Ground Penetrating Radar Evaluation and System Integration: Progress Report

Digital Highway Measurement (DHM) Vehicle Project

Turner Fairbank Highway Research Center

Natchez Trace Ground Penetrating Radar (GPR) Field Trial:

DHM Subsurface Sensor Comparison
Standard Ultra Wide Band GPR and new Step Frequency GPR

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Prepared For

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1. Introduction

The Federal Highway Administration (FHWA) is developing several sensor technologies to satisfy needs for efficient, safe and accurate pavement and infrastructure evaluation. New methods for fusing data from many sensors have made pavement and infrastructure evaluation with integrated, multi sensor vehicles an important application and research area. One type of sensor technology under consideration for these applications is ground penetrating radar (GPR). GPR can be a useful technology for pavement, drainage, bridge, materials evaluation and other subsurface measurement and detection needs. A field trial was carried out for this study to evaluate the performance characteristics of a new type of ground penetrating radar (GPR) instrument. The evaluation consisted of a comparison with standard GPR technology and an assessment of the new GPR instrument’s capabilities to meet needs defined by a FHWA project specification. The specification under consideration was for the FHWA Digital Highway Measurement (DHM) vehicle project. The field trial took place along a designated segment of the Natchez Trace Parkway near Vicksburg, Mississippi. A previous test had already been completed on the same site using standard GPR technology, which was used for comparison.

2. Project Support and Motivation

The DHM project is an integrated sensor system under development by the FHWA Advanced Research Team at Turner Fairbank Highway Research Center (TFHRC). Key support for the DHM project comes from the Federal Lands Highway Division (FLHD). Subsurface sensing needs identified by the FLHD Roadway Inventory Program (RIP) and related projects were used to develop and carry out specific tests during this GPR field trial. Complete surface and subsurface FLHD pavement and infrastructure evaluation needs have been important considerations for all of the integrated sensor development work on the DHM vehicle. The broad range of tests conducted in this trial and the results presented in the analysis of collected data demonstrate methods for addressing many highway measurement and evaluation needs. These tests were also the first large scale Step Frequency GPR infrastructure evaluations carried out in the United States. Additional findings will be reported as more reference data becomes available through FLHD.

3. Natchez Trace Parkway GPR Trial Location

The location of the GPR trial was identical to the area that was previously tested using reference GPR equipment. This area included the north and south bound lanes between mile 66.7 and mile 78.0 on the Natchez Trace Parkway near Vicksburg, Mississippi. The test area is designated by the portion of the boxed region north and east of Route 27 in Figure 1. The entire boxed region designates an area where the National Telecommunications and Information Administration (NTIA) and other federal coordinating organizations determined that test equipment could operate for the purposes of the field trial. Ongoing experimental assignment and licensing discussions regarding the use of the new GPR instrument are anticipated to allow future testing on federal lands.

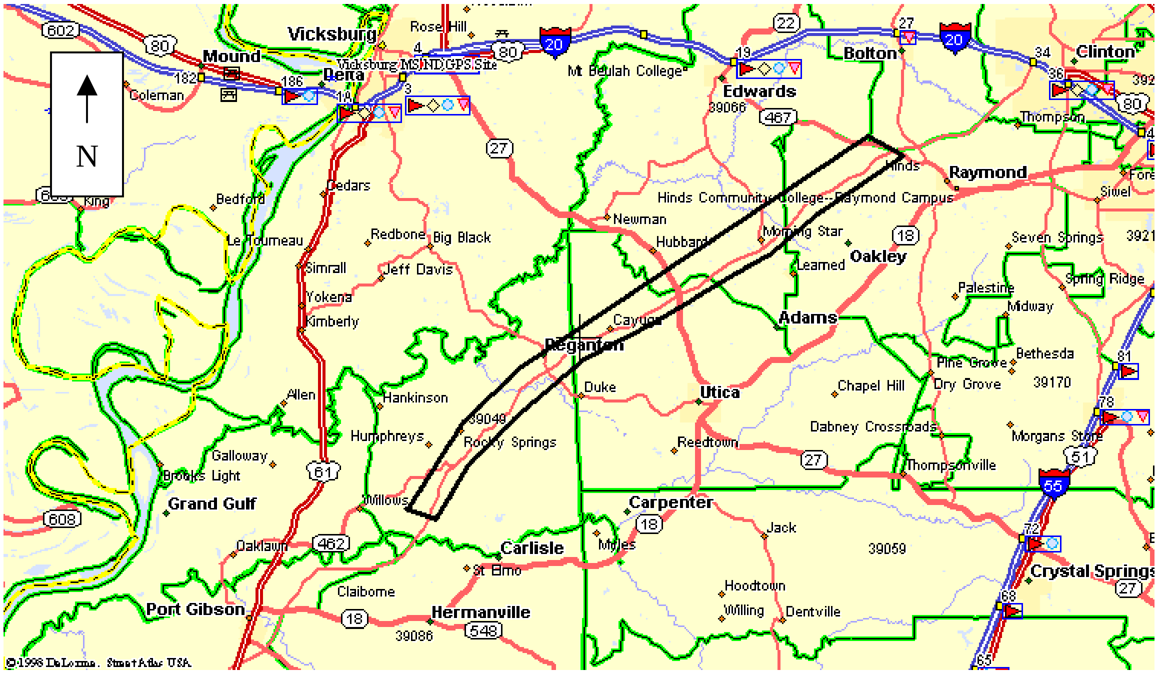


Figure 1. The boxed area designates the zone where new GPR instrument testing was approved for the field trial. Coordinates of the trial were from 32 degrees 16.85 minutes, 90 degrees, 27.94 minutes to 32 degrees 1.86 minutes, 90 degrees, 50.21 minutes.

4. Test Equipment

Two types of GPR technology were evaluated in this study and are often referred to as “Step Frequency GPR” and “Impulse GPR,” respectively. This section will describe the key technical differences between these two GPR technologies and will put these differences into the context of GPR applications to infrastructure. Common features of both GPR technologies will also be highlighted, where they are applicable. The descriptions of the technologies will typically remain generic to each type, but specifications and instrument manufacturer information for both systems used in this study will also be provided.

The primary distinction between Step Frequency GPR and Impulse GPR is the way that GPR energy is transmitted into concrete, soil, rock, pavement, or other materials at an individual test location. For an example pavement at a particular location, an Impulse GPR system transmits a single impulse (Figure 2a) that contains useful signal content over a broad range of frequencies (Figure 2b). The transmitted GPR impulse propagates through the material where reflections from subsurface material layer interfaces (such as an asphalt to base material

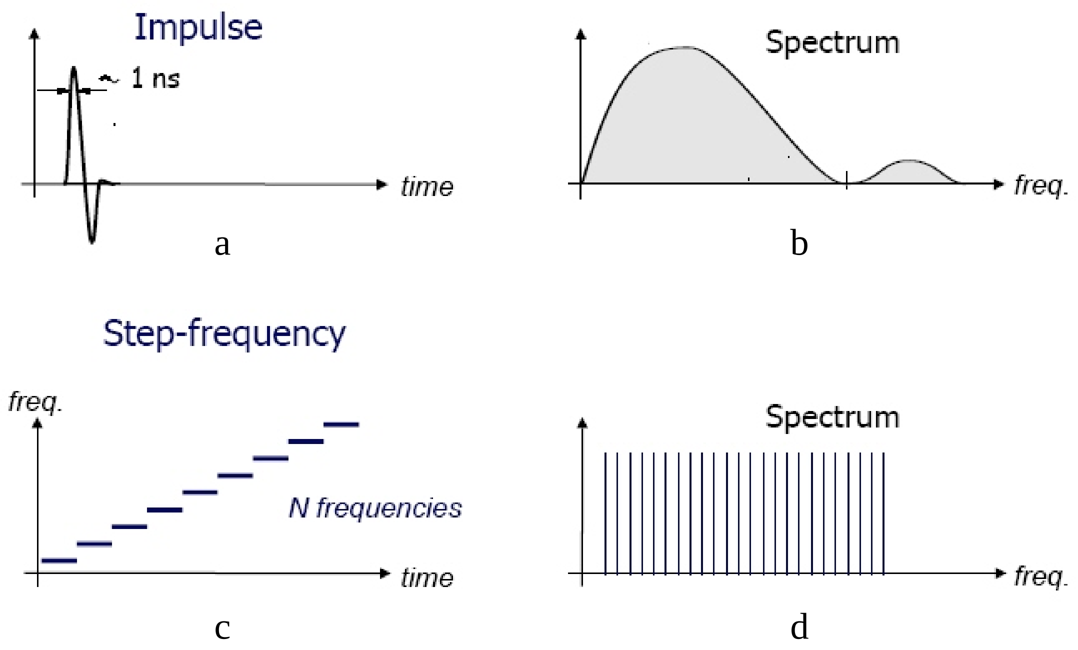


Figure 2. (a) Transmitted impulse (b) Corresponding analog frequency spectrum to impulse “a” (c) Step frequency output (d) digital frequency spectrum corresponding to output “c.”

interface) propagate back to the surface. An antenna detects the impulse reflections and a continuous analog response is subsequently recorded as GPR response data.

In contrast, Step Frequency GPR systems transmit electromagnetic sine waves into the pavement at discrete frequency intervals, (Figure 2c) which are reflected by layers within the pavement structure. The reflections from each discrete frequency sine wave are received (Figure 2d), processed, combined and digitally transformed to obtain GPR response data. Initially, this description does not provide an obvious reason why one technology may have advantages for a given application, but an analogy provides some useful insights.

In basic terms, Step Frequency GPR relies heavily on solid state, digital electronics to obtain its response data, while Ultra Wide Band GPR uses predominantly analog electronics to obtain its response data. An analogy that helps to illustrate the contrast between these two technologies compares two types of home stereo amplifier. One type of stereo uses solid state, digital audio amplifier electronics (Figure 3a) to provide a signal to the audio speakers that is converted to sound waves. The other type of stereo relies on analog tube technology (Figure 3b) to provide a signal that the audio speakers can convert to sound waves. Digital audio amplifiers use reliable, lightweight, efficient, solid state components to provide accurate, high quality sound reproduction that is typically cost effective. In contrast, tube amplifiers use less reliable, heavy, less efficient analog components that are typically relatively expensive. Analog amplifiers can be manufactured to produce accurate, high quality sound, but there are clearly substantial trade offs in component size, weight, efficiency and consistency relative to a solid state, digital amplifier with similar capabilities. In this analogy, both technologies perform many of the same

(a) (b)

Figure 3. (a) Example digital home audio amplifier (b) Example analog home audio amplifier.

required tasks, (in this case accurately reproducing and amplifying sound) but each technology accomplishes the task in a different way that has substantial trade off implications.

As detailed descriptions of the equipment used in this study will illustrate, this analogy provides insights into some of the reasons why a digital Step Frequency GPR system can be manufactured with an array of many, small synchronized antennas while an analog Impulse GPR system typically uses only a few, large antennas. Solid state electronics and digital signal processing techniques allow Step Frequency GPR to accomplish many tasks with smaller, lighter weight components than a standard Impulse GPR can. In addition, the sine waves that the Step Frequency GPR system transmits can be adjusted using digital programming options. This means that the Step Frequency GPR output sine waves can be tuned by manufacturers or users to meet specific needs through software programming. In contrast, Impulse GPR systems are tuned to meet specific needs by manufacturers and have limited adjustment capabilities.

Both Step Frequency GPR and Impulse GPR have advantages and trade offs. Therefore, their respective features and the results produced by both should be considered before deciding which technology is best suited to a particular application. Sections 4.1 and 4.2 provide background information on each technology, respectively. Both GPR technologies were used for pavement and infrastructure testing on the Natchez Trace Parkway and the results were incorporated into this study.

4.1 Impulse GPR technology

Impulse GPR has been used for a wide range of applications, from investigating geologic formations to locating and analyzing anthropological sites, (Daniels). In the past twenty years, pavement and infrastructure applications have also been developed using Impulse GPR technology, (Al-Qadi, Loulizi, Maser, Mesher, Scott, Willet). Impulse GPR offers an effective subsurface investigation technique that has important advantages over alternative techniques, such as acoustic sounding using the impact echo method, (Sansalone). One of the most important practical advantages of Impulse GPR for pavement and infrastructure applications is its effectiveness in highway traffic speed evaluations. Other than Step Frequency GPR, no other practical, subsurface investigation technique has been devised to make measurements such as pavement layer thickness, base course layer thickness, and concrete cover depth at such high speeds while detecting voids, subsidence and moisture concentrations at the same time.

For applications to large civil structures and pavements, Impulse GPR is typically implemented in a configuration similar to the one shown in Figure 4. Here, three antennas are mounted on the front bumper of a test vehicle. At a test vehicle location, each antenna individually transmits an incident radar impulse into the material below the antenna and receives corresponding reflected responses from material layer interfaces below the surface. Adjacent antennas such as those in Figure 4 must be configured properly to avoid interference between response signals. The three antennas shown in Figure 4 are used in order to provide a broad range of frequency spectrum capabilities for this Impulse GPR system. For any type of GPR, a low frequency impulse provides deep subsurface penetration and low-resolution detection capabilities. Conversely, a high frequency impulse penetrates only shallow depths but provides high-resolution detection capabilities. As the Figure 4 caption indicates, each antenna in this example system operates in a frequency range centered at a different frequency. The frequency range emitted by each antenna corresponds to the antenna size and geometry. High frequencies are emitted by the smallest aperture antenna in a typical impulse GPR system, (Figure 4a) while intermediate frequencies come from a larger aperture antenna (Figure 4b) and low frequencies are produced by the largest aperture antenna (Figure 4c).

Figure 4. Three impulse GPR antennas mounted on the front bumper of a typical test vehicle: (a) 1 GHz center frequency, (b) 500 MHz center frequency, (c) 250 MHz center frequency.

For an Impulse GPR system such as the one shown in Figure 4, the data from all of the antennas can be combined to provide information about materials and material interfaces at a broad range of depths. Of course, each of these three antennas collects data at a different position. Therefore, combining data from all of the system antennas provides an estimate of what is occurring below the surface at a particular vehicle test location. Figure 5 schematically represents approximate detection depths and regions of influence that each of the three Figure 4 Impulse GPR antennas responds to, (represented by wedge shaped areas bounded by lines). Solid areas represent depths where each type of antenna can typically provide optimized resolution.

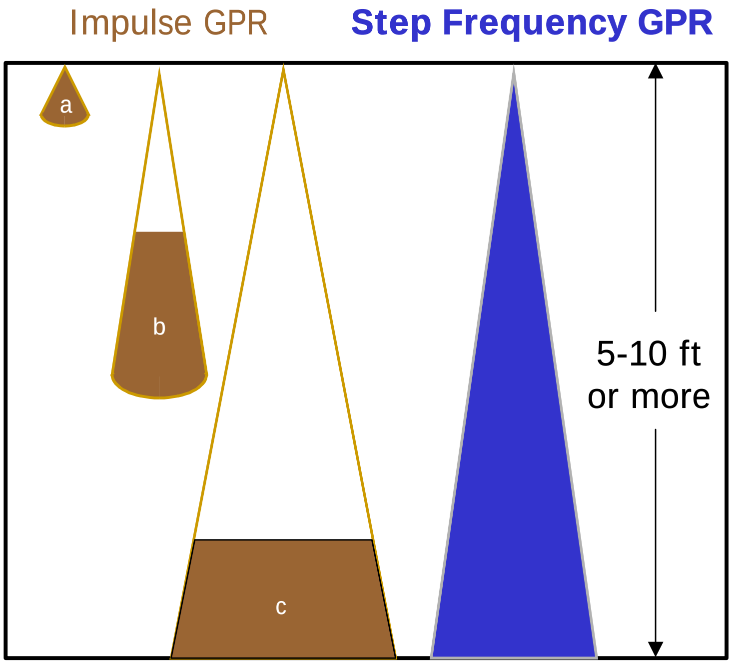


Figure 5. Schematic representation of penetration depth capabilities of Impulse GPR and Step Frequency GPR antennas, (a) 1GHz Impulse GPR antenna, (b) 500 MHz Impulse GPR antenna, (c) 250 MHz Impulse GPR antenna, (blue area) Step Frequency GPR antenna.

It is notable that the three impulse antennas discussed in Figures 4 and 5 are optimized to detect features most effectively at depths that are not contiguous or overlapping. Therefore, there are gaps in the depth resolution where this system cannot detect features optimally. In contrast, Section 4.2 describes how Step Frequency GPR can achieve optimal resolution at a full range of depths with a single antenna, (Figure 5). As a result, for most applications, Step Frequency GPR technology has the potential to provide better resolution over a wider range of depths than Impulse GPR. Testing both types of GPR for a specific application allows the technologies and manufacturer implementations to be compared for this performance characteristic, among others. Specifications for the Impulse GPR hardware used in this study are presented in Appendix A.

4.2 Step frequency GPR technology

Step Frequency GPR capabilities differ from Impulse GPR capabilities in two basic ways. First, a single Step Frequency GPR antenna can evaluate material at a broad range of depths. Impulse GPR would require three or more antennas to evaluate the same depth range, (Figure 5). Second, Step Frequency GPR can be readily implemented in a compact antenna array configuration that provides a large number of antennas for tomographic imaging. In contrast, Impulse GPR can also be implemented using an antenna array, but an equivalent Impulse GPR array must be both heavier and bulkier than a Step Frequency GPR array. The differences between Step Frequency GPR and Impulse GPR capabilities result from the contrasting approaches each technique takes to transmitting and receiving radar signals. The hardware requirements are substantially different for each technique as a result of these distinct approaches.

Instead of transmitting a single impulse that contains a broad range of frequencies, as Impulse GPR does, Step Frequency GPR transmits a stepped series of “N” sine wave frequencies over specified dwell times, (Figure 6).

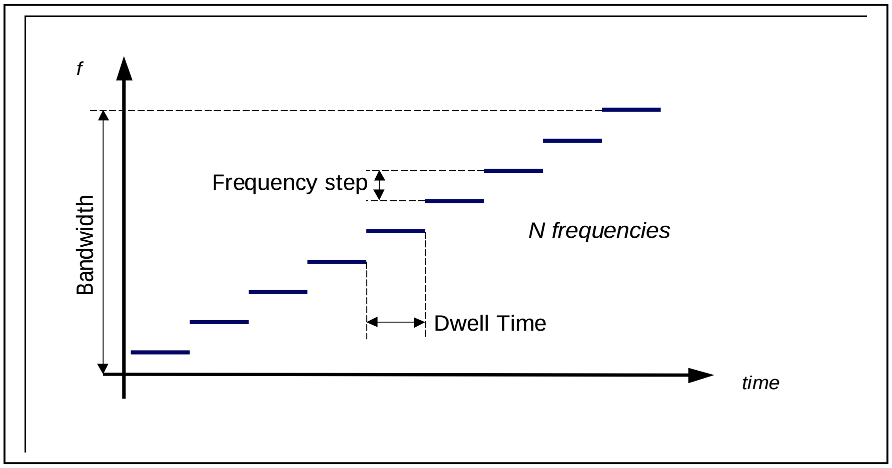


Figure 6. Step-frequency waveform. The main parameters for a step-frequency waveform are the dwell time per frequency, the frequency step size, and the total number of frequencies leading to the total radar frequency bandwidth.

These short pulses are used to transmit radar energy into the ground at specified frequencies that can be programmed by the system manufacturer or user, (depending on the hardware implementation). Reflected pulses are received and recorded during the dwell time of each step and are subsequently processed and transformed from a frequency based data format into a time based data format. The time based data is then in the same format that is familiar to Impulse GPR users and can be processed and displayed in the same way Impulse GPR data can. If the Step Frequency GPR system is implemented in an array configuration, the data can also be processed to produce tomographic images of subsurface features. A larger, heavier Impulse GPR array can be used to produce similar tomographic images of subsurface features.

The components of the Step Frequency GPR used in this study include an antenna array, integrated radar and computer, and a wireless laptop computer for system control, (Figure 7).

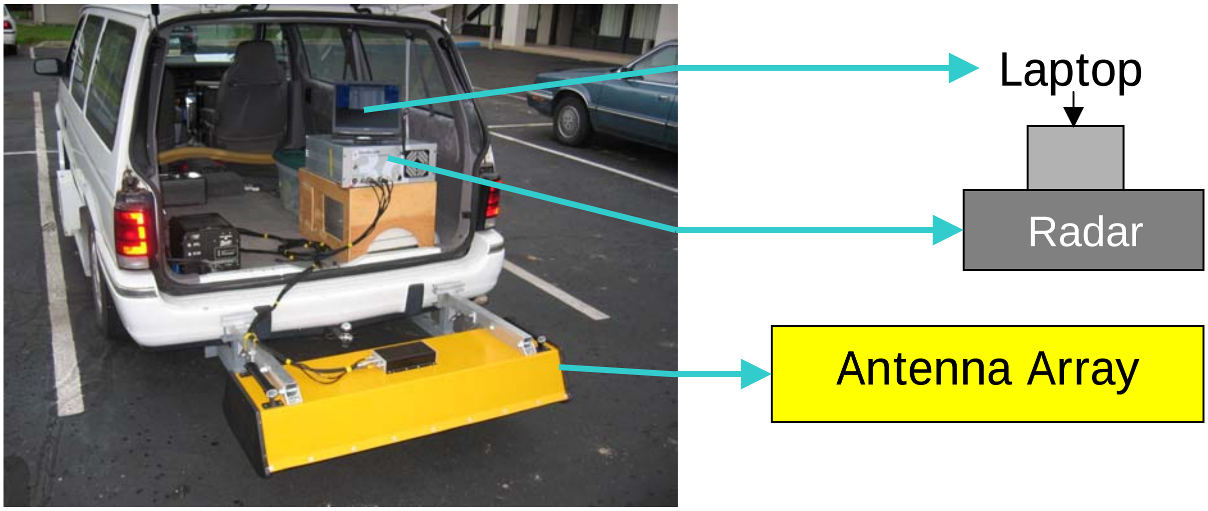
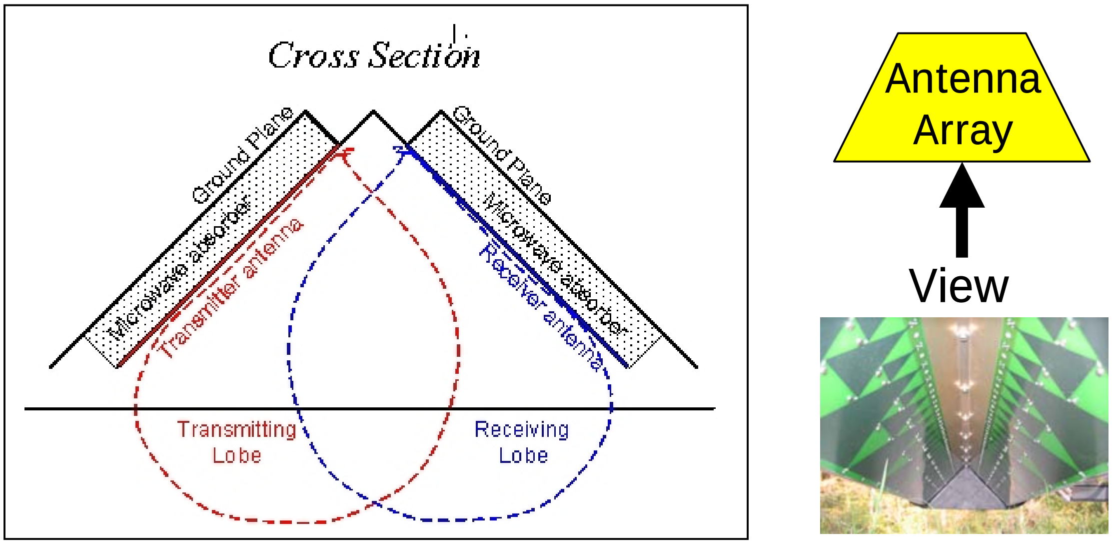


Figure 7. Step Frequency GPR system components {Appendix B}.

This Step Frequency GPR hardware runs on 12 Volt DC power provided by a typical vehicle electrical system. The antenna array can have between thirty one and sixty three elements, depending on the width of the array and the antenna spacing. Each array element consists of a transmitter antenna and a receiver antenna (Figure 8a). A large number of triangular shaped transmitter and receiver antenna elements are pictured in Figure 8b, viewed from underneath the antenna array, (also shown schematically). The largest triangle shaped transmitter and receiver



(a) (b)

Figure 8. Step Frequency GPR antenna array (a) end view schematic (b) underside view.

pairs are capable of producing broad bandwidth signals with depth resolution corresponding to the Step Frequency GPR response depicted in Figure 5 (blue area). There are seven of these largest antennas in this particular array. The additional small and intermediate size antenna pairs are used separately to produce high frequencies and moderate up to high frequencies, respectively. Data from all thirty one antenna pairs can be combined using computational methods to produce tomographic images. Example tomographic data collected using this system are presented in Figure 9. The three dimensional data volume bounded in yellow presents an image of reconstructed GPR data between two feet deep and three feet deep below a tested pavement. The top layer exposed in the image presents features at a depth of 2 feet and has two specific features of interest. The first feature is an image of a buried pipe in an area bounded by a blue box, (Figure 9a). A two dimensional enlarged view of the same pipe is also shown with each end of the buried pipe indicated by a green arrow, (Figure 9b). A second feature, where moisture is believed to be concentrated due to irregularities in the pavement subbase, is highlighted in an aqua colored box. Figure 9c, presents an enlarged view of subsurface irregularities in the pavement subbase, (circled areas).

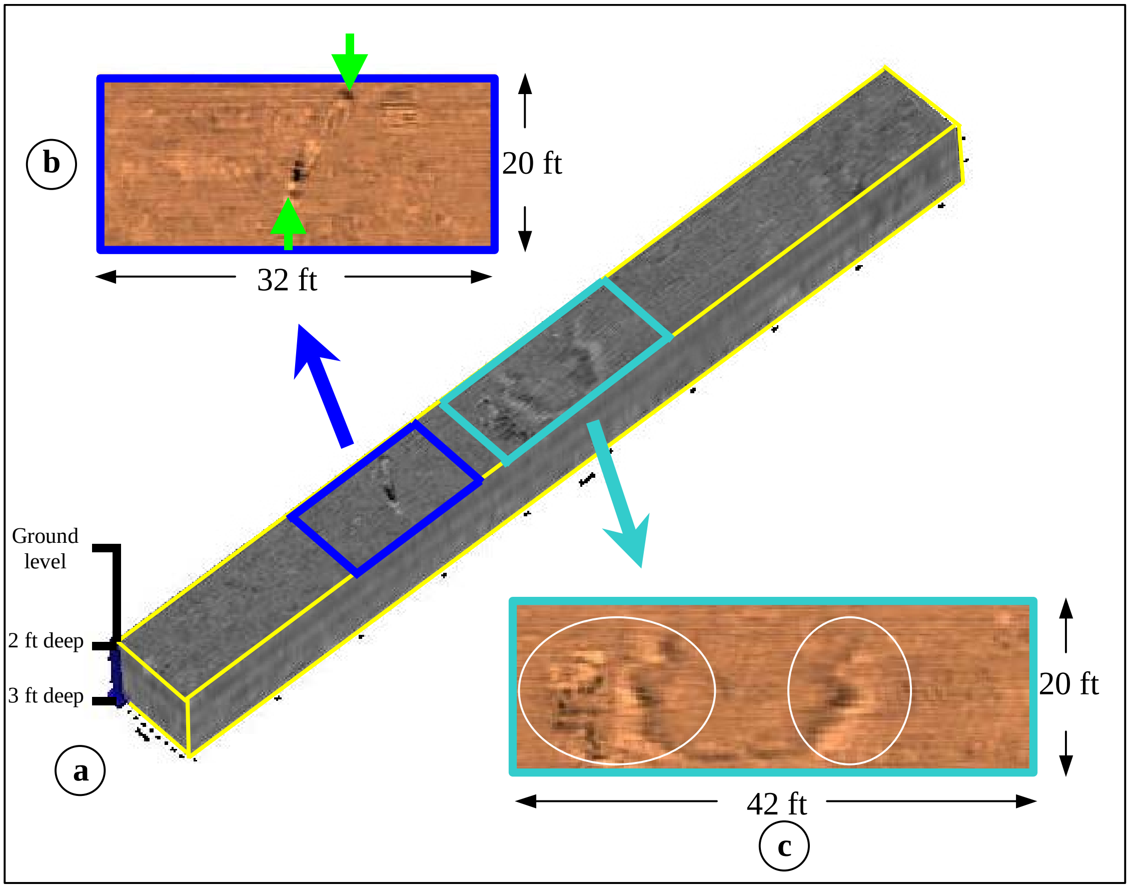


Figure 9. Tomographic images of step frequency ground penetrating radar data, (a) 2 ft deep data slice shown in 3D context with, (b) enlarged 2D view of pipe between two green arrow indicators and, (c) enlarged 2D view of irregularities in pavement subbase material.

Step Frequency GPR technology permits efficient antenna arrays and solid state hardware to be used in configurations that weigh less and take up less space than standard Impulse GPR. However, until recently, Step Frequency GPR was not available for pavement and infrastructure evaluation. Before this recent change, Impulse GPR was the only high speed technology available for nondestructive evaluation of pavements and roads. This study presents results from the first large-scale infrastructure evaluation test carried out with Step Frequency GPR in the United States.

5. Field Test Description

Two types of GPR technology were evaluated in this study. Data was collected from identical locations using both systems to illustrate the relative capabilities of the two instruments.

The Step Frequency GPR system was tested in three different modes, where high speed data was collected using three antennas (at 55 mph), moderate speed data was collected using 7 antennas (at 20 mph) and low speed data was collected using 31 antennas (at 5 mph or below). All moderate and low speed testing was conducted using traffic control. Additional antennas were used in the slower speed tests to allow more detailed data to be collected.

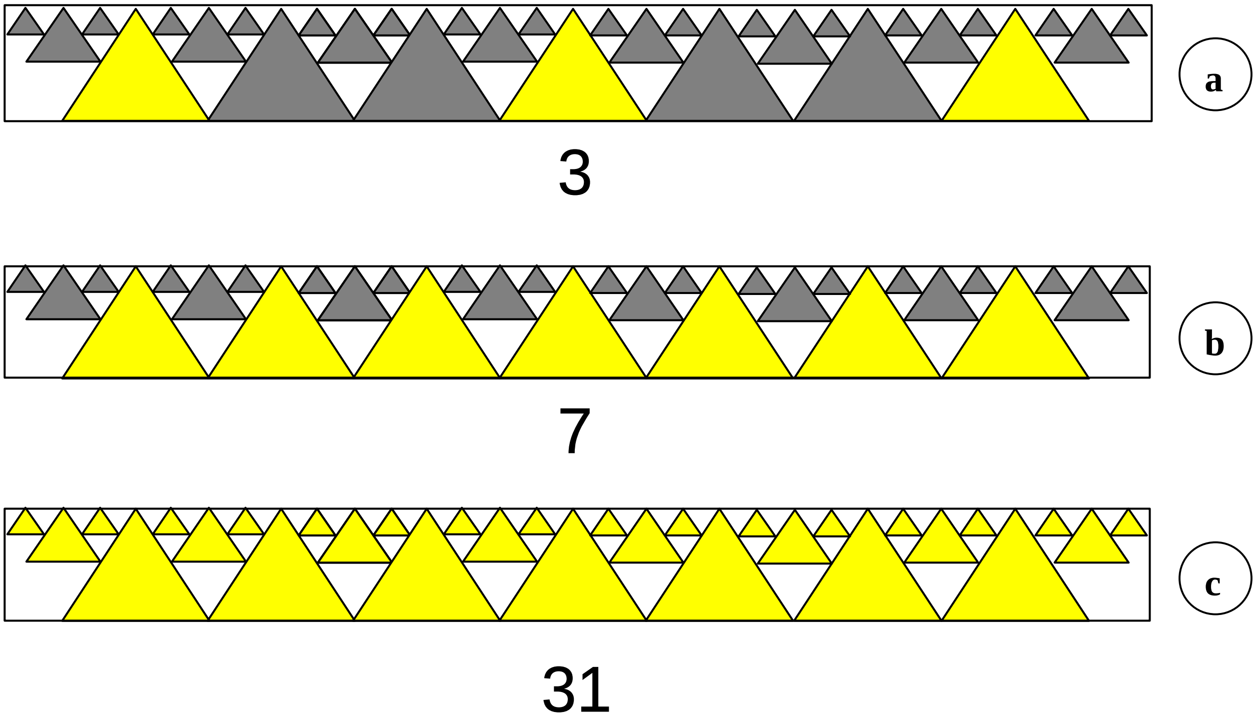


Figure 10. Schematic illustration of a Step Frequency GPR antenna array used for (a) high speed (55 mph) scanning using three antennas, (b) moderate speed (20 mph) scanning using seven antennas and (c) low speed scanning using 31 antennas. For each configuration, yellow triangles represent antennas in use, while gray antennas are not in use.

Impulse GPR data was always collected in the same way, using two different antennas at relatively high speed (40 mph). Impulse GPR offered few options for detailed data collection with additional antennas. However, it is notable that a single ground coupled, low frequency GPR antenna can be used with the Impulse GPR system at slow speeds. For this trial, it was not used due to practical logistical considerations. The same 11.3 mile test section was used for high speed tests of both systems. Within the 11.3 mile test section, five sites were selected for moderate and slow speed data collection using Step Frequency GPR.

The Natchez Trace Parkway site used for this test is a scenic, two-lane road, predominantly supported by clay base materials. These clay materials were described by Roderick Banks as “Jackson clay, one of Nature’s most active clays.” According to Banks, innovative techniques were used to control the clay on the Natchez Trace Parkway during its construction, but it was difficult to work with. These clays were a significant factor during the GPR trial because they attenuate GPR propagation, limiting penetration depth relative to dry, sandy or rocky soils. Never the less, many useful results were obtained.

Specific subsurface features were notable at each of the five sites where detailed data was collected using Step Frequency GPR. As required by the GPR trial work plan, these sites included culverts, a drain pipe and bridges. The five sites are described in the following summaries:

5.1 Site 1

Site 1 was a 0.5 mile section of the Natchez Trace Parkway traversing from the Natchez Trace Parkway entrance ramp at Mississippi State Route 27 and extending to mile post 67, (Figure 13). This section was of specific interest due to the large amounts of fill material used to build up the road elevation and make it level. The results from the Impulse GPR data that were collected prior to the Step Frequency GPR trial provided additional evidence that interesting subsurface features could be detected in this area. A core was obtained by EFLD at mile post 67

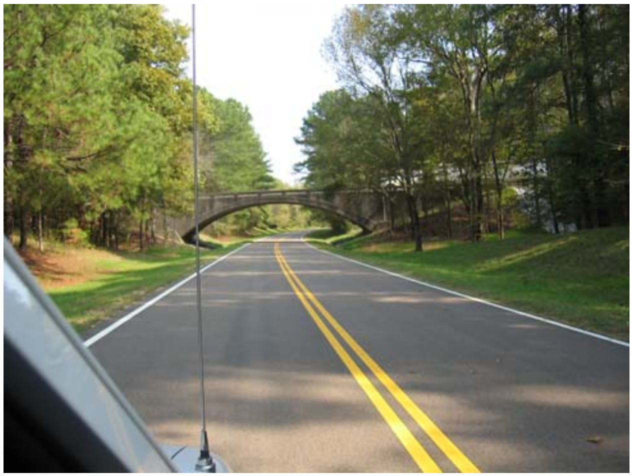


Figure 13. Site 1 roadway, near mile post 67.

two weeks prior to the test. Measurement data will be made available from this core for future analysis.

5.2 Site 2

A section of the Natchez Trace Parkway that traverses a culvert near mile post 69 was selected as Site 2 to compare the depth detection capabilities of both GPR systems. In addition, this site was selected to determine how effective each system was in providing additional information about the culvert, such as its geometry and size. A site schematic is provided in Section 6.

Figure 14. Site 2 culvert, near mile post 69.

5.3 Site 3

Site 3 featured a 1.5 ft drainage pipe that was selected to test depth detection capabilities as well as geometry and orientation characterization capabilities, (Figure 15). The small diameter of the drainage pipe and the relatively deep position of the pipe made it a useful test target for the GPR comparison.

Figure 15. Site 3 pipe, near mile post 70.

5.4 Site 4

Site 4, pictured in Figure 16, was selected due to the proximity of two closely spaced features, a bridge and a culvert that were only a few hundred feet apart. The bridge contained six spans and the culvert had four partitioned sections. A site schematic is provided in Section 6.

(a) (b)

Figure 16. Site 4 bridge (a) and culvert (b) south of mile post 73.

5.5 Site 5

Site 5 is a 3 span bridge at mile post 72 that includes a cast in place concrete bridge deck and concrete beams with an arch geometry. The bridge is built in a skew configuration and also includes large scupper drains. A core was obtained from the approach to the bridge two weeks prior to the test, and Figure 17 shows this location. A site schematic is provided in Section 6.

Figure 17. Site 5 bridge at mile post 72.

6. Field Test Results

A substantial amount of GPR data was collected during the course of the Step Frequency GPR survey conducted for this study and for the Impulse GPR survey that was also included. For the basic comparison required in this analysis, (calibration cores and falling weight deflectometer (FWD) data were not available yet) GPR data from each of the five site locations described in Section 5 was used as the primary means for comparison. Each site has features of specific interest that can be measured or characterized. For all of these sites, high-speed data from both instruments, (collected at the roadway speed limit) will be compared. In addition, moderate and low speed data collected with the Step Frequency GPR at these same sites will also be compared. Together, the comparisons will illustrate the unique capabilities of both GPR systems included in the study.

6.1 Site 1 Result

Site 1 test results demonstrate the unique features of data from both types of GPR systems included in this study by illustrating penetration depth, response quality and data presentation options. For example, Figures 18 and 19 illustrate subsurface variation in the depth of subbase fill material used to build the road up over the existing subgrade along a segment of Site 1. Figure 18 presents data from an Impulse GPR system while Figure 19 presents data from a Step Frequency GPR system. Both figures present a typical response from each respective type

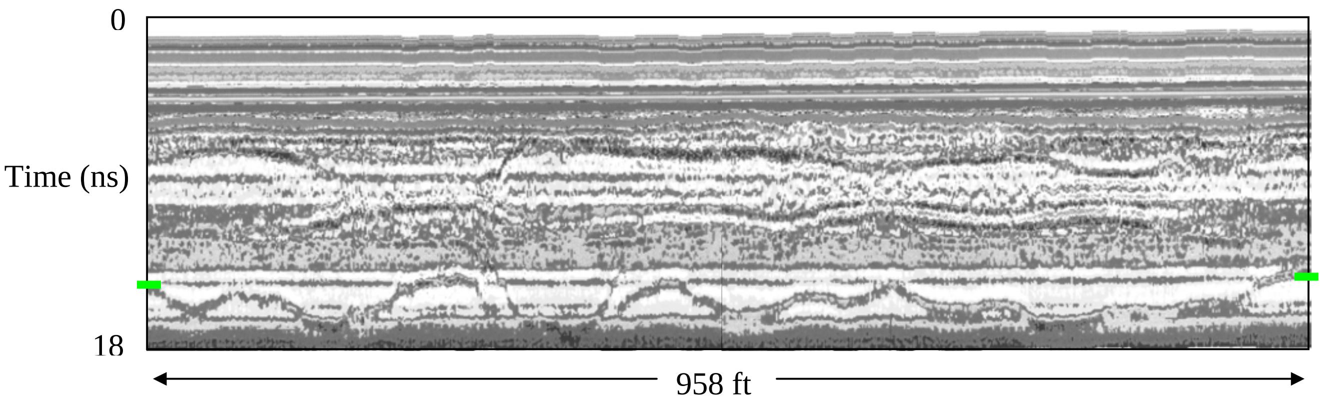


Figure 18. Impulse GPR data from Site 1, (1 GHz antenna).

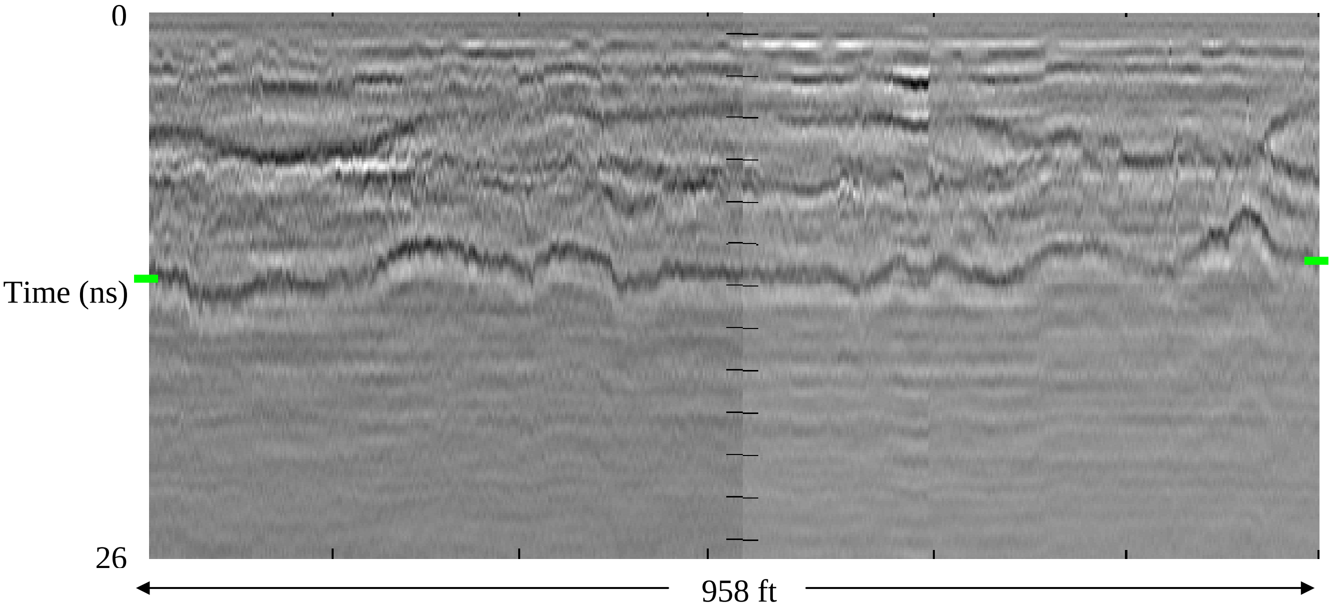


Figure 19. Step Frequency GPR data from Site 1 (data corresponding to Figure 18).

of GPR. In both figures, the length dimension represents position along the survey roadway. Likewise, the time dimension represents the time required for a GPR signal to travel from the transmitter antenna to a feature in the ground and back to the receiver antenna. This total travel time can be correlated with depth if the materials under investigation can be well characterized. The color of the GPR responses shown in both figures corresponds to the magnitude of the response. Extreme dark and light colors represent high magnitude responses to features, while neutral gray tones indicate no substantial feature response. Using typical estimates for pavement material properties to evaluate both GPR survey results, the depth of roadway subbase material varies from approximately 2 feet deep down to 5 or more feet deep along Site 1. The GPR response to the interface between the subbase material and the subgrade material is indicated by green hash marks at both ends of the survey travel distance, (958 ft) represented in Figures 18 and 19. The subbase to subgrade interface response traverses both Figures as a continuous dark colored feature that changes position substantially along the time axis as it traverses from the left green hash mark indicator to the right green has mark indicator. Figure 20 illustrates an analysis

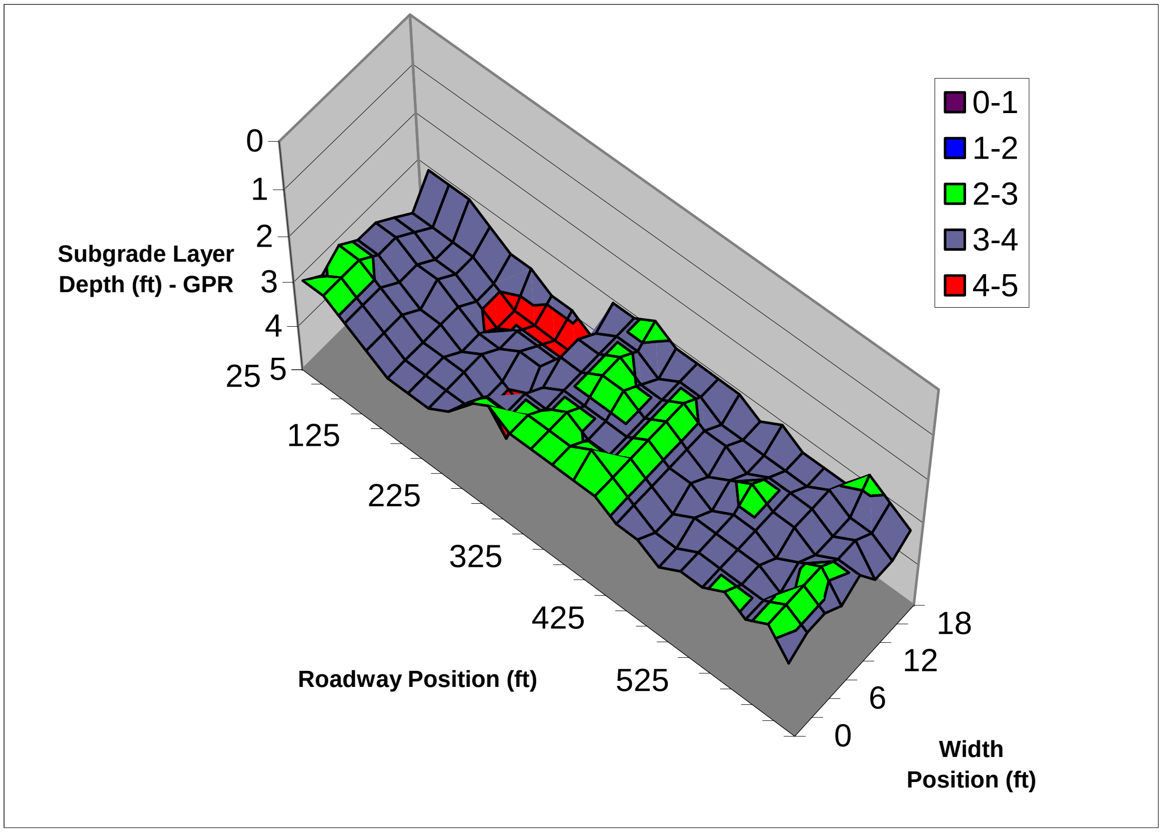


Figure 20. Step frequency GPR data analysis of Site 1 subbase thickness.

of GPR data from Site 1 that has been converted from a time basis (such as Figures 18 and 19) to a depth basis through appropriate calculations. Roadway material thickness, such as the subbase thickness, can be derived from raw GPR data by calibrating or using an engineering estimate.

Step Frequency GPR data collected using the array tested in this study can be analyzed in three dimensions, as the need arises. Figure 20 shows an example analysis of subbase material thickness in an area of Site 1 that corresponds to an over 500 ft length of roadway. In this figure, the subbase thickness was calculated at each position across the two lane roadway using data from an array of Step Frequency GPR antennas and an estimated calibration constant. The result is a simple plot of subbase thickness for the roadway area corresponding to the analyzed section. As the plot legend indicates, subbase thickness is color coded green where it is thin, gray where it has a moderate thickness and red where it is thick. It is notable that this three dimensional analysis allows "bowl" shaped areas to be identified. "Bowl" shaped areas occur where the pavement subbase is thicker near the middle of the roadway than at the edge of the roadway. These "bowl" shaped areas have a higher potential to collect moisture than others and can be useful to identify in pavement evaluation and inventory applications. Three "bowl" shaped areas a foot or more deep can be observed in the Figure 20 plot.

Both Impulse GPR and Step Frequency GPR systems used in this study can also be compared in terms of artifacts and noise within the data they produce. Although a detailed analysis of these issues was not performed for the purposes of this trial, qualitative observations of artifacts due to phenomena such as signal ringing were observed in both data sets. For GPR practitioners, the term signal ringing describes an artifact in GPR data where a response to a shallow feature "echoes" and repeatedly overlaps onto responses to deeper features. Qualitative examination of data sets from this GPR trial indicates that the Step Frequency GPR response had fewer artifacts than the Impulse GPR response. For example, Figure 18 exhibits significant ringing that can be observed as consistent, horizontal dark colored band traversing between the two green hash marks shown. This feature is an artifact of signal ringing and can mask responses to real features represented in the data. Step Frequency GPR data from the same Site 1 location does not exhibit this feature between its two corresponding hash marks in Figure 19.

Finally, it is notable that the data in Figure 18 and Figure 19 display similar features at corresponding times and therefore corresponding depths. However, the features do not always track perfectly between the two data sets along the length of the roadway. This is hypothesized to be due to a minor position offset between the path of the Impulse GPR antenna and the selected Step Frequency GPR antenna as they traveled down the road. Minor stationing discrepancies in locating prominent features in each data set, such as bridges and culverts, and excellent repeatability during the Step Frequency GPR testing support this hypothesis. Both systems performed well on Site 1, but the convenience of performing three dimensional imaging using the Step Frequency GPR system was a distinct advantage it demonstrated over the Impulse GPR system.

6.2 Site 2 Result

Example Impulse GPR data and Step Frequency GPR data from Site 2 are presented in Figures 21, 22 and 23. These figures illustrate an Impulse GPR response to a culvert feature beneath the road and a Step Frequency GPR response to the same culvert feature. Figure 22

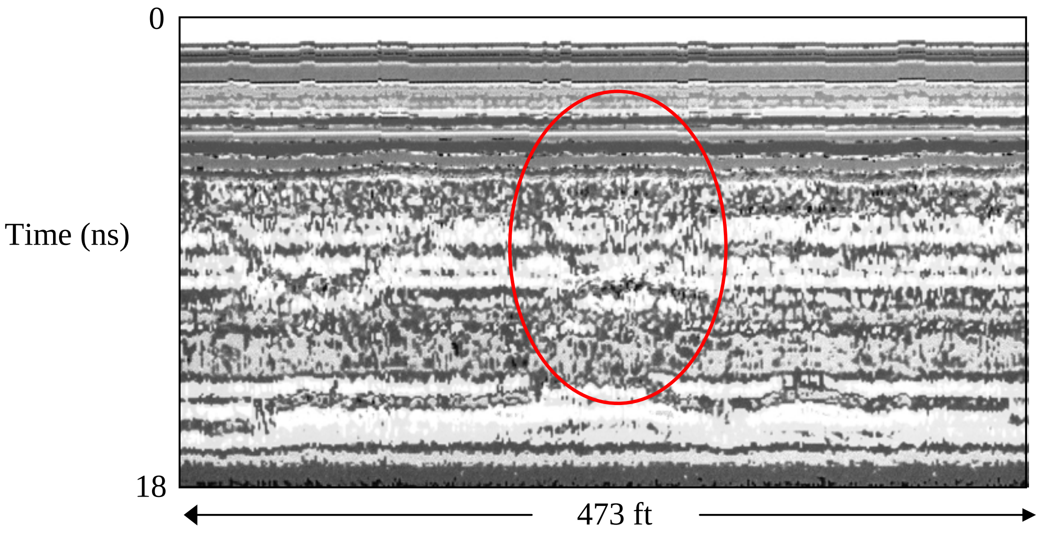


Figure 21. Site 2 Impulse GPR data (single box culvert) using 1 GHz antenna.

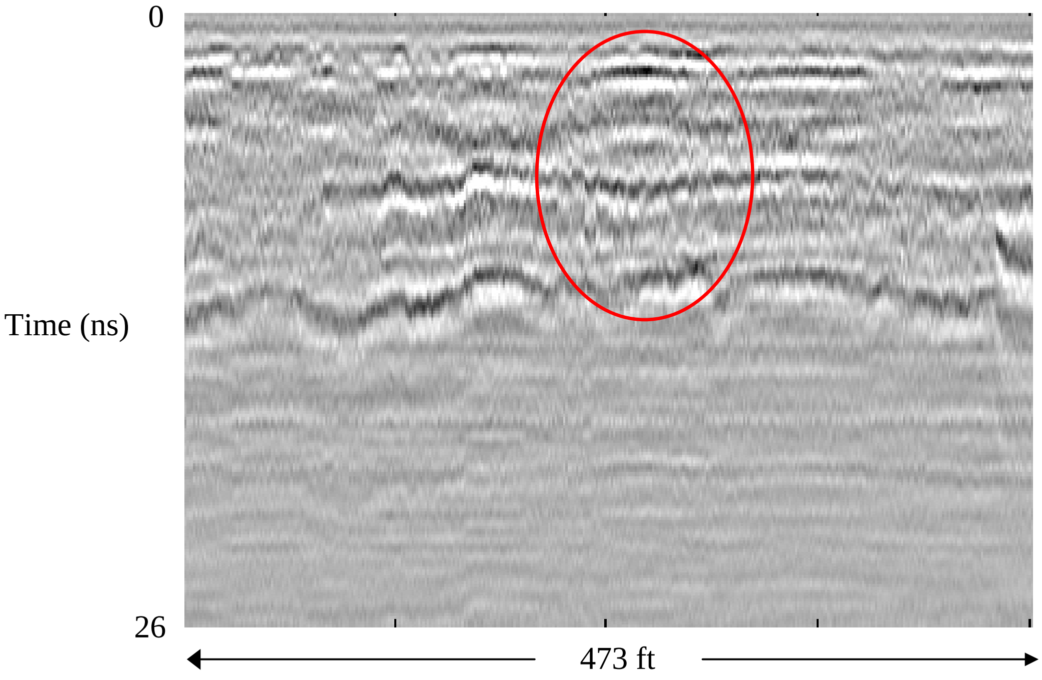


Figure 22. Site 2 Step Frequency GPR data, (single box culvert).

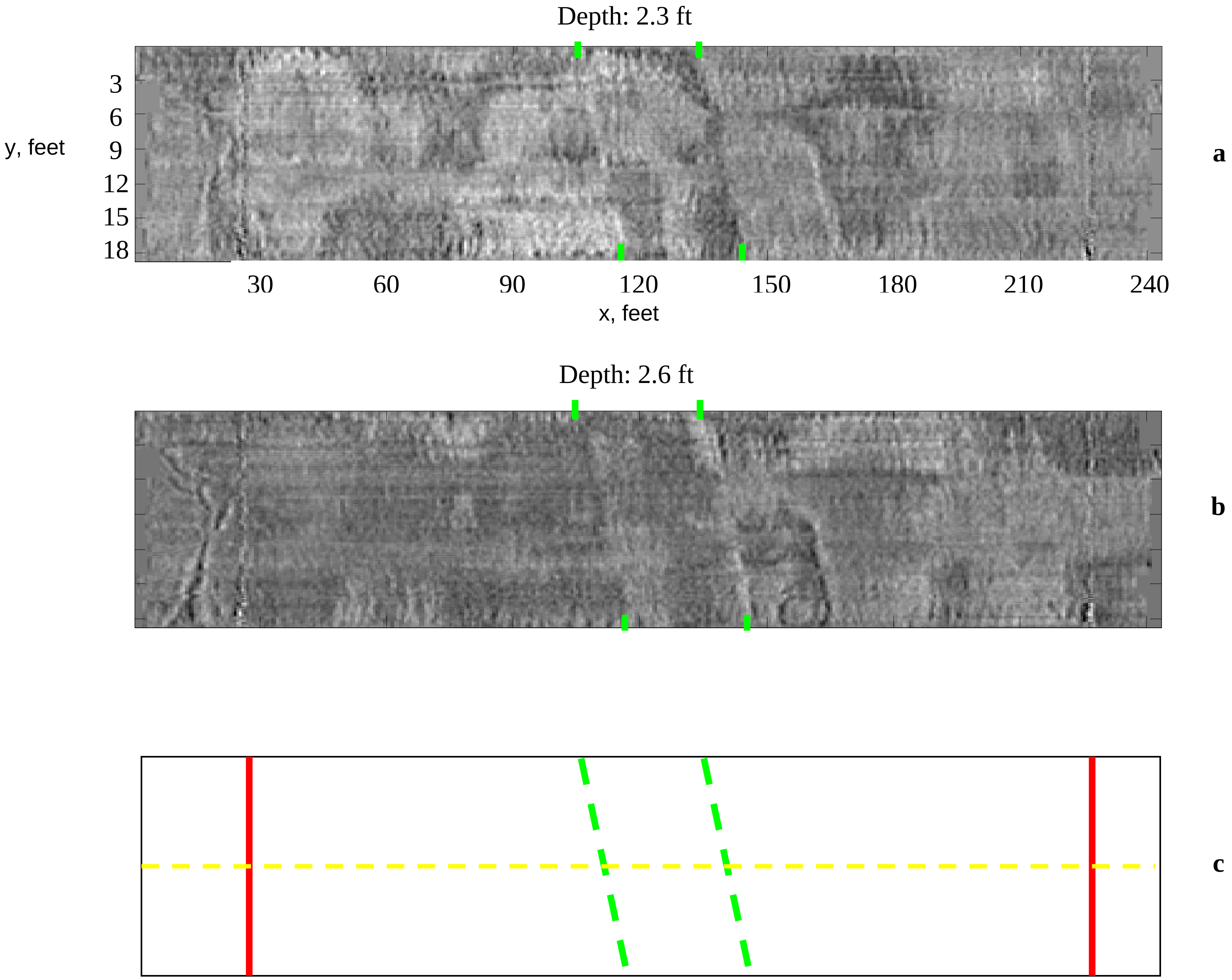


Figure 23. Plan view Step Frequency GPR images of a single box culvert, (a) plan view Step Frequency GPR data at 2.3 ft depth, (b) plan view Step Frequency GPR data at 2.6 ft depth, (c) plan view schematic of roadway with location of yellow centerline, red test site begin and end markers, and green dashed lines denoting culvert boundaries, (note the skew of the culvert).

provides simple, tomographic images of the collected data that will be discussed further. Figure 20 presents Impulse GPR data collected from the same culvert location, where the response to the culvert is indicated by a red, circled area. A corresponding plot of Step Frequency data in Figure 21 provides a clearer response to the culvert, (also circled in red). Both Figure 21 and 22 present data in a two dimensional format, where the vertical axis corresponds to time, (which can be converted to depth through a calibration calculation).

Figure 23 presents two Step Frequency GPR images of the same culvert detected in Figures 21 and 22, but these images are plan view tomographic slices. Each of these slices presents subsurface data from a particular depth below the road surface. Therefore, each slice comes from a plane that is parallel to the roadway surface. Depending on the depth, each slice cuts through different features of interest. Schematically, Figure 23c designates the locations of roadway surface features at the culvert data collection location such as the yellow, two-lane roadway centerline. In addition, test site begin and end markers are shown in red and subsurface culvert boundaries are designated with green dashed lines. The green dashed lines in the schematic correspond to the culvert boundaries observed in both image slices, depicted in Figures 23a and 23b. It is notable that the skewed geometry of the culvert relative to the road is accurately imaged based on site measurements. It is also useful to observe that substantial variations in soil characteristics can be observed between the images from each of the two sample depths depicted, (note variations in response magnitude). Although the Impulse GPR system produced useful response data from the Site 2 culvert that has some engineering value, it was limited. In contrast, the culvert position, size and orientation measurements could all be derived from Step Frequency GPR tomographic image data. This data can be used intuitively by an engineer.

6.3 Site 3 Result

The 1.5 ft diameter drainage pipe target at Site 3 was the most challenging to detect and image for the two GPR systems tested. The GPR signal attenuation caused by the clay soils, (throughout the Natchez Trace Parkway GPR trial survey section), became particularly apparent when the small diameter pipe, buried approximately 3 feet below the ground, was scanned using both the Impulse GPR and Step Frequency GPR. Both GPR systems detected the pipe, as the

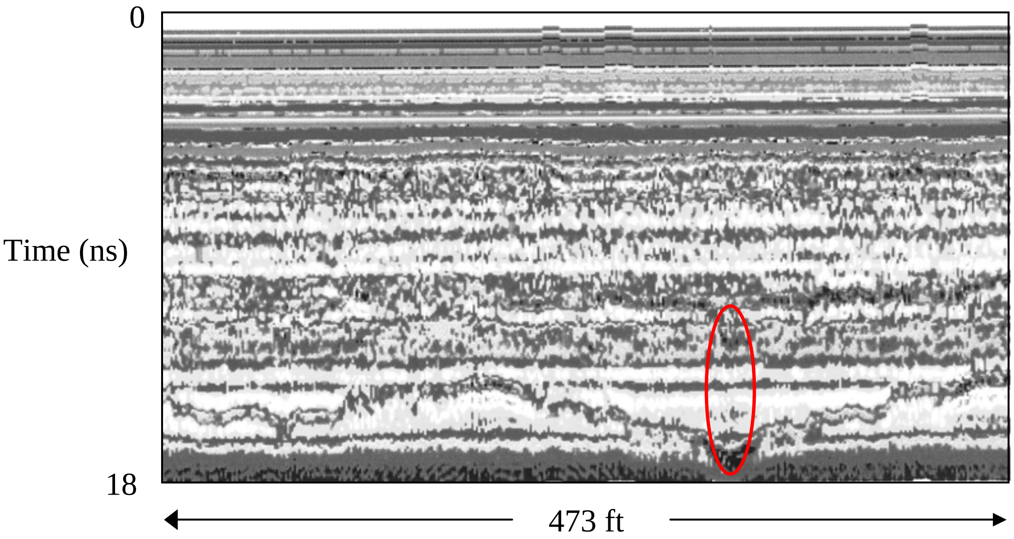


Figure 24. Impulse GPR response to Site 3 drainage pipe (1 GHz antenna).

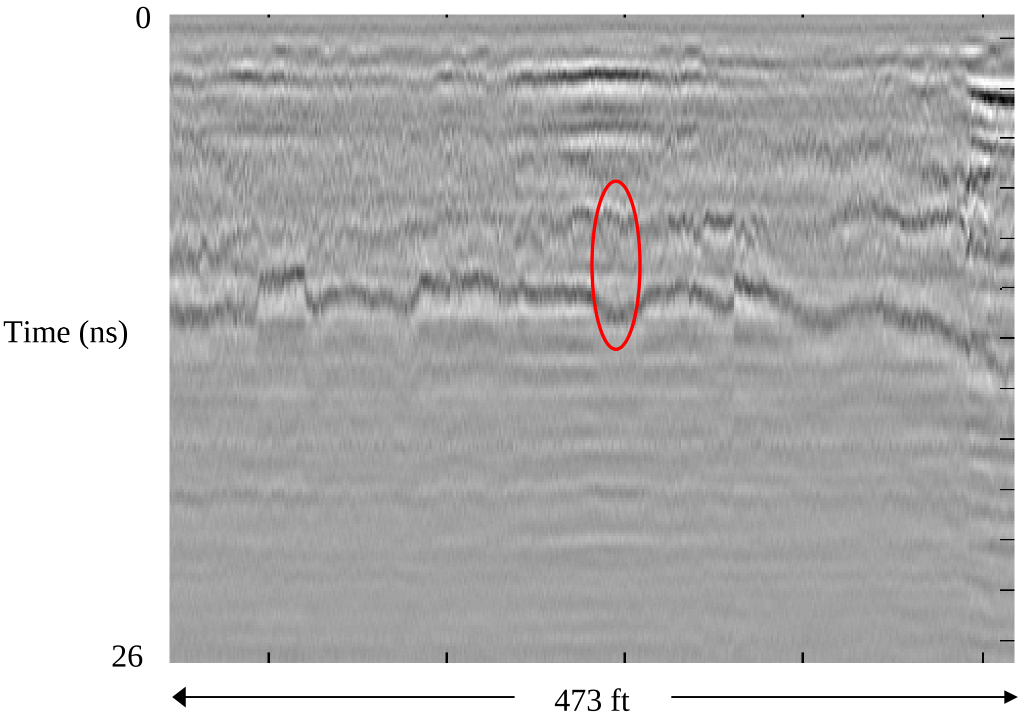


Figure 24. Step Frequency GPR response to Site 3 drainage pipe.

designated responses (circled in red) in Figures 23 and 24 show, respectively. However, the GPR response data from both systems was difficult to interpret due to the low amplitudes of the response data. Data interpretation was improved by Step Frequency GPR imaging, (Figure 25) but the true geometry and orientation of the pipe were not determined by either GPR technique.

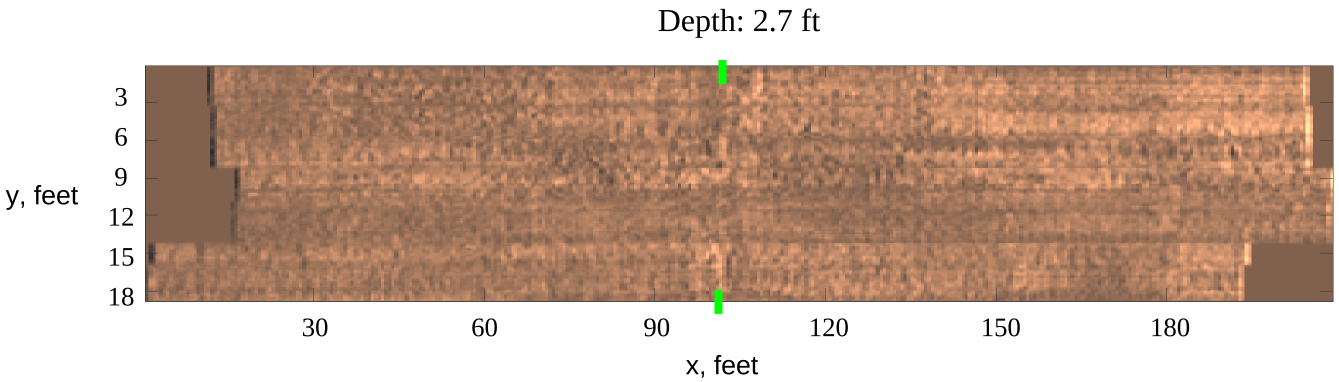


Figure 25. Image of Site 3 pipe - poor response signal attributed to attenuation in clay soil, among other potential factors.

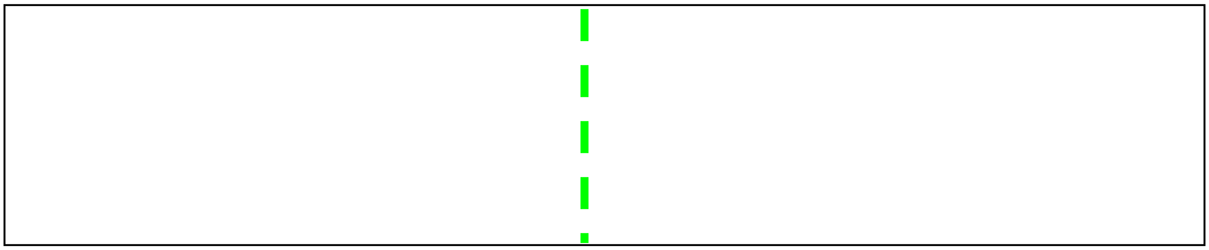


Figure 26. Schematic drawing of Site 3 drainage pipe, with pipe location designated by the green dashed line.

6.4 Site 4 Result

A bridge and a culvert with four large openings were both evaluated at Site 4. The results from the bridge showed that both GPR systems could effectively detect and identify the basic elements of the bridge deck, including the beginning and end of the bridge as well as the bridge

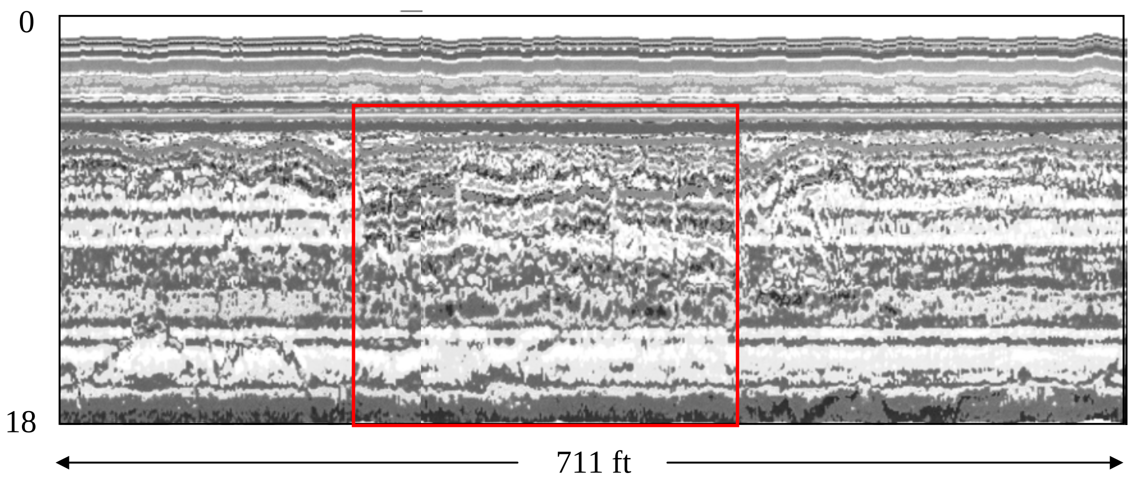


Figure 27. Site 4 Impulse GPR data from a bridge deck, (bridge deck response boxed in red).

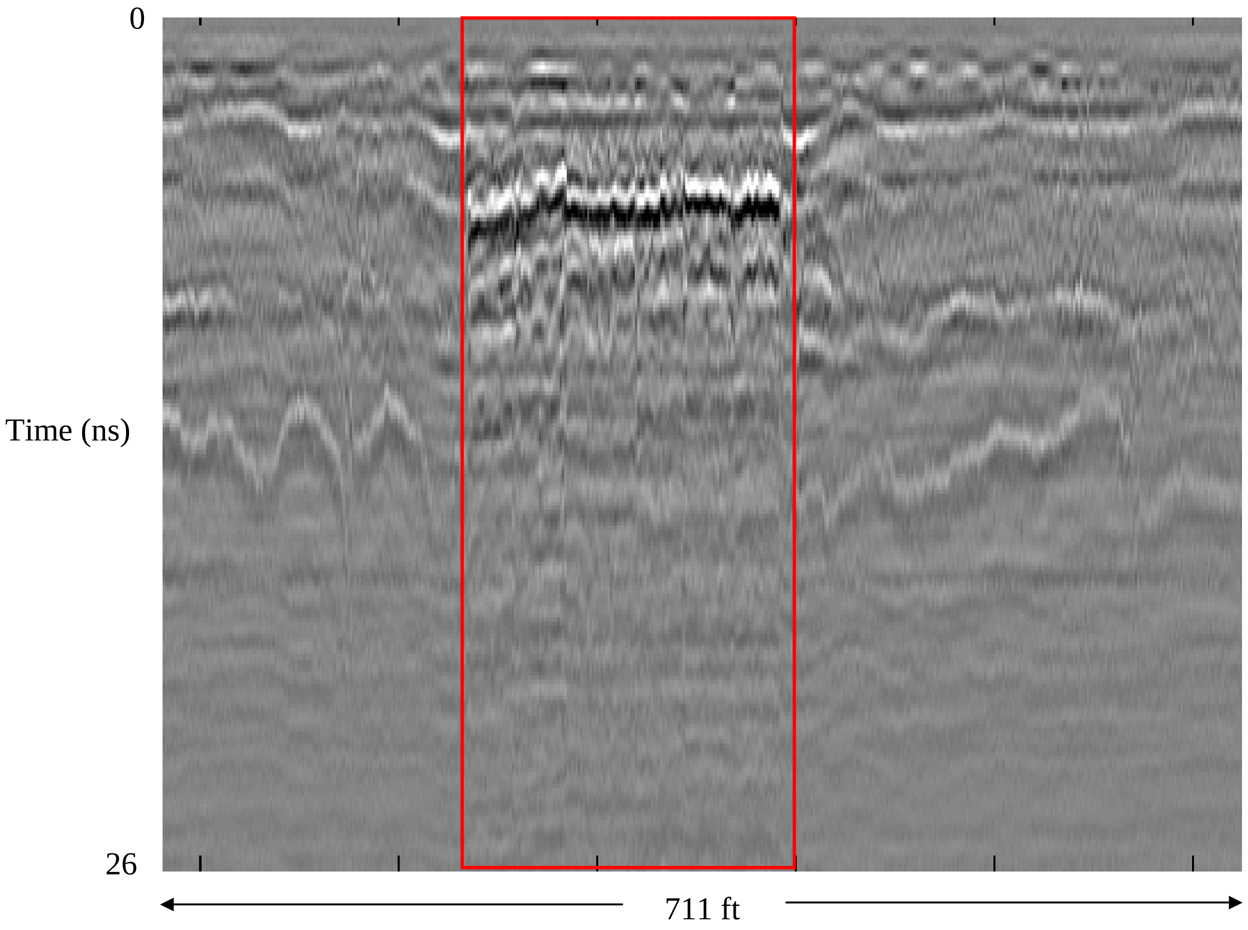


Figure 28. Site 4 Step Frequency GPR bridge deck data, (bridge deck response boxed in red).

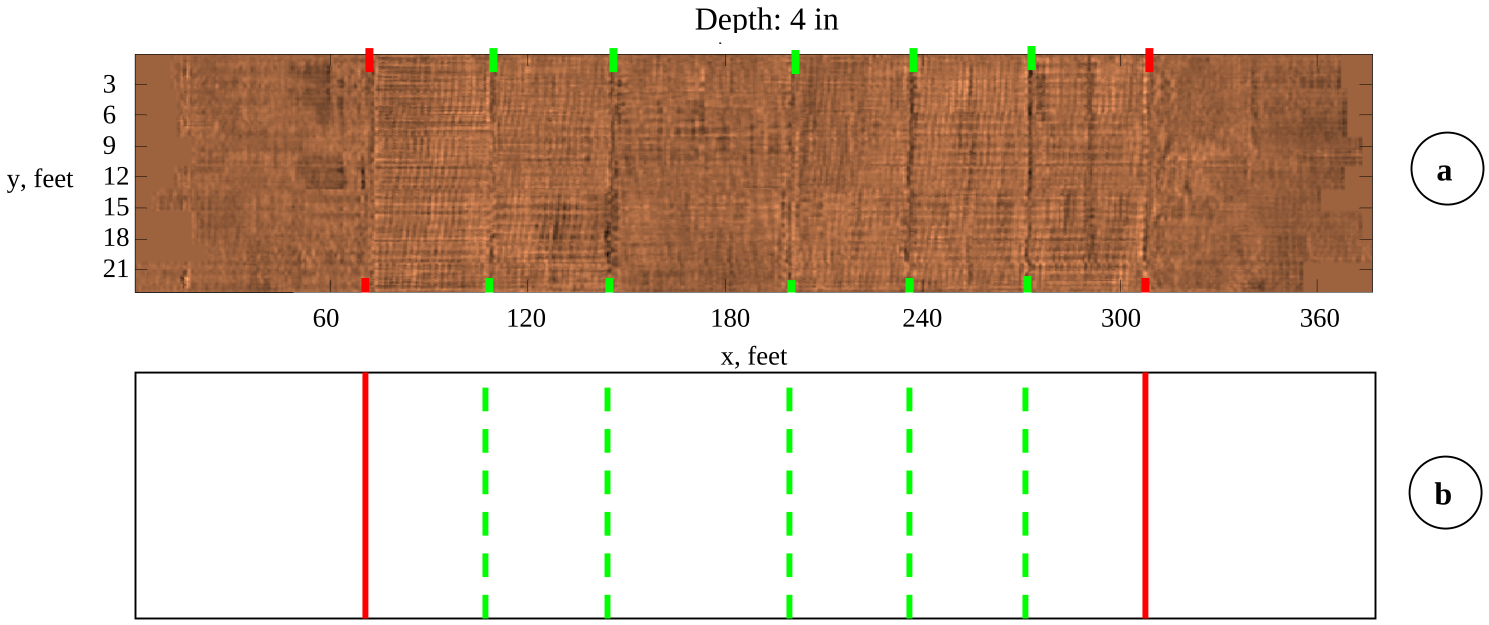


Figure 29. (a) Plan view rendering of subsurface bridge deck features from site 4 bridge deck, including bridge joints in green, (note reinforcing steel pattern within each span), (b) schematic.

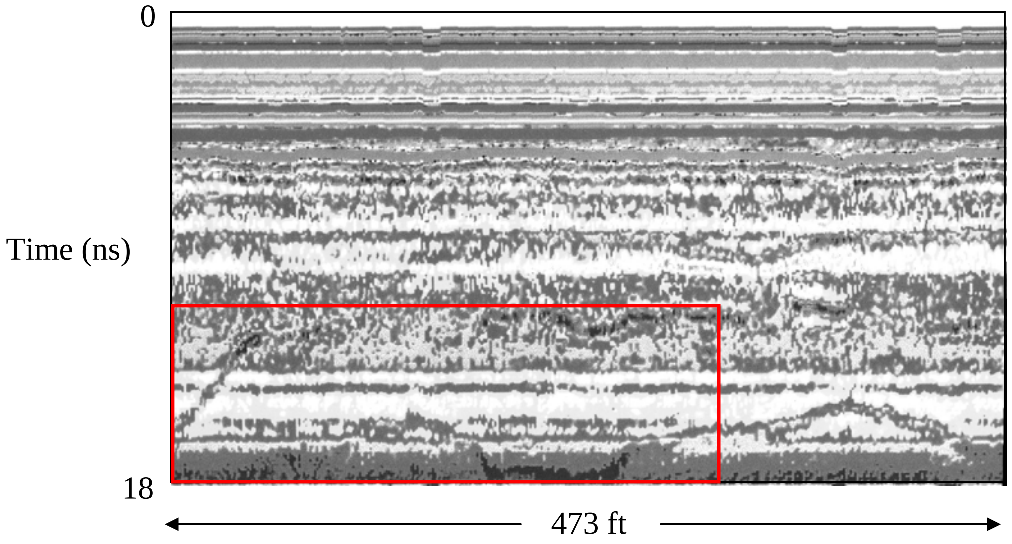


Figure 30. Site 4 Impulse GPR box culvert data (1 GHz antenna).

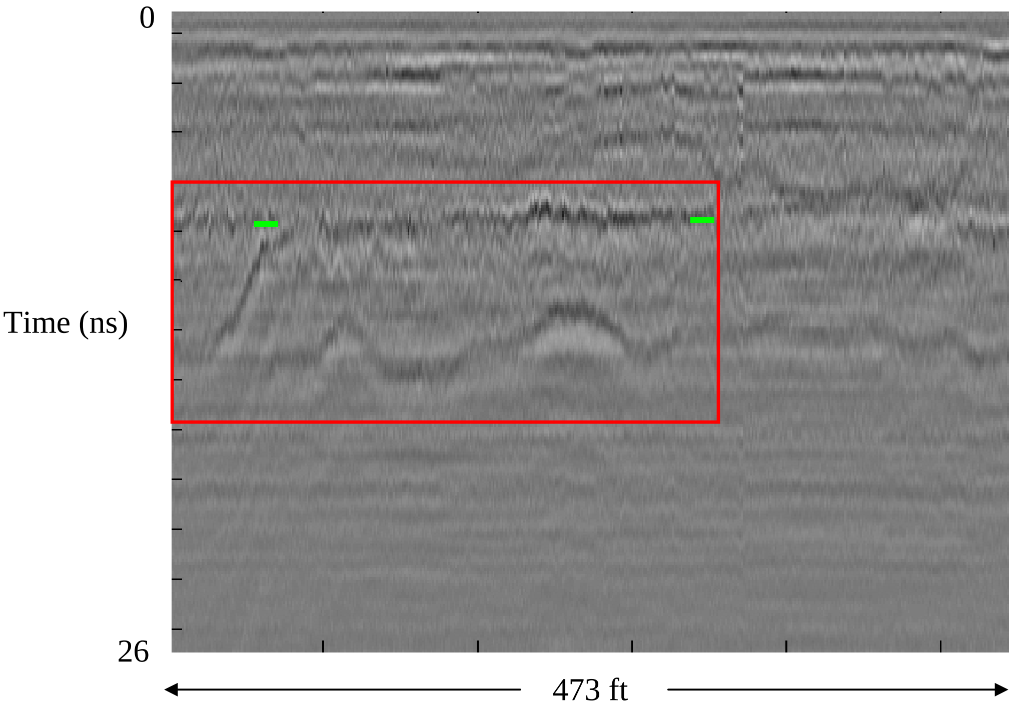


Figure 31. Site 4 Step Frequency GPR box culvert data.

joints. Additional Impulse GPR data are presented in Figure 29. Figure 29a provides a two dimensional plan view bridge deck image of features 4 inches beneath the bridge deck surface. Red lines in the Figure 29b bridge schematic indicate the beginning and end of the bridge, while each bridge joint is indicated with a green dashed line. This image, calculated from a detailed data collection performed using Impulse GPR, allows the reinforcing steel mesh to be seen in addition to variations in the properties of the bridge deck concrete. The scale of the image makes the rendering of the steel mesh look like a textured surface, with small horizontal and vertical stripes. However, close examination reveals that the majority of the reinforcing steel bars in the bridge deck are individually detected and shown in their proper position and orientation. In addition, variations observed in the response magnitude in Figure 29a can be observed as small discontinuities or blurring in the reinforcing steel mesh image. These areas indicate locations where bridge deck material properties are varying and can help to identify where bridge deterioration or damage may be occurring. A more thorough analysis using additional standard bridge deck evaluation methods can verify GPR results for evaluations of this nature.

Figures 30 and 31 present GPR data collected using Impulse GPR and Step Frequency GPR respectively to investigate the culvert at Site 4. The results indicate that GPR responses are substantially attenuated by clay materials in this tested segment. However, both the Impulse GPR and the Step Frequency GPR show basic indications of the boundaries of the culvert. The areas of the data that indicate a response to the Site 4 culvert are highlighted with red boxes. The Impulse GPR response is inconsistent, but the Step Frequency GPR response does indicate a relatively consistent reflection from the concrete ceiling of the culvert, (observed between the two green hash marks shown in the image).

6.5 Site 5 Result

A bridge deck with three spans and built on a skew was the object of the Site 5 survey. Both the Impulse GPR system and the Step Frequency GPR provided useful results from this bridge survey. Each of the three spans can be observed distinctly in both data sets, boxed in red in Figures 32 and 33. However, the Step Frequency GPR result is clearer and more distinct due to less signal ringing and clutter. In addition, Figure 34 illustrates three plan view images of Step Frequency GPR data at successive depths. Figure 34a shows the distinct boundary between the roadway and the bridge deck, as noted in the Figure 34d schematic. In addition, light colored areas within the bridge deck boundaries are indicative of concrete material property variations. These light colored areas correspond to four, more prominent light colored locations in the middle of the bridge deck area in Figure 34b. These variations could be indicative of bridge

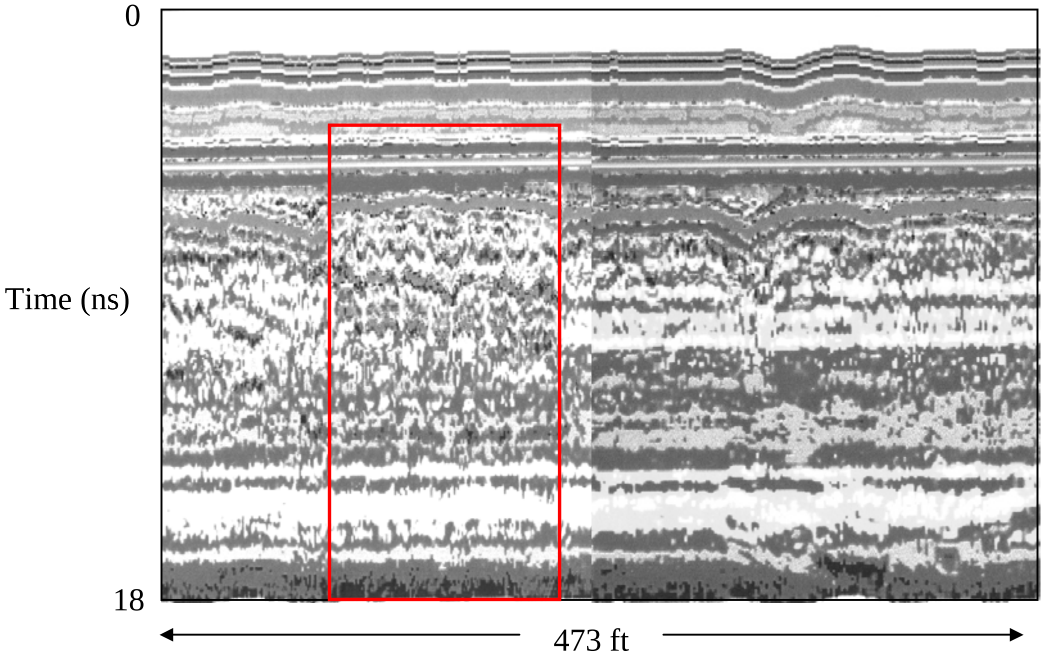


Figure 32. Impulse GPR data from bridge at mile post 72.

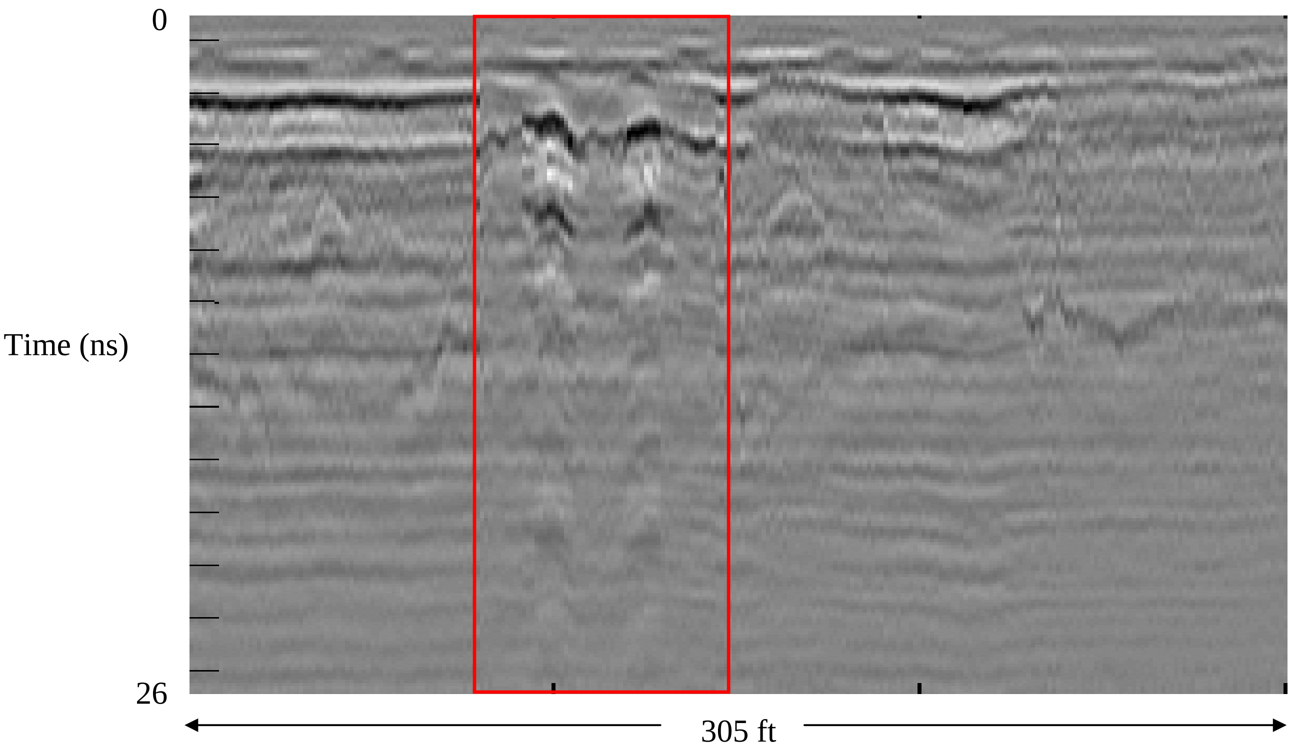


Figure 33. Step Frequency GPR from bridge at mile post 72.

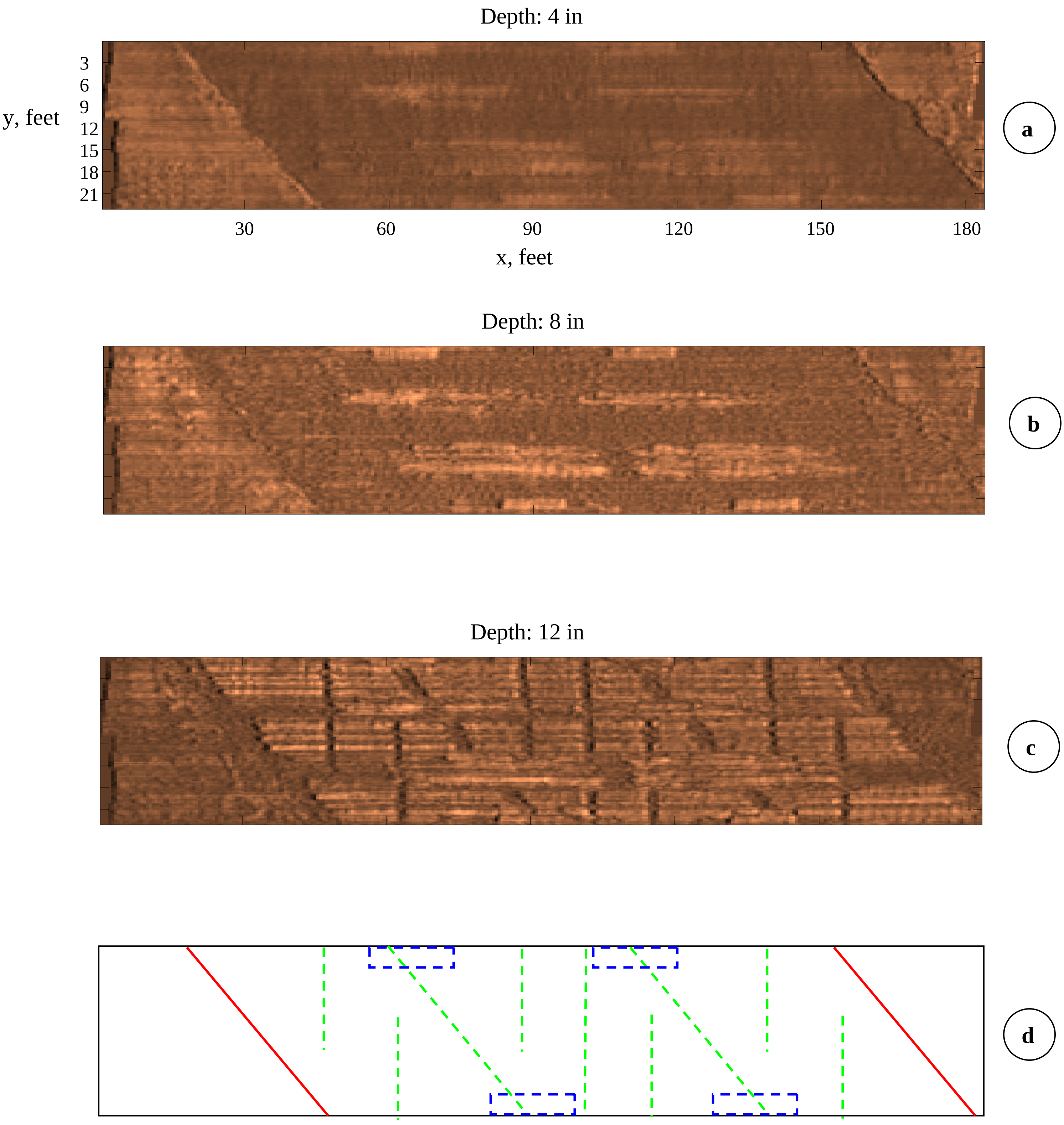


Figure 34. Site 5 plan view images of Step Frequency GPR bride deck data at three depths: (a) 4 inches below the surface, (b) 8 inches below the surface, (c) 12 inches below the surface. (d) Schematic of skewed bridge begin and end locations, (red lines) scupper drains, (blue dashed lines) and support beams (green dashed lines).

deck deterioration processes that may merit additional investigation using other standard techniques at a later time. Bridge scupper drains are clearly imaged in Figure 34c with their corresponding location in the Figure 34d schematic indicated by dashed blue boxes. Finally, bridge beams and diaphragms are imaged through the bridge deck in Figure 34c. Their locations correspond to the green dashed lines in Figure 34d.

These five example survey sites have illustrated GPR applications to detection and measurement tasks relevant to pavement and roadway inventory maintenance and management. Results from the Impulse GPR system and Step Frequency GPR system show that both systems offer useful baseline information. It is equally clear that the Step Frequency GPR system offers additional capabilities to detect and image relevant engineering features. It is notable that all of the raw survey data presented using “time” as the dependent variable on the vertical axis was collected at 55 mph using Step Frequency GPR and 40 mpg using Impulse GPR. Detailed Step Frequency GPR survey data was collected at slower speeds to illustrate the full potential of this type of system.

7. Future Analysis

The analysis of both Impulse GPR data and Step Frequency GPR data from representative sites on the Natchez Trace Parkway has fulfilled the engineering evaluation needs for a comparison between these two types of GPR technology. In the future, it is anticipated that calibration data available from cores collected at selected sites along the parkway can also be used to provide an engineering analysis of pavement layer thickness data from both GPR systems.

8. Recommendation

Test results from this GPR hardware trial indicate that Step Frequency GPR and Impulse GPR are both useful and effective, but Step Frequency GPR is a superior technology for many types of pavement, infrastructure and roadway inventory applications. Step Frequency GPR allows high speed testing to be conducted with three full depth detection antennas (0 to up to 10 or more feet) and lower speed, highly detailed testing with 7 up to 31 or more antennas. These multiple antenna data collection modes take advantage of an integrated antenna array that allows large survey areas to be covered quickly and efficiently. Using this type of system at high speeds provides multiple position measurements of pipes, culverts and other features that traverse the roadway. At slower speeds, complete three dimensional data sets can be collected that can be visualized using tomographic imaging techniques. Impulse GPR can be used with multiple antennas, but each antenna must be tuned to operate at frequencies that are optimized to provide resolution at a narrow range of depths. Therefore, typical Impulse GPR systems for infrastructure applications incorporate two or three antennas in an effort to provide optimized resolution at a wider range of depths. Step Frequency GPR antennas do not have this limitation and can therefore be used to accomplish the same task that two or more Impulse GPR antennas would.

The ideal antenna array for road surveying would cover the whole width of a traffic lane. In practice, this is not feasible due to the increased risk of traffic accidents. Therefore, a practical antenna array for road surveying should strike a compromise and be at least as wide as the vehicle used for the survey. Furthermore, electromagnetic shielding at the edges of the antenna array can be used to suppress reflections from other vehicles in adjacent traffic lanes. Figure 35 shows a 1.9 meter wide antenna array with 47 antenna elements. In this array, microwave absorbers have been added to the edges to shield the antenna from radiating to the sides. This type of array meets the requirements of the DHM vehicle GPR and also offers the potential for a unique, useful height adjustment.

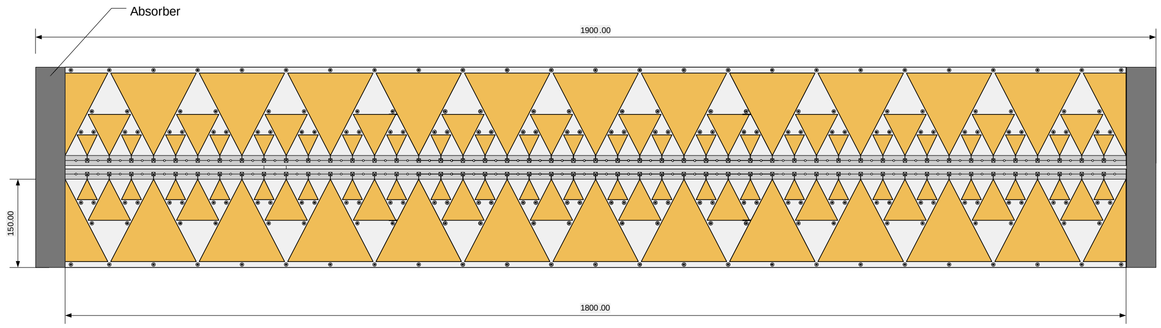


Figure 35. 47 element bow-tie array with microwave absorbers at the outer edges.

Providing the GPR user with the capability to adjust the elevation of the antenna can improve signal quality and usability. For high speed surveying, the antenna should be lifted 15 – 20 cm above the ground to avoid damage from bumps in the road or debris. For detailed surveying, where image focusing is particularly important, the array should be placed as close to the ground surface as possible. Since the high-resolution surveys are always carried out at low speeds, the antenna can be located very close to the surface. Figure 36 shows an adjustable antenna mounted with caster wheels to allow the antenna to roll close to the pavement or bridge deck surface for detailed mapping. Bringing the antenna close to the surface also improves coupling of GPR signals into the ground. This is particularly useful on concrete bridge decks which have high attenuation relative to asphalt.

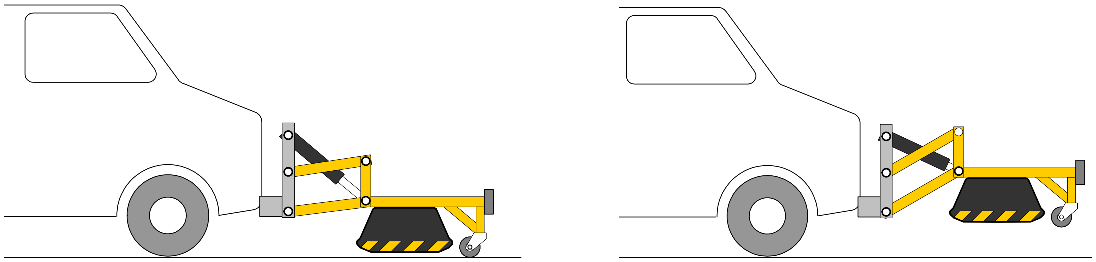


Figure 36. Adjustable antenna mount. Left: Detailed survey, Right: High speed survey.

For bridge deck and detailed culvert surveys it is also mandatory to have higher sampling density along the survey path of the vehicle. Therefore the DMI of the test vehicle should be programmable to provide sampling intervals down to 2cm.

In addition, detailed surveys often consist of multiple parallel swaths that are combined to one large image after data collection. It is desirable to make these swaths as parrallel and aligned as possible to reduce the complexity of combining the datasets. The most practical way of doing this is to implement an automatic spray paining device on the edge of the antenna array. Such a device could make dots of marker paint on the pavement during data collection. This dotted line could help the driver to align the next swath parrallel to the previously collected swath.

Both of the systems in this trial performed well. However the Step Frequency GPR technology showed that its measurement and imaging capabilities added value to the testing while meeting or exceeding the capabilities of Impulse GPR.

8. Summary

Results from the Natchez Trace Parkway DHM GPR comparison show that Impulse GPR and Step Frequency GPR both effectively collect subsurface feature data in roadway inventory applications. Impulse GPR has been used for many years to evaluate roadways and infrastructure in a variety of applications. However, the compact, light weight Step Frequency GPR system in the test showed that it had unique capabilities that make it particularly attractive for roadway inventory applications. Specifically, the Step Frequency GPR system met advanced capability requirements and demonstrated high resolution three-dimensional imaging capabilities that are not available in any other high speed GPR system. The unique design of the Step Frequency GPR system also gives it the potential to detect deep subsurface features that challenge other high speed systems. Step Frequency GPR hardware is recommended for system integration with the DHM vehicle and is anticipated to satisfy the sub-surface detection and imaging requirements of the DHM GPR project.

9. Acknowledgement

Turner Fairbank Highway Research Center project staff would like to acknowledge the cooperation and assistance of Perry Vanderhurst from the Eastern Federal Lands Highway Division, Don Alexander from the US Army Corps of Engineers, Michael Richmond from the Federal Aviation Administration, Jim Arnold from the Federal Highway Administration and staff members from the National Park Service for making this project possible. Their contributions, along with those of other important collaborators, are sincerely appreciated.

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Appendix A

Impulse GPR specifications: Pulse Radar, Inc.

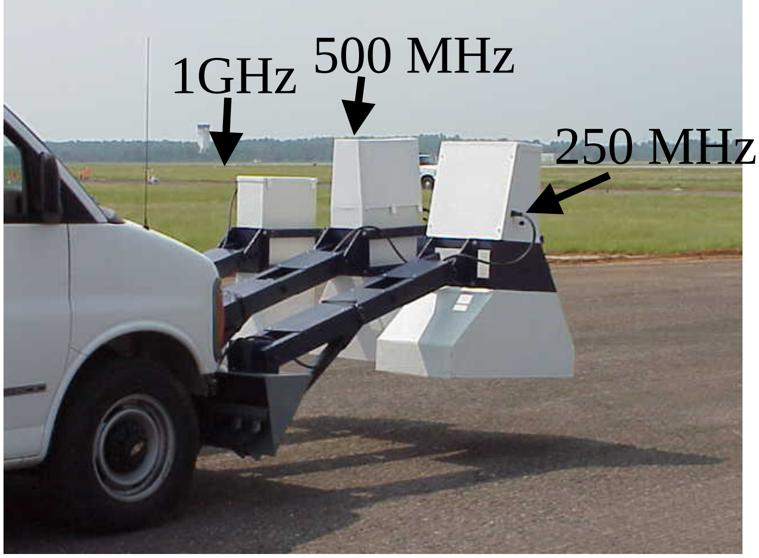
Comparable impulse GPR specifications: Geophysical Survey Systems, Inc.

Equipment: Ground Penetrating Radar – Pulse Radar, Inc. (Houston, TX)
http://www.pulseradar.com/

Speed: Testing Conducted at 40 mph

Personnel: Requirement is two (driver and operator)

Antenna Frequencies: 1 GHz and 500 MHz used for testing on Natchez Trace



Radar System:

- Bistatic
- ERDC systems include four antennas:
  - 1 GHz antenna, which will penetrate 0 to 1 meters
  - 500 MHz antenna, which will penetrate 0 to 2 meters
  - 250 MHz antenna, which will penetrate 0 to 3 meters
  - 100 MHz antenna, which will penetrate 0 to 5-10 meters
- Distance traveled is monitored with a Distance Measuring Instrument (DMI)
- Software
  - Data Acquisition
    - Data acquisition speed is 50 traces per second
    - Data from all four antennas can be collected at the same time
  - GPR waveforms are displayed in three ways:
    - Trace plots – allows user to view individual traces
    - Color coding of the vertical stacking of the traces – allows user to infer thickness variations along the highway
    - Both trace plot and color coded graph
  - Pulse Radar’s proprietary software is used to automatically process the GPR data.

SIR®-20 System Preliminary Specifications

Software

Antennas: Records data from 1 or 2 hardware channels simultaneously; 1 to 4 data channels, selectable.

Display Modes: Linescan, Wiggle Plot and Oscilloscope. In linescan display, 256 color bins are used to represent the amplitude and polarity of the signal.

Automatic System Setups: Storage of an unlimited number of system setup files for different road types, survey conditions, and/or antenna deployment configurations.[1]

Range Gain: Manual adjustment from -20 to +100 dB. Number of segments in gain curve is user-selectable from 1 to 8.

Vertical Filters: Individually filter the scans in the time domain. Low and high Pass, Infinite Impulse Response (IIR), Finite Impulse Response (FIR), Boxcar and Triangular filter types are available.

IIR	
Low Pass	2 poles
High Pass	2 poles
FIR, Boxcar and Triangle	
Low Pass	up to ½ scan length
High Pass	up to ½ scan length

Horizontal Filters:

IIR	
Stacking	1 to 16384 scans
Background Removal	1 to 16384 scans
Static	
Stacking	2 to 32768 scans
Background Removal	

Radar System Connectors

- (2) Antenna inputs
- (1) 12 VDC input power
- (1) Survey wheel or DMI input
- (1) Marker input

Mechanical

Size: 466 mm x 395 mm x 174 mm (18.4 x 15.5 x 6 in)

Weight: 10 kg (22 lbs)

Electrical

Antennas: Operates with any GSSI model antenna and can handle up to 2 antenna inputs simultaneously.

Resolution: 5 picoseconds.

Range: 0-8,000 nanoseconds full scale, selectable.

Output Data Format: 8- or 16-bit, selectable.

Number of samples per scan: 256, 512, 1024, 2048, selectable.

Scan Rate: 2 to 800 scans/second, selectable.
U.S.: 2 to 160 scans/second, selectable.

Input Power: 12 volts, DC nominal with operating range of 11-15 volts, 60 watts.

Thermal

Operating Temperature: -10°C to 40°C external.

Relative Humidity: <95% non-condensing.

Maximum Temperature Variation: <1°C per minute, <10°C per 30 minutes.

Storage Temperature: -40°C to 60°C.

Data Storage, Standard (Internal)

Greater than 6.0 GB

Data Storage, Optional (External)

Any standard PC peripheral using the PC parallel port, USB port, or Ethernet port

Radar System Paramenters[2]

Signal to noise ratio	> 110 dB
Dynamic range	> 110 dB
Time base accuracy	.02%

Fully FCC Compliant

[1] Limited only by computer hard disk capacity
[2] Does not include antenna figures

Geophysical Survey Systems, Inc.

Geophysical Survey Systems,Inc.
13 Klein Drive, North Salem, NH 03073-0097
Phone: (603) 893-1109 Fax: (603)889-3984
Email: sales@geophysical.com

Appendix B

Step Frequency GPR specifications: 3D-Radar AS

Opening a new dimension for Ground Penetrating Radar

The GeoScope GPR is designed for high-resolution 3-dimensional subsurface mapping using innovative radar and antenna technology.

The fastest step-frequency system available

The GeoScope GPR is the fastest step-frequency radar on the market. By using a digital frequency source instead of traditional phase-locked loop technology, the GeoScope can generate waveforms from 30 MHz up to 2 GHz with as much as 1000 frequencies with waveform lengths of 0.5-10 milliseconds. The step-frequency technique has a coherent receiver which means that the whole waveform length in milliseconds is used as 100% efficient integration time. (In comparison, impulse GPRs use stroboscopic sampling with significant loss of energy.) Figure 1 shows an overview of the GeoScope system.

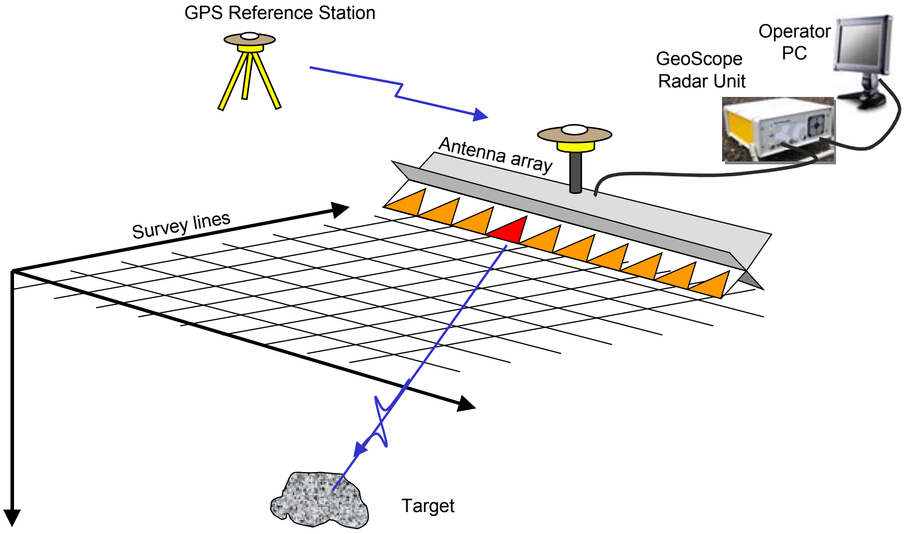


Figure 1. *GeoScope GPR system overview.*

The step-frequency waveform gives optimum source signature with a uniform frequency spectrum. The computer control allows the user to set the dwell time on each frequency as well as the start and stop frequencies.

The radar system perform real-time time domain conversion through Fast Fourier Transform allowing the user to view B-scans from one antenna at a time. Raw data can be stored either in time-domain or frequency domain for post-processing.

The radar is controlled from a laptop computer through a ethernet cable. The system can also be configured with Wireless LAN remote control and GPS interface to allow recoring of postion data.

Collect up to 63 survey lines simultaneously

The GeoScope GPR is designed to operate with an electronically scanned antenna array with up to 63 antennas. The antennas are scanned sequenctially by the radar. The unique antenna system consists of air-coupled bow-tie monopole pairs as shown in Figure 2. This gives a quasi-monostatic antenna configuration with practically zero-offset distance.

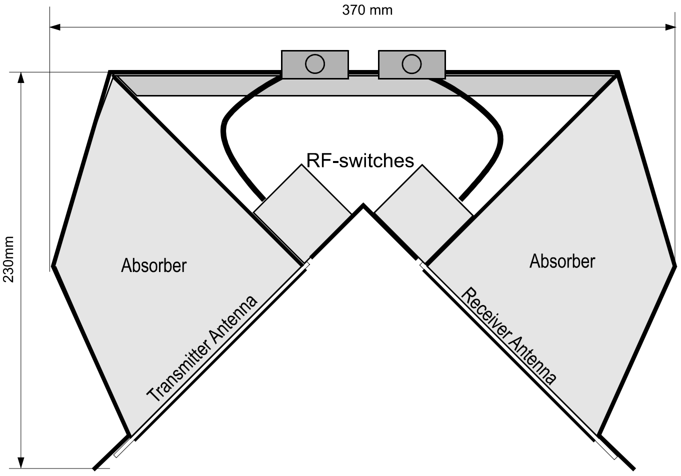


Figure 2. *Ultra-wideband bow-tie antenna pair (cross section).*

In opposition to traditional octave-band GPR antennas the ultra-wideband bow-tie monopoles have a continuous frequency coverage from the 100 MHz range up to 2 GHz. In practice this allows the user to collect data from 100 MHz to 2 GHz without changing antennas. By comparison, a similar survey using impulse GPR would require use of 200MHz, 400 MHz, 800 MHz and 1600 MHz antennas.

The antenna elements are arranged in an interleaved pattern consisting of antenna elements with differnet sizes to fulfill both the Nyqist spatial sampling criterion for high-resolution imaging and sufficient low-frequency radiation for deep penetration. The antenna pattern is shown in Figure 3. Depending on the application the system can be programmed to use all the antennas in the array for full 3-d imaging mode. For regular road survey, the system can be programmed to use fewer elements for depth sounding on a more sparse spatial grid.

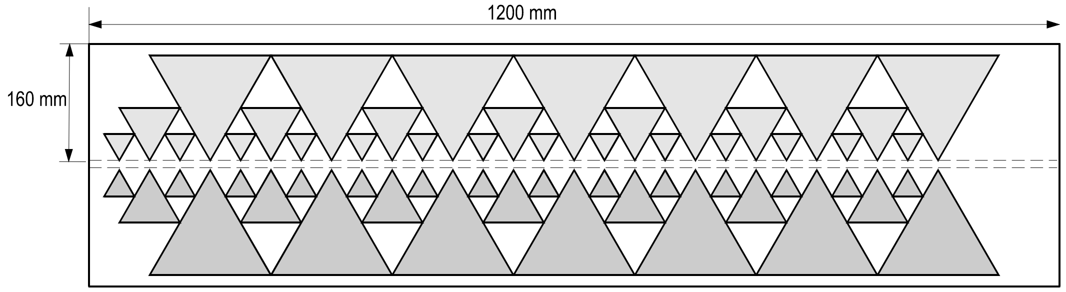


Figure 3. *Interleaved bow-tie antenna pattern (Model B1231).*

The standard range of antenna arrays includes the following models:

Antenna Model B1231
1.2 meter wide, 31 elements, 3.75 cm line spacing, 400 – 2000 MHz

Antenna Model B2463
2.4 meter wide, 63 elements, 3.75 cm line spacing, 400 – 2000 MHz

Antenna Model B2627
2.6 meter wide, 27 elements, 9.0 cm line spacing, 100 – 1100 MHz

Custom antenna models with other line spacings, frequency ranges, and array lengths available on request.

Antenna Model B1231

Ultra-Wideband Antenna Array

3d-radar as

The antenna Model B1231 is a 1.2 meter wide antenna array with 31 antenna elements designed for use with the GeoScope 3-dimensional Ground Penetrating Radar.

The electronically scanning antenna array allows efficient and accurate 3-dimensional data acquisition for applications such as utility mapping, road/railway inspection, and landmine/UXO detection.

Specifications:

Frequency range:	400 MHz - 2000 MHz
Antenna elements:	Bow-tie monopole antennas
Number of elements:	31 transmit/receive antenna pairs
Antenna separation:	37.5 mm
Effective scan width:	1125 mm
Scanning:	Electronically switched
Direct wave suppression:	> 30 dB
Polarization:	Linear
Sealing:	IP40
Size & Weight:	1200 x 370 x 230 mm, 24kg
Shipping container (option):	1270 x 460 x 360 mm, 18kg
Accessories:	Lightweight antenna trailer mount 2 or 4 wheel assembly

3d-Radar AS, O.S. Bragstads Plass 2A, N-7491 Trondheim, Norway
www.3d-radar.com Egil Eide: egil@3d-radar.com Tel: +47 7359 4750

...the ground is no limit.

Appendix C

Impulse GPR price quotation: Geophysical Survey Systems, Inc.

Geophysical Survey Systems, Inc.

P.O. Box 97, 13 Klein Drive
North Salem, NH 03073-0097
Phone: (603) 893-1109
Fax: (603) 889-3984
Toll Free: (800) 524-3011

Date: 06-Jul-2004
Sales Quote No.: 02076
Page No: 1

SALES QUOTE

Send To: STARODUB
6300 GEORGETOWN PIKE
McLEAN, VA 22101-2296

Delivery: 75 days ARO
Ship Via: PLEASE ADVISE
Terms of Sale: North Salem, NH
Validity: 06-Oct-2004

Sales Rep: KC
Terms of Payment: CIA
Currency: US Dollars

Freight Billed

Special Instructions:

Qty Ordered	Part Number	Description	Unit Price	Extended Price
1	FGROADSCAN1F	ROADSCAN 1 SYSTEM (1GHz HORN) RoadScan System - 1GHz Horn Road structure evaluation system, includes: SIR-20 Data Acquisition System, FGMOD4108F Antenna, 7-meter cable (FGCB07/19-11), Antenna Mounting Kit, FGMOD630A Distance Measuring Unit, and RADAN software with Road Structure module. Note: Must specify wheel lug size at time of order.	45,000.00	45,000.00
1	FGMF20/2000	MF-20 MAINFRAME W/COMPUTER SIRveyor SIR-20 Two channel GPR Data Acquisition System with attached Panasonic Toughbook computer. AC and DC power adaptors included. RADAN post-processing software (WINRAD5) with 3D QuickDraw mapping module (FGWINRAD5-3D) are pre-loaded on the computer.	27,500.00	27,500.00
1	FGMOD5106	MODEL 5106 ANTENNA 200 MHz center frequency antenna, depth of investigation to 30 feet.	4,990.00	4,990.00
1	FGMOD5103	MODEL 5103 ANTENNA 400 MHz (center frequency) antenna, depth of investigation to 15 feet. Includes location marker switch and handle.	4,990.00	4,990.00
1	FGMOD3101D	MODEL 3101 ANTENNA 900 MHz (center frequency) antenna, depth of investigation to 3 feet. Includes location marker switch and handle.	4,990.00	4,990.00
2	FGCB07/19-11	ANTENNA CONTROL CABLE, 7.5M BLUE	850.00	1,700.00

Geophysical Survey Systems, Inc.
P.O. Box 97, 13 Klein Drive
North Salem, NH 03073-0097
Phone: (603) 893-1109
Fax: (603) 889-3984
Toll Free: (800) 524-3011

Date: 06-Jul-2004
Sales Quote No.: 02076

SALES QUOTE

Send To: STARODUB
6300 GEORGETOWN PIKE
McLEAN, VA 22101-2296

Delivery: 75 days ARO
Ship Via: PLEASE ADVISE
Terms of Sale: North Salem, NH
Validity: 06-Oct-2004

Sales Rep: KC
Terms of Payment: CIA
Currency: US Dollars

Freight Billed

Special Instructions:

Qty Ordered	Part Number	Description	Unit Price	Extended Price
1		SURVEY WHEEL EXTENSION CABLE FGSW-EC15	390.00	390.00
			Total	**89,560.00**

Appendix D

Step Frequency GPR price quotation: 3D Radar AS

3d-radar as

Address:
Vestre Rosten 81
NO-7075 Tiller
Trondheim, Norway

Phone: +47 72 89 32 00
Cell: +47 91 73 00 00
Fax: +47 72 89 32 01
E-mail: nilssen@3d-radar.com

FHWA Advanced Research Team
Turner Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101
U.S.A

Attn: Dr. Michael Scott

(Quotation number Q2403EP)

Trondheim, 2004-12-22

Quotation 3d-Radar GPR System Purchase

We refer to our quotation dated August 2, 2004 and we want to thank you for your interest in purchasing our 3-dimensional Ground Penetrating Radar System (GPR).

It is very important for us to provide the best possible information to make the right choice of equipment. We will provide the best service and support possible, and based on our conversation, we are sure the equipment will meet your needs.

In this updated quotation you will find:

- Executive overview
- System recommendation
- System price
- Return on investment
- Why select 3d-Radar AS
- About 3d-Radar AS
- Success stories
- Next step

We appreciate your interest in purchasing our 3d GPR system and we look forward to start working with you. If you have any questions, please do not hesitate to contact us by email egil@3d-radar.com , nilssen@3d-radar.com or phone + 47 72 89 32 00.

We look forward to hearing from you.

Yours Sincerely,
3d-Radar AS
Børge Nilsen
Børge Nilssen
Vice President

Executive Overview

3d-Radar AS is offering the most cost-efficient and advanced GPR system available. The unique system configuration provides accurate and high quality three-dimensional subsurface data. Our goal is to contribute to your success and we will be happy to deliver a system that makes your business even more competitive.

You can expect a good return on the investment. Traditional 2d systems are very time-consuming and inaccurate to use in practice. With the 3d-Radar system it is easier to locate and image the subsurface objects of interest.

To secure your investment, we will provide you with necessary training of your personnel. The equipment is easy to use and field proven. Our high responsive support service is available for you to take care of any questions related to using the equipment.

The system is especially designed for road and railway applications where high speed data acquisition is of high importance. The unique programming feature of the digital frequency source and the advanced antenna array make the system suitable for both fast road profiling and detailed scanning of bridge decks.

The investment is $ 143,500. The Federal Highway Administration has been granted a 25% R&D discount on the system price.

System Recommendation

The Ground Penetration Radar (GPR) system we are offering is designed to address your needs for a modern and efficient GPR system for road and bridge deck diagnostics.

3d-Radar has developed a disruptive Ground Penetrating Radar (GPR) technology that introduces a new era of significantly more accurate and detailed three-dimensional images of underground objects.

This is the first novel step-frequency GPR system available that uses an advanced antenna array designed specifically for high-resolution 3-dimensional subsurface mapping. 3-dimensional GPR data is collected using a linear array of elements in the cross-line direction in combination with physical motion in the so-called in-line direction.

The GeoScope 3d-GPR system can be programmed to operate in the frequency range from 30 MHz to 2.0 GHz using digitally generated step-frequency waveforms. The high bandwidth can provide 3-dimensional image resolution in the order of 5 centimeters or less depending on soil conditions. The proposed version of the antenna array can operate from 300 MHz to 2.0 GHz. The system was designed to operate as a standoff antenna array to obtain maximum resolution at all depths. This makes the system suitable for high speed highway measurements as well as detailed bridge deck scanning.

With the WiFi option, the system can be operated remotely from a laptop using a 2.4 GHz Wireless connection. In addition, the system is designed to record GPS data if accurate positioning is required. Detailed specifications for the GeoScope GPR system and 3 different versions of the standard antenna arrays is available on the 3d-Radar AS web site (www.3d-radar.com). The web page also contains a number of technical papers authored by the President of the Company, Dr. Egil Eide.

Competitive price and high performance gives customers great value and short return on investments.

Key features

- Multi-channel system
  - Collects up to 47 survey lines simultaneously
  - Fast and accurate field survey, more efficient data collection
  - Easy to survey large areas

- Compact antenna array
  - High lateral sampling density
  - High resolution radar images
  - Suitable both for high speed and detailed scanning.

- Reliable and stabile step-frequency technology
  - Stable source wavelet
  - No warm-up time and temperature drift during operation

- Ultra-Wideband Antenna Array
  - No need for repetitive surveys using different frequency band antennas
  - One antenna covers all frequencies

- High bandwidth
  - Frequency range from 300 MHz to 2.0 GHz
  - You can make high resolution images and map more subsurface details

- Flexible system
  - Easy to reconfigure for different modes of operation
  - Multi purpose system – same instrument – many applications
  - Antenna covers 1.8 meters wide swaths – at your choice

- Non-destructive technology – no damage to the surface
  - Easy to operate
  - Can be handled by one person
  - Low transportation and field operation costs

More technical information, system benefits and application notes are available on our web site www.3d-radar.com.

System Price

This is the cost information for the purchase of GeoScope 3d GPR and antenna system:

- System price: $ 143,500.00

- System configuration:
    - GeoScope GPR (2GHz option)
        - 30 MHz – 2.0 GHz
    - Antenna array Model B1847
        - 300 MHz to 2.0 GHz continuous frequency coverage
        - 1.8 meter array length, 47 antennas
    - Shipping Containers for the GeoScope and the Antenna Array
    - Software support and maintenance for 2005 is included.

- Terms of delivery:
    - The prices are FCA, Trondheim (Free Carrier, Incoterms 2000), Norway. Shipping cost and applicable US taxes comes in addition. Delivery date is estimated to 12 weeks after received order.

- Terms of payment:
        - $ 47,500 - Day of purchase order + 15 days
        - $ 96,000 - Day of delivery + 15 days

- Training:
    - We recommend 2 days on-site training for your operation personnel. Training cost, travel and Per Diem come in addition.

- Options not included in this price quotation:
    - WLAN – Wireless Connection to control computer
    - GPS Interface

Warranty: 1 year on labour (hardware and software). Included in the price is one year of free software support.

Discount: Ordinary price for this system configuration is $ 191,412.00
A 25% R&D discount is included in the system price offered.

The quotation is valid for 30 days.

Return on Investment (ROI)

Our 3d GPR system is the most efficient system in the market. You can collect real and "ready to use" three-dimensional data at a very high speed. Compared with a single antenna system using standard frequency band antennas, the GeoScope GPR system is theoretically up to 200 times more efficient.

The traditional 2d systems are very time consuming and inaccurate. Our 3d GPR system gives you the information you need. Once you have surveyed an area, you know what's under the surface. There is no need for running up and down, spending hours on collecting and analyzing data from different survey lines.

Success Stories

Archaeology survey

The purpose of this survey was to locate the foundations of historical buildings at Avaldsnes near the City of Haugesund, Norway for planning purposes of future archaeological excavations. A 30 x 50 meter large area was surveyed within 3 hours using the GeoScope 1GHz system with the Antenna Model B2627. The radar image clearly points out the most interesting area for archaeological excavation.

Environmental mapping

On behalf of our client, the Norwegian Defence Museum, we surveyed a location close to Kjevik Airfield, Kristiansand, Norway. The purpose of the survey was to locate buried German aircraft spare parts buried right after World War II. Several aircraft wrecks, engines and spare parts are supposed to be buried in the area, but until the 3d GPR survey was performed, the location was unknown.

Railway ballast and tunnel inspections

We surveyed a tunnel on the railroad between Oslo and Trondheim where our client the Norwegian Railway Authorities wanted to investigate the depth of the ballast inside the tunnel. The purpose of this survey was to determine whether it was possible to lower the rails to make room for larger trains to pass through the tunnel. The radar data show a clear echo between the ballast and the base layers. It is also possible to identify objects in the ground below the ballast. The 3d GPR is an efficient tool for mapping and quality control of railroad ballast.

Unexploded Ordnance

Our client, T&A Survey BV told us after performing a UXO survey on the railway track between Utrecht and Den Haag The Netherlands, that they were impressed by the efficiency of the system. "We are happy with the speed of the survey, the range of the measurements and the nice cooperation", they said. The survey was stipulated to take 20 hours. We managed to survey twice the area in only 10 hours. The efficiency was 4 times higher than the traditional GPR equipment the used, and the result high quality 3d images were not possible to create with an old-fashion 2d system.

Why select 3d-Radar?

A new dimension

3d-Radar introduces a new era of three-dimensional imaging of underground infrastructures. Our vision is to be the global leader that raises the bar to a new standard of safety for companies concerned with detecting underground conditions.

Technology

3d-Radar's core competitive advantage is embodied in its high quality three-dimensional radar technology. 3d-Radar is the first in the GPR market in having completed a technology shift from the traditional impulse based technology to the new step-frequency technology.

Customer support

High quality equipment in combination with the best customer service and support possible is the best way to move forward.

Customer's success is the key to a prosperous future.

About 3d-Radar AS

3d-Radar's headquarter is located in Trondheim, Norway. Trondheim is known as the technology capital of Norway. The Norwegian University of Science and Technology (NTNU) is located in Trondheim, and 3d-Radar is a spin-off company from NTNU.

Our business idea is based on 15 years of research and development. We are the first GPR manufacturer to introduce to step-frequency technology in combination with a unique antenna array.

The Company is privately owned and established in 2001. Our office is in a 15 storey triangle shaped building (see photo). Here you will find our sales department and core technicians. The location of the production site is close to the Campus of the NTNU.

Our Mission

By providing a high quality range of GPR systems, we aspire to be renowned for our capacity to assist our customers in becoming more competitive, in a world where businesses transact at an unprecedented speed.

Our Business Model

3d-Radar markets and supports its products through direct sales from headquarter, co-marketing agreements and strategic partnerships with providers, resellers and sales representatives. In addition to our own expertise, we foster close relations to a select group of value-added resellers to provide clients with specialized knowledge and regional expertise.

Next step

After reviewing this document, the following process steps must be performed in order to establish the sales agreement. We have listed specific actions that will move us closer to a successful implementation.

Next step for 3d-Radar AS

▪ Analyses of need	Completed
▪ Proposal verification process	Completed
▪ Sales agreement draft	Completed
▪ Detailed customer requirements	Completed

Next step for FHWA

▪ Analyses of equipment need	Completed
▪ Proposal analyses	Completed
▪ Feedback to 3d-Radar on quotation	Completed
▪ Special requirements, delivery date, payment plan	Completed
▪ Verify sales agreement	Pending