Implementation of an FCC Compliant Radar

Technical Report 5-4820-01-2

Performed in Cooperation with the Texas Department of Transportation and the Federal Highway Administration Project Number 5-4820-01

By
Dr. Richard Liu
Wei Ren
Huaping Wang

Subsurface Sensing Laboratory
Department of Electrical and Computer Engineering
University of Houston

URL: http://subsurface.ee.uh.edu/documents/5-4820-01.pdf

April 2010

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
5-4820-01-2		

4. Title and Subtitle	5. Report Date
Implementation of an FCC Compliant Radar	April 15, 2010
	6. Performing Organization Code
7. Author(s) Dr. Richard Liu, Wei Ren, and Huaping Wang	8. Performing Organization Report No. 5-4820-01-2
9. Performing Organization Name and Address Subsurface Sensing Lab 4800 Calhoun Rd. N308 Engr. Bldg. 1, ECE Houston, TX 77204	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address TxDOT, Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080	13. Type of Report and Period Covered Technical Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This project implemented air-coupled and ground-coupled Ground Penetrating Radar (GPR) systems, developed by the Project 0-4820, to provide TxDOT with the ability to collect network and project level survey data. The GPR software can extract and report top layer thickness information as well as dielectric constant automatically without operator's interpretation.

This report analyzes the effectiveness, cost, and recommendations for state-wide implementations of such GPR systems.

17. Key Word	18. Distribution Statement
Ground Penetrating Radar, Thickness, Dielectric Constant, Implementation	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
		22	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Implementation of an FCC Compliant Radar

5-4820-01

Deliverable R2

Costs, Effectiveness, and Recommendations of Statewide Survey for the FCC Compliant Radar

PD: Dr. Feng Hong, CST

RS: Richard Liu, UH

Table of Contents

1 Abstract

This project implemented air-coupled and ground-coupled Ground Penetrating Radar (GPR) systems, developed by the Project 0-4820, to provide TxDOT with the ability to collect network and project level survey data. The GPR software can extract and report top layer thickness information as well as dielectric constant automatically without operator's interpretation. The delivered products included the following features:

1. Both GPR systems have the automatic parameter setup function to reduce operation complexity.
2. Both GPR systems were lab and field tested and compared with existing GPR systems. The results show that both GPR systems are effective.
3. Software and User Manuals are also delivered and revised from original versions to facilitate easy usage.
4. The air-coupled GPR can be mounted onto the front bumper of any TxDOT vehicle without modification to the vehicle. A distance measurement device (DMI) is necessary on the vehicles for distance information collection.
5. The cost of the GPR system is rather low (about $20k for each system including mounting fixtures and DMI) and they can be implemented in each district. Compared to a commercial GPR system, which costs more than $60k, the savings are significant.
6. If TxDOT equips each district with these two GPR systems, the dollar cost savings on maintenance, road closure, and possible damage prevention will be in the tens of millions each year.

This report analyzes the cost, effectiveness, and recommendations for state-wide implementations of such GPR systems.

2 Introduction

Ground penetrating radar (GPR) is a unique non-invasive and non-destructive means for characterizing surface and subsurface features. GPR can be used in a variety of media, including rock, soil, ice, fresh water, pavements and other structures. In runway and highway pavement surveys, GPR can determine pavement thickness (asphalt and concrete), detect voids underneath the road pavement, identify de-bonding between layers and determine layer thickness. The thickness of the various layers of a road can be measured using radar analysis techniques. The great advantages of this method are the nondestructive and high speed (e.g. >40mph for air-coupled unit) collection capabilities that can be applied dynamically to achieve a continuous profile or rolling map. The resolution and detecting depth are determined by the working frequency, transmitting power and the signal-to-noise ratio (SNR) of the GPR system.

In Project 5-4820-1, an improved air-coupled GPR, a ground-coupled GPR and the software for data acquisition and signal processing are developed and implemented. Both of the GPR systems passed the FCC tests for reduced RF radiation.

2.1 The Ground-Coupled GPR

The ground-coupled GPR, as shown in Figure 1, is designed for road and construction surveys. With its low signal-to-noise ratio system design, it has deeper detecting depth than other similar commercial products. It has wireless data transmission which provides a great convenience in field application. Due to the low power design a longer battery life between charges is achieved. The battery lasts up to 8 hours when fully charged compared with commercial GPR of less than 4 hours. Together with the portable push cart and encoder, this ground coupled GPR can be used in many roadway applications including:

1. Road inspection
2. Base and sub-base evaluation
3. Utility detection, metallic and non-metallic
4. Environmental remediation
5. Damage prevention
6. Geological investigation

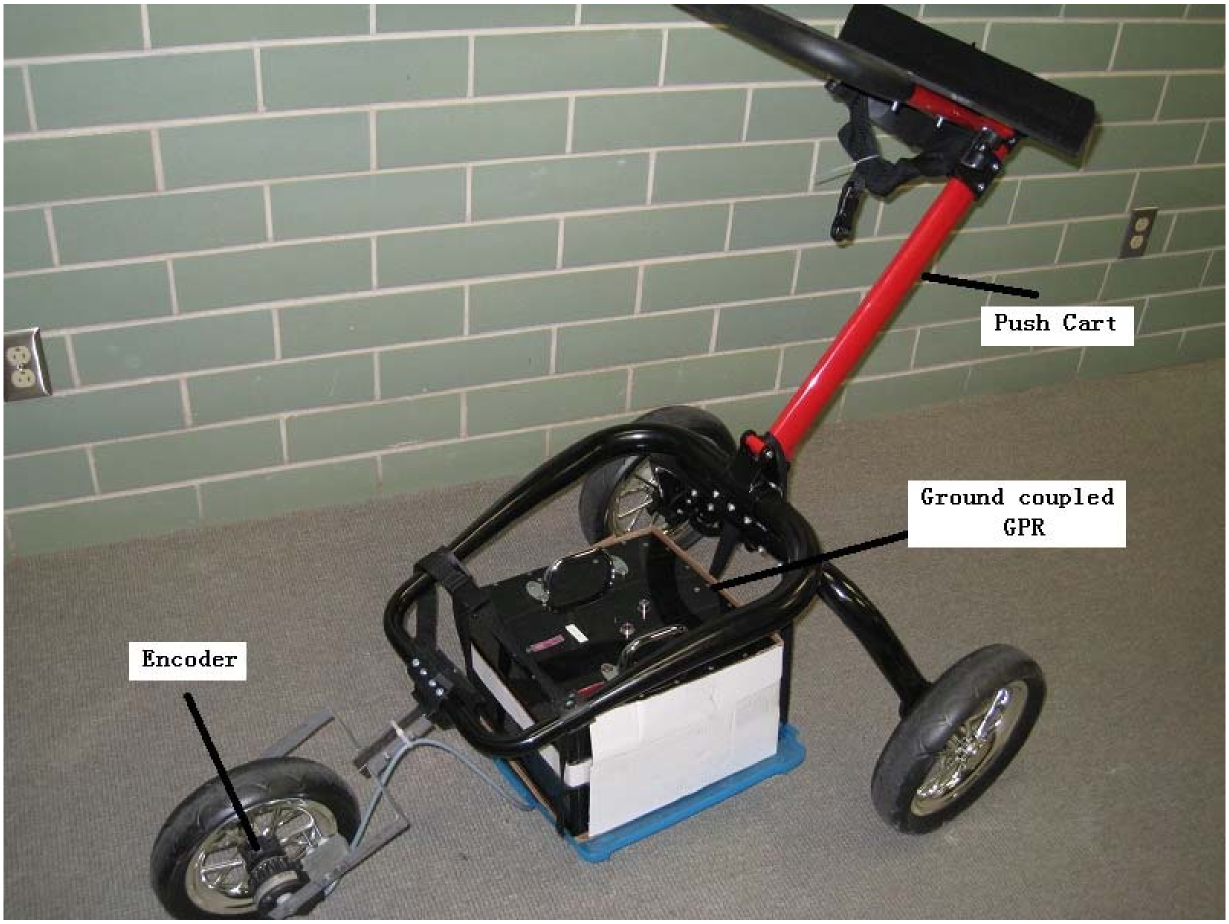


Figure 1, Ground-Coupled GPR system

2.2 The Air-Coupled GPR

The air-coupled GPR system, as shown in Figure 2, provides TxDOT engineers with an effective and accurate tool for quickly determining pavement layer thickness. It can be used for the following project/network level applications:

1. Top layer thickness inspection;
2. Delamination;
3. Voids detection;
4. Early detection of cracks;
5. Moisture detection;
6. Segregation; and
7. Base and sub-base evaluations.

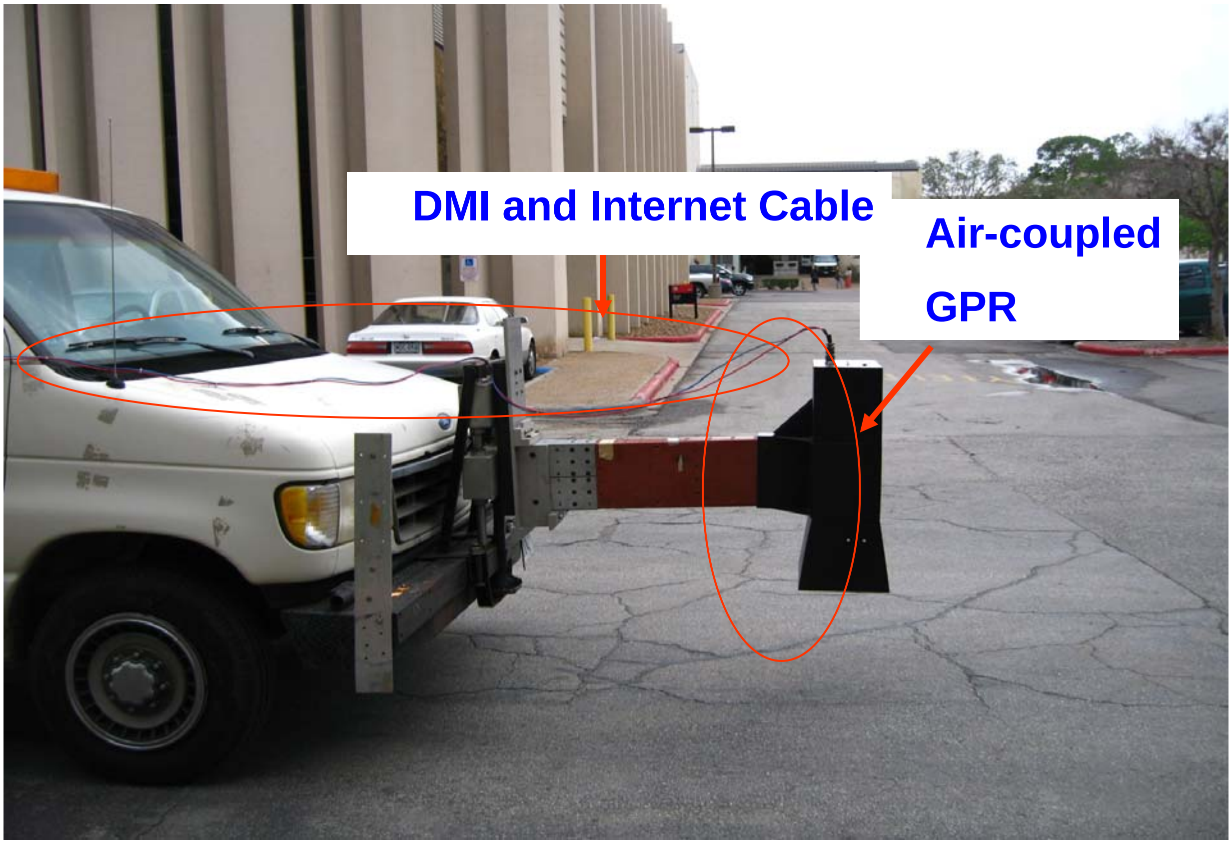


Figure 2, Air-Coupled GPR system.

2.3 GPR Software

The GPR software designed for this project is *GPR TxDOT*. Two modules, data acquisition and data processing, are integrated into a single software interface. The software provides both an automatic and manual way to set all the GPR parameters, and can acquire the data by wired or wireless connections. The highlights of the software include:

1. Easy-to-use Windows TM based system
2. Wireless data acquisition and hardware initialization
3. Adjustable color scheme to increase the resolution
4. Automatic hardware parameter setup
5. Dielectric constant display
6. Layer thickness computation
7. Automatic layer identification
8. One software package for both data acquisition and data processing

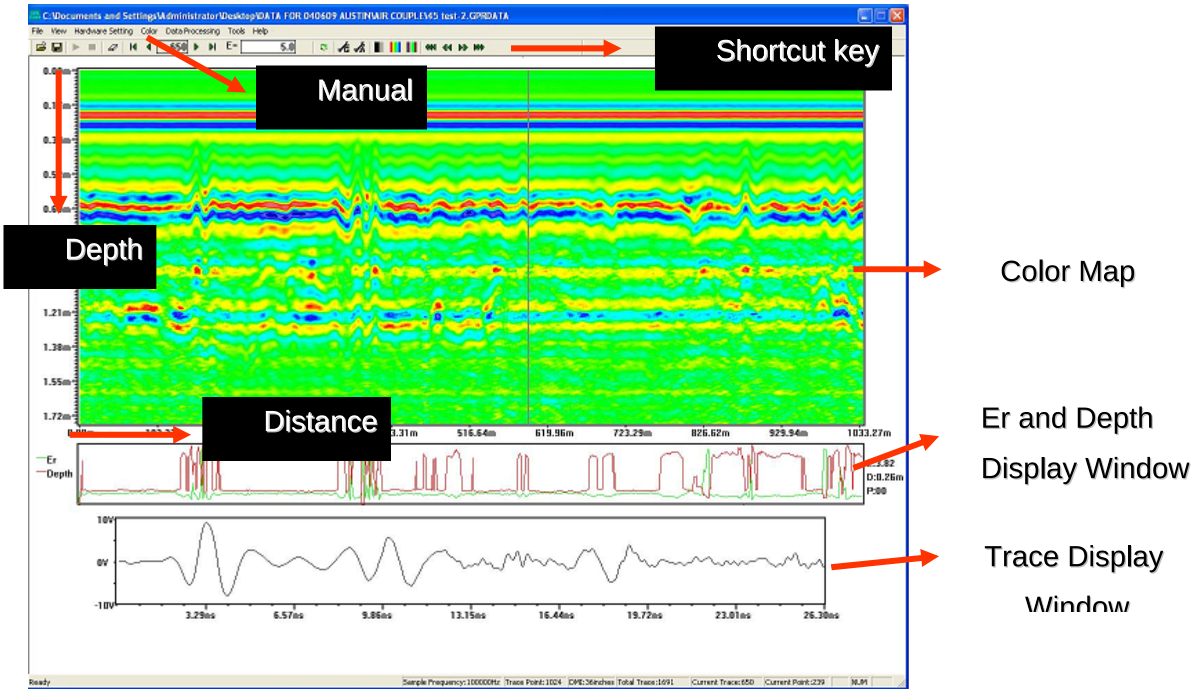


Figure 3, The software GPR TXDOT layout.

3 Field Evaluation Results

3.1 Grayson County US-69

A GPR test was conducted on 04/14/2009 on US 69 in the Grayson County northeast of Dallas. The road surface is asphalt and layer thicknesses were unknown before measurements. Both the new project developed GPR and TxDOT's old GPR systems were used independently for verification purposes. Coring was done immediately after GPR measurements. Data were processed on site. TxDOT engineer participants included Dr. Hong Feng, John Bilyeu and Dr. Dar-Hao Chen, besides district-level engineers. UH participants included Dr. Richard Liu and two of his Ph.D. students: Wei Ren and Huaping Wang.

Figure 4, Field test at HW69.

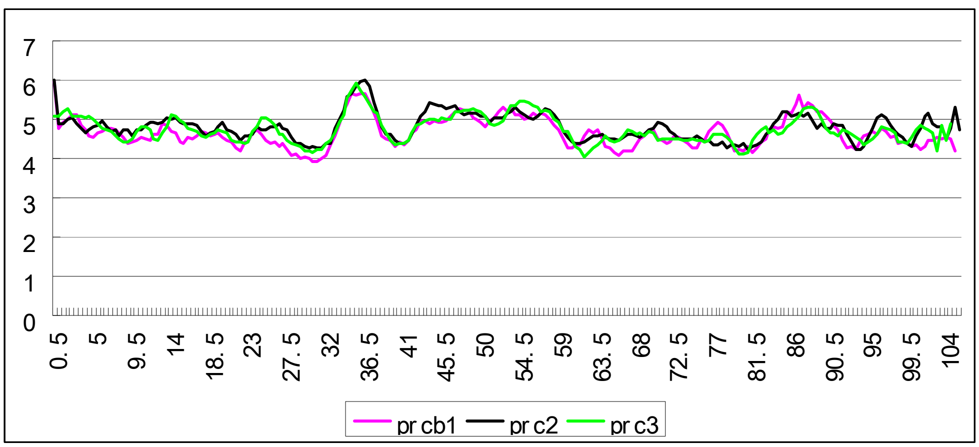
Radar data were collected by using air-coupled GPR and the software *GPR TXDOT*. Data analysis was done by using the same software. Total survey distance was about 1 mile. Table 1 shows the GPR thicknesses measured by this air-coupled GPR. The ground-truth information is the average value of 3 measurements of the sample cores. The results prove that the measurement by the air-coupled GPR is accurate and reliable.

Sample No.	Distance (feet)	Top Layer Thickness				Base Layer Thickness		Sub-Base Depth	
		GPR (in)	Core (in)	Error (in)	Error %	GPR (in)	Core (in)	GPR (in)	Core (in)
1	450	2.6	2.67	-0.07	-2%	6.3	N/A	11	N/A
2	1170	2.9	3	-0.1	-3%	6.9	N/A	12.5	N/A
3	5090	2.4	2.31	0.09	4%	6.6	N/A	14.4	N/A
Average		2.63	2.66	-0.03	-1.10%	6.6	N/A	12.6	N/A

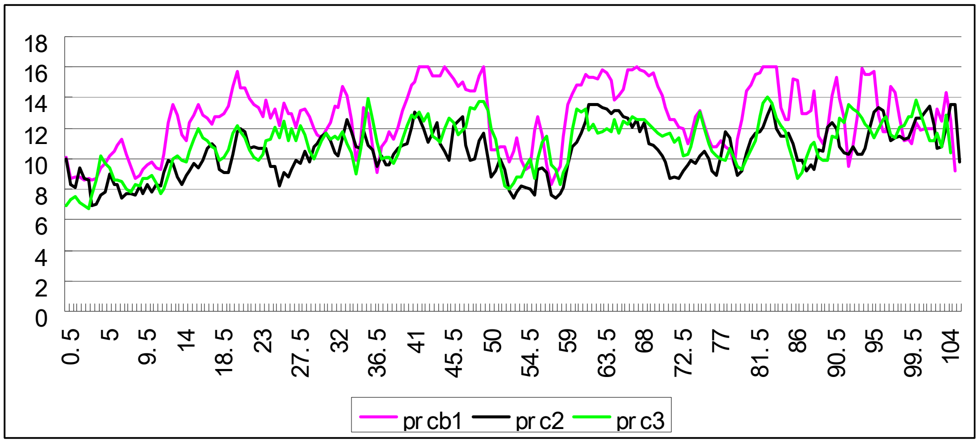
Table 1. Measured Pavement Layer Thickness Compared with Core Thickness

3.2 Pickle Research Center (PRC) Test

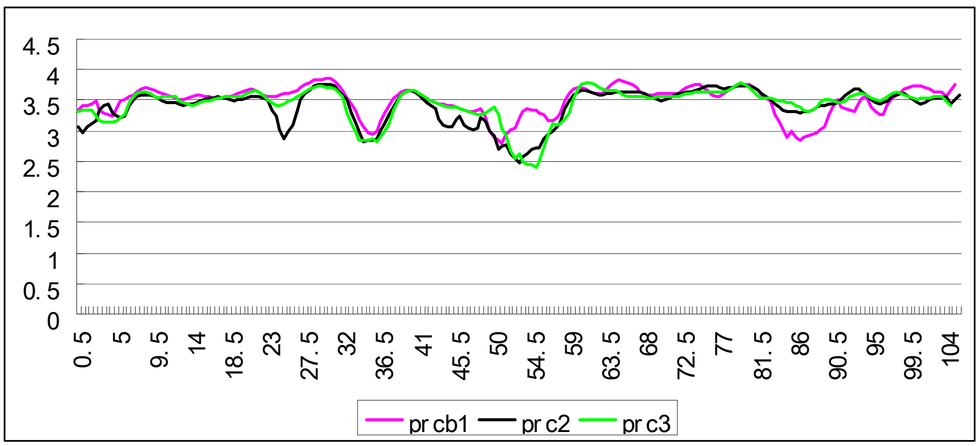
Dr. Feng Hong conducted GPR measurements on 10/21/2009 at PRC using the implementation project air-coupled GPR system to verify the reliability and accuracy of the new system. In this test, three measurements were conducted along the same lane, prcb1, prc2, and prc3. In these tests, both the dielectric constant and layer thickness of the surface layer and bottom layer are measured. The test results are shown in Figure 5 and the comparison is shown in Table 2.



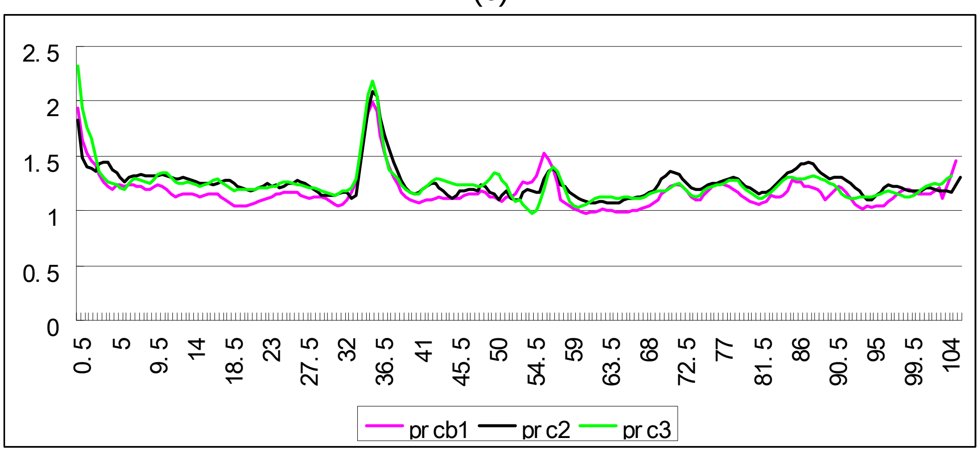
(a)



(b)



(c)



(d)

Figure 5. Measurement results: (a), dielectric constant of the first layer; (b), dielectric constant of the second layer; (c) thickness of the first layer, unit: inch; (d) thickness of the second layer, unit: inch .

Item	Prcb1	Prc2	Prc3
Average Surface Dielectric Constant	4.7	4.8	4.7
Average Base layer Dielectric Constant	12.7	10.4	11.0
Average Top layer Thickness (inch)	3.5	3.4	3.4
Average base Thickness (inch)	1.2	1.3	1.2

Table 2. Measured pavement layer thickness compared with core thickness

According to the results of the data, we can see that the three sets of data are reasonably close, which indicates the good repeatability and stability of the radar measurements.

4 Cost Analysis

4.1 GPR Hardware Costs

The hardware cost of the ground-coupled and air-coupled GPR systems are listed in Table 3.

		Cost ($)				Cost ($)
Ground Coupled GPR	**Electronics**	**6500**		**Air Coupled GPR**	**Electronics**	**6500**
	PCB Manufacture	**500**			**PCB Manufacture**	**500**
	Radar Box	**1000**			**Radar Box**	**1500**
	Battery/Charger	**100**			**AC Charger**	**100**
Total Amount		**8100**		**Total Amount**		**8600**

Table 3. Hardware costs of the air-coupled and ground-coupled GPR systems

4.2 GPR Pushcart Costs

The cost of GPR pushcart is listed in Table 4:

	Cost ($)
Push Cart	1000
Encoder	500
Total Pushcart	1500

Table 4. GPR pushcart cost

4.3 GPR Vehicle Mounting Cost

To operate the GPR with any TxDOT vehicle, a vehicle mounted DMI is necessary. The cost of the DMI varies depending mainly on the installation cost. An estimated total cost is $1000 for the DMI and installation. Mounting the GPR antenna requires a mounting fixture, including a boom and corresponding fixture hardware. The cost of the mounting fixtures is about $1000.

4.4 Total System Cost

The total system cost of the GPR (less the host vehicle) is tabulated in Table 4. The labor cost includes manufacturing, cost of GPR tuning and assembling. Compared to a commercial GPR cost of more than $60k, these GPR systems are much more cost effective.

		Cost ($)				Cost ($)
Ground Coupled GPR	GPR Hardware	8100		Air Coupled GPR	GPR Hardware	8600
	Pushcart	1500			DMI	1000
	Labor	10400			Labor	10400
					Mounting Fixture	1000
Total Amount		**20000**		Total Amount		**21000**

Table 4. Total GPR implementation cost

4.5 Savings to TxDOT

Considering the existing TxDOT GPR system costs, if each district is equipped with an air-coupled and ground-coupled GPR system, the potential equipment cost savings to TxDOT is more than $1.6 million.

GPR systems provide a non-destructive method to detect the sub-surface anomalies within the pavement structure. Many road defects can be detected early and maintenance costs can be significantly reduced. The cost savings are difficult to quantify but considering lane closure time for destructive sampling and repair, material cost savings allowed by more timely repair, possible road hazard prevention, and impact to the economy, the savings are very significant.

5 Recommendations for State-wide Implementation

5.1 Use of Ground-Coupled GPR for Project Monitoring and Fault Detection

Project monitoring and fault detection needs a reliable, non-destructive method to locate subsurface anomalies prior to digging, trenching, conducting site assessments and mapping. The ground-coupled GPR system together with the push cart, which has a DMI and can provide accurate distance offsets, can perfectly meet these requirements. Typical uses for project monitoring and fault detection include:

1. Concrete scanning and inspection, rebar monitoring and inspection, an example shown in Figure 6
2. Locating underground anomalies and faults, an example shown in Figure 7
3. Measuring concrete pavement thickness
4. Mapping environmental remediation limits
5. Inspecting bridge deck
6. Locating underground utilities
7. Preventing further damage

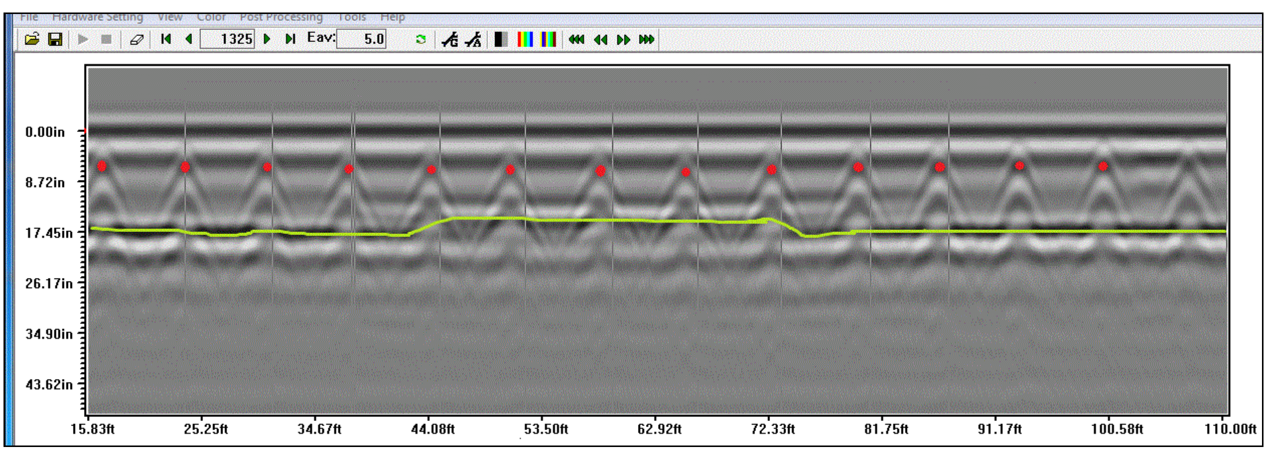


Figure 6, Concrete road monitoring by using the ground coupled GPR system. The red dots represent the rebars and the yellow line is the bottom layer of the concrete.

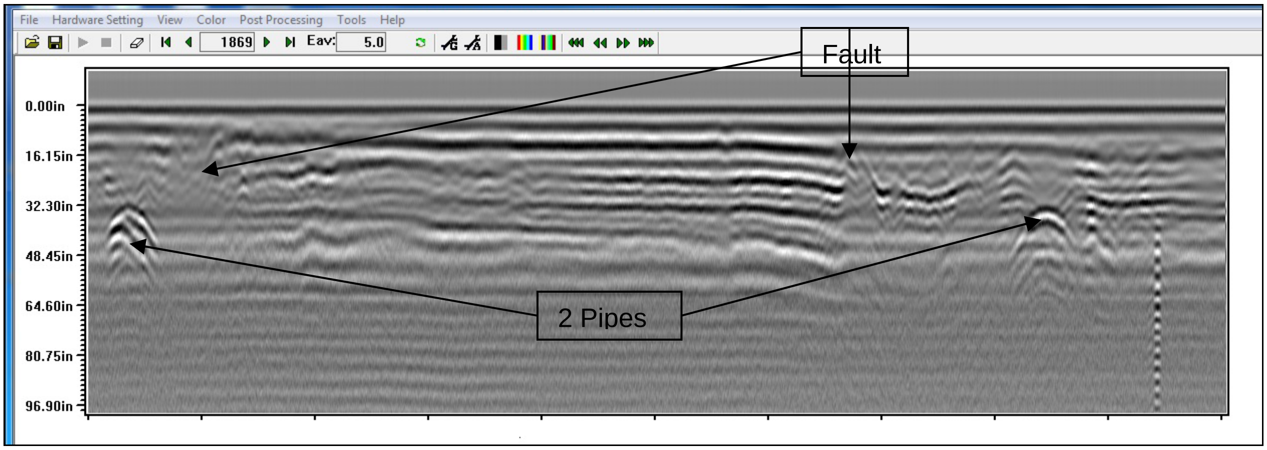


Figure 7, Faults detecting by using the ground coupled GPR system.

5.2 Use of Air Coupled GPR System for Network Level Survey in Districts

The air-coupled GPR system provides users with an affordable effective tool for quickly determining pavement layer and sub-layers thicknesses as well as locating faults beneath the ground surface. The GPR data can be acquired at highway speeds, which eliminates the need for lane closures and provides a safer working environment. Typical uses for project or network level surveys include:

1. Measuring pavement top layer thickness at highway speeds
2. Evaluating base and sub-base moisture levels at highway speeds, an example is shown in Figure 8
3. Locating voids in roadways
4. Concrete scanning and inspection, an example is shown in Figure 9

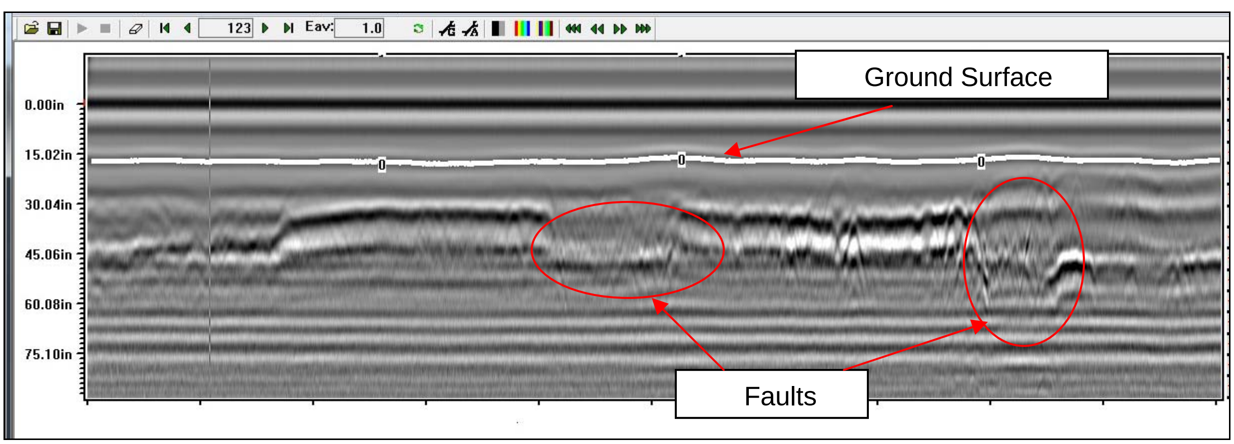


Figure 8, Base and sub-base evaluations by air coupled GPR.

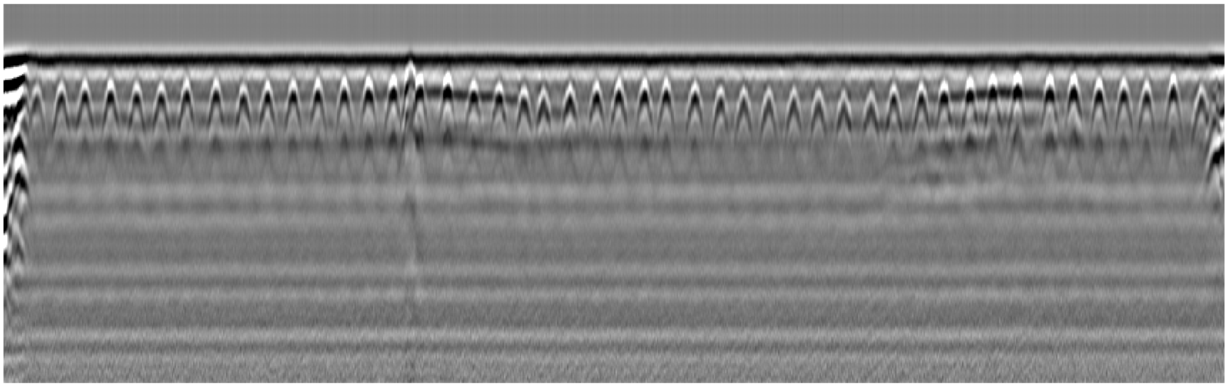


Figure 9, Concrete scanning and inspection by air coupled GPR.

5.3 Recommendation

Based on the success of this project, the recommendations are:

1. Implement air-coupled GPR systems and equip each district with such a system for network level road surface inspection as a routine maintenance procedure. Annual radar road surface inspection by each district is recommended. Since the both the GPR systems are highly integrated, installation of the GPR is relatively easy, and the GPR system is easy to use, no specialists are necessary.

2. Equip each TxDOT district with ground-coupled GPR for project level applications to monitor contractors, detect subsurface road hazards, and inspect bridge decks.

3. Regular training of the GPR applications to district-level engineers should be done to improve data collection quality and data interpretation skills.

4. An annual GPR application forum and web-based experience exchange among TxDOT engineers is recommended to broaden GPR application fields and share application experiences.

6 Conclusions

The air-coupled and the ground-coupled GPR systems, developed by the Project 5-4820-1, can provide TxDOT with the ability to collect GPR data on a network level and project basis. The GPR software, *GPR TXDOT*, can acquire the data, extract and report top layer thickness information, as well as the surface dielectric constant, without the operator's interpretation. The final products are easy-to-use GPR systems. Both the GPR systems were lab and field tested and compared with TxDOT existing GPR systems. The results indicate that both GPR systems are effective and reliable. These GPR systems are cost effective and can be quickly implemented for each TxDOT district.