Subsurface Sensing Lab
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Research Summary Report 0-4820
Project 0-4820: Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection

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PROJECT SUMMARY REPORT

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

FCC adopted a new rule on 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 is developed which includes the following two individual radars: 1) A pulse GPR radar 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 3.1GHZ 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 TxDOT software, which benefits the information sharing and the implementation of this FCC compliant GPR system. A lot of lab tests have been performed. Field tests have been conducted on TTI Annex, FM2818, Texas Avenue, and Sh21 in College Station and Bryan, respectively. The measured results agree with the real cases very well. 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 only work in the two separate frequency bands: DC-960MHz and 3.1GHz to 10GHz. In this project, two types of GPRs, a low frequency pulse GPR and a high frequency FMCW GPR, are developed to form a hybrid GPR system, ultimately utilizing the FCC permitted frequency resources. Fig. 1 shows the developed low frequency ground coupling version pulse GPR. Fig. 2 is a air lunching version pulse GPR, and Fig. 3 gives the high frequency FMCW GPR. Tree sets of GPRs are all vehicle-mounted. In the process of GPR development, the following research jobs have benn 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 960MHz. Two methodologies are employed in this project to confine the GPR frequency range within DC-960MHz. The first one is to adjust the parameters of transmitters, and the second one is using low pass filter to remove the components above 960MHz. Table 1 shows the simulated relationship between the frequency range and the time duration of Gaussian type pulse wave.

Table 1Frequency range vs. time duration of a pulse wave

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

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

(2) FMCW GPR Frequency Range Control

Fig. 1 Ground-coupling version of the pulse GPR

Fig. 2 Air-lunching version of the pulse GPR

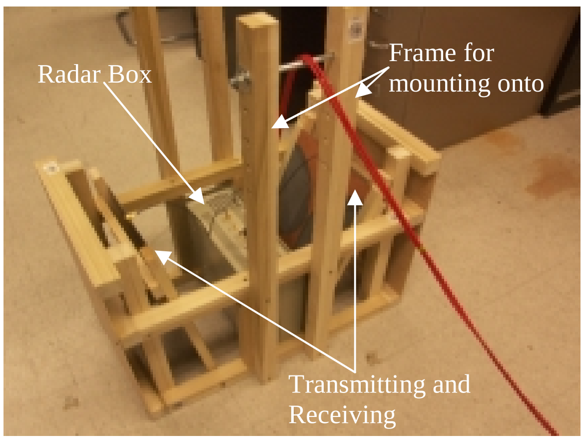

Fig. 3 FM-CW GPR

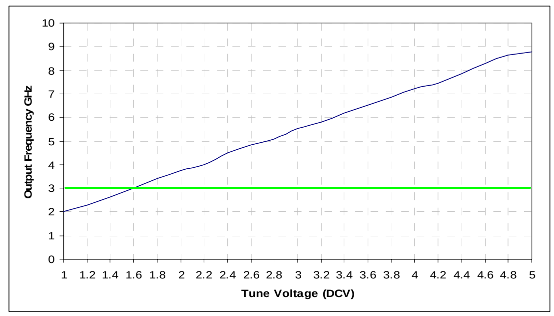

Fig. 4 Output frequency vs. applied tune voltage

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

(3) Measured Frequency Range of Pulse and FMCW GPR

The spectrum of the pulse GPR, as shown in Fig. 5, is obtained by doing FFT of its time domain response. From this plot, we can see that the spectrum amplitude is almost nothing when the frequency goes beyond 960MHz. 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 3.1GHz.

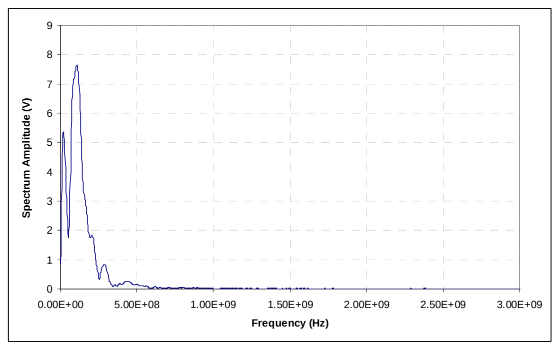

Fig. 5 Spectrum of pulse GPR

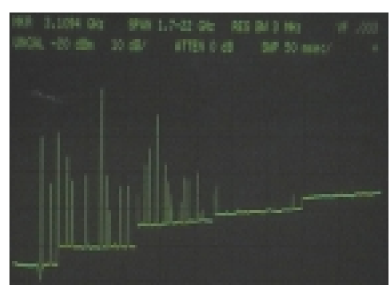

Fig. 6 Measured Spectrum of FMCW GPR

(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 lunching mode, the dielectric constants of pavement materials are usually measured by 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 surface reflection can not be determined. Hence the surface reflection method does not apply to ground coupling GPR. After numerical simulation by 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. With the dielectric constant predetermined, the thickness can be easily solved. This method is very time saving and suitable for real time applications.

What We Found…

The developed device was first tested in laboratory using the constructed asphalt slabs. The slab has the thickness of 11.5”.
According to the received waveforms, the thickness and the dielectric constant were measured. The measured results are given in Table 2.

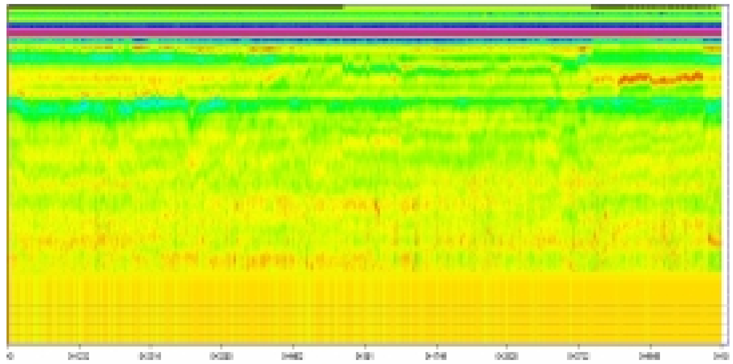

Fig. 8 FM2818 SB 2mile centered@60

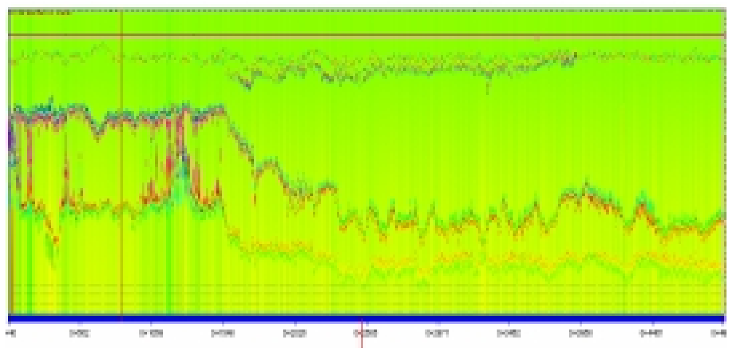

Fig. 9 Measured result on Sh21in Bryan

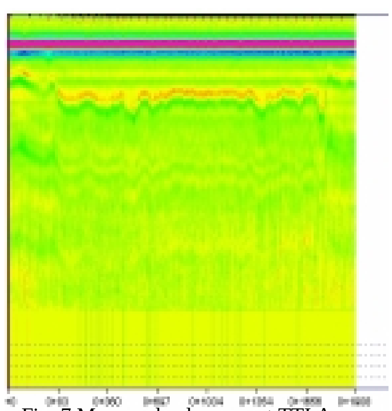

Fig. 7 Measured color map at TTI Annex by Air-lunching GPR

Table 2 Measured results on slab

Dielectric const.	Thickness
5.08	11.48

The measured thickness of the slab is very close to the actual values.
After lab experiments, field tests were also carried out on TTI Annex, FM2818, Texas Avenue, and Sh21 in College Station and Bryan, respectively. Fig. 7 shows the measured GPR color map by the air lunching GPR over the annex. Fig. 8 is the result measured on FM2818 at SH60. Fig. 9 shows the result measured on Texas Avenue between FM2818 and Bush Drive. The Annex data and the SH21 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.

For More Details...

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TxDOT IMPLEMENTATION STATUS
March 2006

Implementation of the FCC compliant GPR system for pavement layer information collection is delayed.

For more information, please contact Dr. German Claros, P. E., Reasearch and Technology Implementation Office, (512) 467-3381 or email: gclaros@dot.state.tx.us.

YOUR INVOLVEMENT IS WELCOME!

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation and the U. S. Department of Transportation, Federal Highway Administration. The content of this report reflects the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TXDOT. This report does not constitute a standard, specification, or regulation, nor is it intend for construction, bidding, or permit purposes. Trade names were used solely for information and not for product endorsement. The engineer in charge was Dr. Richard C. Liu.