Subsurface Sensing Lab
University of Houston

SUBSURFACE SENSING LAB
THE UNIVERSITY OF HOUSTON

PROJECT SUMMARY REPORT

Project Summary Report 0-4820-S
September 2006
Project 0-4820: Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection

Authors: Richard Liu, Jing Li, Xuemin Chen, Huichun Xing, Aditya Ekbote, and Ying Wang

Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection: Summary Report

The Federal Communications Commission (FCC) adopted a new rule for ground-penetrating radar (GPR) devices on July 12, 2002, that permits the operation of GPRs and wall imaging systems only below 960 MHz and between 3.1 and 10.6 GHz. To comply with new FCC regulations, a hybrid GPR system has been developed which includes the following two individual radars:

1) a pulse GPR working in the frequency range from DC to 900 MHz for thick pavement layer and subgrade layer thickness and moisture detection;
2) a frequency-modulated-continuous-wave (FMCW) radar working in the frequency range from 3.1 GHz to 8.5 GHz for measuring thin asphalt layers.

The software for signal processing and format setting has also been improved for real-time measurement, and no post-processing is required. The GPR data format is now compatible with Texas Department of Transportation (TxDOT) software, which facilitates information sharing and the implementation of this FCC compliant GPR system. Numerous lab tests have been performed. Field tests have been conducted at the Texas Transportation Institute Riverside Campus and on FM 2818, Texas Avenue, and SH 21 in College Station and Bryan. The measured results agree very well with the actual cases.

The developed GPR system is able to collect pavement layer information accurately and in real time. The system is completely ready for implementation.

What We Did …

To comply with FCC regulations, GPRs can work only in the two separate frequency bands: DC-960 MHz and 3.1 GHz to 10 GHz. In this project, two types of GPRs, a low-frequency pulse GPR and a high-frequency FMCW GPR, were developed to form a hybrid GPR system, ultimately utilizing the FCC-permitted frequency resources. Fig. 1 shows the developed low-frequency ground-coupled version pulse GPR. Fig. 2 is an air-coupled version pulse GPR, and Fig. 3 shows the high-frequency FMCW GPR. All three GPRs are vehicle-mounted. In the process of GPR development, the following research jobs have been conducted.

(1) Transmitter Frequency Range Control for Pulse GPR

To comply with FCC rules, the frequency band of low-frequency GPR must be controlled within the range of 960 MHz. Two methodologies are employed in this project to confine the GPR frequency range within DC-960 MHz. The first is to adjust the parameters of transmitters, and the second is to use a low-pass filter to remove the components above 960 MHz.

Table 1 shows the simulated relationship between the frequency range and the time duration of a Gaussian-type pulse wave.

Fig. 1 Ground-Coupled Version of the Pulse GPR.

Fig. 2 Air-Coupled Version of the Pulse GPR.

Table 1 Frequency Range vs. Time Duration of a Pulse Wave.

Time Duration	Frequency
0.75 ns	DC-4 GHz
1.5 ns	DC-2 GHz
3.0 ns	DC-1 GHz
3.7 ns	DC-0.96 GHz
4.0 ns	DC-0.85 GHz

According to the numerical simulation results in Table 1, the pulse GPR transmitter should have a pulse width of 4 ns or above to keep the frequency range below 960 MHz.

(2) FMCW GPR Frequency Range Control

In the FMCW system, the output frequency is controlled by an adjustable control DC voltage. The output frequency increases with the increase of the control voltage. Fig. 4 shows the measured relationship between the control voltage and the output frequency of the developed FMCW GPR. From Fig. 4 we see that if the applied control voltage is above 1.6 DCV, the output frequency of the transmitter will always be above 3.1 GHz, posing no conflict with FCC regulations. However, because the micro-wave transmitter may have multiple modes being excited, high-pass filters should be employed to cut off the possible frequency components below 3.1 GHz.

(3) Measured Frequency Range of Pulse and FMCW GPR

The spectrum of the pulse GPR, as shown in Fig. 5, is obtained by running a fast Fourier transform (FFT) of its time-domain response. From this plot, we can see that the spectrum amplitude is very small when the frequency goes beyond 960 MHz. Hence the pulse GPR is compliant with FCC rules. For the FMCW radar, a spectrum analyzer is used to measure the frequency response of the radar. Fig. 6 is the measured result that shows no microwave energy transmitted when frequency is lower than 3.1 GHz.

(4) New Algorithm for Estimating Dielectric Constant Directly from Ground-Coupled GPR Data

When using GPR to measure pavement thickness, we have to measure dielectric constant simultaneously. In air-coupled mode, the dielectric constants of pavement materials are usually measured by the surface reflectivity method. But to the ground-coupled GPR, the reflection wave and the direct wave arrive at the same time such that the amplitude of the

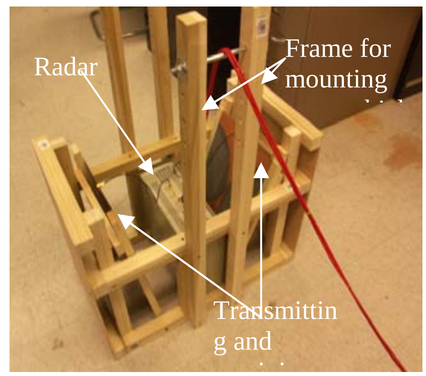

Fig. 3 FMCW GPR.

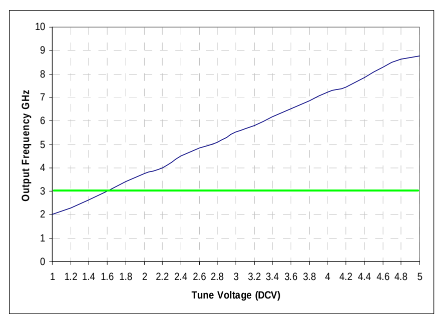

Fig. 4 Output Frequency vs. Applied Tune Voltage.

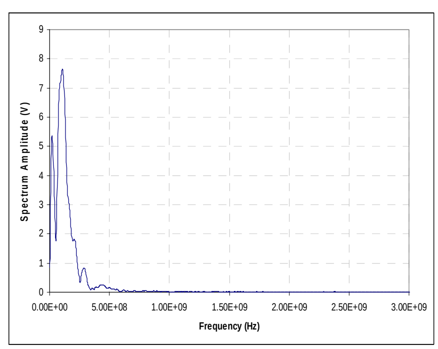

Fig. 5 Spectrum of Pulse GPR.

surface reflection cannot be determined.

Hence the surface reflection method does not apply to ground-coupled GPR. After numerical simulation by the transmission line matrix (TLM) method and experimental observation, we verified the existence of the ground-surface wave. By measuring the travel time of the ground-surface wave, the dielectric constant of the pavement can be directly determined by

$$\varepsilon_r = \left(\frac{c\,\Delta t}{L} + 1 \right)^2 \qquad (1)$$

where L is the transmitter-receiver offset; c is the velocity of light; and Δt is the measured travel time with respect to the direct wave. The predetermined dielectric constant enables the thickness to be easily solved. This method saves time and is suitable for real-time applications.

What We Found…

The developed device was first tested in the laboratory using a constructed asphalt slab with the thickness of 11.5 inches. The thickness and dielectric constant were measured according to the received waveforms. The measured results are given in Table 2. The measured thickness of the slab is very close to the actual values.

Table 2 Measured Slab Results.

Dielectric const.	Thickness
5.08	11.48

After lab experiments, field tests were carried out at TTI, FM 2818, Texas Avenue, and SH 21 in College Station and Bryan. Fig. 7 shows the measured GPR color map by the air-coupled GPR at TTI. Fig. 8 is the result measured on FM 2818 at FM 60. Fig. 9 shows the result measured on Texas SH 21. The TTI data and the SH 21 data have been proven very close to that measured by TxDOT radar.

The Researchers Recommend…

The developed GPR system is able to collect pavement layer information accurately and in real time. The system is completely ready for implementation. Higher measurement accuracy can be achieved by increasing the sampling points and dynamic range in the GPR system.

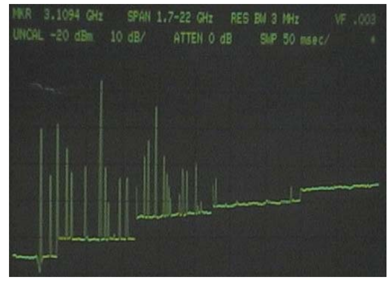

Fig. 6 Measured Spectrum of FMCW GPR.

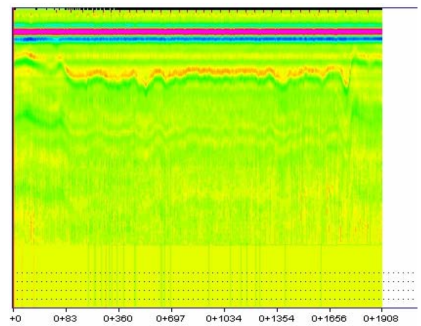

Fig. 7 Measured Color Map at TTI by Air-Coupled GPR.

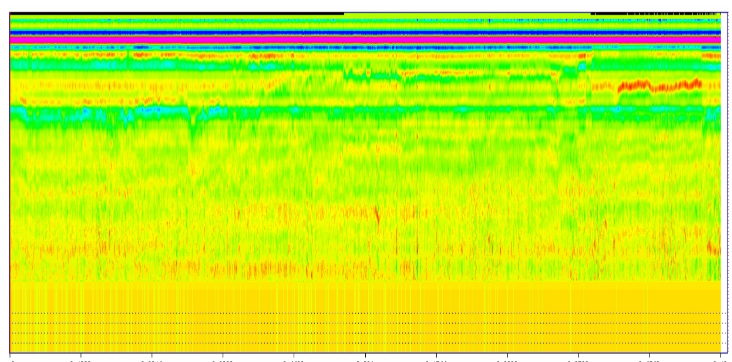

Fig. 8 FM 2818 SB at FM 60.

Fig. 9 Measured Result on SH 21 in Bryan.

For More Details...

Research Supervisor: Richard Liu, Ph.D., P.E., (713) 743-4421, cliu@uh.edu

TxDOT Project Director: Brian Michalk, Construction Division, (512) 465-3681 BMICHALK@dot.state.tx.us

TxDOT Program Coordinator: Ed Oshinski, Aviation Division (512) 416-4534 eoshinsk@dot.state.tx.us

TxDOT Research Engineer: German Claros, Ph.D., P.E., Research and Technology Implementation Office, (512) 465-7403 gclaros@dot.state.tx.us

This research is documented in the following reports:

0-4820-1, *Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection – Hardware and algorithms*

0-4820-2, *Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection – Test Procedure and Facility*

0-4820-3, *Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection – Technical Report*

To obtain copies of the report, contact CTR Library, Center for Transportation Research, (512) 232-3138, email: ctrlib@uts.cc.utexas.edu

DISCLAIMER

Texas Transportation Institute/TTI Communications
The Texas A & M University System
3135 TAMU
College Station, TX 77843-3135