Advanced Electromagnetic Induction (EMI) Systems for Subsurface Targets Detection and Identification

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Electromagnetic Sensing Group (EMSG)

22 years of extensive experience in:

- Detecting and classifying buried explosive hazards;
- Solving very fundamental, low-frequency EMI problems;
- Developing, designing, and building advanced EMI (frequency and time domain) sensor concepts;
- Developing, demonstrating, and validating advanced EMI models, data processing, and discrimination approaches for unexploded ordnance (UXO) cleanup at live-UXO sites; and
- Building and testing lightweight subsurface sensing technologies.

Buried Explosive Hazards (BEH) Detection and Classification

Metallic Targets:

Projectiles, mortars, rockets





Intermediate Conductive Materials:

Carbon fiber, depleted uranium…




Nonmetallic:

Plastic mines, homemade explosives

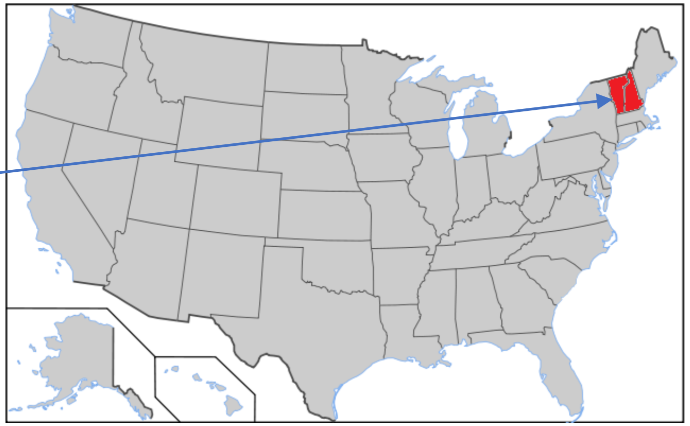


UXO Problem in the World

- First and Second World Wars
  - European countries have UXOs.
  - Former Soviet Union countries.
- Southeast Asian Countries
  - 270 million bombs dropped over Laos between 1964 and 1973.
  - 80 million estimated bombs failed to explode.
  - Active and former military bases.
- Cluster bombs are main threat for public.

UXO Problem in the USA

- Army's #1 environmental problem:
  - Approximately 11 million acres of land infected with UXO, area of NH & VT.
  - 10 million underwater areas are also contaminated with UXOs.



Challenge is classification not detection;
1 UXO vs. 1000s false positives.

Too many false positives

Subsurface Targets Detection

- Magnetometer
- Electromagnetic Induction

- Detects metal
- In-service

- Ground-Penetrating RADAR

- Detects metal & dielectric
- Experimental/small-scale service

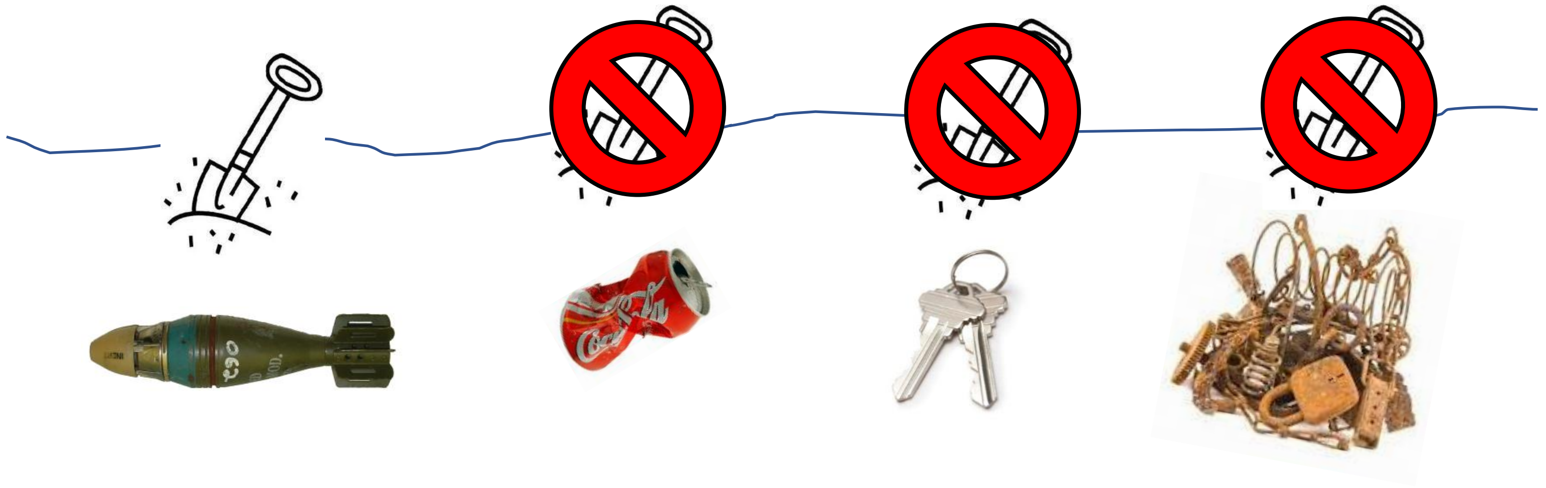
- Trained Animals
- Nuclear Detection

- Detects explosive/ compound

Problem With Standard Metal Detectors

It is difficult, time-consuming, and expensive to clean up UXO sites:

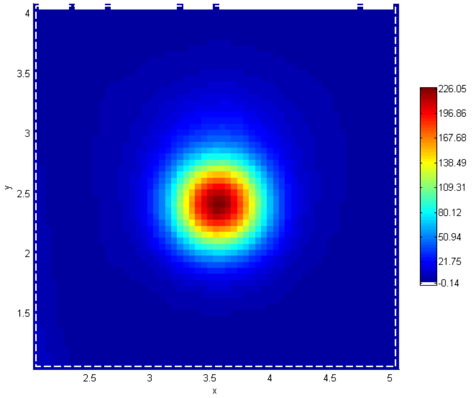
- 1 UXO vs. 1000s false positives.
- Cleanup cost in 10's of billions.
- Classification is the solution.



Classification

1. Data Collection

Sensor data: d



2. Data Inversion

Forward Operator

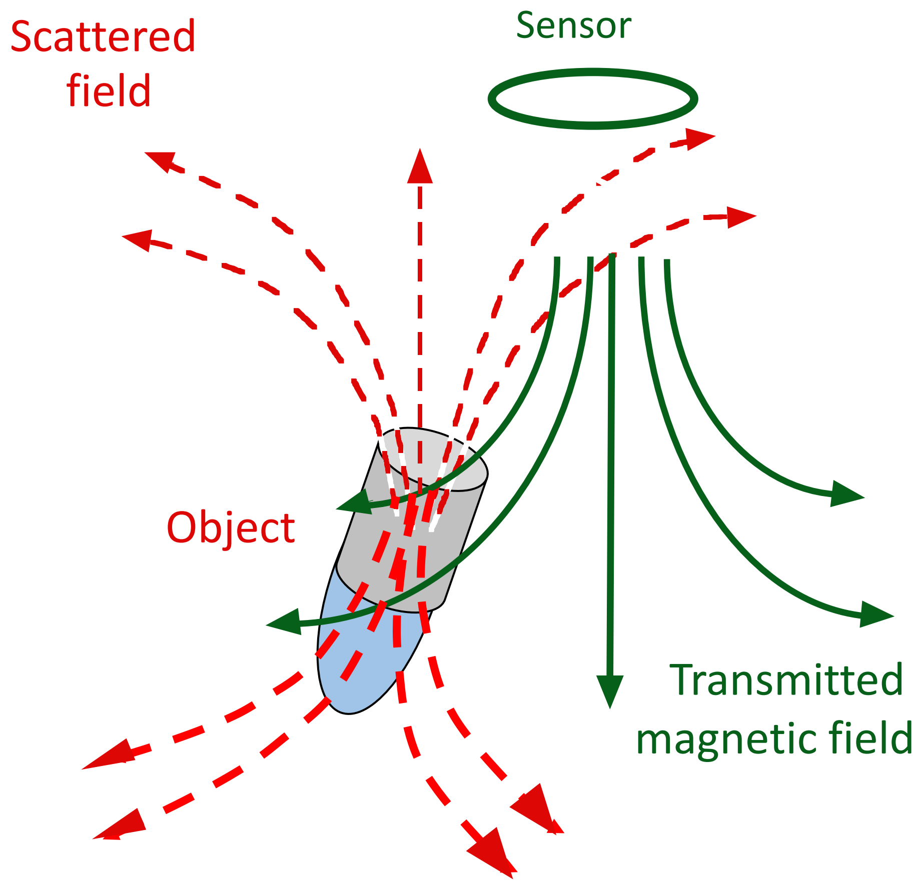
$$d = F\,[p]$$

$$p = F^{-1}\,[d]$$

Inverse Operator

3. Classification

EMI Sensing

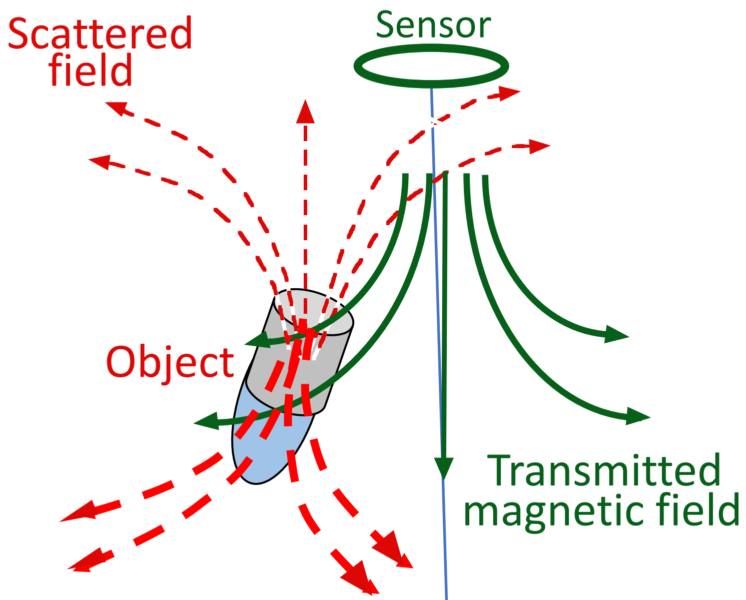


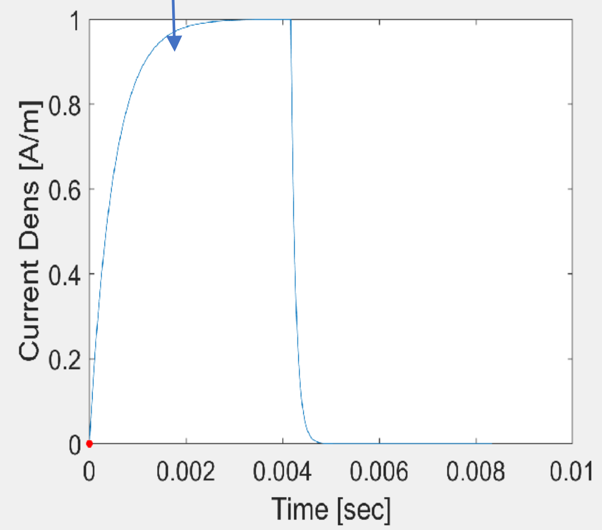
Traditional EMI frequency range: 10's Hz up to 10's KHz.

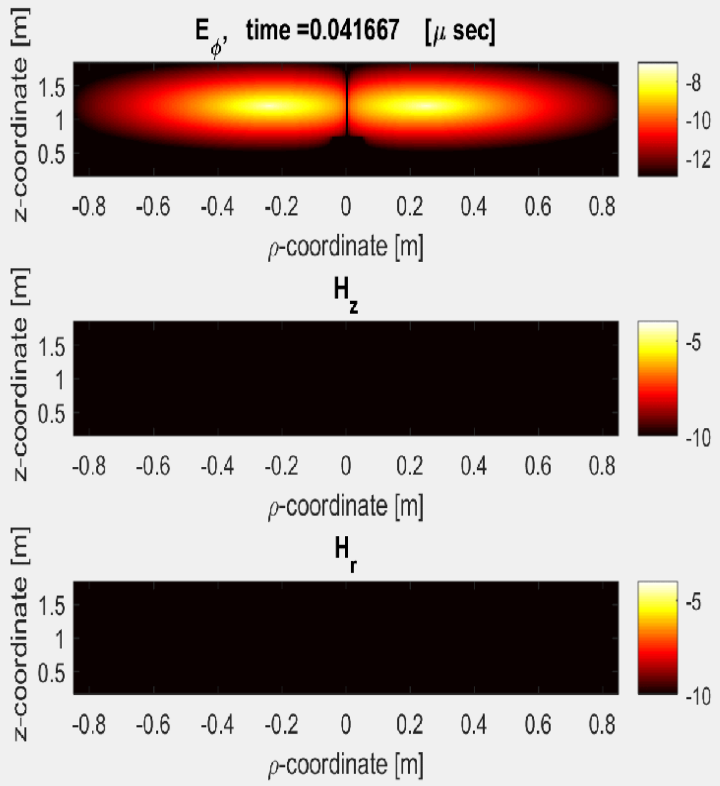
EM penetrates inside target and induces volume/surface currents.

The induced currents produce secondary EM field that is out of phase with the primary field.

Time Domain EMI Sensing







EM penetrates inside target and induces volume/surface currents.

The induced currents produce secondary EM fields that are detected with a set of receivers.

Advanced EMI Sensors

ULEMA: Ultra Lightweight EM Array

Custom Rx Designed

- Small and lightweight
- 10-layer PCB
- 10 turns on each layer, 10-cm square
- Center tap for instrumentation amp
- 3-channel Rx amplifier board, low-noise preamp

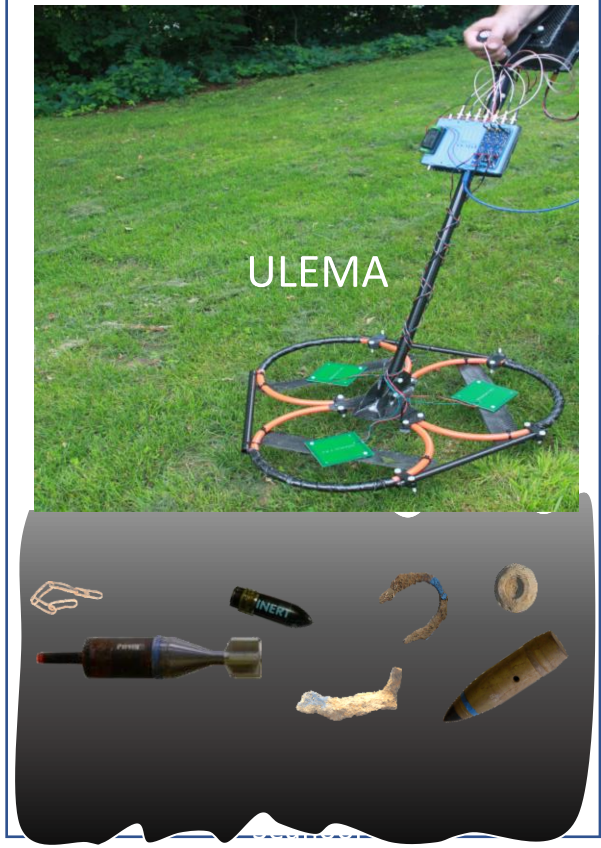
Data Pathways and DAQ System

- Laptop/tablet computer running Windows 10
- 2-8-channel Picoscope (max 80 MS/s)
- Custom Tx PCBs

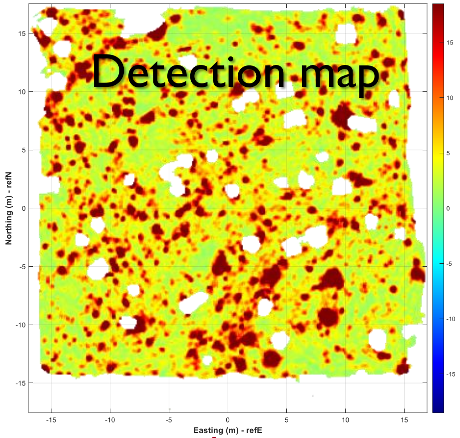
UAS-Based EMI

Subsurface Targets Classification

1. Data Collection



2. Data Inversion



Forward Operator

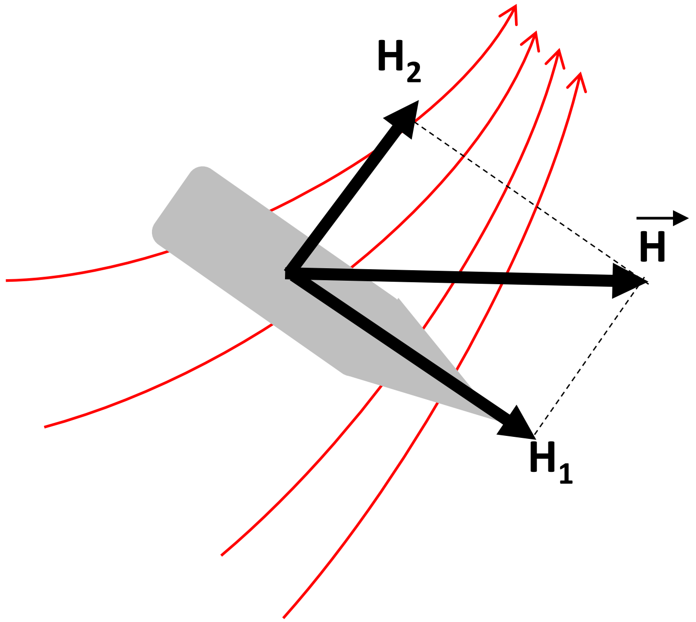
$$\mathbf{d} = \mathbf{F}\,[\mathbf{p}]$$

$$\mathbf{p} = \mathbf{F}^{-1}\,[\mathbf{d}\,]$$

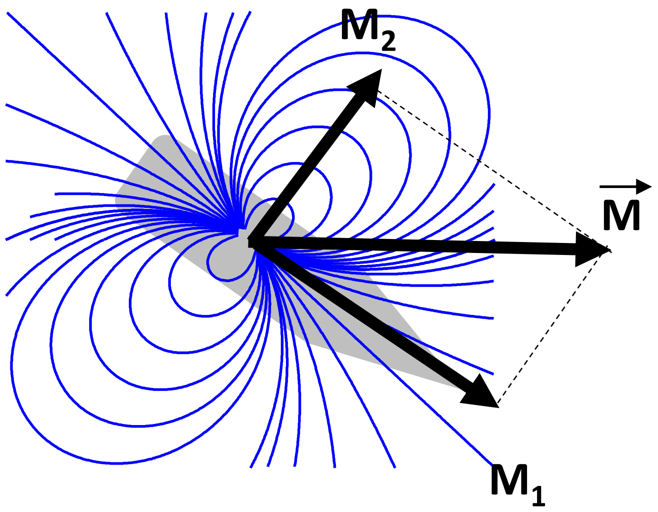
Inverse Operator

3. Classification

The Dipole Model



Secondary field is represented by induced dipole at target center.



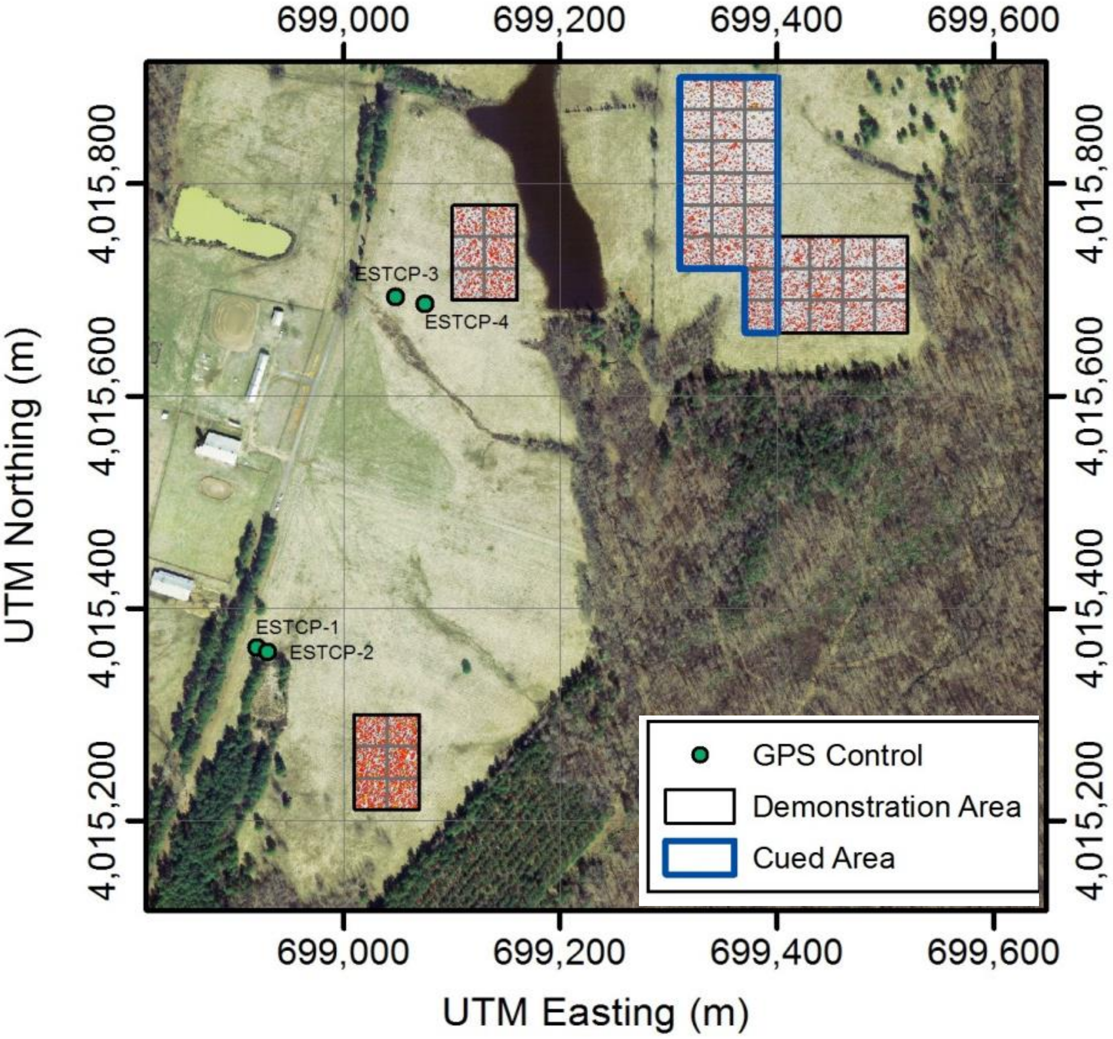
Primary field components along the target's principal axis directions excite magnetic dipoles. In return, these dipoles produce the secondary field.

Dipole moment components:

$$M_i = \beta_i(t)\, H_i$$

β_i are intrinsic target parameters (principal axis polarizabilities).

Live UXO Site: Camp Butner, NC



SERDP-ESTCP live UXO classification demo conducted on 10 acres.

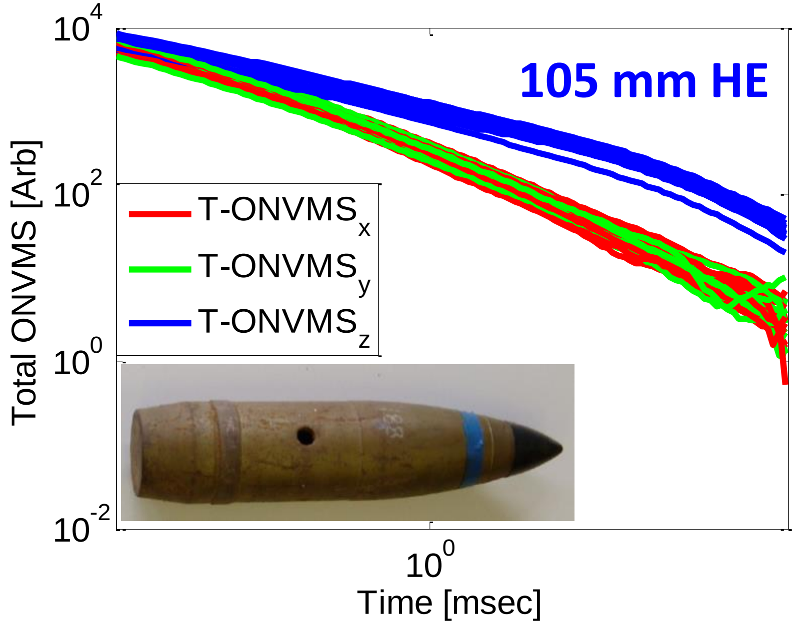
Demo area was subdivided into 44 grids measuring 30 m x 30 m.

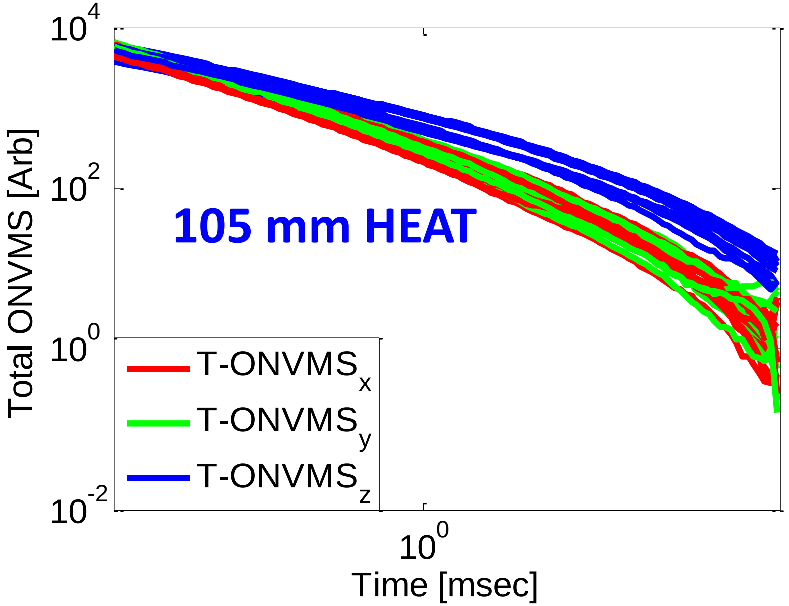
The two survey instruments, EM61-MK2 cart and MetalMapper, were used for targets detection.

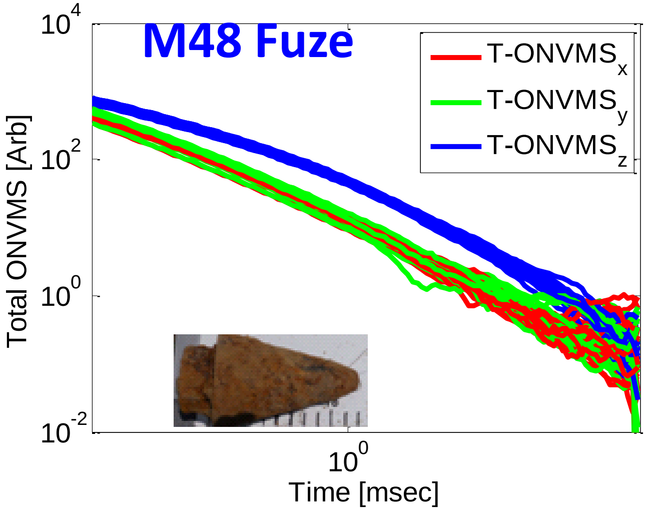
Approximately 2500 anomalies were selected for intrusive investigation.

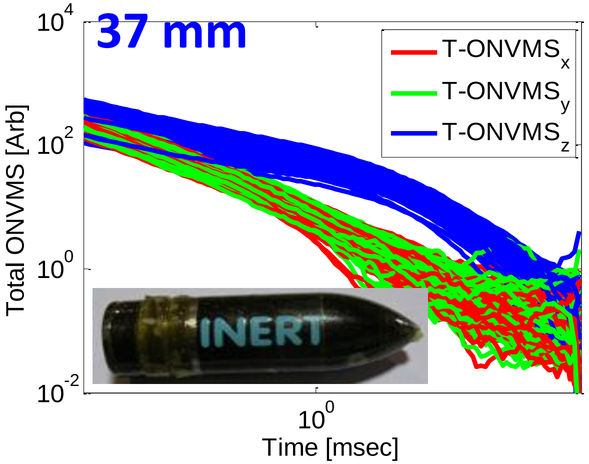
The cued sensors were only deployed on these anomalies, which were dug and scored.

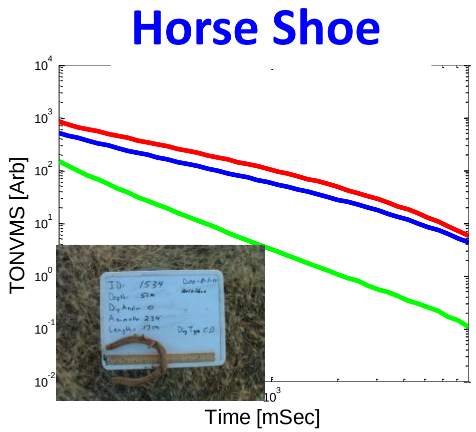
Effective Magnetic Polarizability





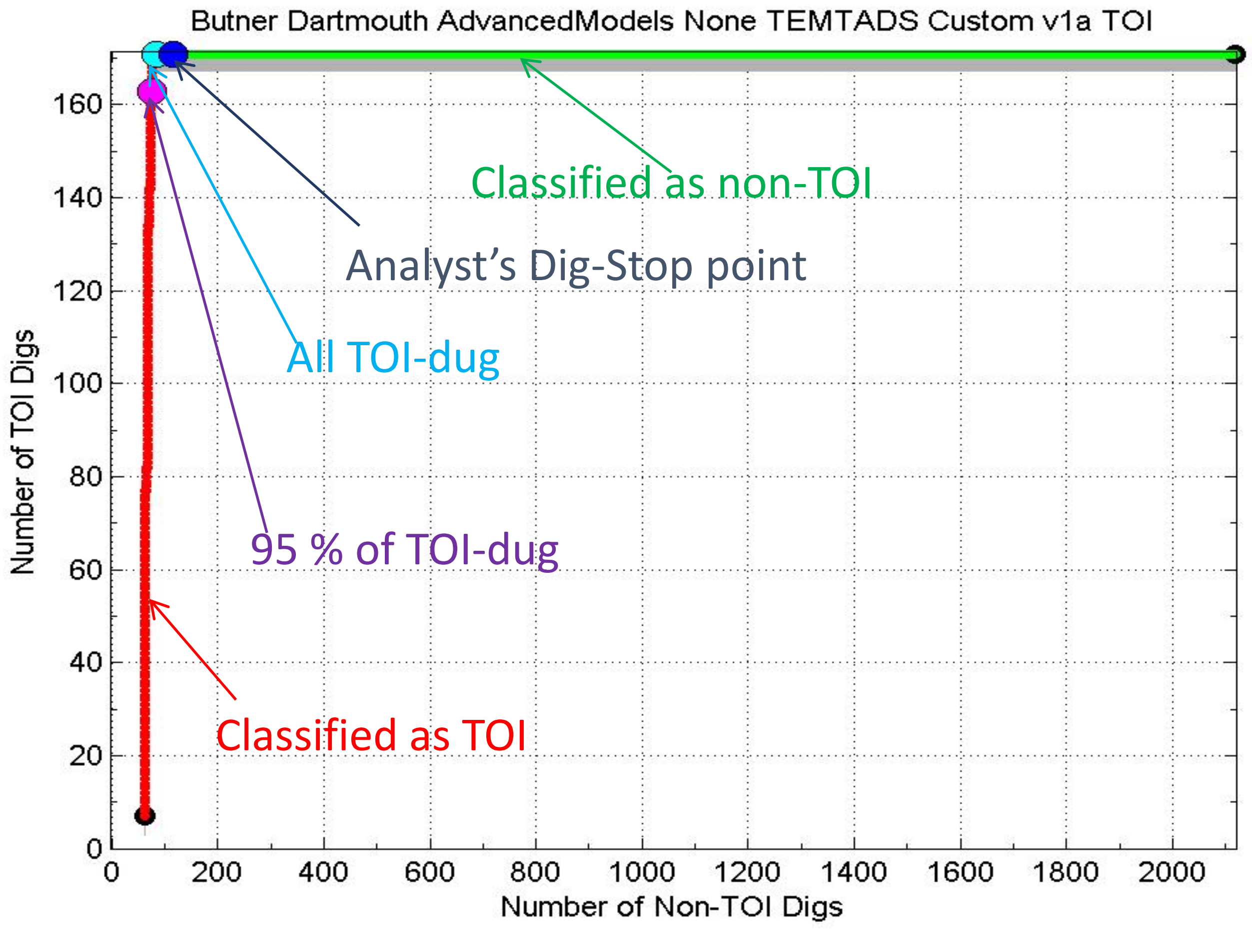






Camp Butner, NC

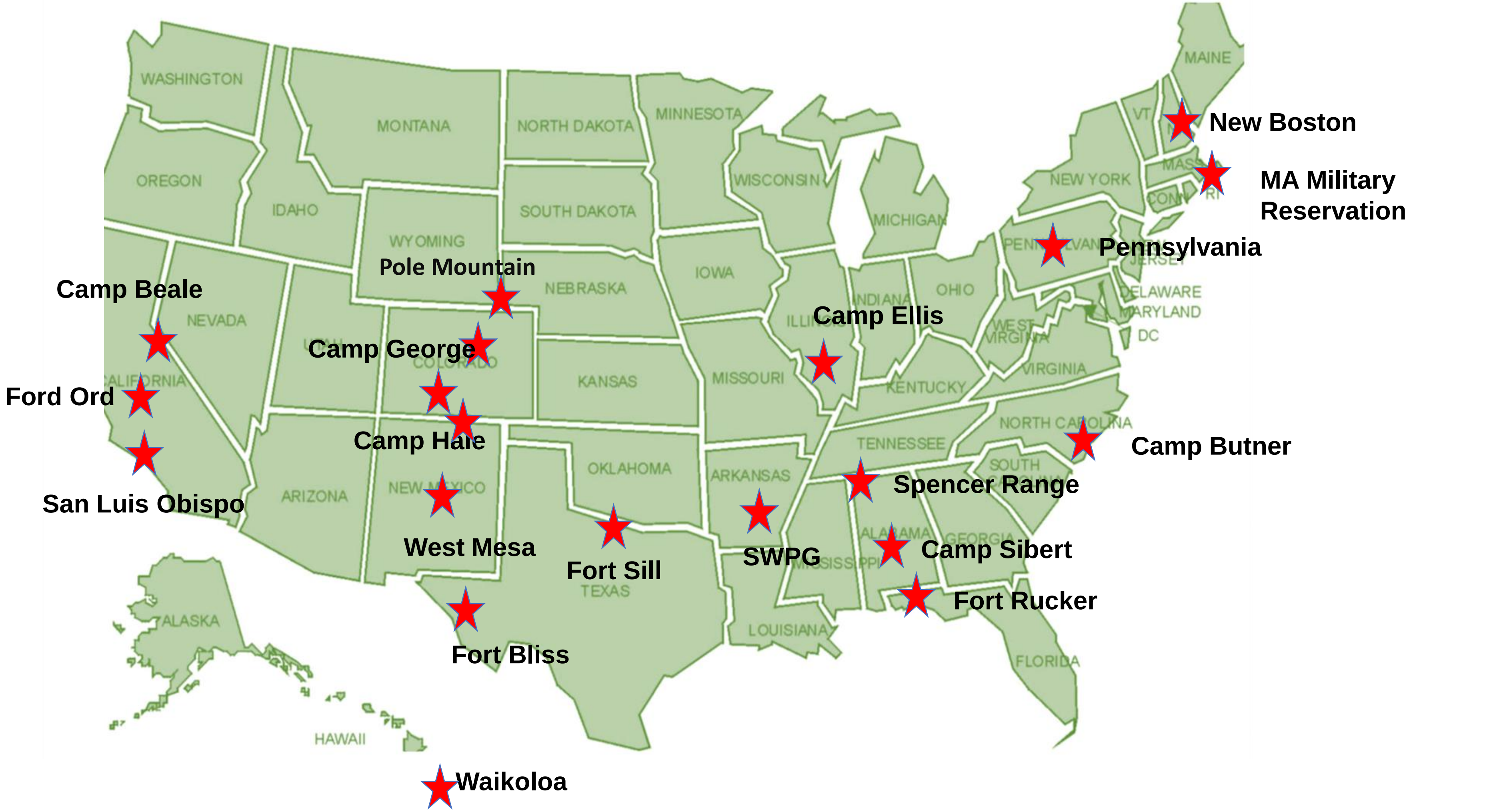
Independently Scored Classification Result



- All data were inverted and analyzed.
- No false negatives: all TOI were identified correctly.
- All 105 mm and 37 mm were identified by caliber/type.

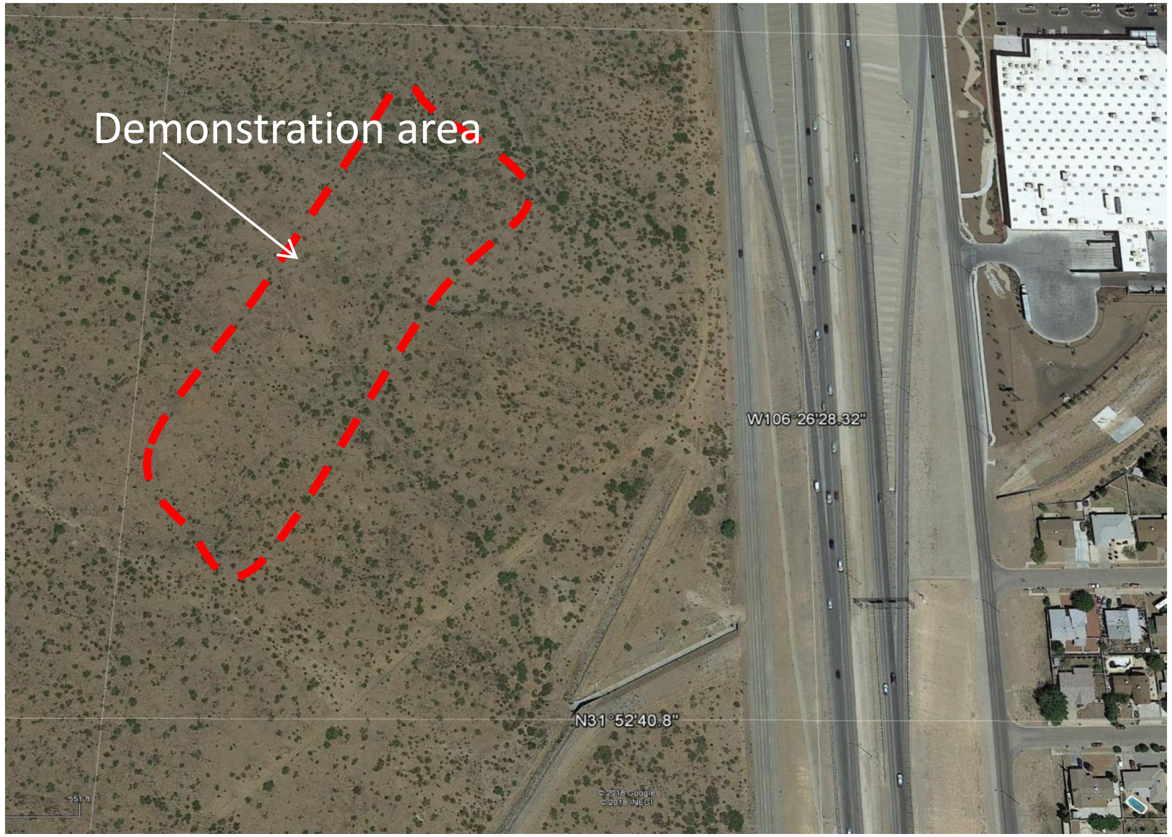
TOI: Target of Interest

Advanced EMI Systems Detection and Classification Performance Was Tested at Live UXO Sites.

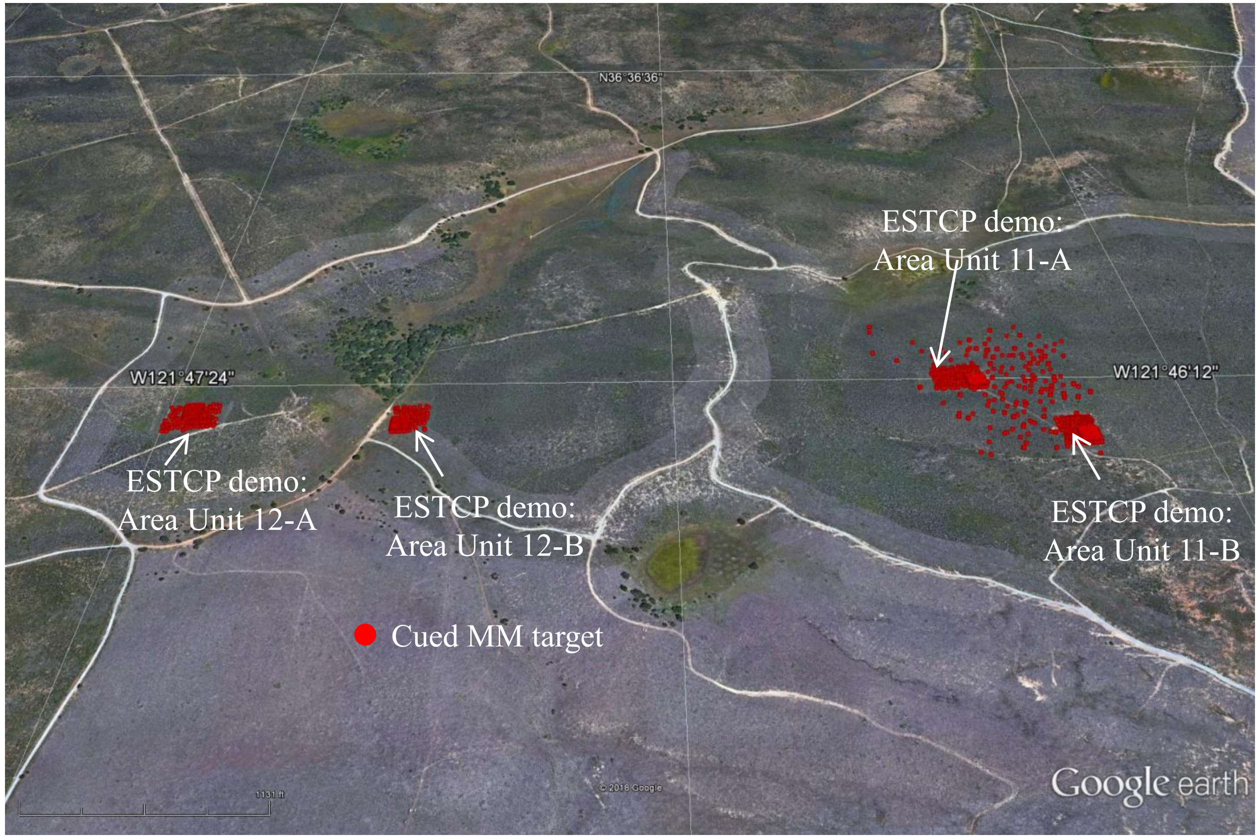


Live UXO Sites

Fort Bliss, TX

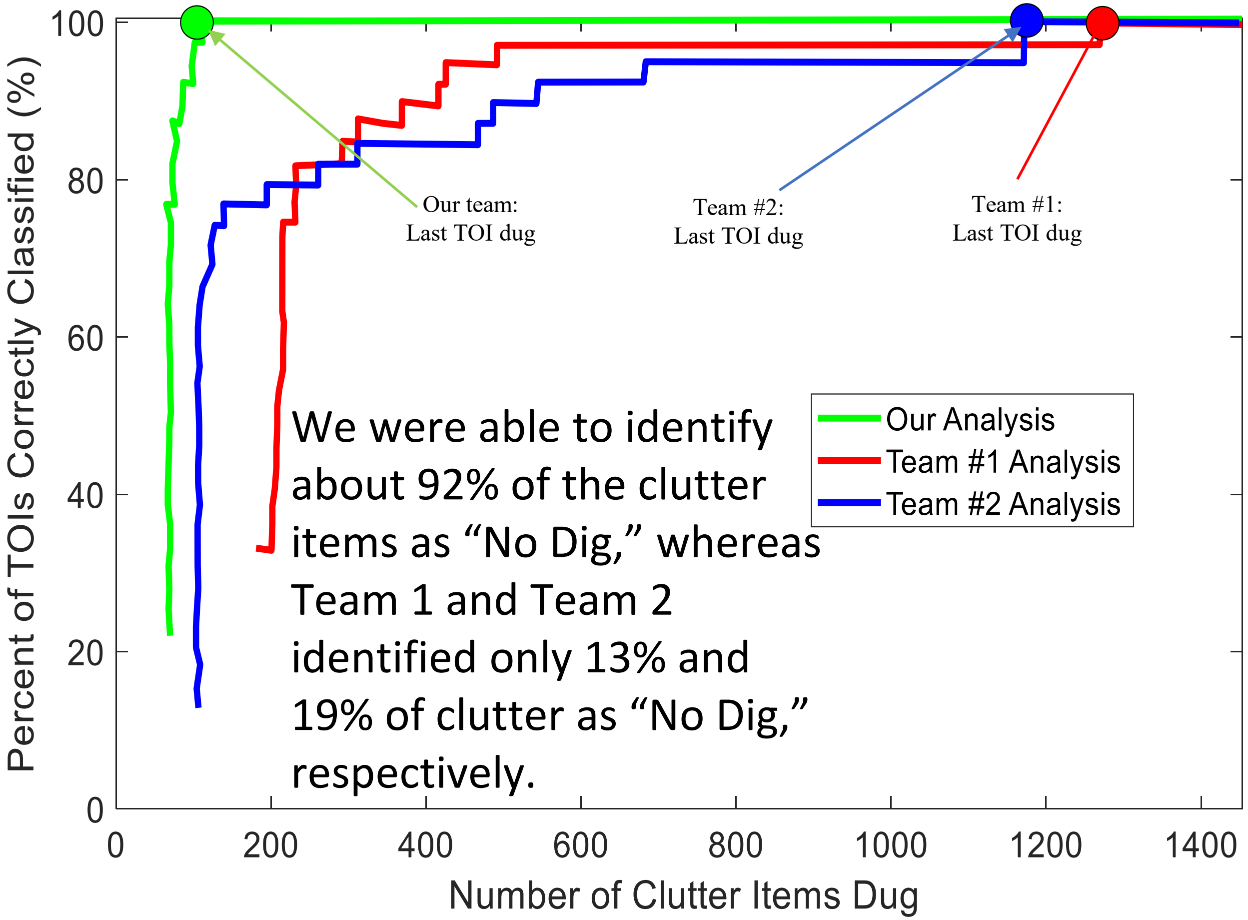


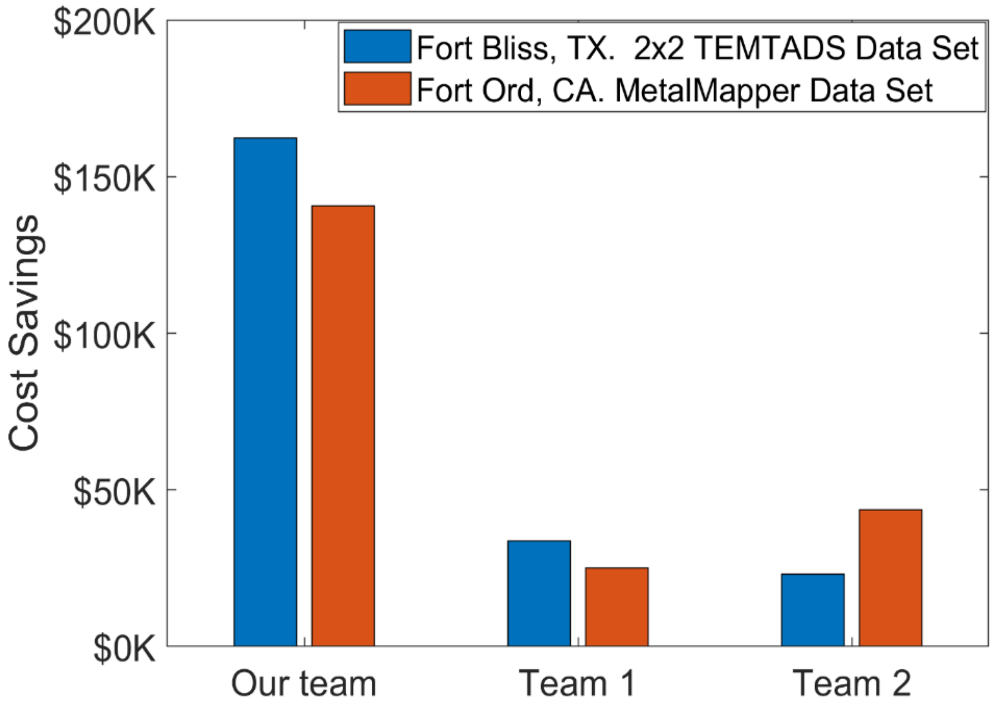
Fort Ord, CA



Courtesy: https://www.serdp-estcp.org/Program-Areas/Munitions-Response

Comparisons Between Classification Results

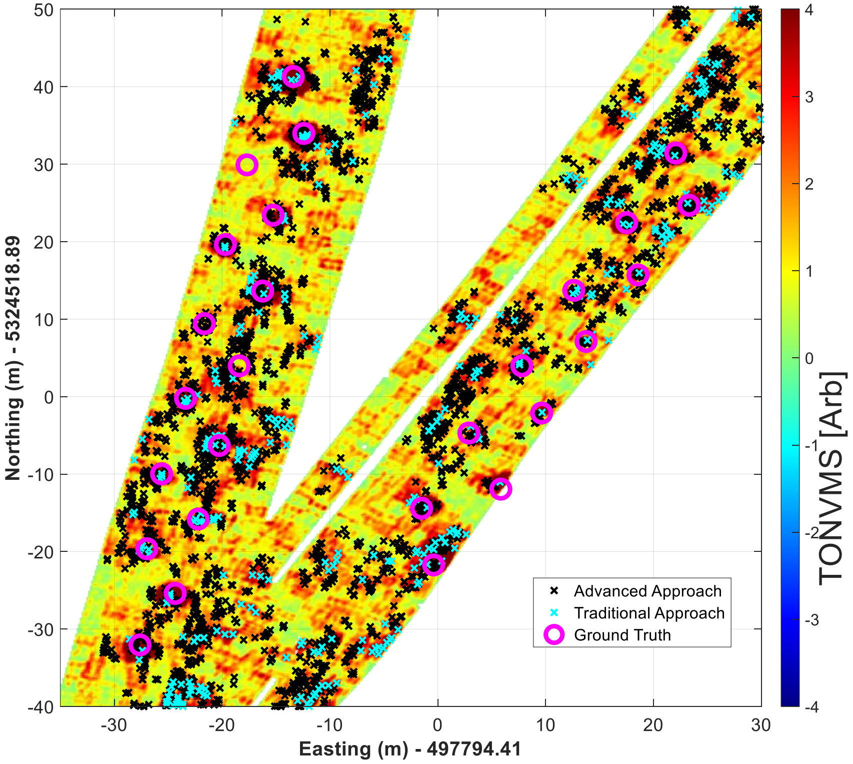




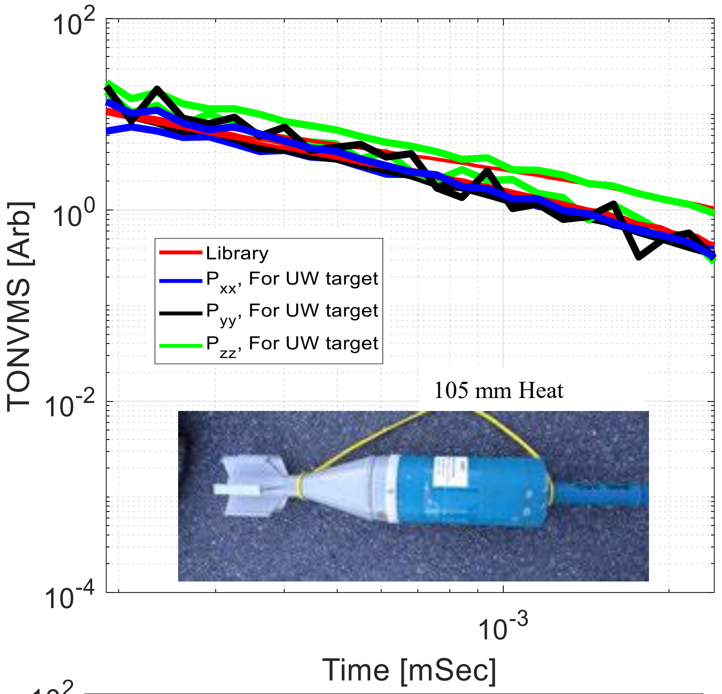
Underwater Targets Detection and Classification

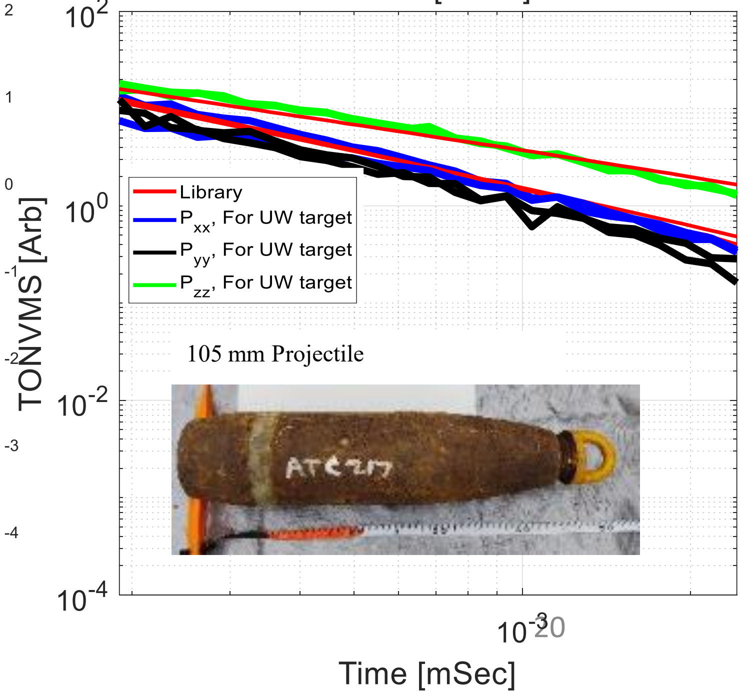
Test Area

Detection Map



Extracted Effective Polarizabilities

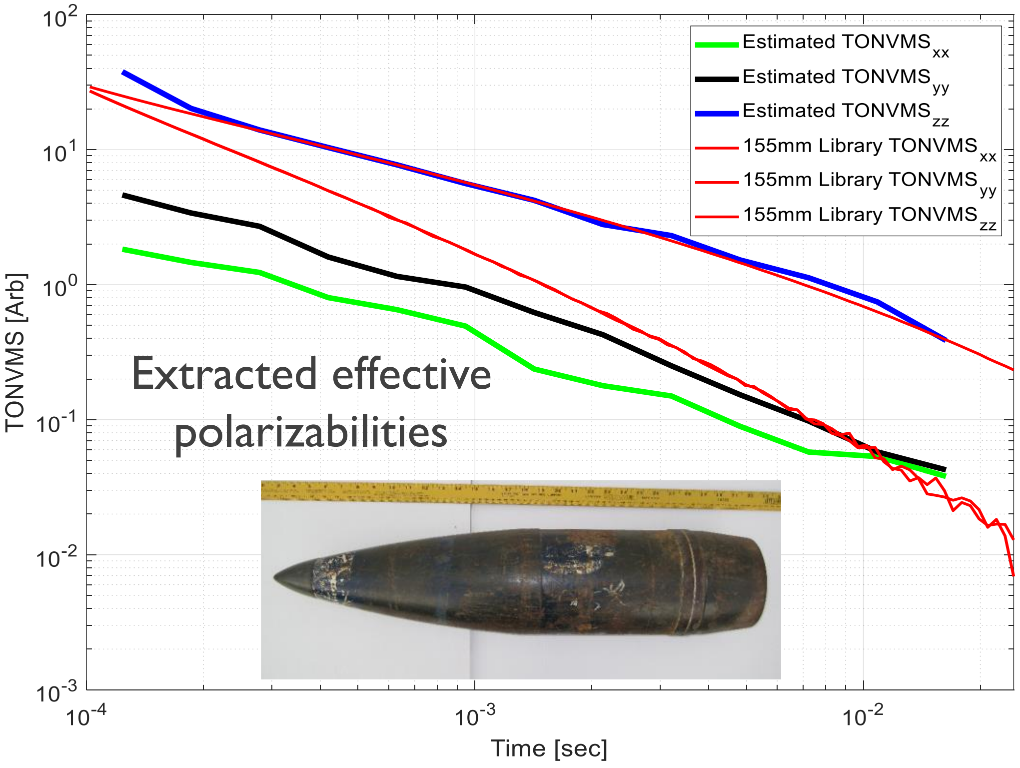




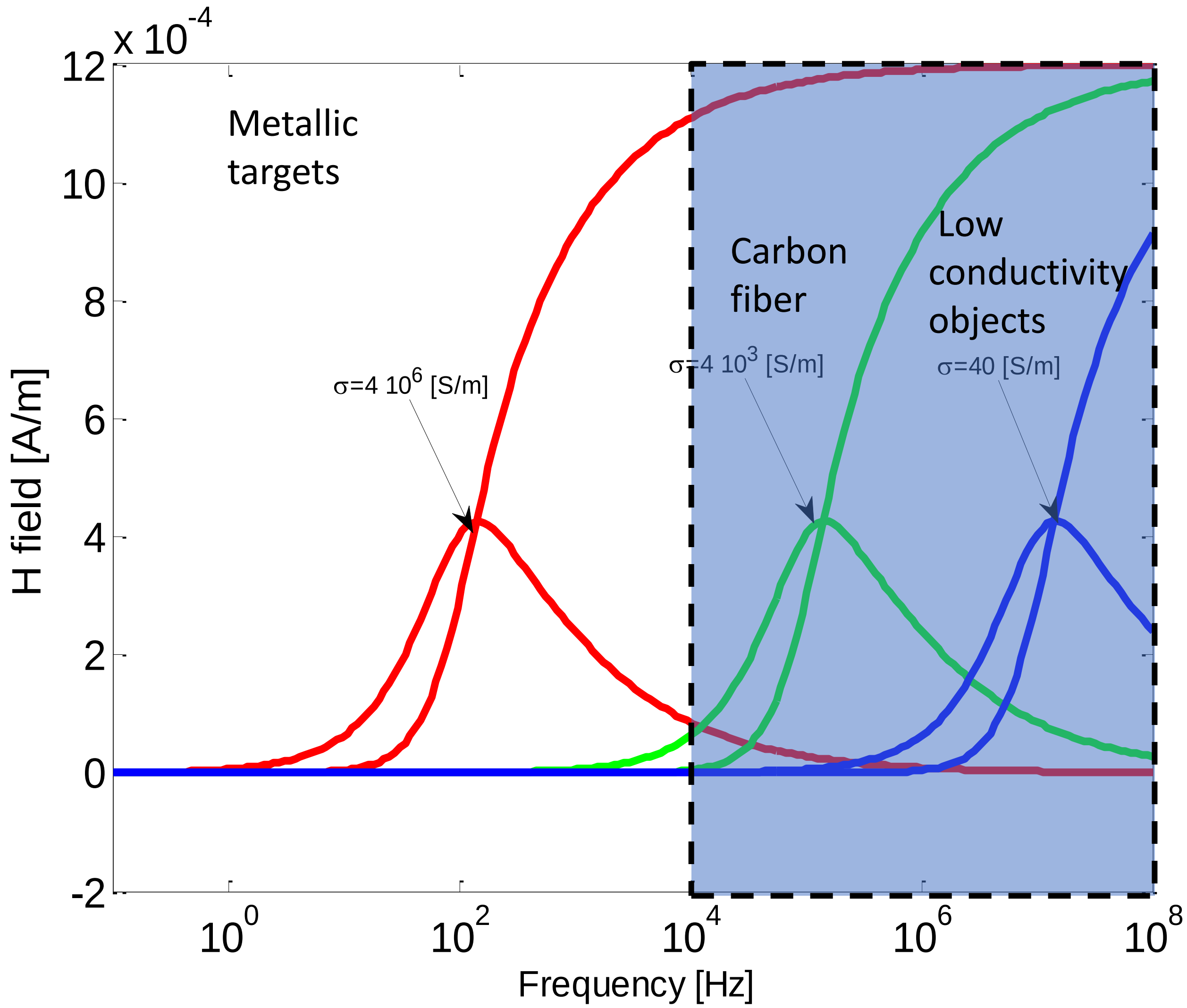
UAS-Based Detection and Classification Technologies

Data Collection

Targets Classification

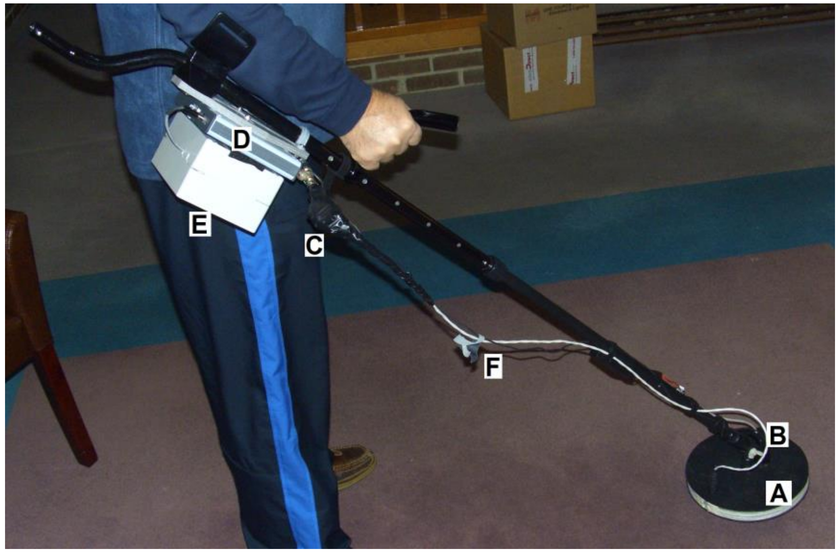


High-Frequency EMI Sensing for Intermediate- and Low-Conducting Targets



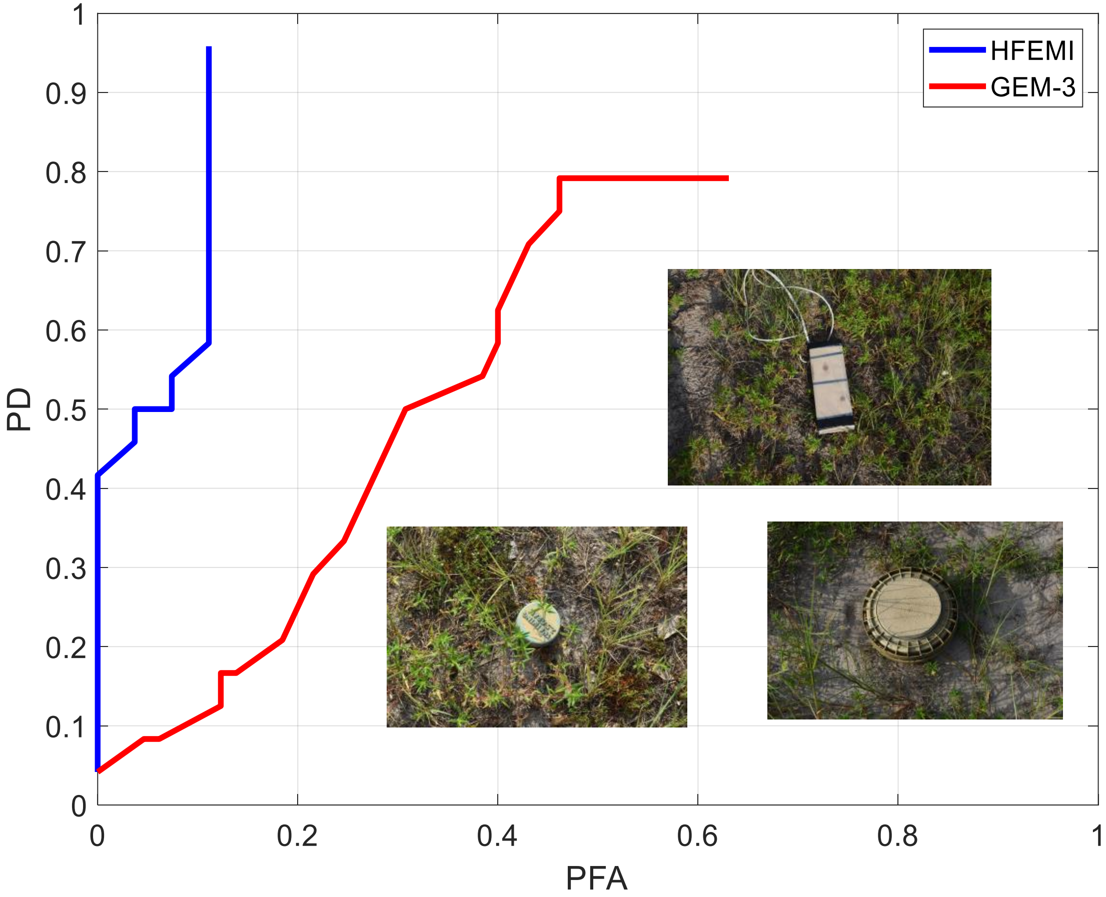
- Carbon fibers and void are undetectable by traditional EMI systems.
- HFEMI sensors are needed.
- Response is unique to the target.

HFEMI System

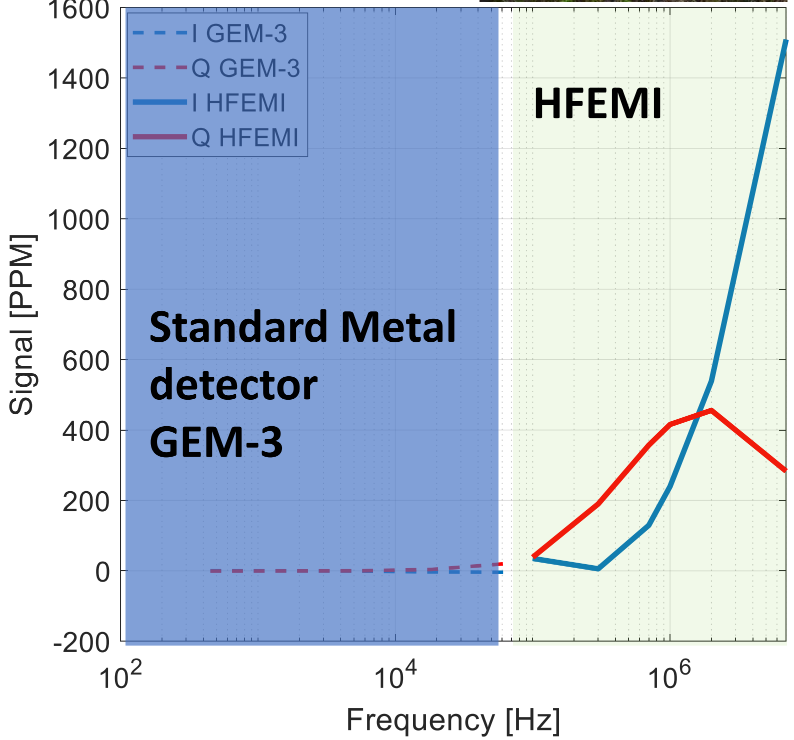


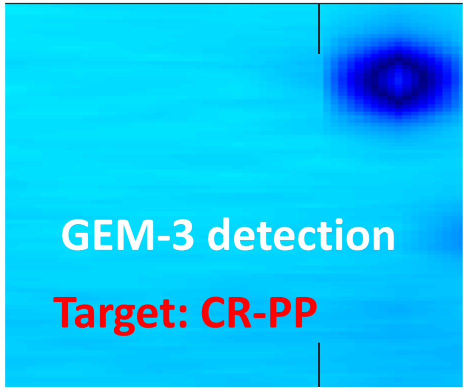
A. Search head with transmit (TX), bucking (BX), and receive (RX) coils.
B. Custom 2-stage preamplifier board.
C. Impedance matching transformer to replace the linear amplifier.
D. PicoScope 5000 to generate TX output and receive RX and reference signals.
E. Custom power supply box with Li-ion batteries.
F. Connecting cables.
G. The system shown weighs approx. 5 pounds.

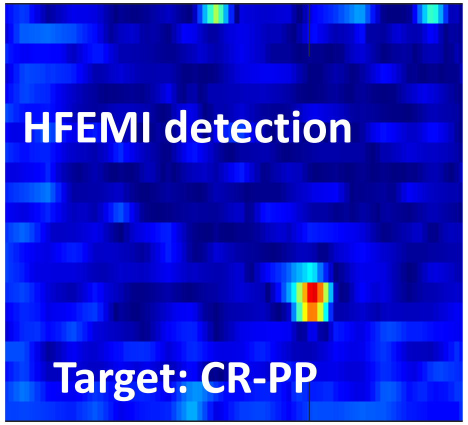
ROC: Standard Metal Detector (GEM-3) vs. HFEMI



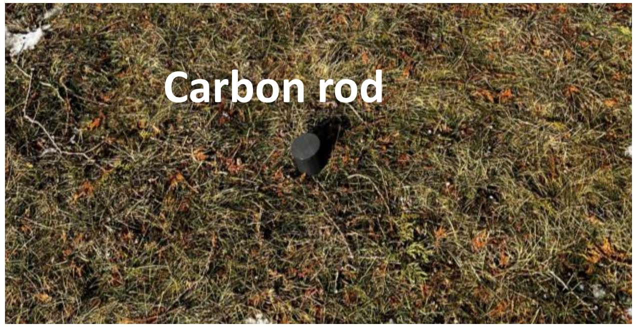
Carbon Rod PP Detection GEM vs. HFEMI

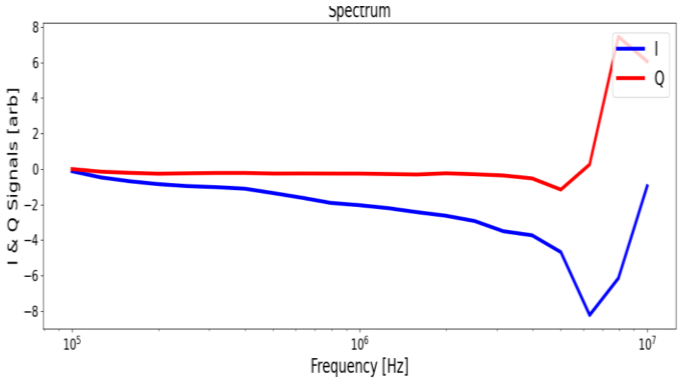






Recent Developments





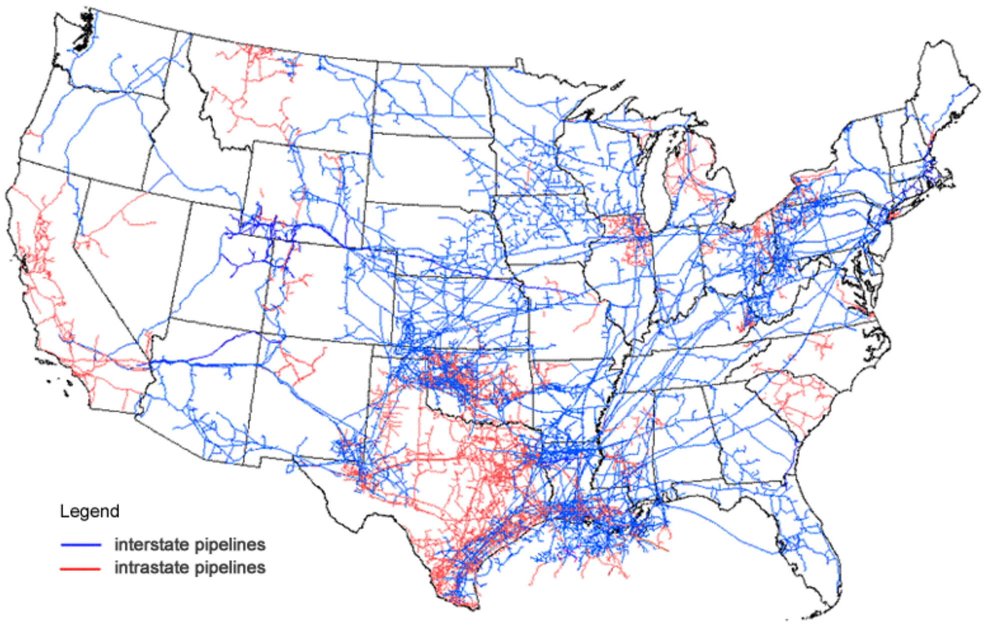
EMI Systems for Underground Infrastructure Detection and Mapping

- Detecting and locating underground utility pipes and wires are needed.
- By estimate, there are more than 35 million miles of underground utilities in the United States alone.
- Identifying deep and long underground wires and pipes is a difficult problem.
  - ➢ Magnetic
  - ➢ Traditional EMI
  - ➢ GPR
  - ➢ Acoustic

  Are used for detecting pipes

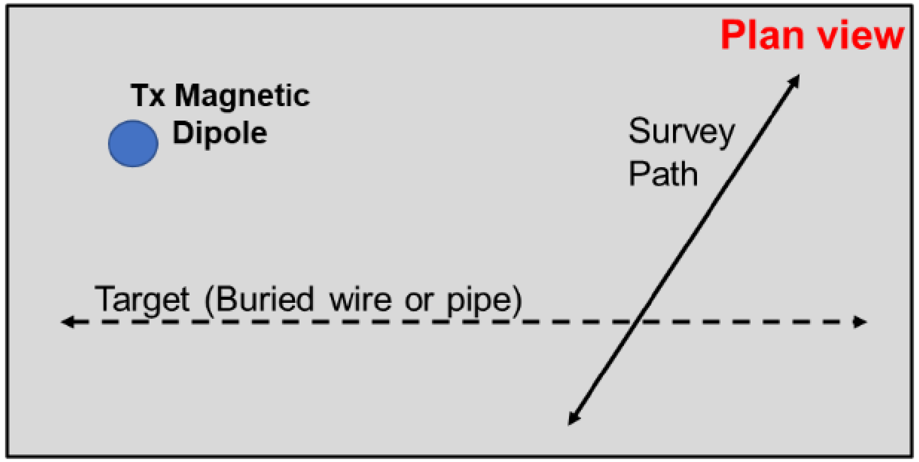
We are pursuing a new linear, electric current source-sensing method .

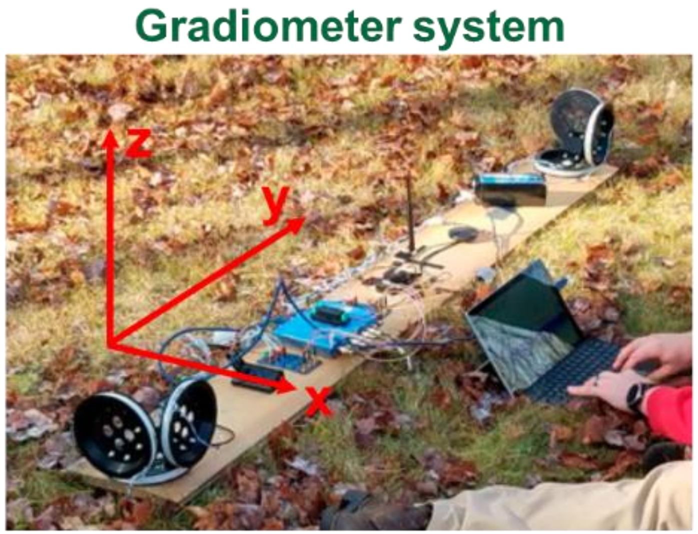
Map of U.S. interstate and intrastate natural gas pipelines



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

Linear Current Source Sensing (LCSS)





CONOPs:

- Magnetic dipole Tx excites electric currents along target.
- Current scatters and E&H field.
- Gradiometer is carried along survey line.
- Measures H field.
- Signal is inverted to determine depth.

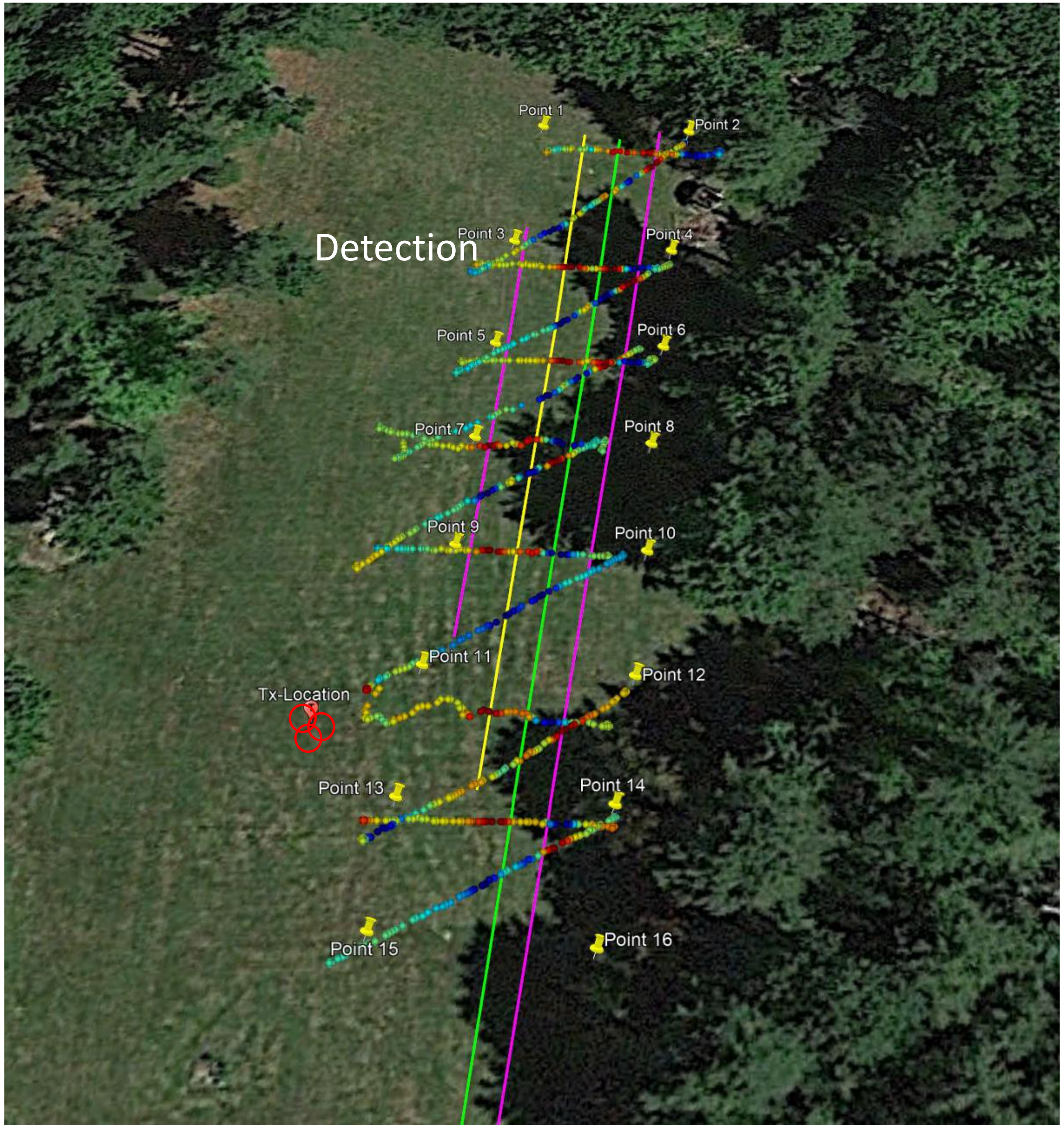
Triaxial Gradiometer:

- 6 receive coils: 2 groups of three measuring x, y, z components of H field.
- 20 windings each.
- Digitized at 10 MSps.

Wire Detection and Mapping

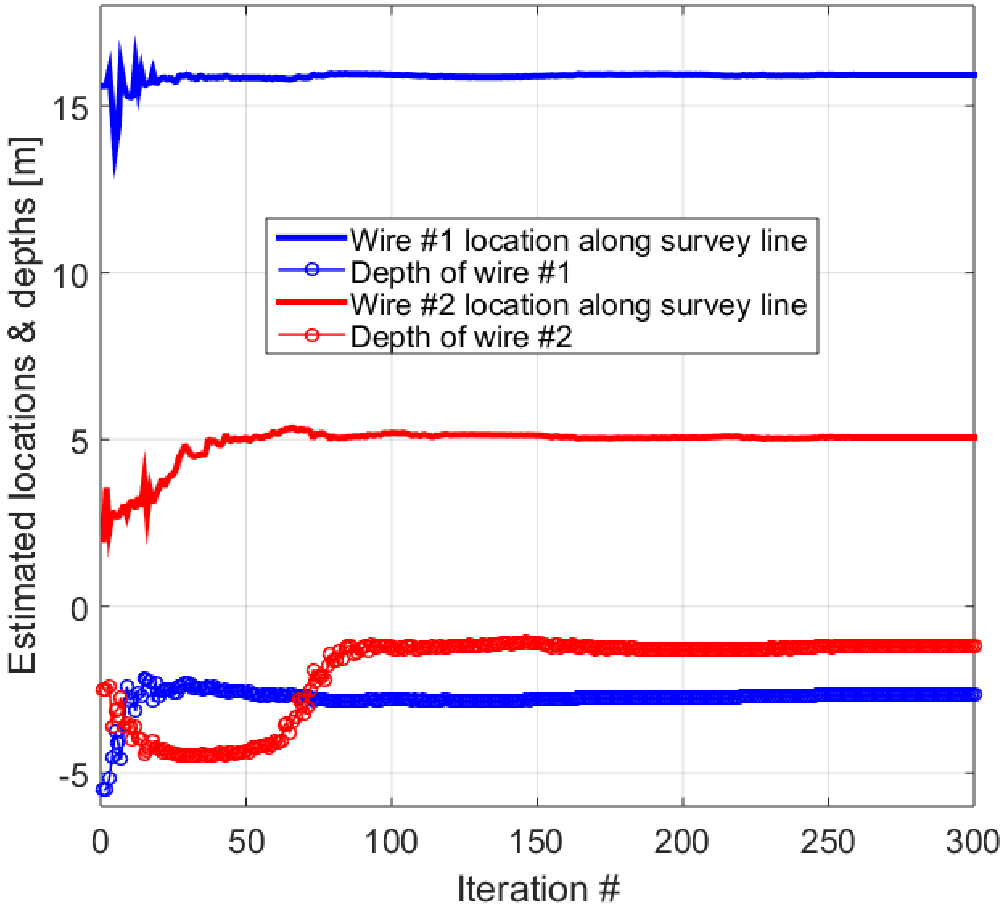
Triaxial Gradiometer

PC for Real-Tme Display



Subsurface Wires Detection

Overhead view of a test site for two subsurface wires



Two wires inverted depths and orientations vs. iteration number

iFROST Mapper

- Current ground surveying methods are slow/expensive to characterize permafrost ice content, detect seasonal frost depth, and quantify subsurface moisture conditions.
- There is a need for developing an In-Flight Rapid Observation & Surveying Tool for Ground Ice Mapping (iFROST Mapper).
- Rapid ground surveying tool enables rapid site selection for construction (avoid expensive to construct ground conditions).

FD EMI Sensor – for ground conductivity/ resistivity mapping (0-10 m deep)