University of Massachusetts UMASS Lowell

Structural Engineering Research Group (SERG)
Summer Seminar Series #3
June 6, 2014

2D-FINITE DIFFERENCE TIME DOMAIN (FDTD) NUMERICAL SIMULATION
(REBAR SIZE DETECTION IN FREE SPACE)

Jones Owusu Twumasi

Doctoral Student
Department of Civil and Environmental Engineering
The University of Massachusetts Lowell
Lowell, Massachusetts

Outline

- Introduction
- Objective
- Literature Review
- FDTD Numerical Simulation
- Results and Discussions
- Conclusion
- References

Introduction

- Deterioration of aging civil infrastructure due to corrosion
- Federal Highway Administration (FHWA) estimated the direct cost of corrosion between 1999~2001 to be $276 billion per year (~3.1 % of 1998GDP).
- Nondestructive Evaluation (NDE) techniques (e.g., Eddy Current, ultrasonic) have been developed to solve this problem.

Introduction

- Radar NDE has proved to be successful among these techniques in detecting damages in corroded civil infrastructures.

- Radar NDE involves the generation and sending of electromagnetic (EM) waves which interact with the target through its dielectric properties and geometry.

Objective

- To detect the size (diameter) of a steel rebar by:
  - observing changes in the return signal of the rebar.
  - comparing the input and the return signal of the rebar.
  - developing mathematical models for predicting the size of rebar.

Literature Review

- Simulated Transient Electromagnetic Response for the Inspection of GFRP-Wrapped Concrete Cylinders Using Radar NDE. Yu et. al., 2013 [1]

- Analysis of the Electromagnetic Signature of Reinforced Concrete Structures for Nondestructive Evaluation of Corrosion Damage. Roqueta et. al.,2012 [2]

- Effectiveness of 2-D and 2.5-D FDTD Ground Penetrating Radar Modeling for Bridge-Deck Deterioration Evaluated by 3-D FDTD. Belli et. al.,2009 [3]

FDTD Numerical Simulation

- Maxwell's Curl Equations

- Four Mathematical equations that govern the radiation of EM waves (e.g., radar signals) by relating the Electric Field, E (v/m), and the magnetic field, B (wb/m^2), to the charge, ρ (C/m^3), and current, J (A/m^3), densities that specify the fields.

- For source-free problems in linear and isotropic media, it is given by [4]:

$\nabla \times H = \partial/\partial t\, D$ ………….(1)

$\nabla \times E = -\partial/\partial t\, B$ ……….(2)

$\nabla \times D = 0$ ………..(3)

$\nabla \times B = 0$ ………….(4)

H = magnetic field strength (A/m) , D = electric displacement (C/m^2)

FDTD Numerical Simulation

- FDTD Methods
  - Maxwell's Curl equations were evaluated in both space and time domains numerically by finite difference methods. Discretization is based on Yee's algorithm [5].

  - Two dimensional code written in Matlab (Matrix Laboratory ®) by [1] was used in this study.

  - Three fields were simulated; electric field in x and y direction (E_x and E_y) and magnetic field in the z direction (H_z).

FDTD Numerical Simulation

- Input signal: Modulated Gaussian signal with a carrier frequency (f_c) of 2.81GHz.
- Computational domain: 300 grids x 900 grids with spatial increment ($\Delta x = \Delta y$) of 0.00025m and $\Delta t = 4.1696 \times 10^{-4}$ ns .
- Six numerical simulation cases were studied.

FDTD Numerical Simulation

- Computational domain

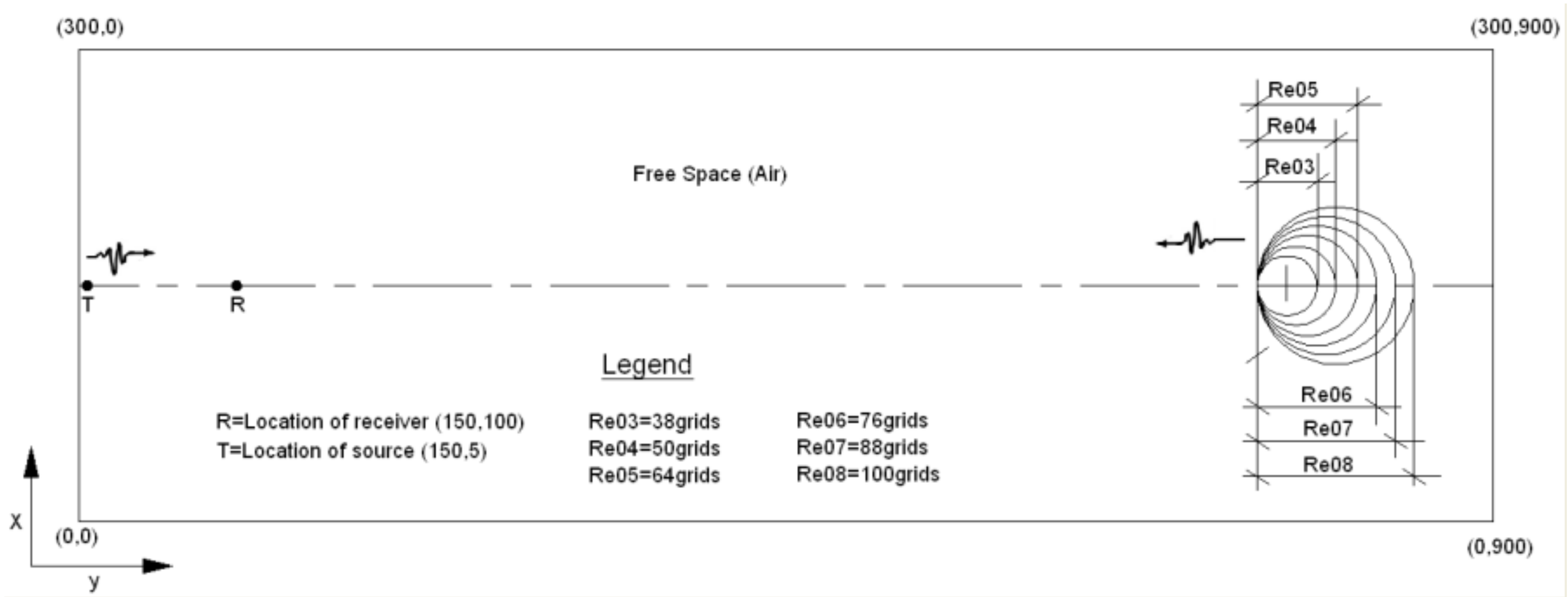


Figure 1. Configuration of the rebars and the computational domain.

FDTD Numerical Simulation

- Table1: Summary of numerical simulation cases

Case	Standard Rebar Diameter (D_s) (mm)	Rebar Diameter (D) grids (mm)	Coordinate of Center (x,y)	Remarks
Re03	9.525	38 (9.5mm)	(150,769)	#3
Re04	12.7	50 (12.5mm)	(150,775)	#4
Re05	15.875	64 (16mm)	(150,782)	#5
Re06	19.05	76 (19mm)	(150,788)	#6
Re07	22.225	88 (22mm)	(150,794)	#7
Re08	25.4	100 (25mm)	(150,800)	#8

- Dielectric constant and conductivity of steel were numerically chosen as 3000.

Results & Discussions

- Incident signal

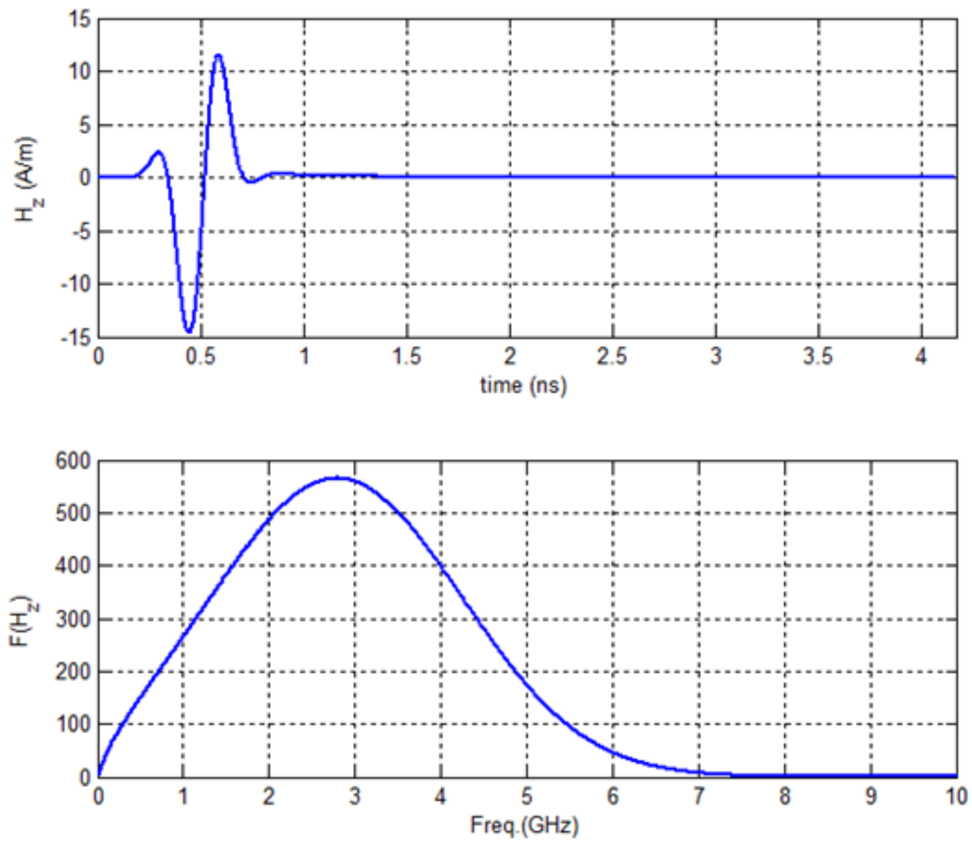


Figure 2. Time and frequency domains representations of the incident signal (2.81GHz modulated Gaussian input signal).

Results & Discussions

- Total response of rebar to EM waves.
  - Total response = Incident signal + Net response

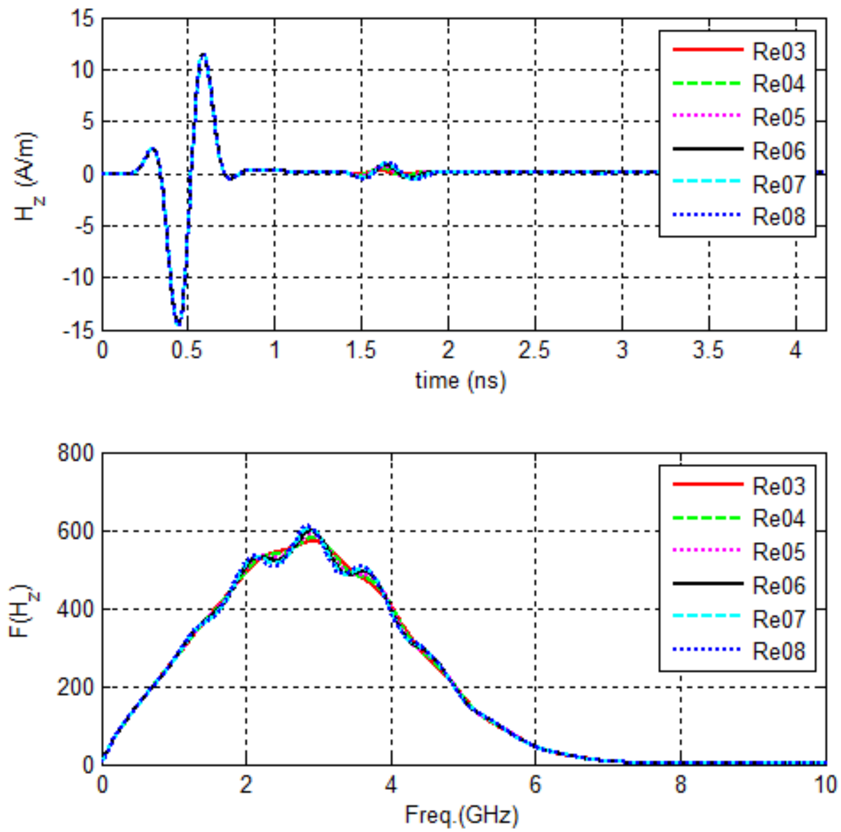
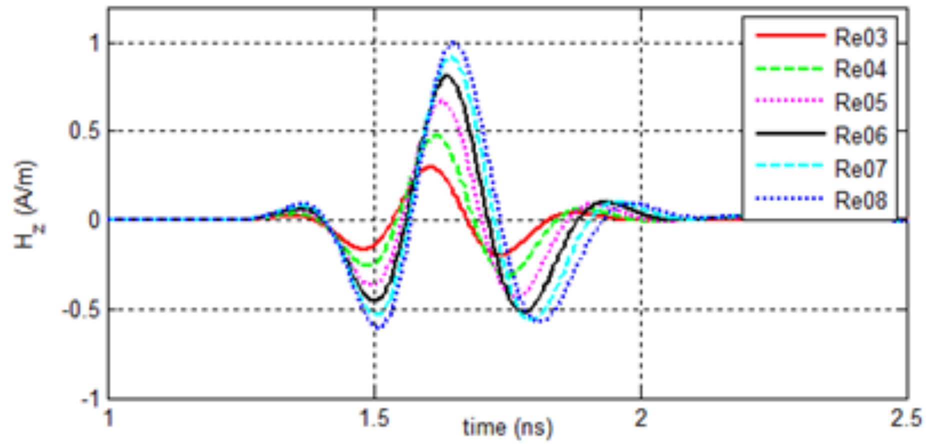


Figure 3. Total time and frequency domains response of rebar to EM waves.

Results & Discussions

- Net response of rebar to EM waves.



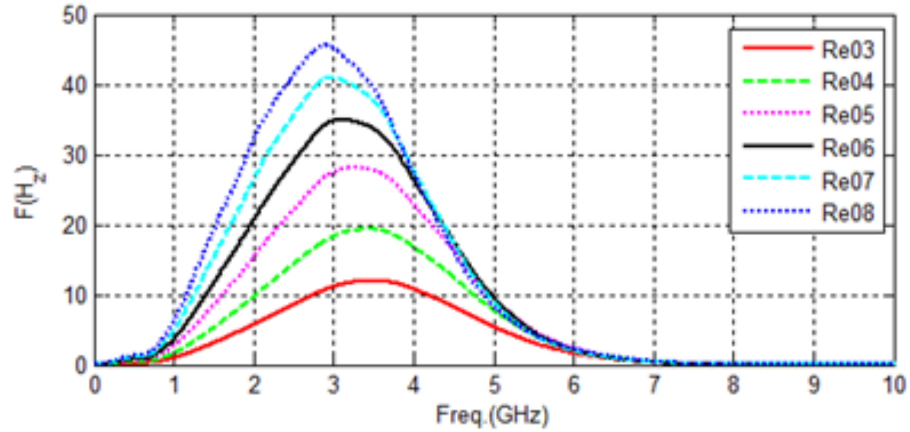


Figure 3. Net time and frequency domains response of rebar to EM waves.

Results & Discussions

- Relationship between diameter of rebar (D) and maximum peak amplitude, $(H_z)_{max}$, in net time domain response.

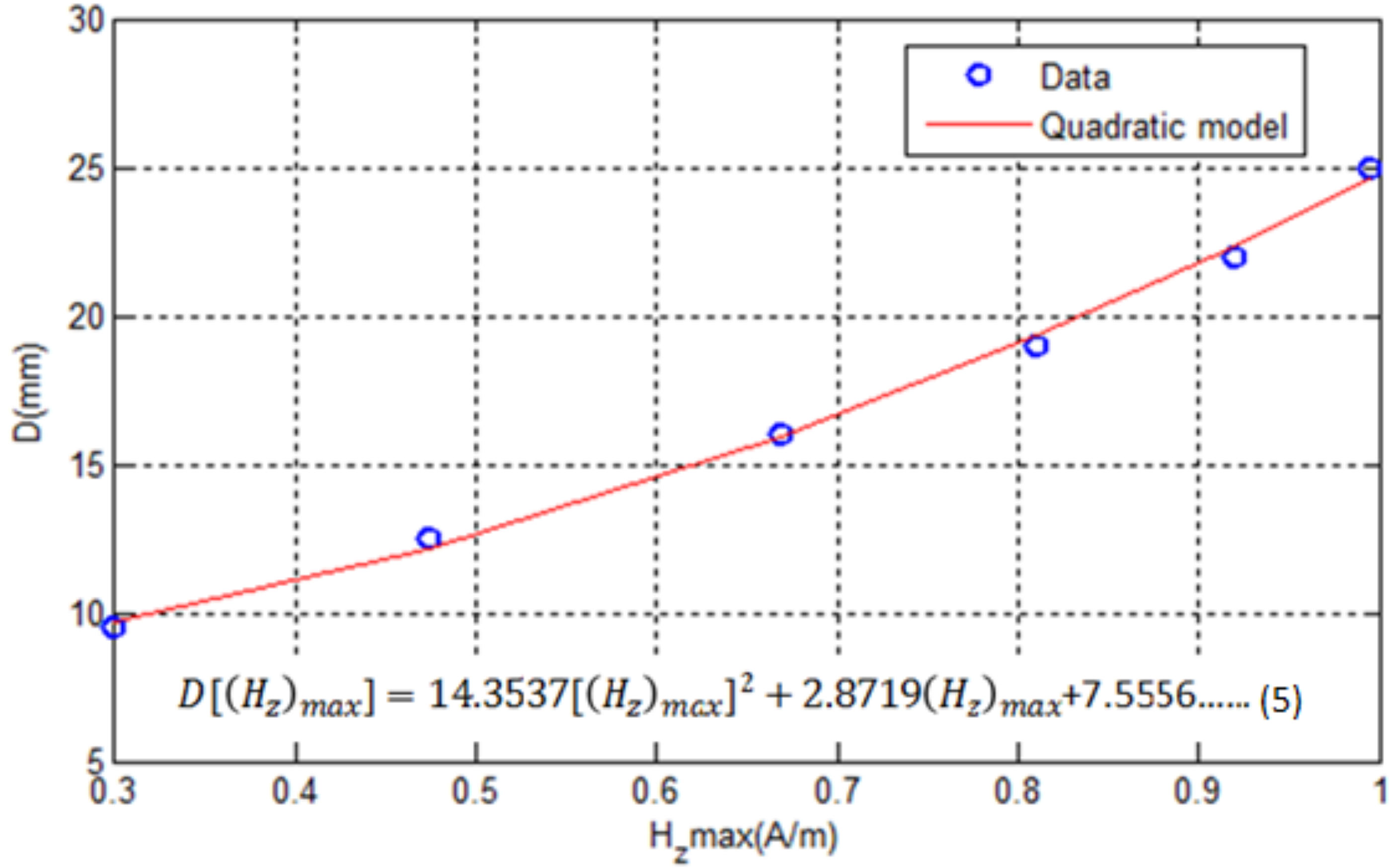


Figure 4. Diameter of rebar versus maximum peak amplitude in net time domain response.

Results & Discussions

- Findings from Figure 4.

  - Linear increase of rebar diameter does not correspond to large increase in maximum peak amplitude in net time domain response.

  - Large difference between two maximum peak amplitudes does not suggest large increase of rebar diameter. For example when the maximum peak amplitude increases from 0.29 A/m to 0.47 A/m (62%), the rebar diameter increases from 9.5mm to 12.5mm (31.5%).

  - The coefficients of Equation 5 give the best fit of the non-linear model to the rebar diameter data.

Results & Discussions

- Relationship between rebar diameter (D) and frequency shift (Δf)
- $\Delta f = f_{peak} - f_{c.}$
- f_{peak} = *Peak frequency in net frequency response*
- f_c = *Carrier frequency of input signal*

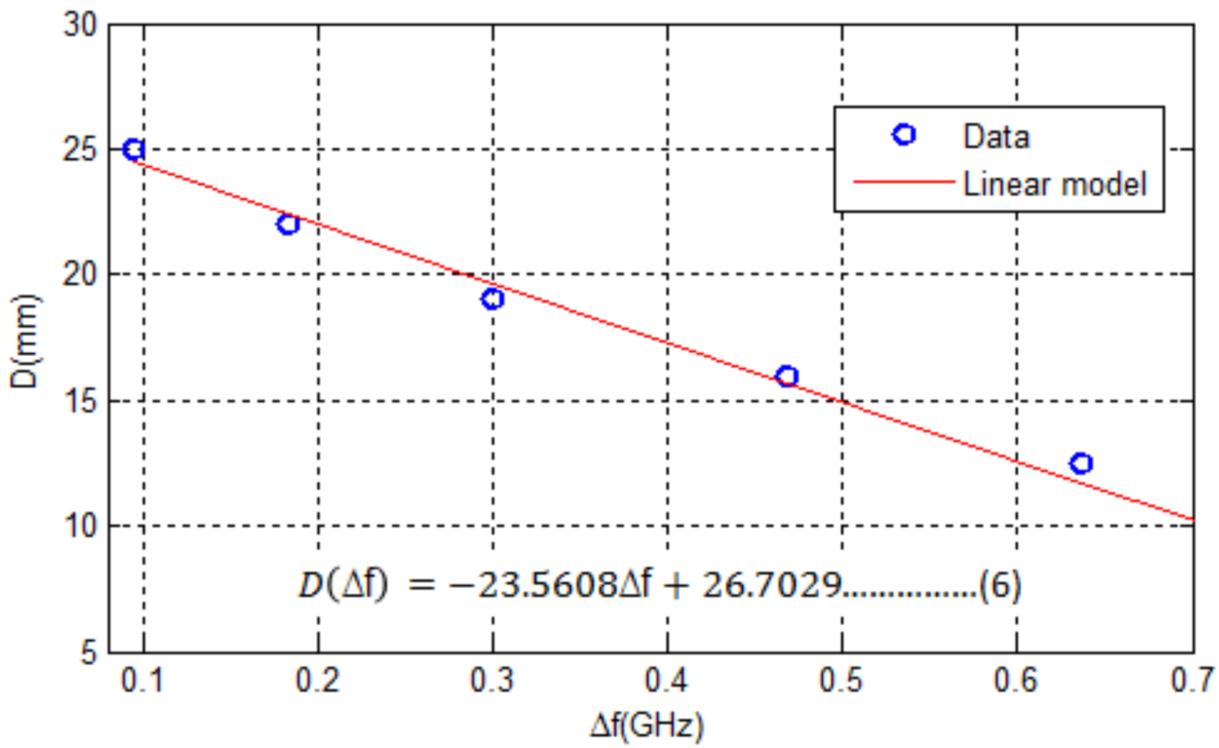


Figure 5. Rebar diameter versus frequency shift

Results & Discussions

- Findings from Figure 5.

  - Linear increase of rebar diameter corresponds to a decrease in frequency shift.

  - Larger frequency shift suggests smaller rebar diameter and vice versa.

  - The coefficients of Equation 6 give the best fit of the linear model to the rebar diameter data.

Ongoing and Future

- Rebar size detection in concrete (ongoing)
- Rebar size detection in concrete with rust layer (future).
- Coupling of rust thickness and crack density (future)

References

[1] Tzuyang Yu, Burack Boyaci, H. Felix Wu. Simulated Transient Electromagnetic Response for the Inspection of GFRP-Wrapped Concrete Cylinders Using Radar NDE. *Journal of the America Society for Non-destructive Testing* RNDE-24(3):125-153 (2013).

[2] Gemma Roqueta, Lluís Jofre, Maria Q. Feng. Analysis of the Electromagnetic Signature of Reinforced Concrete Structures for Nondestructive Evaluation of Corrosion Damage. *IEEE Transactions On Instrumentation and Measurement* 61(4): 1090-1098 (2012).

[3] Kimberly Belli, Carey M. Rappaport, He Zhan, Sara Wadia-Fascetti. Effectiveness of 2-D and 2.5-D FDTD Ground Penetrating Radar Modeling for Bridge-Deck Deterioration Evaluated by 3-D FDTD. *IEEE Transactions On Geoscience and Remote Sensing* 47(11):3656-3663 (2009)

[4] Jin A. Kong. *Electromagnetic Wave Theory*. EMW Publishing, Cambridge, MA (2000).

[5] Kane S. Yee. Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations In Isotropic Media. *IEE Transactions on Antennas and Propagation* AP-14(3):302-307 (1966)