GROUND PENETRATING RADAR

→ GPR System and Operation

→ Ultra-wide Band Antenna Designs

→ Landmine Detection by Hand-held GPR

→ Non-destructive Testing by GSSI Geo Radar

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GPR SYSTEM

- **Overview: What's GPR?**
- **How does it work?**
- **System Description**
- **General Requirements**
- **RF Hardware: Transmitter/Receiver/Antenna Blocks**
- **Control and Software: Data/Signal Processing**

GPR OPERATION

- GPR is a near-zone electromagnetic radar system, which is used to detect, locate, identify and image subsurface objects
- Ultra-wide band (UWB) operation is proposed to benefit both low and high frequencies that determines depth and resolution

Impulse GPR

- Uses high frequency pulsed E.M. waves
- Particularly used in geo-technical, mining and archeological surveys
- Depth of penetration varies from less than a meter to over kilometers, depending on the material properties
- Higher scan and sampling rate

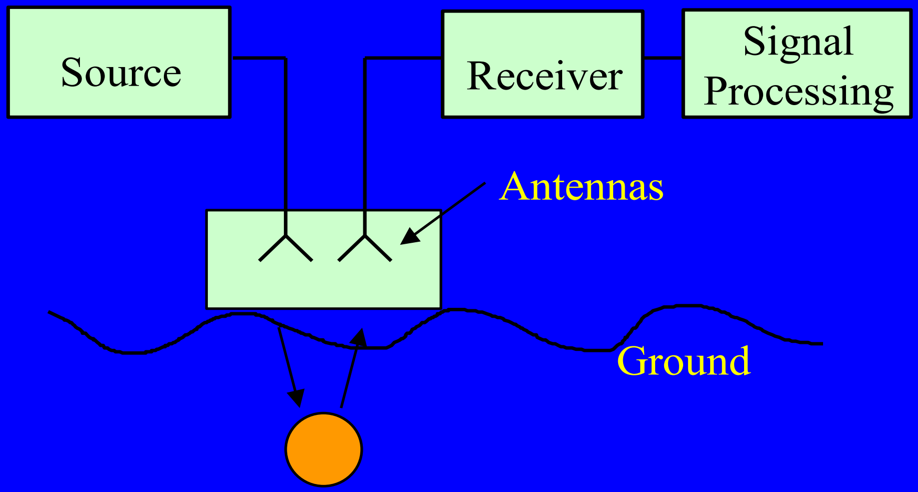
Stepped-frequency GPR

- Uses high frequency swept or stepped continuous electromagnetic waves
- Operational frequency band is selectable depending on the required range resolution and penetration depth of the target
- Better dynamic range performance
- More complicated signal processing

Near Surface Impulse GPR

→ **AIM**

- to detect, locate and identify the buried objects/sub layers
- penetration depth is up to 1 m. even for hard/wet ground
- multi-sensor, hand-held or vehicle-mounted operation

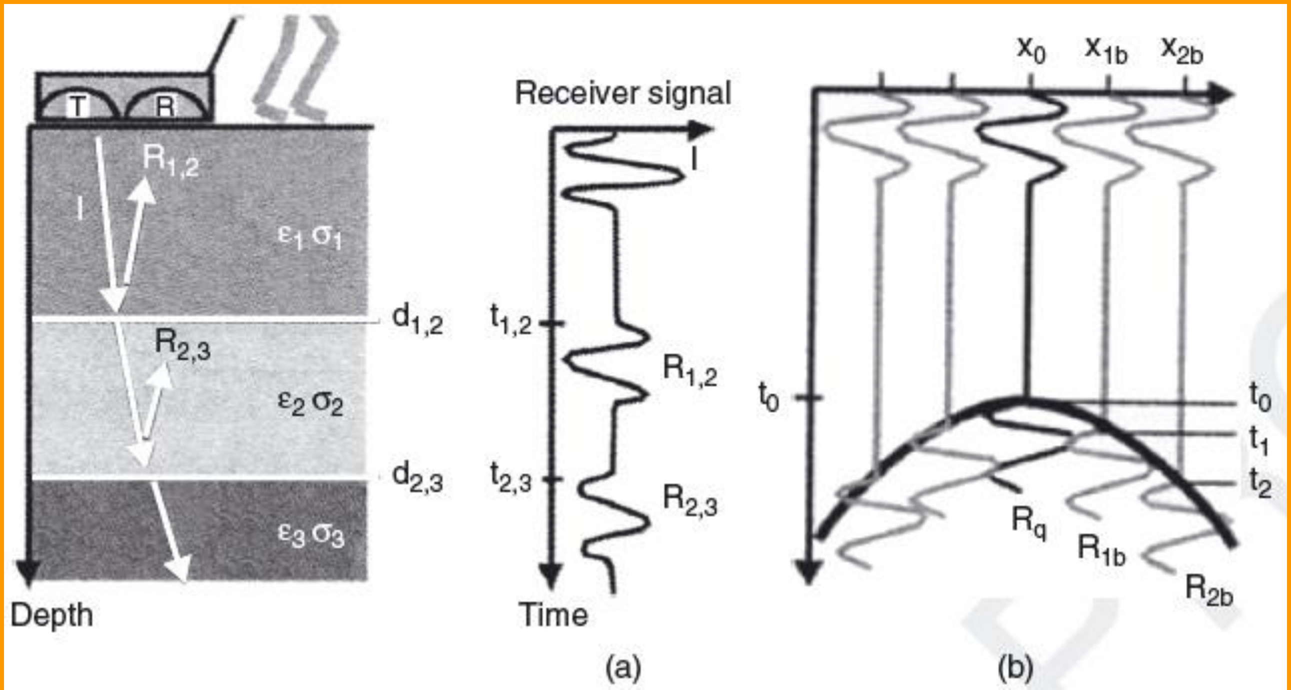


Operating Principle

- Generation of electromagnetic field (**RF source**)
- Radiation of electromagnetic field (**T/R antennas**)
- **Characterization** of the soil and air/earth interface, and the target properties such as structure, shape, etc.
- **Reception** and synthesis of the scattered RF fields
- High-speed **controller** unit for synchronization and signalization of the transmitter and receiver blocks
- Adaptive **signal processing** techniques for detection and identification of buried target objects
- Robotic **test environment** for performance analysis

Impulse GPR Operation

Typical Illustration



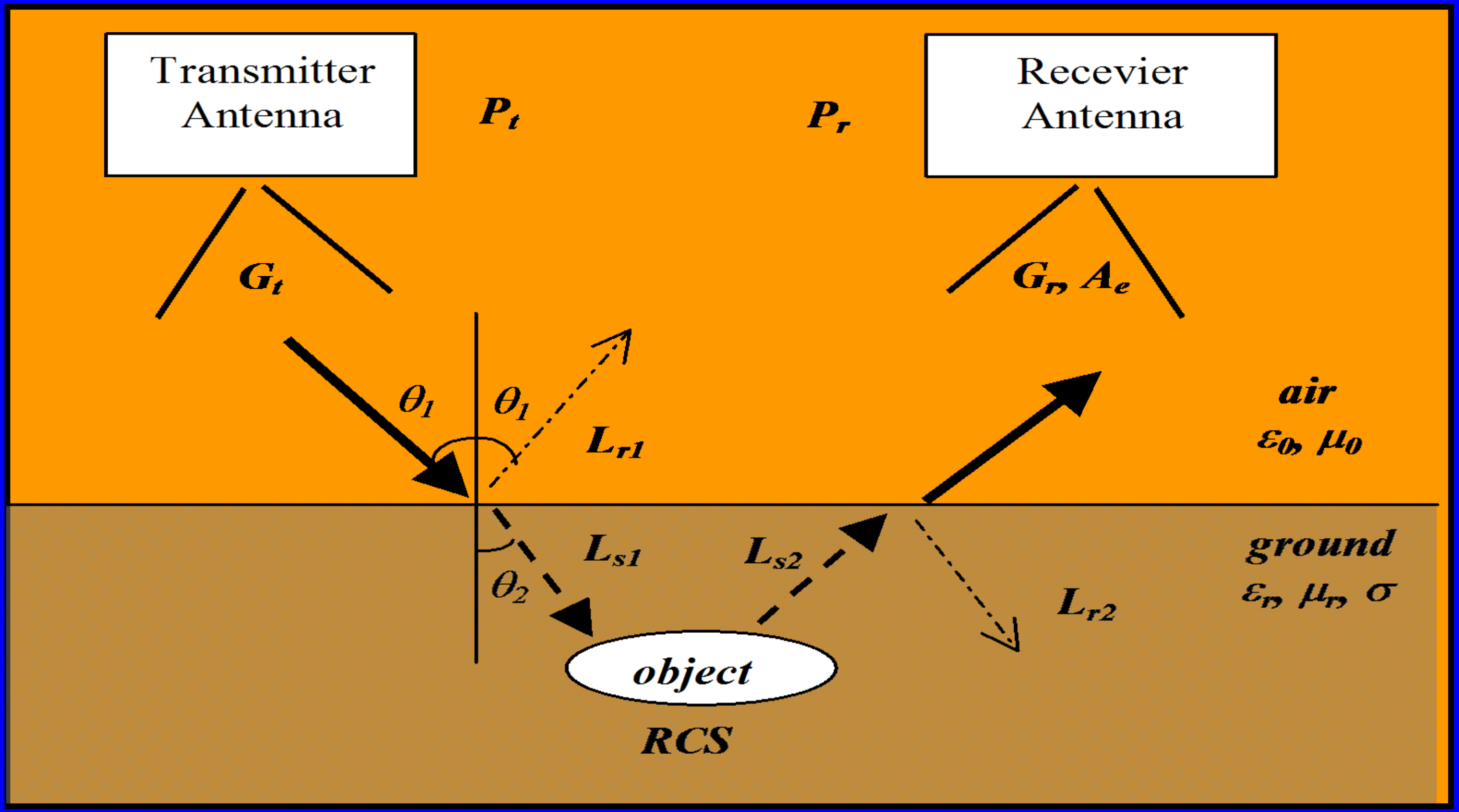
a. A-scan GPR impulse signal received by the multi-layer reflection

b. B-scan GPR impulse reflected from an object along the direction (see parabola shape)

Parabola on B-scan appear **ONLY** for objects, **NOT** for continuous sub-layers!

Design Procedure

RADAR Scenario



Design Procedure

RADAR Equation

$$P_r = \frac{P_t G_t G_r}{(4\pi)^3 R^4} \frac{RCS}{L_t} \lambda^2$$

- Received Power → P_r
- Transmitted Power → P_t
- T/R Antenna Gains → G_t, G_r
- EM reflectivity of the target → RCS
- Wave length = (speed/frequency) → λ
- Distance of the target object (to GPR antenna, in meters) → R
- Wave propagation losses → L_t:
  - Antenna coupling loss
  - Surface reflectivity loss
  - Soil attenuation loss

Design Procedure

Equation Parameters vs. Frequency

RECEIVED POWER

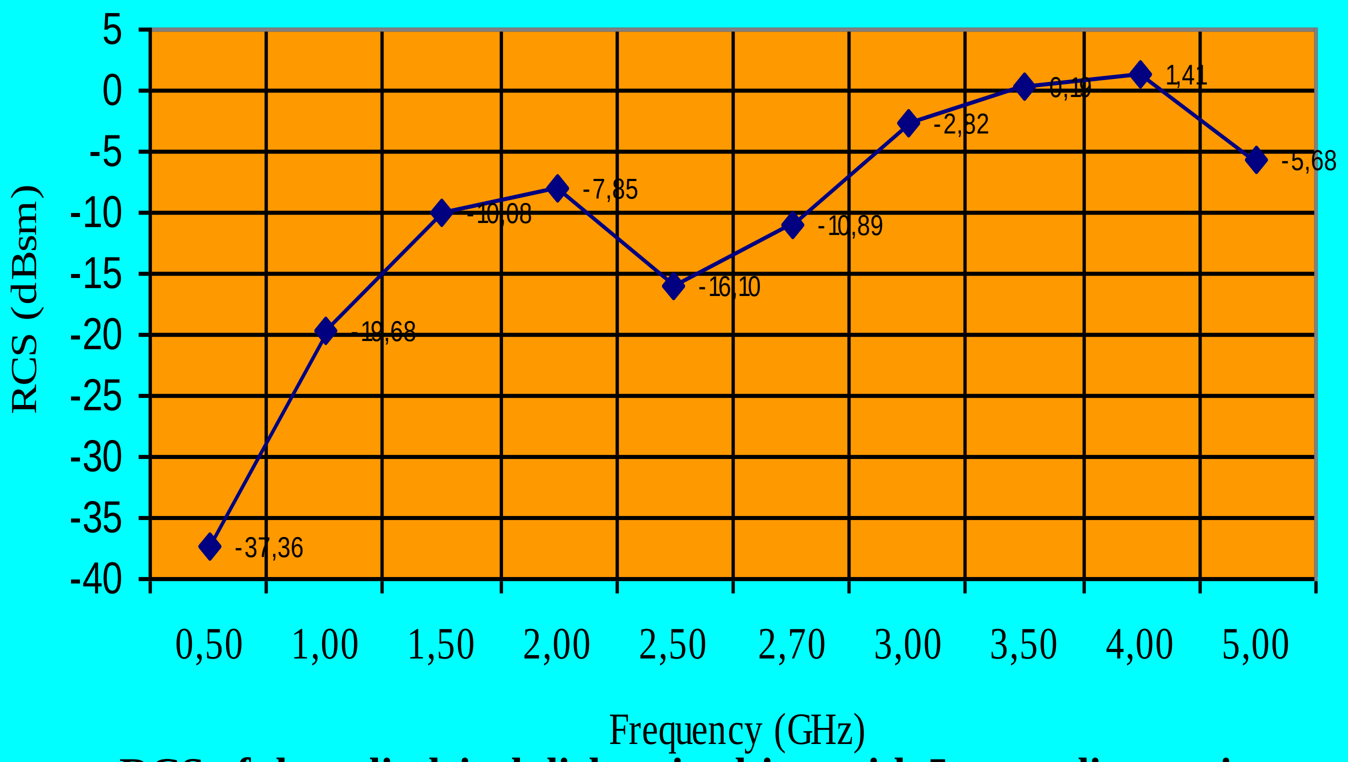
- Antenna Gains (directivity)
- Transmitter Power (watt)
- E.M. reflectivity of the object
- Wave length (meter)

- Target Distance (meters)
- Surface reflectivity losses
- Soil attenuation losses

FREQUENCY

Design Procedure

Target RCS vs. Frequency



RCS of the cylindrical dielectric object with 5 cm radius at air.

Design Procedure

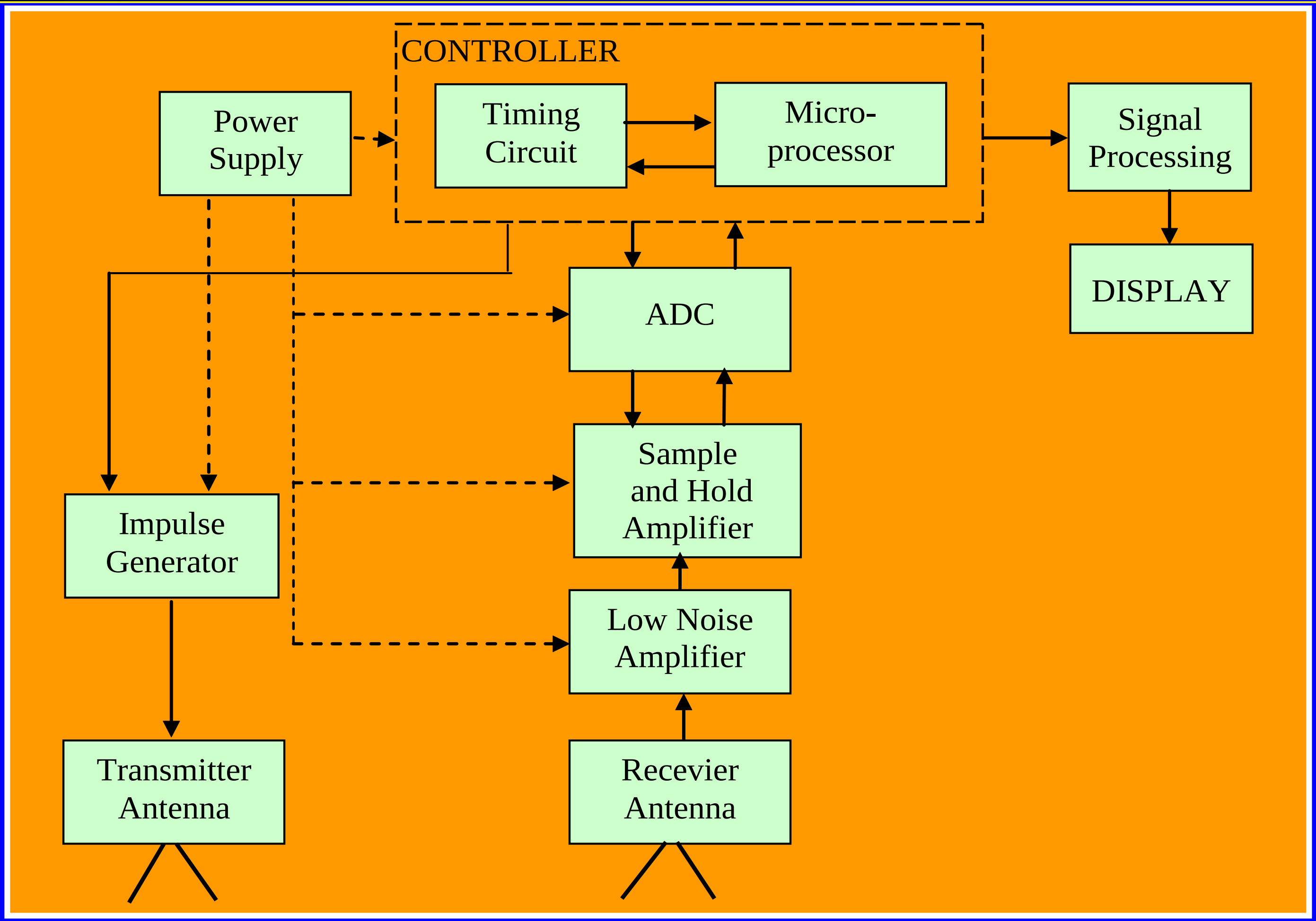
Essential Remarks

- Selection of the transmitter power and operating frequency are the key factors in GPR design.
- Surface reflectivity and soil attenuation losses highly increase for after 1 GHz, especially for wet soils.
- Nevertheless, higher frequencies are needed to obtain for better range/layer resolution and radar echo.
- So, lower frequency bands are used for deeper analysis, higher frequency bands are used for detection of smaller sub-surface objects or thinner layers located at shallow.

→ Thus, Ultra-wide band (UWB) GPR is mostly preferred in order to benefit from both low and high frequencies!

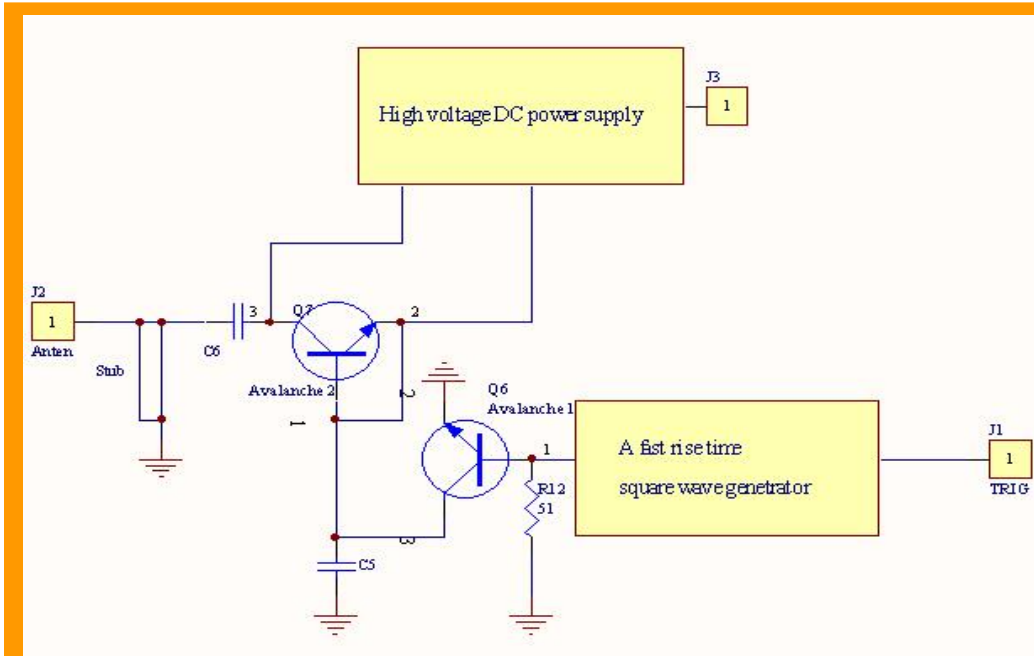
Impulse GPR System

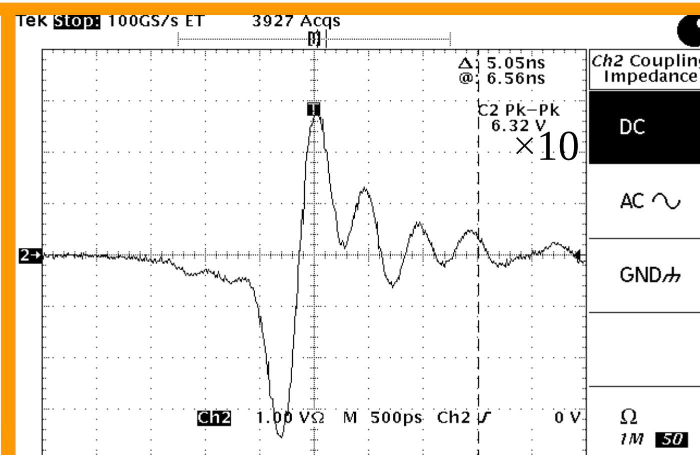
Block Diagram

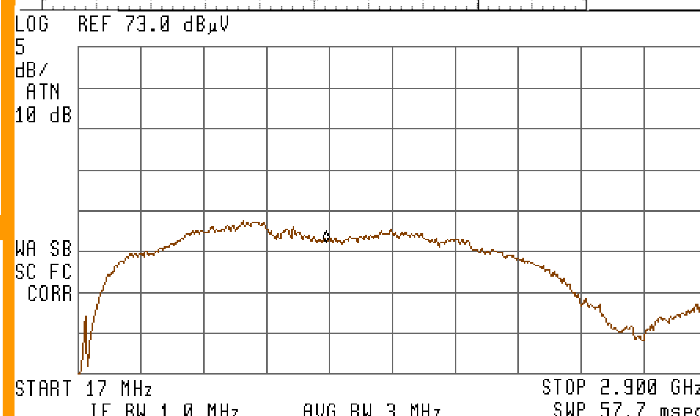


GPR Transmitter

Impulse Generator Design



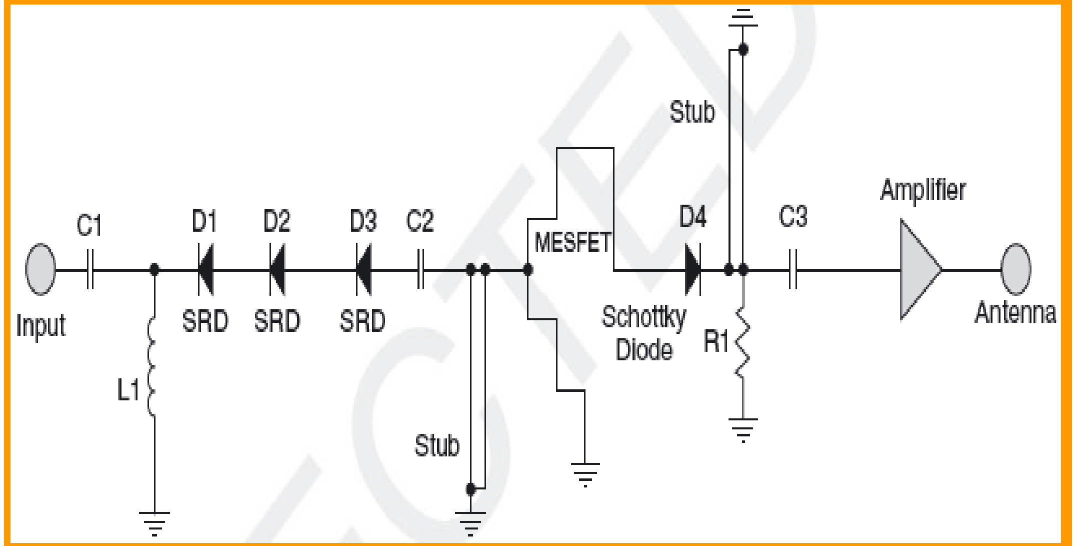




Pulser Design using Avalanche Transistor

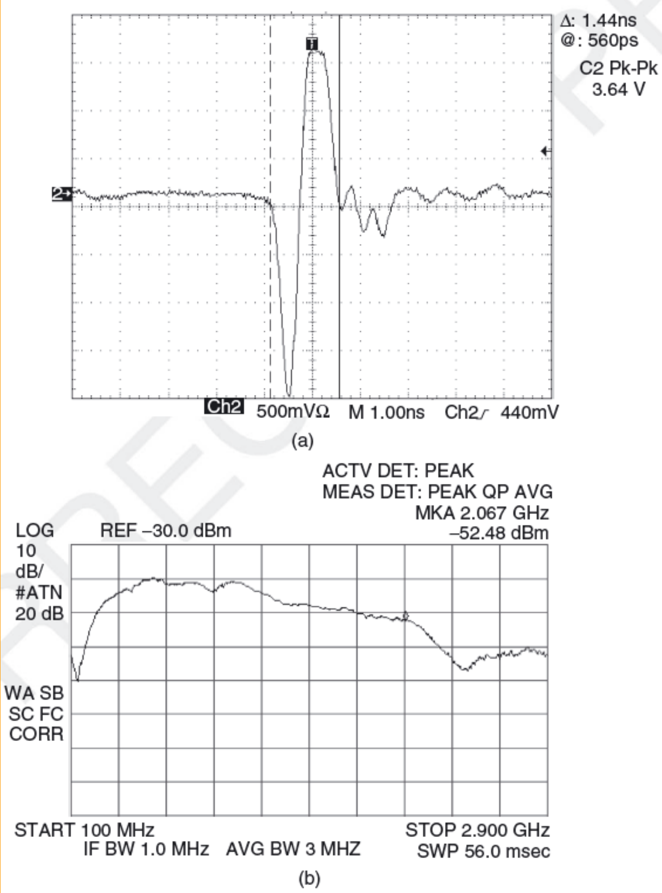
Monocycle waveform, 800ps impulse period, 2 GHz bandwidth and 64Vpp amplitude

GPR Transmitter
Impulse Generator Design



Impulse Generator Design using SRDs (Step Recovery Diodes)

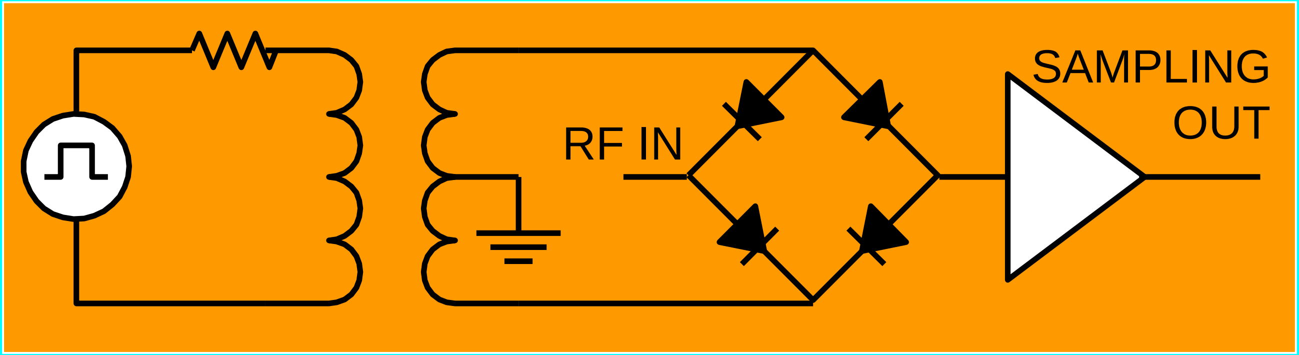
Monocycle waveform, 500ps impulse period, 2.5 GHz bandwidth and 4Vpp amplitude



GPR Receiver
Sample and Hold Circuit

GPR receiver includes:

- Sample and Hold (S/H) circuit and signal amplifier
- S/H trigger signal from controller with adjustable PRF: 100kHz - 400kHz
- 16-bit fast read Analog to Digital Converter (ADC)
- Low Noise Amplifier (LNA) for RF input: 200MHz - 2.5GHz (optional)
- High speed switching using ultra fast Schottky Diode Bridge



Sample and Hold circuit (simplified block diagram)

GPR Signal

Target Detection Algorithms

Signal Processing Techniques

- ✓ **Raw Data Collection** – *scanning for each sensor and different test sites*
- ✓ **DC level Subtraction** – *to clear hardware dc level abnormalities*
- ✓ **Background Removal** – *to distinguish the object backscattering signal*
- ✓ **Time Varying Gain** – *to eliminate RCS suppression due to soil losses*
- ✓ **Filtering Analysis** – *to adapt the focus on deep or shallow buried objects*
- ✓ **Pattern Recognition** – *to obtain object shape information*
- ✓ **Data Integration** – *combining data received from multi sensors*
- ✓ **Decision Algorithms** – *for buried object classification such as size, type..*

SECTION 2
GPR ANTENNAS

GENERAL REQUIREMENTS

- **UWB capability** to radiate impulse signal properly
- **High directivity** and efficiency on impulse radiation
- **Good input matching** over the wide band to reduce ringing
- **Narrow beam** width to enhance azimuth resolution
- **Shielded enclosure** to eliminate coupling & interference
- **High F/B** (front to back) ratio and side lobe suppression
- **Linear phase response** over the operational band
- **Compatible polarization** with respect to object alignment
- **Physical suitability**: Lightweight &small size for hand-held
- **Multi-sensor adaptive** for GPR operation with metal detector

Planar and 3D Antenna Types

LINEAR and CIRCULAR POLARIZED ANTENNAS

Dipole/Bow-tie

- Relatively broad frequency band characteristics with arm length and optimum plate angle
- Performance improvement with dielectric/resistive loading
- Low radiation efficiency
- Poor directivity, wide beam
- Small size and light weight
- Good T/R coupling
- Quasi-linear phase response over the wide band
- More convenient for hand-held impulse GPR applications

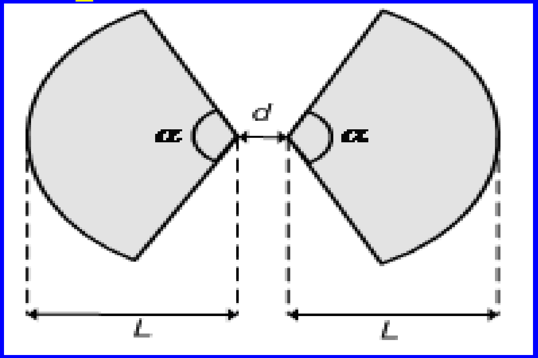
Planar Spirals

- Resonance or wide band characteristics with respect to arm length
- Low radiation efficiency
- Poor directivity gain, wide beam
- Small size and light weight
- Good T/R coupling performance
- Quasi-circular polarization over the wide band
- More convenient for stepped frequency applications

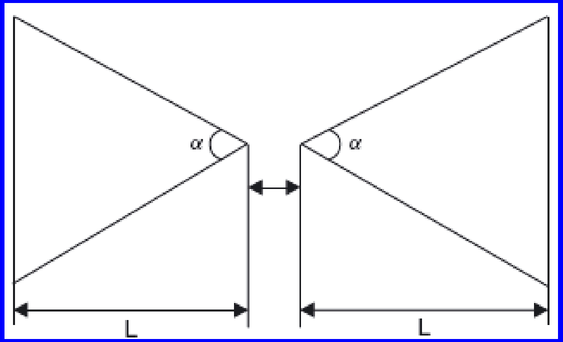
TEM Horn

- Broad band characteristics with opt. plate and flare angles
- Larger in size, 3-D geometry
- Better radiation efficiency
- Good directivity gain
- Average T/R coupling
- Quasi-linear phase response
- Some dielectric and absorber loading techniques can be applied to improve antenna characteristics
- More convenient for vehicle-mounted GPR applications

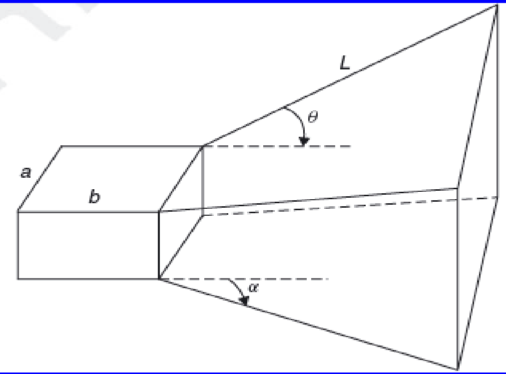
GPR Antenna Models



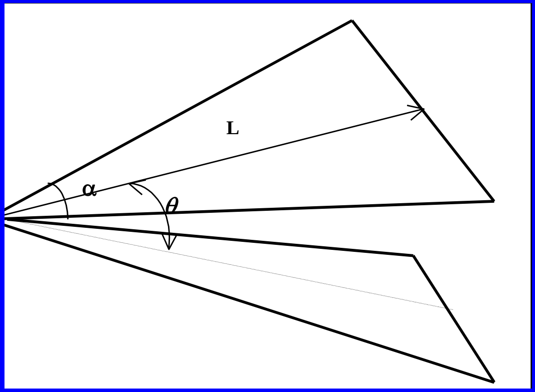
(a) Circular plate bow-tie



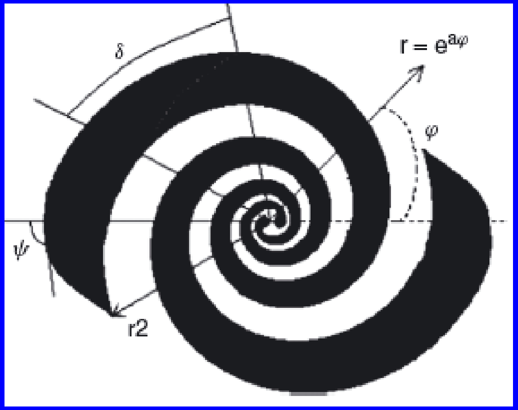
(b) Triangular plate bow-tie



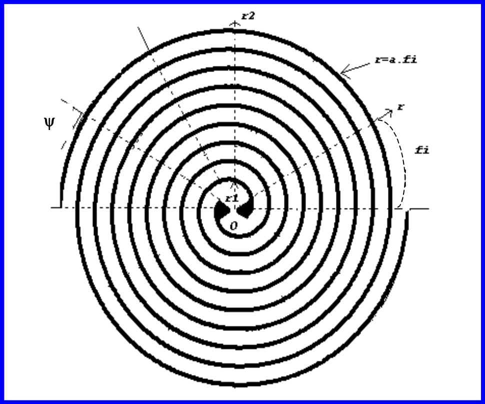
(c) Horn antenna geometry



(d) TEM horn configuration 3D

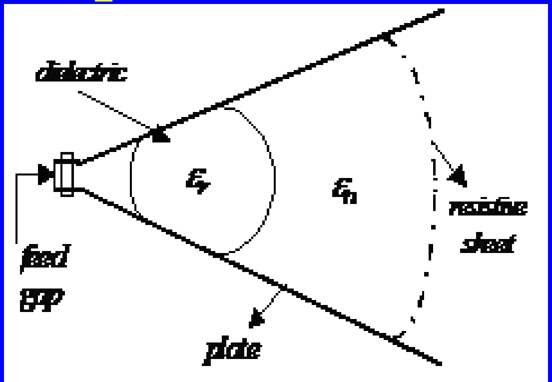


(e) Two-armed Archimedean spiral

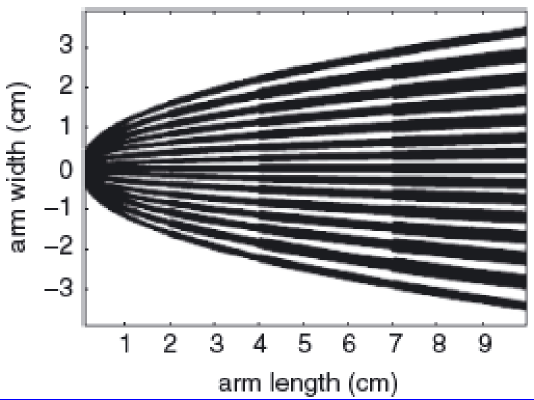


(f) Two-armed logarithmic spiral

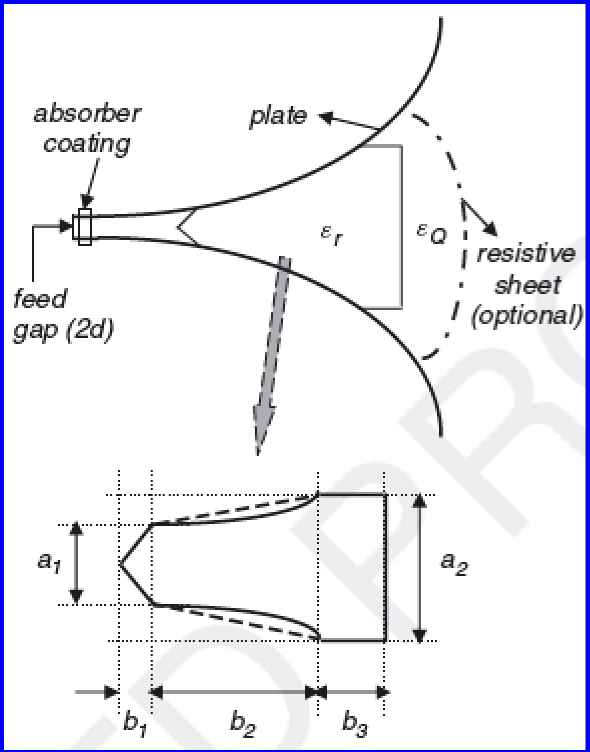
GPR Antenna Models



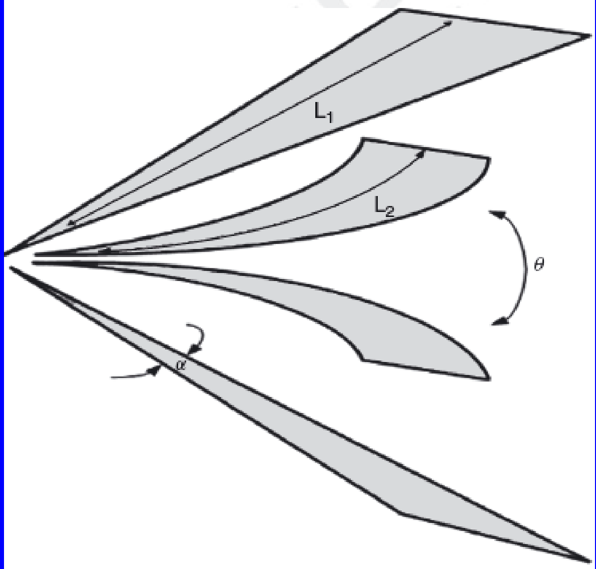
(g) PDTEM horn (side) geometry



(h) Multi-sensor adaptive arm shape



(i) Vivaldi form (side) TEM horn



(j) TEM horn array configuration for hyper-wide band radiation

Antenna Designs

Table of the designed GPR antenna models

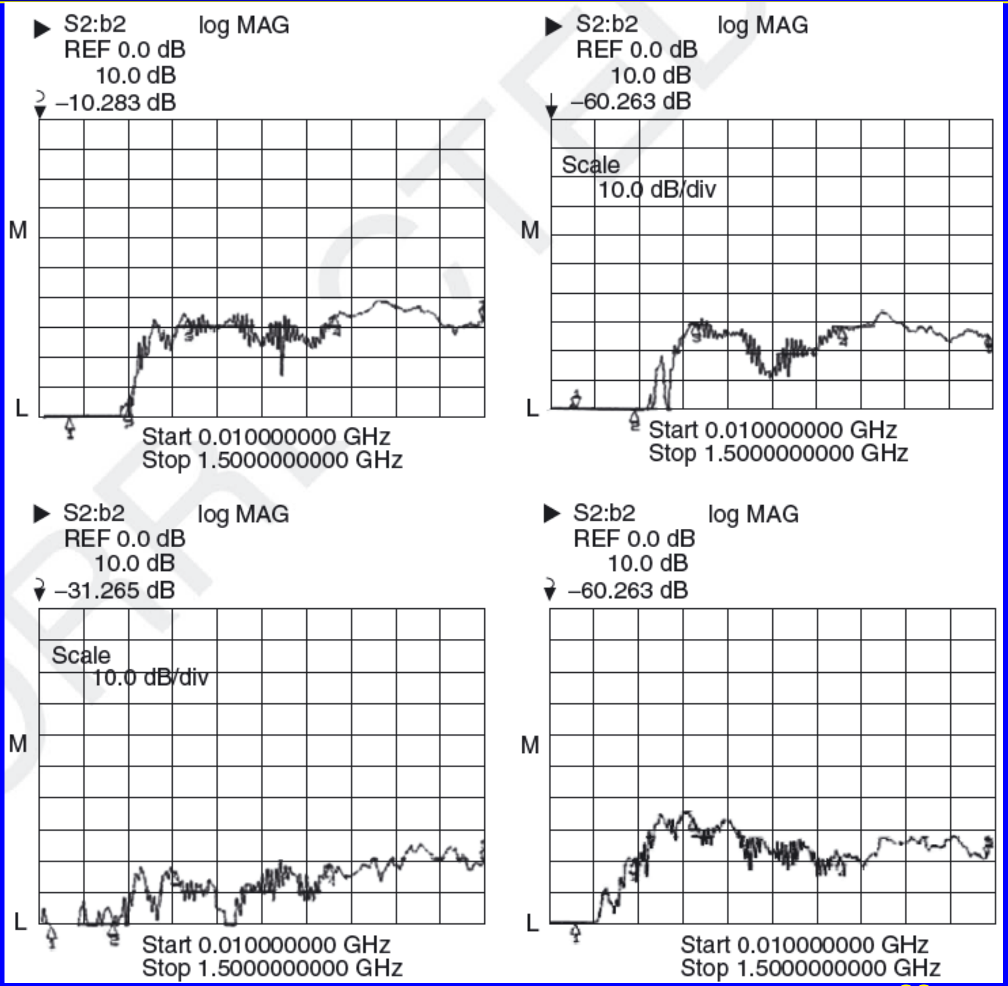
TABLE 3.3 Description of GPR Antenna Models

Figure	Model	Physical Description
3.15c	Spiral	$r_1 = 0.5$ cm, $r_{2y} = 5.5$ cm, $r_{2d} = 7.3$ cm, $N = 4.5$ turns
3.15a	BT-10	$\alpha = 90°$, $\theta = 180°$, $d = 0.25$ cm, $L = 5$ cm
3.15b	TEM-10	$\alpha = 20°$, $\theta = 60°$, $d = 0.15$ cm, $L = 10$ cm, $\varepsilon_r = 1$ air-filled
3.15b	PDTEM-10	$\alpha = 20°$, $\theta = 60°$, $d = 0.15$ cm, $L = 10$ cm, $\varepsilon_r = 3$ dielectric loaded
3.16b	VA-10	$\alpha = 20°$, $\theta \in 0°$ to $160°$, $d = 0.4$ cm, $L = 10$ cm, $\varepsilon_r = 1$ air-filled
3.16b	PDVA-10	$\alpha = 20°$, $\theta \in 0°$ to $160°$, $d = 0.4$ cm, $L = 10$ cm, $\varepsilon_r = 3$ dielectric-loaded
3.16c	PDTEMA-45	$\alpha^1 = 20°$, $\theta^1 = 90°$, $d^1 = 0.25$ cm, $L^1 = 45$ cm, aperture: 10×15 cm $\alpha^2 = 20°$, $\theta^2 = f(l) \in 0°$ to $120°$, $d^2 = 0.2$ cm, $L^2 = 25$ cm, dielectric profile: $\varepsilon_r = 3.5$, $a_1 = 4$ cm, $a_2 = 13$ cm, $b_1 = 3$ cm, $b_2 = 9$ cm, $b_3 = 7$ cm, 5.5 cm thick

Antenna Designs

Experimental Results

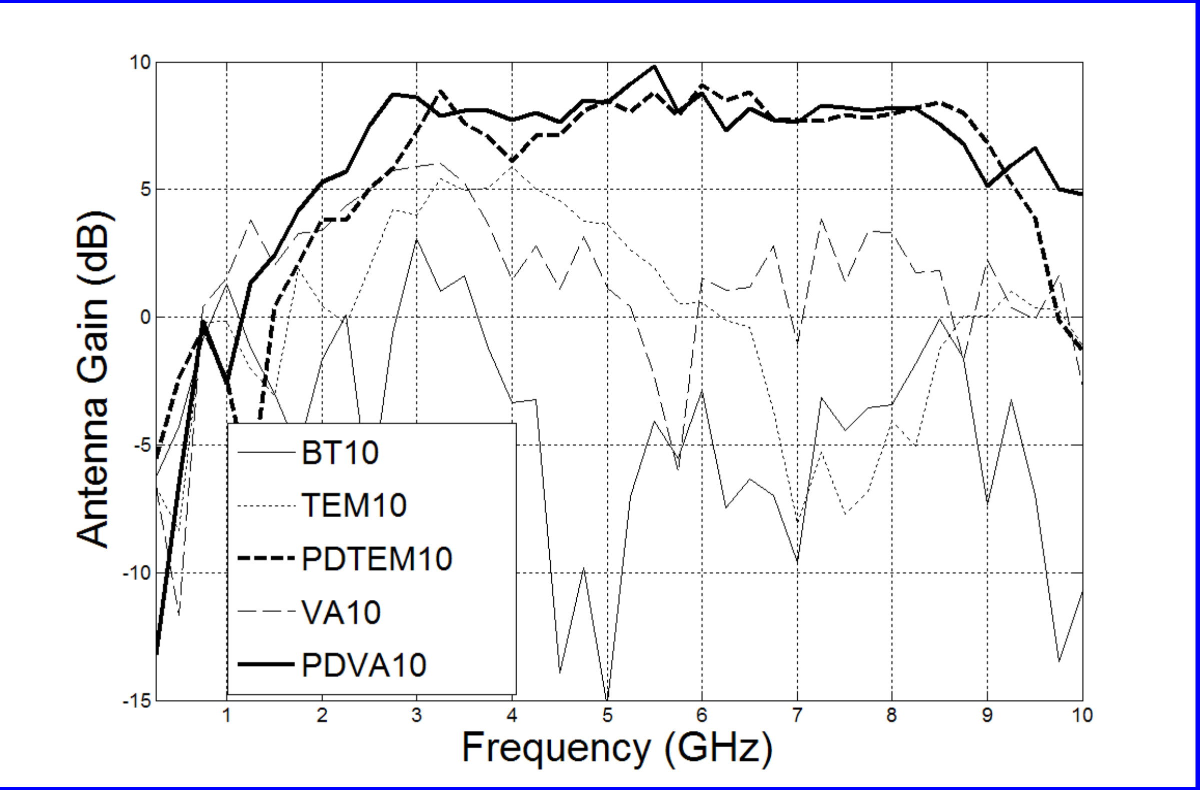
Gain characteristics of planar antenna models for dry soil
(a) Logarithmic spiral
(b) Archimedean spiral
(c) Bow-tie: cross-polarization
(d) Bow-tie: co polarization



Antenna Designs

Experimental Results

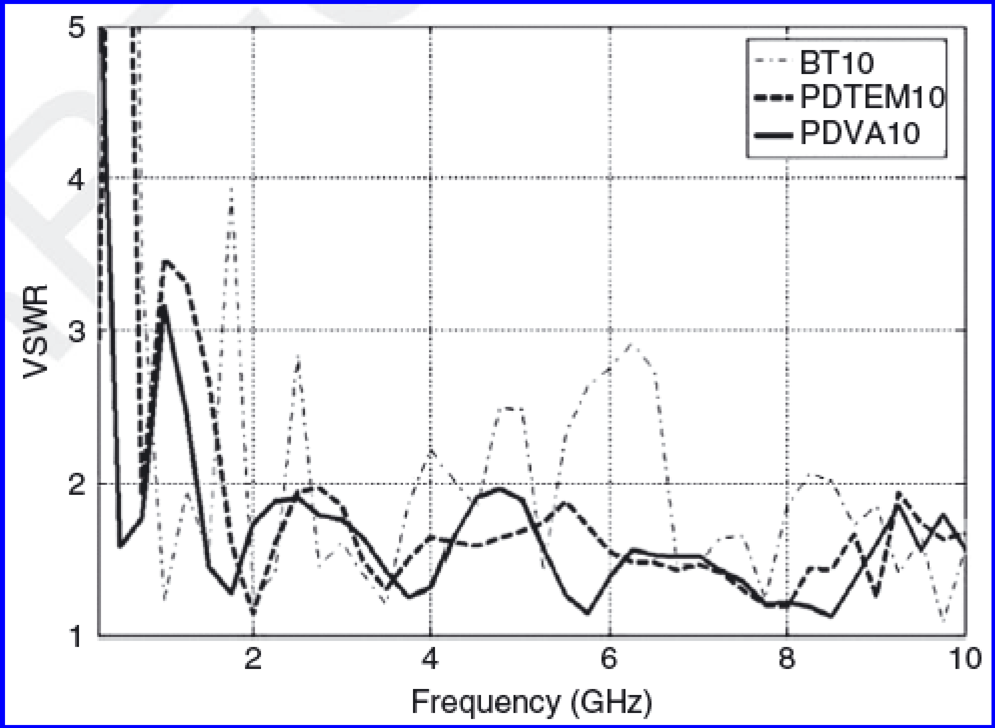
UWB gain characteristics of bow-tie and TEM horn models



Antenna Designs

Experimental Results

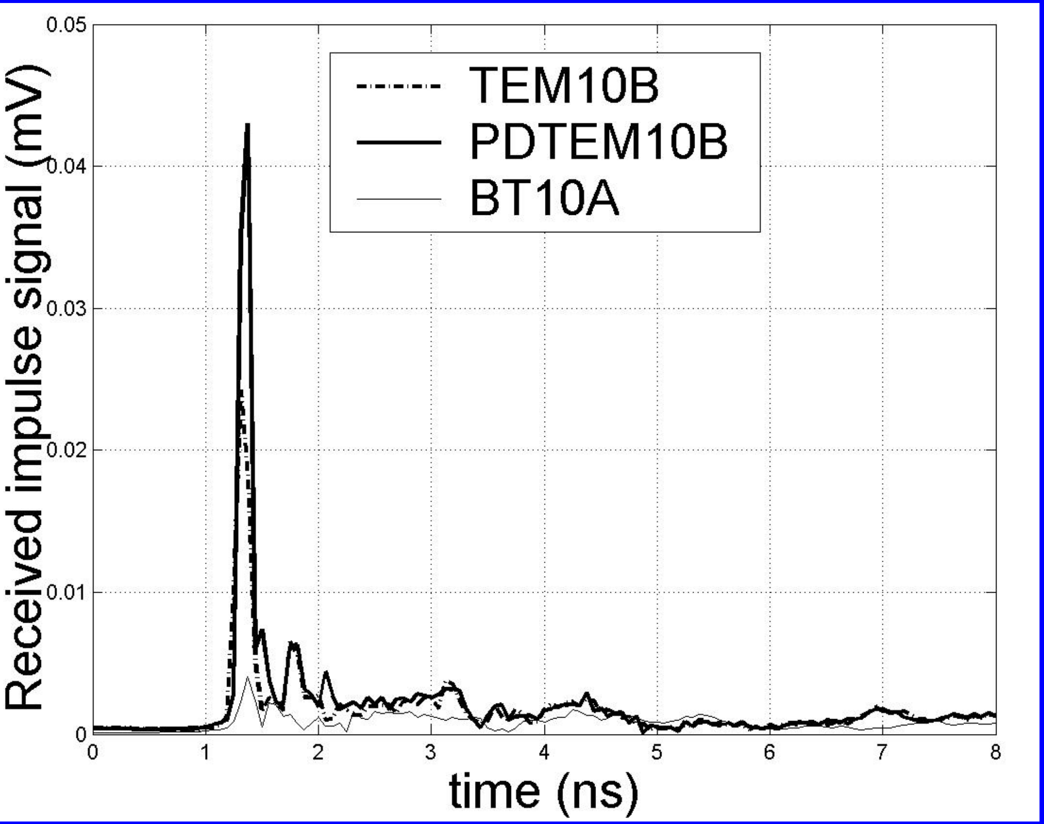
UWB input reflection characteristics of bow-tie and TEM horn models



Antenna Designs

Experimental Results

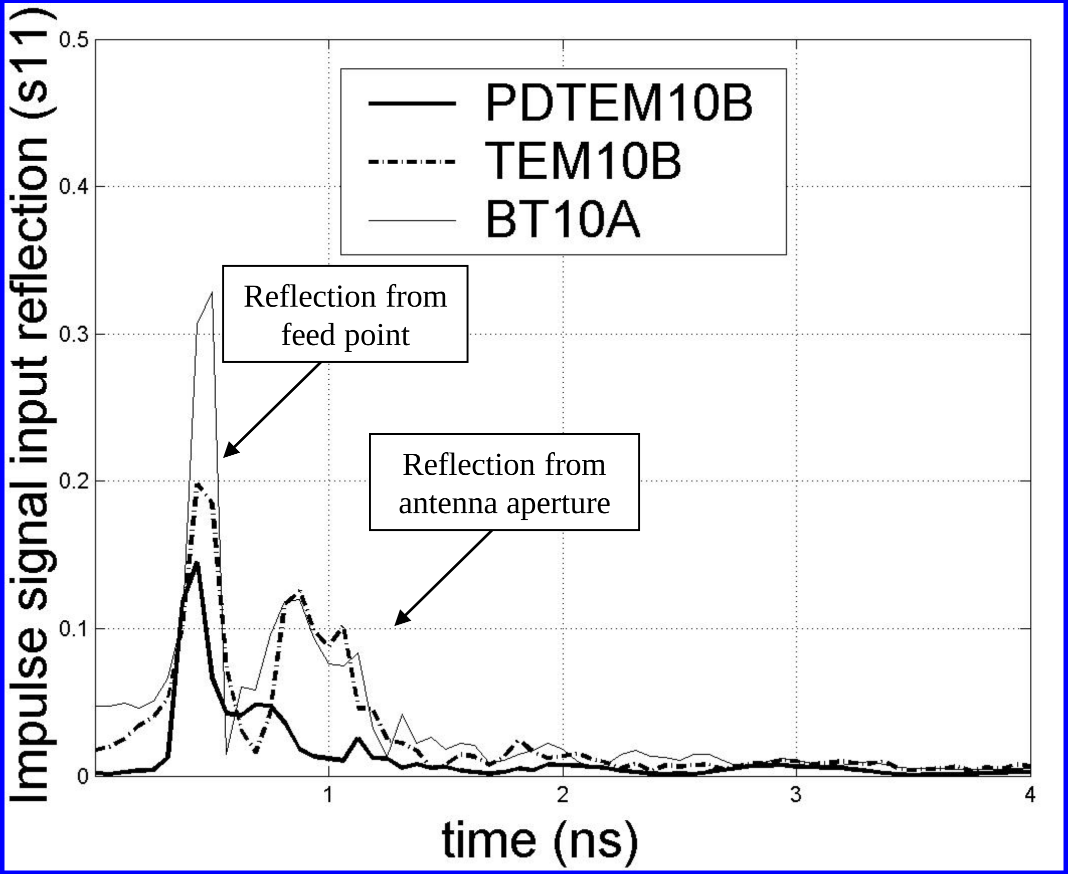
Received impulse signals at bore-sight for different T/R antenna pairs
(Same T/R antennas, 7 GHz bandwidth, 50 cm distance, 1V input pulse)



Antenna Designs

Experimental Results

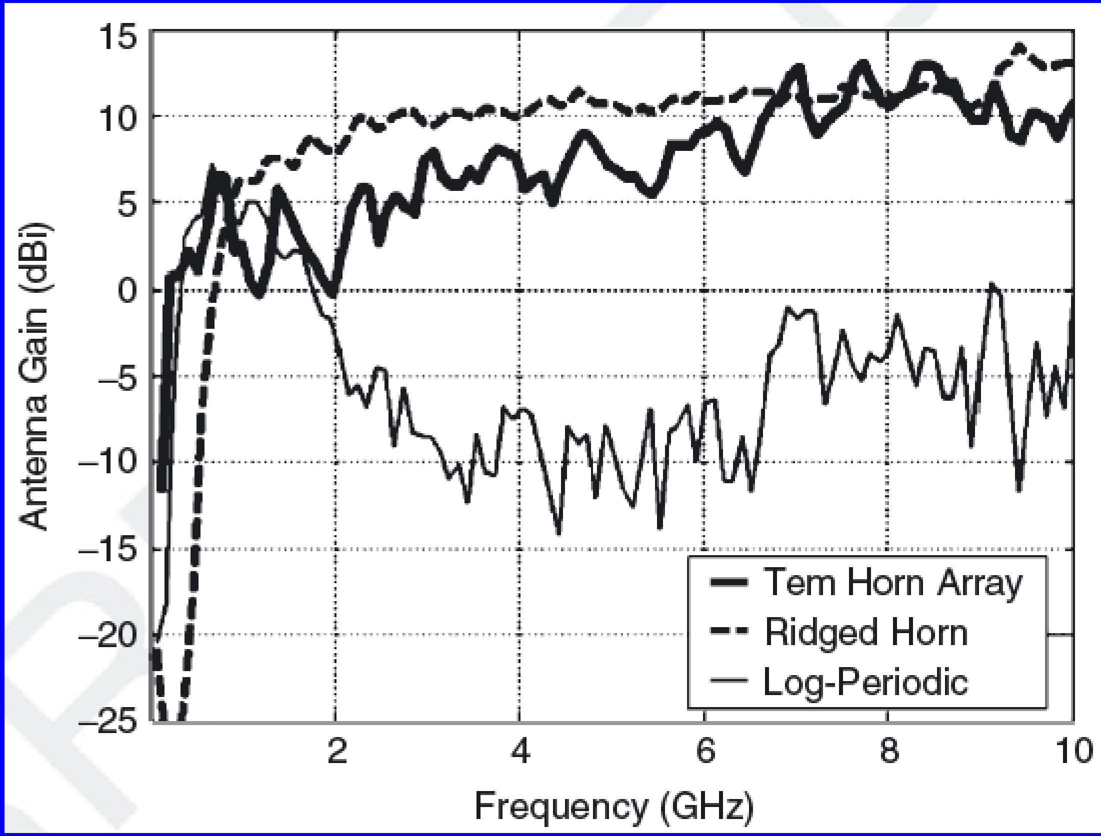
Input impulse reflection characteristics of antennas in time domain

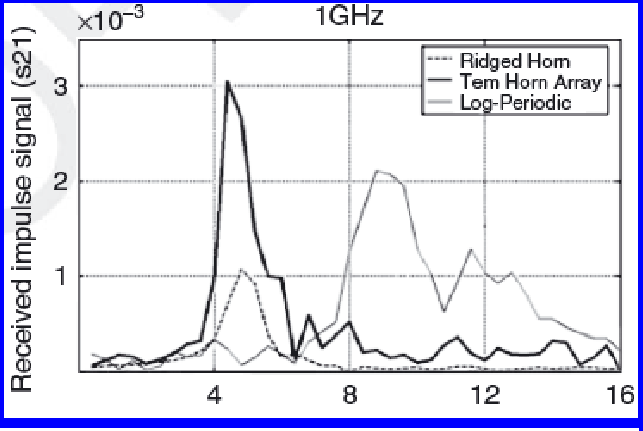


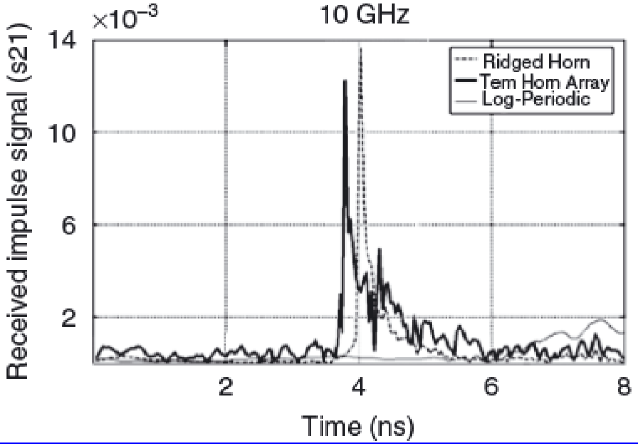
Antenna Designs

Experimental Results

Hyper-wide band gain characteristics of TEM horn array model



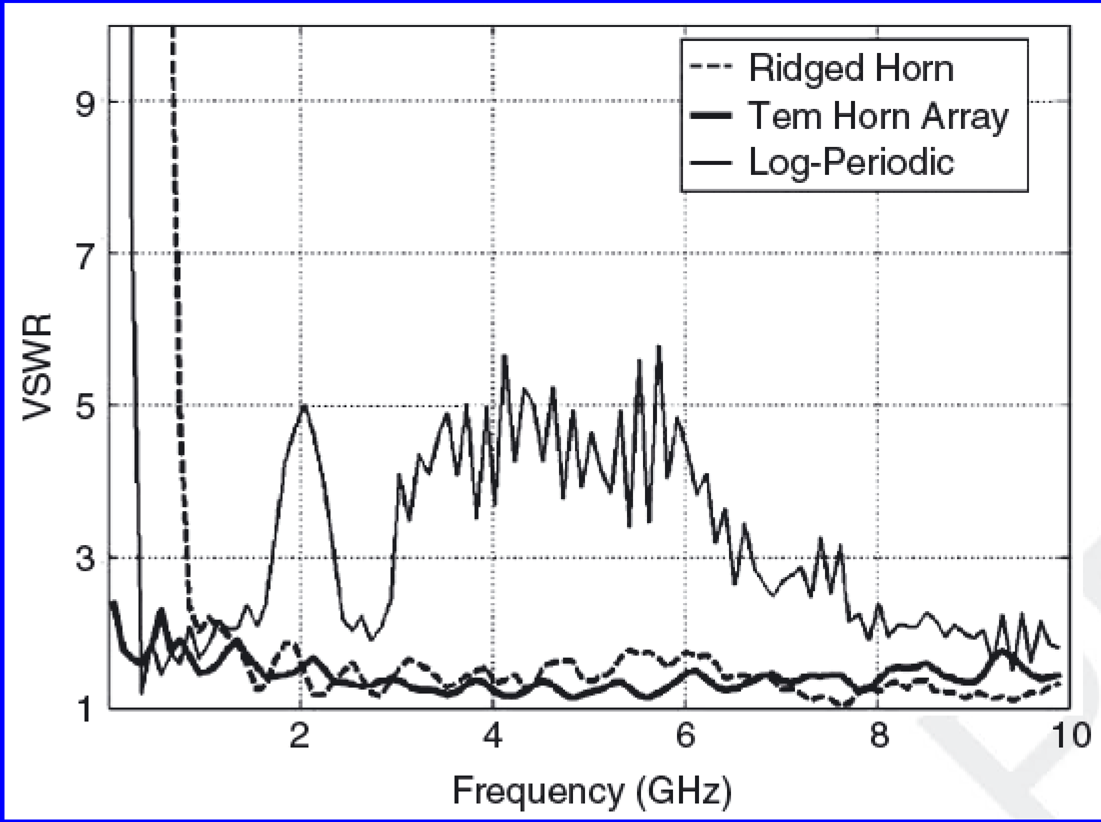




Antenna Designs

Experimental Results

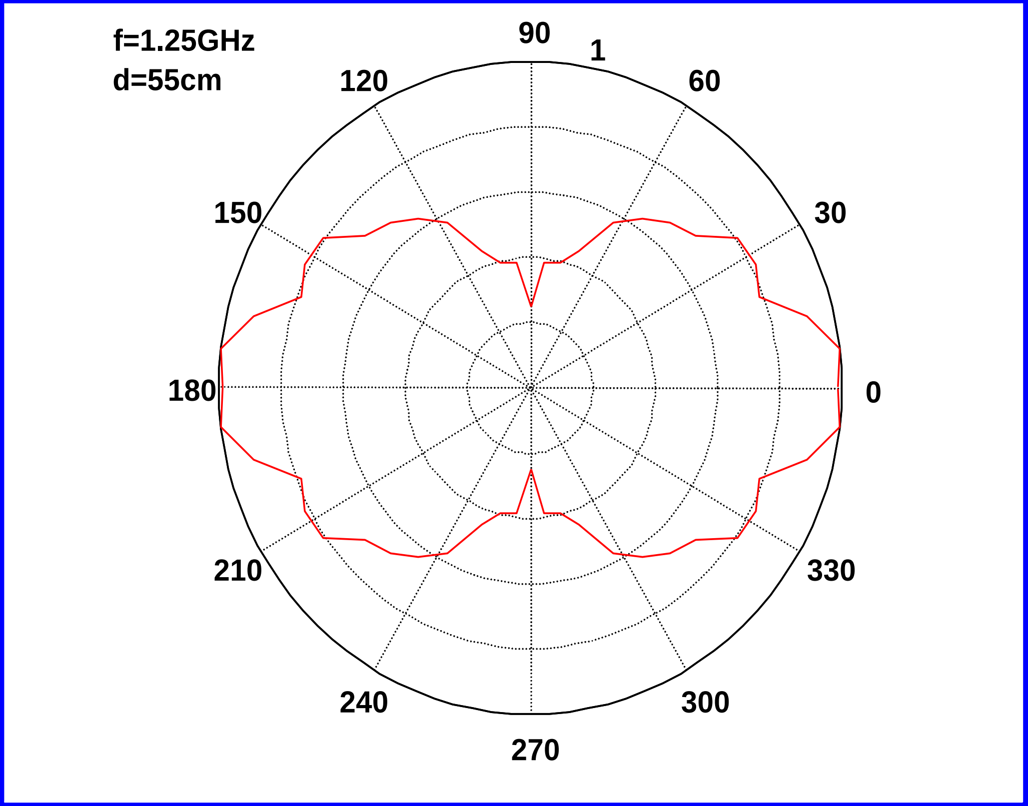
UWB input reflection characteristics of TEM horn array model



Hand-held GPR Antenna

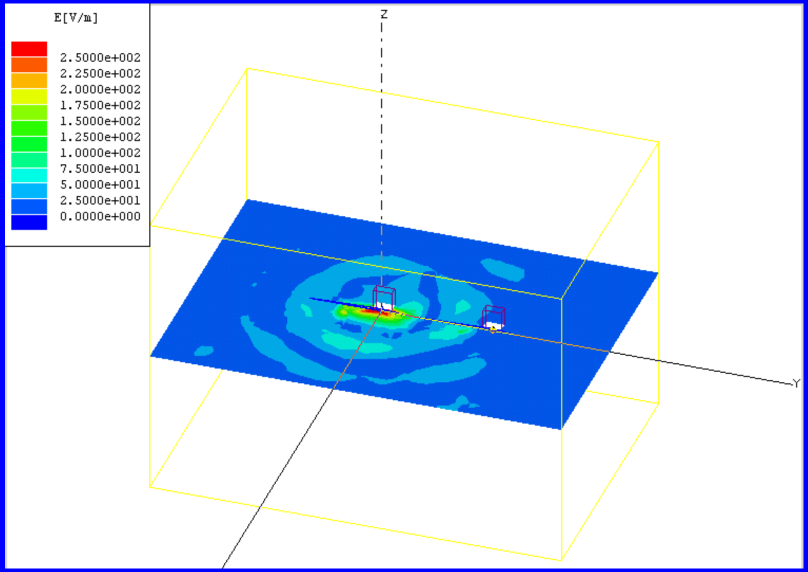
Radiation Pattern Measurement

Azimuth radiation pattern of dipole antenna at 1.25 GHz for dry soil



GPR Head

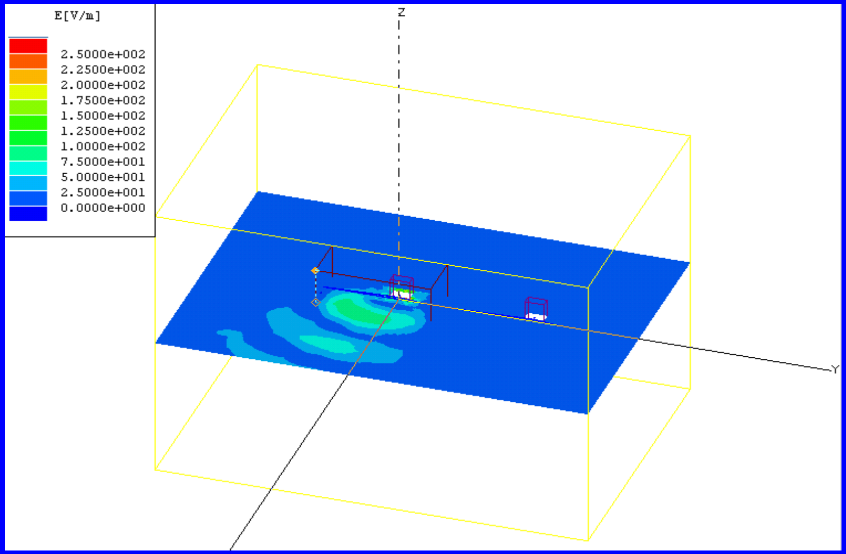
Simulation of Shielding Box Effects



GPR system is explicitly effected by the clutter on the receiver antenna induced by T/R coupling fields. One of the most effective solutions is to put antennas inside a metallic box.

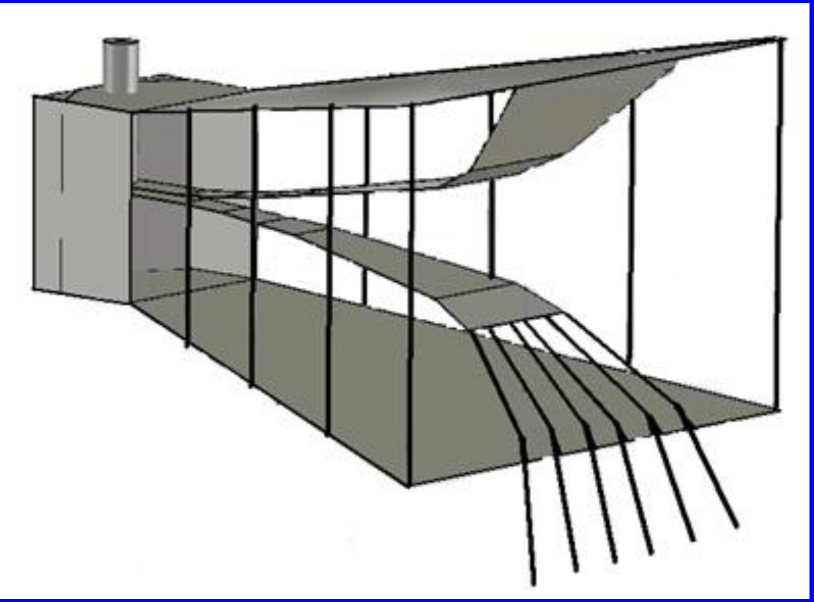
Field distribution at the aperture of TEM horn antenna (f=750MHz)

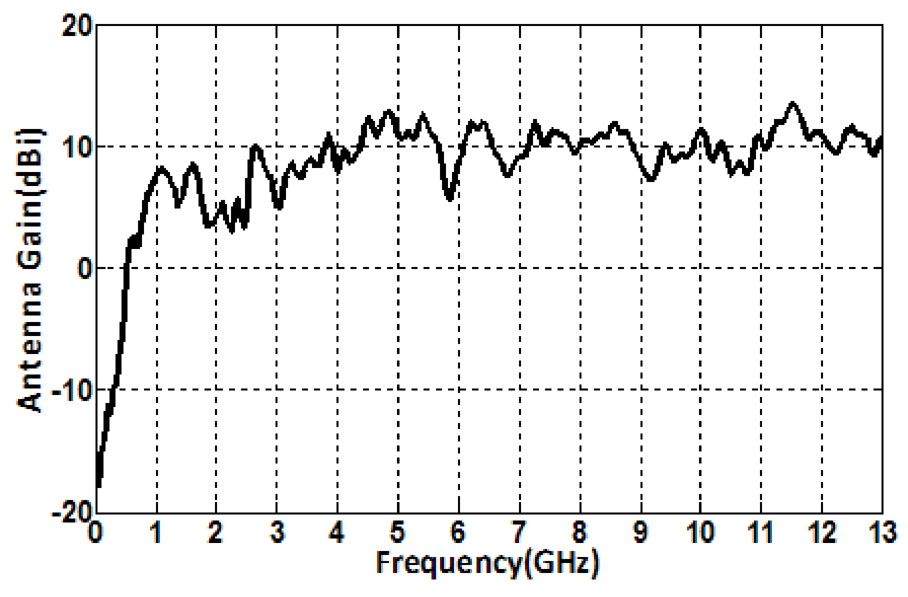
(a) without shielding (b) with shielding



Novel Designs for Multi-band GPR

TEM horn fed ridged horn antenna (TEMRHA)

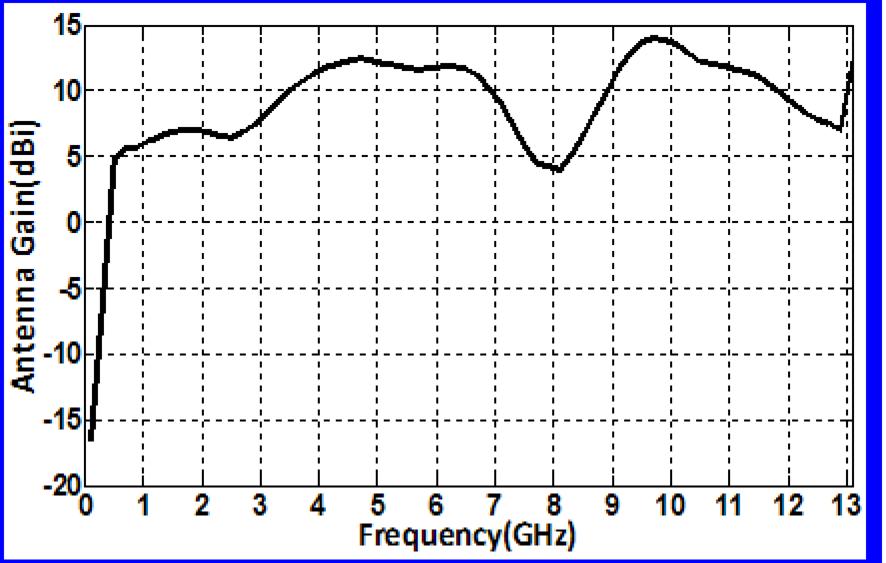


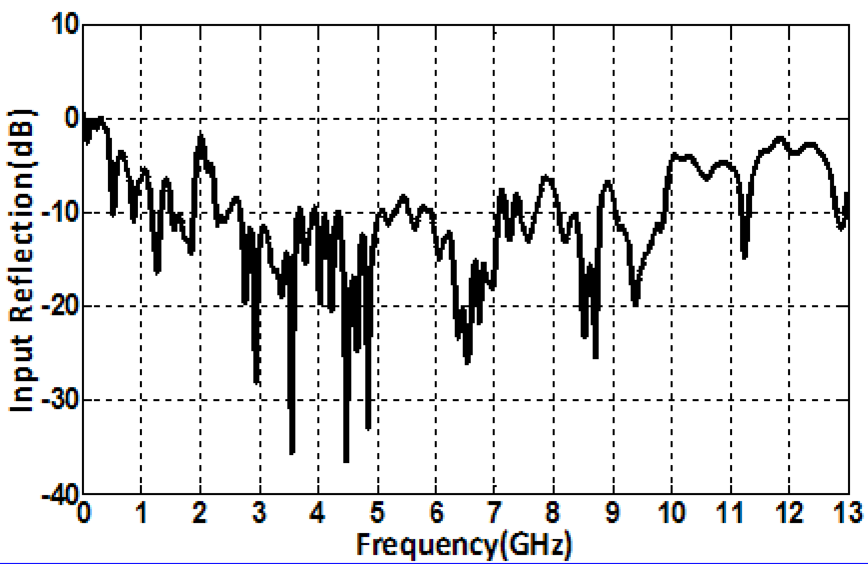


Geometric illustration and hyper-wide band gain measurement of *TEMRHA* model

Novel Designs for Multi-band GPR

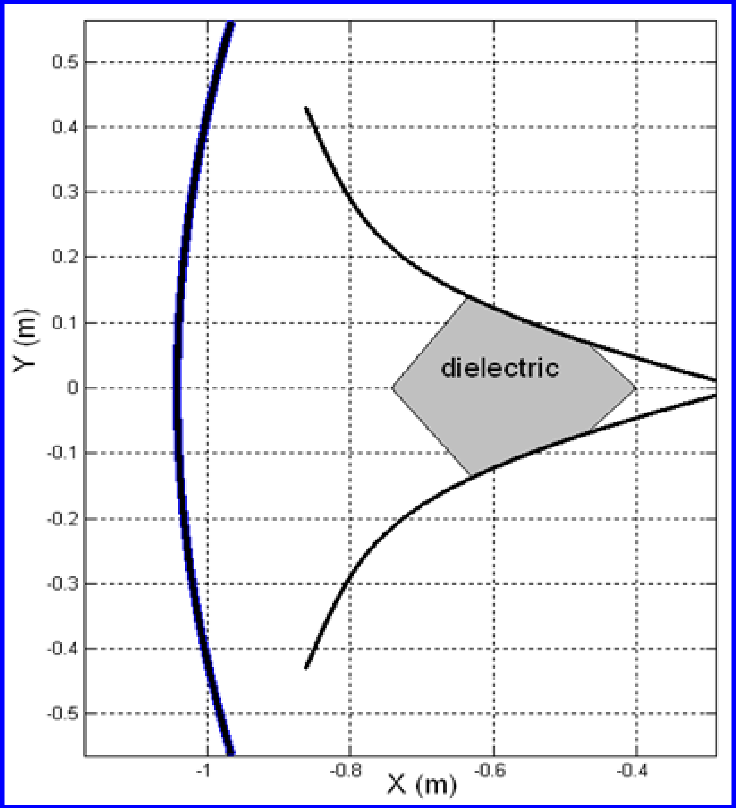
TEM horn fed ridged horn antenna (TEMRHA)

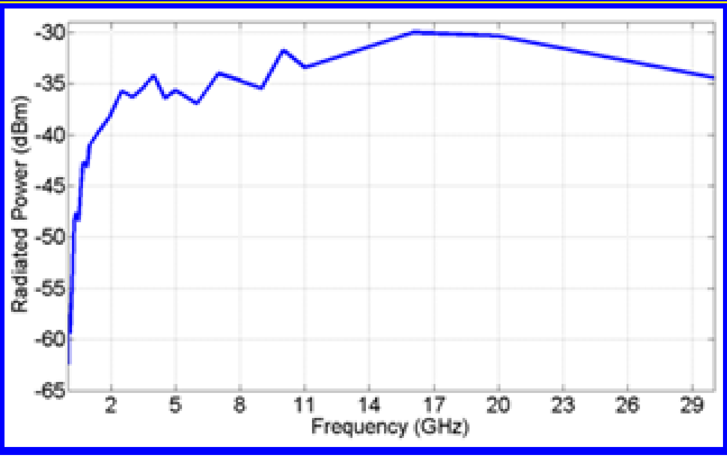


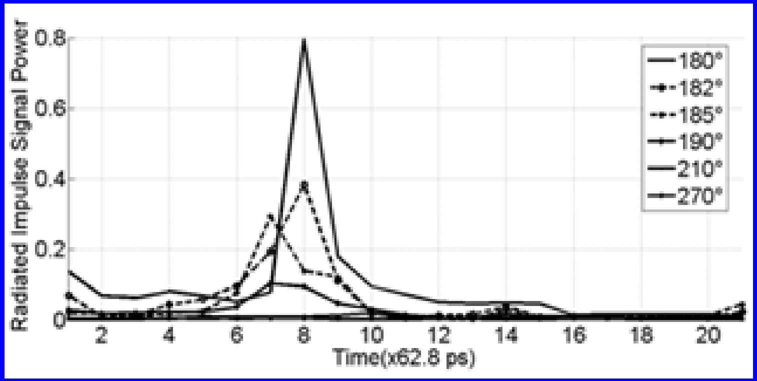


HWB gain and input reflection simulation results by CST of *TEMRHA* model

Novel Designs for Forward-looking GPR
PD*TEM horn fed parabolic reflector antenna*



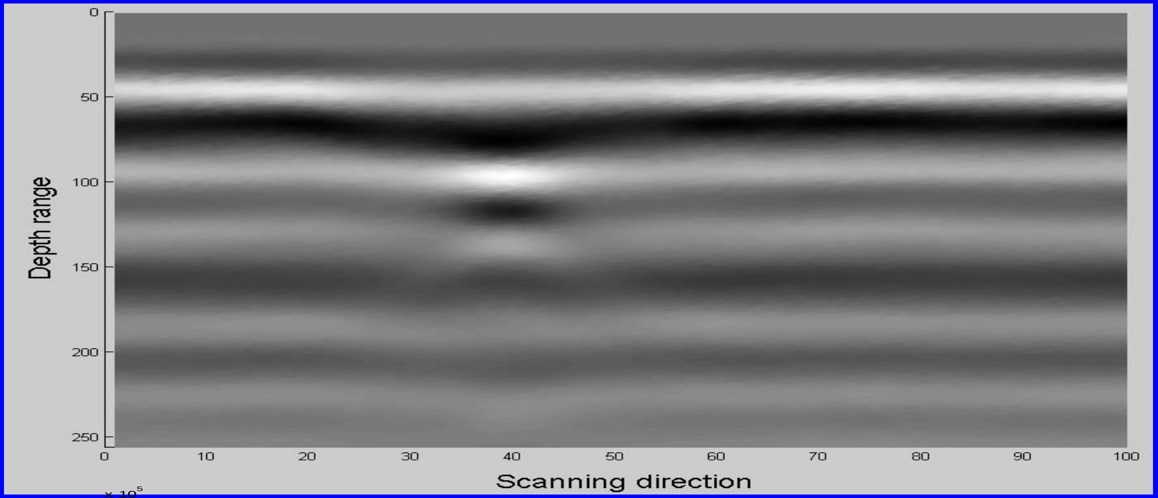




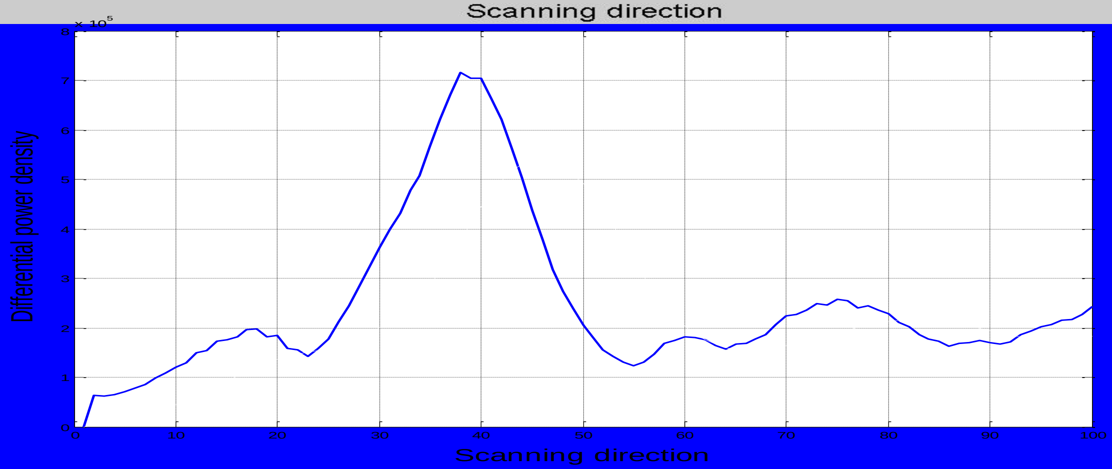
Geometric illustration

HWB and impulse gain simulations by ARM

Performance Results

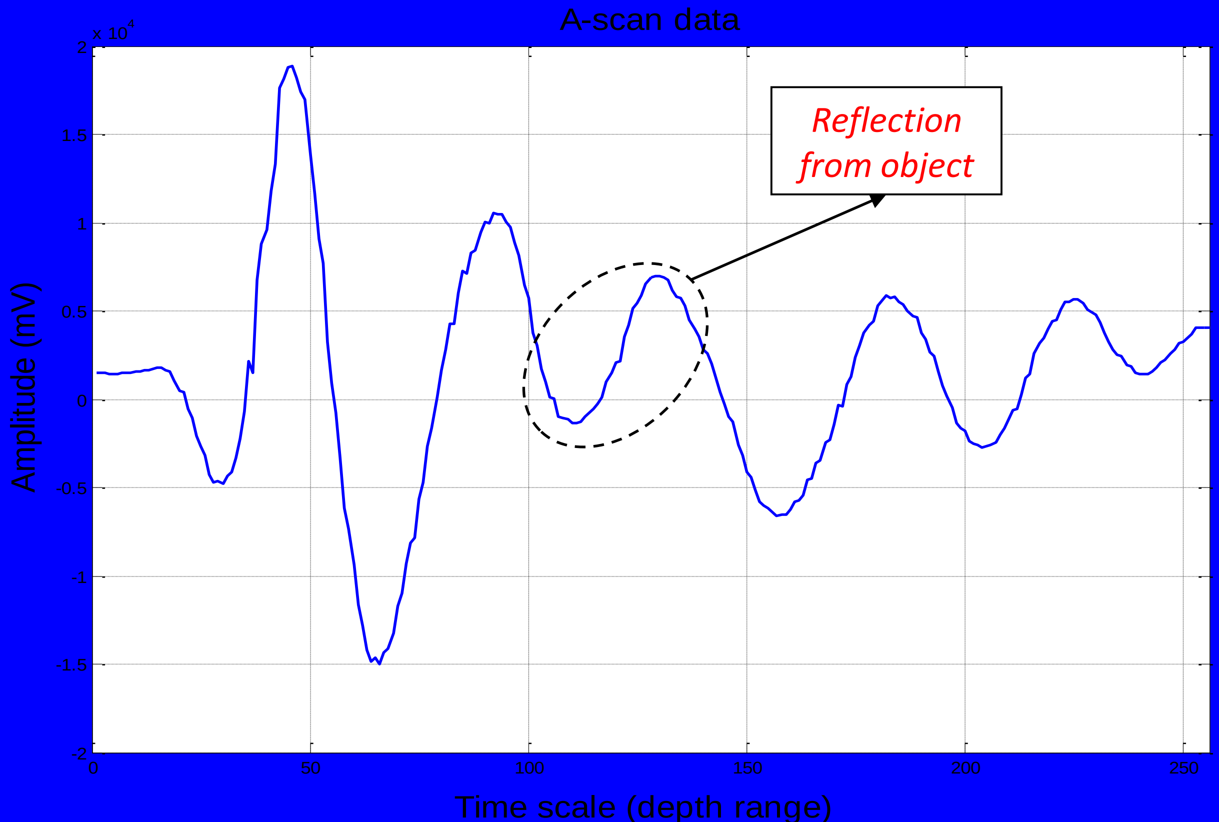


Original
B-scan data



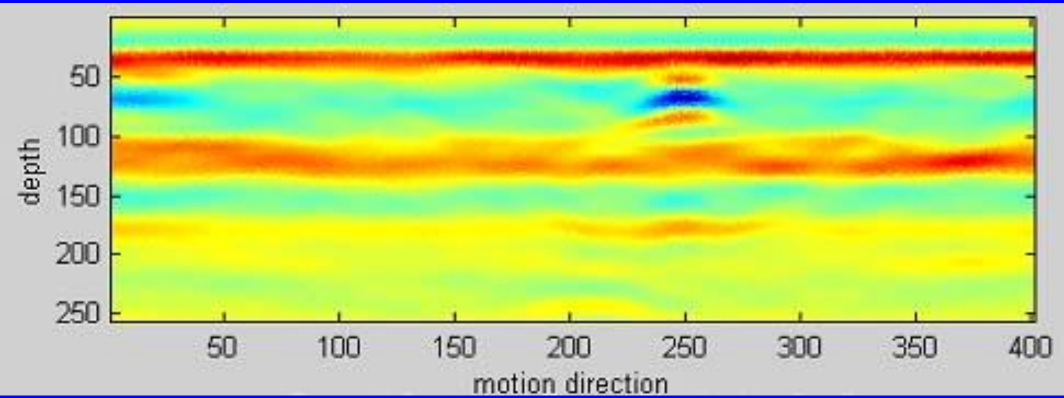
Cumulative
energy
distribution
after BG Removal

Performance Results

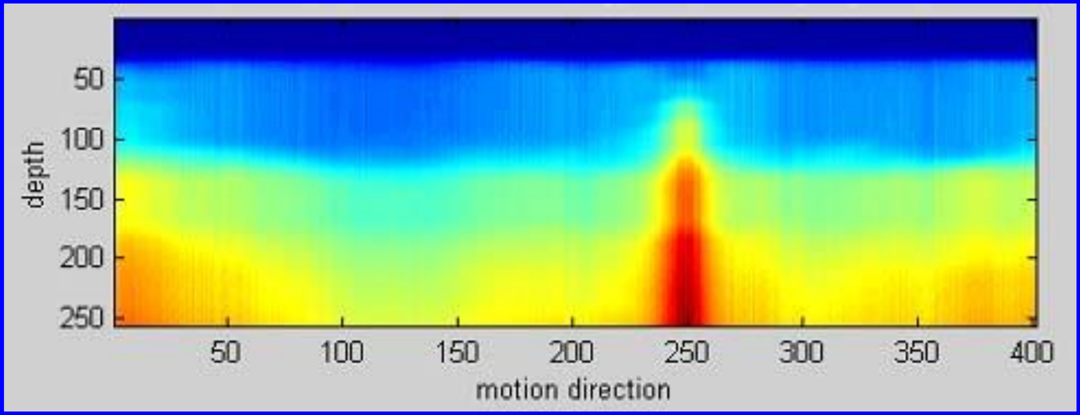


A-scan impulse data at 40th scanning line

Performance Results



Original
B-scan data

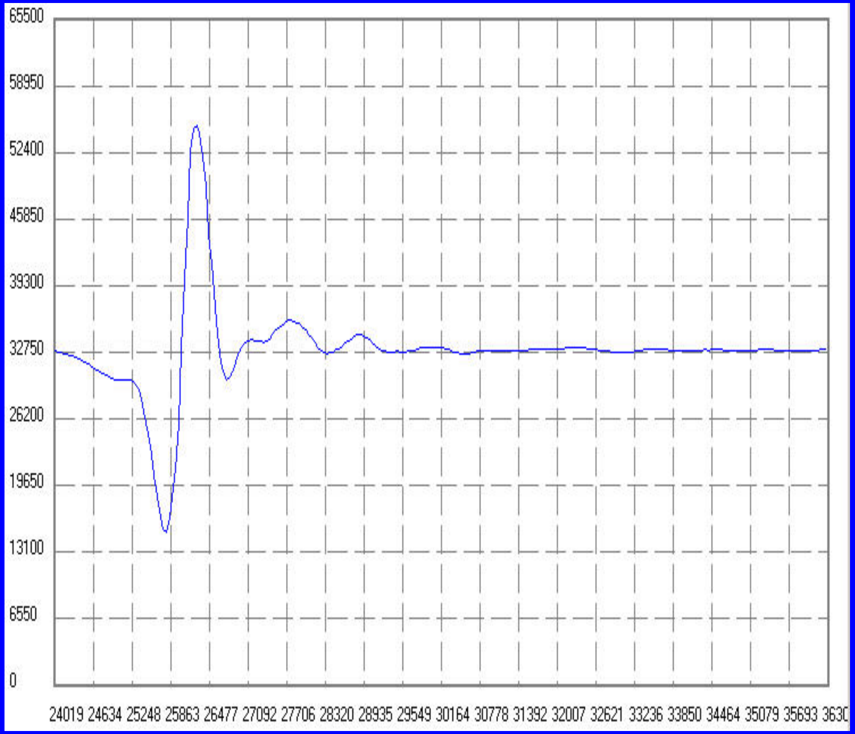


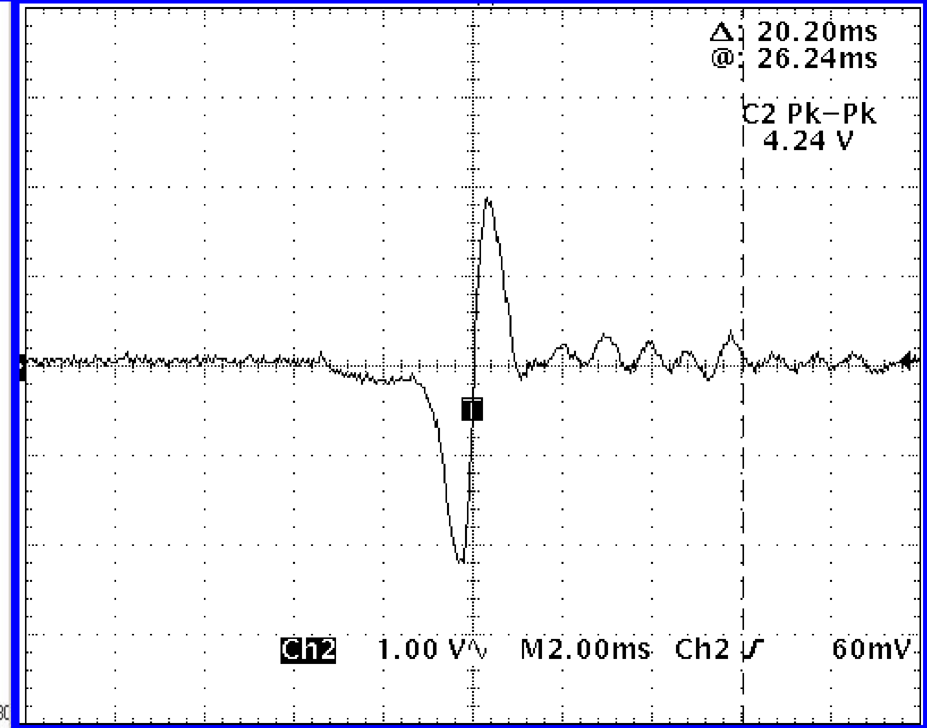
Cumulative
energy
distribution

Cylindrical dielectric object with 5cm radius at 3cm: data taken by handheld GPR, lifted 5cm off ground.

GPR Prototype

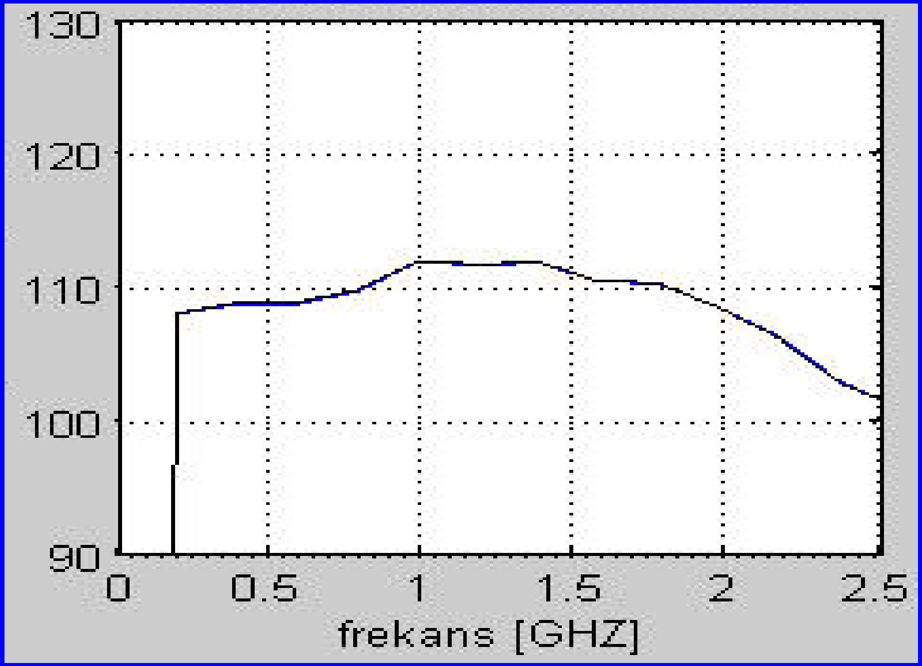
Impulse Generator & S/H Performance

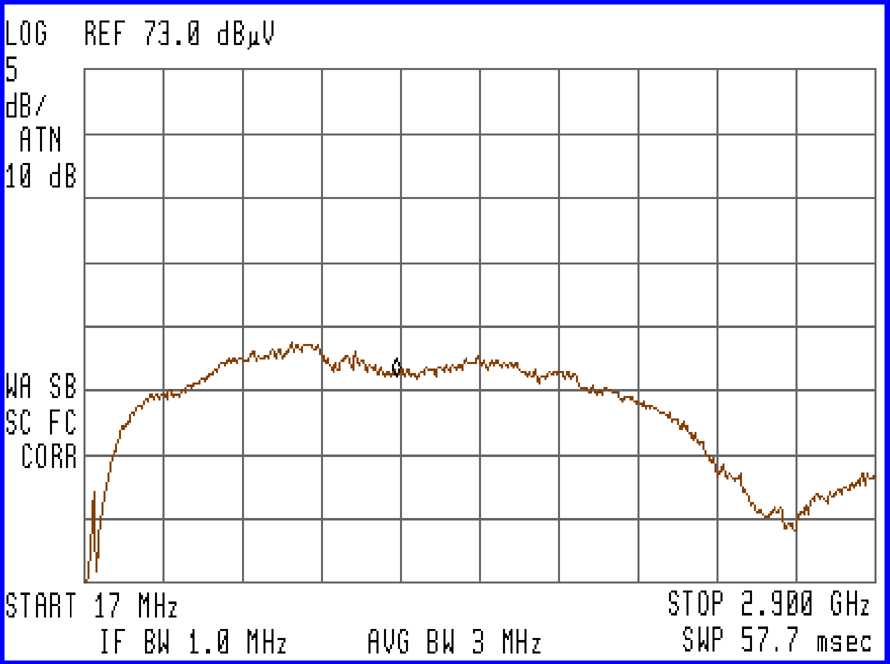




GPR Prototype

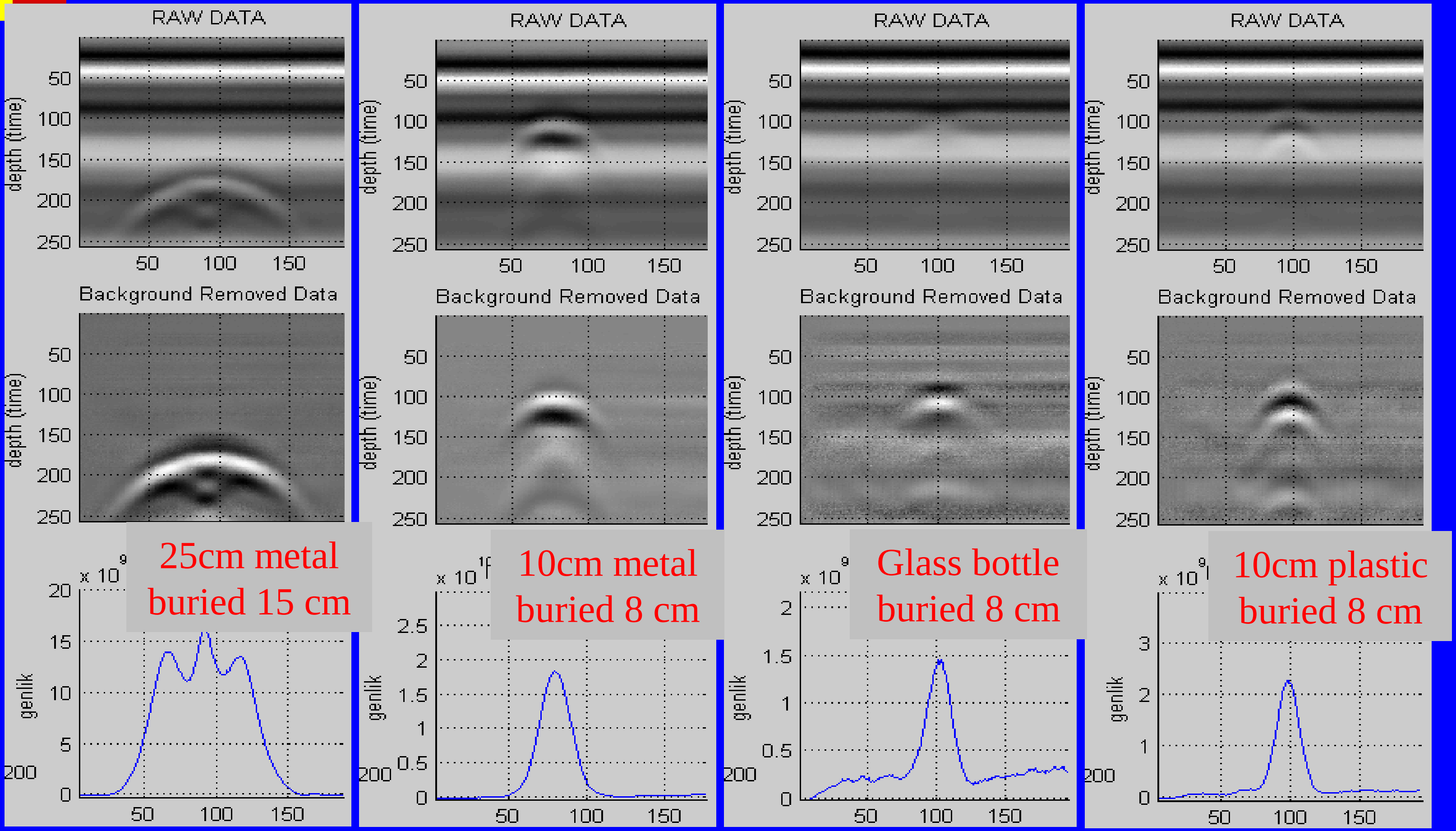
Impulse Generator & S/H Performance





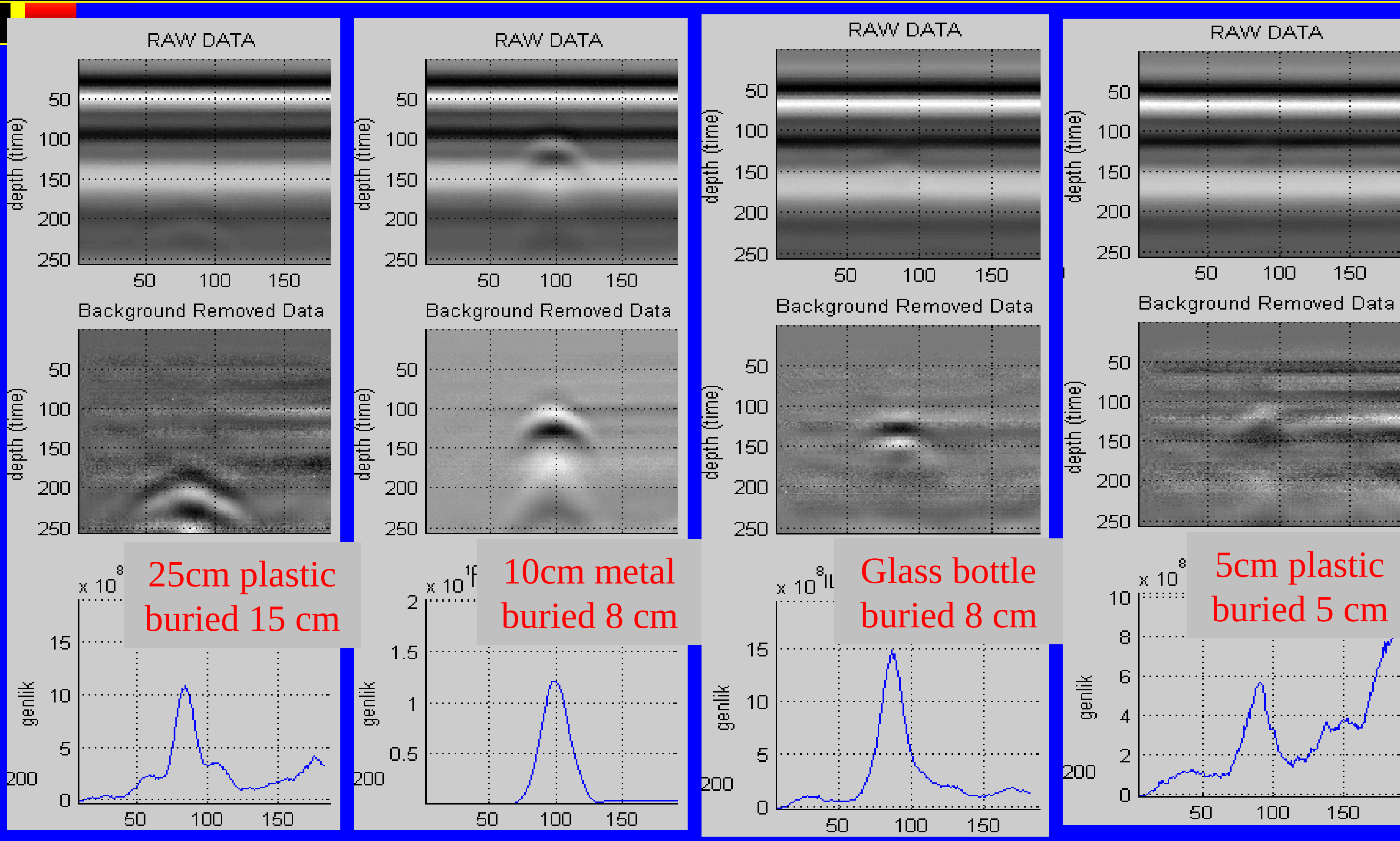
Detection Performances

Sandy Soil



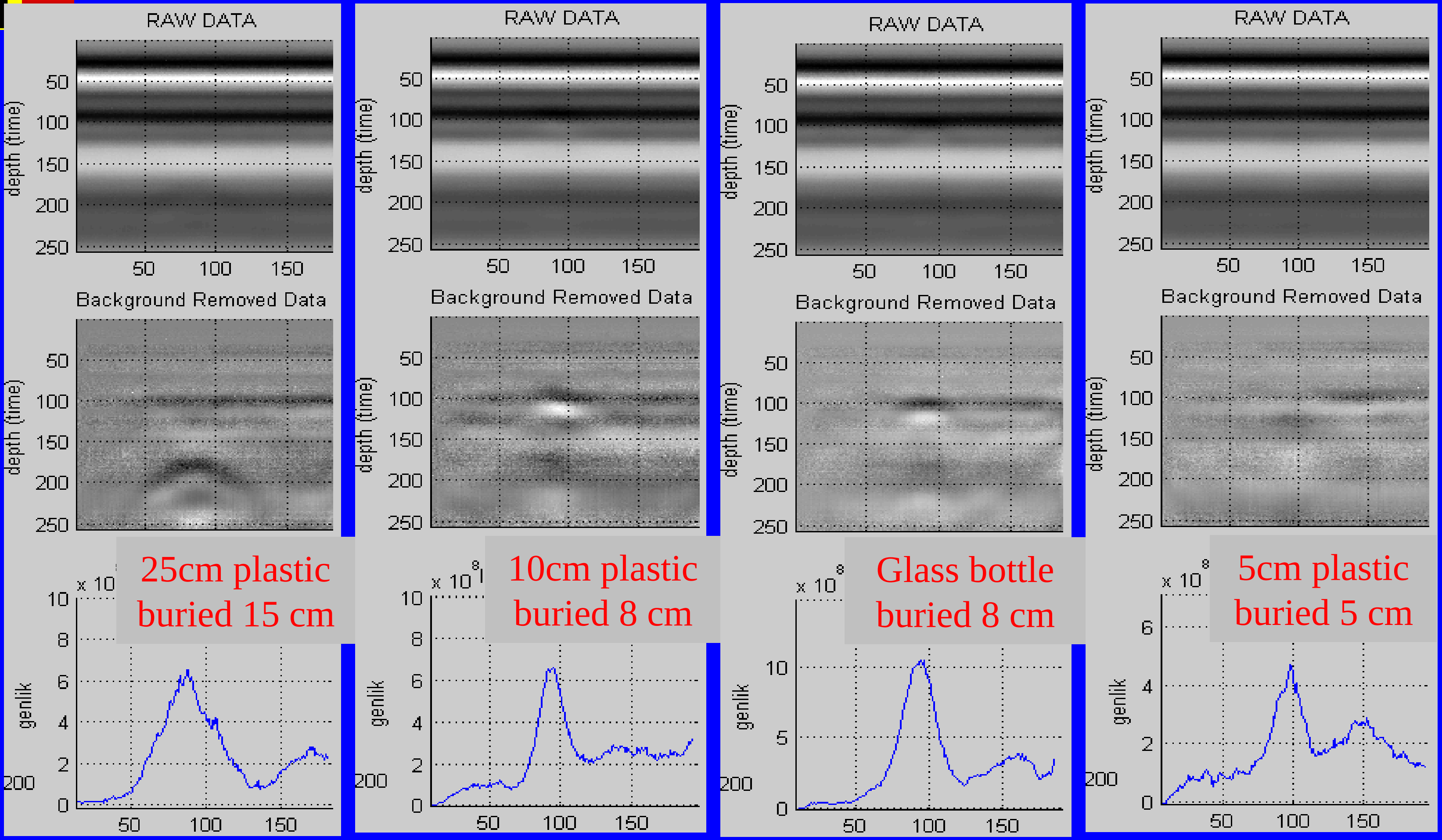
Detection Performances

Soft Loamy Soil



Detection Performances

Hard Loamy Soil



Remarks and Conclusion

- **GPR** is a **portable** non-destructive testing device **easy-to-use** for subsurface imaging, such as landmine detection, mining, archeology, road mapping and quality control of concrete slabs.
- The GPR operation is based on soil characteristics, target depth and size, required resolution and scanning speed.
- Thus, the performance of the GPR strongly connected with the **best choice of the operational parameters,** such as frequency, range gaining and coverage height, depending on the test scenarios.
- **Signal processing methods**, such as filtering, averaging, background removing, range gain should be applied in order to discriminate the targets from the received signal **more visibly**.
- Some experimental NDT and road survey results obtained by using **GSSI GeoRadar** are presented in the following slides.

SECTION 3

GSSI GeoRadar System

- GeoRadar is an **impulse GPR system**, which produces impulse signals from 100 MHz to 3 GHz depending on the selected GPR antenna head.
- **Hand-held** (for non-destructive material testing) and **vehicle-mounted** (for high-scan rate, high-speed road measurements) modules are available.
- **1.6 GHz** hand-held and **1 GHz** vehicle-mounted GeoRadar modules are used for tests and measurements at CDV.
- The detailed information are given at the following documents:

→ GSSI SIR-20 brochure
→ GSSI RADAN brochure
→ GSSI Antenna brochure
→ EPAM3-Portugal (sample application)

Test and Measurement

TEST CASES

- Non-destructive Testing of Concrete Slab
  (*by 1.6 GHz module, 8 scenarios*)
- Road Joint Points Analysis
  (*by 1.6 GHz module, 5 scenarios*)
- Asphalt Road Sub-layer Analysis
  (*by 1.6 GHz module, 5 scenarios*)
- Road Joint Points Analysis
  (*by 1 GHz module, 4 scenarios*)
- Lulec Asphalt Way Construction Tests
  (*by 1 GHz module, 1-way scenario)*
- Hradcany-Cebin Asphalt Way Analysis
  (*by 1 GHz module, 1-way&4-bridges scenarios*)

Test and Measurement

Setup Photos