Utility Locating Technologies (R01B)
Training and Field Demonstrations

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Discuss Todays Agenda (*changes*)

- Classroom till Noon
- Lunch (*on your own*)
- Equipment Demos
- Field Data Review
Introduction: Utility Bundle Overview

• **Product Overview**
  - 3D Utility Location Data Repository (R01A)
  - Identifying and Managing Utility Conflicts (R15B)
  - Utility Locating Technologies (R01B)

**SHRP2 – Strategic Highway Research Program**

**IAP – Implementation Assistance Program**

**Round 6: Proof of Concept ($150K each agency)**
California, Ohio, Arkansas, Oregon, Virginia

**Round 7: Lead Adopter ($100K each agency)**
States California, Indiana, Montana
SHRP2 at a Glance

- **SHRP2 Solutions** – 63 products
- **Solution Development** – processes, software, testing procedures, and specifications
- **Field Testing** – refined in the field
- **Implementation** – 350 transportation projects; adopt as standard practice
- **SHRP2 Education Connection** – connecting next-generation professionals with next-generation innovations

350 SHRP2 projects nationwide
SHRP2 Implementation: Moving Us Forward

$122 million
FUNDING ASSISTANCE

63
SHRP2 SOLUTIONS

350
PROJECTS IMPLEMENTED

- DOT: 52 Recipients
- MPO/LOCAL: 29 Recipients
- UNIVERSITY: 10 Recipients
- FEDERAL/TRIBAL: 7 Recipients

- RENEWAL: 179
- CAPACITY: 95
- RELIABILITY: 65
- SAFETY: 11
SHRP2 Implementation: Moving Us Forward

145,831 Participants Engaged

5,713 Outreach Activities

6,155 Hours of Technical Assistance

- Training: 5,474
- Workshops: 152
- Peer Exchanges: 40
- Demos: 29
- Showcases: 18
Why Using Advanced 3D Utility Location & Delineation is Important
Utility Bundle (R01A/R01B/R15B)

Challenge: Locating and Managing Utilities
Solution: Three Products
Moving from 2D to 3D utility management.

SME: Cesar Quiroga
Senior Research Engineer
Texas A&M Transportation Institute
Email: C Quiroga@tamu.edu
Utility Locating Technologies (R01B) – Today’s Effort

MCGPR and TDEMI for 3D Utility Location
Managing Utility Conflicts Ahead of Construction

SME: Cesar Quiroga
Senior Research Engineer
Texas A&M Transportation Institute
Email: C-Quiroga@tamu.edu
ASCE Standard

Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data

QL-D
QL-C
QL-B
QL-A
2D Utility Mapping

• Utility location services: X, Y
• Test holes at specified locations: Z (X, Y if surveyed)
• American Society of Civil Engineers ASCE 38-02

Standard Guideline:
- Quality Level D: Review of existing records: X, Y
- Quality Level C: Survey of visible appurtenances: X, Y
- **Quality Level B: Geophysical methods for underground utilities: X, Y**
- Quality Level A: Exposed utilities at specified locations: X, Y, Z
  - Test holes
  - Valves
  - Manholes
  - Vaults
  - Building basement walls
Traditional 2D Multi-Sensor/Technology Toolbox

Many types of systems:
- Radio-Frequency (RF)
- Electromagnetic Induction (EMI)
- Ground Penetrating Radar (GPR)
- Magnetometers (Mag)
- Acoustic sensors
- Inertial mapping inside pipes
- Use of sondes inside pipes
SHRP2 Technologies Developed

2 Technologies chosen for SHRP2 IAP to SUPPLEMENT the standard tool box for utility locating!

Advanced Geophysical Hardware

• Multi-Channel Ground Penetrating Radar (MCGPR)
• Time-Domain Electromagnetic Induction (TDEMI)

Advanced Software

• Software for processing, interpretation and visualization of MCGPR in 3D, and TDEMI data in 2D (plan-view)
Today’s Training Outline

Advanced Geophysical Methods: MCGPR & TDEMI

• Basic Theory
• Limitations
• Complications
• Variations
• Applications
• Why is works for utility mapping
• When it won’t work for utility mapping
• Requirements for effective use
• Final Products – What do you get out of the method?

Same outline for both methods!
Start with Multi-Channel Ground Penetrating Radar
Basic GPR Theory

• Uses electromagnetic energy normally in the 10 MHz to 1500 MHz frequency range
  • Lower frequencies (longer wavelengths) image deeper but with lower resolution than higher frequencies (shorter wavelengths)

• Any change in the dielectric constant value (next slide) will generate a reflection. The polarity of the reflected wave is effected by whether the reflecting material is more or less conductive than the surrounding material

• Reflected energy is measured at the GPR receiver
GPR – The Dielectric Constant

This is the material property that governs how well GPR signals transmit through or reflect off of layers / objects

www.cflhd.org/resources/agm/
Conductivity/Resistivity

- GPR does not measure or sense soil ‘conductivity’
- Higher soil conductivity conditions adversely affect signal penetration and clarity.
- Material conductivity values of .01 $mSiemens/meter$ can make GPR a poor choice

Dielectric Constant

- Dielectric is the ability of a material to act like a capacitor
- GPR senses changes in dielectric properties within the survey area
- No absolute dielectric values are determined; only relative changes within the survey area
GPR Signal Penetration vs. Material Conductivity

*You will see this graphic again when we discuss TDEMI*
# GPR Signal Penetration in Various Materials

<table>
<thead>
<tr>
<th>Good Radar Media</th>
<th>Poor Radar Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Salt</td>
<td>Salt water</td>
</tr>
<tr>
<td>Snow</td>
<td>Metals</td>
</tr>
<tr>
<td>Ice and fresh water</td>
<td>CLAY</td>
</tr>
<tr>
<td>Peat</td>
<td>CLAY RICH SOILS</td>
</tr>
<tr>
<td>Wet or dry sand</td>
<td>Conductive minerals</td>
</tr>
<tr>
<td>Dry rocks</td>
<td></td>
</tr>
<tr>
<td>Concrete and pavement</td>
<td></td>
</tr>
</tbody>
</table>

Works

Doesn't Work
Conductivity is the inverse of Resistivity.

**GPR – Conductivity in Soils**

- **GOOD**
- **BAD**
Basic GPR Concepts
Soil Suitability Map of the US

Suitability of GPR in Areas
GPR – Reflected Signals

“Antenna”

Signal at Receiver

Transmitted Signal
(direct wave)

Reflected Signal

Top of Utility (Pipe)

Transmitter Wave

Transmitter

Wavefronts

Void

Reflected Wave

Receiver

(direct wave)
GPR Antenna Size/Frequency & Depth/Resolution

<table>
<thead>
<tr>
<th>Antenna Size</th>
<th>Frequency</th>
<th>Depth of Penetration</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>High</td>
<td>Shallow</td>
<td>High</td>
</tr>
<tr>
<td>Big</td>
<td>Low</td>
<td>Deep</td>
<td>Low</td>
</tr>
</tbody>
</table>
Basic Concepts

Types of GPR Antennas

- Air-Horn
- Bi-static
- Adjustable Low Frequency (MLF-Multi-Low Frequency)
- Mono static

Note the lack of GPS (need)

*Mapping rebar and PST’s
Visualization of the concept of ‘frequency’ for a GPR wave.

Note Error in your books

Antenna Frequencies

Shallow

Deep

2 GHz 1 GHz 400 MHz
Basic Concepts – A Series of Cartoons to Demonstrate How GPR Works

We record the two-way travel time, and the amplitude of the reflected wave.

Courtesy: Geophysical Survey Systems, Inc.
Basic Concepts – Reflections from Multiple Layers

Reflections are produced when the GPR pulse encounters a material with different dielectric constant – for this Model:

**Dielectric Constant:**
- Air = 1
- Asphalt = 3-5
- Concrete = 6-8

Courtesy: Geophysical Survey Systems, Inc.
Basic Concepts

Electromagnetic Reflection Theory

Measurements of Times and Amplitudes

Traces are Digitized

Scans of reflected pulses shown side by side

From here – the next slide shows how GPR data are presented from this ‘wiggle trace’ plot to a ‘waterfall’ plot
Basic Concepts
Wiggle Trace to Linescan Data

Same Wiggle Trace Data Displayed as...

Amplitudes are assigned colors (greyscale or multi colors) to create a linescan GPR ‘profile’ or ‘section’.
Basic Concepts

Creating a 2D Linescan Data & Interactive Re-Locating

*Single antenna system

Courtesy: Geophysical Survey Systems, Inc.
Development of the GPR

*Hyperbola*
Basic GPR Theory

\[ v = f \lambda = \frac{c}{\sqrt{K}} \]

- \( v = velocity \)
- \( f = frequency \)
- \( \lambda = wavelength \)

Speed of Light

Dielectric Constraint

Propagation of a Photon through a Medium

Propagation of a Photon through a Vacuum
Basic GPR Theory

- The scans are then typically plotted as *waterfall plots* of all of the individual data traces collected.
- The lightness or darkness (or color) of each point in the plot shows the *amplitude and polarity* of the data at a given time in each trace.

**Typical Material GPR Velocities**

- Air = 2 ns/ft
- Water = 18 ns/ft
- Dry Concrete = 4.5 ns/ft
- Asphalt = 4.5 ns/ft
- Dry Sand = 4 ns/ft
- Dry Clay = 4 ns/ft
- Wet sand = 7.5 ns/ft
- Wet Clay = 10.5 ns/ft
Basic GPR Theory – Wave Transmission

\[ R = \frac{\sqrt{K_1} - \sqrt{K_2}}{\sqrt{K_1} + \sqrt{K_2}} \]

- **Dry Sands** – \( K = 5 \)
  - R = -0.38
  - Wet Sands – \( K = 25 \)
  - R = +0.38
  - Sandstone – \( K = 10 \)
  - R = -0.17
  - Metal – \( K = \infty \)
  - R = -1

- **Wet Sands** – \( K = 25 \)
  - Dry Sands – \( K = 5 \)
  - R = -1
Basic GPR Theory

Mathematical/Graphical representation of GPR wave transmission through materials with different material conductivities.

- **Sand**
- **Shale**
- **Clay**

**RELATIVE SIGNAL AMPLITUDE** vs **RELATIVE SIGNAL PENETRATION**

Diagram showing the relative signal amplitude and penetration for different materials, illustrating how materials like sand, shale, and clay affect GPR wave transmission.
Same transect – two different GPR frequency antennas

400 MHz Transect

200 MHz Transect
Frequency vs. Resolution of Anomalies

Same transect – three different frequency antennas

*Same time scales

Lower Frequency 'sees' Deeper
What Makes GPR Complex

• **Will a feature cause a reflection?**
  • Depends on:
    • Dielectric constant of feature
    • Dielectric constant of material feature is in or next to
    • Signal strength at feature (is your signal strong enough to go from surface, to feature, and back?). Depends on initial signal strength and absorption/attenuation of material between the surface and the feature of interest.

• **Data requires expert interpretation**
  • Is a reflection caused by a utility, rock, void?
  • Near surface or even surficial features will create “echoes” downward in time. Important to note the earliest time (or shallowest depth) that the feature is present
  • Interpretation is, to a large part, subjective. Two experts can come to different conclusions

• **Often GPR will simply not work due to geologic conditions**
  • It is very important to understand why and when this will be the case
  • Requires background research or knowledge of the site

• **Even single sensor and single frequency system generate large data sets. Advanced systems generate huge data sets that require special software and organization to make the most of.**
Example
Where GPR Does Not Work
Effect of Scan Direction vs. Utility Orientation

*Single Antenna System

Same pipe diameter -

*Single Antenna System
Effect of Burial Depth on Hyperbola Shape

Same pipe diameter -
GPR Signal “Ringing” Response from Surface Metal

For example – a manhole cover!
Direct Air Signal and Ground Reflections

- **Direct Air Signal** is the direct reading of the transmitter (Tx) signal in the receiver (Rx)
- **Ground Reflection** is a very large, horizontal reflector that is the signal reflecting from the ground surface
- Both show up in the beginning of records, but can “echo” down to later times
- Both can be reduced by using a horizontal filter
External Noise Sources

- Radio Signals
- Police RADAR guns
- Cell Phones
- Hand Held Radios
- And more…
• The results from GPR surveys are often complicated to understand

• The Y axis is often time, not depth
  • This is because the response as a function of time is what is actually measured
  • Can be converted to depth if a velocity is assumed

• Often responses from multiple features overlap
  • Responses from shallow features can cause echoes going down in time (or depth) that can complicate interpretations of deeper features

• Uneven terrain can cause the instrument to bounce, causing false anomalies
Converting ‘Time to Depth’

How to estimate/calculate material velocity?

\[ Dist = 2 \sqrt{\left(\frac{dX}{2}\right)^2 + (\text{Depth})^2} \approx 2(\text{Depth}) \]

\[ \text{Depth} \approx \frac{\text{time} \ast \text{Velocity}}{2} \]
Average Velocity by Hyperbola Fitting

Note: Only works if the source of the hyperbola is a point source or linear source that is perpendicular to direction of movement.
Once you have a material velocity calculated, hyperbolas can be “reduced” to a smaller anomalies at their actual location/position.

*Collapses the Hyperbola at the position of the reflector*
• Not all features seen on a radargram are from the subsurface
  • Nearby objects such as buildings, lamp-posts and the like can cause reflections if antenna are not ‘shielded’
  • These can be identified by estimating the velocity as shown above
    • If the velocity is the same as the speed of light in air ($3 \times 10^8$ m/s) it should be considered suspect or an above ground feature
    • EM waves travel slower in solid / earth materials (soil, rock, roadway etc…) than in air
    • Remember, these will be broader anomalies to go along with the higher velocity values
    • Buildings and other extended features will cause broad flat anomalies
      • If approaching a building, anomaly could look linear
    • Light posts, trees etc. will generate hyperbolic anomalies
Basic Concepts – Building a 3D Data Set (Cube)
Advanced Multi-channel GPR - MCGPR

IDS Stream-EM System

3D Radar System
Monostatic, Bistatic vs. Multi-channel GPR

- **Monostatic** GPR uses the same antenna for transmission and reception.
- **Bistatic** GPR use separated antenna for transmission and reception.
- **Multistatic** / multi-channel systems use multiple receivers and a transmitter.

Diagram:

- **Monostatic**
  - Tx/Rx

- **Bistatic**
  - Tx
  - Rx

- **Multistatic**
  - Tx
  - Rx
  - Rx
  - Rx
  - Rx

SIMPLE ——— COMPLEX
<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monostatic GPR</strong></td>
<td><strong>Bistatic/Multistatic</strong></td>
</tr>
<tr>
<td>• Single antenna is simpler to deploy</td>
<td>• Larger aperture</td>
</tr>
<tr>
<td>• Simple position determination</td>
<td>• Multiple angles of illumination</td>
</tr>
<tr>
<td>• No relative sensor motion issues</td>
<td>• Possible clutter rejection</td>
</tr>
<tr>
<td></td>
<td>• Tomography possible</td>
</tr>
<tr>
<td></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td></td>
<td>• Requires very accurate Tx/Rx positions</td>
</tr>
<tr>
<td></td>
<td>• Requires accurate time sync</td>
</tr>
<tr>
<td></td>
<td>• Relative motion between Tx and Rx corrupts signal</td>
</tr>
<tr>
<td></td>
<td>• Direct signal must be removed</td>
</tr>
</tbody>
</table>
IDS STREAM-EM: Modularity and Array Architectures

**GPS or Total Station**

- 1x200 MHz DML array for detecting main pipes along the road (6 cm transversal sampling; VV polarization)

**4 dual frequency 200-600 MHz antennas (DCL array) for the detection of shallow and deep junctions (HH polarization)**

**MF Hi-Mod: the DCL array can be extracted from the Stream-EM to be used in the MF Hi-Mod configuration for mapping sidewalks and areas with difficult accessibility.**

**Modular composition: easily reassembled**

**Stream X: the DML array can be extracted from the Stream-EM to be used in the Stream-X configuration for archaeology or environment surveys.**
IDS Systems (we will see today)

**SYSTEM SPECIFICATIONS**

<table>
<thead>
<tr>
<th><strong>OVERALL WEIGHT (PC NOT INCLUDED)</strong></th>
<th>228kg (500 lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RECOMMENDED LAPTOP</strong></td>
<td>Panasonic CF-31 Tough-Book or similar</td>
</tr>
<tr>
<td><strong>MAX. ACQUISITION SPEED (@ STD. SCAN INTERVAL)</strong></td>
<td>15 kph (9mph)</td>
</tr>
<tr>
<td><strong>POWER CONSUMPTION</strong></td>
<td>72 W</td>
</tr>
<tr>
<td><strong>POSITIONING</strong></td>
<td>Survey wheel and/or GPS or total station</td>
</tr>
<tr>
<td><strong>NUMBER OF CONTROL UNITS</strong></td>
<td>3 synchronized DAD MCH FW</td>
</tr>
<tr>
<td><strong>SCAN RATE PER CHANNEL:</strong> (@512 SAMPLES/SCAN)</td>
<td>87 scans/sec</td>
</tr>
<tr>
<td><strong>SCAN INTERVAL</strong></td>
<td>17 scans/m @ 200 MHz</td>
</tr>
<tr>
<td><strong>SCANNING ENERGY</strong></td>
<td>33 scans/m @ 600 MHz</td>
</tr>
<tr>
<td><strong>POWER SUPPLY</strong></td>
<td>SLA Battery 12VDC 100 Ah</td>
</tr>
</tbody>
</table>

**SYSTEM SPECIFICATIONS**

<table>
<thead>
<tr>
<th><strong>OVERALL WEIGHT (PC NOT INCLUDED)</strong></th>
<th>31 kg (68 lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RECOMMENDED LAPTOP</strong></td>
<td>Panasonic CF-19 Tough-Book</td>
</tr>
<tr>
<td><strong>MAX. ACQUISITION SPEED (@ STD. SCAN INTERVAL)</strong></td>
<td>36 kph (22 mph)</td>
</tr>
<tr>
<td><strong>POWER CONSUMPTION</strong></td>
<td>28 W - 200 MHz version</td>
</tr>
<tr>
<td><strong>POSITIONING</strong></td>
<td>Doppler radar and/or GPS or total station</td>
</tr>
<tr>
<td><strong>NUMBER OF CONTROL UNITS</strong></td>
<td>1 DAD MCH @ 200 MHz</td>
</tr>
<tr>
<td><strong>SCAN RATE PER CHANNEL:</strong> (@512 SAMPLES/SCAN)</td>
<td>87 scans/sec</td>
</tr>
<tr>
<td><strong>SCAN INTERVAL</strong></td>
<td>8 scans/m</td>
</tr>
<tr>
<td><strong>POWER SUPPLY</strong></td>
<td>SLA Battery 12VDC 12 Ah + electric crane battery</td>
</tr>
</tbody>
</table>

**ANTENNA SPECIFICATIONS**

| **IP GRADE**                        | IP65 |
| **SCAN WIDTH**                      | 1.80 m Width |
| **NUMBER OF CHANNELS**              | 15 / 44 |
| **ANTENNA CENTER FREQUENCIES**      | 200MHz or 600MHz |
| **POLARIZATION**                    | VV |
| **ANTENNA SPACING**                 | 12cm / 4cm |
| **CERTIFICATION**                   | EC, FCC, IC |

**ANTENNA SPECIFICATIONS**

| **ENVIRONMENTAL**                   | IP65 |
| **ANTENNA FOOTPRINT**               | 38x43 cm (single antenna) |
| **NUMBER OF HARDWARE CHANNELS**     | from 2 to 8 |
| **ANTENNA CENTER FREQUENCIES**      | 200 MHz / 600 MHz or 400 MHz / 900 MHz |
| **ANTENNA POLARIZATION**            | HH |
| **ANTENNA SPACING**                 | 50 cm |
| **CERTIFICATION**                   | EC, FCC, IC |
STREAM-EM: Main Benefits

- GPR solution towed by a vehicle (speed > 10mph).
- Data collection in longitudinal direction (without the need of moving the array in the transversal directions) but detection of utilities and connections.
- High productivity
- High modular structure
- High detection capability
- Avoid blocking the road traffic
- Exploit the same advanced processing feature of RIS MF Hi-Mod
- Possibility of different kind of towing frames
The GRED HD software comes with a 3D graphic interface, and advanced software features making it an advanced and complete tool for post processing Ground Penetrating Radar data. The software is able to show:

- Tomography (time slices),
- Radar scans parallel to the acquisition direction,
- Virtual Radar scans orthogonal to the acquisition direction
- 3D view.
GPR Results
Depth Slicing 3D Volume
3D Radar Theory Of Operation

Principle of Operation

3D-RADAR DX/DXG-Series Multi-Channel Air and Ground Coupled Antenna Arrays

RTK Base Station (optional)

UHF Data link

RTK GPS antenna (optional)

GeoScope Radar Unit

Operator PC

Survey wheel (odometer)

Antenna array

Inline direction, x

Cross-line direction, y

Depth, z (time, ns)
3D Radar Theory Of Operation
Step-frequency waveform

![Diagram showing step-frequency waveform with Dwell Time and Frequency step]
DXG-Series multi-channel antenna arrays

- 200 MHz - 3.0 GHz frequency range
- All elements have uniform size and frequency response
- Simultaneous recording on two receiver antennas
- 2.95 inch (7.5cm) antenna spacing
- Multi-offset and automatic CMP-recording
- Built-in GPS for time stamp and coarse positioning
3D-Radar Examiner

Designed to handle huge datasets
- No data reduction
- Post processing performed on full dataset

Drastically reduced processing time
- Data available for analysis almost immediately after the survey

Intuitive GUI
- Easy extraction of meaningful data

High positioning accuracy
- State-of-the-art GPS outliers filtering

Easy to use annotation function
- Annotations exported with subsurface images

Import/Export of geo-referenced maps and images
- AutoCAD, Google Earth, Video

Fully documented SW development kit
- Integration of specific algorithms
Airport Runway Inspection

Copenhagen Kastrup airport:
Area covered: 3 km x 60 m
Survey duration: 5 h 20 min

No closure necessary

Power cables – 1
Power cables – 2
Tunnel ceiling
3D Radar Example datasets
Next Section: Time-Domain Electromagnetic Induction

QUESTIONS ON GPR?
SHRP2 TDEMI

Diagram showing a transmitter (Loop) and a receiver (Coil) setup.
TDEMI - Applications

- Unexploded Ordnance (UXO) detection
- Utility locating & imaging
- Identify **metallic objects** (*ferrous or non-ferrous*)
- Geologic mapping (1D or 2D)
- Environmental problems (UST, wells, etc.)
Current is transmitted though the transmitter loop (Tx) in a time varying manner with on and off cycles
  - Most commonly a square wave
  - Normally cycle frequency 60hz or higher

Receiver loops (Rx) record data after the transmitter is turned off
  - The goal is to measure the current induced in metallic objects such as utilities, not the primary field created directly by the transmitter current
  - Typically, measurements are made over windows of time after transmitter turnoff.
    - Referred to as “time-gates”
Faraday’s Law

\[ \nabla \times E = -\frac{\partial B(t)}{\partial t} \]

The Curl of Electric Field
A measure of the rotation of the vector electric field

The partial derivative of the magnetic field with respect to time
Measures how the magnetic field changes with time

What does this mean?

- A magnetic field that is changing in time will generate a rotating electric field
- A rotating electric field will generate a time varying magnetic field
- Which, in turn produces a current in a TDEMI receiver loop
The EM field in the earth
EMI in a Metal/Utility Object
Red – Transmitter current
Black – Receiver current
Colors – Example time gates

*NOTE THE TIME SCALE (60 per second)
Number of pulses per second is termed the “Duty Cycle”
TDEMI Theory

a) Current in Transmitter Loop

b) Induced Electromotive Force Caused by Current

c) Secondary Magnetic Field Caused by Eddy Currents
• Data collection parameters can vary significantly between systems and applications.
  • Tx frequency – number of times per second that the Tx turns on and off
    • Lower frequencies allow for longer recording after turn-off, and potentially deeper investigations
    • Higher frequencies allow for more stacking or higher sample rates
      • Stacking response from multiple Tx turn-offs increases signal to noise at the expense of sample rate
  • Number and size of time gates
    • More time gates allow for better discrimination of targets, but fewer allow for larger signal to noise ratios due to longer time periods being added together
<table>
<thead>
<tr>
<th>Tx Frequency</th>
<th>Stacking</th>
<th>Effective Sample Rate (per sec)</th>
<th>Down-line sample distance at 5 mph (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>270</td>
<td>1</td>
<td>270</td>
<td>0.3</td>
</tr>
<tr>
<td>270</td>
<td>10</td>
<td>27</td>
<td>3.3</td>
</tr>
<tr>
<td>270</td>
<td>100</td>
<td>2.7</td>
<td>32.6</td>
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<tr>
<td>270</td>
<td>500</td>
<td>0.54</td>
<td>163.0</td>
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<td>120</td>
<td>1</td>
<td>120</td>
<td>0.7</td>
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<td>120</td>
<td>10</td>
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<td>1.2</td>
<td>73.3</td>
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<td>0.24</td>
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<td>3</td>
<td>29.3</td>
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<tr>
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<td>100</td>
<td>0.3</td>
<td>293.3</td>
</tr>
<tr>
<td>30</td>
<td>500</td>
<td>0.06</td>
<td>1466.7</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>15</td>
<td>5.9</td>
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<tr>
<td>15</td>
<td>10</td>
<td>1.5</td>
<td>58.7</td>
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<tr>
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<td>0.15</td>
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<tr>
<td>15</td>
<td>500</td>
<td>0.03</td>
<td>2933.3</td>
</tr>
</tbody>
</table>
TDEMI Applications

• TDEMI is very flexible and can be used for everything from metal detection to geology mapping

• For Geology mapping, larger Tx and Rx loops are used, and transmitter turn-off is very controlled and measured. The important information is not just signal amplitude, but where the amplitude is in time after transmitter shut-off (which time gates)

• For metal mapping, smaller Tx and Rx loops are used, often with many turns in the wire.
• UXO
• Buried Tanks, barrels, utilities, cars (yes, we have found buried cars)
• Geologic targets
  • Faults
  • Gravel deposits
  • Clay layers
• Groundwater
  • Contamination plumes
  • Water quality (salinity)
  • Aquifer thickness, extents
TDEMI “Metal-Detecting” Instrument

Geonics EM-61MK2
(with GPS)
TDEMI “Metal-Detecting” Instrument

Zonge’s Dynamic Nano-TEM (with GPS)
TDEMI - Environmental (UST)

FORMER GASOLINE STATION
EM-61 BOTTOM COIL

Reference Location Grid (feet)
0
-20
-40
-60
-80
-140
-120
-100
-80
-60
-40
-20
0

Field Strength (FPT)
-50 0 50 100 200 400 800 1600 3200 6400 12800 25600 51200 9800

UST

Concrete reinforced driveway

Street

Building
TDEMI – Environmental (UXO)
UXO – Unexploded Ordnance
“Dig Results”
TDEMI – Engineering (sand/gravel mapping)

DNT – 3m x 3m Tx Loop
Inverted resistivities sliced at a depth of 10 feet b.g.s.
Able to distribute plan and profile results easily for viewing in Google Earth
TDEMI – Engineering (Levee Inspection)
Sand deposit in foundation
TDEMI for Geologic Mapping

Off Topic – TDEMI on another scale: Geologic mapping for clay/gravel and groundwater applications
Wrap-up ‘Other’ TDEMI Applications

• Is used on scales measured in inches and miles – mineral exploration

• Loops as large as a mile on side or as small as a centimeter

• Can be installed on carts, hand carried, laid out on the ground or be installed on helicopters or airplanes
When Does TDEMI Work Well for Utilities?

- When the target utility is metal (*ferrous & non-ferrous*)
- When utility is within the top 5-10 feet (*or so*)
- In any (*or at least most*) geologic settings
Range of Conductivity in Various Earth Materials

WHY DOES TDEMI WORK? ➞ Material Contrasts!
An Example Where GPR Does Not Work

- When the survey area has too much metallic items at the surface.
  - For example, TDEMI will not work along a guard rail, near cars or through reinforced concrete
- When utility is non-metallic, such as:
  - Fiber optic cables without tracer wires
  - PVC, clay or non-reinforced cement pipes
  - Utilities that are too deep
- When depth to the utility is required (TDEMI only maps the lateral location, not depth).
An Example Where GPR Does Not Work
When is TDEMI better than GPR?

![Diagram showing EM61 Time Gates and Distance vs. Amplitude graph.]

**EM61 Time Gates:**

- SIMPLE
- Distance

**Amplitude (millivolts):**

- 1
- 2
- 3
- 4

**Distance:**

- 45240
- 45260
- 45280
- 45300
- 45320
- 45340
- 45360
- 45400
- 45415
TDEMI an GPR over the same site
TDEMI system used for the outdoor demo: Geonics EM61-MK2

Specifications

MEASURED QUANTITIES
- Four time gates of secondary response in mV

EM SOURCE
- Air-cored coil, 1 x 0.5 m size

CURRENT WAVEFORM
- Unipolar rectangular current with 25% duty cycle

EM SENSORS
1. Main: Air-cored coil, 1 x 0.5 m in size, coincident with EM source
2. Focusing: Air-cored coil, 1 x 0.5 m in size, 30 cm above main coil

DYNAMIC RANGE
- 18 bits

OUTPUT MONITORS
- Color active matrix TFT-LCD 240x360 pixels, and audio tone

DATA STORAGE
- 512 MB internal disk; SD and CF slots, user accessible

DATA OUTPUT
- RS232 - serial port, Bluetooth

POWER SOURCE
- 12 V rechargeable battery for 4 h continuous operation

OPERATING TEMPERATURE
- -30°C to +60°C

OPERATING WEIGHTS & DIMENSIONS
- 41 kg trailer mode;
- 100 x 50 x 5 cm (bottom),
- 100 x 50 x 2 cm (top)
The graph shows the relationship between down-line sample rate (inches) and tow speed (mph) for the Geonics EM61 system. The graph indicates that there are approximately 10 readings with the coil over the top of each point.

The insert graph on the right shows the amplitude over distance (inches) with a red arrow indicating the range of distances measured.
TDEMI Conceptual Cart Design (*for Demonstration)
TDEMI Actual Cart for Demo
TDEMI Output - Time for Field Demonstration

TDEMI Line Path Map
Time for Lunch
Then MCGPR and TDEMI
Field Demonstrations

QUESTIONS ON TDEMI?
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**GoSHRP2 website**
www.fhwa.dot.gov/goSHRP2
- Product details
- Information about SHRP2 implementation phases

**SHRP2 Utility Bundle website**
http://shrp2.transportation.org/Pages/UtilityRelatedProducts.aspx
Implementation Information for AASHTO members