1. Report No. FHWA/TX-05/0-4820-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection – Test Procedure and Facility		5. Report Date February 2006 Published: July 2006 6. Performing Organization Code
7. Author(s) Richard Liu, Jing Li, Xuemin Chen, Aditya Ekbote, Huichun Xing, and Ying Wang		8. Performing Organization Report No. 0-4820-2
9. Performing Organization Name and Address Department of Electrical and Computer Engineering, University of Houston, 4800 Calhoun Rd., Houston, TX 77204-4005		10. Work Unit No. 11. Contract or Grant No. 0-4820
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report: September 1, 2003 – August 31, 2005 14. Sponsoring Agency Code
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project title: Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection URL: http://tti.tamu.edu/documents/0-4820-2.pdf		

16. Abstract:

To comply with FCC rules on GPR devices, it is necessary to fully understand the test procedures and facilities for EM radiation measuring. This report introduces the procedures and facilities for radiation spectrum measurements. The developed GPR system is measured under the similar conditions. The test results demonstrate that the developed GPRs are able to comply with FCC rules. The impacts of FCC rule on the FMCW GPR are more serious, because FMCW GPR transmits continuous sinusoidal waves, and the limitation on emission level would definitely decrease its penetration depth.

17. Key Words FCC Rules on GPR, FCC-Compliant GPR, Pavement Thickness and Dielectric Constant Measurement, Network Level Layer Information Collection	18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Service, Springfield, Virginia, 22161, www.ntis.gov.

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

Form DOT F 1700.7 (8-72)

This form was electrically by Elite Federal Forms Inc.

Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection – Test Procedure and Facility

by

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

Technical Report 0-4820-2

Project Number: 0-4820
Project Title: Investigation of a New Generation of FCC Compliant NDT Devices for Pavement Layer Information Collection

Performed in Cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

by the

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

February 2006
Published: July 2006

DISCLAIMERS

The contents of this report reflect 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 views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

University of Houston
4800 Calhoun Rd.
Houston, TX 77204

ACKNOWLEDGMENTS

This project was sponsored by the Texas Department of Transportation. The research work was greatly supported by: the Project Director, Brian Michalk; the Program Coordinator, Ed Oshinski; and the TxDOT Research Engineer, Dr. German Claros.

Table of Contents

CHAPTER 1: INTRODUCTION 1

CHAPTER 2: MEASUREMENT INSTRUMENTS TEST SITE SETUP 3
2.1 MEASURING INSTRUMENT 3
2.2 REQUIREMENTS ON TEST SITES 4
2.2.1 RADIATED EMISSIONS TEST SITE FOR MEASUREMENTS BELOW 30 MHZ 5
2.2.2 RADIATED EMISSIONS TEST SITE FOR MEASUREMENTS 30 MHZ TO 1 GHZ 6
2.3 TURNTABLE 6

CHAPTER 3: FREQUENCY BAND MEASUREMENT OF THE DEVELOPED HYBRID GPR SYSTEM 7
3.1 FACILITY AND CONDITION FOR FREQUENCY BAND MEASUREMENT 7
3.2 MEASURED FREQUENCY RESPONSE OF THE DEVELOPED SYSTEM 7
3.2.1 PULSE GPR 7
3.2.2 FMCW GPR 9

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS 11
4.1 CONCLUSIONS 11
4.2 RECOMMENDATIONS 11

REFERENCES 13

List of Figures

Fig. 1-1 UWB Emission Limits for GPRs, Wall Imaging, & Medical Imaging Operation is limited to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies 1
Fig. 2-1 Radiated Emissions Measurement Site 4
Fig. 3-1 Measured time domain response of pulse GPR 8
Fig. 3-2 Spectrum of pulse GPR obtained by FFT of the time domain signal 8
Fig. 3-3 pulse waves transmitted by a GPR at a repeating frequency of 50 kHz 9
Fig. 3-4 waveforms transmitted by a continuous radiator 9
Fig. 3-5 Measured Transmitter Spectrum of FMCW GPR 10

CHAPTER 1: INTRODUCTION

FCC adopted a new rule on February 14, 2002, to limit the application of GPR devices and wall imaging systems [1]. The new rule stated that: GPR devices must be operated with their –10 dB bandwidth below 960 MHz or in the frequency band 3.1-10.6 GHz as shown in Fig. 1-1 by blue line and red line, respectively. GPRs operate only when in contact with, or within close proximity of, the ground for the purpose of detecting or obtaining the images of buried objects. The energy from the GPR is intentionally directed down into the ground for this purpose.

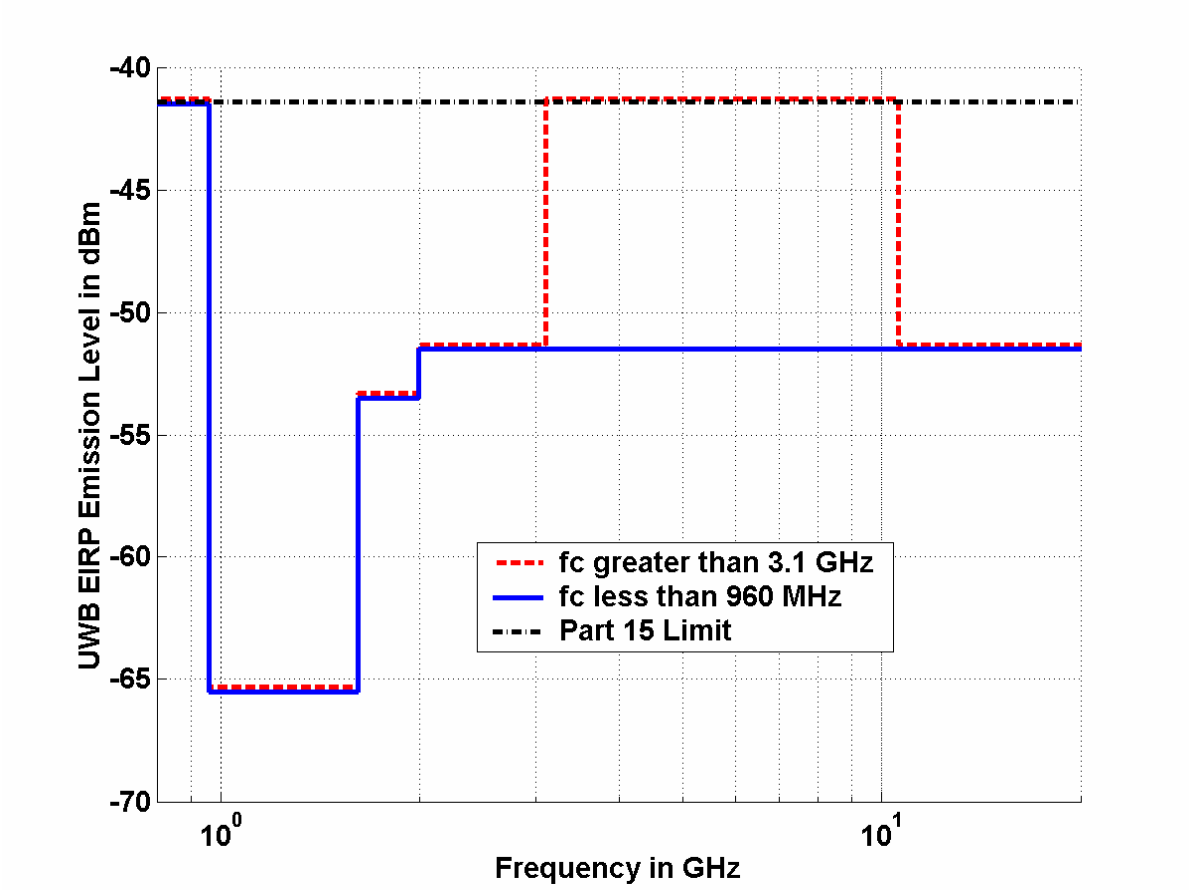

Fig. 1-1 UWB Emission Limits for GPRs, Wall Imaging, & Medical Imaging Operation is limited to law enforcement, fire and rescue organizations, scientific research institutions, commercial mining companies, and construction companies.

Based on this new rule, the GPR emissions must be strictly controlled in the frequency range from 960MHz to 3.1GHz. To facilitate the monitoring and controlling the radiation strength of the designed GPRs, the FCC certified measurement instruments and requirements on the emission test sites are investigated.

In Chapter 2, the measurement instruments for the qualified test site will be described. The measured results of the developed GPRs will be given in Chapter 3. The conclusions and recommendations will be delivered in Chapter 4.

CHAPTER 2: MEASUREMENT INSTRUMENTS TEST SITE SETUP

Use of proper measurement instrumentation is critical to obtaining accurate, reproducible results. The instrument selection and test site setup follow the guideline of American National Standard for Instrumentation (ANSI) [2] [3] [4] [5].

2.1 Measuring Instrument

Measurements of radiated signal shall be made with a measuring instrument conforming to ANSI or with a spectrum analyzer. In this project, a spectrum analyzer was used to measure the spectrum of the frequency-modulated continuous-wave (FMCW) GPR in the frequency rage from 1GHz to 10GHz and a wideband oscilloscope was used to measure the radiated field of the pulsed GPR.

When the spectrum analyzer and oscilloscope are used, the accessories needed depend upon the specific measurement task and include preamplifiers for improving sensitivity, filters and attenuators for overload protection, and additional quasi-peak detection circuits.

The use of specific antennas is determined by the frequency range and field (electric or magnetic) being measured in performing radiated emissions measurements. For electric field measurements in the frequency range of 9 kHz to 30 MHz, calibrated monopole (rod) antennas as specified in [2] shall be used to measure electric fields in the frequency range. Generally, a 1.04 m (approximately 41 in) vertical monopole antenna is used with or without a counterpoise as specified by the manufacturer. For electric field measurements in 30 MHz to 1000 MHz range, calibrated, linearly polarized dipole antennas as specified in [2] shall be used. Tunable dipoles should be used. For the electric field in the range of 1 to 40 GHz, calibrated, linearly polarized horn antennas as specified in [2] should be used. These include double-ridged guide horns, rectangular waveguide horns, pyramidal horns, optimum gain horns, and standard gain horns.

2.2 Requirements on Test Sites

For electromagnetic field test, the test site should be set up similar to Fig. 2-1, including power supply, a turntable, an receiving antenna, measuring instrument, and coaxial

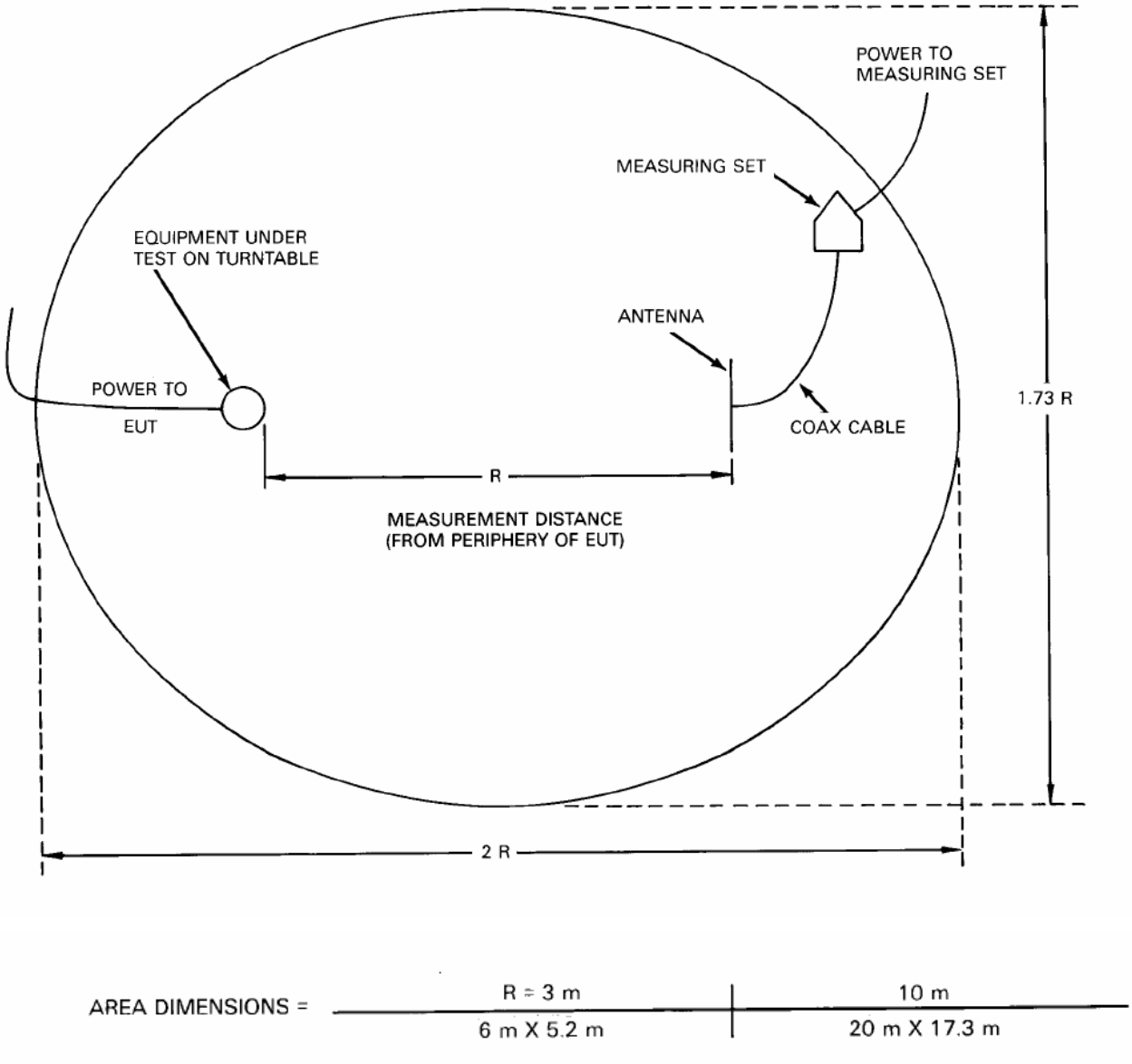

Fig 2-1 Radiated Emissions Measurement Site

cables. The receiving antenna is set at distance of R from the equipment under test (EUT). R takes 300m for signals below the frequency of 490 kHz, takes 30m for the frequency range of 490 kHz to 88MHz, and takes 3m for signals above 88MHz. The requirements for a test site include:

1.) Radiated measurements shall be made in an environment that assures valid, repeatable measurement results;

2.) Sufficient power shall be available to operate the EUT at its rated voltage, current, power, and frequency;

3.) Radiated ambient radio noise and signal levels should be at least 6 dB below the allowable limit of the applicable specification or standard; Ambient Radio Noise and Signals are measured at the test site with the equipment under test (EUT) de-energized.

If the ambient field exceeds the applicable limit(s), the following alternatives may be used: 1) In the case of radiated measurements, perform measurements at the closest distance permitted and extrapolate results to the specified limit distance. The method of extrapolation shall be justified and described in the test report; 2) Perform measurements of critical frequency bands during hours when broadcast stations are off the air and at times when ambient from industrial equipment is reduced to less than the 6 dB level; 3) Perform measurements in an absorber-lined room; 4) Orient the test site so as to discriminate against such ambient signals insofar as possible; 6) Rotate the EUT on a turntable while observing possible correlation between emission amplitude and EUT azimuth.

2.2.1 Radiated Emissions Test Site for Measurements below 30 MHz

For magnetic field strength measurements, a site similar to that of Fig 2-1 should be established. If permitted by the procuring or regulatory agency, measurements may be made in a shielded enclosure at frequencies below its resonant frequency.

2.2.2 Radiated Emissions Test Site for Measurements 30 MHz to 1 GHz

The reference site for radiated tests is an open, flat area (open area test site) characteristic of cleared, level terrain. Such a site shall be void of buildings, electric lines, fences, trees, underground cables, pipelines, etc., except as required to perform the test. A suggested layout of an open area test site is shown in Fig 2-1, where the recommended distance for *R* (measured from the nearest perimeter of the EUT) is 3, 10, or 30 m. All reflecting objects including test personnel shall lie outside the perimeter of the ellipse.

2.3 Turntable

A continuously rotatable turntable shall be used for measuring radiated emissions from all sides of the EUT. It is recommended that this turntable be remotely controlled to prevent test personnel from coming into close proximity to the EUT and thus affecting test results.

With the above required instruments and test sites, the GPR radiation frequency bands can be measured.

CHAPTER 3 FREQUENCY BAND MEASUREMENT FOR THE DEVELOPED HYBRID GPR SYSTEM

According to the discussions in the P0-4820 Technique Report-1, the frequency range of the pulse GPR can be confined below 960MHz by transmitting smooth Gaussian type pulse with a time duration larger than 4 ns, and the frequency of FMCW GPR can be controlled to the range above 3.1 GHz by applying tune voltage above 1.6 DCV. Also by applying low pass filter to the pulse GPR and high pass filter to FMCW GPR, the use of frequencies away from the banned band can be further guaranteed for the hybrid GPR system. This chapter will discuss and measure the real frequency bands of the developed system.

3.1 Facilities and Conditions for Frequency Band Measurement

To measure frequency response of a pulse GPR, a spectrum analyzer should be used. For a pulse GPR, an alternative method is to use a wideband oscilloscope (4 GHz and above) to roughly estimate its spectrum by fast Furrier transforming (FFT) time domain signals into spectrum signals. Measurement procedures are:

1) setup GPR and the measuring instruments as illustrated in Fig. 2-1, and set standard antenna three meters away from GPR under test;
2) turn on power for both GPR and the measuring instruments;
3) rotate GPR device and record the received signals, and
4) find the one with maximum amplitude from all measured signals; check the amplitude to see if it is small enough in the banned frequency range.

3.2 Measured Frequency Response of the Developed System

3.2.1 Pulse GPR

To investigate the spectrum of the developed pulse GPR, a wideband oscilloscope is used first to measure the transmitted signals of pulse GPRs in time domain at a closer distance (12 inches). Fig. 3-1 is the recorded time domain signal of the developed pulse

GPR by the oscilloscope. After FFT transform, its spectrum is obtained and displayed in Fig. 3-2. From this plot, we see that the spectrum amplitude becomes very small when the frequency goes beyond 960MHz.

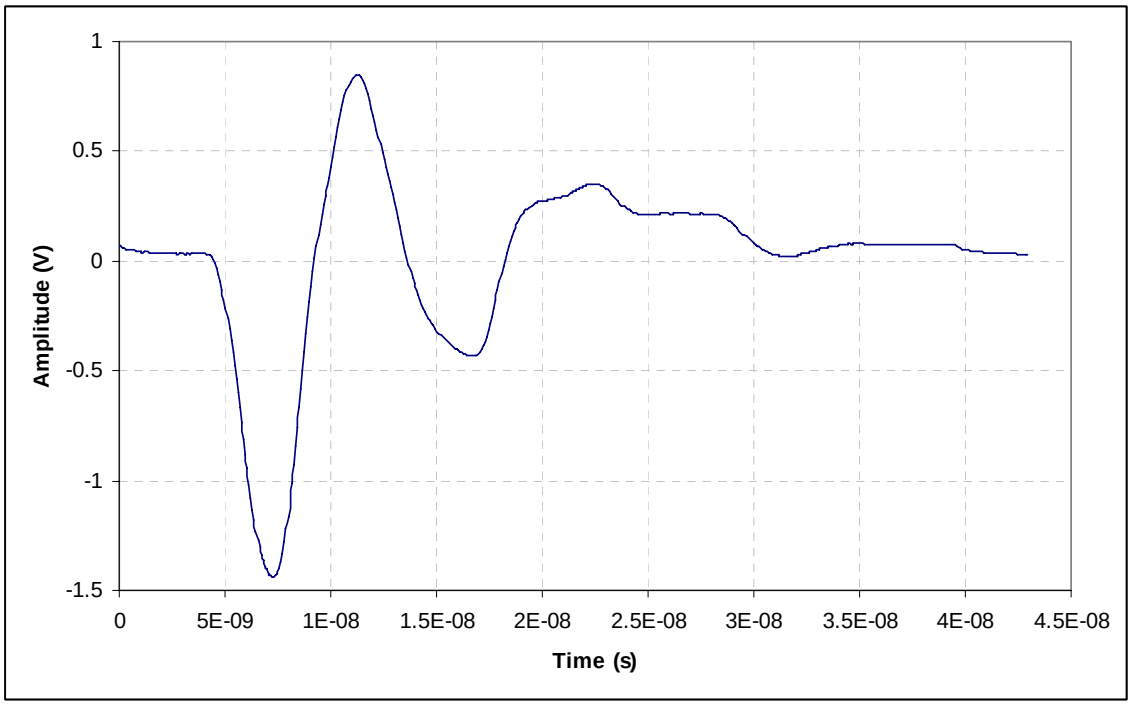

Fig. 3-1 Measured time domain response of pulse GPR

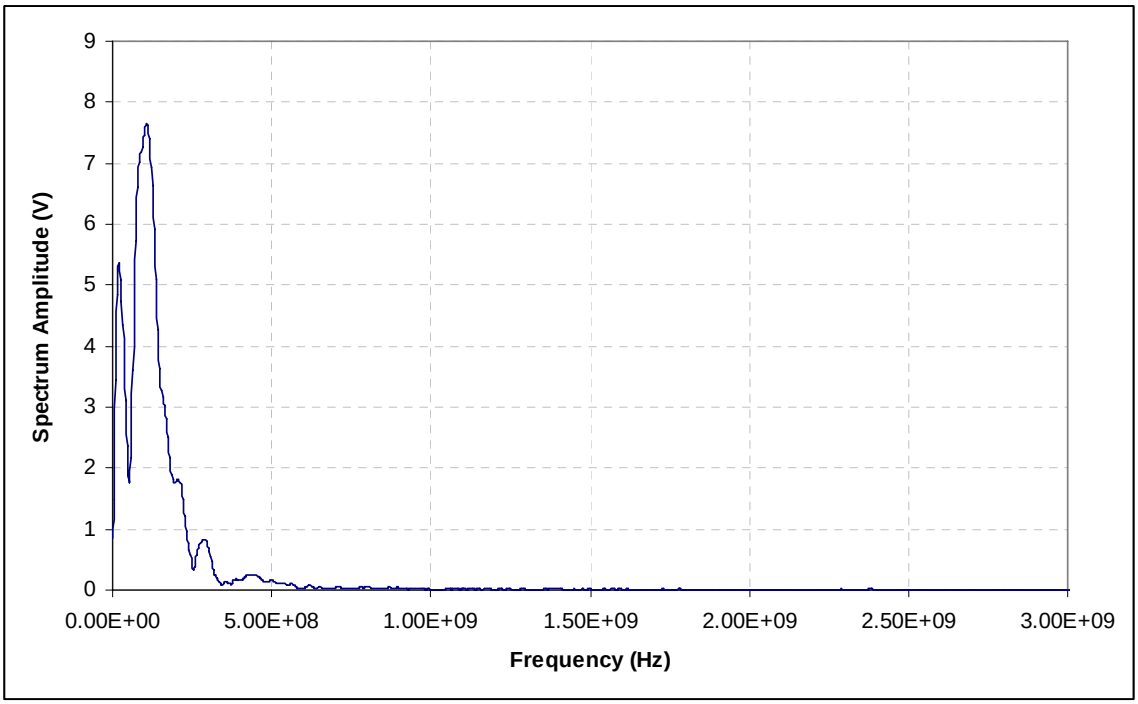

Fig. 3-2 Spectrum of pulse GPR obtained by FFT of the time domain signal

On the other hand, a pulse GPR transmits a pulse of 4ns wide every 20,000 ns as illustrated in Fig. 3-3. Compared to the continuous radiation as shown in Fig. 3-4, the radiated power of a pulse GPR is only two ten thousandth of the power of a continuous radiator, i.e. the GPR radiated power is 37dB less than that of a continuous radiator in the case of having the same amplitude in time domain. Hence the pulse GPR is compliant with FCC Rules.

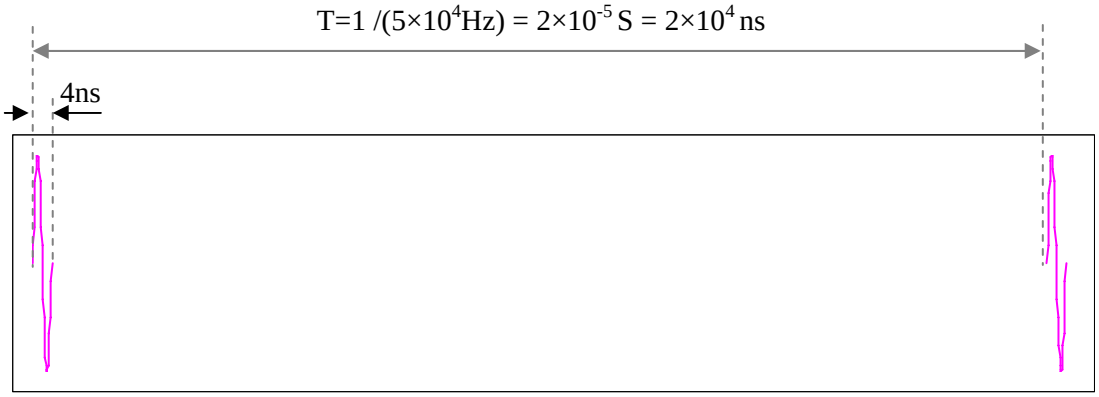

Fig. 3-3 pulse waves transmitted by a GPR at a repeating frequency of 50 kHz

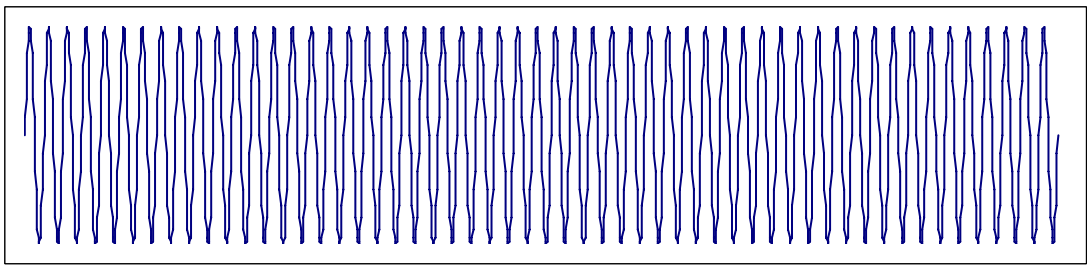

Fig. 3-4 waveforms transmitted by a continuous radiator

3.2.2 FMCW GPR

The FMCW radar works in the frequency domain, a spectrum analyzer should be used to measure the frequency response of the radar. Fig. 3-5 shows the measured result that shows only negligible microwave energy transmitted when frequency is lower than 3.1GHz or above 10.6GHz.

In the range of 3.1 to 10.6 GHz, the radiated power can be easily controlled at a level below the FCC emission limits by using RF attenuators. However, the penetrating depth should be affected if too much attenuation is applied.

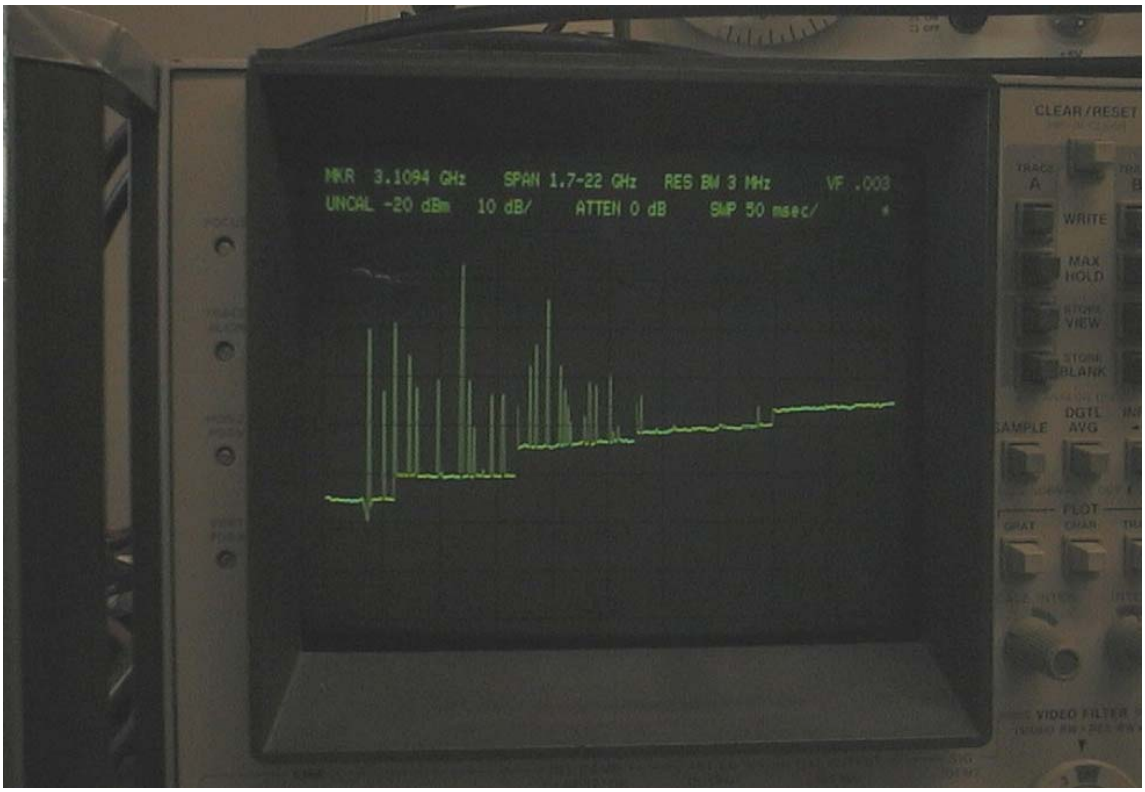

Fig. 3-5 Measured Transmitter Spectrum of FMCW GPR

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

In this report, the FCC rules on GPRs released on February 2002, the test instruments and test site setup and requirements are introduced and discussed. Preliminary tests of the developed pulse GPR and FMCW GPR have been performed. The test results demonstrate that the developed GPRs are able to comply with FCC rules. The impacts of FCC rule on the FMCW GPR are more serious, because FMCW GPR transmits continuous sinusoidal waves, and the limitation on emission level would definitely decrease its penetration depth.

4.2 RECOMMENDATIONS

The GPRs are used for detecting subsurface targets and its power mainly goes down into the earth. No report has been published of GPR interference to other communication systems. Hence more efforts should be made to request FCC to release the limitations on GPR applications.

REFERENCES

[1] FCC 02-48, Adopted: February 14, 2002; Released: April 22, 2002. **http://www.llnl.gov/ipac/technology/profile/sensor/MicropowerImpulseRadar/images/FCC_rules.pdf**

[2] ANSI C63.2-1987, American National Standard for Instrumentation—Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz—Specifications.1

[3] ANSI C63.5-1988, American National Standard for Calibration of Antennas Used for Radiated Emissions Measurements.

[4] ANSI C63.6-1988, American National Standard Guide for the Computation of Errors in Open-Area Test Site Measurements.

[5] ANSI C63.7-1988, American National Standard Guide for Construction of Open Area Test Sites for Performing Radiated Emission Measurements.