TWINS II

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TWINS I = Thin WIre Numerical Solver

Suzana = **Su**stav **za** analizu **a**ntena (Croatian)

- Used for educational purpose and scientific research

What is solved?

- Governing equations for a current distribution along the wire radiating above a half space

Frequency domain solver (FD) | Time domain solver (TD)

Numerical method?

- Galerkin-Bubnov scheme of Indirect Boundary Element Method (GB-IBEM)

Programming language:

- C++

TD vs. FD techniques

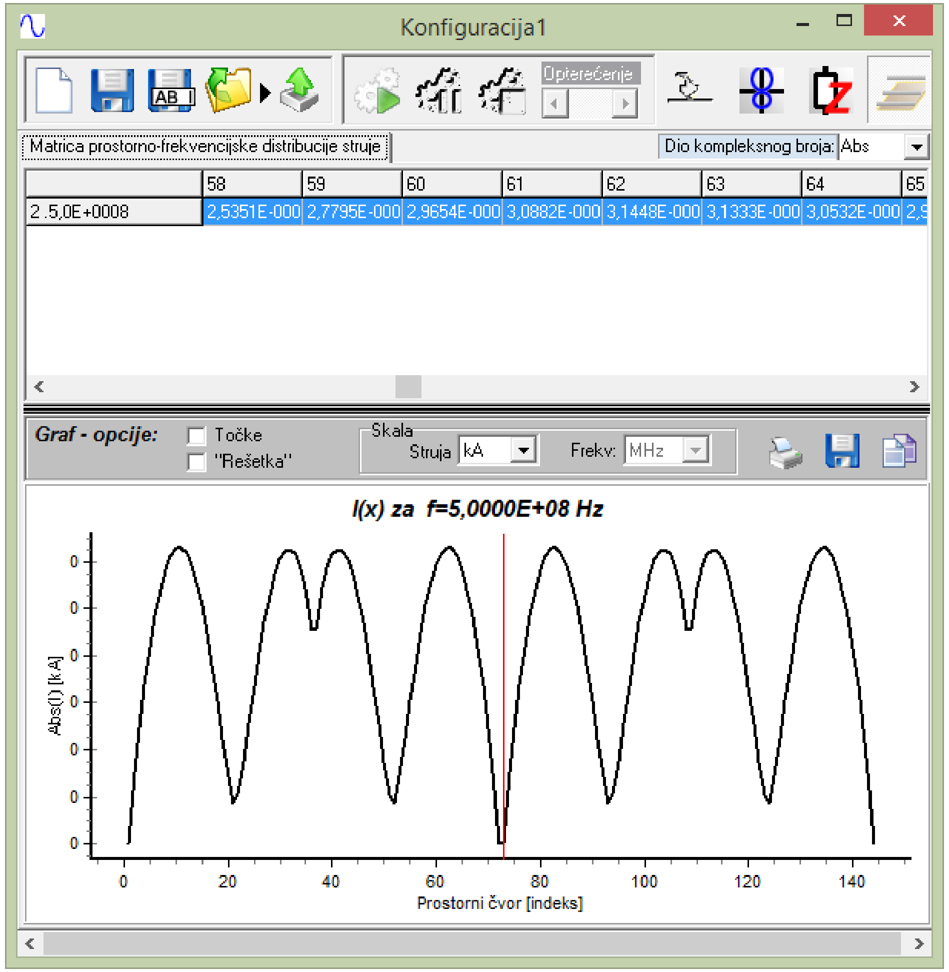
Time domain (TD) techniques:

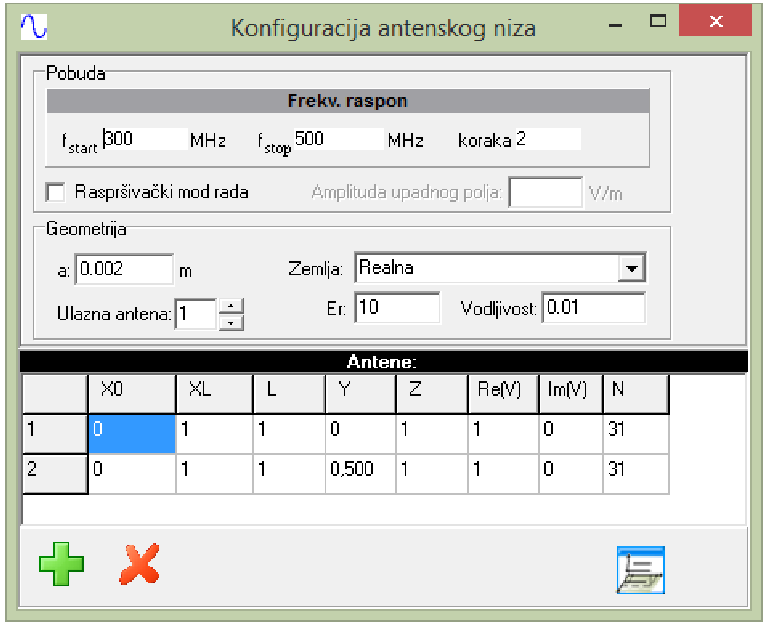
- Applied for a large frequency spectrum, but for single source
- More complex formulation requiring more computational effort
- Deeper physical insight

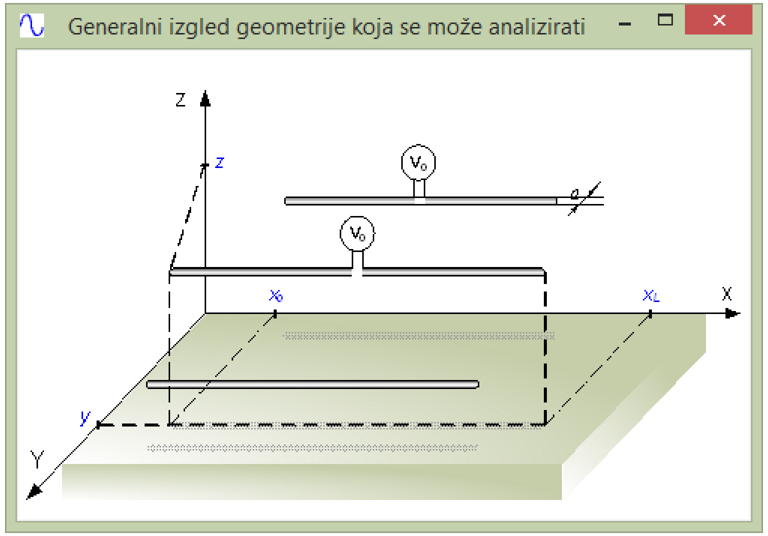
Frequency domain (FD) techniques:

- Applied for more sources, but at a single frequency
- Formulation is substantially less demanding
- In general, regulatory standards are specified in FD form; convenient for analyzing EMC properties

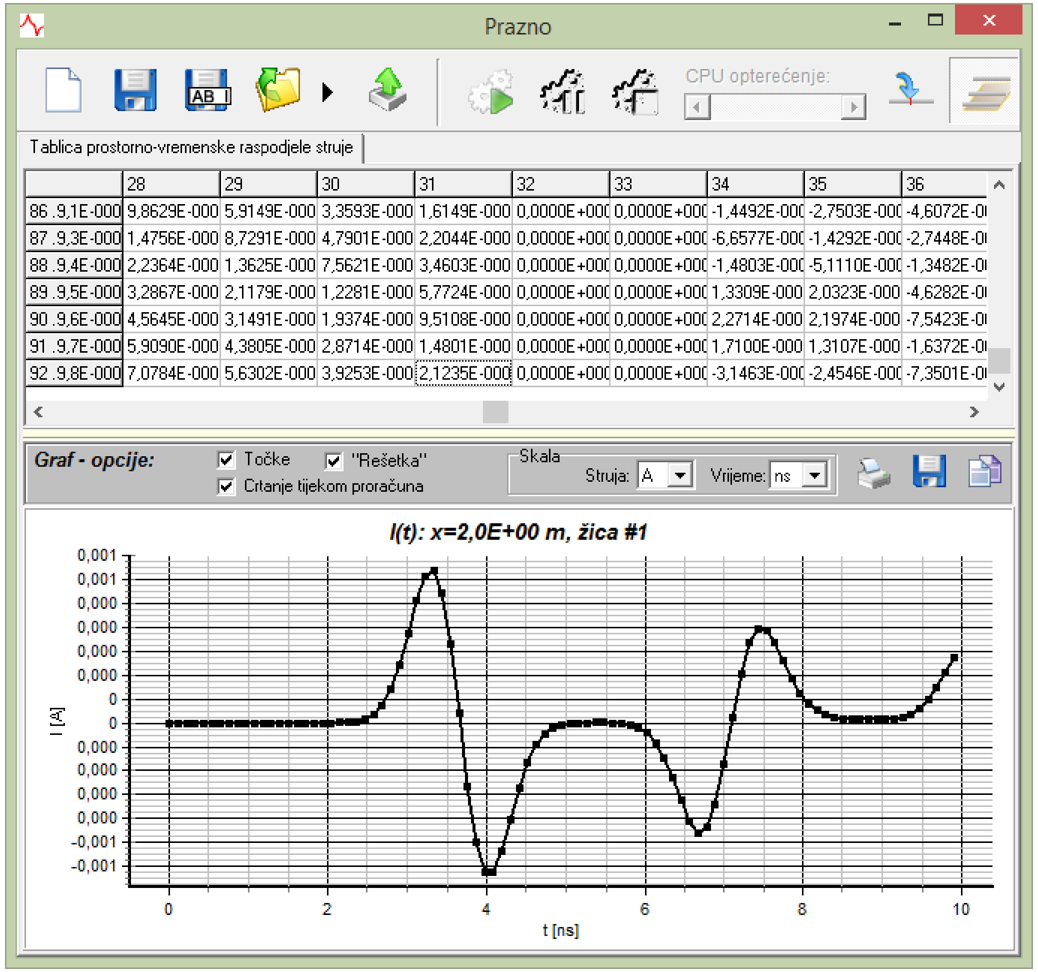
TWINS I – Frequency Domain (FD)

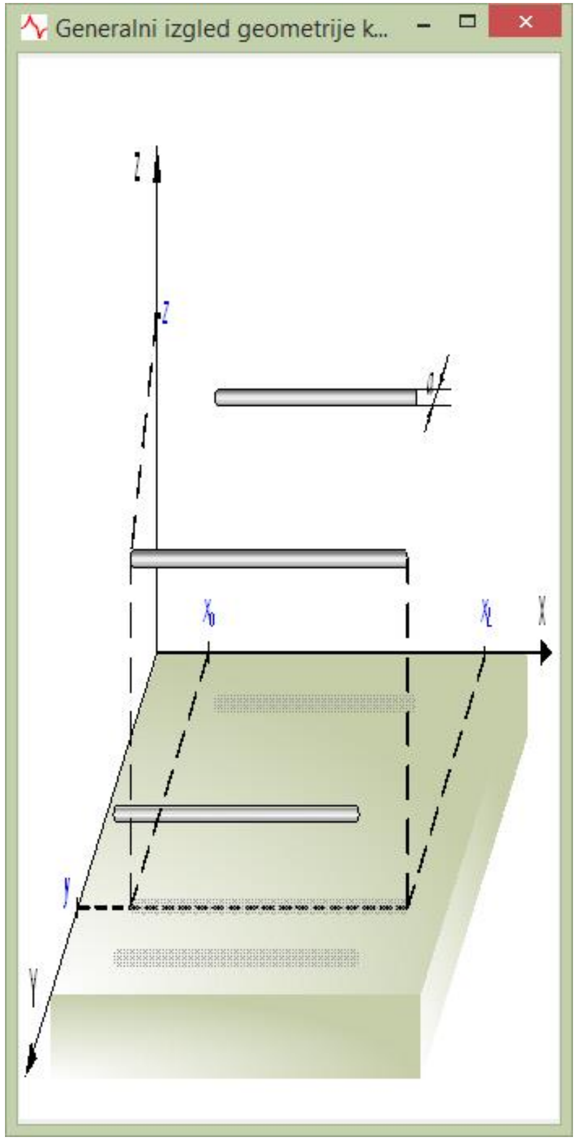


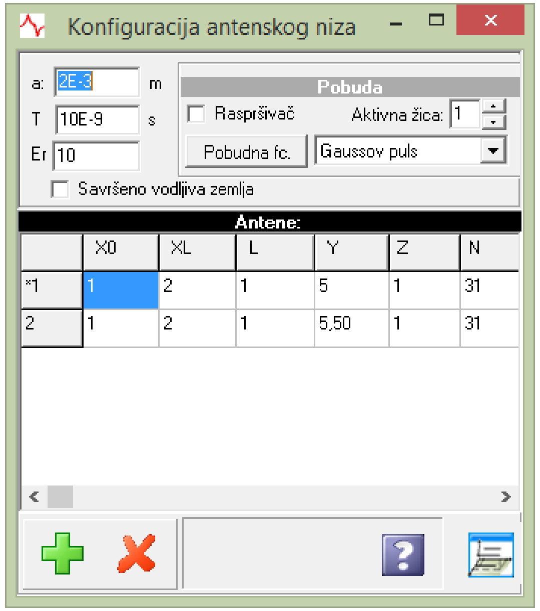




TWINS I – Time Domain (TD)

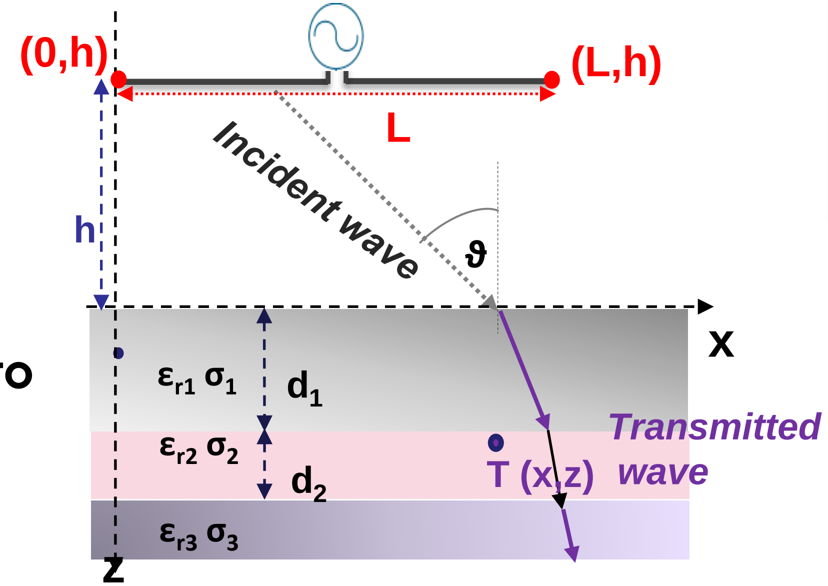






TWINS II

- **F**requency **D**omain (**FD**)
- Presented on final GPR conference in Warsaw

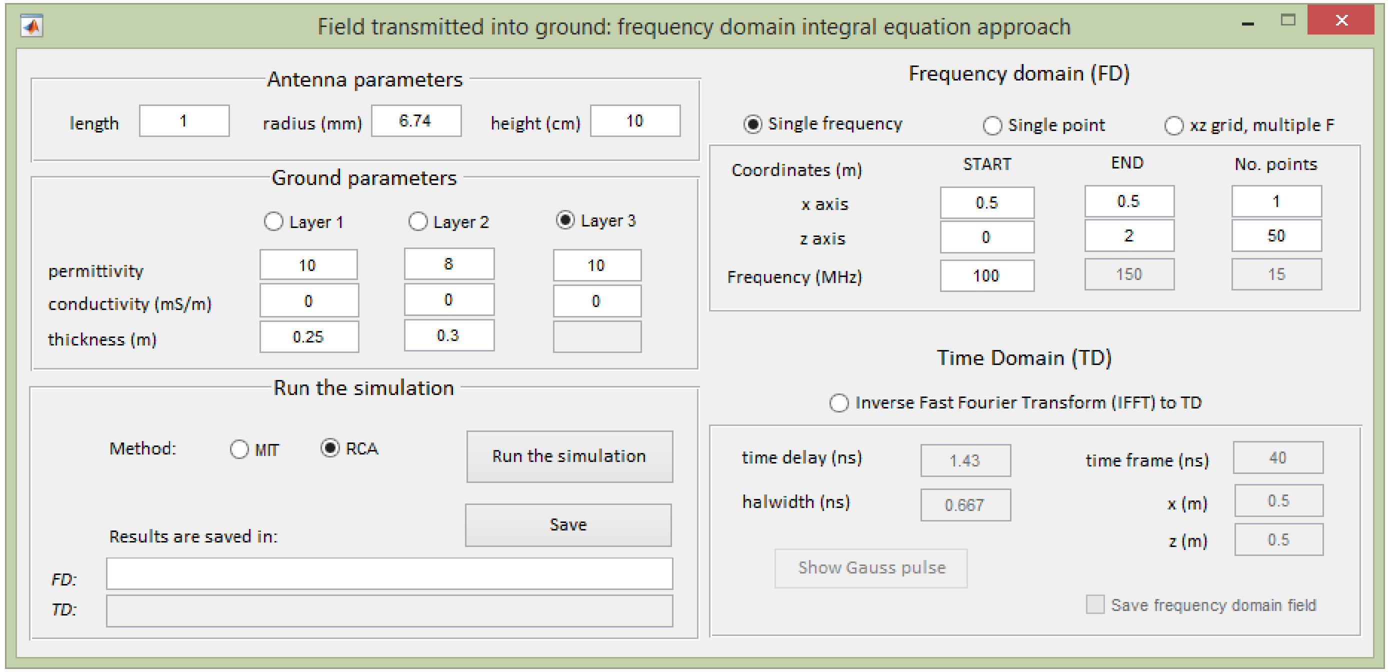


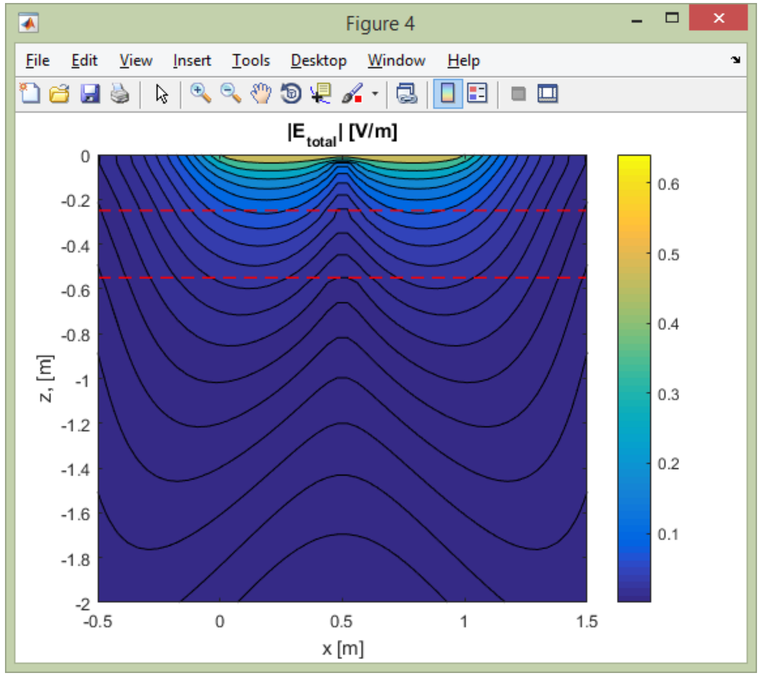
What is solved?

Integral formulas for the electric field transmitted into the subsurface.

NEW!

The subsurface is **non-homogenous**.

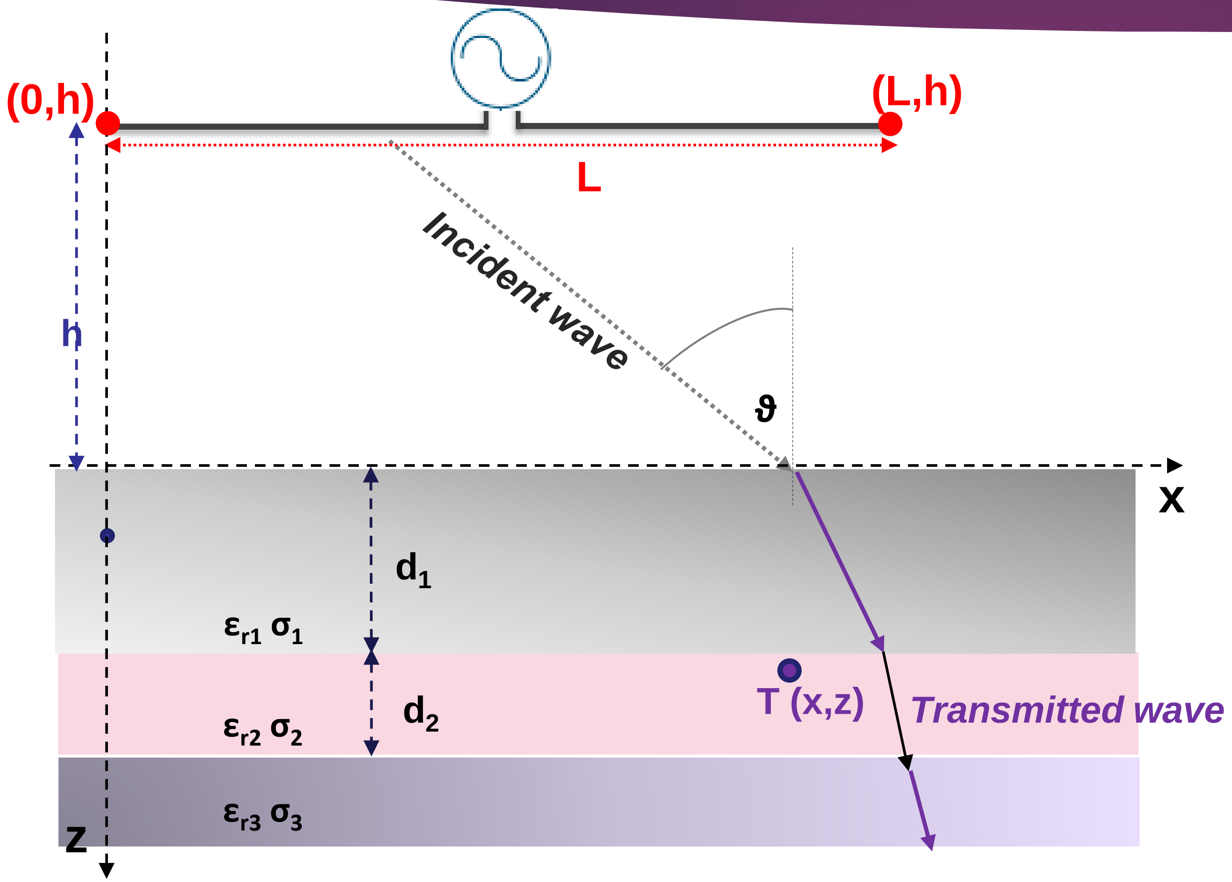




Talk Layout

- **THEORETICAL BACKGROUND**
  - Model geometry
- **INSTALLATION PROCEDURE**
- **USER GUIDE:**
  - Antenna parameters
  - Ground parameters
  - Frequency domain (FD)
  - Time domain (TD)
  - Run the simulation
- **EXAMPLES**
- **REFERENCES**

Model geometry



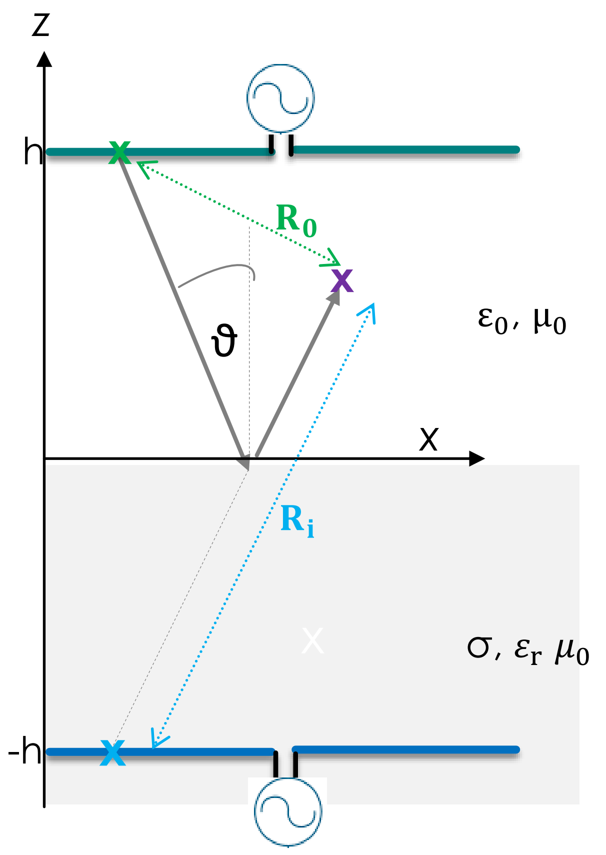
Ground penetrating radar dipole antenna above a lossy half space.

The half space is modeled as a three layered medium.

Pocklington's integro-differential equation:

$$E_x^{exc} = j\,\omega \frac{\mu}{4\pi}\int_{-\frac{L}{2}}^{\frac{L}{2}} \boldsymbol{I(x')}\boldsymbol{g(x,x')}dx' - \frac{1}{j4\pi\omega\varepsilon_0}\frac{\partial}{\partial x}\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\boldsymbol{\partial I(x')}}{\partial x'}\boldsymbol{g(x,x')}dx'$$

Wire above a lossy half-space:



I(x') … the unknown current

g(x,x') … Green's function $\quad \boldsymbol{g(x,x')} = g_0(x,x') - \boldsymbol{R_{TM}}\, g_i(x,x')$

$g_0(x,x')$ … for free space $\quad g_0(x,x') = \frac{e^{-jk_0\boldsymbol{R_0}}}{\boldsymbol{R_0}}$

$g_i(x,x')$ … from image theory $\quad g_i(x,x') = \frac{e^{-jk_0\boldsymbol{R_i}}}{\boldsymbol{R_i}}$

Electric field integral relations:

$$E_x = \frac{1}{j4\pi\omega\varepsilon_0}\left[\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial \boldsymbol{g}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},\boldsymbol{x}')}{\partial x}dx' - \gamma^2\int_0^L I(x')\boldsymbol{g}(\boldsymbol{x},\boldsymbol{x}')dx'\right]$$

$$E_y = \frac{1}{j4\pi\omega\varepsilon_0}\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial \boldsymbol{g}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},\boldsymbol{x}')}{\partial y}dx'$$

$$E_z = \frac{1}{j4\pi\omega\varepsilon_0}\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial \boldsymbol{g}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z},\boldsymbol{x}')}{\partial z}dx'$$

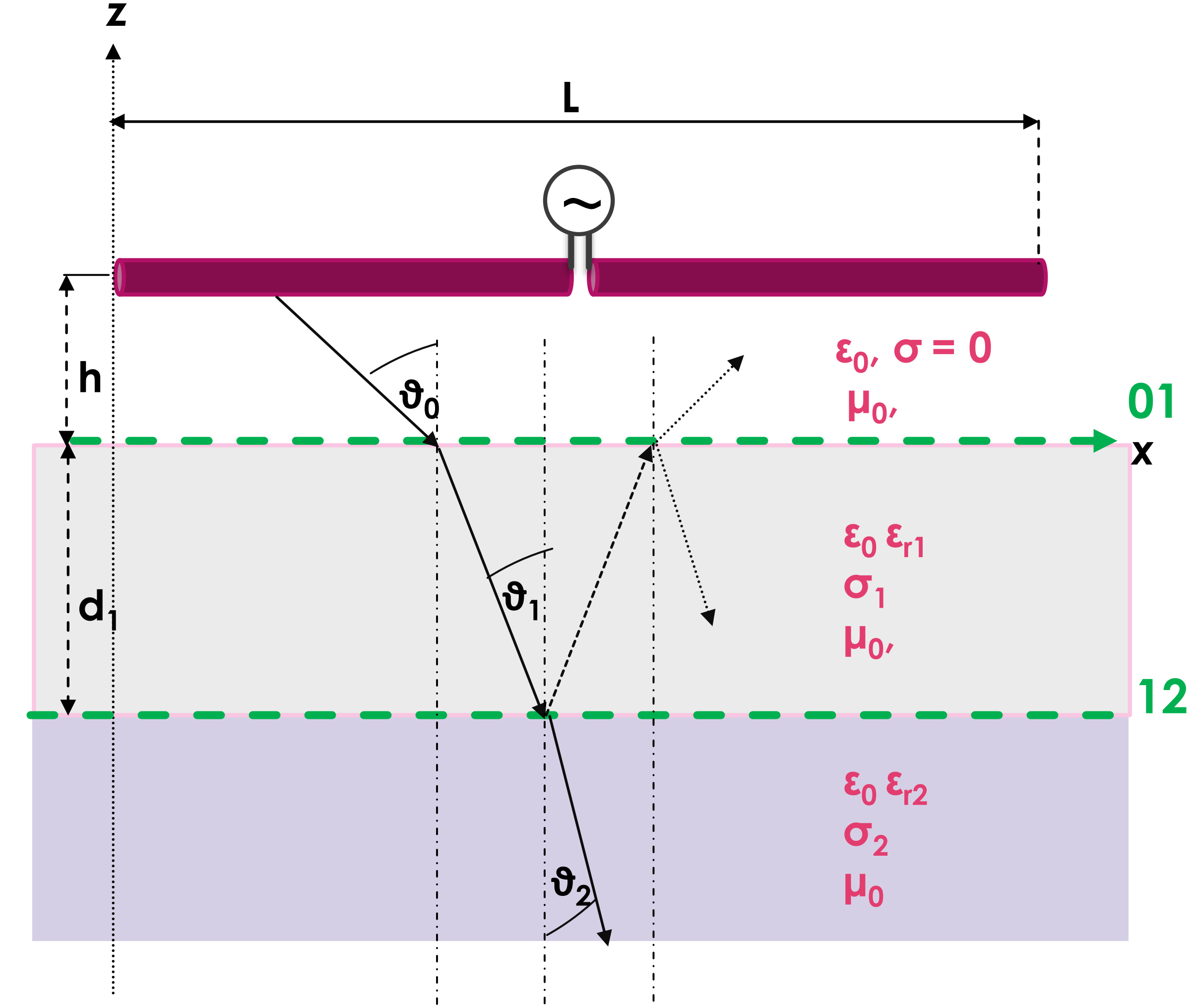
$$\boldsymbol{g}(\boldsymbol{x},\boldsymbol{x}') = \boldsymbol{T_{TM}}\, g_0(x,x')$$

Numerical procedure:

Galerkin Bubnov scheme of Indirect Boundary Element Method (GB-IBEM)

Reflection/transmission coefficients for three layered media configuration:

Air + Layer1 + Layer2



The **plane wave** approximation with **oblique incidence** at interfaces.

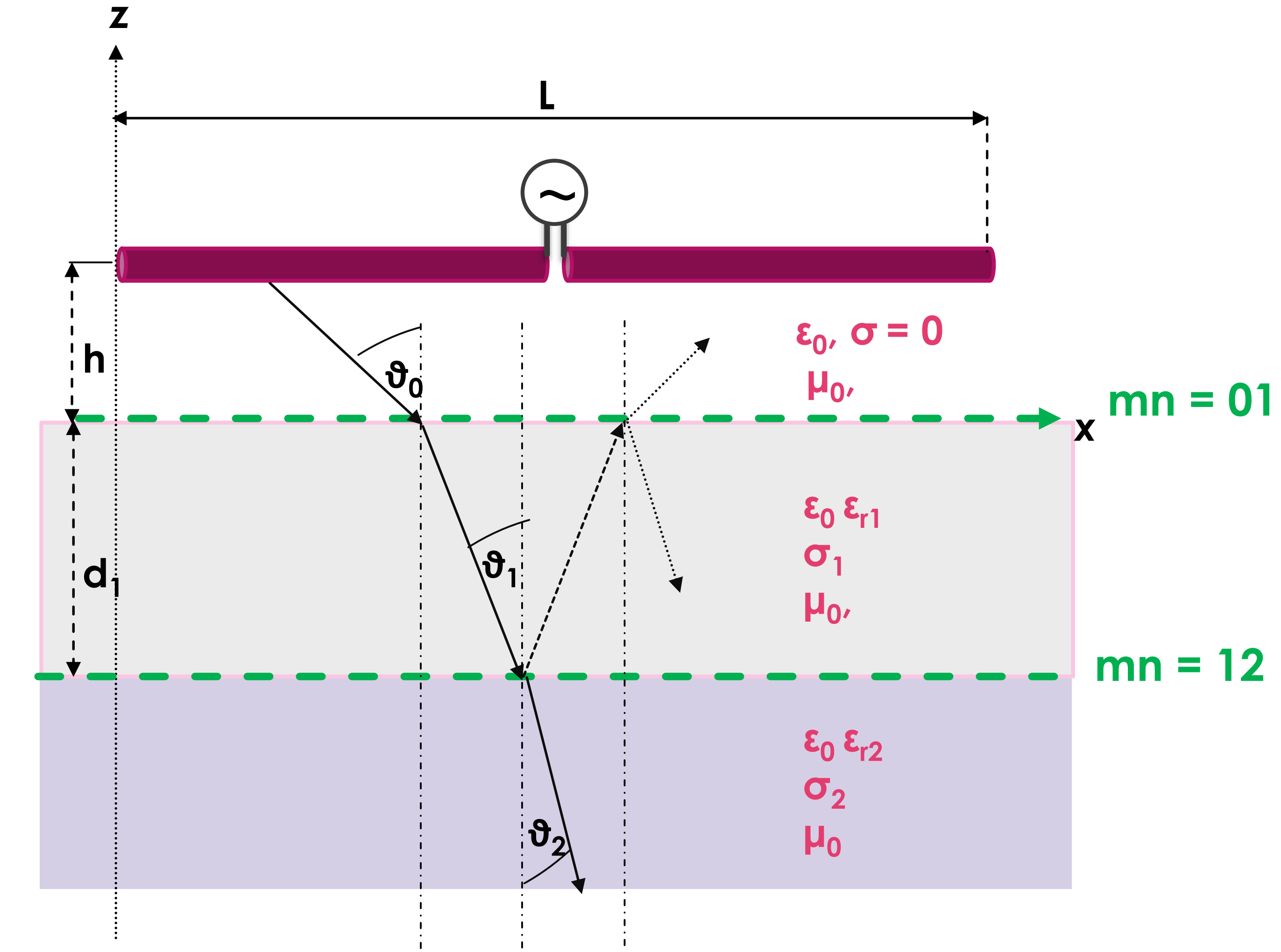
The **continuity conditions** for the tangential components of electric and magnetic fields at two interfaces (**01** and **12**) and the **Snell's law** for wave propagation yield the following equations

$$E_0^+ = \frac{1}{\tau_{01}} E_1^+ + \frac{\rho_{01}}{\tau_{01}} E_1^- \qquad E_1^+ = \frac{1}{\tau_{12}} e^{\gamma_1 \cos\vartheta_1 d_1} E_2^+$$

$$E_0^- = \frac{\rho_{01}}{\tau_{01}} E_1^+ + \frac{1}{\tau_{01}} E_1^- \qquad E_1^- = \frac{\rho_{12}}{\tau_{12}} e^{-\gamma_1 \cos\vartheta_1 d_1} E_2^+$$

E_0^+, E_1^+, E_0^- & E_1^- ...the magnitude of electric field at the layer interfaces for the wave propagating in the negative and positive direction of z axis, respectively

Fresnel's reflection/transmission coefficient approximation at interfaces



$$\rho_{mn} = \frac{Z_n \cos\vartheta_n - Z_m \cos\vartheta_m}{Z_n \cos\vartheta_n + Z_m \cos\vartheta_m}$$

$$\tau_{mn} = \frac{2 Z_n \cos\vartheta_m}{Z_n \cos\vartheta_n + Z_m \cos\vartheta_m}$$

$$m = 0{,}1 \quad n = 1{,}2$$

Impedance of medium

$$Z_k = \sqrt{\frac{j\omega\mu_0}{\sigma_k + j\omega\varepsilon_0\varepsilon_{rk}}}$$

complex propagation constant

$$\gamma_k = \sqrt{j\omega\mu_0(\sigma_k + j\omega\varepsilon_0\varepsilon_{rk})} \quad k = 0{,}1{,}2$$

$$\begin{bmatrix} E_0^+ \\ E_0^- \end{bmatrix} = M_{01} \begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix} \qquad \begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix} = P_{12} M_{12} \begin{bmatrix} E_2^+ \\ E_2^- \end{bmatrix}$$

... Matrix form for equations that solve for field values at layer's interfaces

$$M_{mn} = \frac{1}{\tau_{mn}} \begin{bmatrix} 1 & \rho_{mn} \\ \rho_{mn} & 1 \end{bmatrix} \quad m = 0,1, n = 1,2$$

... matching matrix

$$P_{12} = \begin{bmatrix} e^{\gamma_1 \cos \vartheta_1 d_1} & 0 \\ 0 & e^{-\gamma_1 \cos \vartheta_1 d_1} \end{bmatrix}$$

... propagation matrix

The layers k = 3, ... are readily included by adding the propagation and matching matrices :

By setting $E_0^+ = 1\,V/m$, all the other magnitudes E_m^+ and $E_m^-$are easily determined.

Electric field can be calculated using the following expressions:

$$\vec{E}_0 = E_1^+(\cos\vartheta_0\,\vec{e}_x + \sin\vartheta_0\,\vec{e}_z)e^{-\gamma_0(x\sin\vartheta_0 - z\cos\vartheta_0)} + E_0^-(\cos\vartheta_0\,\vec{e}_x - \sin\vartheta_0\,\vec{e}_z)e^{-\gamma_0(x\sin\vartheta_0 + z\cos\vartheta_0)}$$

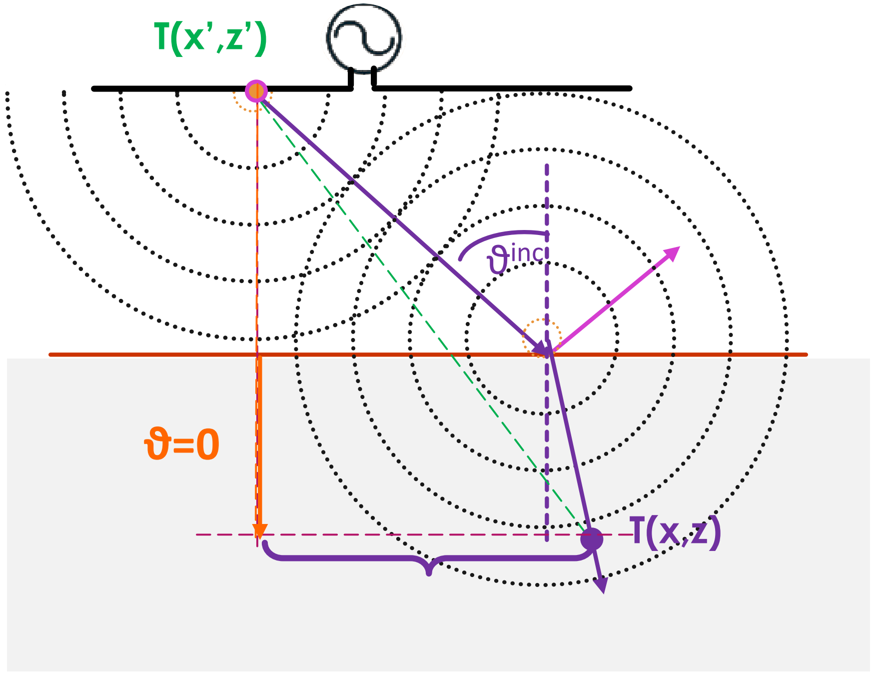
$$\vec{E}_1 = E_1^+(\cos\vartheta_1\,\vec{e}_x + \sin\vartheta_1\,\vec{e}_z)e^{-\gamma_1(x\sin\vartheta_1 - z\cos\vartheta_1)} + E_1^-(\cos\vartheta_1\,\vec{e}_x - \sin\vartheta_1\,\vec{e}_z)e^{-\gamma_1(x\sin\vartheta_1 + z\cos\vartheta_1)}$$

$$\vec{E}_2 = E_2^+(\cos\vartheta_2\,\vec{e}_x + \sin\vartheta_2\,\vec{e}_z)e^{-\gamma_2(x\sin\vartheta_2 - z\cos\vartheta_2)}$$

The reflection and transmission coefficients $\mathbf{R}_{\mathbf{TM}}$ and $\mathbf{T}_{\mathbf{TM}}$ appearing in the Green's function are calculated as the ratio between the field value at the ground surface and the field value obtained from the equations above at the given observation point.

Alternative simplified approach to calculate tranmission / reflection coeffiicients:

- Modified image theory based approach
- convenient for TD computations
- a comparison with the plane wave approximation in FD needed for benchmark



The **MIT** approach assumes the normal incidence of a propagating EM wave, therefore the incidence angles are zero: $\vartheta_m = 0°$.

The expressions for the reflection and transmission coefficients for the two adjacent media indexed with m and n are given as:

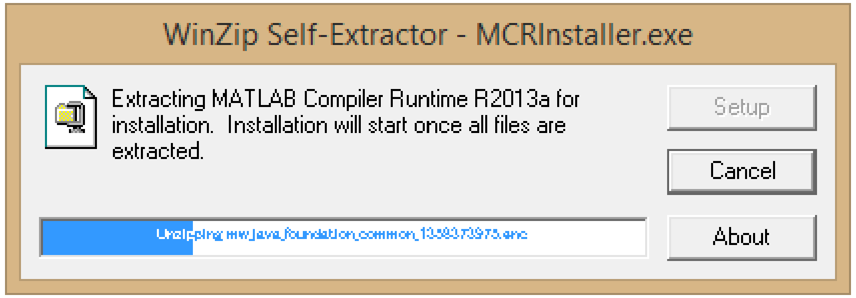
$$\rho_{mn}^{MIT} = \frac{(Z_m^2 - Z_n^2)}{(Z_m^2 + Z_n^2)}$$

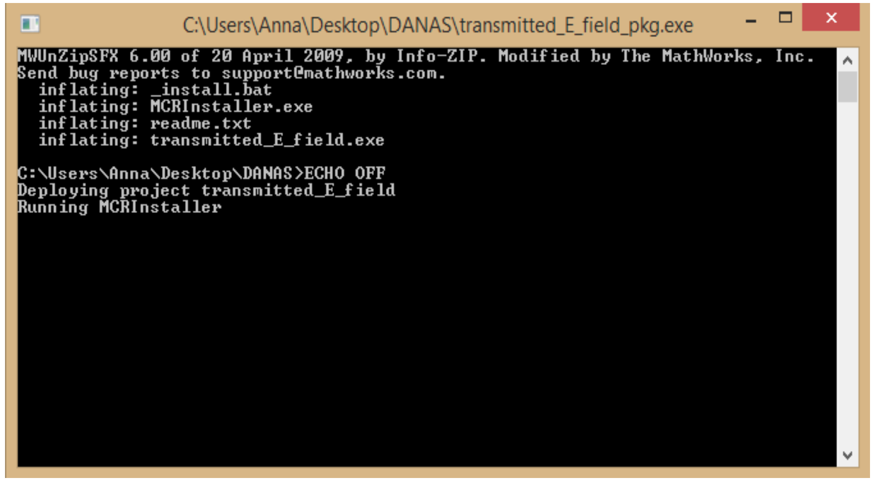
$$\tau_{mn}^{MIT} = \frac{2Z_m^2}{(Z_m^2 + Z_n^2)}$$

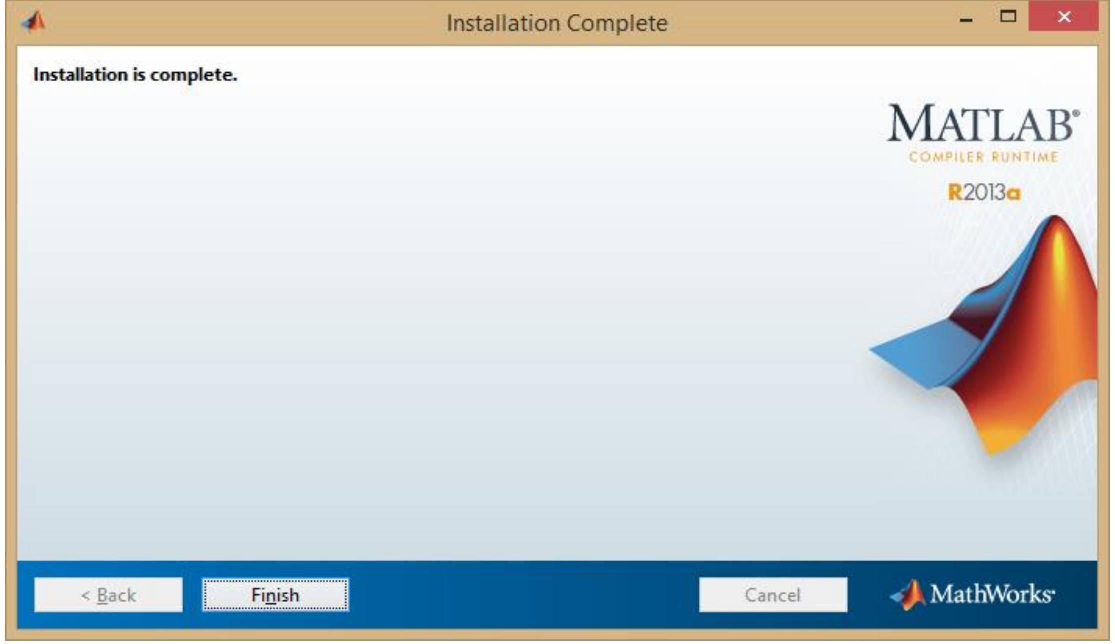
$$m = 0,1 \quad n = 1,2$$

Installation procedure

- Run **transmitted_E_field_pkg.exe**.
- This action installs MATLAB Compiler Runtime (MCR) version 8.1. and extracts the following files:
  - **transmitted_E_field.exe**
  - **MCRInstaller.exe**
  - **readme.txt file**






Installation Complete
Installation is complete.
MATLAB
COMPILER RUNTIME
R2013a
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Finish
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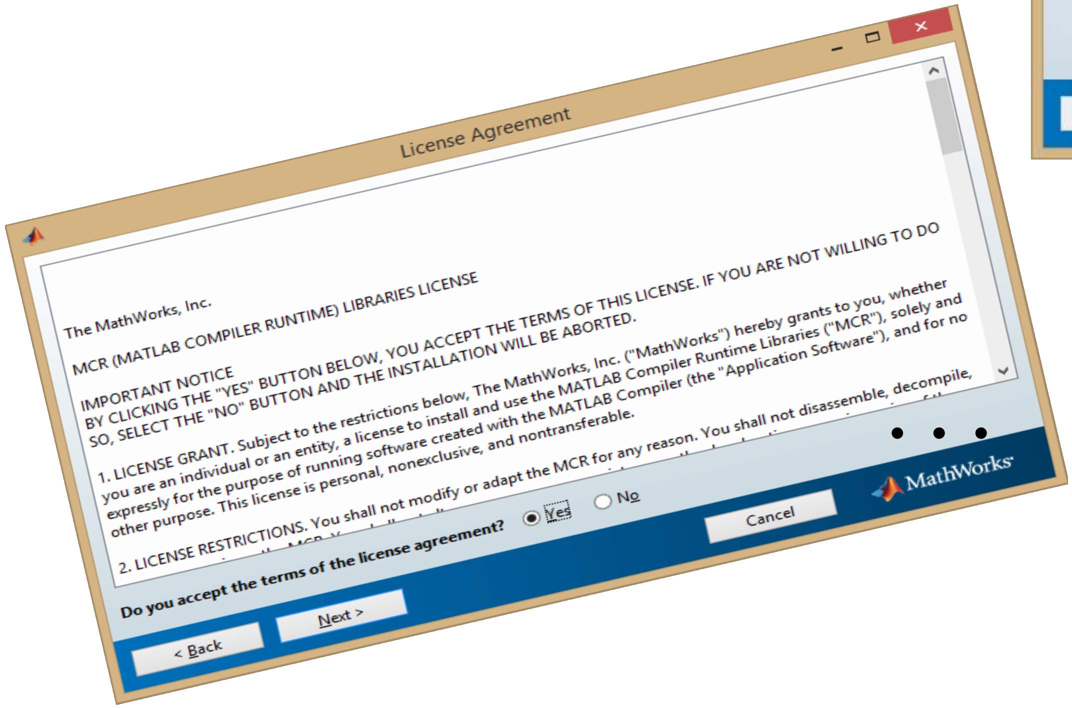
MathWorks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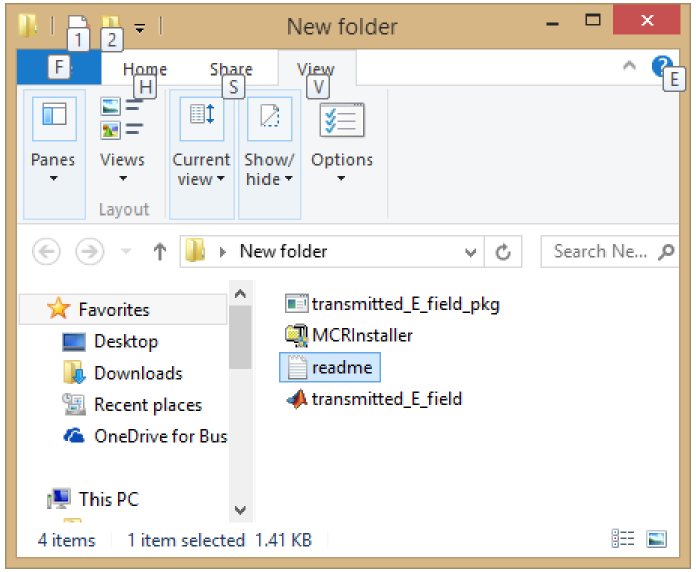
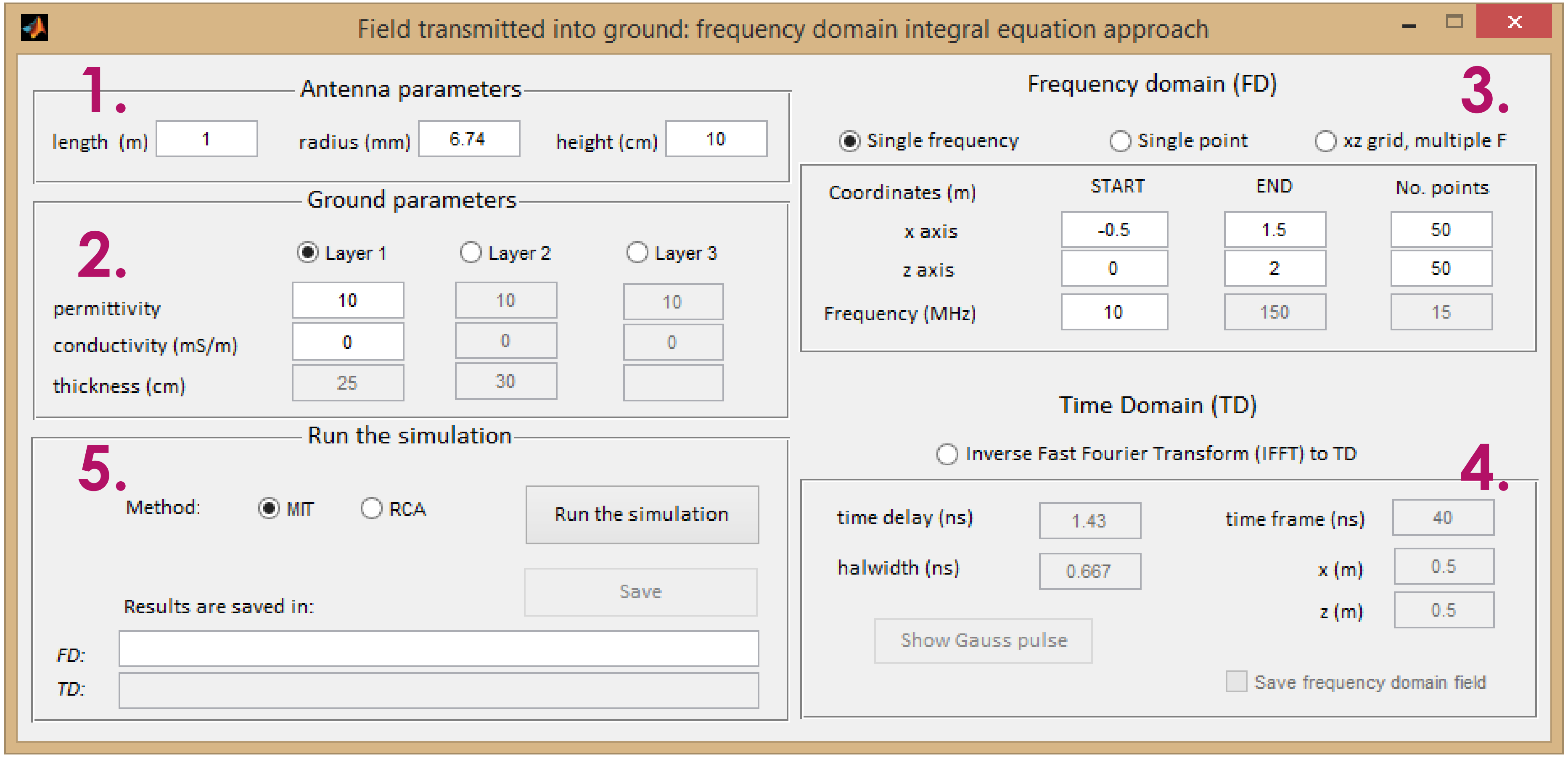

New folder
Home
Share
View
Panes
Views
Current view
Show/ hide
Options
Layout
New folder
Search Ne...
Favorites
Desktop
Downloads
Recent places
OneDrive for Bus
This PC
transmitted_E_field_pkg
MCRInstaller
readme
transmitted_E_field
4 items
1 item selected 1.41 KB

User guide

- ANTENNA PARAMETERS
- GROUND PARAMETERS
- FREQUENCY DOMAIN (FD)
- TIME DOMAIN (TD)
- RUN THE SIMULATION

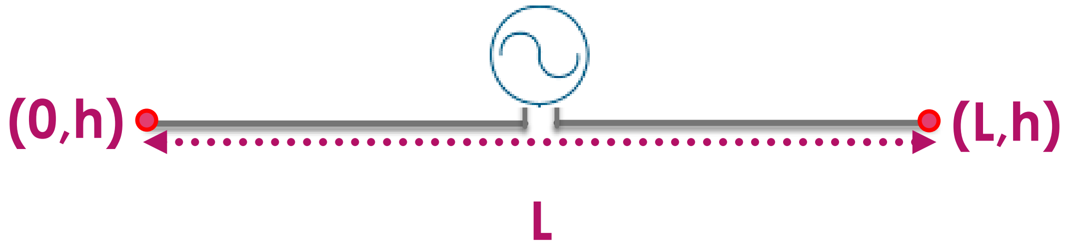
Graphical user interface



Antenna parameters

Antenna parameters

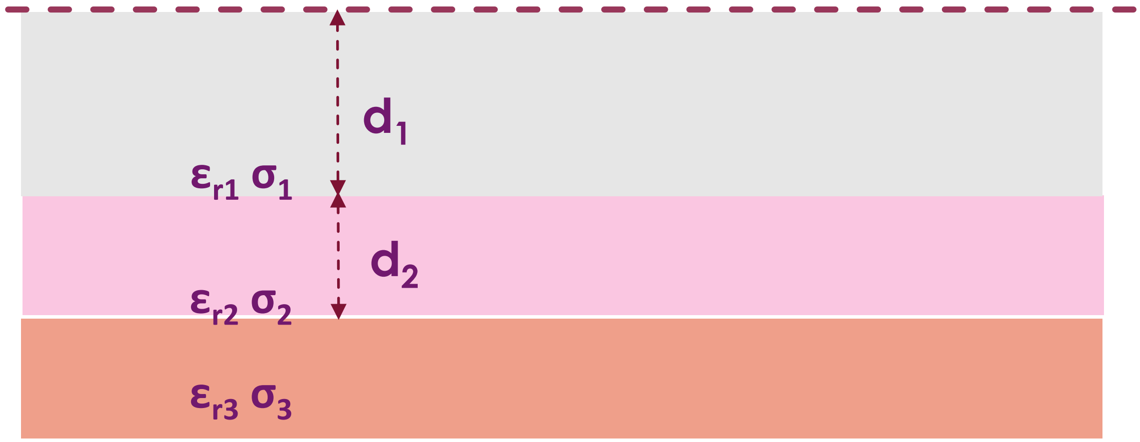
length (m)	1	radius (mm)	6.74	height (cm)	10



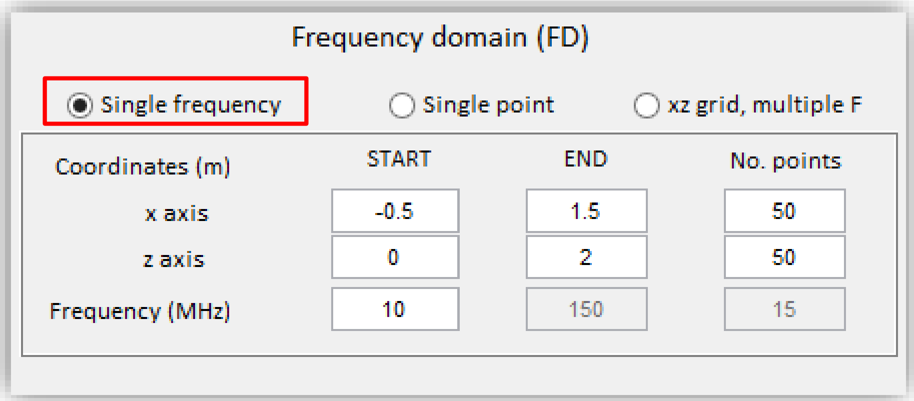
Ground parameters

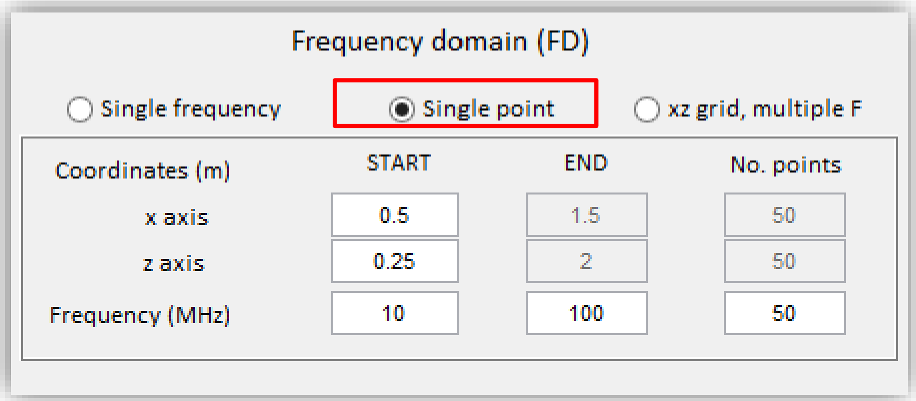
Ground parameters

	Layer 1	Layer 2	Layer 3
permittivity	10	10	10
conductivity (mS/m)	0	0	0
thickness (cm)	25	30	



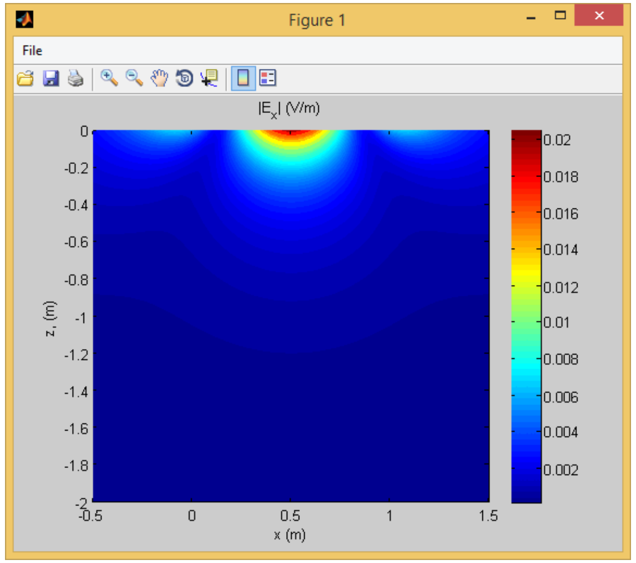
Frequency domain (FD)





Figures generated:

- **E vs. x (z) if only one z (x) point is defined**
- **contours if xz grid is defined**



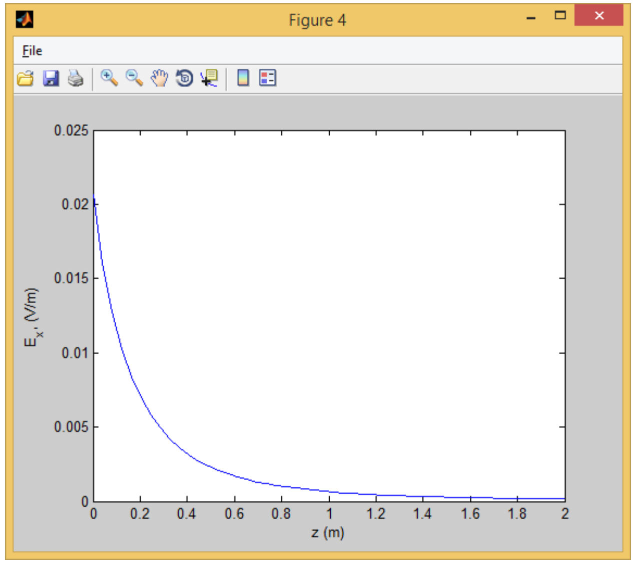
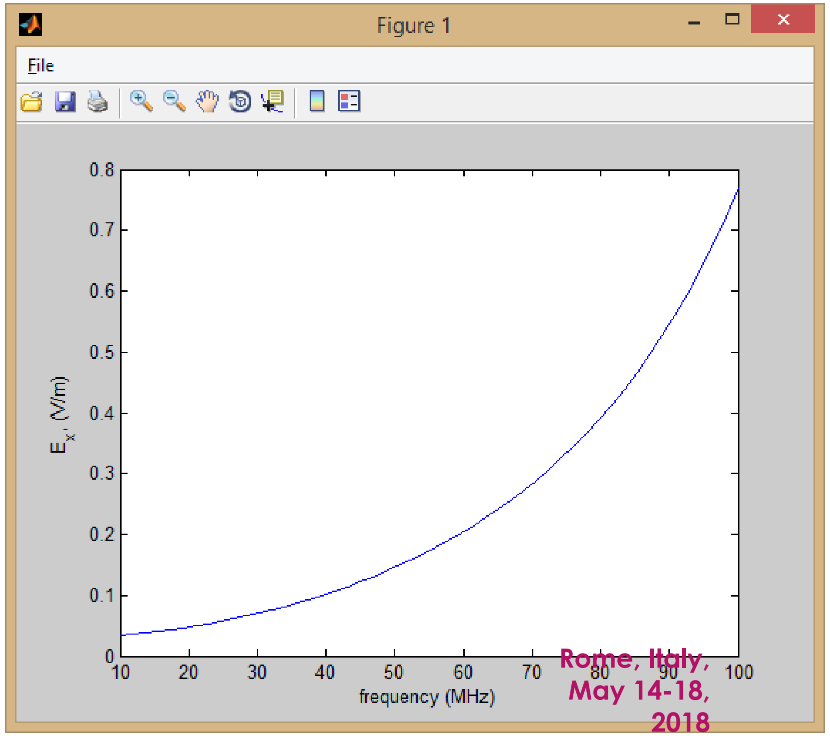


Figure generated:

- **E vs. frequency**



Frequency domain (FD)

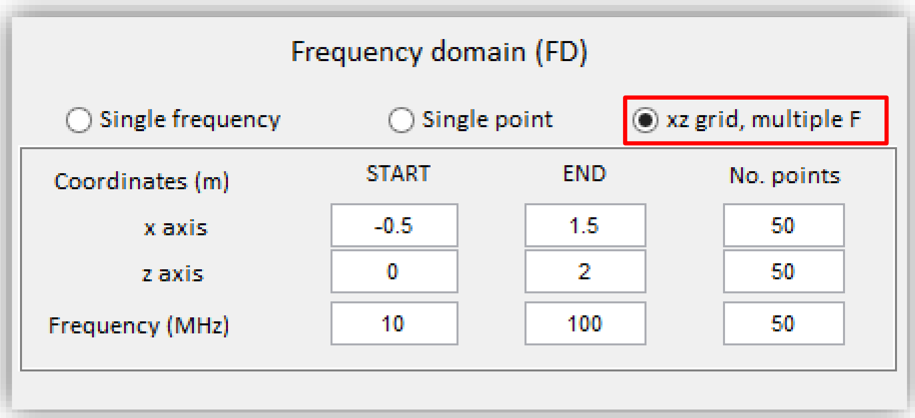


Figure generated:

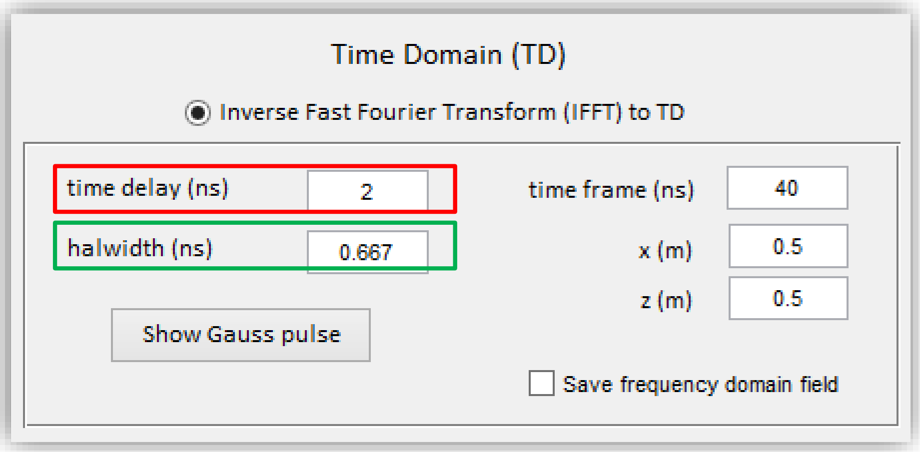
- **None**
- **The results are saved in .txt file**

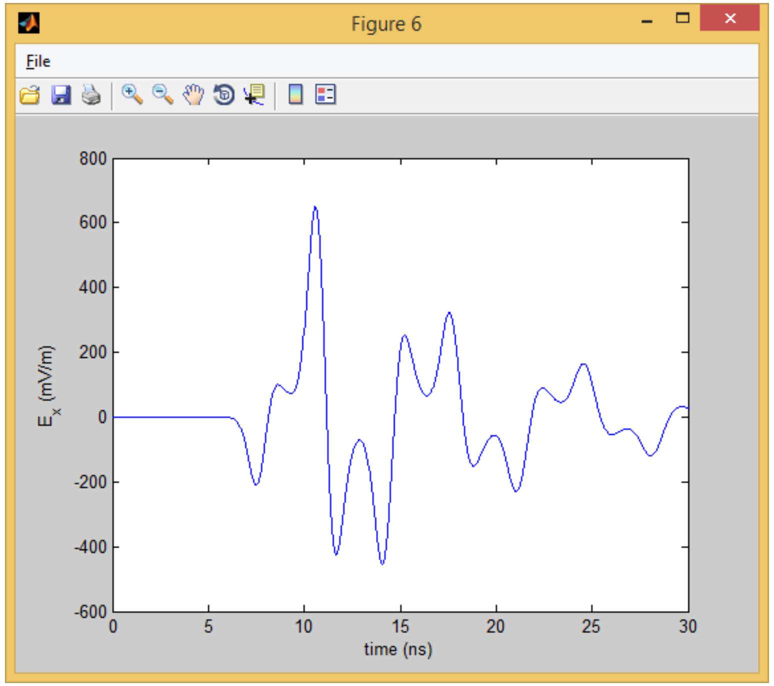
Example_No_1 - Notepad

File Edit Format View Help

Freq. (MHz)	x(m)	z(m)	Real(E_x)	Imag(E_x)	Real(E_z)	Imag(E_z)
10000000.000000	-0.500000	0.000000	-0.001053	-0.002397	0.000729	0.000839
10000000.000000	-0.459184	0.000000	-0.001170	-0.002655	0.000862	0.001014
10000000.000000	-0.418367	0.000000	-0.001306	-0.002949	0.001029	0.001236
10000000.000000	-0.377551	0.000000	-0.001466	-0.003287	0.001240	0.001519
10000000.000000	-0.336735	0.000000	-0.001650	-0.003671	0.001510	0.001883
10000000.000000	-0.295918	0.000000	-0.001860	-0.004104	0.001855	0.002354
10000000.000000	-0.255102	0.000000	-0.002089	-0.004582	0.002301	0.002966
10000000.000000	-0.214286	0.000000	-0.002327	-0.005089	0.002876	0.003761

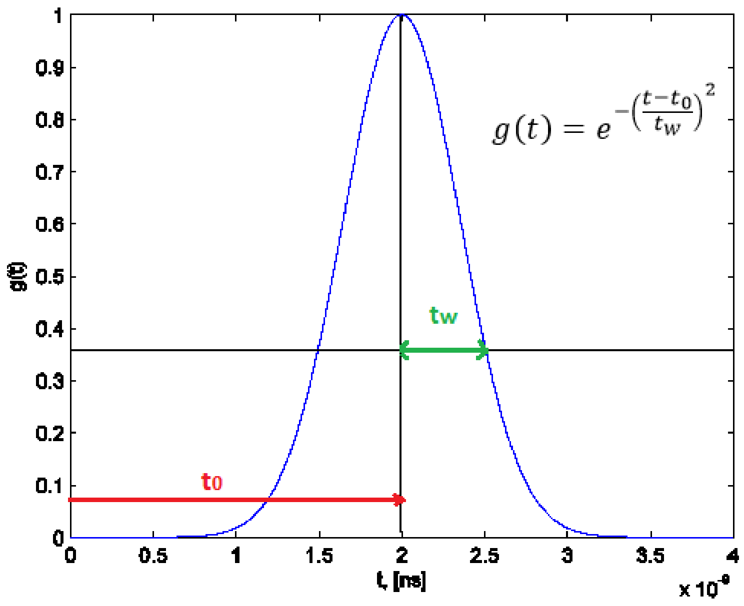
Time domain (TD)





- The excitation is given as a Gaussian waveform where the parameters t_w and t_0 represent the half width and time delay of a pulse
- Figure generated upon the calculation:

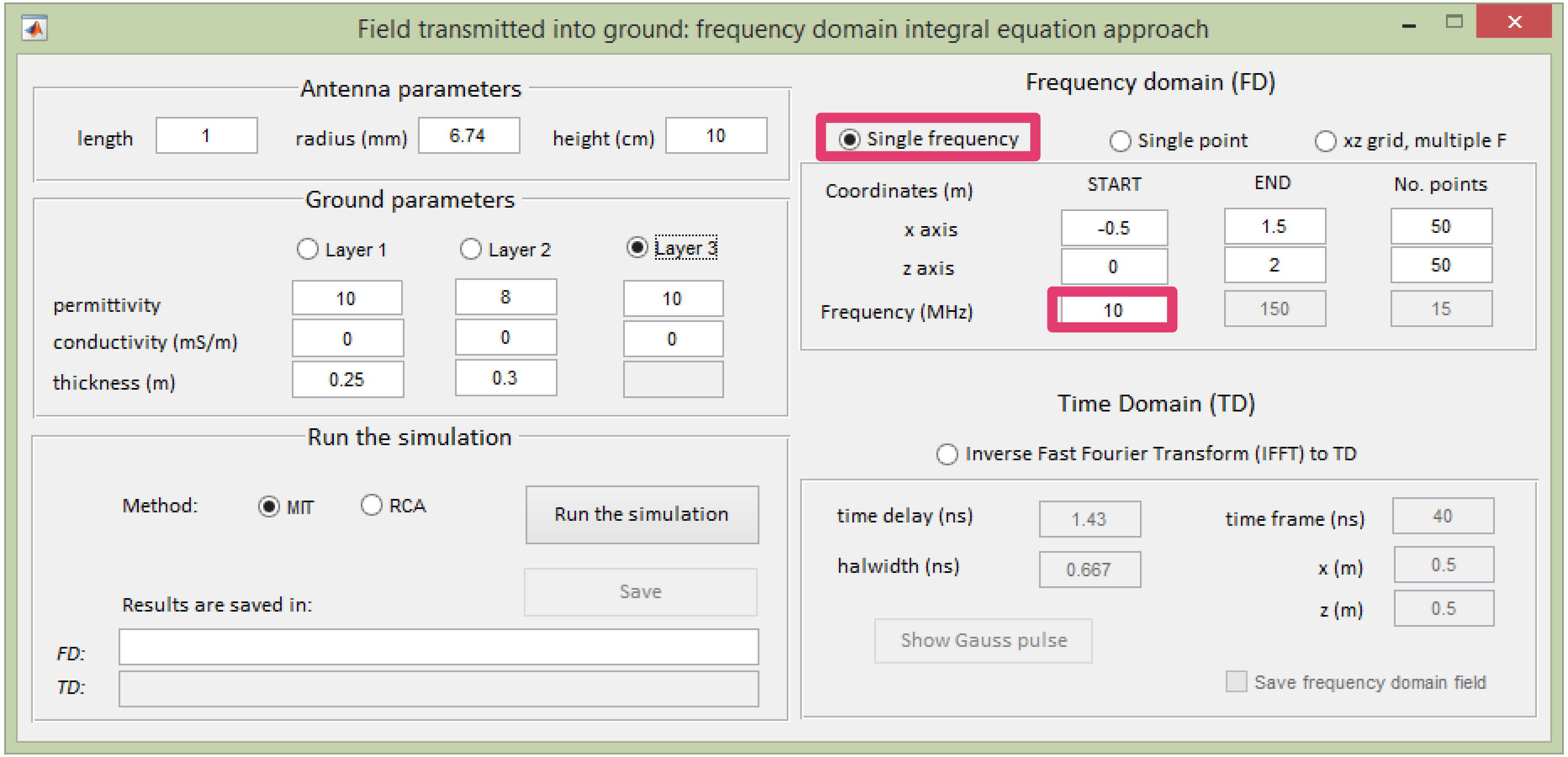
  - E vs. time for tangential component of electric field

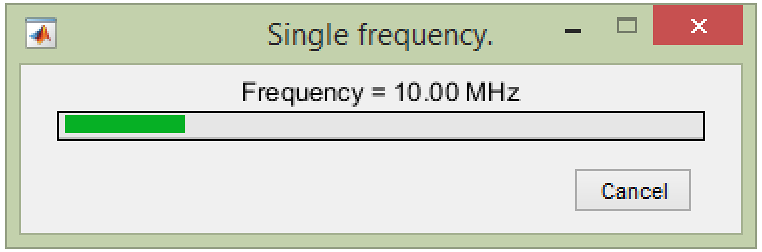


Examples

1. E vs. xz
2. E vs. z
3. E vs. freq
4. E vs. time

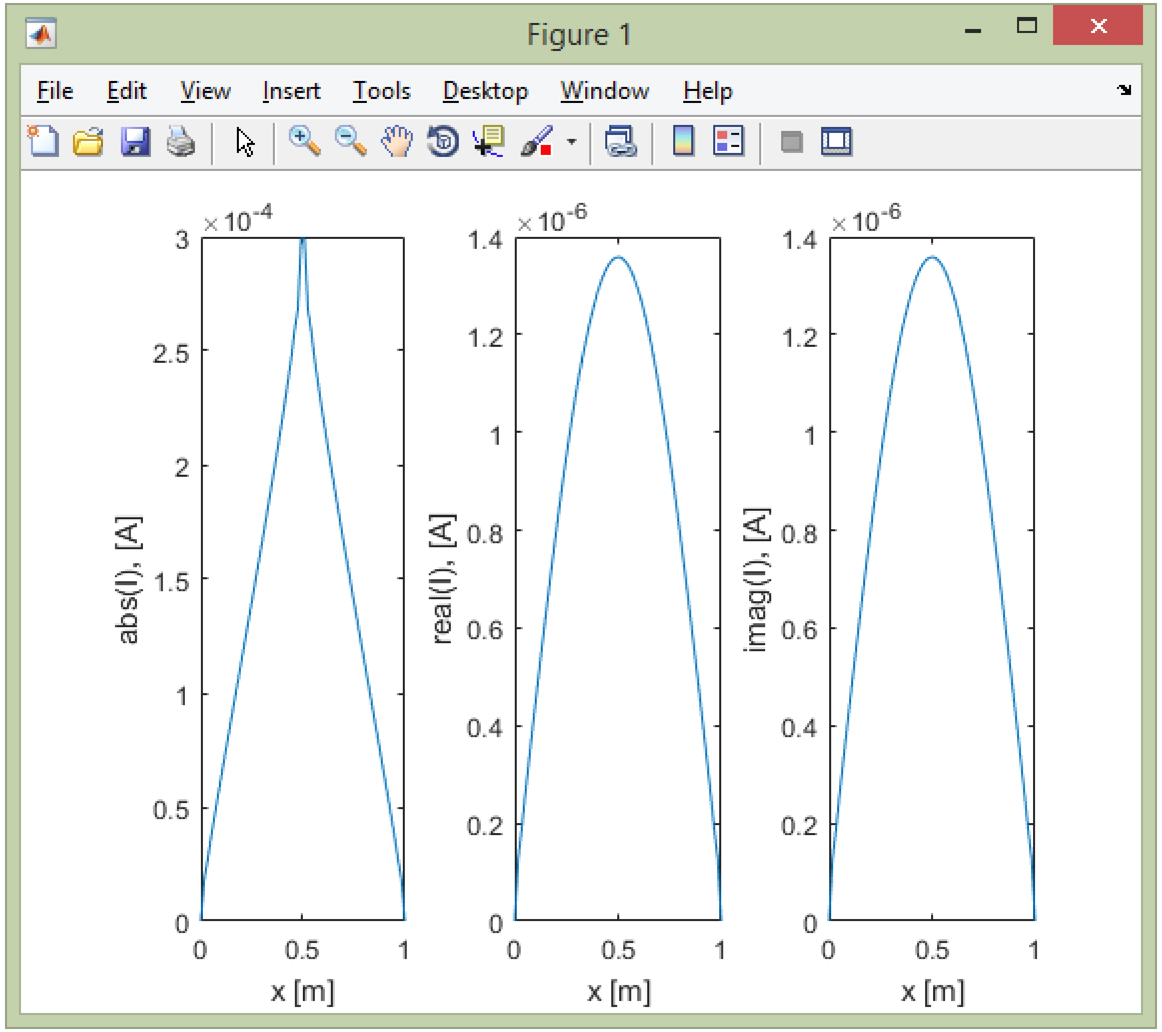
1. E vs. xz

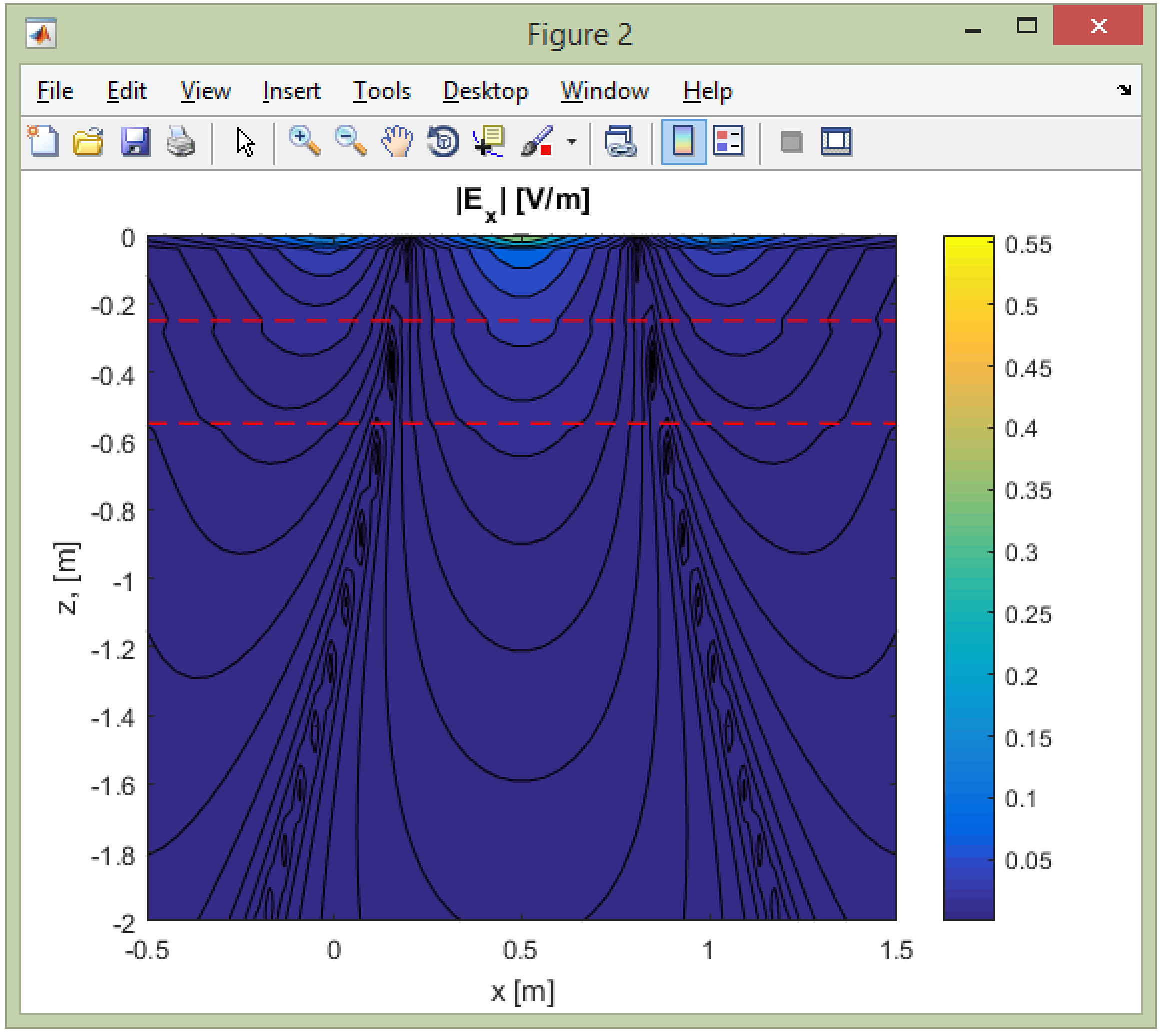

Field transmitted into ground: frequency domain integral equation approach
Antenna parameters
length 1
radius (mm) 6.74
height (cm) 10
Ground parameters
Layer 1
Layer 2
Layer 3
permittivity 10 8 10
conductivity (mS/m) 0 0 0
thickness (m) 0.25 0.3
Run the simulation
Method:
MIT
RCA
Run the simulation
Save
Results are saved in:
FD:
TD:
Frequency domain (FD)
Single frequency
Single point
xz grid, multiple F
Coordinates (m)
START
END
No. points
x axis -0.5 1.5 50
z axis 0 2 50
Frequency (MHz) 10 150 15
Time Domain (TD)
Inverse Fast Fourier Transform (IFFT) to TD
time delay (ns) 1.43
halwidth (ns) 0.667
time frame (ns) 40
x (m) 0.5
z (m) 0.5
Show Gauss pulse
Save frequency domain field


Single frequency.
Frequency = 10.00 MHz
Cancel

1. E vs. xz

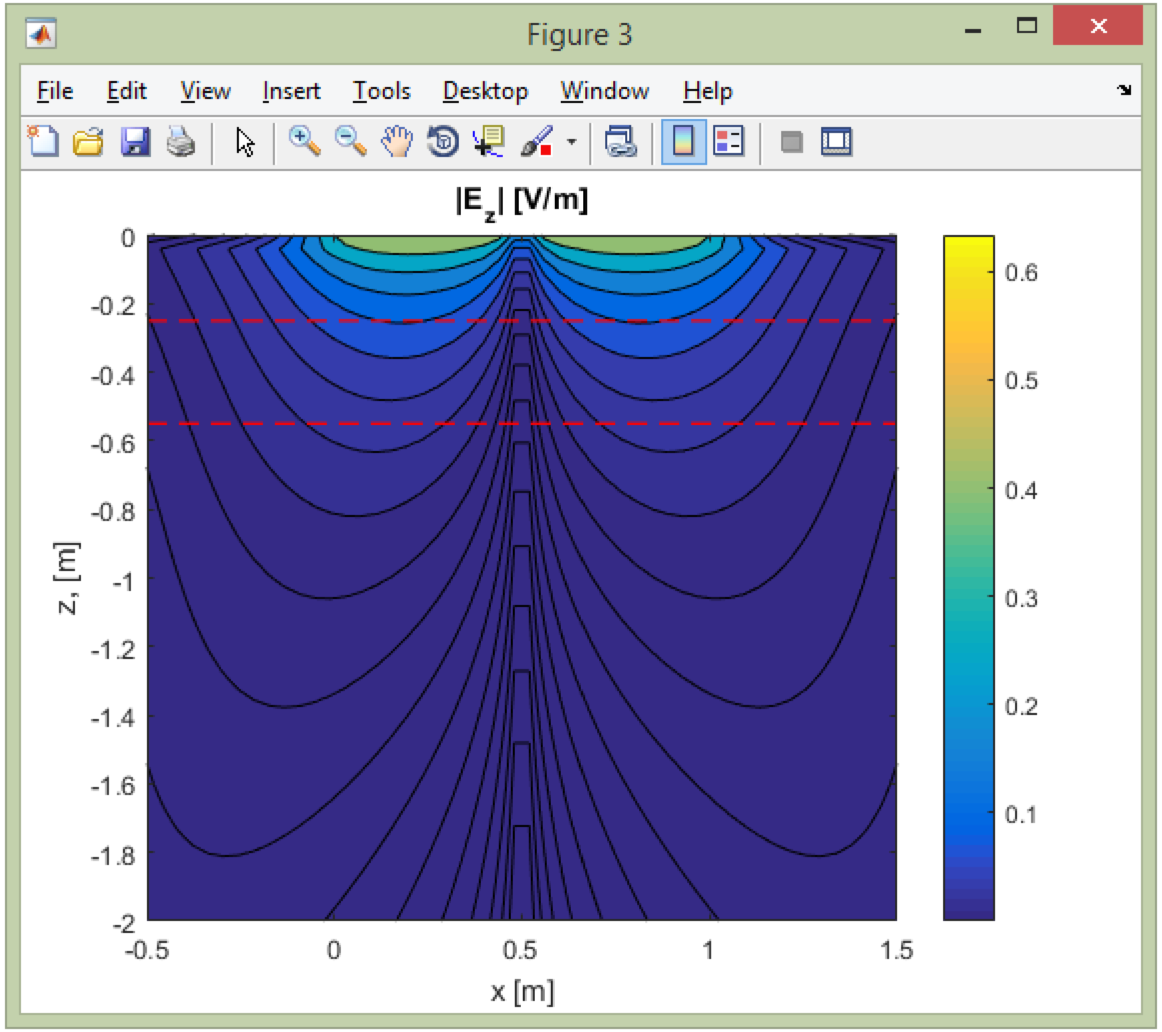
f = 10 MHz

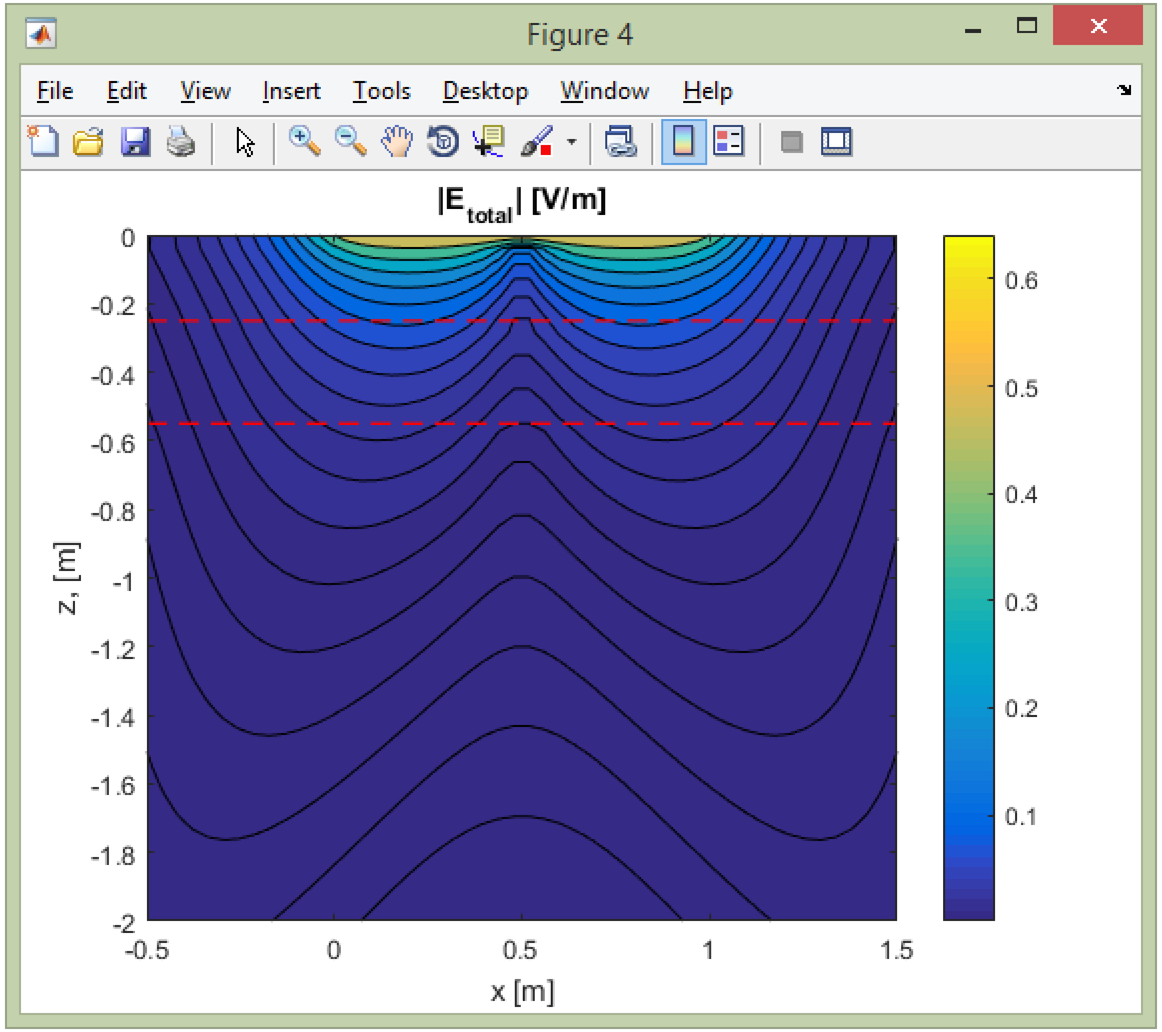




1. E vs. xz

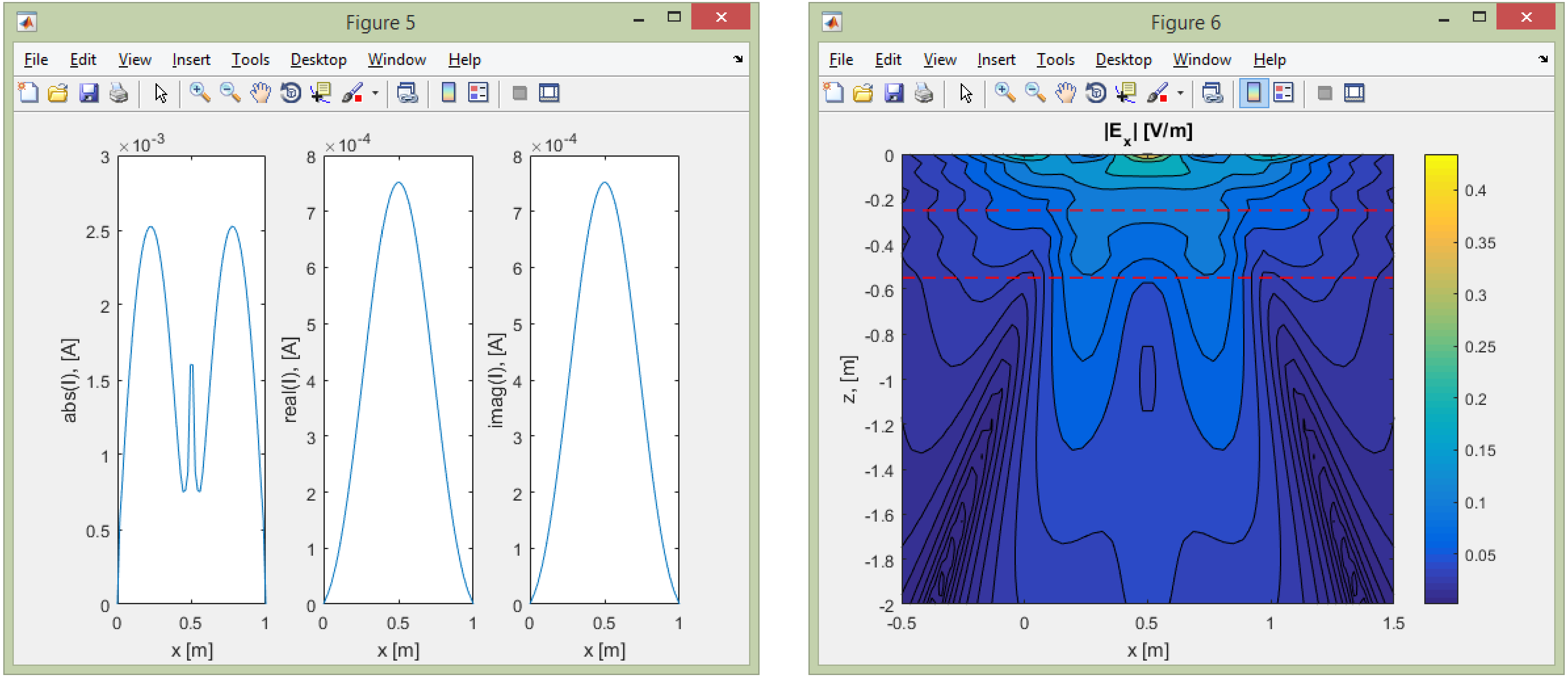
f = 10 MHz





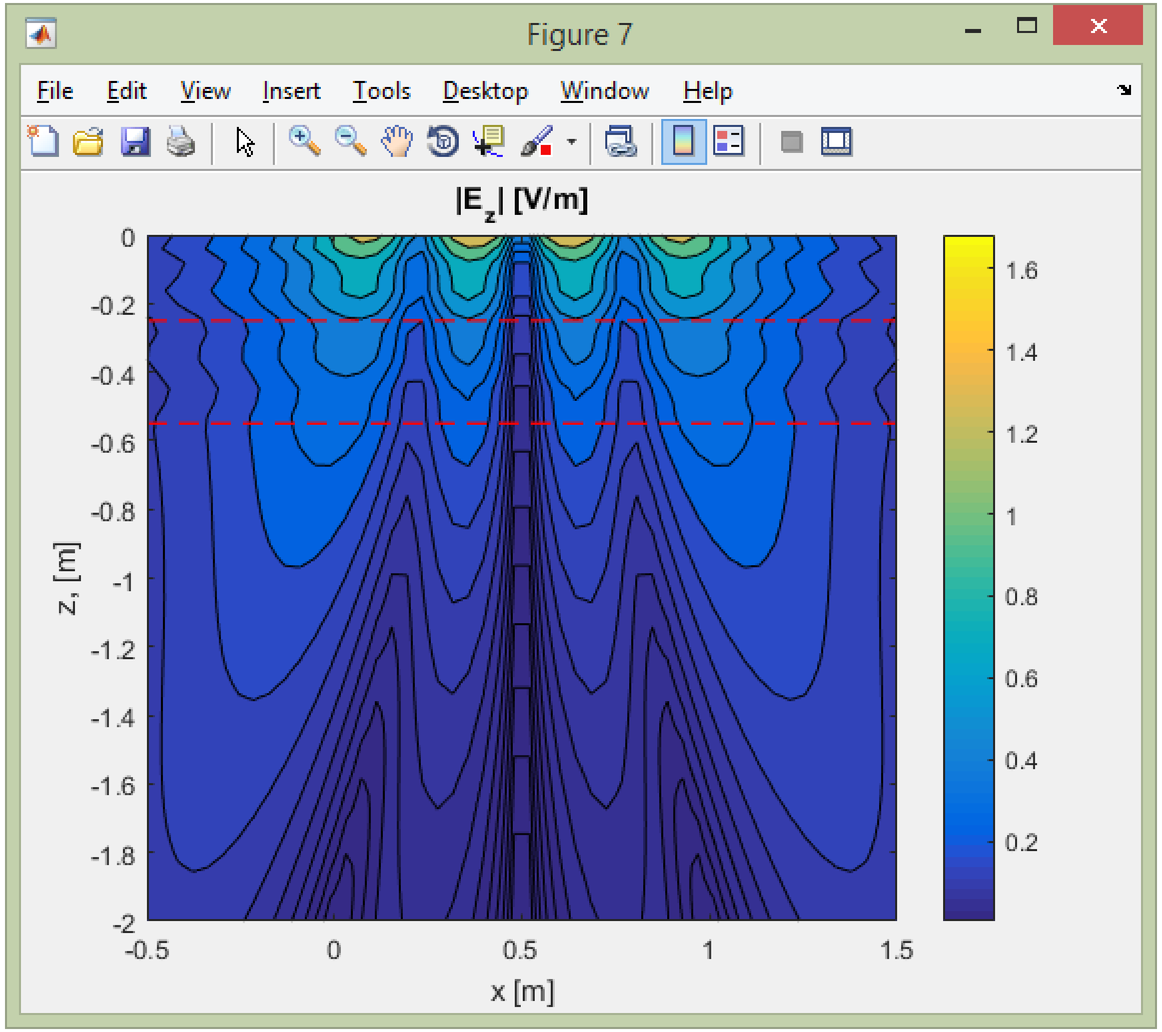
1. E vs. xz

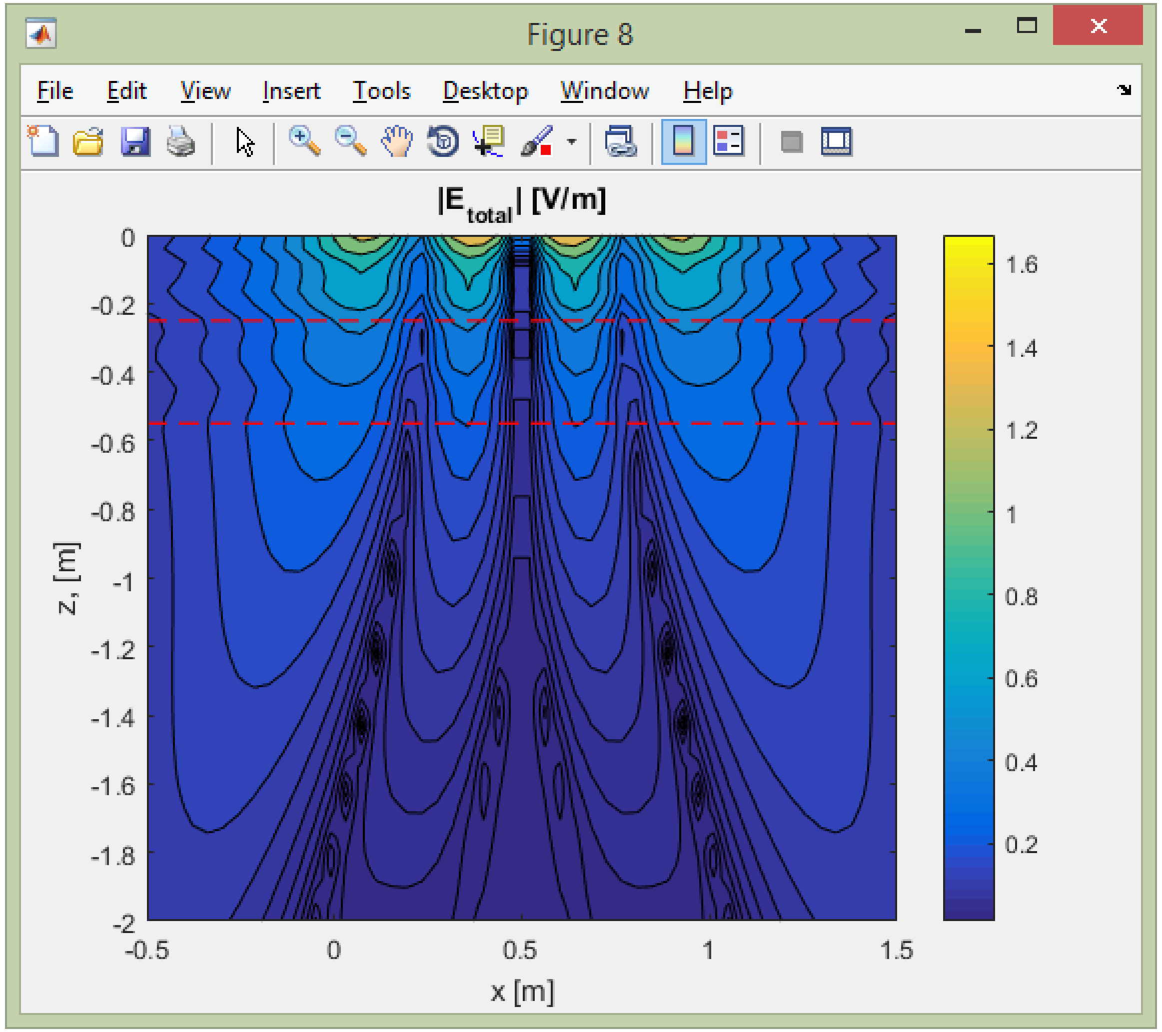
f = 300 MHz



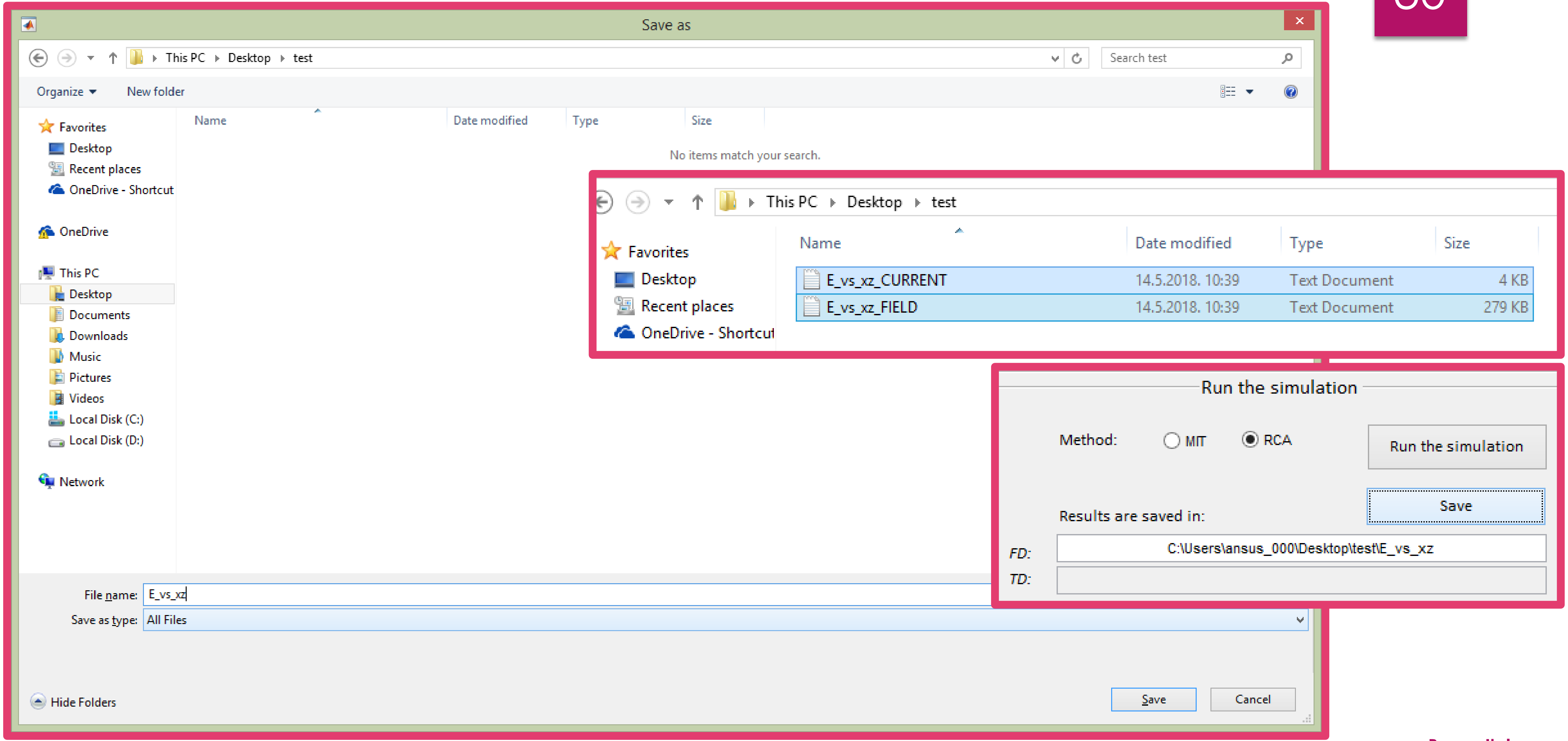
1. E vs. xz

f = 300 MHz





1. E vs. xz


Save as
This PC › Desktop › test
Search test
Organize
New folder
Favorites
Desktop
Recent places
OneDrive - Shortcut
OneDrive
This PC
Desktop
Documents
Downloads
Music
Pictures
Videos
Local Disk (C:)
Local Disk (D:)
Network
Name
Date modified
Type
Size
No items match your search.
File name: E_vs_xz
Save as type: All Files
Hide Folders
Save
Cancel
This PC › Desktop › test
Favorites
Desktop
Recent places
OneDrive - Shortcut
Name
Date modified
Type
Size
E_vs_xz_CURRENT 14.5.2018. 10:39 Text Document 4 KB
E_vs_xz_FIELD 14.5.2018. 10:39 Text Document 279 KB
Run the simulation
Method: MIT RCA
Run the simulation
Save
Results are saved in:
FD: C:\Users\ansus_000\Desktop\test\E_vs_xz
TD:

1. E vs. xz

E_vs_xz_CURRENT - Notepad

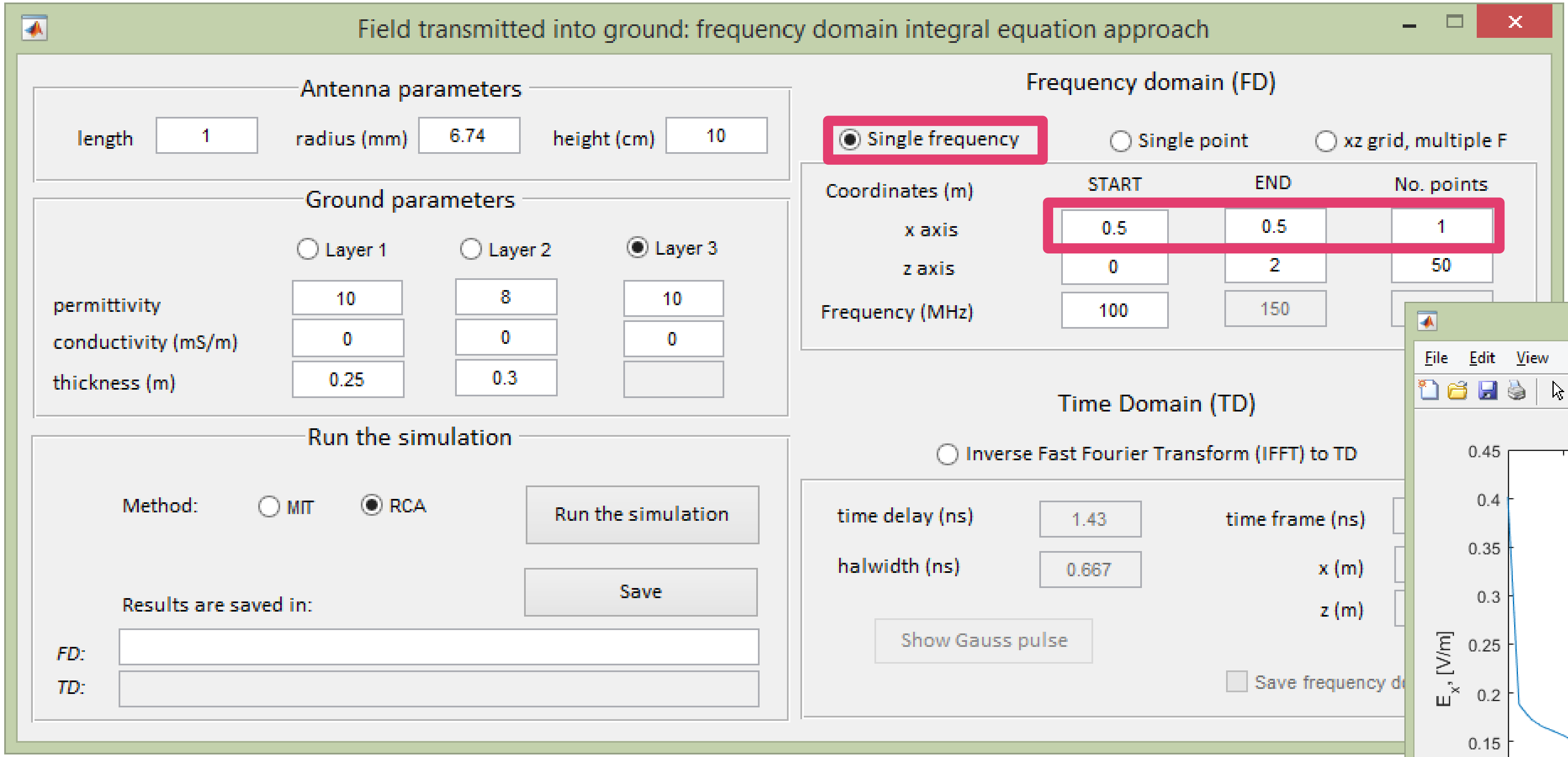
File Edit Format View Help

Freq. (MHz)	x(m)	Real(I)	Imag(I)
300000000.000000	0.000000	0.000000	0.000000
300000000.000000	0.016393	0.000011	-0.000570
300000000.000000	0.032787	0.000021	-0.000814
300000000.000000	0.049180	0.000035	-0.001096
300000000.000000	0.065574	0.000050	-0.001337
300000000.000000	0.081967	0.000069	-0.001562
300000000.000000	0.098361	0.000090	-0.001764

E_vs_xz_FIELD - Notepad

File Edit Format View Help

Freq. (MHz)	x(m)	z(m)	Real(E_x)	Imag(E_x)	Real(E_z)	Imag(E_z)
300000000.000000	-0.500000	0.000000	-0.028258	0.002993	0.093729	-0.101466
300000000.000000	-0.459184	0.000000	-0.029324	-0.012547	0.145006	-0.043515
300000000.000000	-0.418367	0.000000	-0.022069	-0.028614	0.161904	0.040404
300000000.000000	-0.377551	0.000000	-0.006098	-0.040939	0.131095	0.130706
300000000.000000	-0.336735	0.000000	0.016947	-0.044938	0.049877	0.200821
300000000.000000	-0.295918	0.000000	0.043190	-0.036573	-0.070137	0.222559
300000000.000000	-0.255102	0.000000	0.066621	-0.013279	-0.201731	0.173307
300000000.000000	-0.214286	0.000000	0.079468	0.025125	-0.303865	0.044179
300000000.000000	-0.173469	0.000000	0.072807	0.075483	-0.326867	-0.151681
300000000.000000	-0.132653	0.000000	0.037764	0.130120	-0.221772	-0.370922
300000000.000000	-0.091837	0.000000	-0.030657	0.175601	0.042623	-0.533297


Field transmitted into ground: frequency domain integral equation approach
Antenna parameters
length 1
radius (mm) 6.74
height (cm) 10
Ground parameters
Layer 1
Layer 2
Layer 3
permittivity 10 8 10
conductivity (mS/m) 0 0 0
thickness (m) 0.25 0.3
Run the simulation
Method: MIT RCA
Run the simulation
Save
Results are saved in:
FD:
TD:
Frequency domain (FD)
Single frequency
Single point
xz grid, multiple F
Coordinates (m)
START
END
No. points
x axis 0.5 0.5 1
z axis 0 2 50
Frequency (MHz) 100 150
Time Domain (TD)
Inverse Fast Fourier Transform (IFFT) to TD
time delay (ns) 1.43
halwidth (ns) 0.667
time frame (ns)
x (m)
z (m)
Show Gauss pulse
Save frequency d

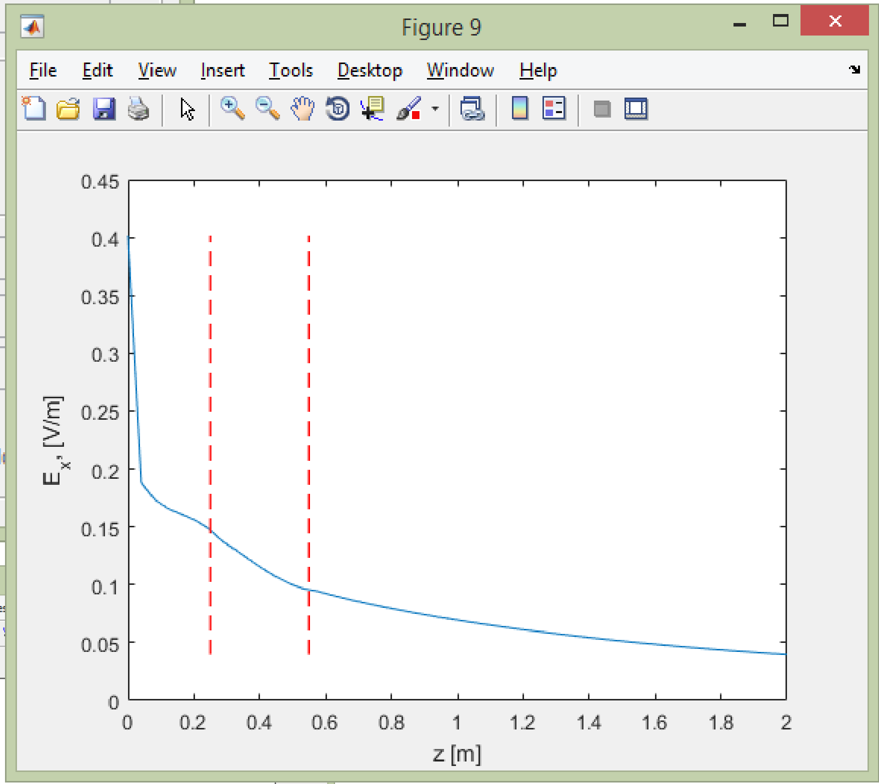


Figure 9
File Edit View Insert Tools Desktop Window Help
E_x, [V/m]
z [m]

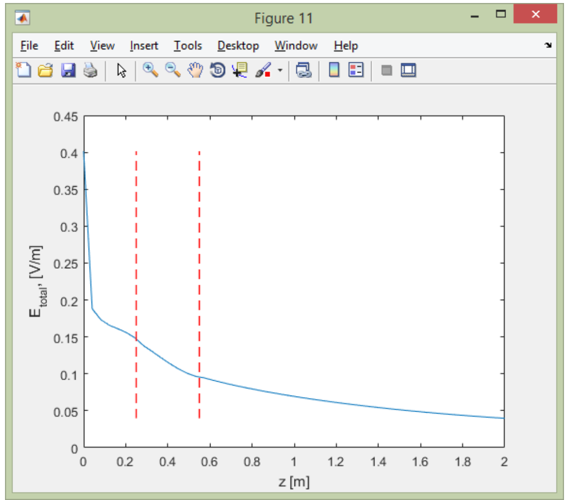
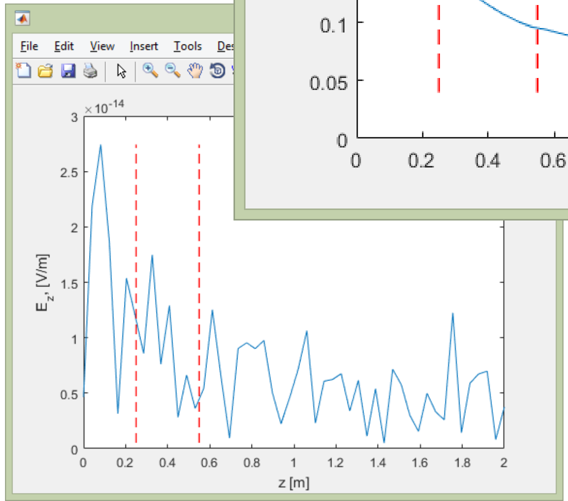
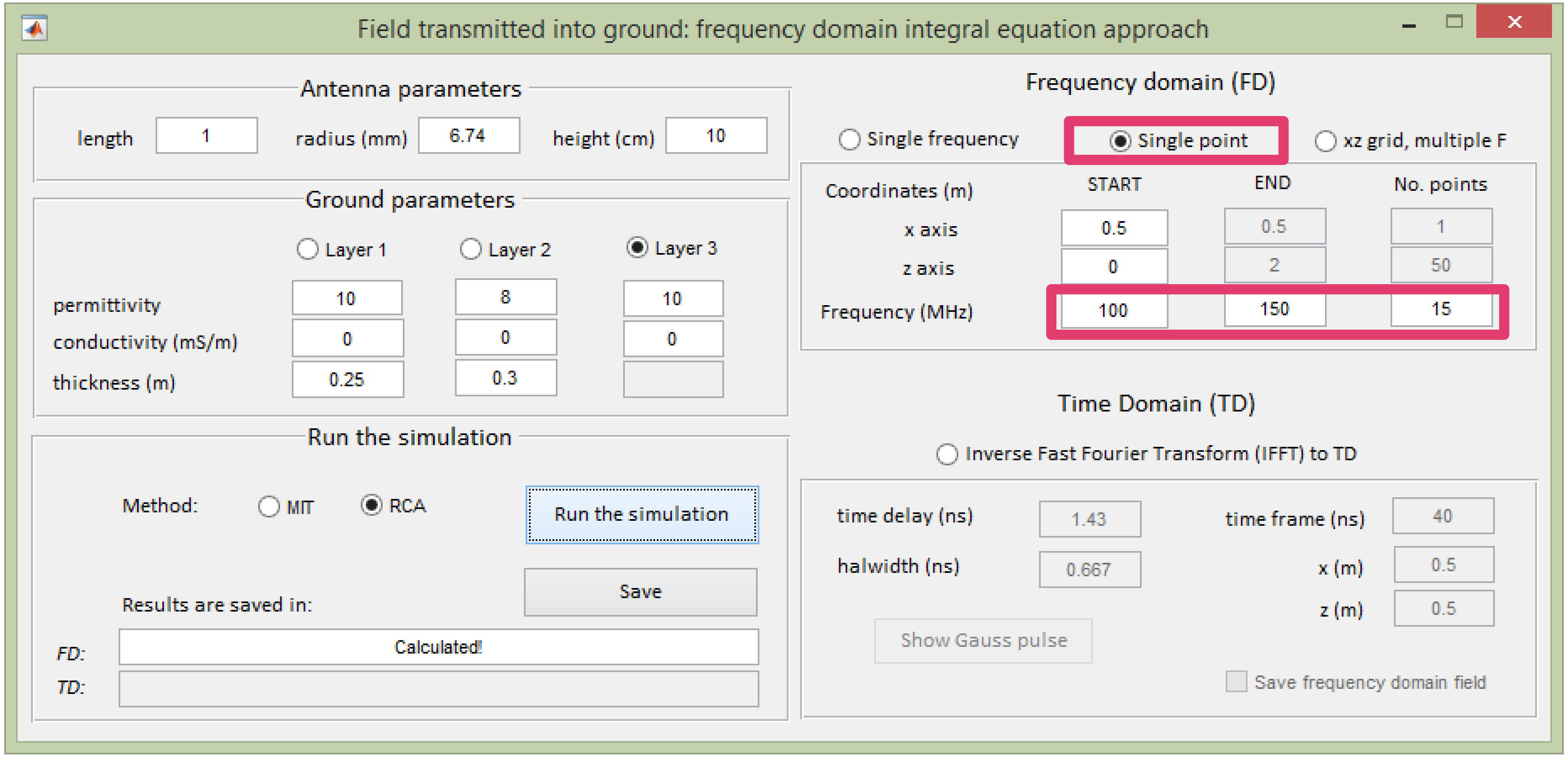


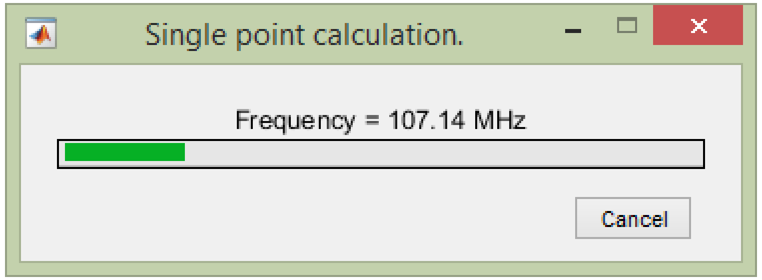
Figure 11
File Edit View Insert Tools Desktop Window Help
E_{total}, [V/m]
z [m]

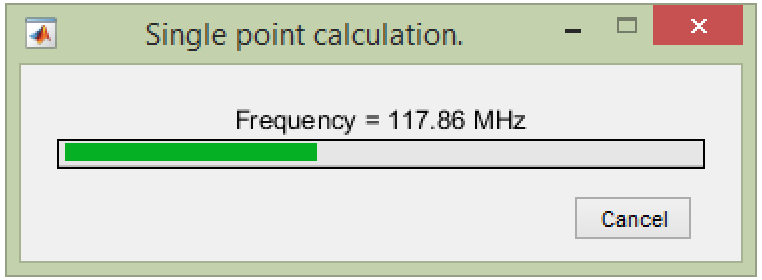

File Edit View Insert Tools
$\times 10^{-14}$
E_z, [V/m]
z [m]

2. E vs. z


Field transmitted into ground: frequency domain integral equation approach
Antenna parameters
length 1
radius (mm) 6.74
height (cm) 10
Ground parameters
Layer 1
Layer 2
Layer 3
permittivity 10 8 10
conductivity (mS/m) 0 0 0
thickness (m) 0.25 0.3
Run the simulation
Method:
MIT
RCA
Run the simulation
Save
Results are saved in:
FD:
Calculated!
TD:
Frequency domain (FD)
Single frequency
Single point
xz grid, multiple F
Coordinates (m)
START
END
No. points
x axis 0.5 0.5 1
z axis 0 2 50
Frequency (MHz) 100 150 15
Time Domain (TD)
Inverse Fast Fourier Transform (IFFT) to TD
time delay (ns) 1.43
halwidth (ns) 0.667
time frame (ns) 40
x (m) 0.5
z (m) 0.5
Show Gauss pulse
Save frequency domain field

3. E vs. f


Single point calculation.
Frequency = 107.14 MHz
Cancel


Single point calculation.
Frequency = 117.86 MHz
Cancel

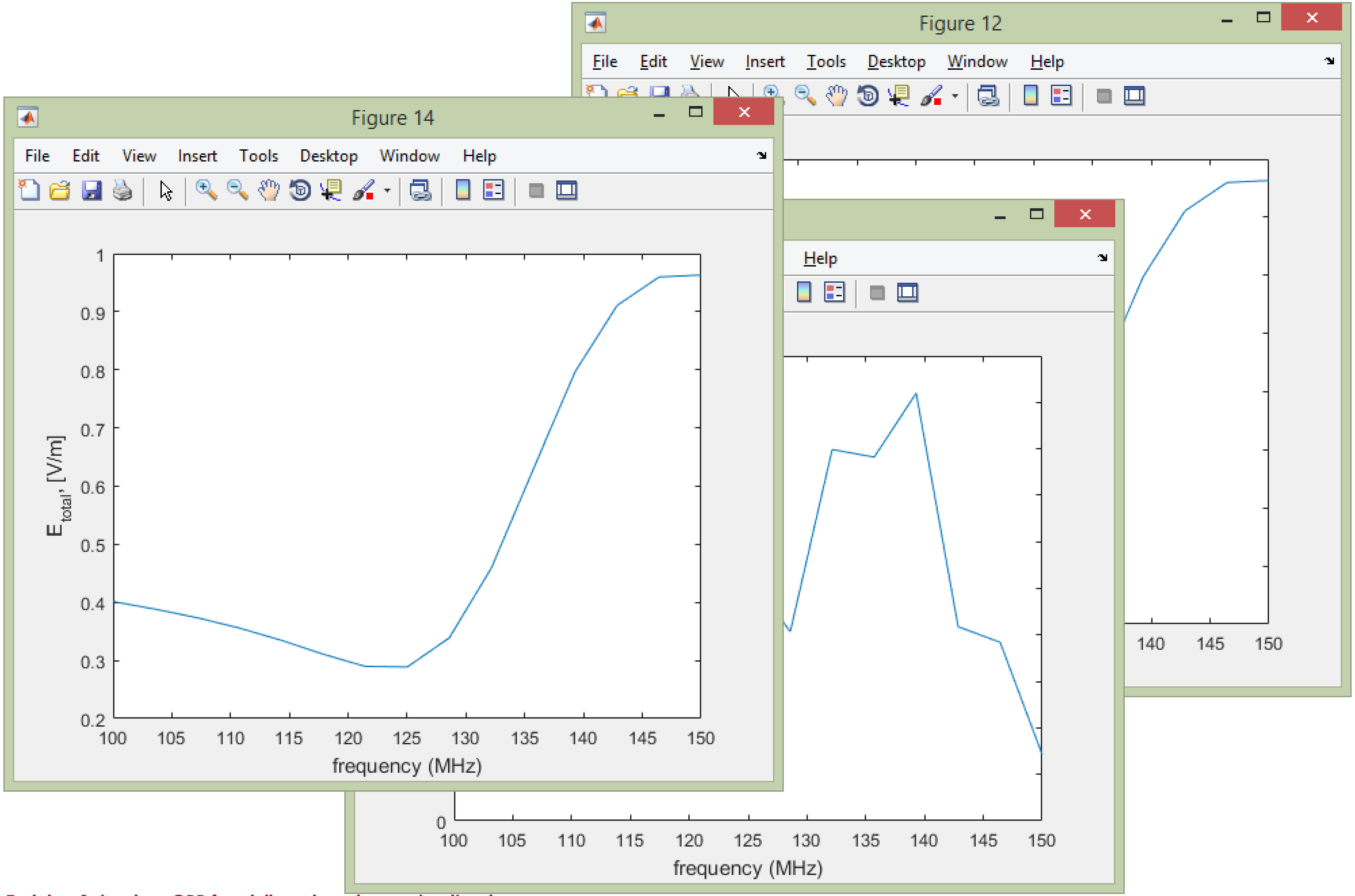
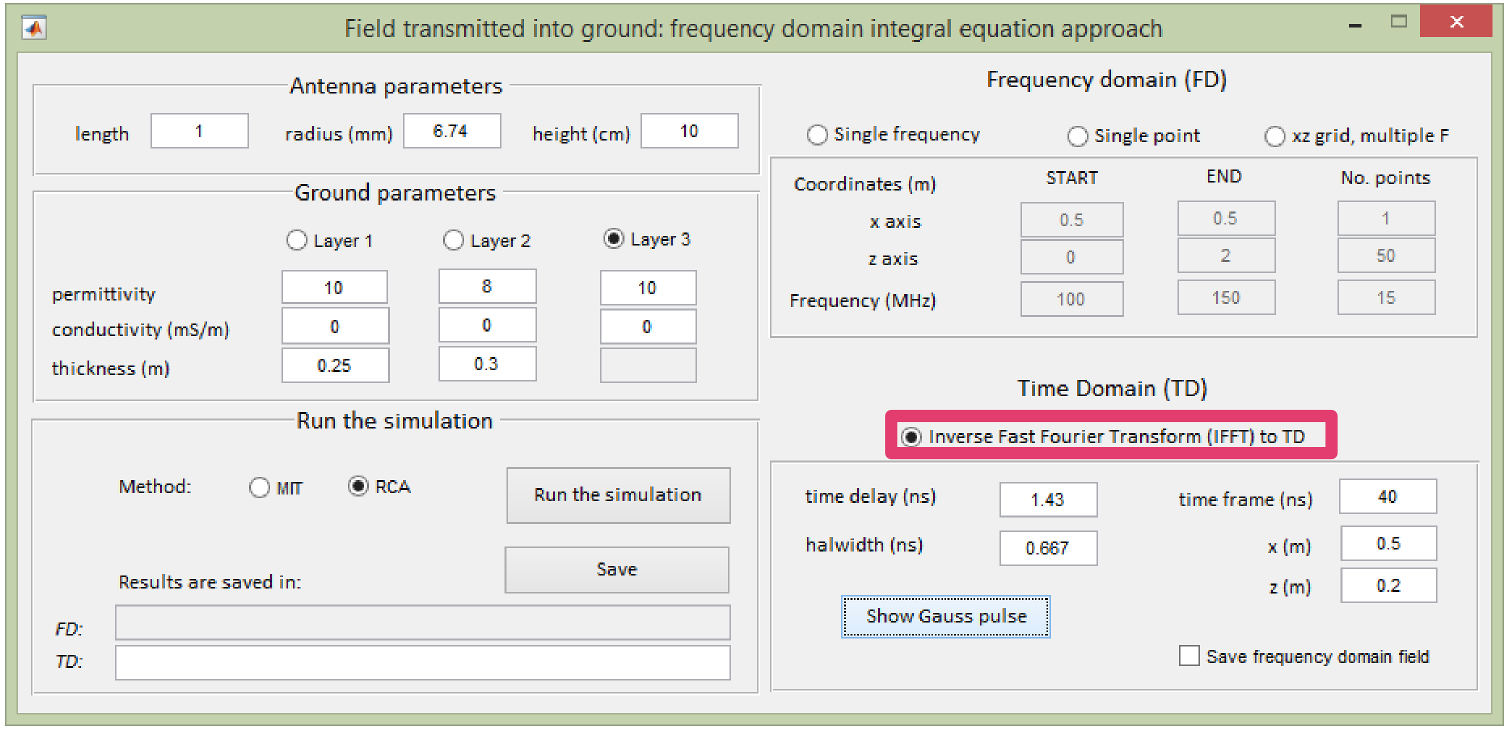


Figure 12
File Edit View Insert Tools Desktop Window Help
140 145 150
Figure 14
File Edit View Insert Tools Desktop Window Help
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
E_total, [V/m]
100 105 110 115 120 125 130 135 140 145 150
frequency (MHz)
Help
0
100 105 110 115 120 125 130 135 140 145 150
frequency (MHz)

3. E vs. f

3. E vs. time


Field transmitted into ground: frequency domain integral equation approach
Antenna parameters
length 1
radius (mm) 6.74
height (cm) 10
Ground parameters
Layer 1
Layer 2
Layer 3
permittivity 10 8 10
conductivity (mS/m) 0 0 0
thickness (m) 0.25 0.3
Run the simulation
Method: MIT RCA
Run the simulation
Save
Results are saved in:
FD:
TD:
Frequency domain (FD)
Single frequency
Single point
xz grid, multiple F
Coordinates (m) START END No. points
x axis 0.5 0.5 1
z axis 0 2 50
Frequency (MHz) 100 150 15
Time Domain (TD)
Inverse Fast Fourier Transform (IFFT) to TD
time delay (ns) 1.43
halwidth (ns) 0.667
time frame (ns) 40
x (m) 0.5
z (m) 0.2
Show Gauss pulse
Save frequency domain field

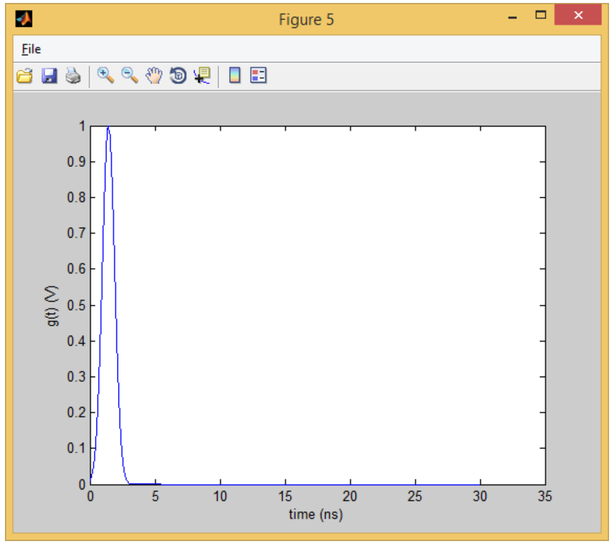


Figure 5
File
g(t) (V)
time (ns)

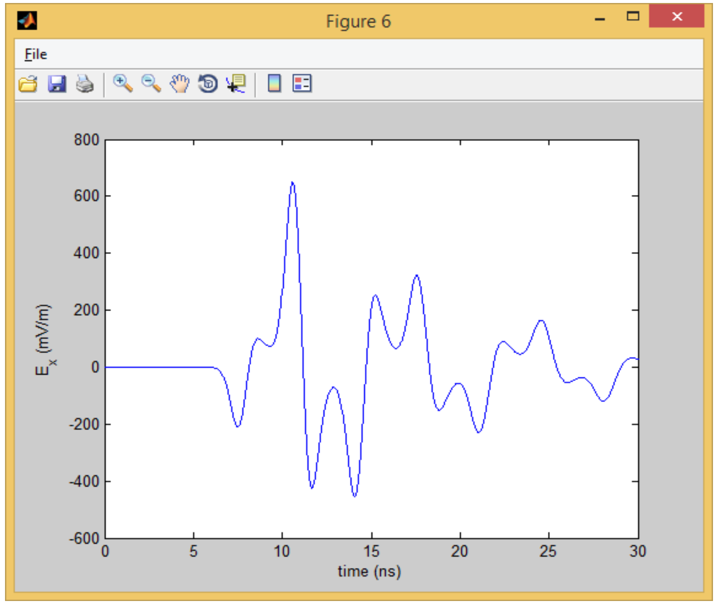


Figure 6
File
E_x (mV/m)
time (ns)

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[3] A. Šušnjara, D. Poljak, S. Šesnić, V. Dorić “Time Domain Integral Equation versus Frequency Domain Boundary Element model for calculation of Transmitted Electrical Field for Ground Penetrating Radar (GPR) Antenna

[4] A. Šušnjara, D. Poljak, V. Dorić, “Electric Field Radiated By a Dipole Antenna Above a Lossy Half Space: Comparison of Plane Wave Approximation with the Modified Image Theory Approach,” SoftCOM conference, Split, 2017

[5] A. Šušnjara, V. Dorić, D. Poljak, “ Electric Field Radiated By a Dipole Antenna and Transmitted Into a Two-Layered Lossy Half Space,” submitted for SpliTECH conference, Split, 2018