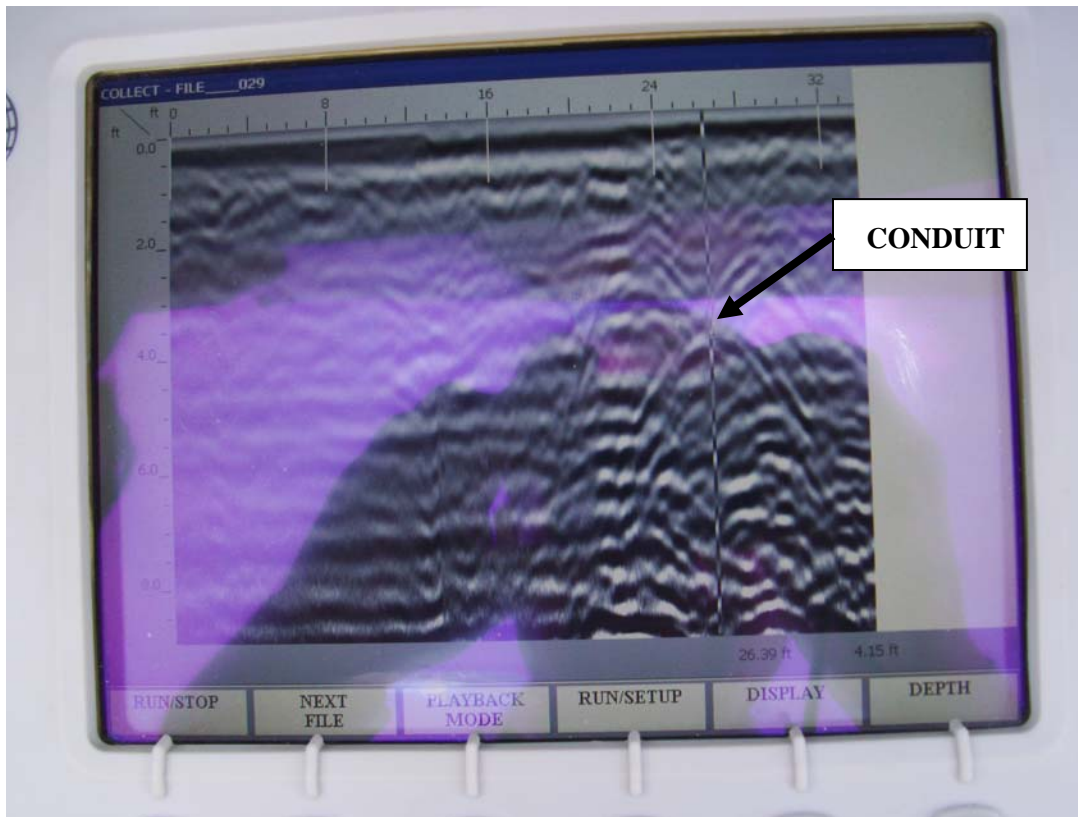


Figure 2: GPR display showing location of the fiber conduit.

2) The unit can then be driven parallel to the conduit for a few feet, and then rotated by 90 degrees to cross again the surface “horizontal” conduit location, in order to get a clear baseline for the conduit location. Both horizontal and depth readings can be ascertained from each “cycle”.

3) This process can be repeated while allowing the distance covered in each cycle to be increased as the process accuracy is established, in order to cover more length and increase throughput.

During the demonstration multiple conduits of known existence were identified (AC power line, flood control pipe), as well as trench limits and the water table. Figure 3 shows the GPR unit during the testing. Figure 4 shows the display with multiple buried objects present. The cursor

is over a trace corresponding the fiber optic conduit, which can be identify by its relative depth (height of the cone relative to the other cones) and the relative width of the cone.



Figure 3: GPR in test operation.

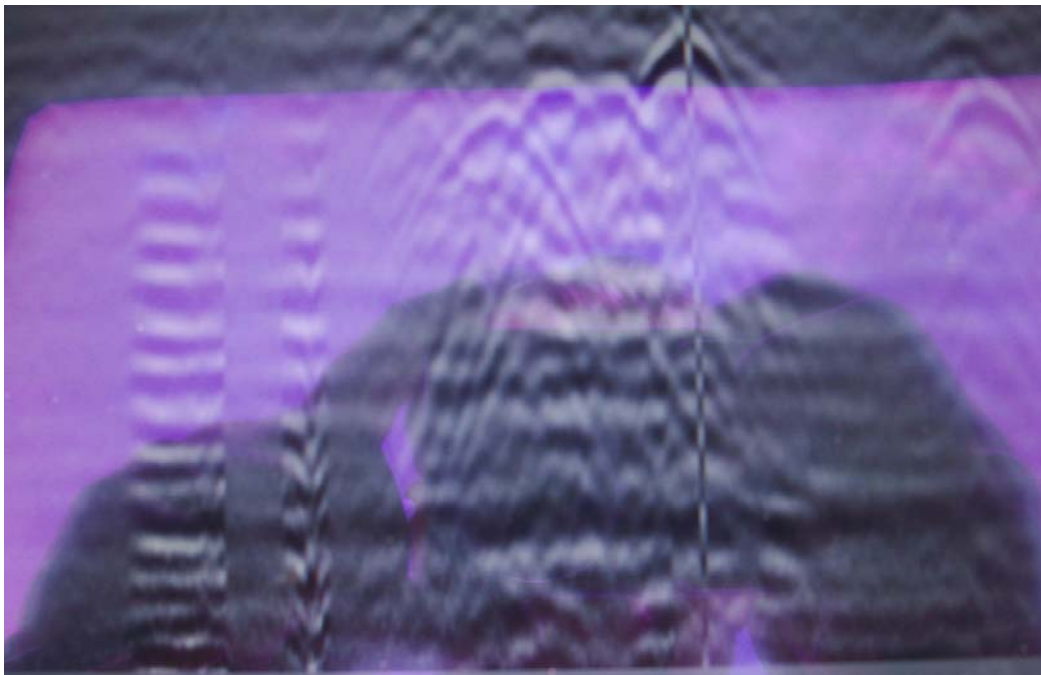


Figure 4: GPR display with multiple buried objects shown.

Observations/Conclusions

The demonstration established the ability of GPR to identify multiple buried utilities, but there was concern regarding its ability to distinguish between such utilities in cluttered areas. The difficulty in distinguishing between co-located multiple objects could be a problem in applying GPR technology. It was also clear (location of the water table) that GPR technology would not function properly under severe flooding or high water table conditions.

APPENDIX E: Report on visit to communication hub on RT. 295 north at Milepost 43 on May 5, 2010

RE: Evaluate Acoustic Transmission System

Present: TCNJ: Allen Katz, Dan Chokola and Tom DeVito, NJIT: Fadi Karaa and Edip Niver, and NJDOT: Robert Sasor and Lou Ranson.

The purpose of this visit was to evaluate an acoustic transmission system that could be used to identify the location of underground conduits when trace wires are not present. The concept behind the acoustic transmission (AT) system is to use the actual conduits as the transmission medium of an acoustic signal, in the same way the trace wire (TW) system uses wires. In the TW system, a radio frequency (RF) signal is sent down wires that are run through a conduit. This RF signal is detected at the surface with a radio receiver and its relative intensity used to locate the position of the conduit. The acoustic signal as the TW RF signal will radiate into the soil surrounding the conduit and should be detectable at the surface. In the case of the AT system, the sound level is detected and its relative intensity used to locate the conduit. Since the conduit is used to carry the acoustic signal, no trace wires are required. A block diagram of an AT system is shown in Figure 1.

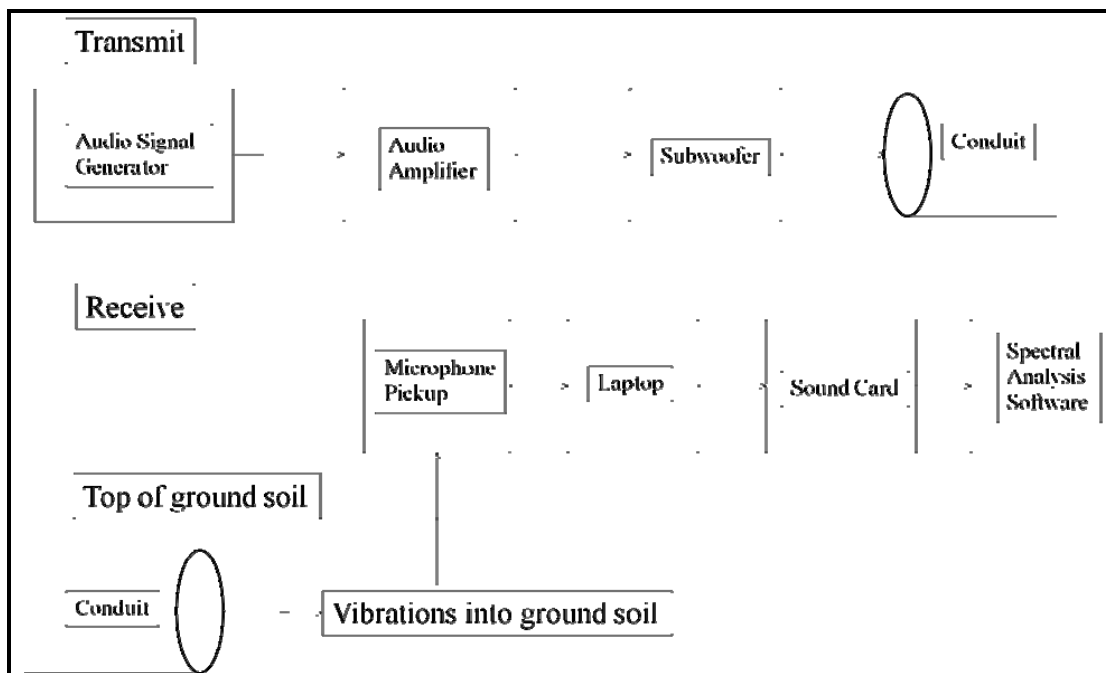


Figure 1: Block diagram of AT system. The top of the diagram shows how the acoustic signal is generated and applied to the conduit. In the bottom half of the diagram, the conduit is shown underground and the system for detecting the acoustic signal emanating from the conduit is illustrated.

To test this concept a prototype AT system was assembled. This system consisted of an audio signal generator, audio power amplifier, subwoofer, subwoofer enclosure, PVC connector, and brackets for attachment to the conduit. We planned on directly connecting the acoustic sending transducer (subwoofer assembly) to the conduit itself. In doing so, the vibrating sound from the back panel of the subwoofer enclosure would directly vibrate the conduit. A frequency in the range of 10 to 300 Hz was selected for testing as it is known that the attenuation of soil to sound waves is low in this frequency range, and components were also readily available for this range. The specific acoustic frequency used for transmission was determined experimentally.

A microphone attached to a rod was used to pick up the acoustic signals. The rod was inserted into the earth to achieve better detection of the soil borne vibrations. The microphone was also insulated to isolate it from air borne noise. The microphone was connected to the input of a sound card in a laptop computer and the signals processed and analyzed with spectrum analysis software. The transmission part of the AT system is pictured in Figure 2. The receiver system is shown in Figure 3 and the screen display in Figure 4. A list of equipment is given in Table 1.

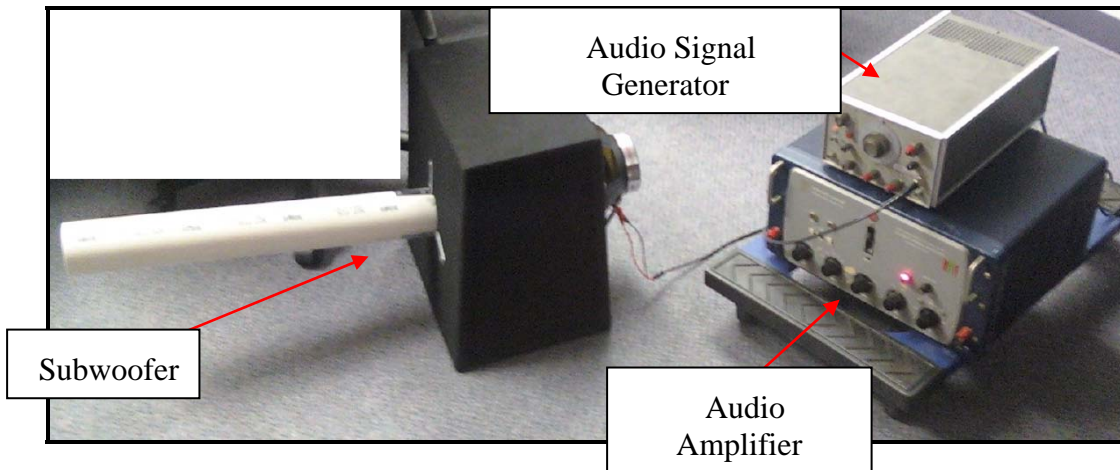


Figure 2: Audio signal generator, audio power amplifier, subwoofer and subwoofer enclosure used to acoustically excite the conduit.



Figure 3: Laptop computer and microphone (center) used to detect acoustic signals

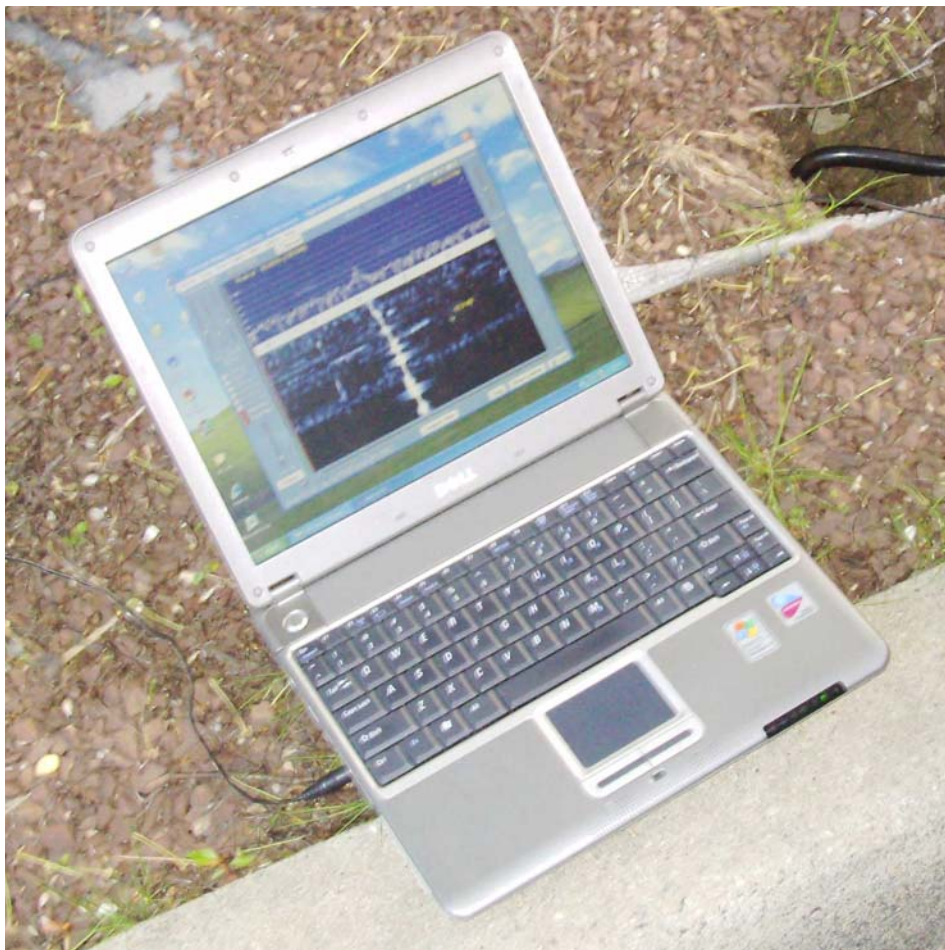


Figure 4: Spectral display of acoustic signal as seen on a laptop computer.

Table 1: List of Equipment/Materials

Description	Make/Model
Amplifier	Krohn-Hite/UF101A
Frequency Generator	Krohn-Hite/5200
12 inch Subwoofer	Scosche
12 inch Subwoofer box	Scosche
Shelving Brackets (3)	N/A
3 inch PVC T-connector	N/A
10 feet of speaker wire	N/A
Laptop computer	Dell
Portable microphone	Gigaware/33-119
Spectrum Analysis	Spectrian

Upon arrival at the site and initial inspection of the conduit in the manhole, it became apparent that the conduit had a diameter for which the prototype was not designed. We had expected a 3” PVC connection, but inspection revealed a 4” PVC conduit was in use in the manhole. To work around this problem, we were still able to fit the 3” connection inside the conduit opening instead of around it to achieve a makeshift coupling. With our connection in place and setup complete, we were able to begin testing.

For our initial testing we set up our microphone pickup directly above the conduit, and about 20 feet from the manhole. The initial readings did not show much attenuation even when going up to 16 feet to the right of the conduit, while maintaining the 16 foot distance, compared to the 18 inches to the left of the initial spot. All spots that were checked at this distance, showed a minimal loss in level at the 65 Hz frequency that was used. The indicated level ranged from 0.2 dB at 18 inches left to -2.0 dB at 16 feet to the right. At this initial location we were only able to obtain about a 0.4 dB variation in level near the conduit location, which was not sufficient for us to clearly pinpoint the position of the conduit.

The next test location was about 528 feet from the manhole location. At this location, we saw more variation in signal level with microphone location, and were able to locate the conduit within a few inches. The 65 Hz signal was -19 dB, when above the conduit as indicated by a ground marker. At 1.5 feet to the left and to the right of this spot, the signal was detected at -22 and -25 dB respectively. The noise from passing traffic was at a constant -35 dB. At this location, we also varied the frequency to see if 65 Hz was the optimum test frequency. At 60, 70, and 200 Hz, we were only picking up the signals at -30 dB at the marker flag, confirming our original selection of 65 Hz as the most suitable test frequency – see Figure 5.

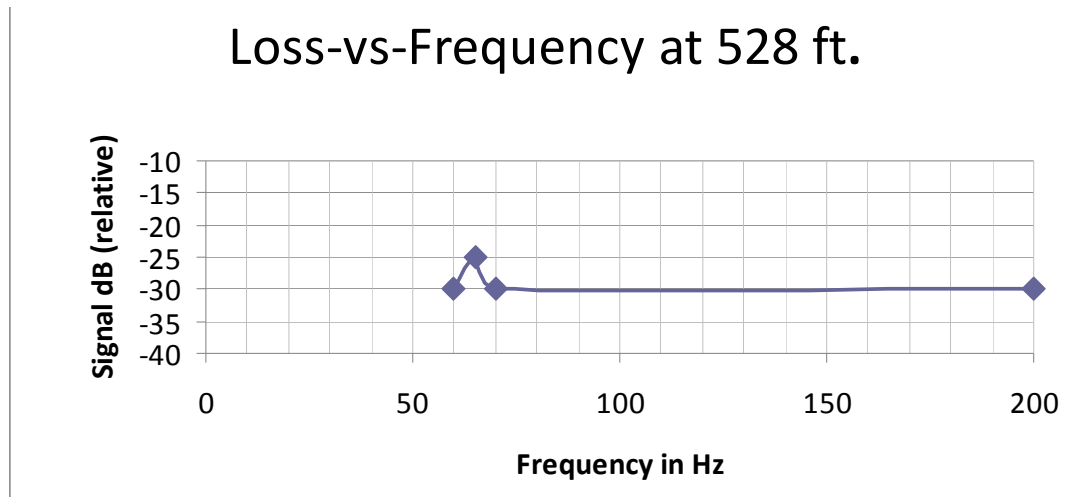


Figure 5: Variation of signal level with frequency at 528 ft. from the initial manhole

We then moved to a further location to determine the distance limits of the system. For this next location, we moved another 528 feet for an approximate distance of 1,056 feet from the manhole starting point. Using existing conduit markers (flags) as a reference, we checked again the variation in level transverse to the conduit. At the flag location, we were picking up a -20 dB 65 Hz signal. At 1.5 feet to the left, the signal was -22 dB and 1.5 feet to the right -24 dB. All three of the readings were again above a constant noise level of -35 dB.

We moved an additional 40 feet to make another signal level measurement, which was found to be -26 dB at the marker flag. We moved to two more locations; both were 40 feet further than the last. At these spots we were able to pick up the signal at about -28 and -31.5 dB over the conduit respectively, only about 6 dB above the noise floor. Our test results are summarized in Table 2, next page.

Table 2. Summary of Measurements.

Fr eq	Level in dB	Distance	Notes
65	0.0	20 ft from manhole center over the conduit	rod 2" in ground
65	-1.5	20 ft from manhole center, 11 ft right of the conduit	rod 2" in ground
65	-0.6	20 ft from manhole center, 11 ft right of the conduit	rod all the way in ground
65	-2.0	20 ft from manhole center, 16 ft right of the conduit	rod 8" (half way) in ground
65	0.0	20 ft from manhole center, 18" left of the conduit	rod half way in ground
65	0.2	20 ft from manhole center, 9" left of the conduit	rod half way in ground
65	0.4	20 ft from manhole center over the conduit	rod half way in ground
65	0.3	20 ft from manhole center, 9" right of the conduit	rod half way in ground
65	0.2	20 ft from manhole center, 18" right of the conduit	rod half way in ground
65	0.2	20 ft from c manhole enter, 27" right of conduit	rod half way in ground
65	-22.0	approx. 528 ft, 1.5 ft right of flag	rod all the way in ground
65	-19.0	approx. 528 ft. at marker flag	rod all the way in ground
65	-25.0	approx. 528 ft, 1.5 ft left of flag	rod all the way in the ground
		These readings were all above the noise threshold of -35 dB	
20 0	-30.0	on the marker flag at 528 ft.	rod all the way in ground
70	-30.0	on the marker flag at 528 ft.	rod all the way in ground
60	-30.0	on the marker flag at 528 ft.	rod all the way in ground
65	-22.0	approx. 1,056 ft, 1.5 ft left of flag	rod all the way in ground
65	-20.0	approx. 1,056 ft, at the flag	rod all the way in ground
65	-24.0	approx. 1,056 ft, 1.5 ft right of flag	rod all the way in ground
65	-26.0	approx. 1,096 ft. over the conduit	rod all the way in ground
65	-28.0	approx. 1,136 ft. over the conduit	rod all the way in ground
65	-31.5	approx. 1,176 ft. over the conduit	rod all the way in ground

After collecting the data, we discovered that the conduit was not laid out as we originally believed. The conduit that we were testing ran from the initial manhole across the northbound side of the interstate to another manhole. At this location the conduit split into seven others. This lead us to believe that our AT system was working quite well as the signal was running across the interstate, through the barrel of a manhole (without a continuous conduit connection), and then down seven conduits, one of which was the one we were testing along.

Conclusions

These tests demonstrate the viability of acoustic transmission for locating underground conduits. Our solution appears to not only fulfill requirements for location accuracy and distance, it is practical to implement, cost effective, and should work with both underground metallic and plastic conduits. Even though we started with an incorrect conduit size and the fact that we were unaware of the presence of a second manhole that connected to seven additional conduits, the AT system we developed proved to work.

APPENDIX F: Report on test conducted at TCNJ stadium on May 21 and 27, 2010

RE: Evaluate Acoustic Transmission System (AT)

Present: TCNJ: Tom DeVito and Dan Chokola

The purpose of this visit was to further evaluate an AT system that could be used to identify the location of underground conduits. The concept behind the AT system has already been discussed in a previous report.

Upon arrival at the site and initial inspection of the conduit, it became apparent that the conduit had a diameter for which the prototype was not designed. We had set up the prototype with a 3" PVC connection and had to add a 3" to 2" PVC connection to allow for the 2" conduit, which was located in at underground junction box (similar to a small manhole) at the TCNJ stadium. With our connection intact and setup complete, we were able to begin our testing.

For our testing we set up our microphone pickup directly in line with the junction box and conduit about 300 feet from it. We decided to begin our testing with a frequency of 157 Hz after "chirping" the audio signal generator and seeing that this frequency was being picked up well. After setting our reference point to what was thought to be the center of the conduit, we began taking measurements transverse to the path of the conduit to determine if we could locate that conduit's position. We took measurements every 6 inches out to 5 feet left and right of the reference point. The initial measurement showed a level of -60.3 dB (arbitrary reference used by the receiver system to which all dB measurements are referenced). When taking measurements (every 6" over a 10 foot distance), we had a variation of 11 dB. The lowest level was -58 dB and the highest was -69 dB as shown in Figure 1.

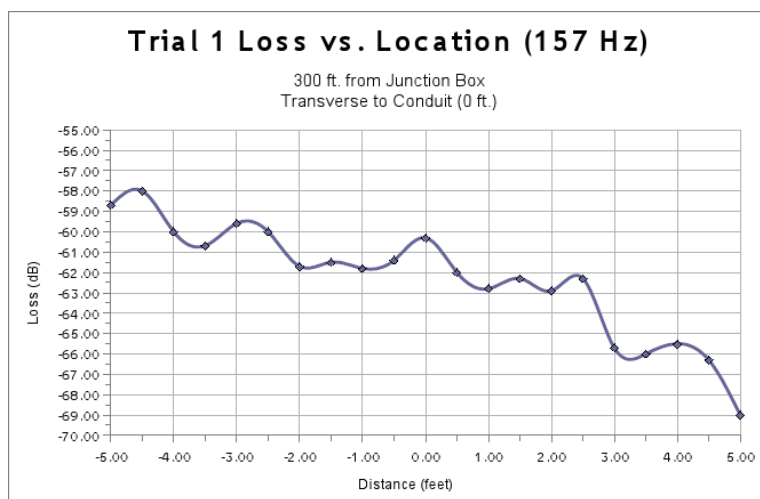


Figure 1: Loss vs Location tested at 300' from the manhole at 157 Hz.

These results seemed to indicate that our initial reference was in error. We then readjusted the reference point (highest signal level) to a position that appeared to be over the conduit. With the new reference point, we took another set of data over a range of 10 feet at the same frequency of 157 Hz. With the new measurements, the maximum variation was only 4.2 dB and a clear peak was distinguishable. This result can be seen in the figure.

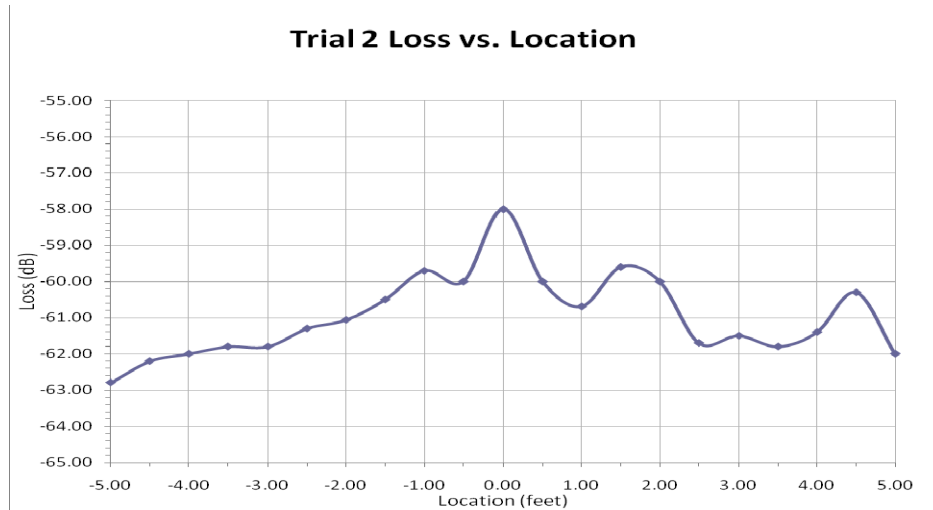


Figure 2: Loss vs location at 300' from the manhole at the new reference point. 157 Hz.

Using the same reference point, we took a third set of data showing how signal level varied with frequency. We sweep the frequency from 30 Hz to about 300 Hz. The levels at all frequencies above 150 Hz are well below -70 dB. We found that 65 to 68 Hz had the least attenuation. These results are shown in Figure.

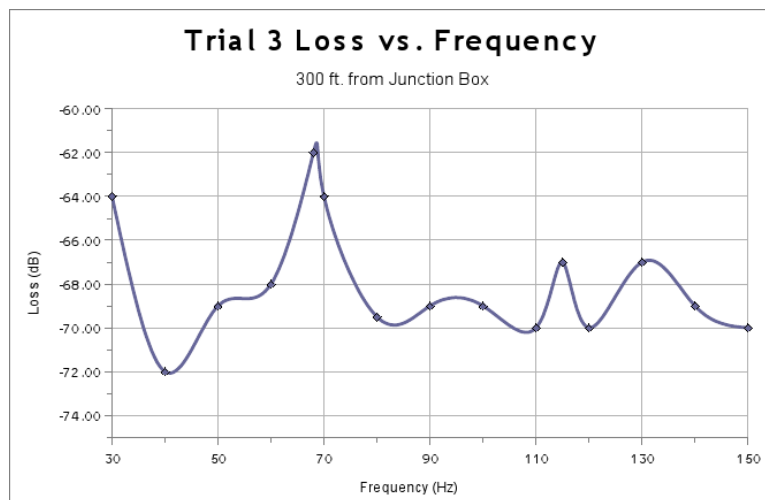


Figure 3: Loss vs. frequency for test at 300' from the manhole.

We then took another set of transverse levels using 65 Hz. These measurements produced the highest signal levels. The loss varied from -51.3 to -53.5 dB. Before we could complete a full set of measurement, a problem developed with the test system. It turned out that one of the wires on our woofer (acoustic driver) vibrated loose. We were able to get 13 measurements to include the initial reference point before the failure.

A new woofer was procured and the AT system put back together. On 27 May we were able to complete the repair of the AT system and return to TCNJ to conduct further testing. For these tests, we set up our microphone pickup directly in line with the small manhole and conduit, and at about 300 feet from the manhole. We decided to continue testing where we left off the on the 21st. We started at a frequency of 68 Hz and a reference position where we thought the conduit to be centered. We again took measurements every 6 inches out to 5 feet left and right of the reference point. The initial measurements showed an reference signal level of -56.6 dB. Over the 10 foot measurement distance, we had a variation of 3.5 dB, with the lowest level -56.6 dB. This result is shown in Figure 4.

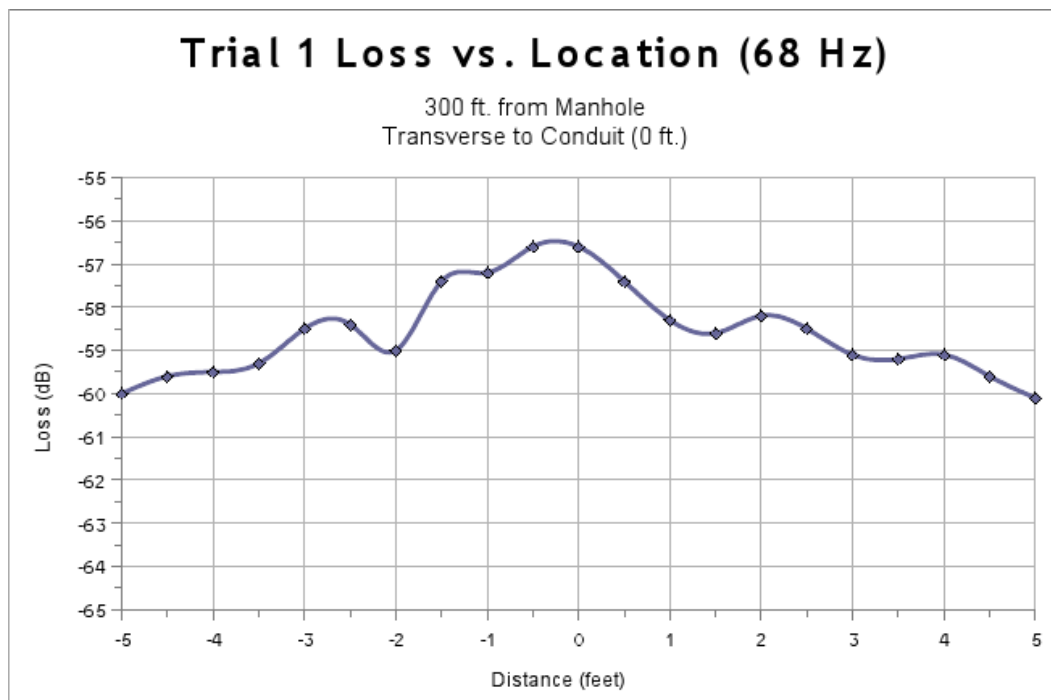


Figure 4: Loss vs location tested at 300' from the manhole at 68 Hz.

A frequency sweep was taken to confirm we were using the best frequency. We also found that when checking for a signal around 15 feet from the conduit on either side, we could detect only noise, which was at a level of about -70 dB.

Using the same reference point, we sweep the frequency from 54 to 76 Hz. 65 Hz had the strongest response, with a reading of -52.7 dB. These results can be seen in Figure 5.

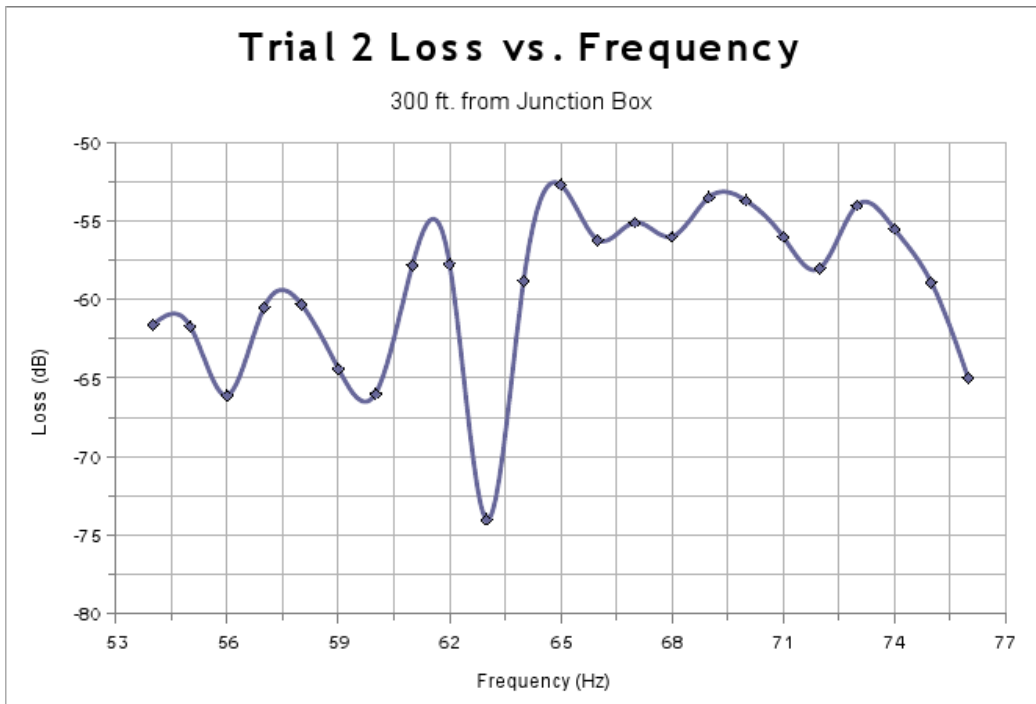


Figure 5: Loss vs. frequency at the reference point 300' from the manhole.

Another trial was run with a 65 Hz signal. These measurements looked promising from the start. The signal level varied from -52.7 to -55.4 dB, and showed a good amount of isolation around the reference point. These results can be seen in Figure 6.

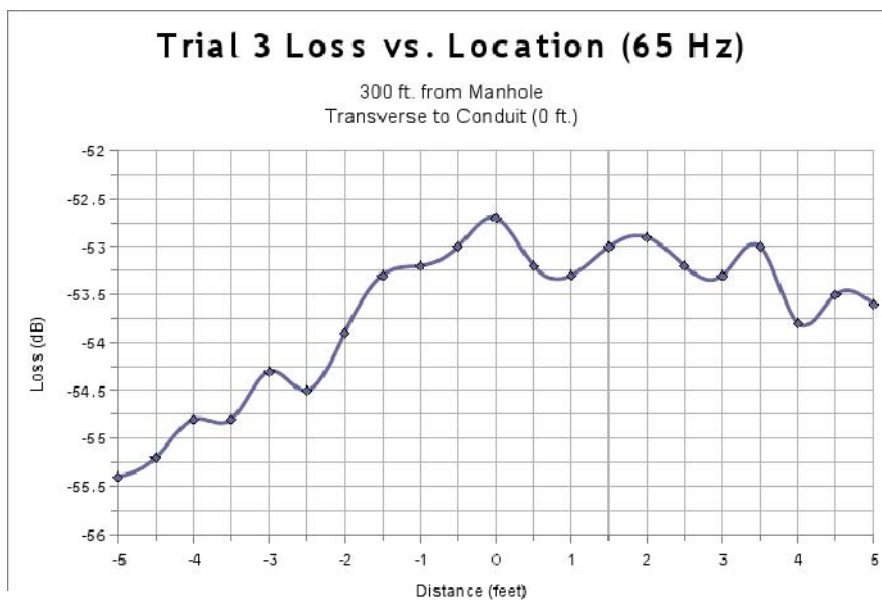


Figure 6: Loss vs. location at 300' from the manhole at 65 Hz.

A comparison of the results of the three frequencies tested can be seen in Figure 7. From this graph, it can be seen that the lowest frequency (65 Hz) had a better signal level and thus maybe better able to penetrate the soil for a further pick up. The highest frequency of 157 Hz, although at a lower signal level, still distinctly shows the location of the conduit.

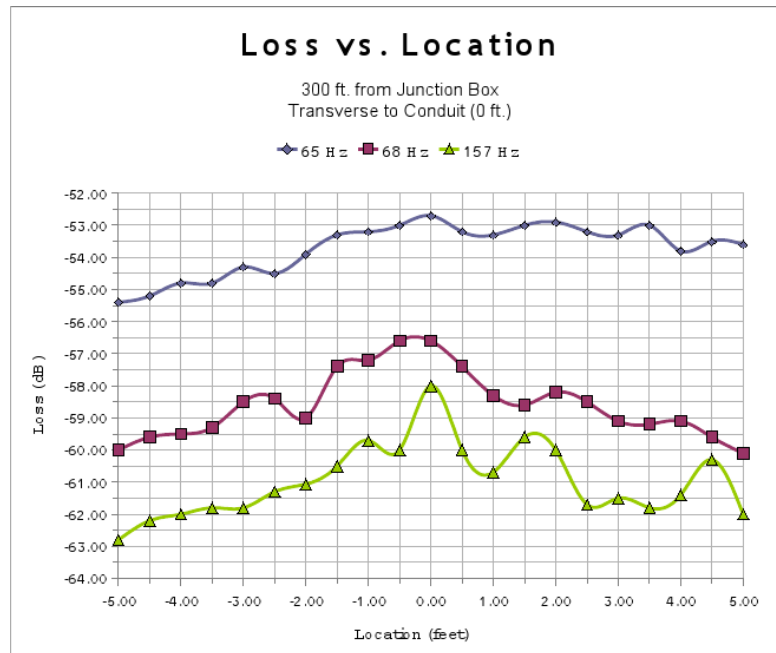


Figure 7: Combined data showing the 65, 68, and 157 Hz frequency results.

The combined frequency sweep data (30-150 Hz) can be seen in Figure 8. It is seen that greatest signal levels are in the frequency range from 65 to 75 Hz. Outside this range, there seems to be a significant drop off in signal level.

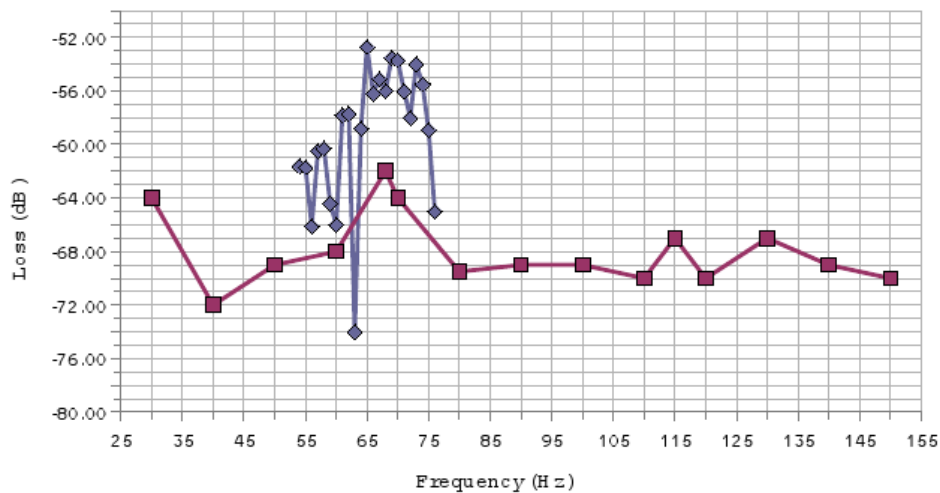


Figure 8: Combined data showing the sweep of frequencies from 30 to 150 Hz.

Conclusions

The AT system continued to show promising performance, but further testing is needed. The system met our goal accuracy (locate conduit within +/- 0.5 feet). It is practical to implement, cost effective, appears to work with both underground metallic and plastic conduits. All of these traits are important to identify buried conduits, resulting in less accidental damage, avoiding major problems including the loss of any fiber optic cable and the critical information being carried by them.

APPENDIX G: Report on visit to site on I-295 median at Milepost 43 on June 7, 2010

RE: Evaluate Acoustic Transmission System (AT)

Present: TCNJ: Dan Chokola, and Tom DeVito; and NJDOT: Lou Ranson.

The purpose of this visit was to conduct further testing at the I-295 test site. During the last visit this site, the conduit to be located was vibrated indirectly through a second manhole in the median. This condition may have affected the range of the AT system. During this visit the conduit to be located was vibrated directly from the manhole in the median. A secondary purpose of the visit was to drive the manhole cover in order to evaluate the usefulness of the AT system for locating conduits when the manhole cover is not removed.

When we arrived, we observed that the ground was much harder and dryer than during the previous visit. During the previous testing, the soil was damp and softer due to previous rainfalls. This condition may have had an effect on soil attenuation. After the initial preparation and setup was completed, the conduit was directly driven at 65 Hz. The signal was detectable; however, it did not produce a distinct peak where the center of the conduit was expected. The frequency was doubled to 130 Hz, which did produce a well-defined peak that made the conduit easier to locate. Data was then gathered in 300 foot intervals from the manhole. At each 300 foot site, a microphone was placed every 6 inches along a 15 foot wide line perpendicular to the conduit and levels were recorded in dB (referenced to an arbitrary level set by the receiver).

Data was first gathered 300 feet from the manhole. The 130 Hz signal measured was -53 dB at the reference point (the expected center of the conduit). The measured results for this location are displayed in Figure 1.

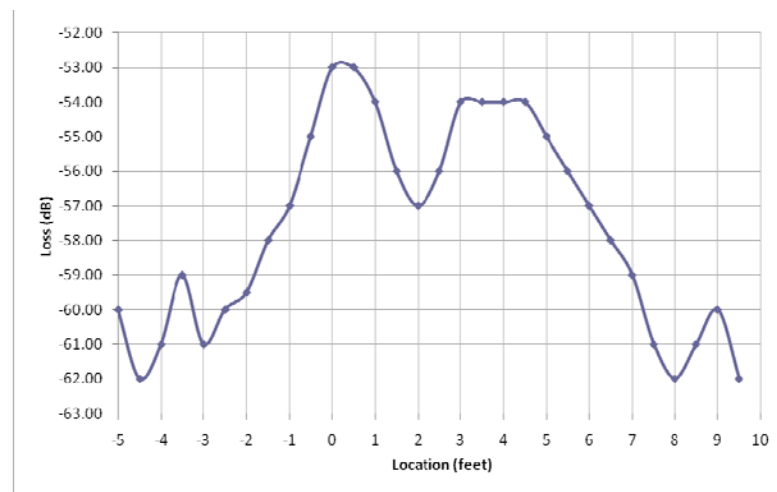


Figure 1: Loss vs. distance from conduit at 130 Hz and 300'.

This data shows that the conduit location was identified very distinctly with a sharp peak present at the reference point. A second peak (around 4 feet from the reference) is also shown. It is

believed this second peak is due to a second conduit that runs parallel to the driven conduit. It is assumed to have been vibrated through the concrete wall of the manhole. Even though this second conduit was vibrated indirectly, it could still be located with similar accuracy to the driven conduit. The data changed 9 dB from the reference at -53 dB to the furthest point measured at -62 dB.

Measurements were next taken 600 feet from the manhole and can be seen in Figure 2. At this location the measurements show a change of 13 dB, from -60 to -73 dB. At this distance the second conduit is still running parallel to the driven conduit, although the two have diverged by approximately a foot. Both conduits can still be located to within about 6 inches. It should be noted that after this location, the secondary conduit diverged into another manhole where it appears to terminate.

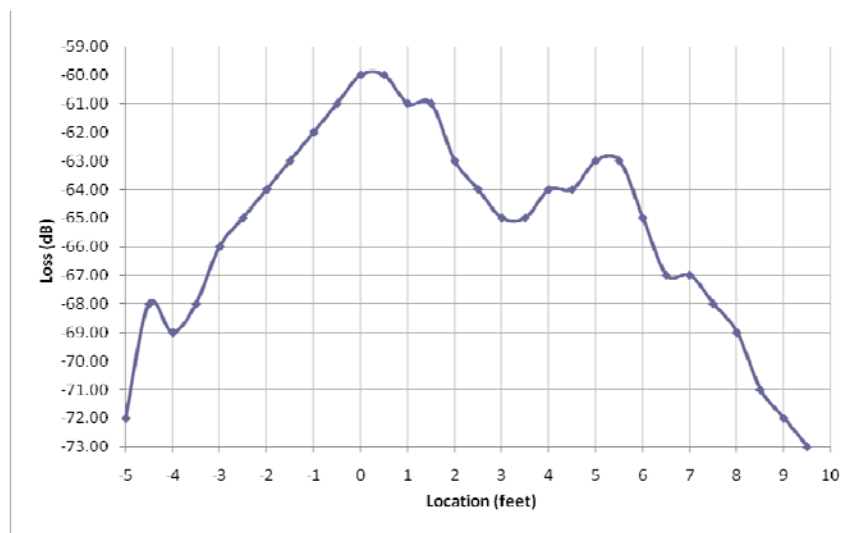


Figure 2: Loss vs. distance from conduit at 130 Hz and 600'.

Moving 900 feet from the manhole, the driven conduit could still be located. As only one conduit was present, the microphone was only swept over a 10 foot swath. The data again showed a distinct peak. The signal level varied 11 dB from -64 to -75 dB. The noise level was around -70 dB making accurate measurements difficult. This noise was primarily due to traffic on the adjacent highway. It was possible to make measurements below this level by waiting for traffic to die down at which times road noise was at a minimum (< -75 dB). Again the conduit could be located to within about six inches, as illustrated in Figure 3.

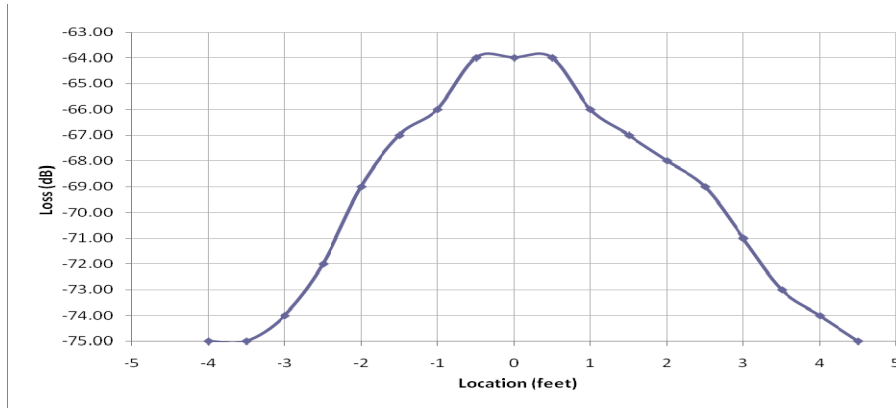


Figure 3: Loss vs. distance from conduit at 130 Hz and 900'.

At 1200 feet from the manhole, measurements were again taken and are shown in Figure 4. At this distance the measurements became very difficult as the signal level was just about at the noise level. By waiting for lulls in the traffic, 5 data points were obtained. From this data it was still possible to locate the conduit to within about 6 inches. No measurement was made beyond 1200 feet from the manhole due to the expected poor signal to noise ratio.

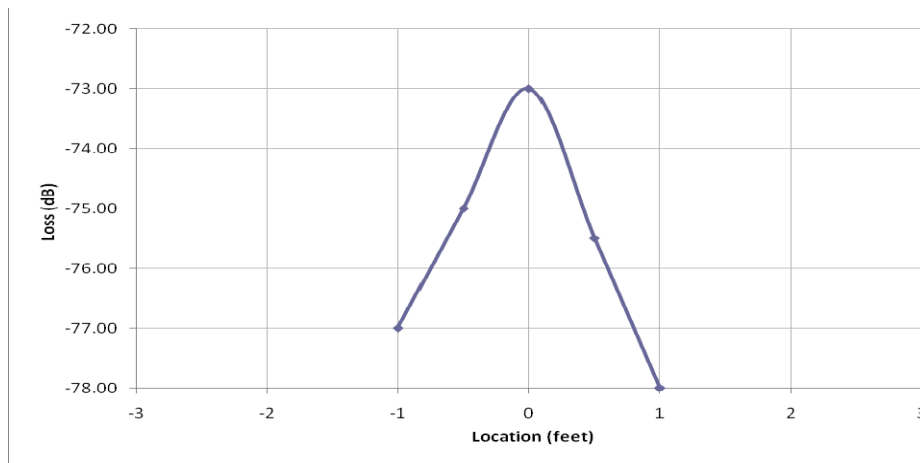


Figure 4: Loss vs. distance from conduit at 130 Hz and 1200'.

We then returned to the manhole and the cover was put back in place over the hole. The cover was driven by placing the speaker on top of the cover. 65 Hz and 130 Hz were used. Measurements were taken in 150 foot increments and over 15 foot wide perpendicular swaths as before.

Measurements at 65 Hz, 150 feet from the manhole were first taken. The signal ranged from -40 to -48 dB when again measuring every 6 inches over a 15 foot path. The results, in Figure 5, show that both conduits can be identified, although without the sharp roll off observed with the direct connection at 130 Hz. A number of smaller peaks but with a steady roll off of the signal are also seen.

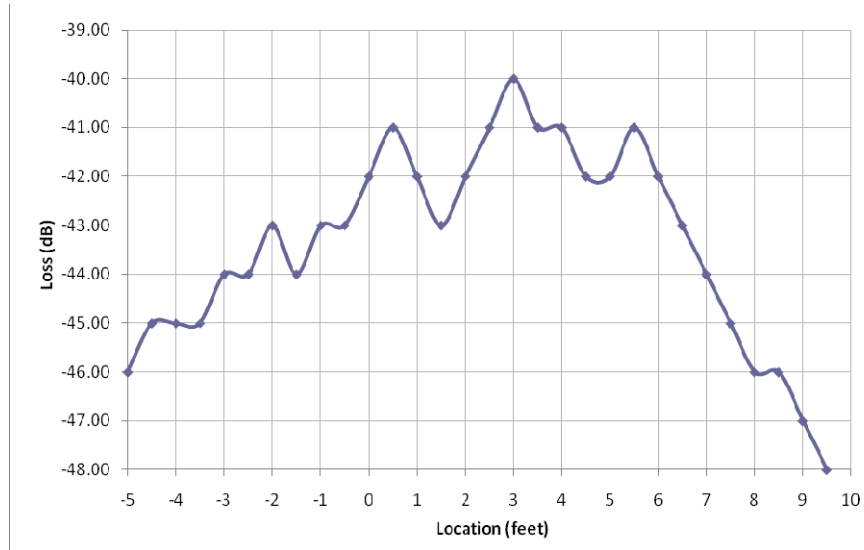


Figure 5: Loss vs. distance from conduit at 65 Hz and 150' when driving the manhole cover.

The same measurement was made at 130 Hz. From the data collected, it was impossible to determine where the two conduits were located. There were many peaks and no clear indication of the conduits' locations. The signal level that was picked up ranged from -41 to -48 dB over the 15 foot span. These results can be seen in Figure 6.

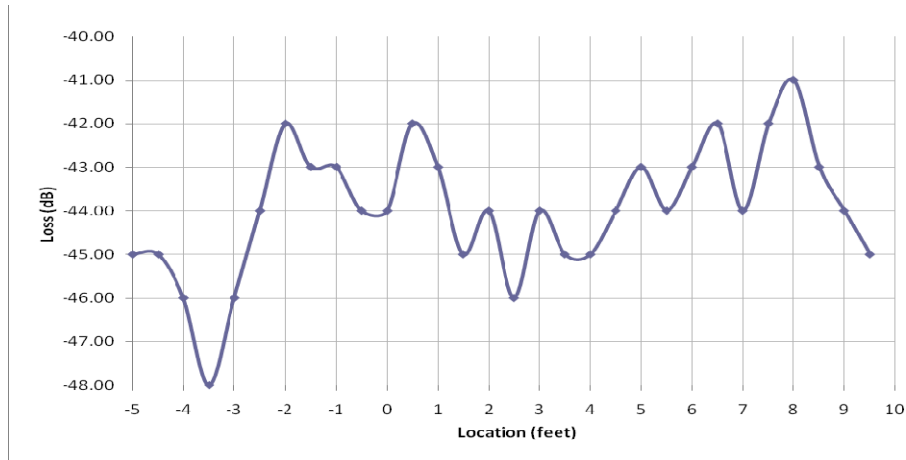


Figure 6: Loss vs. distance from conduit at 130 Hz and 150' when driving the manhole cover.

The same testing was performed 300 feet from the manhole and can be seen in Figure 7. Again, it was not possible to locate the conduits due to multiple peaks. Because of time limitations no additional measurements were made at greater distances.

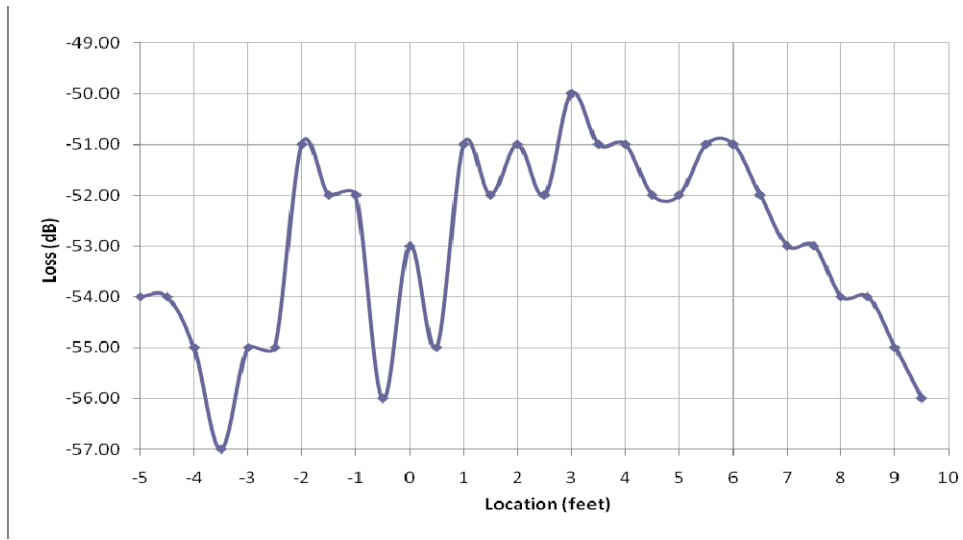


Figure 7: Loss vs. distance from conduit at 130 Hz and 300' when driving the manhole cover.

Figure 8 shows how signal level varied with distance at 130 Hz when directly driving the conduit. Figure 9 shows how signal level varied with distance at 65 and 130 Hz when driving the manhole cover. Both sets of data show a linear increase in attenuation over distance. Directly driving the conduit shows an attenuation of approximately 0.02 dB per foot, while driving the manhole cover shows an attenuation of approximately 0.066 dB per foot. This indicates that driving the manhole cover leads to more than triple the attenuation over distance as does directly driving the conduit. This increase may indicate that the transmission mechanism when the cover is driven is different (possibly by soil/air) than when the conduit is directly excited (primarily by the conduit).

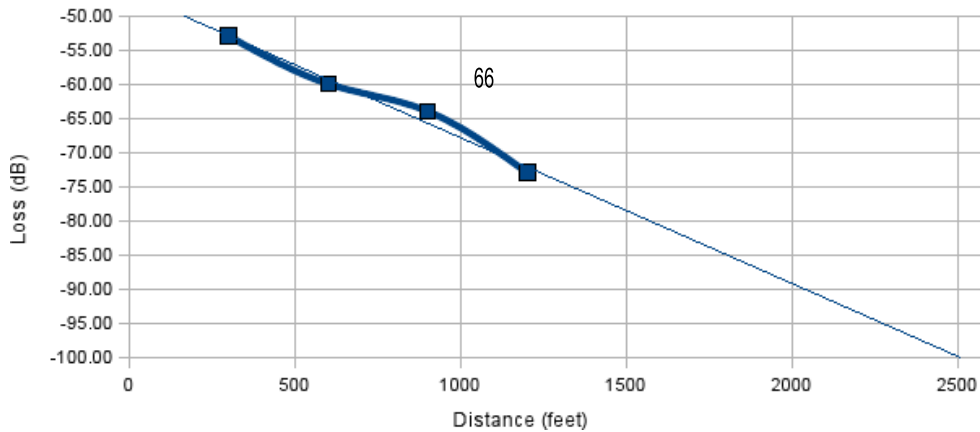


Figure 8: Loss vs. distance from the manhole at 130 Hz when directly driving the conduit.

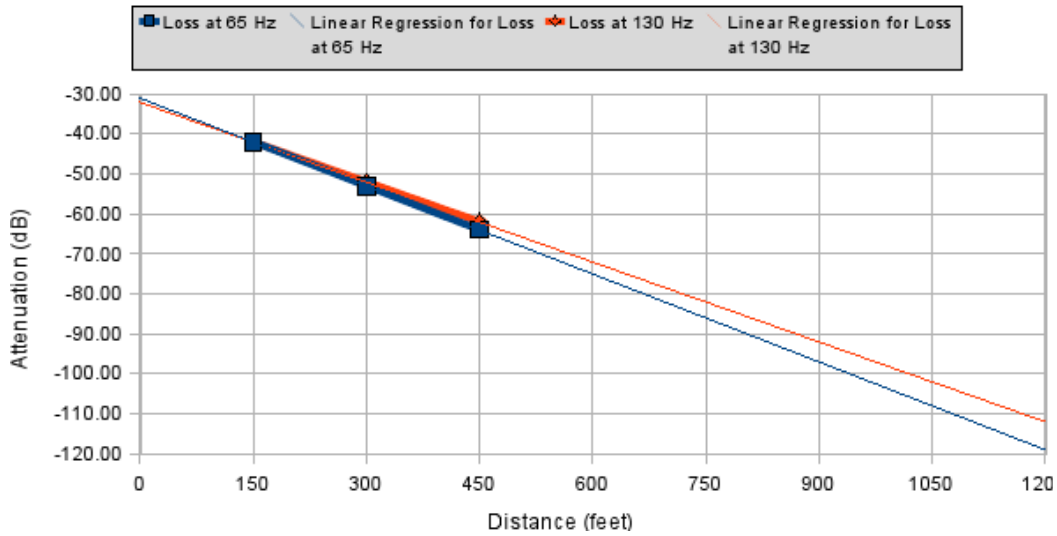


Figure 9: Loss vs. distance from the manhole at 65 Hz and 130 Hz, driving the manhole cover.

A device was constructed to allow easy use of trace wire equipment without removing the manhole cover. This device, shown in Figure 10, is comprised of an existing trace wire connected to a strip of copper, which is itself connected to a short length of wire. This short length of wire protrudes from a hole in the manhole cover and is secured. In this application, it was secured with a tie wrap. The protruding wire can then be connected to a trace wire signal source and used to locate a conduit. The system was connected and tested. It in all ways functioned as if the trace wire transmitter was connected in the normal way, where the manhole cover is removed.

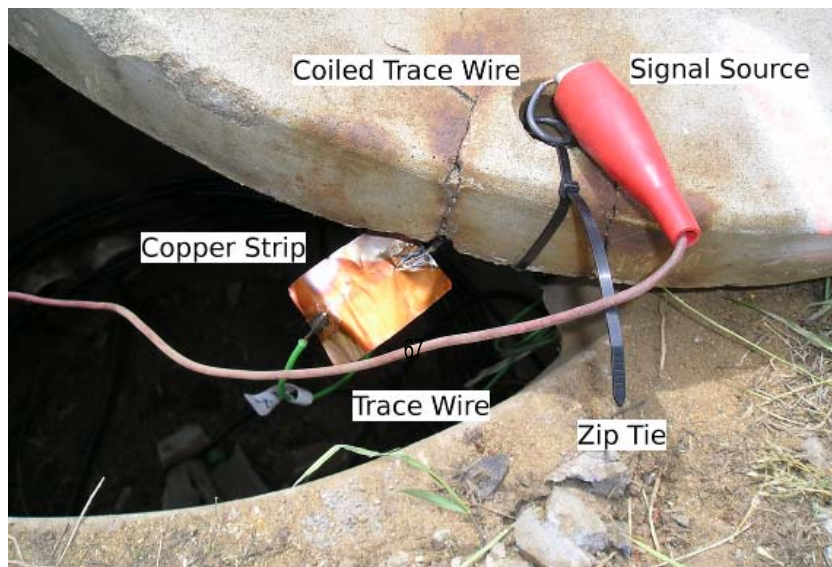


Figure 10: Trace wire implementation. The existing trace wire connects to a copper strip which sits between the rim and cover of the manhole. The manhole cover as pictured is removed to show detail, but would remain closed during operation.

Conclusions

This phase of testing indicated that direct acoustic excitation of a conduit is a useful method for locating conduits, when trace wires are not present. Results of exciting the manhole cover were not as encouraging, but need additional study before this method can be eliminated. A device that allows trace wires, when in place, to be used without removal of the manhole cover was also demonstrated and found to work well. Means for implementing this device in the NJDOT conduit system should be considered in the future.

APPENDIX H: Report on AT tests conducted at Ewing DOT headquarters on July 15-30, 2010

RE: Evaluate Acoustic Transmission System
Present: TCNJ: Tom DeVito and Dan Chokola

The purpose of this visit was to further evaluate our acoustic transmission system that could be used to identify the location of underground conduits when trace wires are not present. As discussed in previous reports, the concepts behind the acoustic transmission (AT) system are the same.

During this test, we planned on connecting the acoustic sending transducer (subwoofer assembly) directly to the conduit, and to the manhole cover (indirectly vibrate the conduit through the manhole barrel). A frequency in the range of 10 to 300 Hz was selected for testing as it is known that the attenuation of soil to sound waves is low in this frequency range, and components were also readily available for this range. The specific acoustic frequency used for transmission was determined experimentally.

As in previous tests, a microphone attached to a rod was used to pick up the acoustic signals. The rod was inserted into the earth to achieve better detection of the soil borne vibrations. The microphone was also insulated to isolate it from air borne noise. The microphone was connected to the input of a sound card in a laptop computer and the signals processed and analyzed with spectrum analysis software. Table 1 shows a complete list of the equipment/materials used.

Table 1: Equipment/Materials

Description	Make/Model
Amplifier	Krohn-Hite/UF101A
Frequency Generator	Krohn-Hite/5200
12 inch Subwoofer	Scosche
12 inch Subwoofer box	Scosche
Shelving Brackets (3)	N/A
3 inch PVC T-connector	N/A
10 feet of speaker wire	N/A
Laptop computer	
Portable microphone	Gigaware/33-119
Spectrum Analysis	Spectrum Lab
3 inch to 2 inch PVC	N/A

All testing was done at the DOT headquarters in Ewing, NJ. The conduit of interest was accessible at a manhole near the corner of Parkway Ave. and Lower Ferry Road. From this manhole, on one side, it left the DOT property. On the other side, it proceeded under a grass surface to a second manhole, and then to one of the DOT buildings. We began our testing with direct coupling to the conduit at the corner manhole. Transverse measurements were made every 2 feet over a 70 foot distance, starting at about 50 feet from the manhole. These measurements were made on a range of ground conditions, which included grass, asphalt, and concrete. We began using a 65 Hz, 26.3 Vrms signal to vibrate the conduit. The signal level ranged from -23 dB to -37 dB on the asphalt as shown by the red curve in Figure 1.

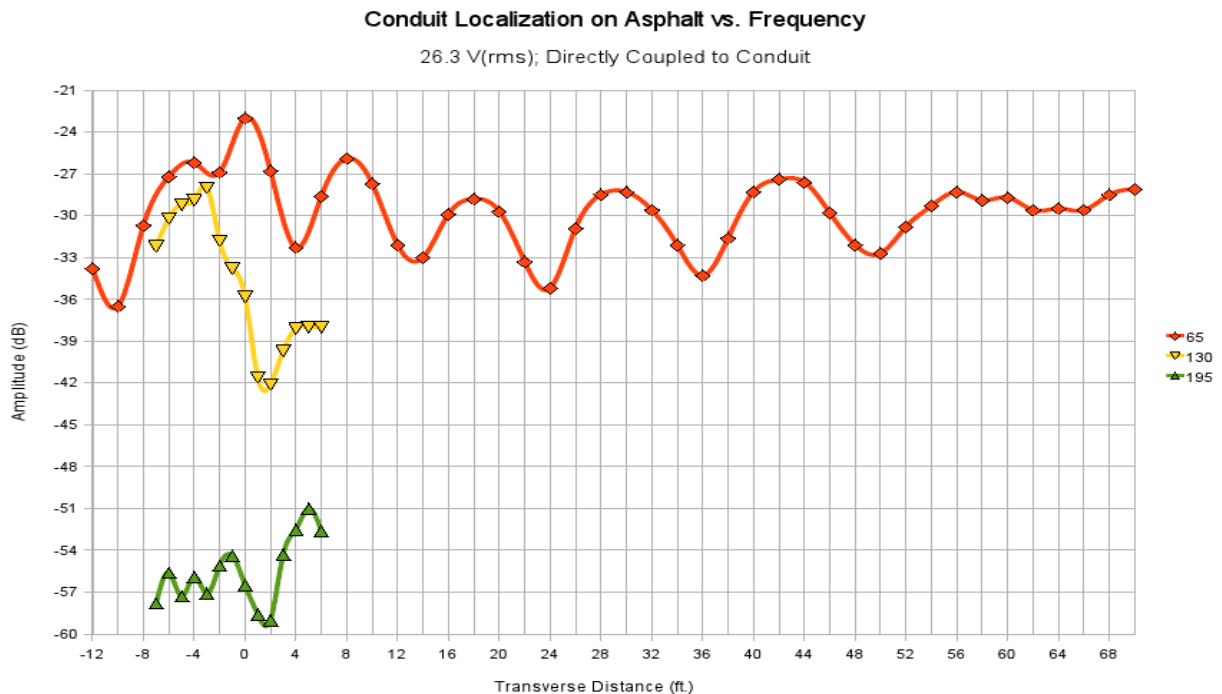


Figure 1: Measurements made transverse to manhole on a asphalt driveway

After finding what we believed to be the conduit’s location, we experimented with 130 and 195 Hz to see if these frequencies would work better. The 65 Hz signal appeared work the best. The 130 Hz signal was lower (by about dB at the peaks) and dropped off by about 10 dB. The 195 Hz signal was even weaker and ranged from -20 to -30 dB below the 65 Hz signal. Both these frequencies had peaks (assumed conduit location) that did not coincide with the 65 Hz signal.

We repositioned near a corner of the DOT building (garden area) to try and follow the conduit under the asphalt. At 65 Hz, the signal level varied from -28 to -44 dB with the peak level (-28 dB) occurring at exactly where we expected the conduit, based on our previous measurements. This can be seen in Figure 2.

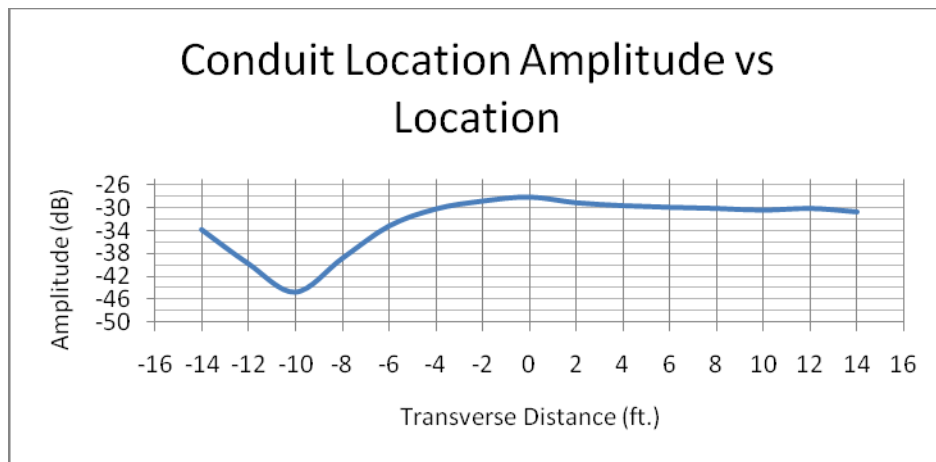


Figure 2: Measurements made on asphalt near garden area.

We next returned to the manhole and reconfigured for indirect coupling tests (woofer on top of the corner manhole cover). Measurements were again taken transverse to the expected conduit path at a range of distances from the manhole. We started at 5 feet from the manhole using both 65 and 130 Hz signals, and measured at six feet intervals over a 54 foot span. At these close distances, interference from acoustics signals reaching the microphone by way of an air borne and a soil born path in addition to the conduit were evident. At the 5 foot point, the noise levels through the air were -48 and -61 dB respectively at 65 and 130 Hz. Through the ground (and conduit) the levels were -45 to -47.5 dB and -54.5 to -58.5 dB at 65 and 130 Hz respectively. These results are shown in Figure 3. Comparing the two signal levels, there seemed to be more of a roll off around the center conduit location for the 130 Hz signal even though the signal level was much lower.

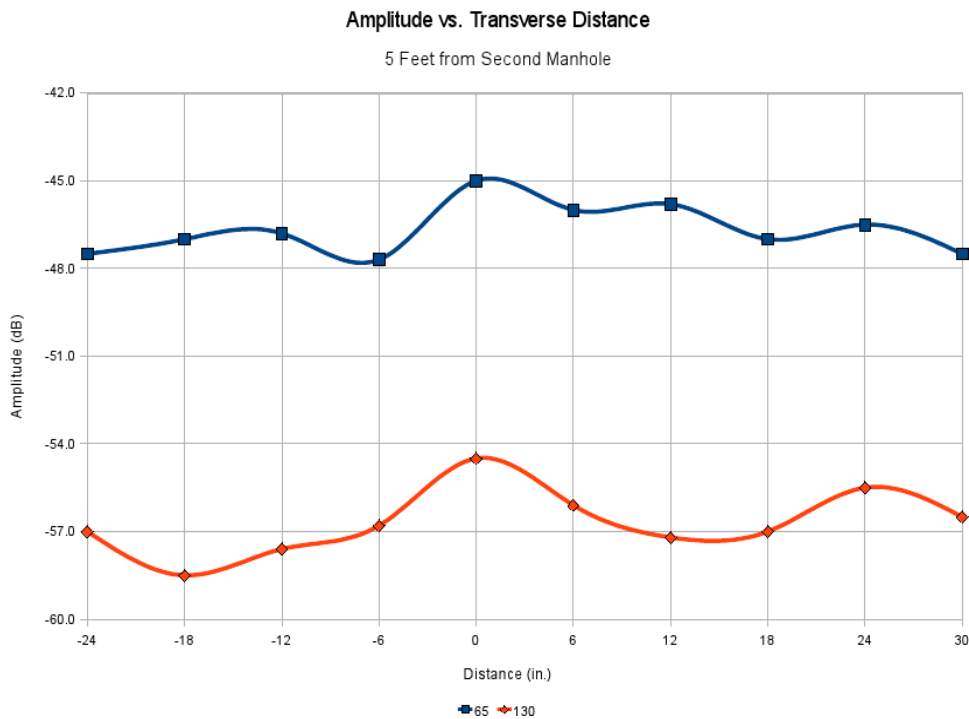


Figure 3: Transverse measurements using indirect coupling at 5 feet.

We repeated the transverse testing at 14.5 feet from the manhole, as shown in Figure 4.

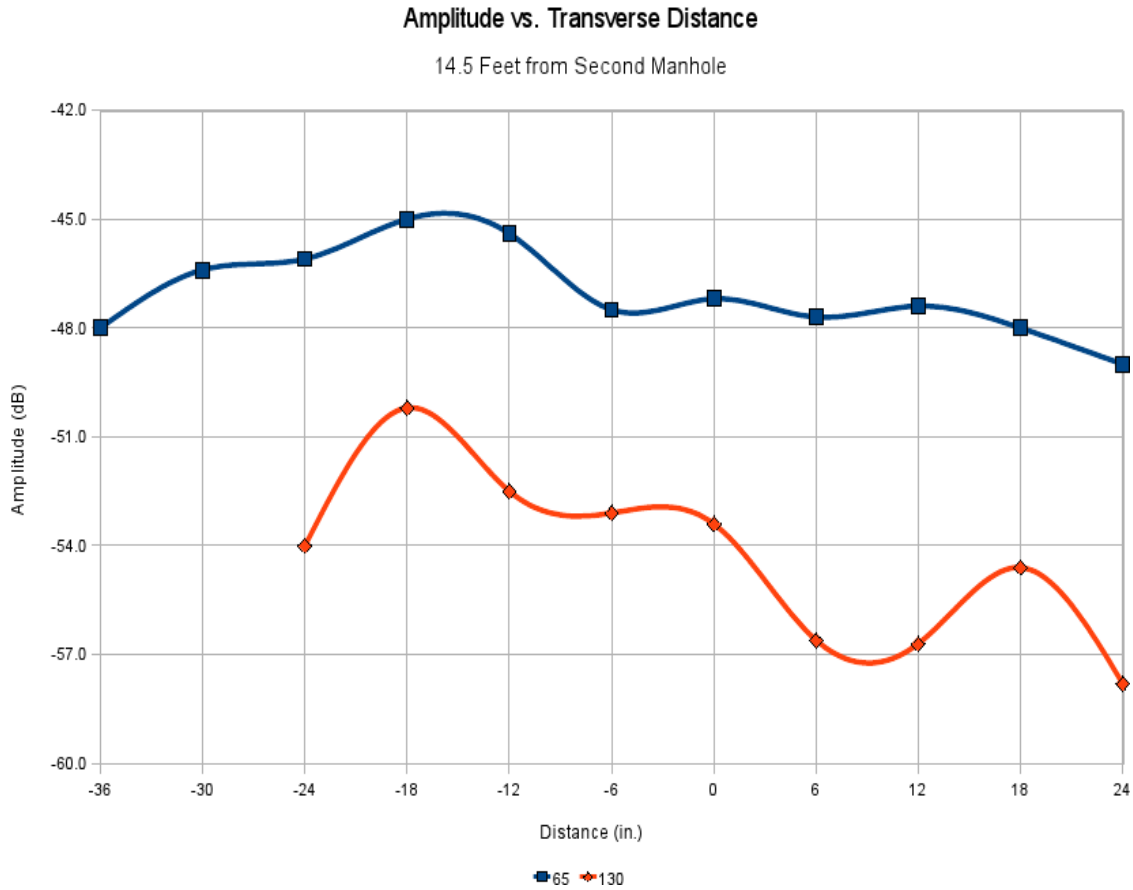


Figure 4: Transverse measurements using indirect coupling at 14.5 feet from the manhole.

From these results the locations of the conduit was not obvious. It was suggested that there might be a second conduit in the area, but we had no proof of this hypothesis. At this close distance, the more likely cause of these ambiguous results is interference between signal arriving by multiple conduction paths.

We tried again at 36 feet from the manhole using both 65 and 130 Hz with similar results as shown in Figure 5. At this location there was a small peak and valley when using the 65 Hz signal, and a larger ripple at 130 Hz, but no peak we could associate with the expected location of the conduit.

We continued testing at a nearby location on a coarse concrete sidewalk. The signal source remained the same (indirect vibration of the first manhole cover). We measured every 2 feet over a 40 foot transverse span. Surprisingly on the concrete, our signal strength was stronger when using 130 Hz than 65 Hz. As with the earlier tests, there was no clear indication of the conduits location - as seen in Figure 6. The two peaks were seen clearly with a difference of about 2.5 dB from peak to valley on either side at a signal level -37 and -38 dB. From the data

collected, it appeared that two or more conduits were present, which we were told is possible in the vicinity of these measurements.

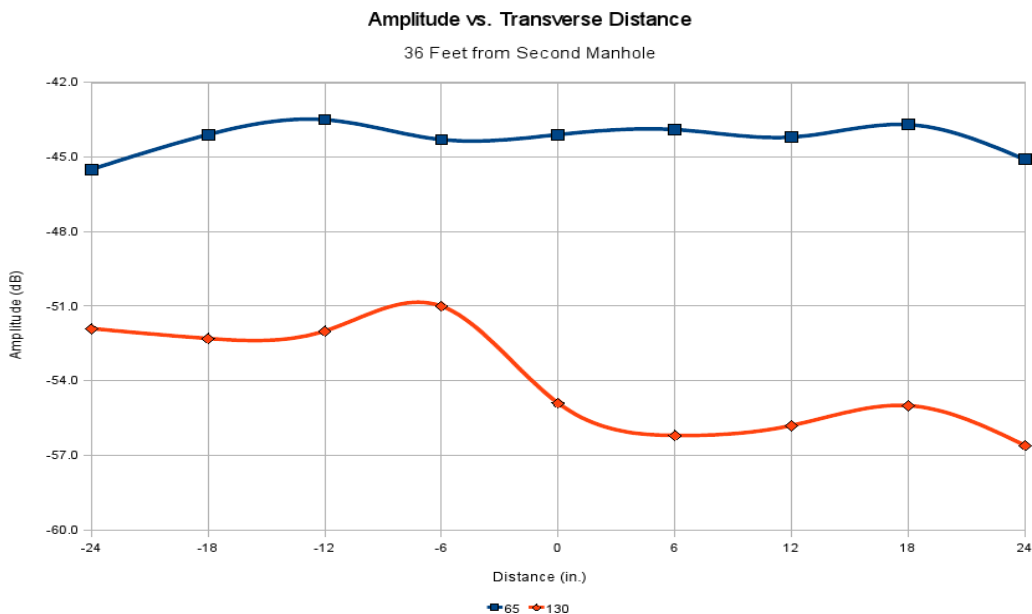


Figure 5: Transverse measurements using indirect coupling at 36 Feet

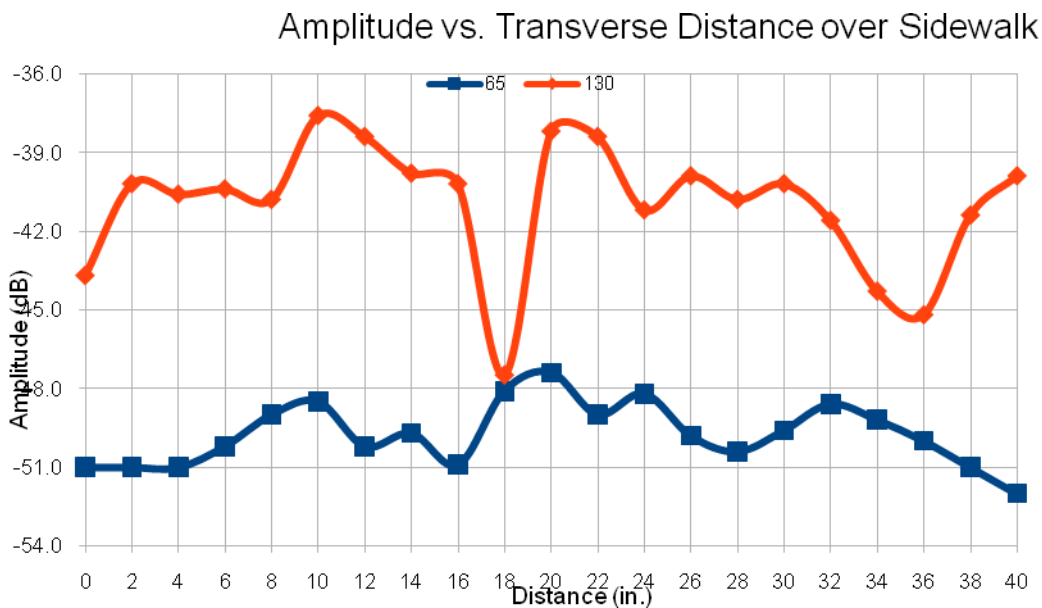


Figure 6: Transverse measurements using indirect coupling over a sidewalk.

Based on the previous results, it was decided to investigate ways to better isolate the driver (woofer) and microphone from sending/receiving signals through the air. We tested shielding the microphone and woofer using cardboard boxes insulated with foam. These boxes were

positioned over the microphone, speaker, or both. We placed the microphone in the ground at an arbitrary point about 100 feet from the speaker. We ran this test using both 65 and 130 Hz signals. We began by covering both the microphone and speaker, and measured the background noise level and the signal level. We then removed the boxes from either the microphone or speaker and then both, and re-measured the noise and signal levels. We found that the signal to noise ratios was greatest when just the microphone was covered for both the 65 and 130 Hz signals. The levels were -42 to -68 dB and -38 to -68 dB for the 65 and 130 Hz signal/noise levels respectively when just the microphone was covered. Covering the speaker actually made the ratio slightly worse. Without any covering, the ratios were -40 to -47 and -37 to -47 dB. These results are illustrated in Figure 7. We decided to use no shielding of the speaker. Shielding of the microphone made a significant improvement and was used in the following tests.

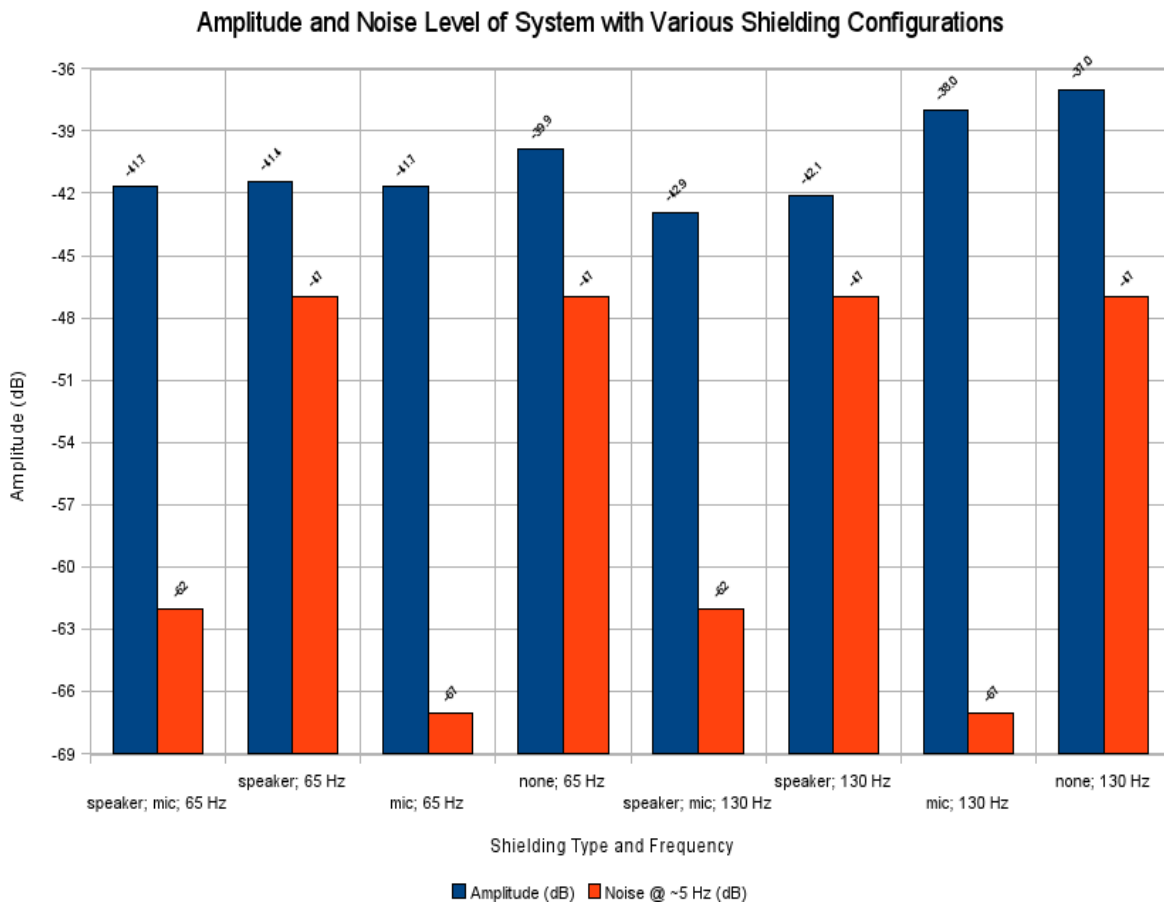


Figure 7: Signal and noise levels of AT system using various shielding combinations.

To better understand the position and placement of the conduits, we decided to make measurements around a circle with a 30 foot radius centered on the second manhole. Measurements taken at every foot at 130 Hz signal. The results of these measurements, shown in Figure 8, seemed to confirm the presence of at least two conduits. One at a 90 degree angle and the other at about a 45 degree angle (the 0 degree reference is to a line between manholes 1 and 2).

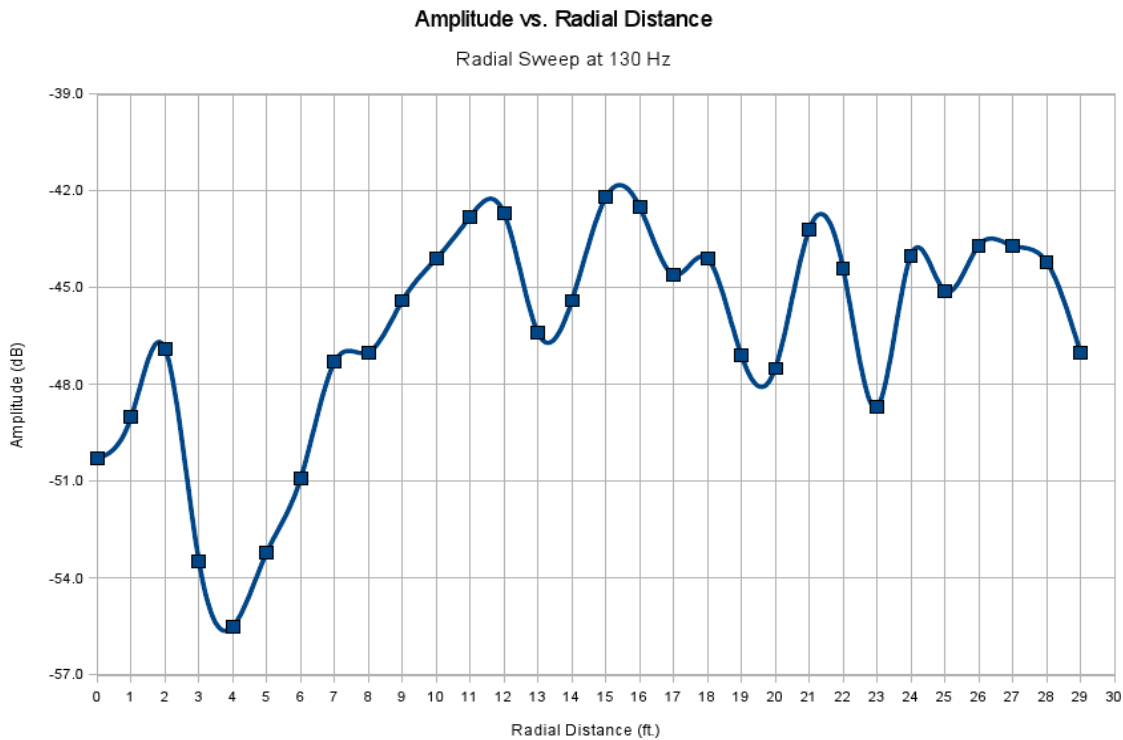


Figure 8: Signal level vs. radial distance along a circle centered at the second manhole.

We could not verify the position of the second conduit from DOT building plans. We were able to follow the signal toward the building. We decided to take additional measurements between the second manhole and Lower Ferry Rd. These measurements using a 130 Hz signal, clearly indicate the conduits location. The data showed a difference in signal level from the peak to valley of 3 and 5 dB on either side of the conduit. Following the conduit further, we found that it possibly connected to a telephone pole on the curb. There was an abandoned conduit just capped off hanging out of the ground. We could also see where there had been a cut in the road in the same direction. The data collected for these measurements is shown in Figure 9.

After being satisfied that we had identified the second conduit's location, we searched for and located the original fiber conduit. We found that it crossed the paved drive way, and passed next to and in the garden area, and into the building. We then were able to verify with the building plans that the fiber conduit did indeed run in this direction. We follow the layout and found where the conduit was supposed to enter the building marked with orange paint. We tried to use a 130 Hz signal to verify the conduit's presence, but there was too much noise from an air conditioner located in this area. We switched to the 65 Hz signal and made an 8 foot sweep, transverse to the building entrance. We were indeed able to clearly see the conduit. These measurements are shown in Figure 10.

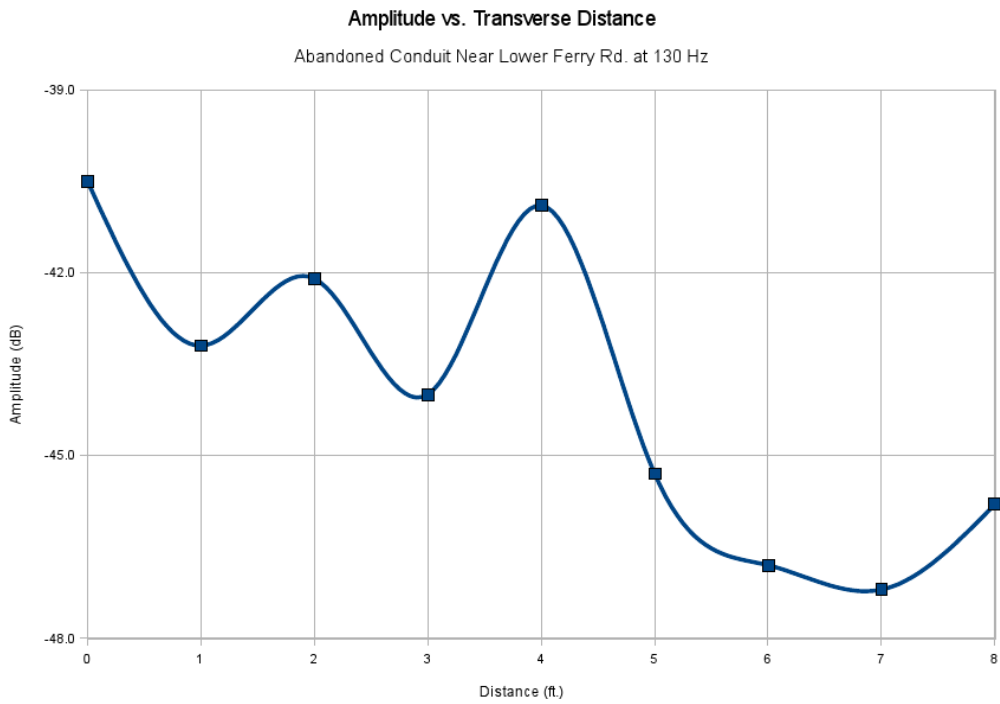


Figure 9: Signal level vs. transverse distance near Lower Ferry Rd.

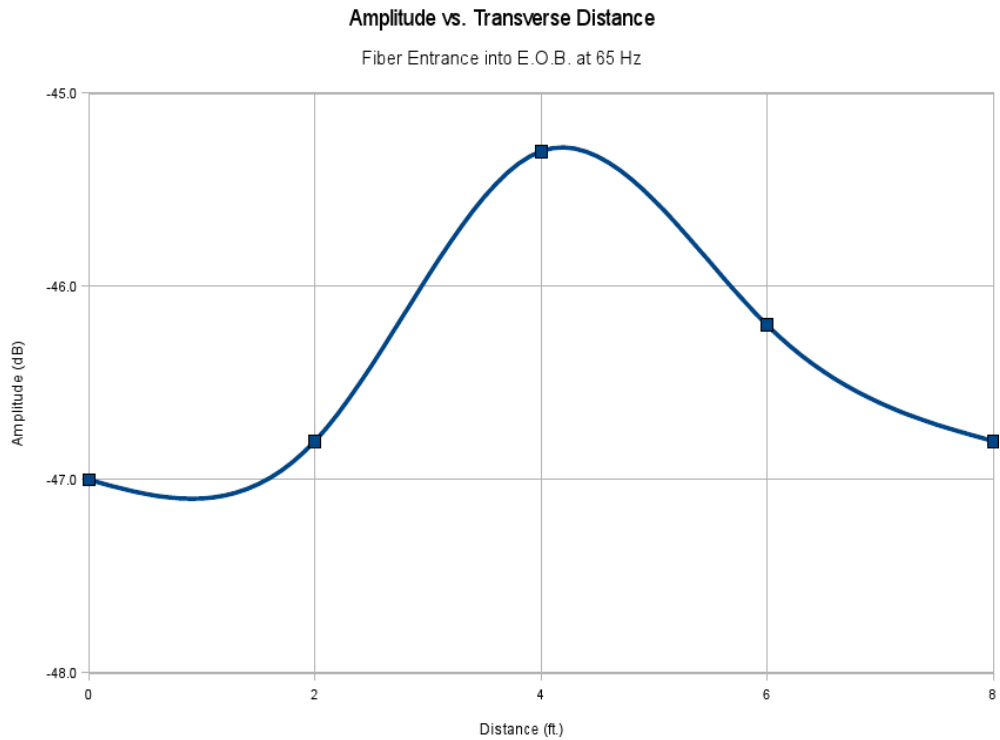


Figure 10: Signal level vs. transverse distance near entrance to the DOT building.

Conclusions

The AT system, although having difficulties when multiple conduits were present, proved useful in locating the fiber conduit of interest. We were able to locate and verify the location of the fiber conduit with both direct to the conduit and indirect (applied to the manhole cover) vibration. We also found the ability to change frequency enabled to obtain useful measurements when interference was present in a particular frequency range.

We believe the Acoustic Transmission method of locating underground conduit will prove a useful and cost effective supplement to already existing techniques for locating both metallic and plastic conduits. Its ability to accurately locate non-metallic buried conduits should be of particular value to NJ DOT and result in less accidental damage, and help avoid the loss of fiber optic cables and the critical information carried by them.

APPENDIX I: Report GPR and Electro-Magnetic Induction tests at NJDOT Headquarters in Ewing July 19, 2010

Present: Al, Bob, Fadi, Edip, Ibrahim, Dan, Omeed, Eastcom: Larry, Verga & Ed Hanna

A Mala GPR 1000 GPR manufactured by Radiodetection, Ltd was demonstration by Eastcom. Figure 1 shows the GPR being tested. The GPR found a conduct that appeared to originate from the same manhole as the fiber conduit, but went to the first building rather than the second where the conduit was supposed to terminate.



Figure 1 – Mala GPR test over asphalt at DOT headquarters.

Figure 2 shows the GPR 1000 display and the location of a conduit. It appeared easy to use. Possibly more user friendly than the GSI GPR, but did not provide any more useful information.



Figure 2 – Mala GPR display – seemed very user friendly.

Eastcom also demonstrated a *snake* like device that allowed a trace wire to be inserted into a conduit that did not have significant bends – see Figure 3. They have versions that can be used to distances of 400'. The one shown could not be test very far because of a bend in the conduit and fears of damaging the fiber inside.



Figure 3 – Snake like device that can functions as a TW in conduit that has none.

Eastcom also demonstrated devices that detected indirectly coupled radio energy that may be present in a metallic conductor (or even a TW that could not be easily connected to).

GPR testing was conducted using a Mala GPR 1000 unit – See Figure 2. It was able to identify the conduits under the grassy area with good clarity and resolution. However, when it came to the conduits running under the paved shoulder, the tests were inconsistent and could not clearly or consistently identify the path of these conduits. (These tests were undertaken with the presence of a NJDOT truck parked in the shoulder area). Having opened earlier a circular junction box (JB), another older rectangular junction box was also opened, showing a possible connection of the cables between the 2 JB's.



Figure 2 – Mala GPR and junction box

The actual routing of the fiber optic conduits seemed to differ from the attached figure, and Larry confirmed that the GPR signal he detected was consistent with the new “expected” routing of the fiber conduits. However, it was clear that the signal under the pavement was more difficult to detect by an operator than the signals identified under grass. Larry’s GPR battery was depleted before being able to make it to the second site.

Electro-Magnetic Induction Testing

Larry conducted some electromagnetic testing by connecting his RD8000 transmitter to a trace wire. The signal was clearly followed and traced the conduit running under the grassy area. However, when the transmitter was no longer directly connected to the trace wire, and the transmitter unit was being used from above ground, coupling with another telephone or electric cable took place, putting in question the accuracy of the EMI method when multiple trace wires are present, or when other conductive conduits are present in the vicinity.

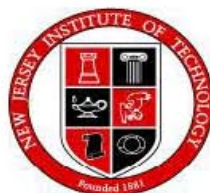


Figure 3a – Inside junction box – left side looking toward road.



Figure 3b – Inside junction box – right side looking toward road.

APPENDIX K: RFID Based TW Patent Disclosure



NJIT
New Jersey Institute of Technology
Invention Disclosure Report

-Confidential-

Docket Number:	URGENT PROCESSING?
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INSTRUCTIONS: This form will be used by the Office of Technology Development and the assigned Intellectual Property attorney to establish the possibility of protecting your invention or other technology. Answering the below questions as completely as possible will enable the Office of Technology Development and the assigned Intellectual Property attorney to decide whether to file for a Patent, and will help in assessing commercialization options.

TYPE OF TECHNOLOGY, PROTECTION & TITLE

1. *Please indicate all of the type(s) of protection you believe applicable to the technology disclosure:*

- Patent (utility, design)
- Trademark associated with the technology
- Copyright
- Other (trade secret, proprietary materials/information)

2. *Please indicate which of the technological areas the invention falls:*

- Biological/Biotechnology
- Chemical
- Electrical
- Computer Hardware or Software or both
- Mechanical
- Other (please describe: _____)

3. *Short descriptive title of invention*

RFID system for identification of underground utilities

4. **CONTRIBUTORS:**

Full name, contact information and identifying information of all University employees or students and any non-University personnel who are potential inventors.

OIP/OLEA Form 8.2.02

1/5

“Inventors” to be listed are individuals who have conceived at least a portion of the novel idea. Do not include individuals who contributed to the invention by merely helping to reduce the novel idea to practice through routine testing and implementation. If any individual listed below holds a joint appointment with any other university, a company or governmental agency, or the like, please note under “affiliations”.

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Nature of Contribution Suggested and developed the concept, verified experimentally

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Nature of Contribution Suggested the concept

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Citizenship USA

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Nature of Contribution Suggested and developed the concept

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Title & Department Associate

Professor, Civil and Environmental Engineering

Home phone number (973) 230-1497

Affiliation (s) NJIT
Citizenship USA

ABSTRACT

5. Please provide a concise abstract of the invention in the space below.
Feel free to attach diagrams, pictures, and other descriptions as needed.

RFID systems are primarily used for tracking assets and more recently have found profound applications in toll collection as well as many other functions. RFID system refers to a tag reader consisting of a transceiver and an antenna that can send/receive a signal to a tag which consists of a chip and an antenna. Tags are primarily function with (active) or without (passive) internal batteries. In case of a passive tag energy in the interrogation signal can energize the tag to provide a response that will be captured and processed by the tag reader. RFID systems have been developed for low, mid and high frequency bands. Lower attenuation at lower frequency bands makes them suitable to probe tags buried in the ground adjacent to utility pipes for further identification and location estimation. The proposed system will consist of a RFID tag and a tag reader operating at low frequency with substantial power to accommodate moderate range defined by a relative depth at which tag is placed in the vicinity or on top of the utility pipe. Tag can be embedded with an ID and data related to its location and its depth for future use, especially could lead to substantial saving in effort and time in case of possible excavation of the utility or digging in related endeavour. Simplified version of an RFID tag can be substituted by a pn-junction diode with non-linear characteristics capable of generating second harmonic of the probe signal coupled to a dual band antenna. When tag is excited with a probe signal of frequency f_0 , the diode will induce a signal of frequency $2f_0$, the dual band antenna tuned to f_0 and its second harmonic will reradiate at the frequency of $2f_0$. This signal will be picked up the the probe(tag reader) antenna. The probe signal strength on the surface of the is directly indicative of the location of the buried equivalent tag comprising of the diode connected to dual band antenna.

- a. Verify that the invention was done using NJIT resources as defined by NJIT policy: Yes No
 - b. Is the invention a fundamental breakthrough or an extension to an existing idea? Novel application for underground utilities location identification
 - c. Is there any third party IP incorporated in the invention such as third party software? No
 - d. Is the invention readily detectable? If yes, how? Experimentally verifiable
 - e. Is this disclosure related to other disclosures? No
6. **CONCEPTION & REDUCTION TO PRACTICE**

- (a) When and where was the earliest conception of the subject invention?

Date: February 2010 Place: New Jersey

- (b) Was the subject invention reduced to practice (e.g. is there a working model or example?)

Yes No

If so, what was the date? May 2010

(c) Is there any experimental data available associated with the invention? If yes describe.

Low frequency RFID system (TIRIS) at 134.2 kHz was used to detect tags buried at 15 inches depth in dry soil at NJIT. Dual band thin wire antenna coupled to a semiconductor diode has been tested at frequency of ??? MHz.

7. CHRONOLOGY OF DISCLOSURE AND PUBLICATIONS

(a) Please list all past and prospective dates of public disclosure and or commercialization activity (whether done orally, in writing, website, poster session or in any other manner) pertaining to the proposed invention.

Date:

To whom was (will) the disclosure (be) made?

Date:

To whom was (will) the disclosure (be) made?

(b) To the extent not identified in (a) identify date and place (e.g., particular periodical) of any publication regarding invention (whether past or projected), or any attempted commercialization or other public disclosures (e.g., poster session or talk).

(c) Were there any non-disclosure agreements (NDAs) in place, or other existing understandings of confidentiality relative to each of the events detailed in (a) and/or (b)? (please attach additional sheets or explain as needed.)

If there is an imminent public disclosure (upcoming academic publication), commercialization activities, or other type of disclosure outside of NJIT personnel, please check the box titled "Urgent Processing" on top of page 1

PRIOR ART

8. Describe the prior art (e.g. related technology), which you believe is relevant to this subject invention, and also describe the principle novel features of your invention over this prior art.

RFID systems have a long history since its early inception of its predecessors as Identification of Friend or Foe (IFF) systems in 1939 in England, was routinely used by the allies in World War II to differentiate the aircraft as friend or foe. These transponders are still in use in aircraft industry to this day. Then, Radio Frequency Identification System is invented by Léon Theremin as a spying tool for the Soviet Union which retransmitted incident radio waves with audio information in 1946. Sound waves vibrate a diaphragm which slightly alters the shape of the resonator, which modulates the reflected radio frequency. Even though this device was a passive secret listening device, not an identification tag, it has been attributed as a predecessor to RFID technology. Another early work exploring RFID is the landmark 1948 paper by Harry Stockman, titled "Communication by Means of Reflected Power" (Proceedings of the IRE, pp 1196-1204, October 1948). Stockman predicted that "... considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored." Mario Cardullo's U.S. Patent 3,713,148 in 1973 was the first true ancestor of modern RFID; a passive

radio transponder with memory. The initial device was passive, powered by the interrogating signal, and was demonstrated in 1971 to the New York Port Authority and other potential users and consisted of a transponder with 16-bit memory for use as a toll collecting device. The basic Cardullo patent covers the use of RF, sound and light as transmission media. The original business plan presented to investors in 1969 showed potential uses in transportation (automotive vehicle identification, automatic toll system, electronic license plate, electronic manifest, vehicle routing, vehicle performance monitoring), banking (electronic check book, electronic credit card), security (personnel identification, automatic gates, surveillance) and medical (identification, patient history) applications. A very early demonstration of reflected power (modulated backscatter) RFID tags, both passive and semi-passive, was performed by Steven Depp, Alfred Koelle and Robert Freyman at the Los Alamos National Laboratory in 1973. The portable system operated at 915 MHz and used 12-bit tags. This technique is used by the majority of today's UHF and microwave RFID tags. The first patent to be associated with the abbreviation RFID was granted to Charles Walton in 1983 U.S. Patent 4,384,288 [1]. In recent 30 years the state-of-the-art has advanced to numerous systems and applications.

However, none of them focused on direct application of tags buried underground to identify utilities. Our research has shown that low frequency systems have an advantage from lower attenuation of signals generated by the tag reader. Such systems usually operate based on inductive coupling between the tag reader antenna and the tag as shown in Figure 1 to include the path length inside the ground at which the tag can be placed in the near proximity of the utility. Commercially available systems have a typical range in the vicinity of 6 feet in free space. Commercially available tags are well encapsulated to weather adverse conditions within the ground and consist of coils coupled to the chip as shown in Figure 2.

We extend application of such system which can be placed above the ground and its antenna be placed either on the earth surface or slightly elevated from the ground as shown in schematic representation of Figure 3. The physical system that was used in experimental verification is Texas Instruments TIRIS system operating at 134.2 kHz is shown in Figure 4.

The experimental results are shown in Figure 4. The experiment was conducted in dry soil conditions. The tag depth was varied while tag reader antenna was either kept elevated at a distance of 1 foot. The tag became undetectable as its depth reached 10 inches as shown in Figure 5. However, if antenna was kept on the earth surface, the tag was detectable at the depth of 15 inches.

The simplified tag comprised of a diode coupled to the thin wire dual band antenna of length L could be placed on or near the buried utility. The tag reader will excite this simplified tag with a signal of frequency f_0 . The diode will generate and re-radiate second harmonic at frequency $2f_0$, which is detected on the subsurface. The receiving antenna will scan the area just above this simplified tag, and the location where peak signal is observed will correspond to the approximate projected location of the simplified tag. The schematic representation of this scenario is shown in Figure 6.

FUNDING

9. List all sources of funding (external and internal) related to the conception and development of this Intellectual Property. It is important that this information be accurate and complete because sponsors may have certain rights in the Intellectual Property.

(a)

<u>Agency Grant Number:</u>	<u>NJIT Fund and Account:</u>
NJDOT and UTRC	

- (b) *Of those federal funding sources identified above (if any), indicate the federal funding source(s) that provided the primary source of funds for the invention.* A grant, contract or cooperative agreement is a primary source of funds if the invention was conceived or reduced to practice in the performance of work sponsored by the federal funding agreement. If you list more than one federal funding source, indicate the source you consider to be the lead funding source.

<u>Grant, Contract Or Cooperative Agreement Funding Number</u>	<u>NJIT Fund And Account Number</u>

10. Identify and attach any agreements that the inventors have entered into with any funding source identified in question 9, along with any other agreement that you believe may grant a right of any sort in this invention to a company or other non-governmental party (e.g., material transfer agreements, commercially sponsored research agreements, consortia agreements, consulting agreements, confidentiality agreements, etc.). If none, check here.

11. Please list any subcontractors involved in the project (s) that relates to the subject invention. Please detail the nature of their subcontracted work:

COMMERCIAL VIABILITY

12. *In what specific domestic and/or international markets do you see your technology being commercially successful?*

(a) Domestic:

(b) International:

(c) Please list specific commercial firms that may be interested in your technology.
Please include contact information.

13. *What potential impediments do you see to the legal and appropriate protection and/or the successful commercialization of your technology?*

Name of person filing report (please
print or type _____
Department _____
Email address _____
Campus phone number _____
Date: _____

THIS INVENTION DISCLOSURE REPORT SHOULD BE FORWARDED TO:

**Attn: Intellectual Property Docketing Clerk
Office of Legal and Employment Affairs
211 Cullimore Hall
University Heights
Newark, New Jersey 07102-1982**

APPENDIX L: Information on 3M RFID Buried Marker Products

3M™ Electronic Marker System (EMS) Ball Markers

The 3M™ Ball Marker makes the job of precisely locating underground facilities easier. Other buried markers can be disturbed by backfill dirt or installed improperly so they don't stay positioned correctly. The 3M ball marker's unique self-leveling design ensures the marker is always in an accurate, horizontal position regardless of how it is placed into the ground.

The addition of the new 3M-iD markers provides additional functionality by enabling facility data to be stored in the marker to ensure positive identification of facilities. The pre-programmed unique serial number integrates with back office mapping and GIS systems when used for mapping new and legacy assets and points of special interest for construction and maintenance applications.

The ball marker is buried over key facilities during construction or maintenance. Later, the marker is easily and accurately located using a 3M™ Dynatel™ Locator. The locator transmits a signal to the buried marker. The marker returns the signal to the locator, indicating the marker's exact position. The compact electronic locator gives both a visual reading and an audible tone.



3M™ Electronic Marker System (EMS)
XR/iD Ball Markers

Features	Benefits
Accurate even in congested areas	Helps eliminate mislocates
Underground marker	Protected from damage from above-ground environment
Durable	Long-lasting passive antenna encased in waterproof shell helps identify underground facilities for years to come
Frequency- and color-coded	Helps identify specific utility
Easy to Use	Minimal training
RFID capability	Positive identification using facility information
Physical Specifications	
Size	4" diameter sphere (10.4 cm diameter)
Weight	Net: 0.7 lb. (0.35 kg)/ Shipping: 24 lb. (10.4 kg)
Packaging	30 per carton
3M iD Markers Read Range	With a 'U' model (U.S.) locator: 5 ft. (1.5 m) With a 'E' model (Export, CE) locator: 1.2 m (Tel, Gas, WW, Comm)/1.0 m (Pwr, Wtr)
3M Passive Markers Detection Range	5 ft (1.5 m)
Environmental Specifications	
Operating Temperature	-4°F to 122°F (-20°C to 50°C)
Storage Temperature	-40°F to 158°F (-40°C to 70°C)



3M™ Full Range Markers

Image	Product	Application	Stock Number
	3M™ EMS Ball Marker 1401-XR	Telecommunications industry	80611161136
	3M™ iD Ball Marker 1421-XR/iD	Telecommunications industry	80611142193
	3M™ EMS Ball Marker 1402-XR	Power industry	80611161144
	3M™ iD Ball Marker 1422-XR/iD	Power industry	80611142201
	3M™ EMS Ball Marker 1403-XR	Water industry	80630000323
	3M™ iD Ball Marker 1423-XR/iD	Water industry	80611143225
	3M™ EMS Ball Marker 1404-XR	Wastewater industry	80630000331
	3M™ iD Ball Marker 1424-XR/iD	Wastewater industry	80611143233
	3M™ EMS Ball Marker 1405-XR	Gas industry	80630000257
	3M™ iD Ball Marker 1425-XR/iD	Gas industry	80611143241
	3M™ EMS Ball Marker 1407-XR	Cable TV and communications	80611161151
	3M™ EMS Ball Marker 1427-XR/iD	Cable TV and communications	80611142219
	3M™ EMS Ball Marker 1408-XR	General purpose and reclaimed water	80611168354
	3M™ iD Ball Marker 1428-XR/iD	General purpose and reclaimed water	80611142227

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