TEST PLAN FOR DETERMINING THE EFFECTS OF STEP FREQUENCY GROUND PENETRATING RADAR (GPR) DURING USE FOR FEDERAL HIGHWAY ADMINISTRATION (FHWA) APPLICATIONS

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OBJECTIVE

The objective of these tests is to determine whether (a) the Ground Penetrating Radar (GPR) can comply with the general Part 15 standards using the Federal Communications Commission (FCC) measurement procedure, (b) the GPR can, in a Part 15 compliant configuration, meet the requirements of the Federal Highway Administration (FHWA), and (c) the GPR will protect aviation systems.

BACKGROUND

The GPR is an electronic imaging device that transmits signals that are capable of "seeing" objects underground. To date, the only type of GPR analyzed or tested utilized ultra-wideband (UWB) technology. The GPR in this test program utilizes frequency-hopping techniques over a large portion of the spectrum. This GPR is not a UWB device. The GPR in this test effort can be programmed to operate anywhere within the frequency range 30 MHz – 2.05 GHz with 2 MHz frequency steps. The dwell time at each frequency can be programmed within the range 1.54 – 3.0 microseconds. Hence, the full bandwidth frequency scan consisting of maximum 1011 frequencies is completed within 1.6 – 3.03 milliseconds depending on the programmed dwell time. It is also possible to program the system to use smaller portions of the available system bandwidth and also to avoid transmitting within dedicated frequency bands. The Pulse Repetition Frequency (PRF) of the frequency scan is typically between 30 and 160 Hz during data collection. The maximum output power to the antenna is +15 dBm. The antenna system consists of an array of broadband bow-tie monopole antennas with very low efficiency (5%). When these antennas are facing toward the ground, the typical shielding efficiency for undesired radiation into the air is 20 – 25 dB. These tests are intended to help determine whether this GPR technology can operate under the general Part 15 rules and minimize the potential to cause harmful interference to licensed systems.

GPR EMISSION MEASUREMENTS (FCC 02-48 APPENDIX F) FOR PART 15 COMPLIANCE

The emissions (radiated and reflected) from the GPR will be measured with a spectrum analyzer. Below 1000 MHz GPR Emissions will first be measured with the spectrum analyzer in its peak measurement mode. If GPR frequencies are identified, then the spectrum analyzer will be switched to the Quasi-Peak mode for the final measurement. This procedure is needed to speed up the testing due to the long sweep times of the quasi-peak measurement. If a GPR signal is detected in the VHF/UHF communications band a victim receiver will be tuned to the closest frequency corresponding to the maximum GPR signal found in its operating band.

<u>Test Methodology</u>. The FAA will determine the GPR emission characteristics *in FAA frequency bands* using the Measurements Procedures of FCC 02-48 Appendix F. A sand pit 20 inches deep and 10 feet by 10 feet will be used. This will accommodate the FHWA 1.2 meter wide array or the 2.0 meter wide array.

The tests will begin with a system noise and environmental noise measurement. The system noise measurement will be performed by disconnecting the antenna from the coaxial cable and connecting a 50-ohm termination to the same coaxial cable. The spectrum analyzer will be used to measure the system noise in dBμV. This establishes the noise floor of the measurement system.

Baseline measurements of the environmental noise are made by re-connecting the antenna to the coaxial cable and sweeping the band with the spectrum analyzer. This measurement provides us with the environmental noise floor for each frequency band we will test the GPR in.

Depending on the frequency band, these measurements will be either in μV or dBμV. To convert these measurements to μV/m or dBμV/m the cable loss, antenna calibration factor, and if used the pre-amplifier gain will be factored in.

The GPR will be operated as it is intended to be, with its antenna oriented towards the sand pit. A calibrated measurement antenna will be placed 3 meters from the closest point of the GPR antenna enclosure. The calibrated antenna will be raised or lowered until the height that produces the maximum signal is found. This signal level will be measured using a spectrum analyzer with a CISPR quasi-peak detector. This measurement will be performed with the calibrated antenna operated in its horizontal polarization and then in its vertical polarization mode. Since a ground plane will not be used, 4.7 dB will be added to each measurement.

In addition to the quasi-peak detector measurements, which use a 120 kHz bandwidth for equipment operating between 30 MHz and 1000 MHz, the spectrum analyzer also will be used to measure the peak radiated emission. These peak measurements will be made at the same distances/heights/antenna polarizations as the quasi-peak measurements at frequencies below 1000 MHz. Since the FAA equipment in the VHF/UHF Communications band has a 6 dB bandwidth of $\pm$ 9 kHz minimum and a 60 dB bandwidth of $\pm$ 25 kHz maximum, a spectrum analyzer resolution bandwidth of 10 kHz and/or 30 kHz will be used for the peak measurements. The narrower bandwidths will also enable us to identify any GPR spectral lines that may affect our radios. These measurements will be made using the analyzer's maximum-hold trace mode.

Measurements using an RMS detector also will be performed for frequencies above 1000 MHz. All of the compatibility analyses that were performed are based on average RMS emission levels. Until experience is gained with this type GPR, measurements above 1000 MHz will also be performed with a peak detector. The detector that produces the most accurate results will be use for the final measurements.

An attempt will be made to make measurements around the GPR antenna at 45^{o} intervals and the above measurements repeated. This will produce 16 horizontally polarized and 16 vertically polarized data points for each frequency band tested. As the tests progress and experience is gained, means will be established to reduce the number of data points.

<u>Test Setup</u>. Figure 1 shows the FCC Measurement Procedures test setup.

TESTS TO DETERMINE GPR USEFULNESS TO FHWA IN PART 15 COMPLIANT CONFIGURATION

GPR applications to Federal Highway Administration (FHWA) tasks include subsurface investigations of bridge decks, pavements, concrete structures and roadway support materials. These applications have measurement parameters that include geometry and materials at typical test sites. In addition, the GPR vehicle must typically be in motion during data collection. Frequently, FHWA civil engineering measurement tasks require GPR to operate up to highway speeds. High-speed measurements prevent traffic disruptions on roadways and bridges that are being evaluated using GPR. All of these test related issues should be accounted for while characterizing GPR radio frequency emissions compliance with applicable rules. This will ensure that emissions test results reflect emissions that will take place in field use. Two separate testing regimes will be used to address these GPR radio frequency emissions test requirements for FHWA applications.

Representative radio frequency emissions test configurations for FHWA GPR applications will include both a stationary test regime and a moving GPR vehicle platform test regime. The stationary tests will follow the methods this plan already describes in other sections. The moving GPR vehicle tests will add more requirements, but the GPR vehicle will always be stopped before the conclusion of each moving GPR test for stationary test measurements. The purpose of the stationary GPR tests is well established and is primarily based on federal regulatory requirements described in the first section of this test plan. The purpose of the moving GPR vehicle test is to augment emissions measurement data provided by static tests, while simultaneously measuring GPR performance for typical FHWA applications. The facility requirements for the moving GPR vehicle test involve two material systems, a flexible asphalt pavement and a reinforced concrete pavement. Testing on both material systems will use a common geometry and methodology.

The geometry of the pavements for moving vehicle GPR tests will be a minimum of 1 lane wide (12 feet) and a minimum of 240 ft long. The emission measurement antenna will be positioned adjacent to the test lane, 3 meters from the closest GPR antenna position measured as the GPR vehicle passes the test antenna. The GPR test vehicle will be driven at 5 mph or less while collecting data along the full length of the pavement lane and periodic measurements will be made using the emissions measurement antenna. A measurement will also be made when the GPR antenna is in closest proximity to the emissions measurement antenna, (3 meters apart). Pavement markings and visual techniques, (or other appropriate methods), will be used to approximate the distance between the measurement antenna and the GPR antenna at the time each GPR emission measurement is made. Measurements will be carried out on both asphalt pavement and concrete pavement test sites. Horizontal and vertical polarizations of the emission measurement antenna will be used for measurements at each test site. All of the basic measurement provisions made for stationary GPR testing will also be made for moving vehicle GPR testing, when possible. Testing will be repeated at speeds up to 55 mph if enough space is available and practical results can be obtained.

The step frequency GPR system under test will be programmed to transmit at frequencies that are useful for FHWA applications, (from approximately 200 MHz up to 2 GHz). Three tests will be performed for each test configuration corresponding to three different power emission levels. The step frequency system will be programmed to transmit at predicted low, medium and high emission levels across the programmed frequency spectrum to conduct these tests. The transmitted GPR frequency spectrum will be programmed to exclude frequency notches specified by federal regulatory agencies.

Pavement GPR test data will be evaluated in comparison with reference cores and as built pavement plans. Pavement layer thickness values and other parameters derived from GPR data will be used for comparison. Subsurface defects, utilities, reinforcing steel and other features will be documented and compared with plans and core data. Capabilities of the step frequency GPR to effectively measure, detect and image features at a representative range of depths for each testing scenario will be documented. GPR resolution will also be estimated for each testing scenario. Through this data analysis process, a practical envelope of parameters for step frequency GPR operations can be estimated for typical FHWA applications. This operational envelope can subsequently be compared with emissions measurement data to gage the operational limits that allow for compliant operation under federal regulations.

TESTS TO DETERMINE SUSCEPTIBILITY OF GROUND COMMUNICATIONS RECEIVERS FROM GPR EMISSIONS

Background scans will be performed several times throughout the day to monitor the ambient signal environment. These background measurements will be used to determine if it is the GPR signal causing interference or some other signal.

The ground VHF and UHF communications receivers will be tuned according to the manufacturer’s tune-up procedures. They will also meet the FAA Maintenance Specification requirements for operational systems.

All ground tests will start with the GPR turned *off* to ensure there are no other radiation sources that may affect the measurements. If other radiation sources are detected the receiver will be tuned to the next strongest GPR emission frequency where no other emissions are found.

Interference Criteria. The interference criteria for the FAA VHF and UHF ground communications receivers will be:

> GPR *off* with desired signal *on* and *unmodulated* to determine a baseline (not interference criteria)
>
> GPR *off* with desired signal *on* and voice (using recorded standard aviation phrases) modulated 90% to determine a baseline (not interference criteria)
>
> GPR signal breaking squelch with desired aeronautical radio signal *off*
>
> GPR disrupting the desired signal, i.e. hearing GPR in background, with desired signal *on* and *un*modulated

GPR disrupting the desired signal, i.e. hearing GPR in background, with desired signal *on* and voice (using recorded standard aviation phrases*)* modulated 90%.

The test is performed as shown in figure 2 with both the desired signal and GPR signal entering the receiver's input port through its antenna. The desired signal is produced by a signal generator and then radiated through the air to the victim receiver. The -98 dBm is measured at the victim receiver's antenna input port. The signal generator maintains a constant output.

<u>Test Methodology</u>. A CM-200 VHF (UHF) receiver will be tuned to the frequency corresponding to the maximum GPR signal found in their respective bands. The GPR will be oriented so that maximum emissions will be directed towards the victim receiver. The GPR will be kept in a normal operating mode.

FAA Order 6580.5 requires VHF (UHF) ground communications receivers to break squelch with the desired on-tune signals as low as -103 dBm. These tests will be conducted with the receiver's squelch adjusted for -103 dBm.

The signal generator will be tuned to the VHF (UHF) communications receiver's frequency and connected to a tower mounted VHF (UHF) antenna. This antenna will be used to transmit the desired signal to the VHF (UHF) communications receiver. A second VHF (UHF) antenna will be connected to the VHF (UHF) communications receiver. This antenna will receive both the desired signal and the GPR emissions. The audio output of the receiver will be recorded. Therefore, both the desired signal and the GPR signal will be radiated in space and received by the receiver antenna.

The signal generator will be adjusted to produce a desired signal of -98 dBm at the receiver's antenna port. When a modulated signal is required the signal generator will be amplitude modulated 90% with voice. This is the desired signal for the receiver under test.

The test will start with the GPR turned *off* and an audio recording of standard aviation phrases made of this baseline condition. This baseline condition will be performed with no desired signal, a -98 dBm desired carrier signal, and the desired signal amplitude modulated 90% by voice.

Next the GPR will be turned *on* and the above tests repeated. The GPR will be moved to find locations where interference occurs and at what distance the interference stops. Since the receivers located in building 176 are not transportable, the GPR will be moved. The first measurements will be made over the sand pit. Audio recordings will be made for all test conditions. At each point, the GPR received RF signal level will be recorded. Next, the GPR vehicle will be driven away from the vicinity of our receiver's antenna towers and stopped whenever a squelch break occurs. Audio recordings and signal level measurements will be made at these locations. The audio recording will be made at the audio output of the receiver and the signal level measurement will be made by disconnecting the antenna cable form the receiver and re-connecting it to the spectrum analyzer.

Finally, with the desired signal turned on, the GPR vehicle will be driven from the building out towards the road and the audio will be recorded continuously. Spectrum analyzer measurements will be made at key locations.

Test Setup. Figure 2 shows the test setup for determining the interference effects on the VHF and UHF communications receiver due to the GPR.

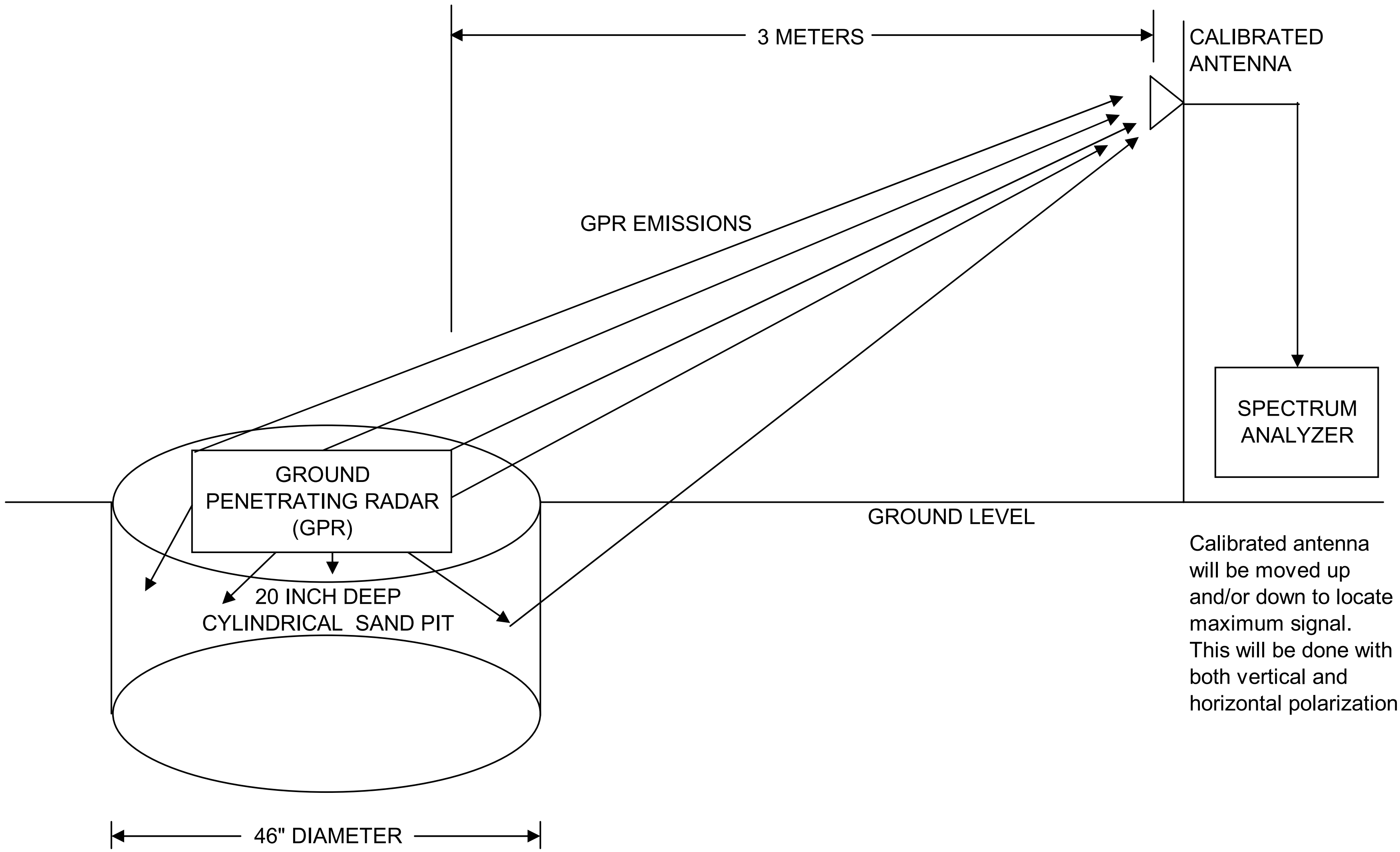

FIGURE 1. TEST SETUP FOR "FIRST REPORT AND ORDER FCC 02-48 MEASUREMENT PROCEDURES APPENDIX F"

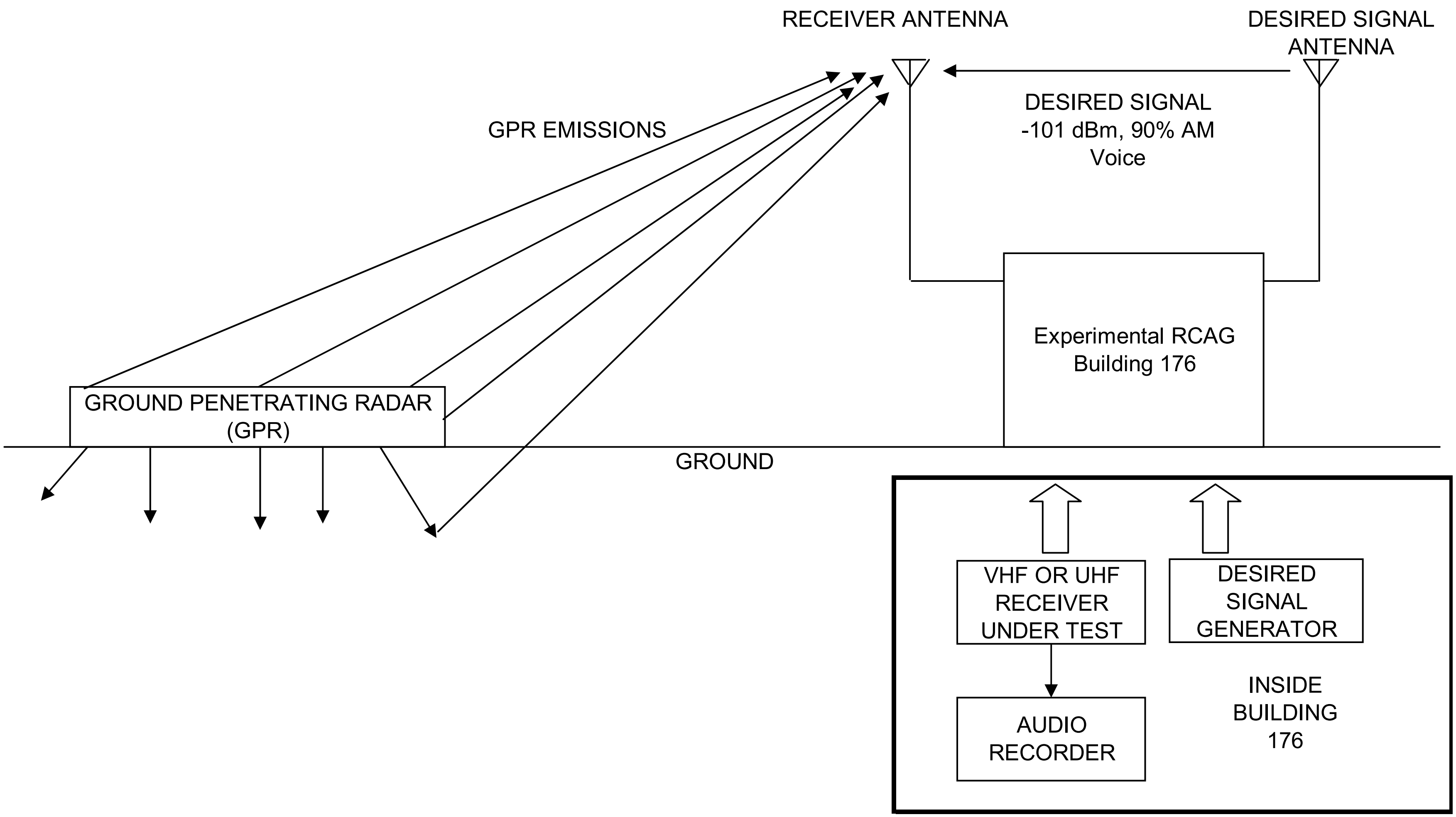

FIGURE 2. TEST SETUP FOR DETERMINING THE EFFECT OF GROUND PENETRATING RADAR ON VHF AND UHF GROUND COMMUNICATIONS RECEIVERS