REMOTE SENSING OF SUBSURFACE ELECTROMAGNETICALLY PENETRABLE OBJECTS

LANDMINE AND IMPROVISED EXPLOSIVE DEVICE DETECTION

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The Worldwide Landmine Problem

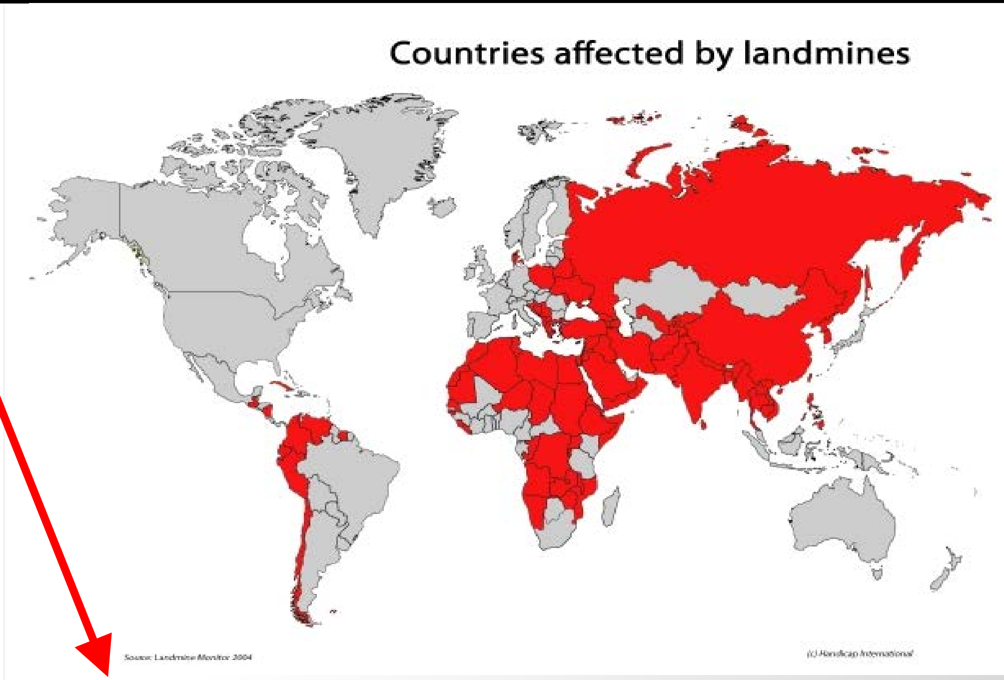
(1999-2008)	
Regions	**Casualties**
Africa	**33,627**
Asia-Pacific	**16,390**
Americas	**8,558**
Russia	**7,202**
Europe	**4,628**
Middle East and North Africa	**3,171**
Total	**73,576** [9]

Since 1975, more than **500,000** civilians (50% children) have been killed or maimed by landmines [8]

The Worldwide Landmine Problem

- ➔ Tens of millions of live mines remain buried in ***70 countries***
  - ◆ Most of these countries make up ⅔ of the world's poorest nations [8]
  - ◆ Removal costs: **$300–$1000 per mine** [11] Cheap removal is extremely important
- ➔ Solution:

SUBSURFACE SENSING

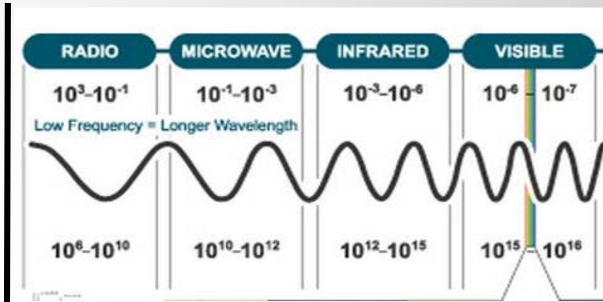


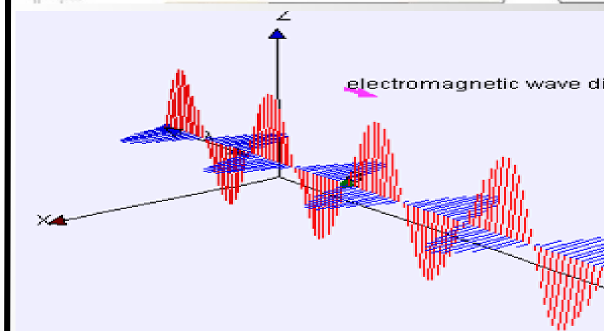
Afghanistan 10,000,000; Angola 15,000,000; Azerbaijan 100,000; Bosnia and Herzegovina 3,000,000; Cambodia 6,000,000; Chad 70,000; China 10,000,000; Croatia 3,000,000, Cyprus 16,942, Denmark 9,900, Ecuador 60,000, Egypt 23,000,000, El Salvador 10,000; Eritrea 1,000,000; Ethiopia 500,000, Falklands Islands (Malvinas) 25,000; Georgia 150,000l Guatemala 1,500l Honduras 35,000 Iran, Islamic Republic of 16,000,000 Iraq 10,000,000 Korea, Republic of 206,193 Latvia 17,000 Lebanon 8,795 Liberia 18,250 Mozambique 3,000,000 Namibia 50,000 Nicaragua 108,297 Rwanda 250,000 Somalia 1,000,000 Sudan 1,000,000 Ukraine 1,000,000 Viet Nam 3,500,000 Yemen 100,000

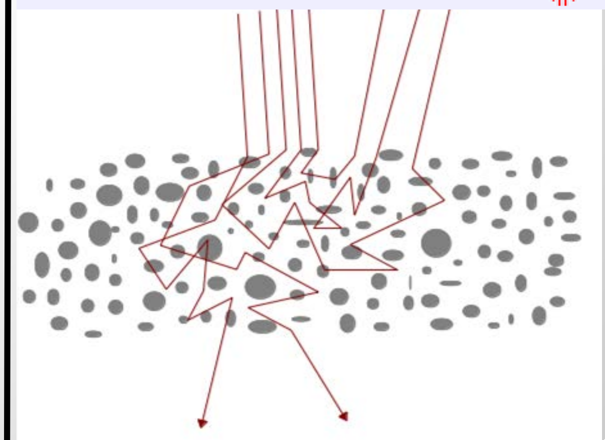
[10]

Subsurface Sensing

- ***Detecting*** and ***identifying*** underground objects
- Transmission, **Scattering**, & Absorption of **Electromagnetic Waves (EMW)**
  - Scattering dependent on *microphysical properties* of individual materials involved
    - ex: landmines, soil, air
    - relative permittivity, permeability, conductivity
  - **Radio waves**: longer waves = optimal detection wavelength for landmine sizes; greater scattering effects





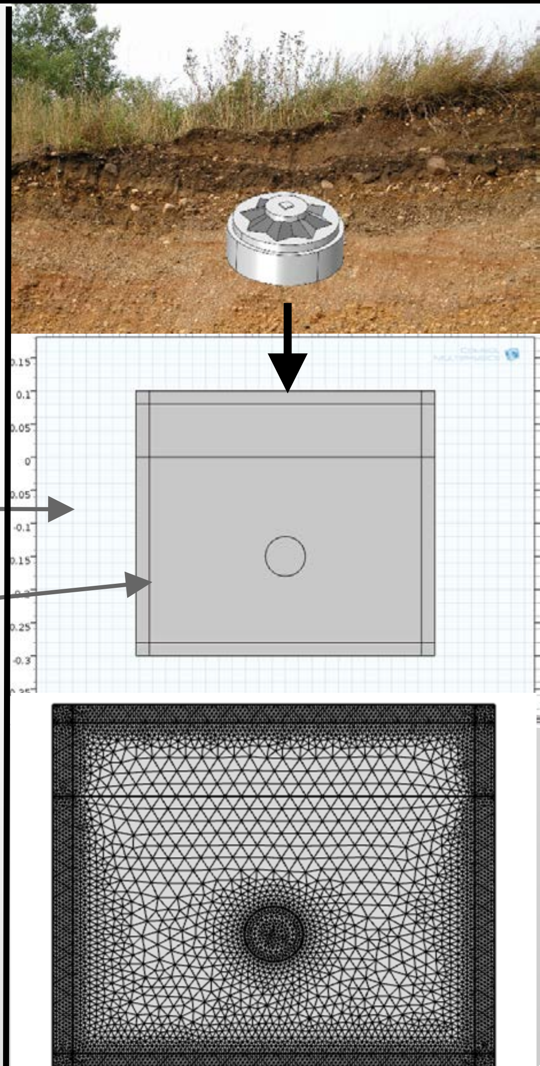


Simulating the Real World Problem in COMSOL Software

Comsol Multiphysics Software allows modal creation and an accurate *computational simulation* of a subsurface sensing scenario

Sequence of Simulation Creation

- Geometry Creation }
- Defining Materials
- Defining Boundaries
- Meshing
- Specify Solver Equations
- Post Processing



Real Problem for Simulation

- Landmines can be embedded under many layers of the ground
- Deminers can not accurately know which layer the mine lies in or what the layers are made of
  - wet soil, dry soil...
- Simulating all situations > **TEMPLATE**

Distinguishing Landmines from Other Anomalies

Average Specifications

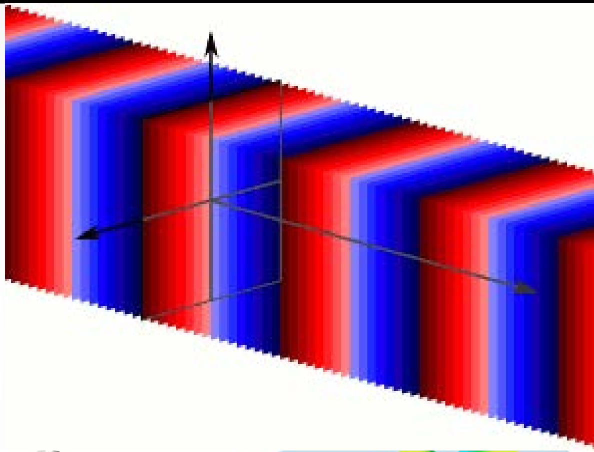
- Diameter: 20-125 mm
- Length: 50-100 mm
- Weigh as little as 30g
- Buried Shallowly
- Various shapes

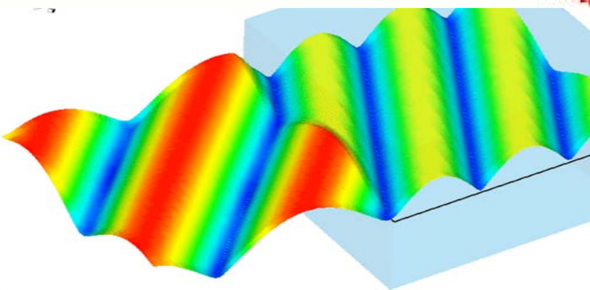
Specific Microphysical Properties

Material	Relative permittivity	Relative permeability	Conductivity
Air	1	1	0
Dry Soil	2.9	1273+31i	0.004
Wet Soil	4	1756+395i	0.049
TNT/IED Composition	2.86	1256+2.26i	2.86e-4

EM Wave Physics Equations for Simulation

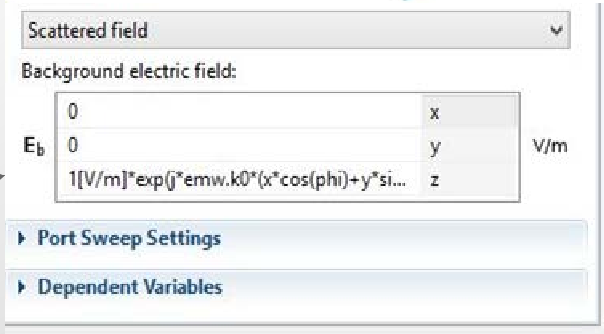
- **Plane Waves**
  - Simple 2D wave propagating in one direction
  - No variation in the Z direction and EM field
  - Propagates in the model x-y plane
- Described Using the **Plane Wave Equation**
  - This defines the plane wave's propagation
    - a linearly polarized plane wave traveling parallel to the y-axis





E= Electric field
E_0 = Incident Electric Field
i = complex numbers
k = propagation constant
r = position vector

$$E_o = \left(0, 0, e^{ik_0 y}\right)$$

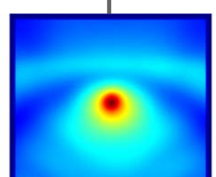


Scattering Physics for Simulation

Computing Scattering

- **Helmholtz Equation**
  - solves for individual scattering of waves based on the initial wave as well as the electromagnetic properties of the materials in the simulation

$$\nabla^2\vec{E} + \mu_r\mu_0\varepsilon_c\omega^2\vec{E} = 0$$



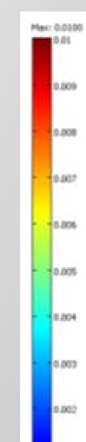
Measuring Scattering

- **Radar Cross Section (RCS)**
  - represents the emw scattering results from Helmholtz Equation
- **Scattering Width Equation**
  - the RCS per unit length- Results

$$\sigma_{2D} = \lim_{\rho\to\infty}\left[\frac{|E_s|^2}{|E_i|^2}\right]$$

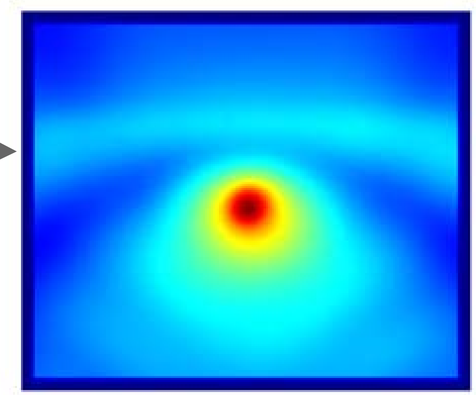
ρ = distance from target to observation point

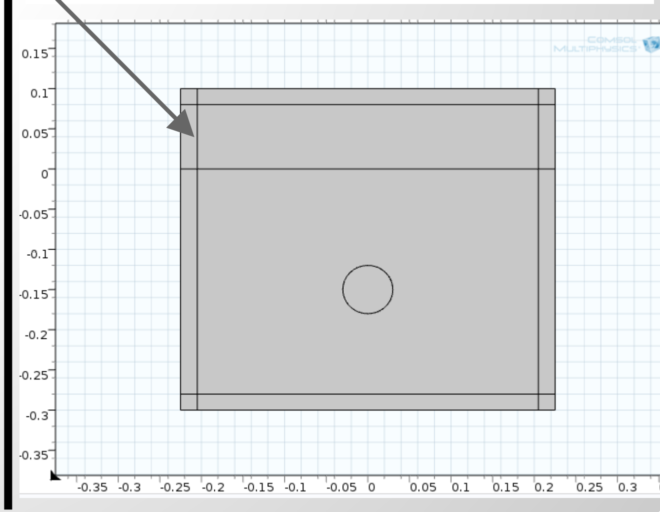
Ei and Es - incident and scattered electric field



Reabsorbing Boundary Condition Physics in COMSOL

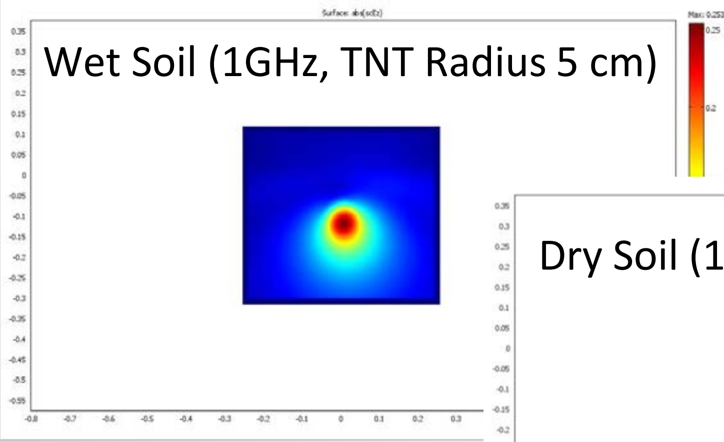
- **Absorbing Boundary Conditions**
  - non perfect absorbing layer
- Improved Results with **Perfectly Matched Layers** (PMLs)-
  - Artificial absorbing *domains*
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb scattered waves to eliminate reflection that causes interference
  - Size matched to wavelength

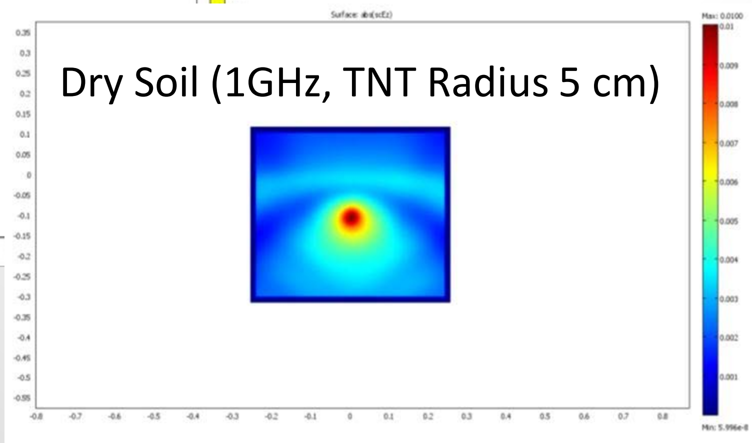


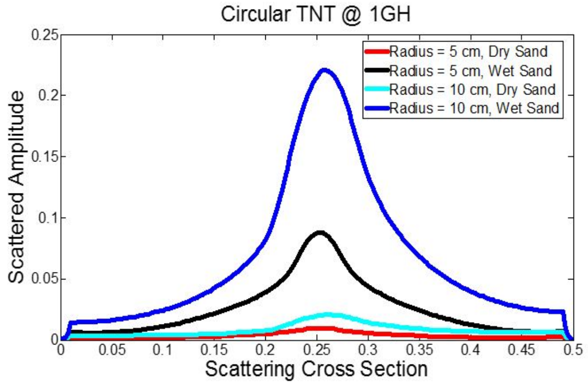


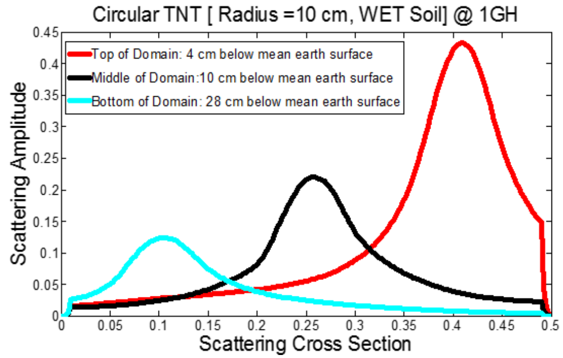
Results and Discussion

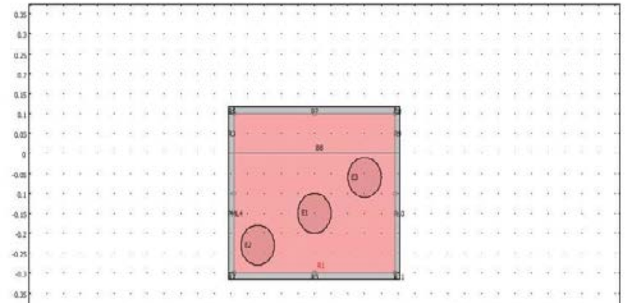
- Main independant varibales:
  - Size of Mine (radius)
  - Depth Buried
  - Soil Type and Layer Variations
  - Frequency



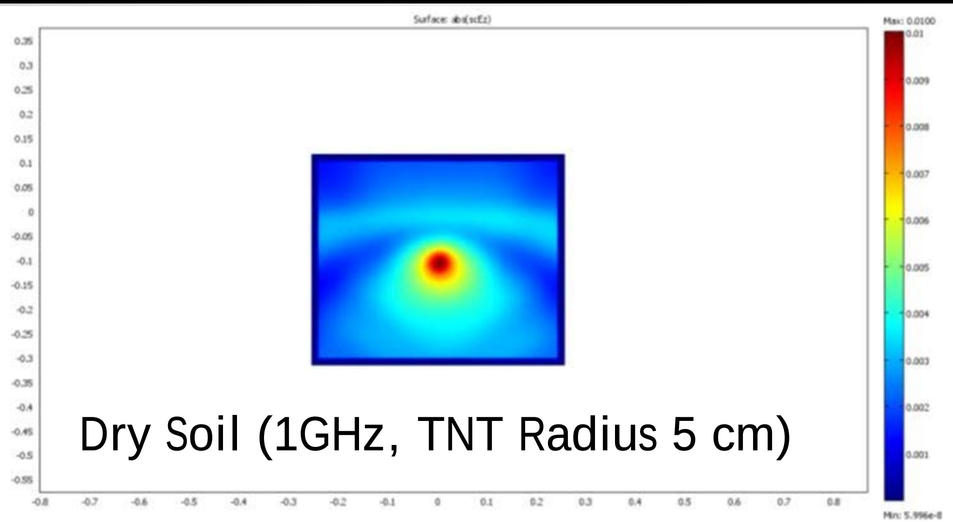


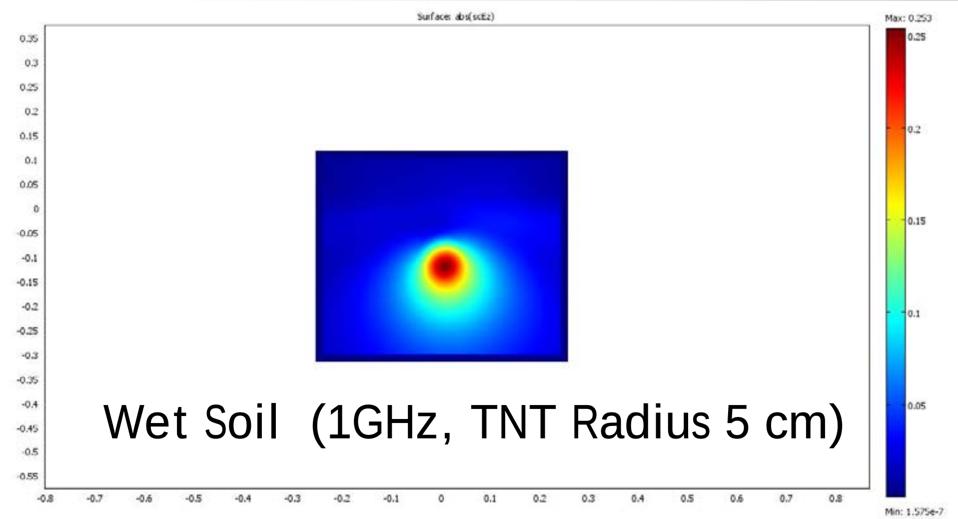






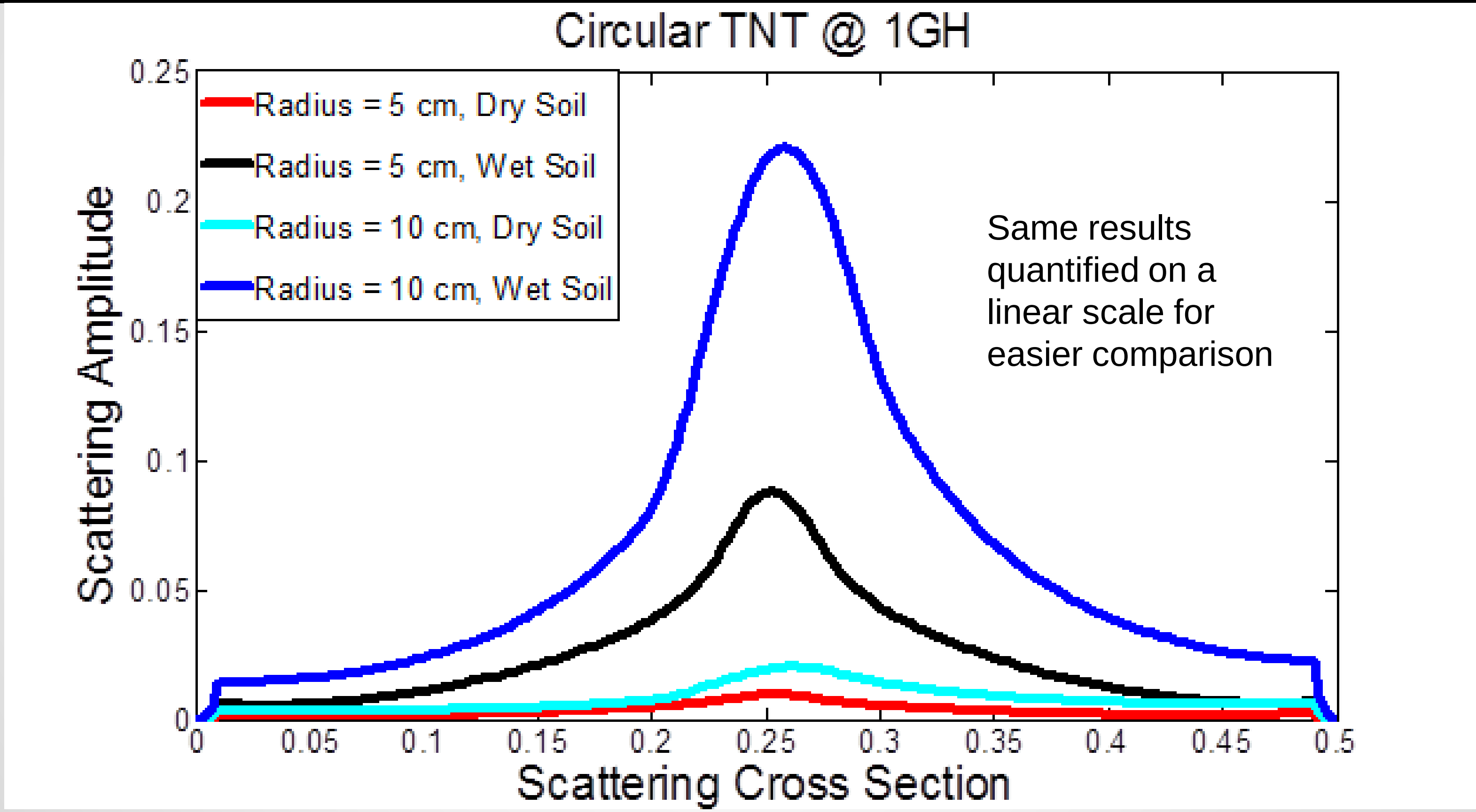
Dry and Wet Soil Type Results





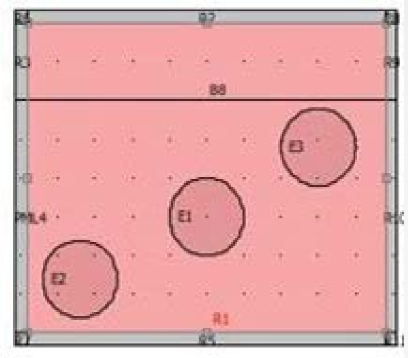
- Wet soil is more conducive to target scattering than dry soil due to its **higher conductivity** as a product of it’s *higher water concentration*
    - The higher conductivity allows the wave to stay in the medium and interfere more with the target object than the medium itself

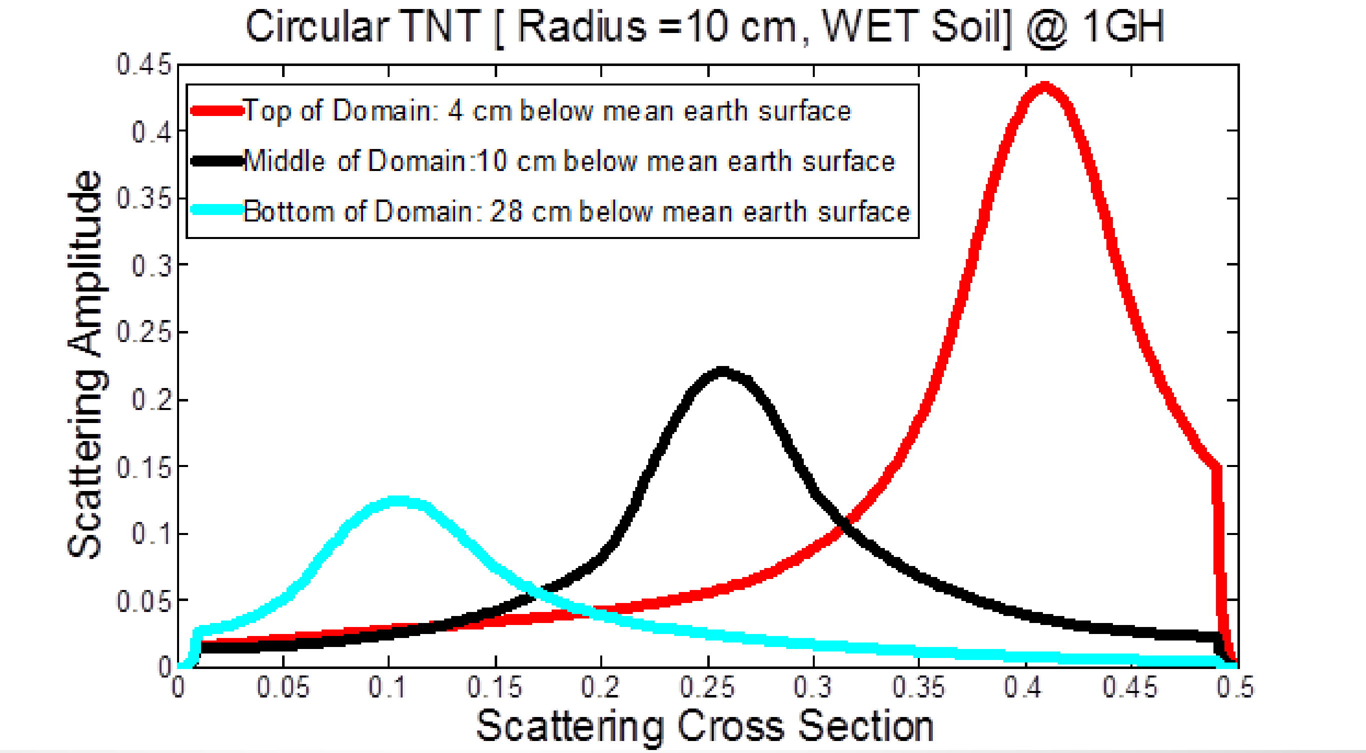
Sizes Results



- Size of landmine directly correlates to the amount of scattering (less scattering= small object = not a mine)

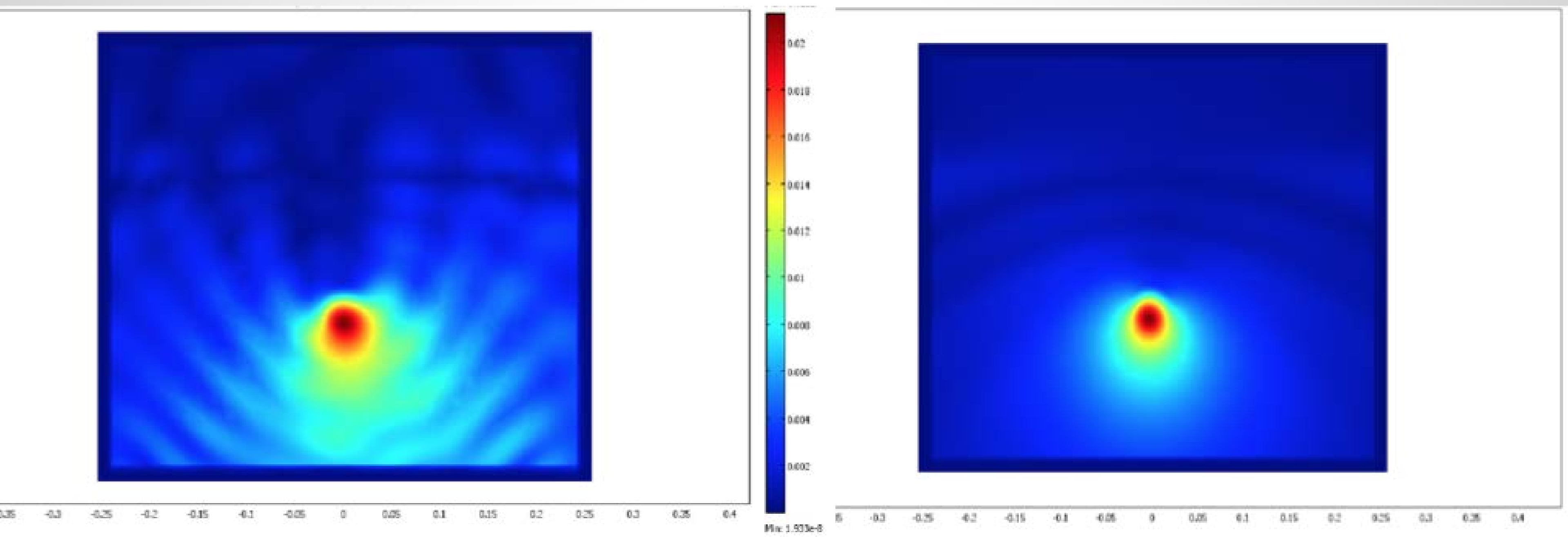
Depth Variation Results





- TNT from higher up in the domain produces the highest amplitude of scattered waves and is most easily detected (landmines buried shallowly)

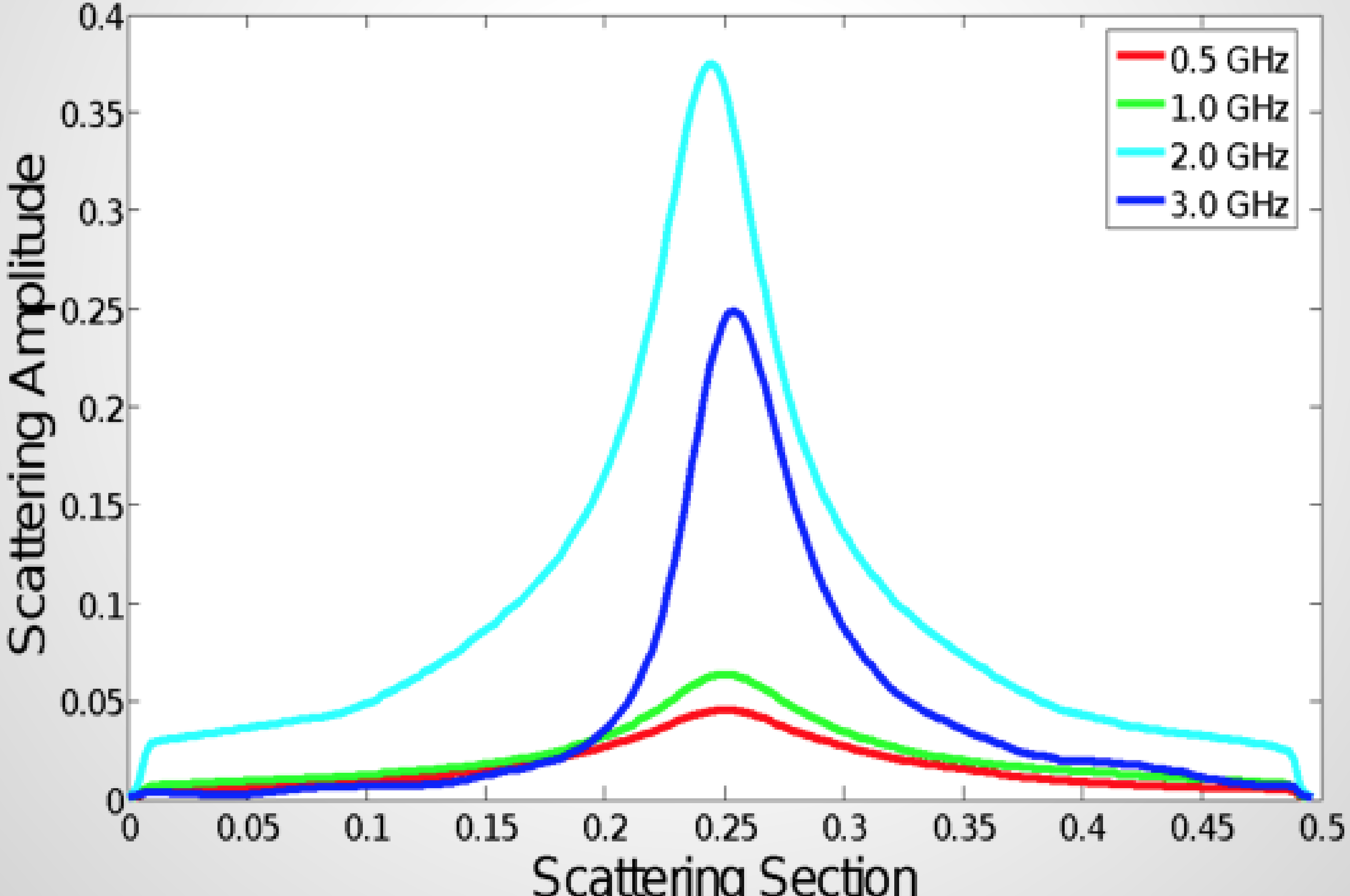
Soil Layer Scattering Amplitudes Comparison



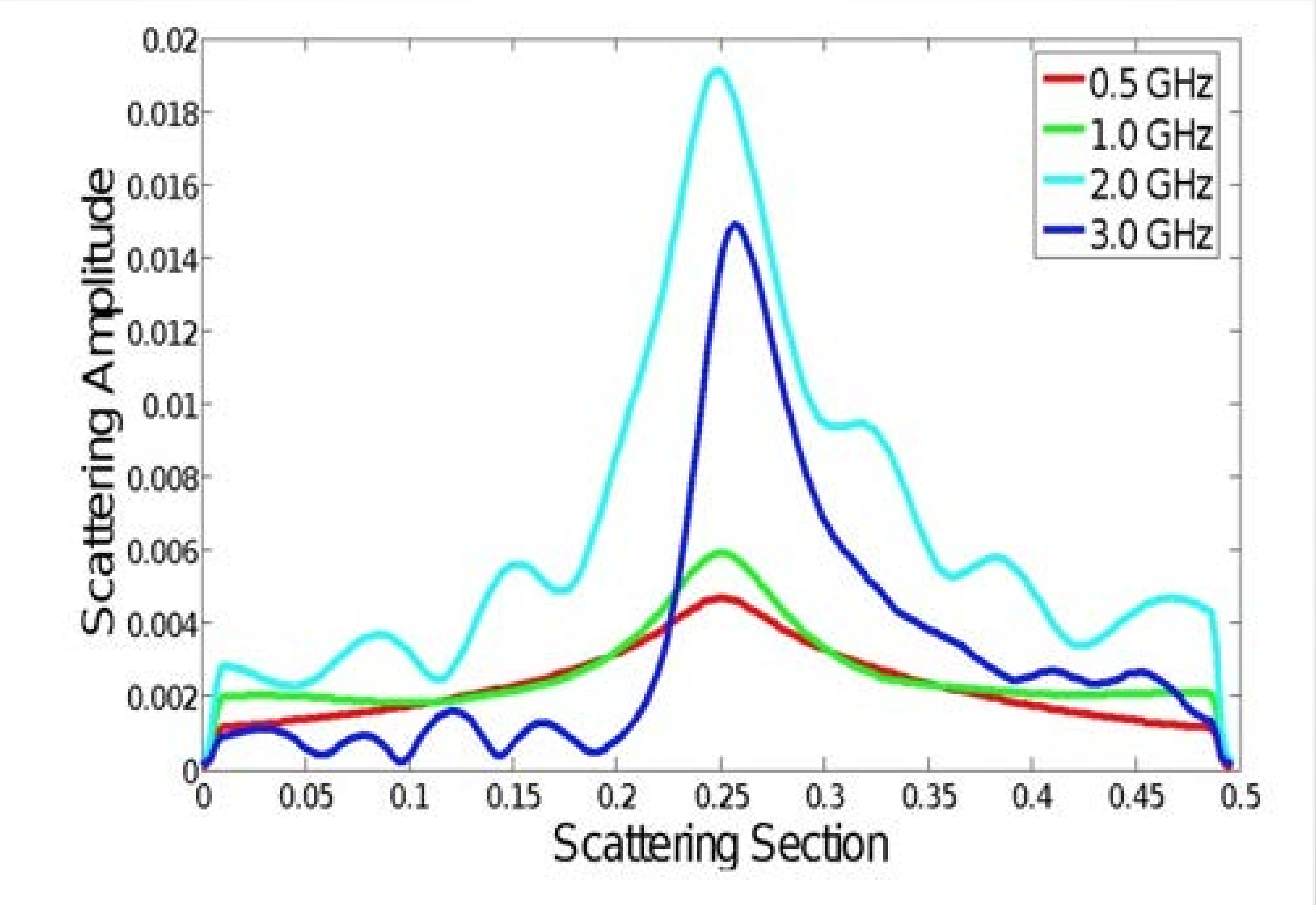
Air/Wet/Dry Soil Scattering
(1GHz, TNT Radius 5 cm)

Air/Dry/Wet Soil Scattering
(1GHz, TNT Radius 5 cm)

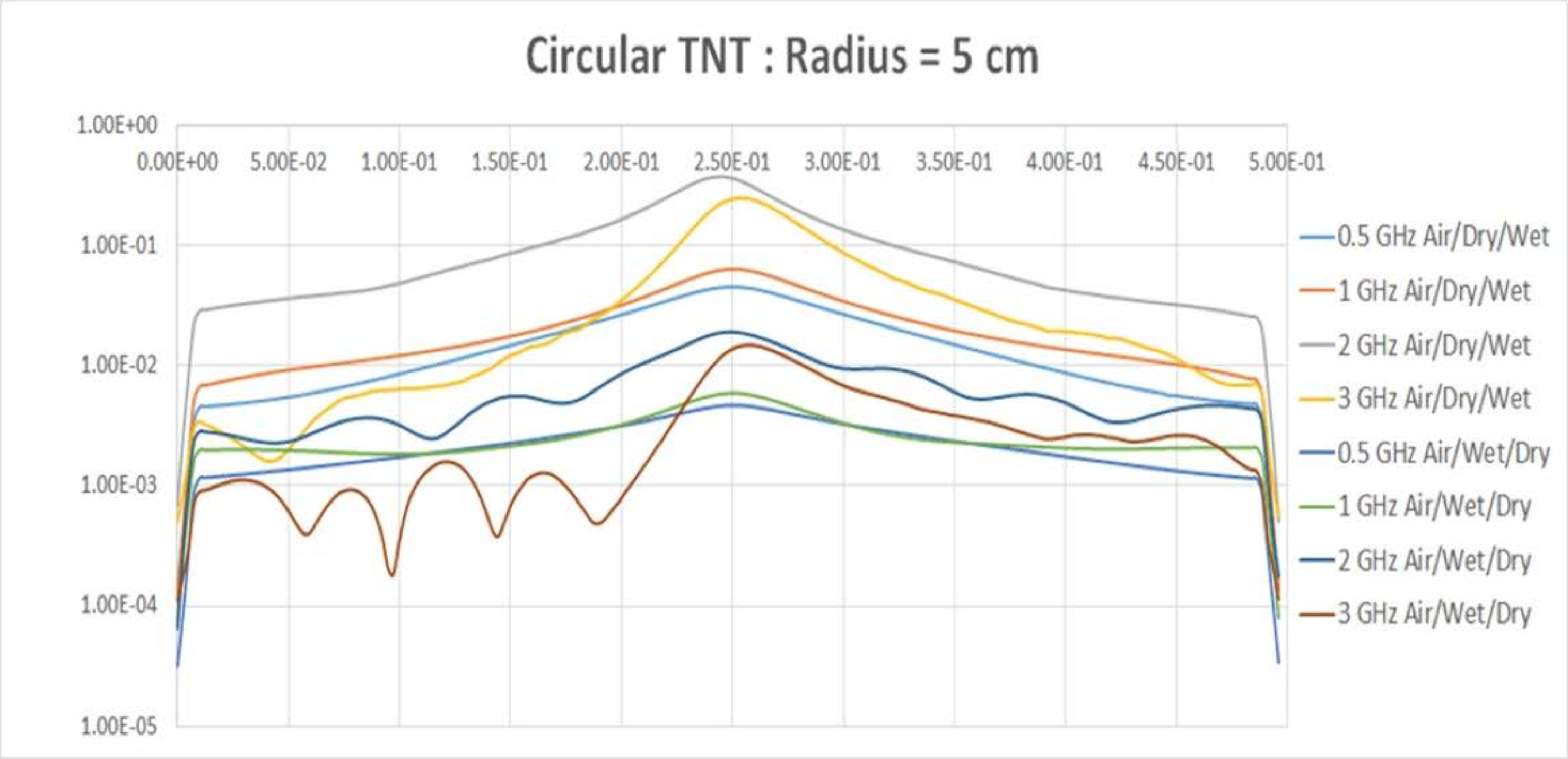
Parametric Study-
Air/Dry/Wet Soil Layers



Parametric Study- Air/Wet/Dry Soil Layers



Parametric Study- Wavelengths & Soil Layers



CONCLUSION

- Successfully developed a template of various variations that may affect subsurface sensing of landmines in real world Ground Penetrating Radar situations
  - The template can also be applied to other sub-surface imaging problems with similar variations
- Future research and goals
  - Test variables of
    - other compositions of soil (clay, sand, silt)
    - different explosive types (RDX, C4, tetryl etc.)
    - variations in surface roughness

References

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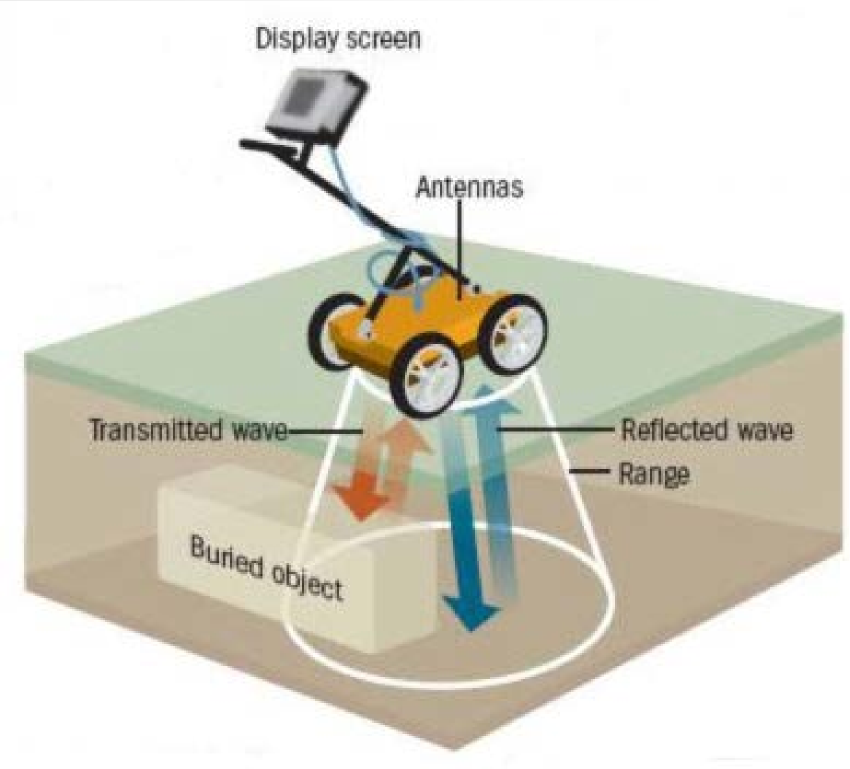
Thank You!

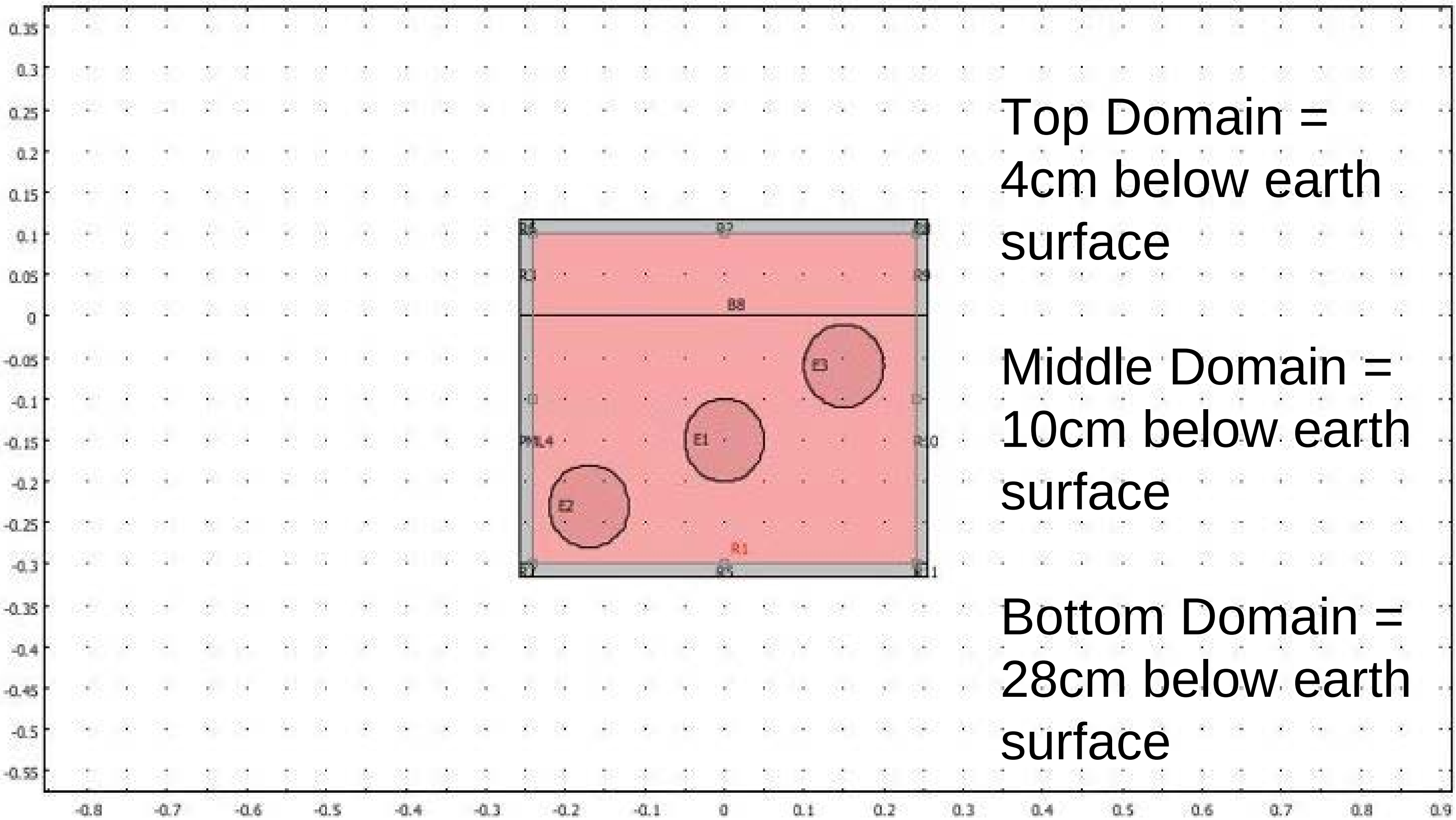
Boundary Condition Physics In Comsol

- Boundary conditions necessary to truncate numerical domain
- Scattering Boundary Conditions
  - The boundary condition is transparent for an incoming electromagnetic waves.
  - It allows it to pass through perfectly matched layer.
  - The boundary condition are also used when we want boundaries to be transparent for scattering electromagnetic waves.
- PML- not a boundary condition in reality
  - Artificial absorbing domains
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb all scattered waves to eliminate reflection that causes interference

Ground Penetrating Radar



Depth Variation Modeling



Top Domain = 4cm below earth surface

Middle Domain = 10cm below earth surface

Bottom Domain = 28cm below earth surface

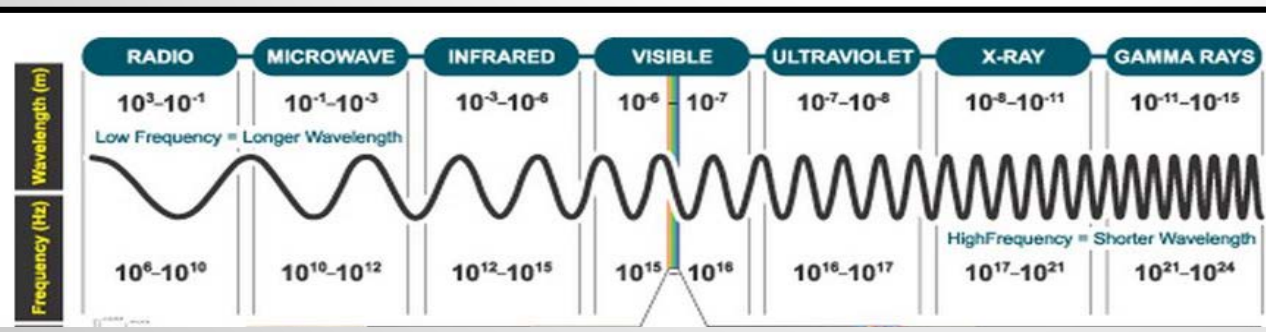
Electromagnetic Waves

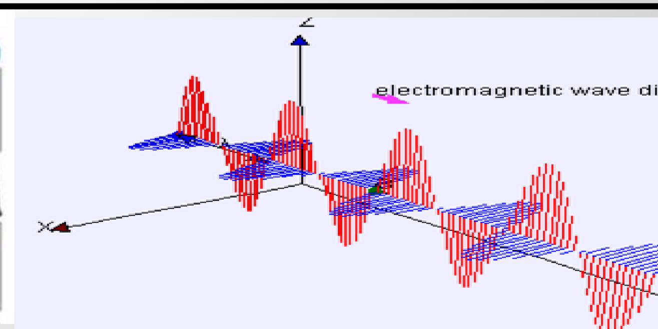
Electric and Magnetic field vectors propagating perpendicular to each other

Scattering dependent on microphysical properties of individual materials involved

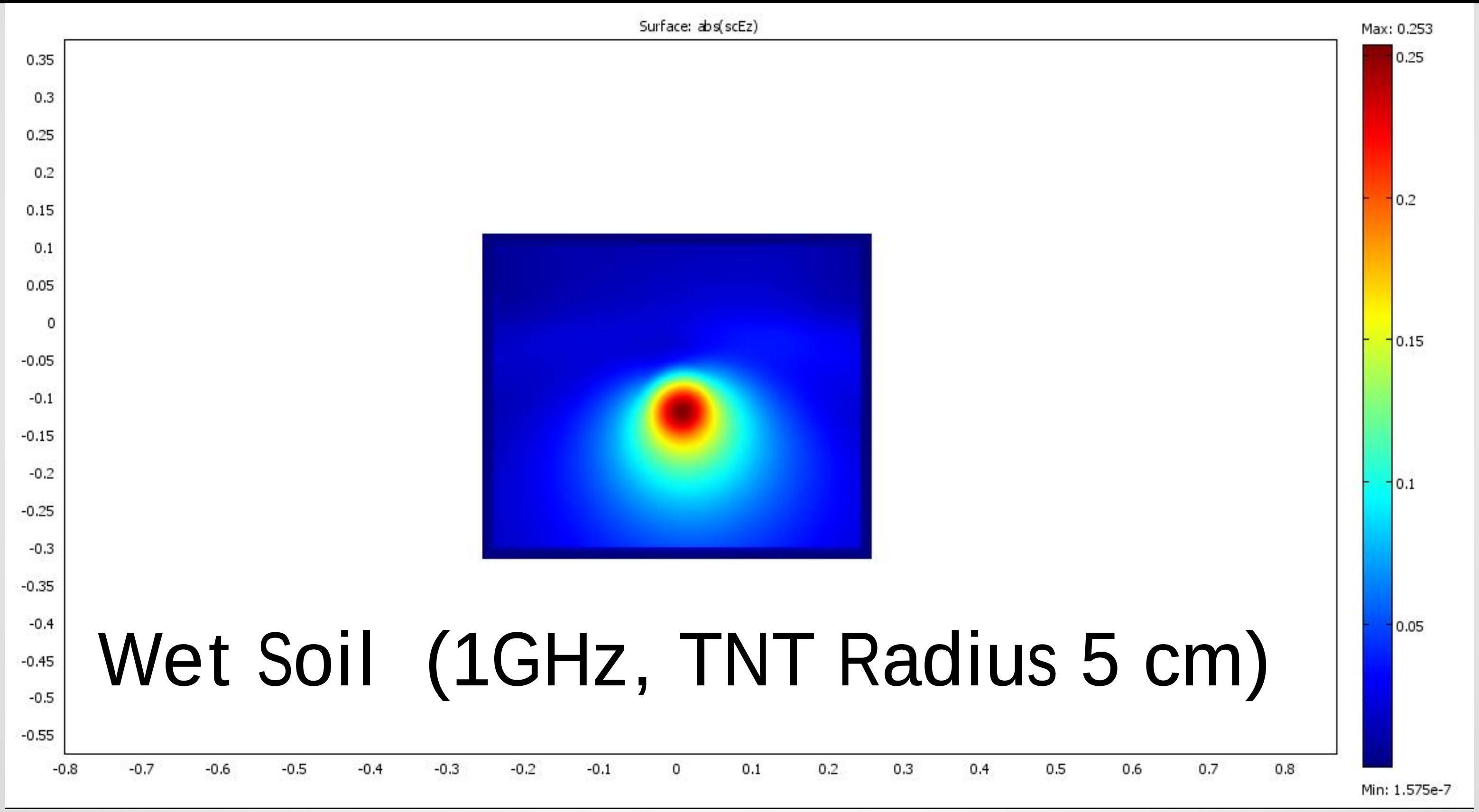
- ex: landmines, soil, air
- relative permittivity, permeability, conductivity

<u>Radio waves</u>: longer waves = optimal detection wavelength for landmine sizes





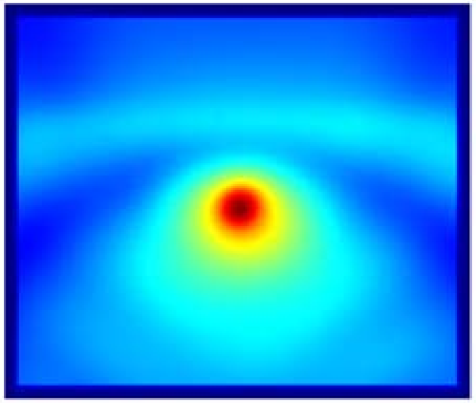
Wet Soil Type Results

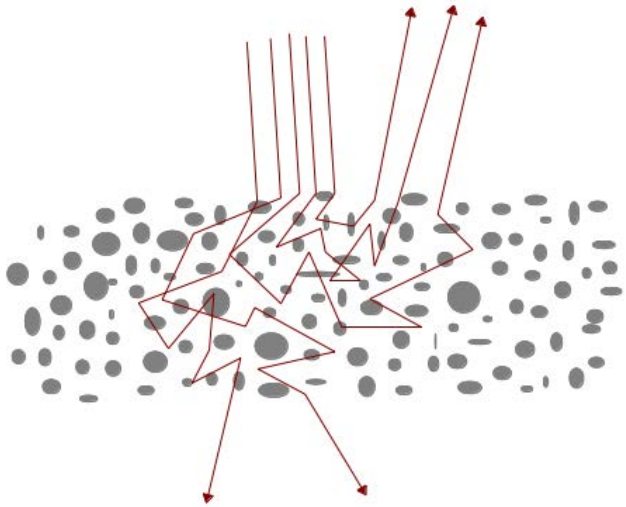


Wet soil is more conducive to target scattering due to the higher conductivity as a product of higher water concentration

Subsurface Sensing

- ***Detecting*** and ***identifying*** underground objects
- Transmission, Scattering, and Absorption of **Electromagnetic Waves (EMW)**
- **CenSSIS-** Center for Subsurface Sensing and Imaging Systems
  - biomedical, environmental, and geophysical problems
- Problem: distinguishing the effect that the medium has on the EM wave from that of the desired object





Thank You!

Microphysical Parameters of Materials

Material	Relative permittivity	Relative permeability	Conductivity
Air	439.2	1	0
Dry Soil	1273+31i	2.9	0.004
Wet Soil	1756+395i	4	0.049
TNT	2.9	1	4.8e-4

COMSOL

Comsol Finite Element Method Software allows modal creation and an accurate *computational simulation of real world problems*

- Easily allows editing and testing of various variables

Other Finite Element Packages

- PZFlex - www.pzflex.com
- MSC/NASTRAN - www.mscsoftware.com
- ANSYS - www.ansys.com
- ADINA- www.adina.com
- AbaqusFEA – www.3ds.com
- ALGOR – www.algor.com

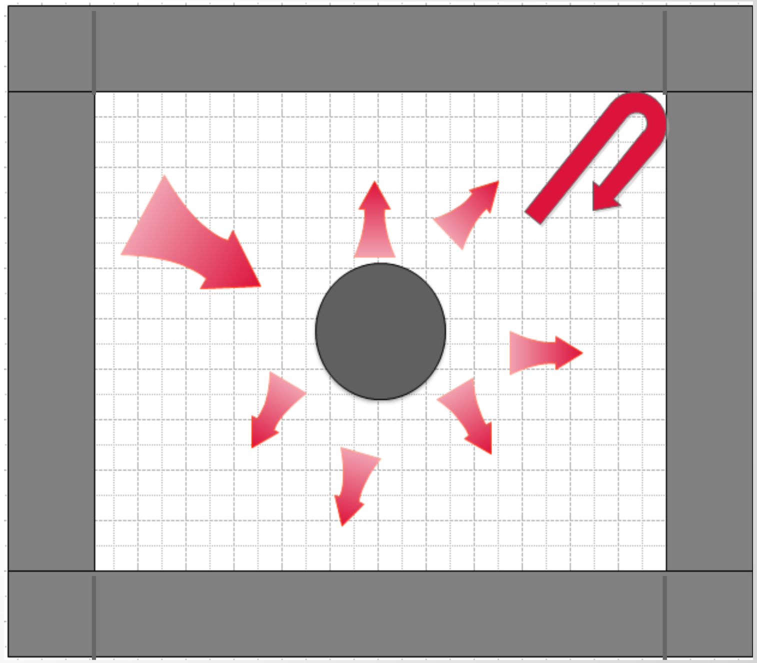
Why COMSOL?

- Most recent FEM (Finite Element Modeling) software
- Integrates well with MATLAB and uses MATLAB syntax
- Allows user programing of unincluded differential equations
- Interfaces with most CAD software and allows for import of CAD drawings

PML (Perfectly Matched Layer)

Importance

If we model a wave hitting some device or object, it will scatter the applied wave into potentially many directions. We don't want these scatter waves to reflect from the boundaries of the grid. We also don't want them to re-enter from the other side of the grid

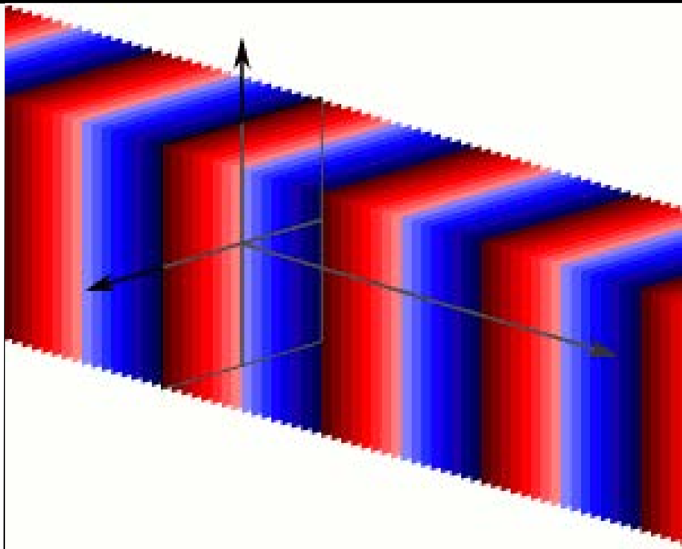


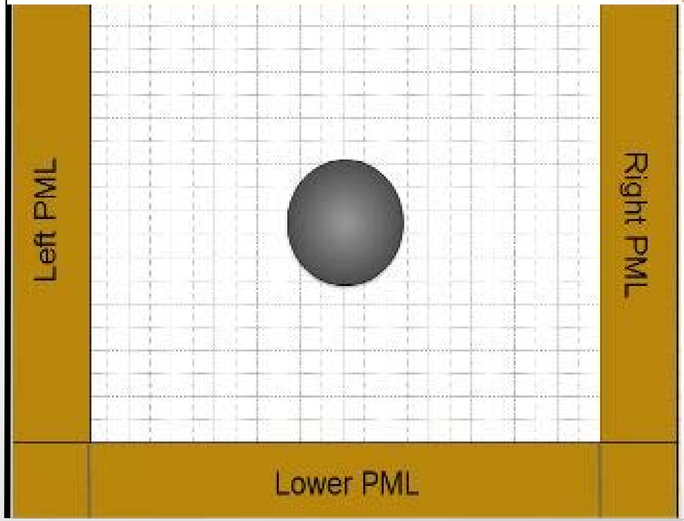
Applications

Detecting objects underneath water surface, buried mines, pollutants, unexploded ordnance, tunnels and much more

EM Wave Physics In Comsol

- **Plane Waves**
  - Propagating in one direction
  - Simple in computing
- **Perfectly Matched Layers**
  - Artificial absorbing domains
  - Commonly used to truncate computational regions in numerical methods to *simulate problems with open boundaries*
  - Reabsorb all scattered waves to eliminate reflection that causes interference





Scattering Physics In Comsol

- The wave propagate from top to bottom through air and is scattered by a target in different directions
- Some waves reflects back while others enters into the medium due to continuity and refractive index
- After the wave enters into another medium and hits the target wavelength will be smaller due to refractive index