Manual for WCT EM-IMG Package

Windows Version

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Content

Cont.

- Imaging performance comparison between ideal dipole and real antenna, with measurement data from antenna
- Advance functionality
  - Normalize the image by source field
  - Use E field magnitude to imaging instead of E field
- Result displaying in WCT GUI
- Tutorial/demo package
  - 5 group of cases.
    - Groups 1 - 3 use ideal point dipole source and point receiver, include cases for imaging scheme I, II & III.
    - Group 4 is for antenna imaging, all cases use scheme III only
    - Group 5 is demo for how to use adjusted signal to obtain a better imaging region
  - The imaging performance comparison between ideal dipole and real antenna is provided also

Introduction

- Wavenology EM-IMG Package uses the Reversed Time Migration method to image a specified 3D region in a 3D simulation space.
- Wavenology EM-IMG imaging package can produce an image with three kinds of transmitters/receivers scan schemes, as shown in the following pages
  - Single simulation --- (support multiple source excitation at one time)
  - Separated transmitters array and receivers array --- (single source excitation at one time)
  - Switching transmitters and receivers array --- (single source excitation at one time)
- All three imaging scheme include two steps
  - A forward simulation
  - A backward simulation

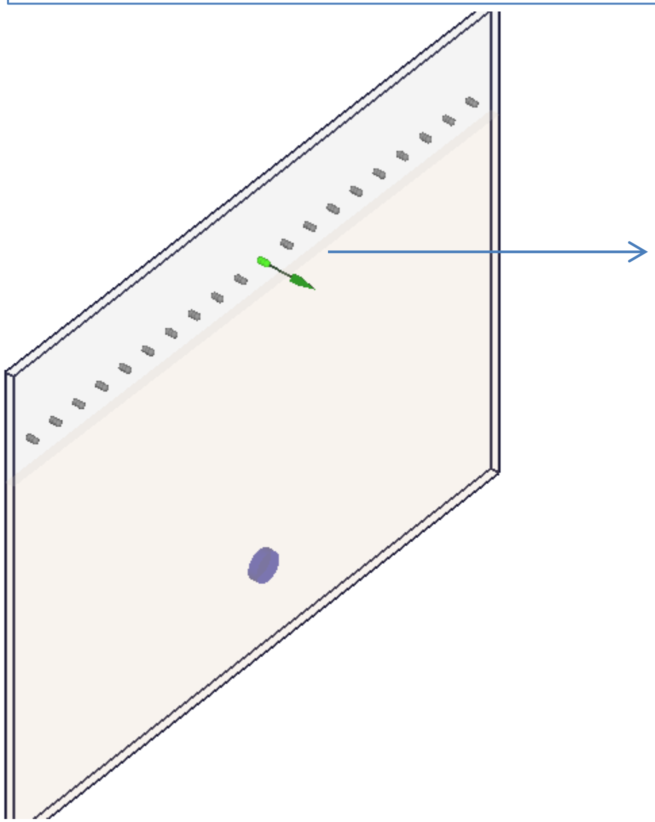
Requirements

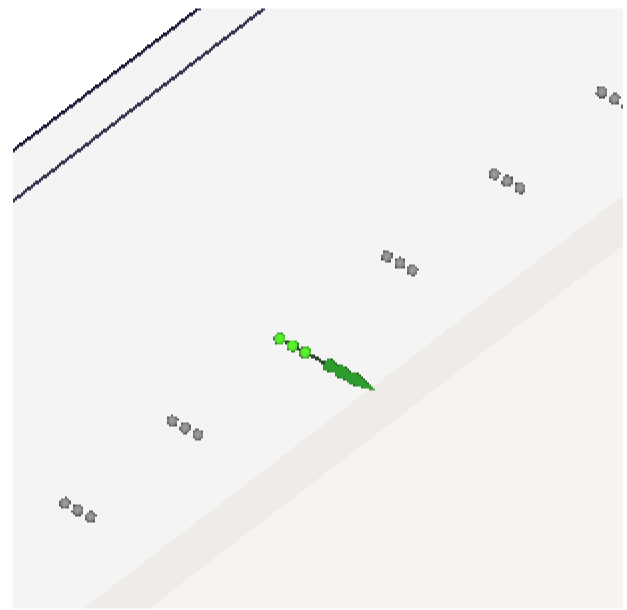
- Transmitters
  - Ideal Electric dipole
  - Lumped port
- Receivers (Sensor)
  - Ideal point Receiver to receiving E field
  - Lumped ports to detect voltage
- Measured signal
  - transient E field
  - transient voltage
- Material property in an imaging simulation
  - Except PEC, the material should be lossless, or the conductivity is very small

Simulation Schemes

Scheme I: Single simulation

In this scheme, multiple sources can be simultaneously excited with individual pulse.



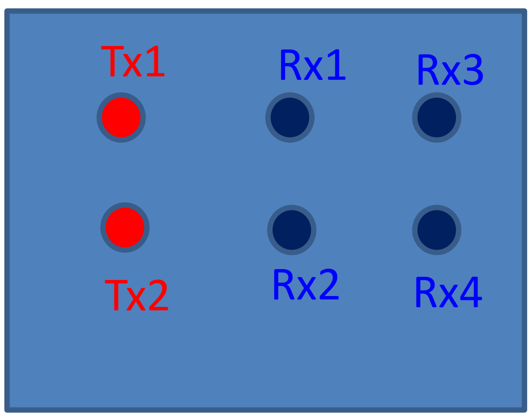


Here, there are 3 sources that will be simultaneously excited in one simulation

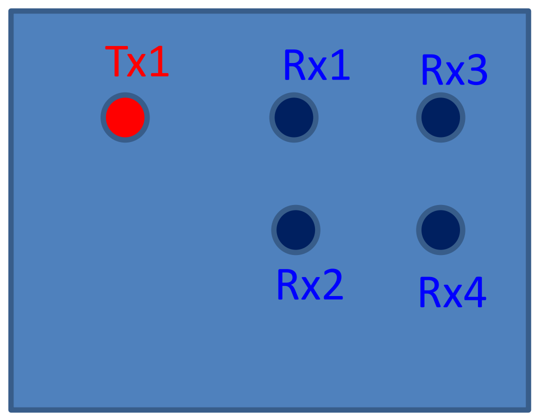
Scheme II: Separated transmitters array and receivers array

In this scheme,

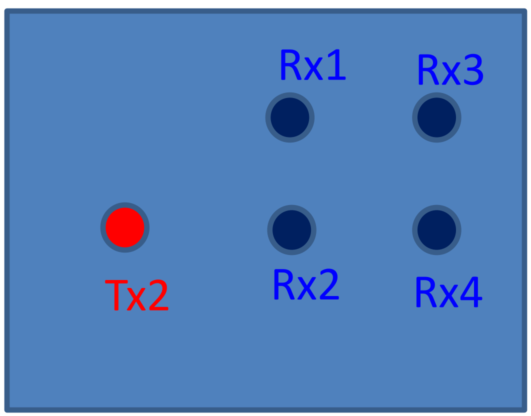
- user can define multiple sources, if we say it is N.
- user can define multiple receivers
- sources array is separated from receiver array
- the simulation will include N runs. Each will excite one source only, but the receiver array keeps the same in each run. Each source can use individual pulse.



T/R array in definition



Run1

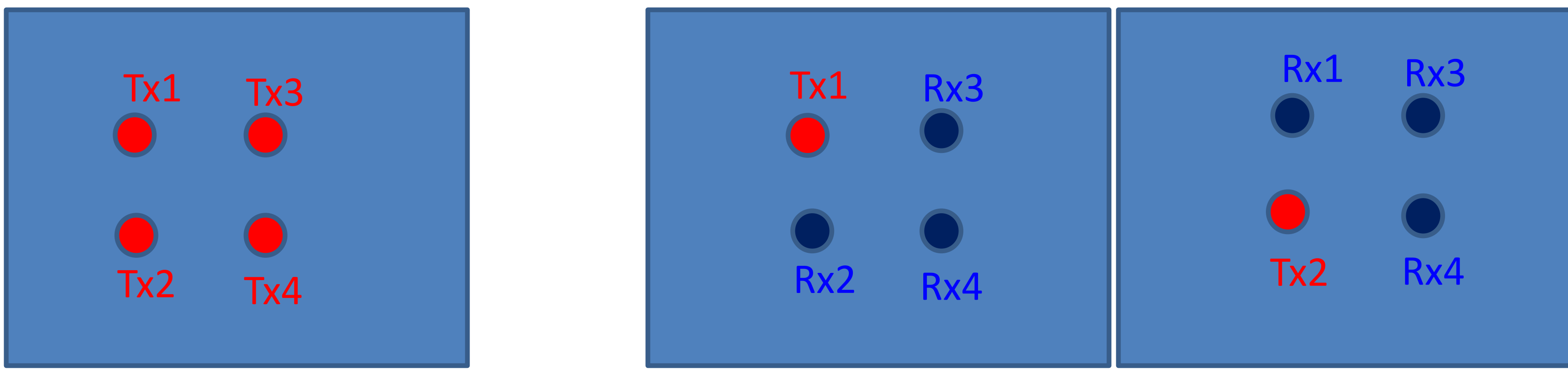


Run2

Scheme III: Switching transmitters/receivers array

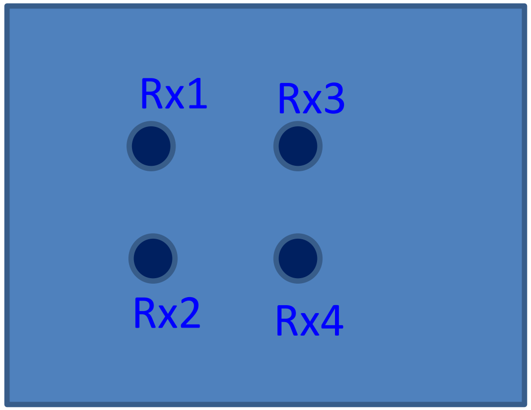
In this scheme,

- user can define multiple receivers (or multiple sources), if we say it is N. (note: must be receivers only or source only, can not mix)
- the simulation will include N runs.
  - If define as receiver only, each run will convert one receiver to source and excite it only. Each source will use the same pulse, which is defined as the WCT project pulse.
  - If define as source only, each run will excite one source, other sources will be converted as receiver. Each source can use individual pulse.

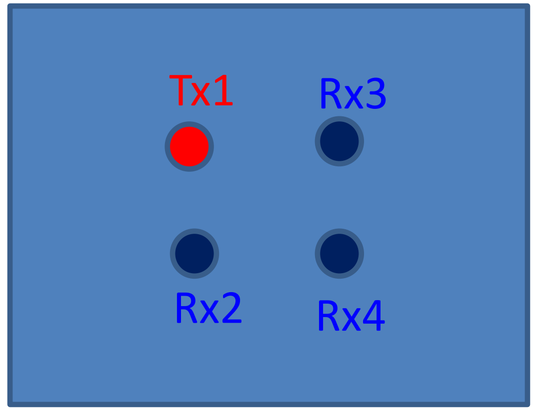


T/R array in definition | Run1 | Run2 | ....

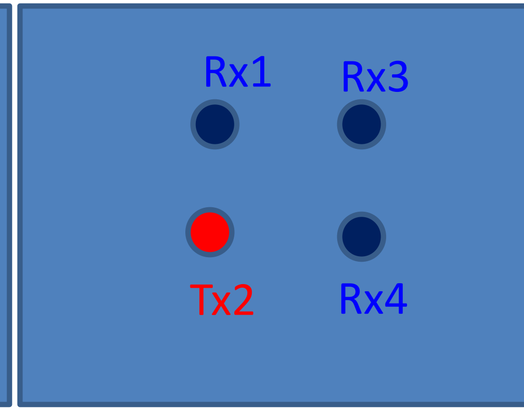
Or



T/R array in definition



Run1



Run2 ....

Receiver Naming System

- In defining receiver's name in WCT imaging package, please make sure all receivers' name is following the ACSII sequence as following examples,
  - if the receiver number is < 10, user can define as: obv1, obv2, … obv9
  - if the receiver number is in the range 10-99, user can define as: obv01, obv02, … obv09, obv10, obv11, … obv99

We recommend this is due to WCT I/O the trace data file and mapping to receiver with a ASCII sequence. For a 3-obv system as obv1, obv2, obv10, not matter how to define the sequence of these 3 obv. In WCT GUI, the ASCII sequence is always: obv1, obv10, obv2. This will mess the trace sequence after loading and cause imaging problem.

Recorded Field on Receiver

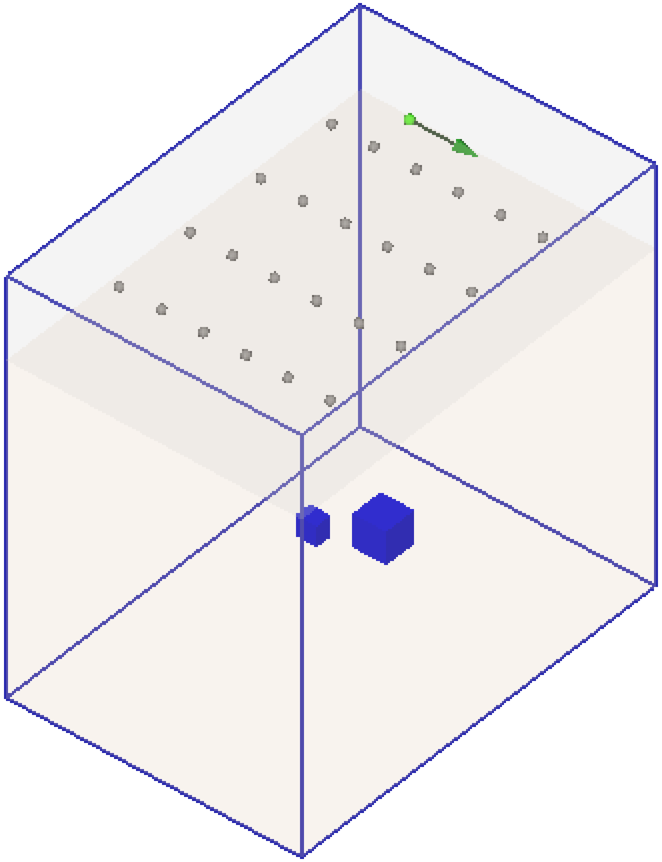
- In defining the receiver capturing field in imaging, it should be single component only, for example, Ex, or Ey, or Ez, or Hx, or Hy, or Hz only. Please do not combine two or more components.

- The reason is that, the current imaging code will convert receiver to source with a polarization. With more than one components, there is challenge in defining the source.

- If user want to use more than one components to imaging, the workaround is defining multiple observers at the same position, which captures single component only.

Setup an Imaging Simulation

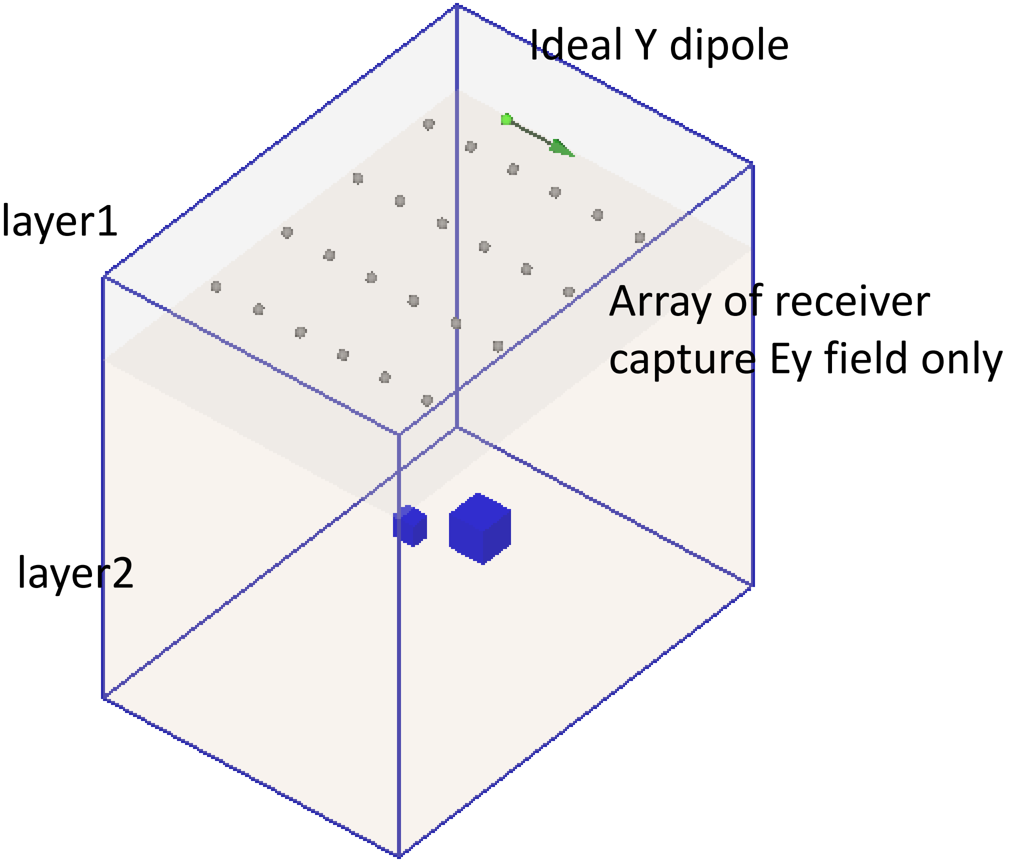
1. Define a WCT EM simulation case
   - ➢ With some kind of source
   - ➢ Array of receivers



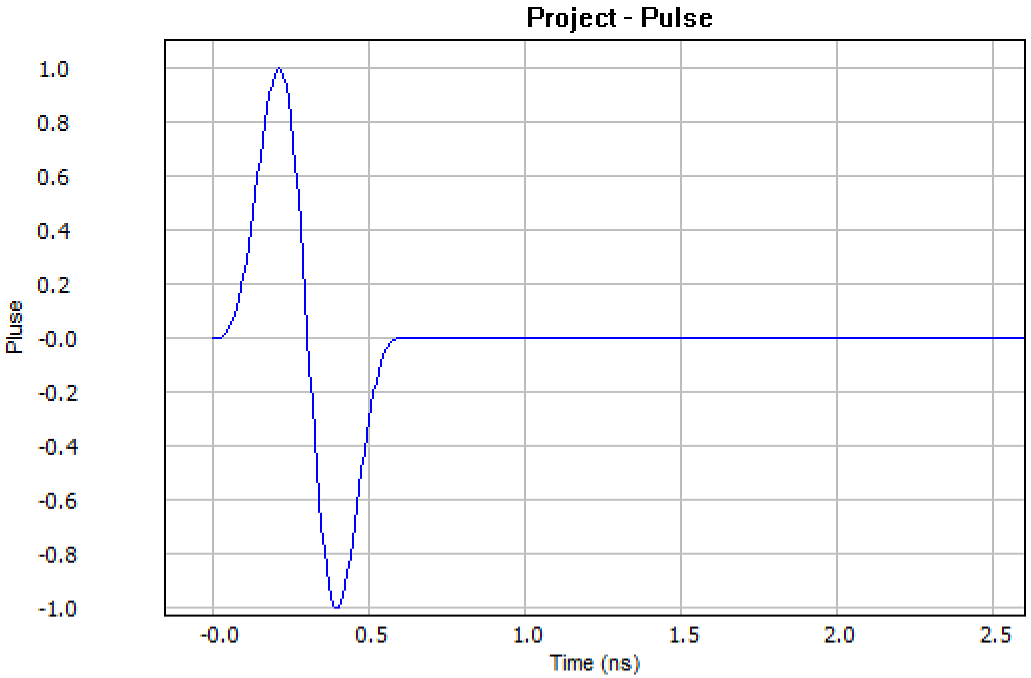
The right figure is a demo of a GPR case.

It has 2 layers media, one ideal point Y dipole source, and an array of receiver to capture Ey field only.

There is two objects in the bottom layer.

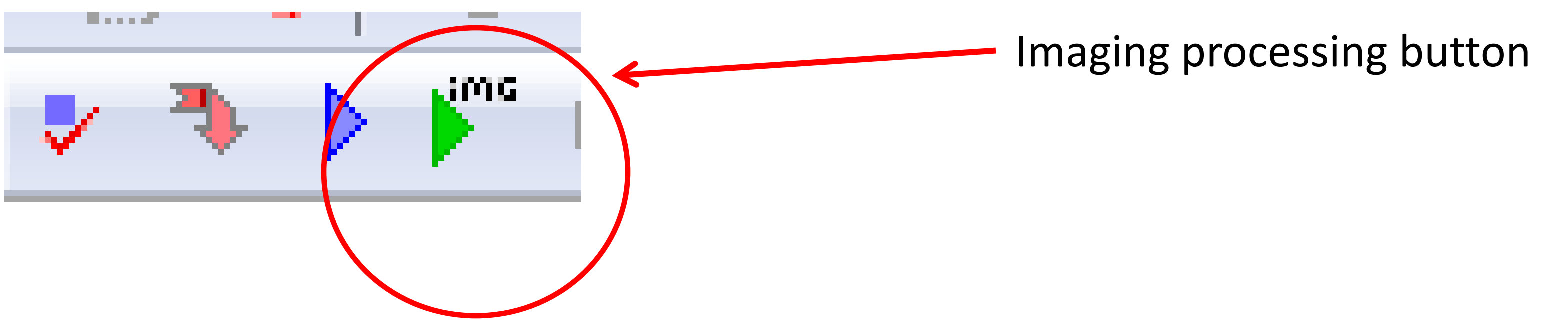


The source pulse in this case is a BHW pulse with fmax = 5.5 GHz, as shown in the right figure.



Imaging Processing

- After the case setup is finished, user can use Wavenology EM-IMG solver to image any region in the computational domain.



Imaging Processing Setup

Imaging scheme

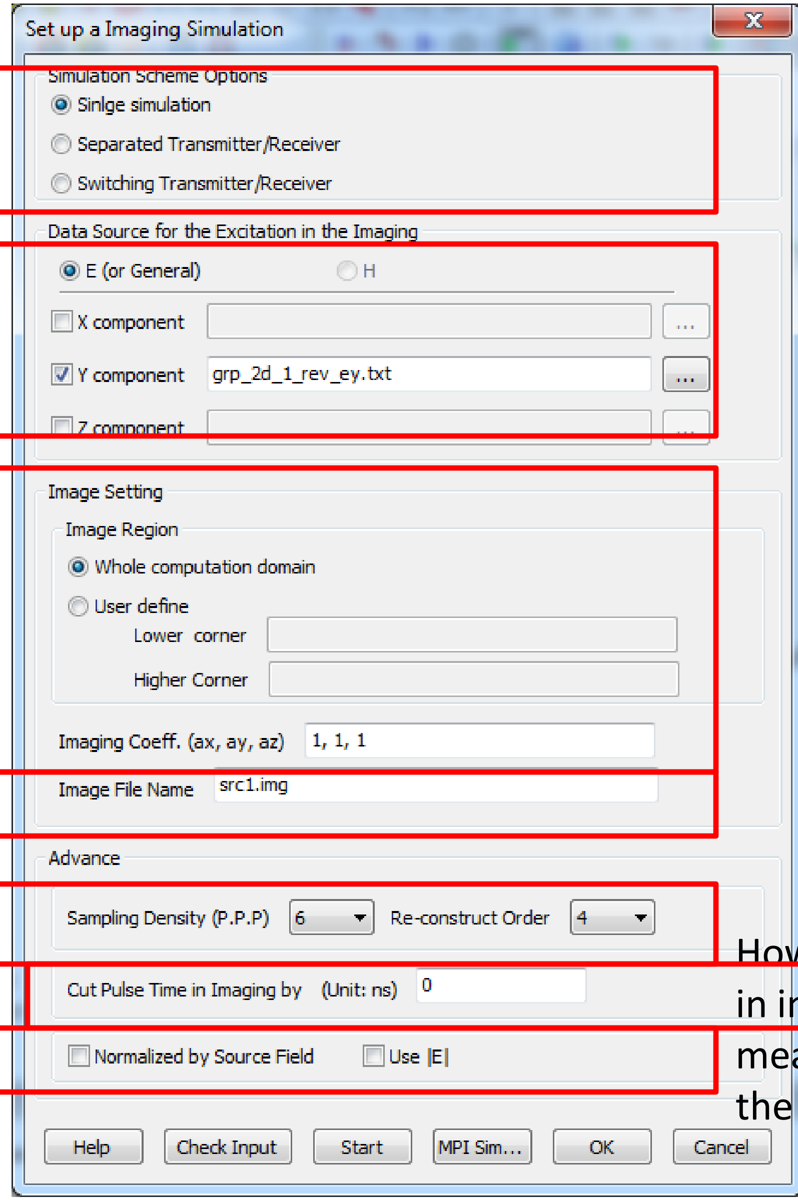
Signal on the receiver in the backward processing. If user want to use the signal outside the WCT EM package, it should follow the format as shown in the following slides.

Imaging region & the weights of E components used in imaging. a_i is for E_i component (i=x, y, z)

Image file name. The format will be provided in the following slides.

Advanced parameters in control imaging. Please do not change it.

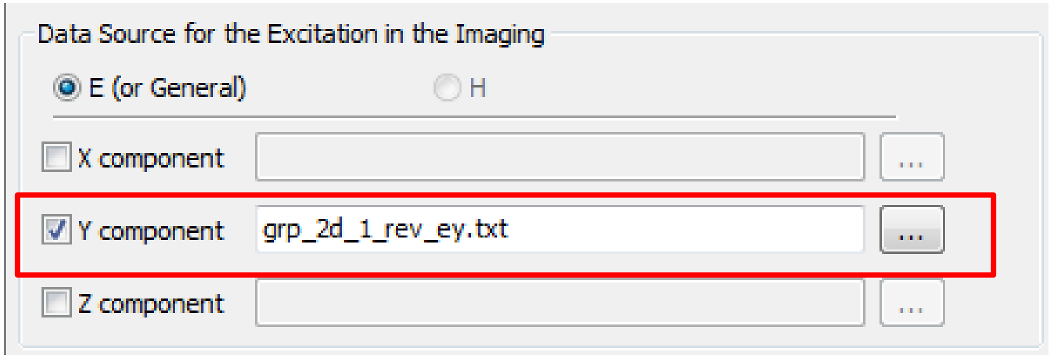
Advanced imaging control.



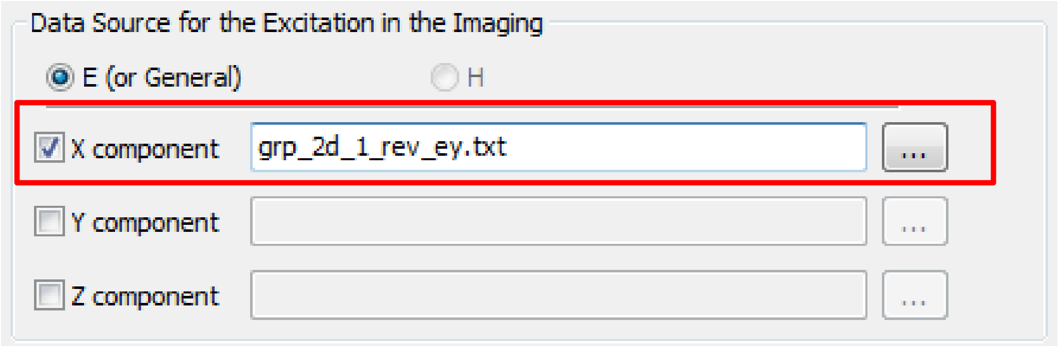
How to use the input signal in imaging. Default is 0, means that do not process the input signal.

Note on the measured data

For ideal point sensor with E field signal, user need to specify which component will be used for imaging, as following figure, we set the measured data as Y component



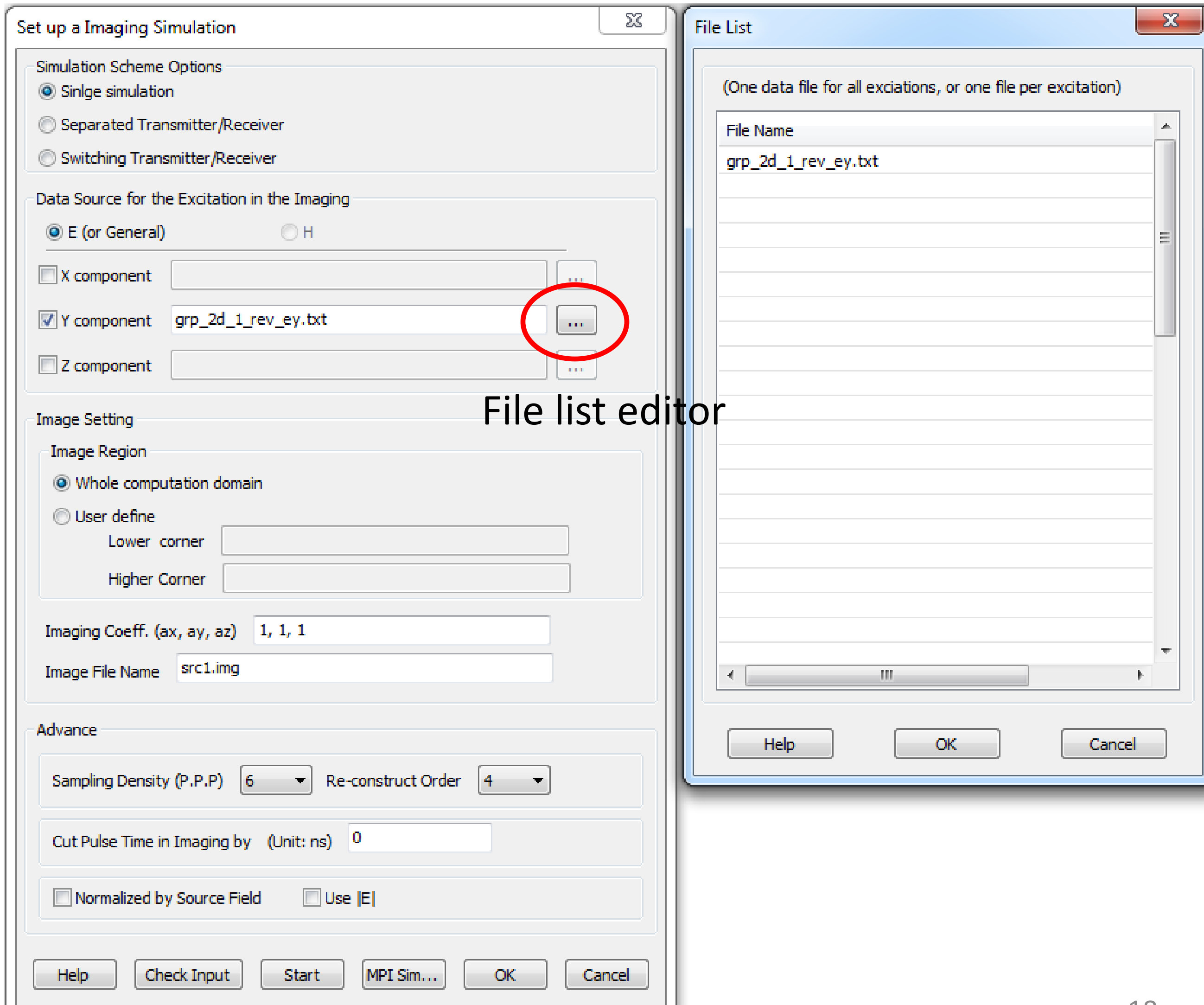
For voltage data (general data type), please place the signal file as “X component”.



Imaging Processing Setup *Cont.*

Signal files for backward simulation

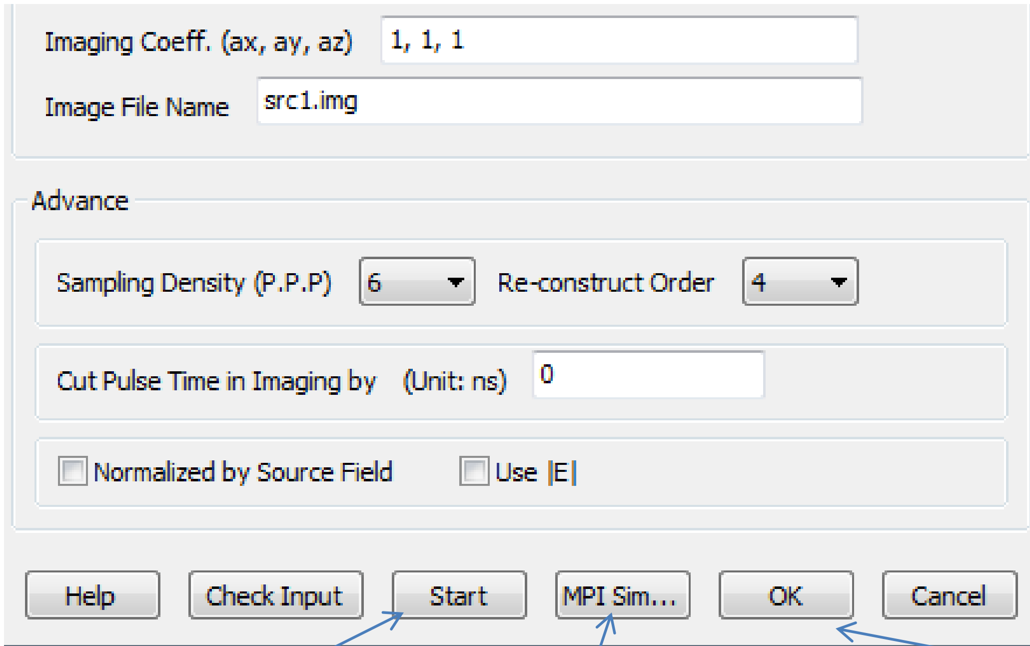
In general, for scheme II & II, there are multiple runs in a simulation, and the signal for each source is stored in one file only. So, it requires multiple data files.



Imaging Processing Setup

Cont.

After the imaging setup is finish, user have several action options



Start a "Forward+backward" processing to generate image.

This setup will be stored also for the future usage.

Generate a project file for this "Forward+backward" processing by WCT EM MPI solver.

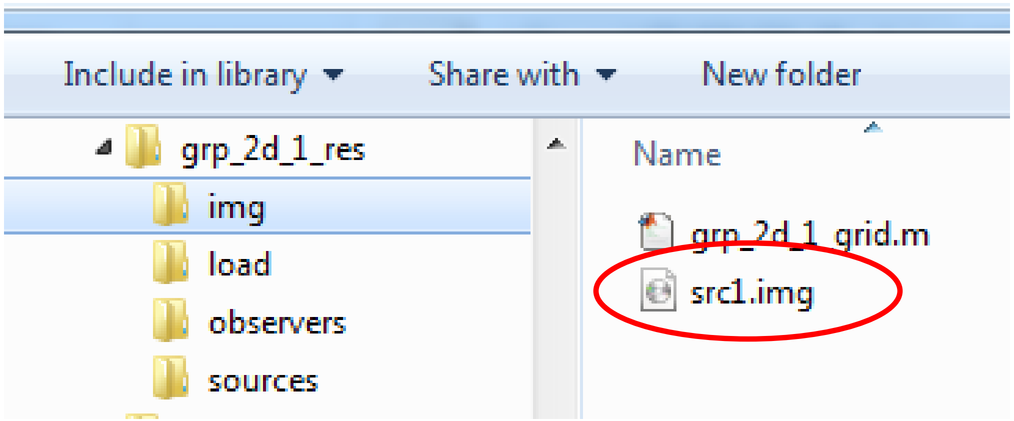
This setup will be stored also for the future usage.

Save this setup for future usage. But do not make processing right now.

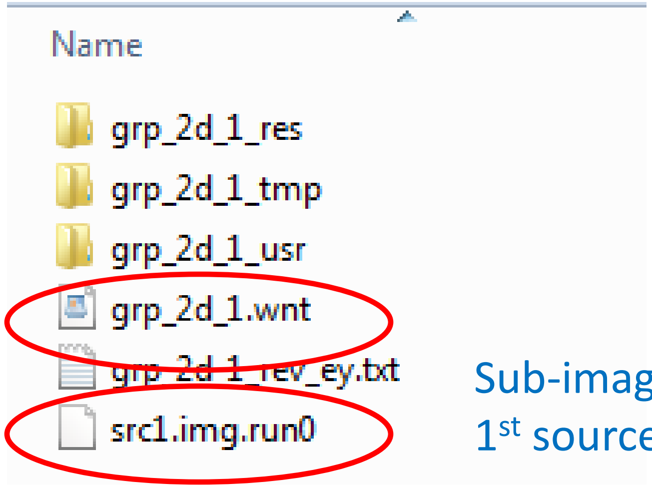
```
Log
Simulation is completed normally at 01/06/16 17:55:05.  Total simulation time is 2 seconds  (2 sec)
..............................................................................
 Run 3 RTM backward simulation is completed ...... Start next run RTM forward simulation..........
..............................................................................

Validating the design
          Body positons, layer positons, observer positons, user defined control points, source combination are verified.

Simulation has been started at 01/06/16 17:55:05 by Wavenology EM 1.9.0 (x64)
          Preprocessing...
                    ........Begin to generate snapshot mesh...
                    ........end of snapshot mesh generation...
                    Domains: 1 x 1 x 1,  Cells: 100 x 3 x 76,  Delta time: 2e-011 sec,  Mesher version: 1,  CPU Time: 0.076 sec,  Explicit solver is used.  Single thread is used.
          Time Stepping...
          Postprocessing... Last time window: 20 ns,  Number of time step: 1000,  Time for time-stepping: 0.832 sec,  Postprocessing: 0.011 sec
Simulation is completed normally at 01/06/16 17:55:06.  Total simulation time is 1 second  (1 sec)
..............................................................................
 Run 4 RTM forward simulation is completed ...... Start RTM backward simulation..........
..............................................................................
Validating the design
          Body positons, layer positons, observer positons, user defined control points, source combination are verified.

Simulation has been started at 01/06/16 17:55:06 by Wavenology EM 1.9.0 (x64)
          Preprocessing...
                    ........Begin to generate snapshot mesh...
                    ........end of snapshot mesh generation...
                    Domains: 1 x 1 x 1,  Cells: 100 x 3 x 76,  Delta time: 2e-011 sec,  Mesher version: 1,  CPU Time: 0.075 sec,  Explicit solver is used.  Single thread is used.
          Time Stepping...
          Postprocessing... Last time window: 20 ns,  Number of time step: 1000,  Time for time-stepping: 1.875 sec,  Postprocessing: 0.012 sec
Simulation is completed normally at 01/06/16 17:55:08.  Total simulation time is 2 seconds  (2 sec)
..............................................................................
 Run 4 RTM backward simulation is completed ......Whole RTM simulation is totally completed & temporary results are removed.
..............................................................................
..............................................................................
```

The simulation log will report the status of each imaging run.

If user click “Start” button to generate image, if there is not error report in the processing and the Imaging can be finished successfully, a target file “src1.img” (as it is defined in the setup dialog) will be created in the image result folder: ***xxxx_res/img/*** , as shown in the following figure,



Meanwhile, the sub-image for each source will be placed in the project root folder as following:



Project file

Sub-image for the 1st source

The Signal File Format in the WCT EM-IMG Package

Signal on the receiver for the backward simulation

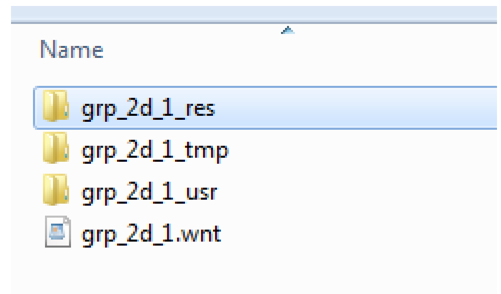
- ASCII TEXT file
- if user want to use the data directly from a WCT forward simulation, please use the data file: "forward_project_folder/projectname_res/observers/projectname_rev_componentname.txt"
    - it is better to copy this file to the root folder of the imaging project and set this file as the signal source in the imaging simulation

Line number	meaning
1-3	comment
4	number of frames in the file
5	comment
6	frame start time, unit: s
7	comment
8	frame end time, unit: s
9	comment
10	Frame time step, unit: s
11	comment
12	Length of each frame
13 : n0	Frame 1
n0+1 : n2	Frame 2

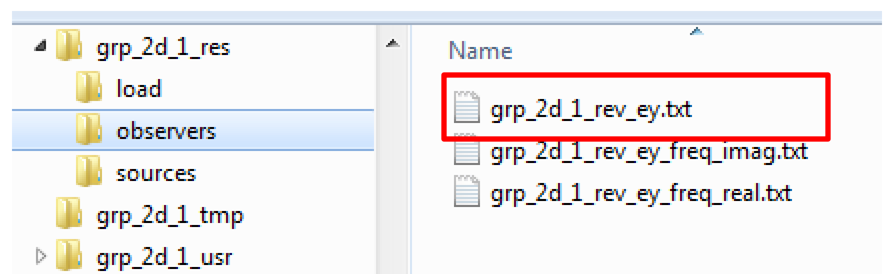
Example File

```
%Wave Computation Technologies simulation waveform data, version 1.0 ::
%Time (ns)
%frames number
31
%frame start
0
%frame end
1.98e-008
%frame step
3.6e-010
%frame length
56
0.0000000e+000
0.0000000e+000
0.0000000e+000
0.0000000e+000
-6.5508699e-033
-3.2401052e-027
-1.5777409e-023
3.9143431e-020
5.3799126e-017
1.5878495e-014
1.8202063e-012
1.0259642e-010
3.2743763e-009
6.5165523e-008
8.6780892e-007
8.1612652e-006
5.6583969e-005
2.9980612e-004
1.2526923e-003
4.2461860e-003
.....
```

Example File Folder for a simulation to obtain the signal on the receiver for the backward simulation



Project root folder for project: grp+2d_1



Sub-folder for project and the data file will be used for the backward simulation

The Image File Format in the WCT EM-IMG Package

Binary file

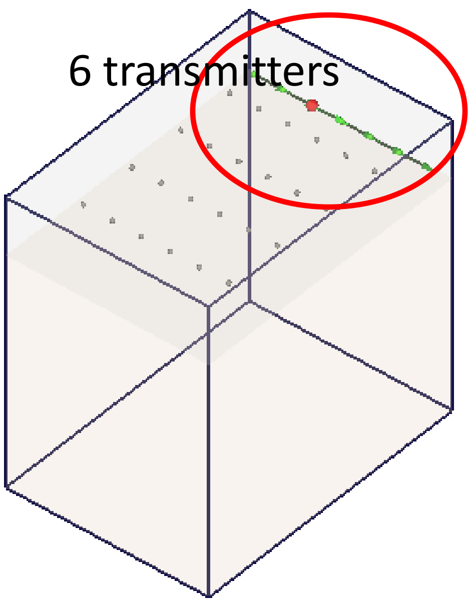
Meaning	Data type	Length (Bytes)	Comment
header	char	128	
version	int	4	sizeof(int), the value is: ***1***
array 3D start index (cell)	int	4 (int)* 3	x0, y0, z0
array 3D end index (cell)	int	4 (int)* 3	x1, y1, z1
array size	int	4 (int)* 3	x, y, z
array content	float	4*(nX*nY*nZ)	nK=k1-k0+1, (k=x,y,z) sequence as: inner(Z)->middle(Y)->outer(X)

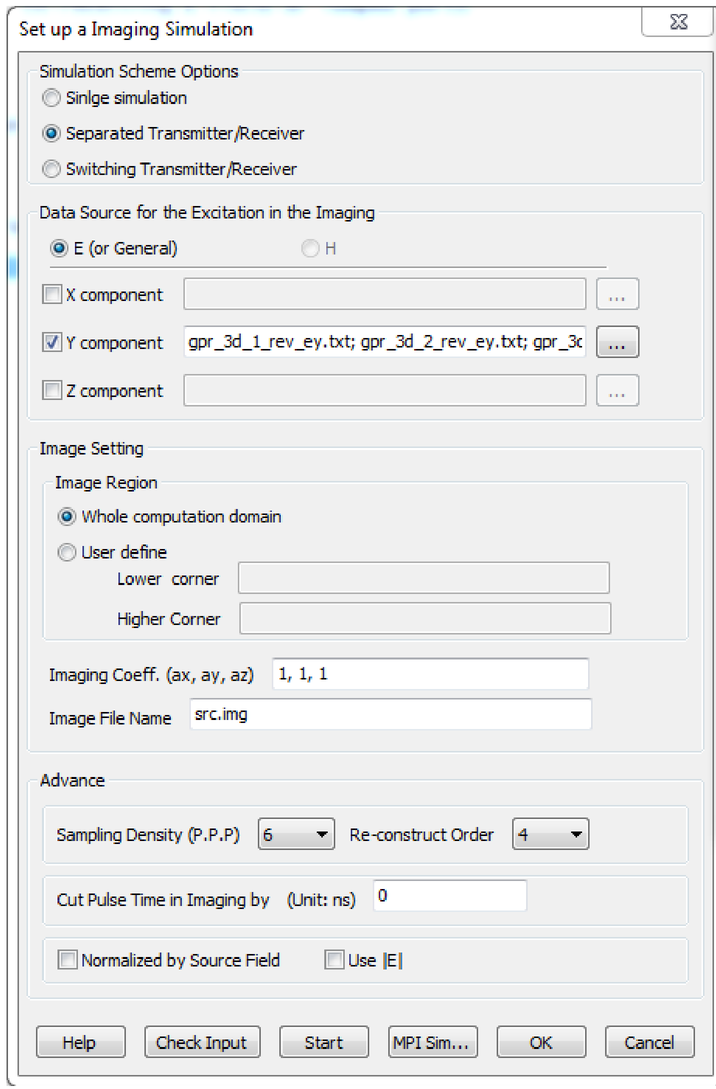
Attached is a Matlab code to load this image file and display the image. More details can be checked with the attached matlab code in each demo case.

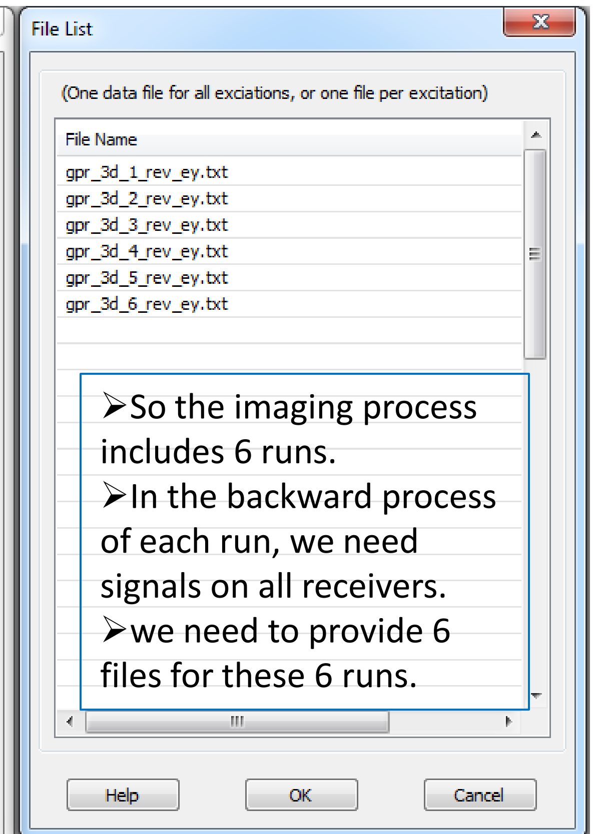
```
close all;

%%% define the data file name
sFile = 'a.img';

%%% open file as binary mode
fid = fopen( sFile, 'rb' ); % target file
if( fid == -1 )
   return;
end;

%% read 128 file header info
info = fread( fid, 128, '*char' );

%% file version number
version = fread( fid, 1, '*int' );

%% image grid range in the whole system, 6 numbers as [x0,y0,z0,x1,y1,z1]
img_range = fread( fid, 6, '*int' );

%% image size by cell number, 3 numbers as [nx,ny,nz]
img_sz = fread( fid, 3, '*int' );
sz = img_sz(1) * img_sz(2) * img_sz(3);

%% read whole array
my_img = fread( fid, double(sz), '*float' );

%% reshape this 1D data to 3D array
my_img = reshape( my_img, img_sz(3), img_sz(2), img_sz(1) );
                        %% the 3D array is ordered as [z, y, x]

%% close file
fclose( fid );

%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  show image
slide_id = ceil(img_sz(1) / 2);

my_slide = my_img( :, :, slide_id );
my_slide = squeeze( my_slide );

figure;
imagesc( my_slide );
xlabel( 'X (cell)' );
ylabel( 'Z (cell)' );
```

File System for an Imaging Project with Imaging Scheme II

3D GRP Imaging with separated transmitter array and receiver array







File system for this 3D imaging project

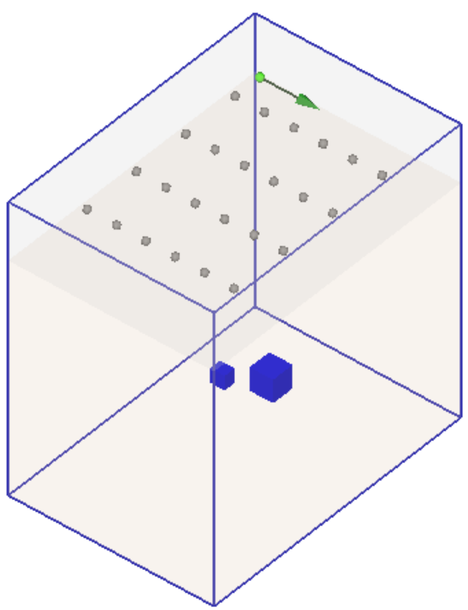
Name	Date modified	Type	Size
gpr_3d_1_res	1/7/2016 11:37 AM	File folder	
gpr_3d_1_tmp	1/7/2016 11:37 AM	File folder	
gpr_3d_1_usr	1/6/2016 2:57 PM	File folder	
check_img.asv	1/7/2016 12:34 PM	ASV File	2 KB
check_img.m	1/7/2016 5:14 PM	MATLAB M-file	2 KB
gpr_3d_1.wnt	1/7/2016 11:20 AM	WNT File	11 KB
gpr_3d_1_rev_ey.txt	1/7/2016 12:29 AM	Text Document	631 KB
gpr_3d_2_rev_ey.txt	1/7/2016 12:49 AM	Text Document	631 KB
gpr_3d_3_rev_ey.txt	1/7/2016 1:09 AM	Text Document	631 KB
gpr_3d_4_rev_ey.txt	1/7/2016 1:29 AM	Text Document	631 KB
gpr_3d_5_rev_ey.txt	1/7/2016 1:50 AM	Text Document	631 KB
gpr_3d_6_rev_ey.txt	1/7/2016 2:10 AM	Text Document	631 KB
src.img	1/7/2016 5:07 PM	Disc Image File	45,287 KB

Imaging project

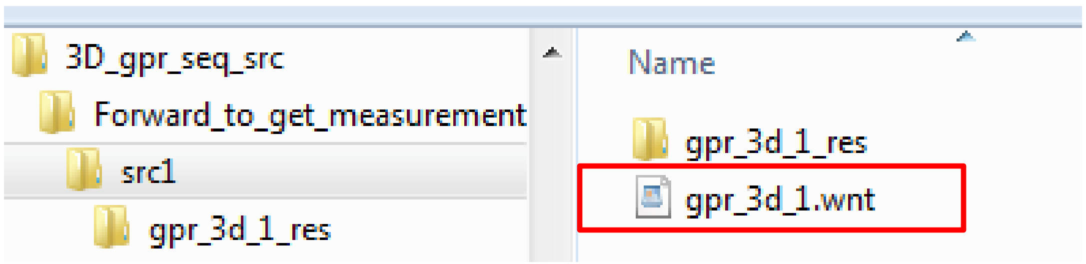
Backward signal data files

For example, data file “gpr_3d_1_rev_ey.txt”

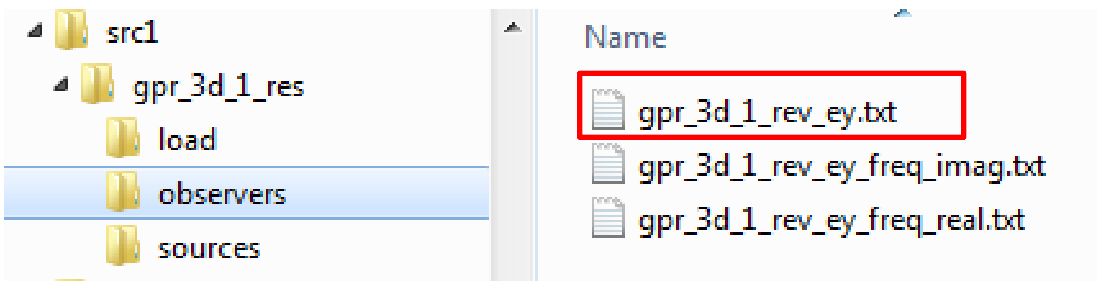
- can be user measurement but written as WCT format
- comes from a WCT EM project as following



Project



Received signal on receivers

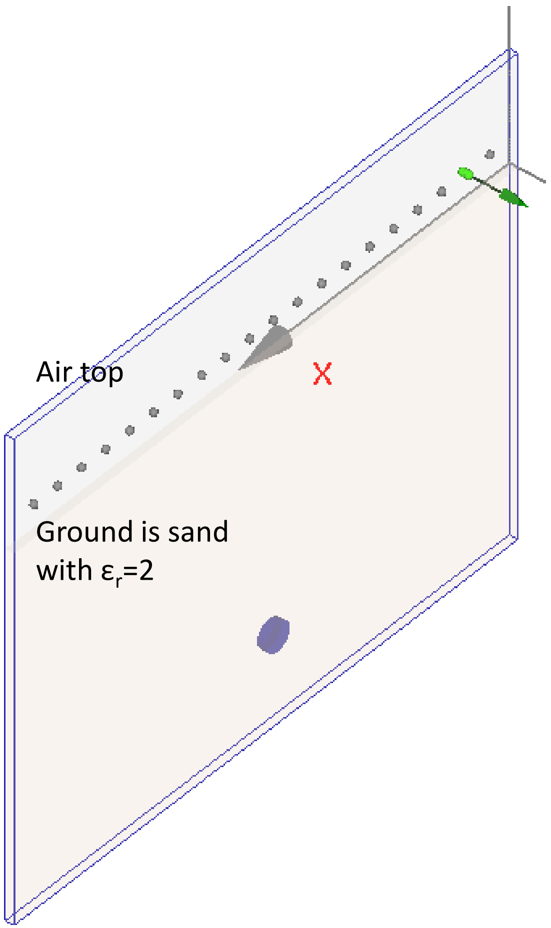


Case I : Pure 2D Imaging Single object with f_{max}=1 GHz

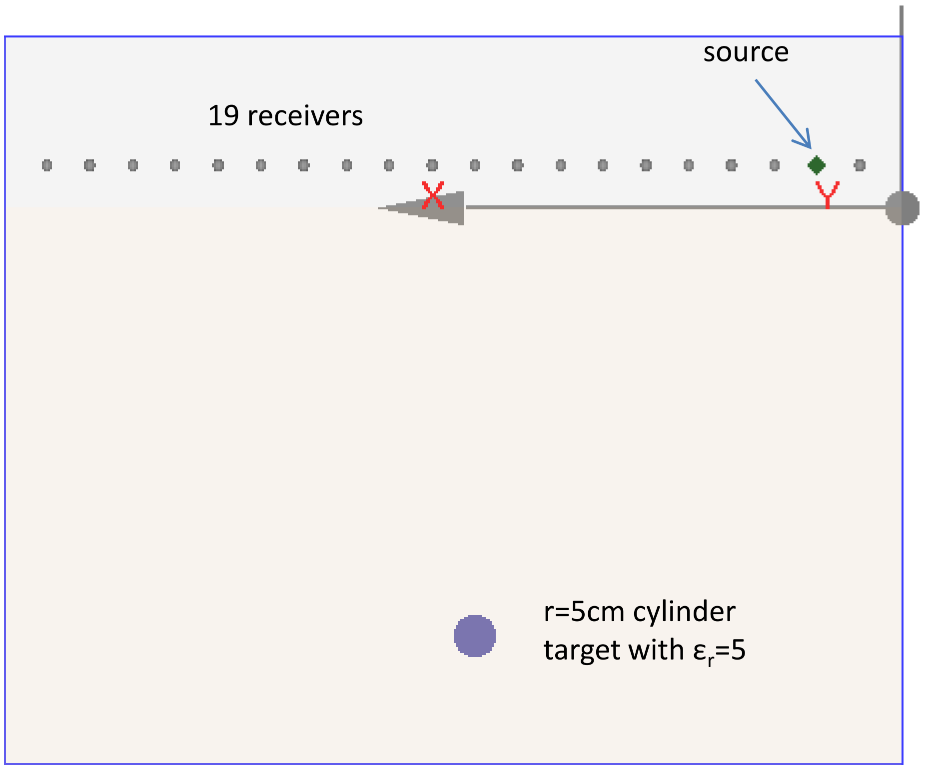
(note: we use (3 dipole sources) to work as a line source. Therefore, we also need to use (3 point receiver together) to working as a line receiver also. Due to there are 3 sources need to simultaneously excited, we need to use scheme I. In order to have a big enough aperture, we use 5 source positions, which means 5 separate cases.)

- Freq: f_{max}=1GHz, f_c ≈300 MHz
- Two layers background: top is air, bottom is sand with ε_r=2 (λ≈0.2 m at f_{max} ; λ≈0.063 m at f_c)
- Target is a r=5cm cylinder with ε_r=5
- Signal on receiver: from WCT EM solver
- 19 receivers with a distance as 0.1 m (0.5λ at f_{max} ; 1.6λ at f_c)
- 1 line sources

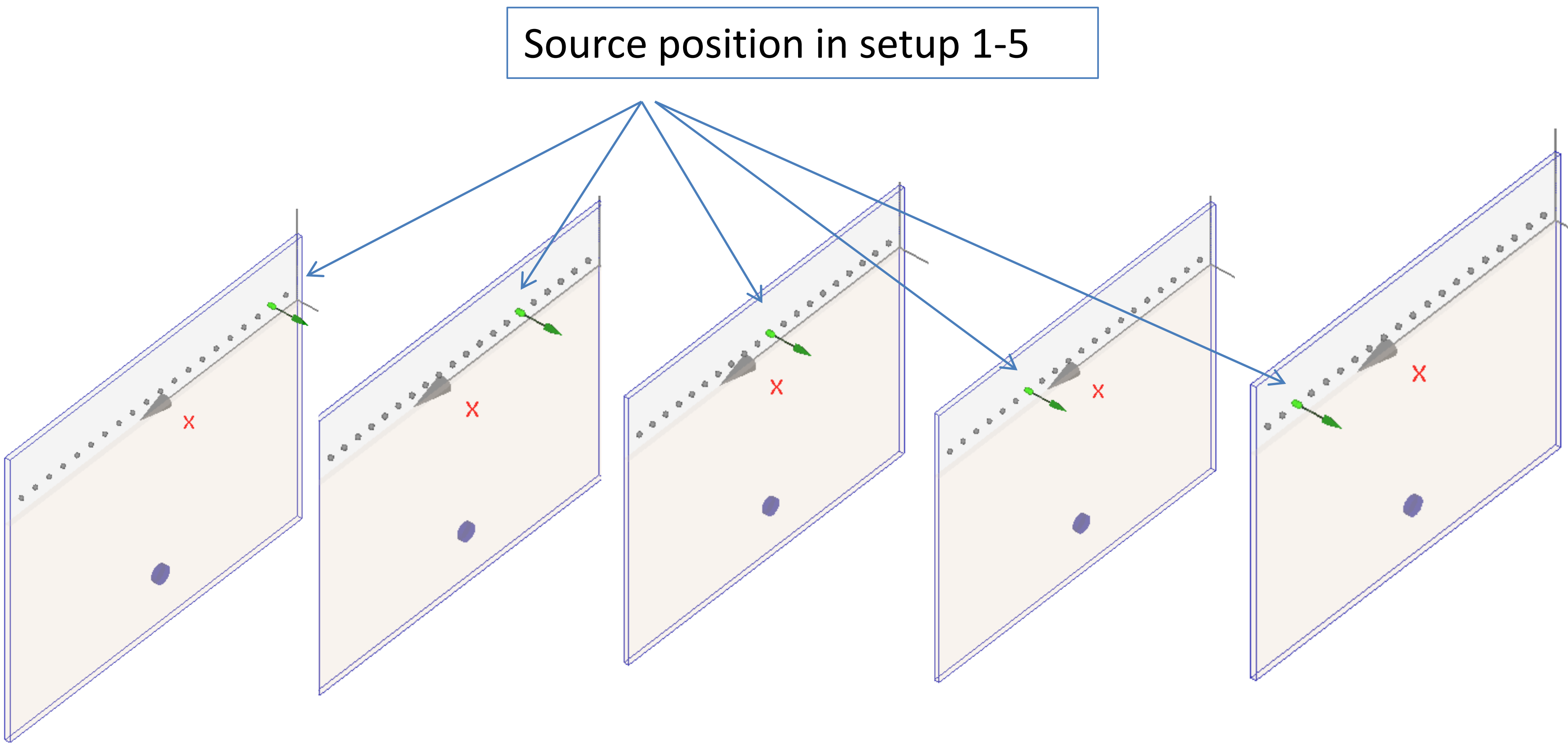
Angle View



Front View



5 Forward Simulations to Obtain Measured Signal (Synthetic Data)



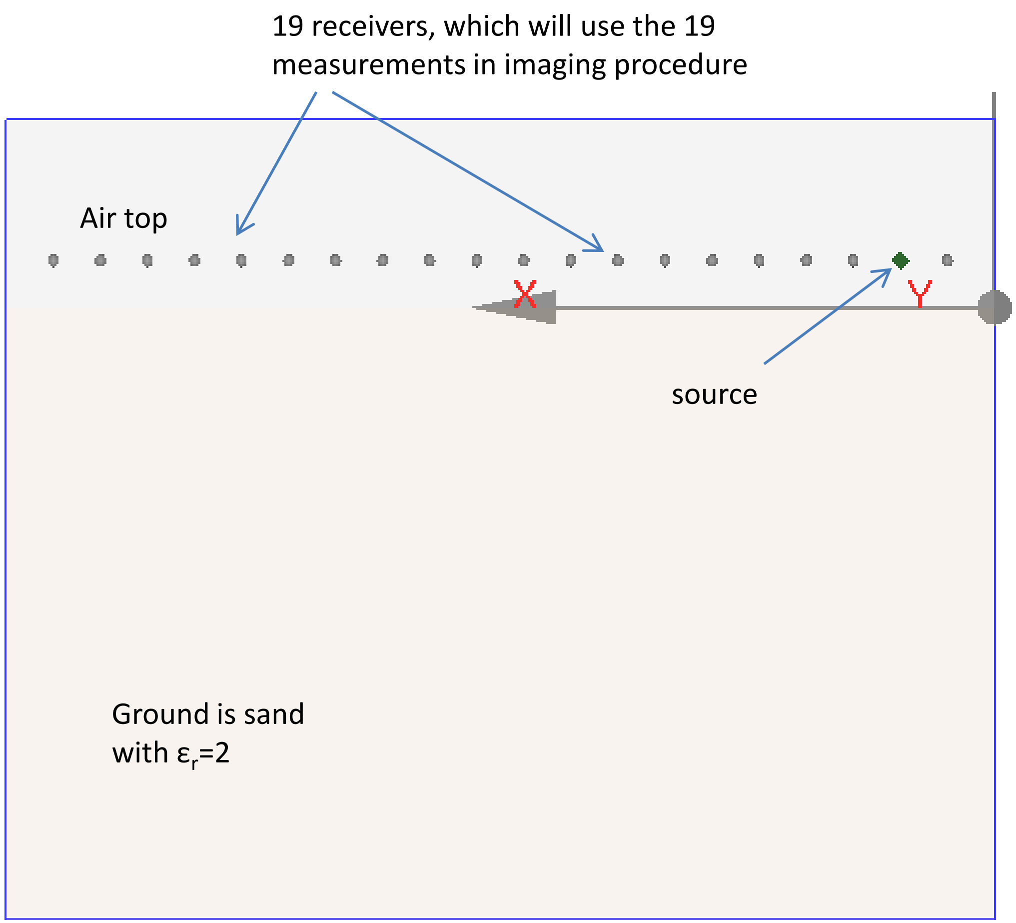
If user have a real measurement, he can skip this step.

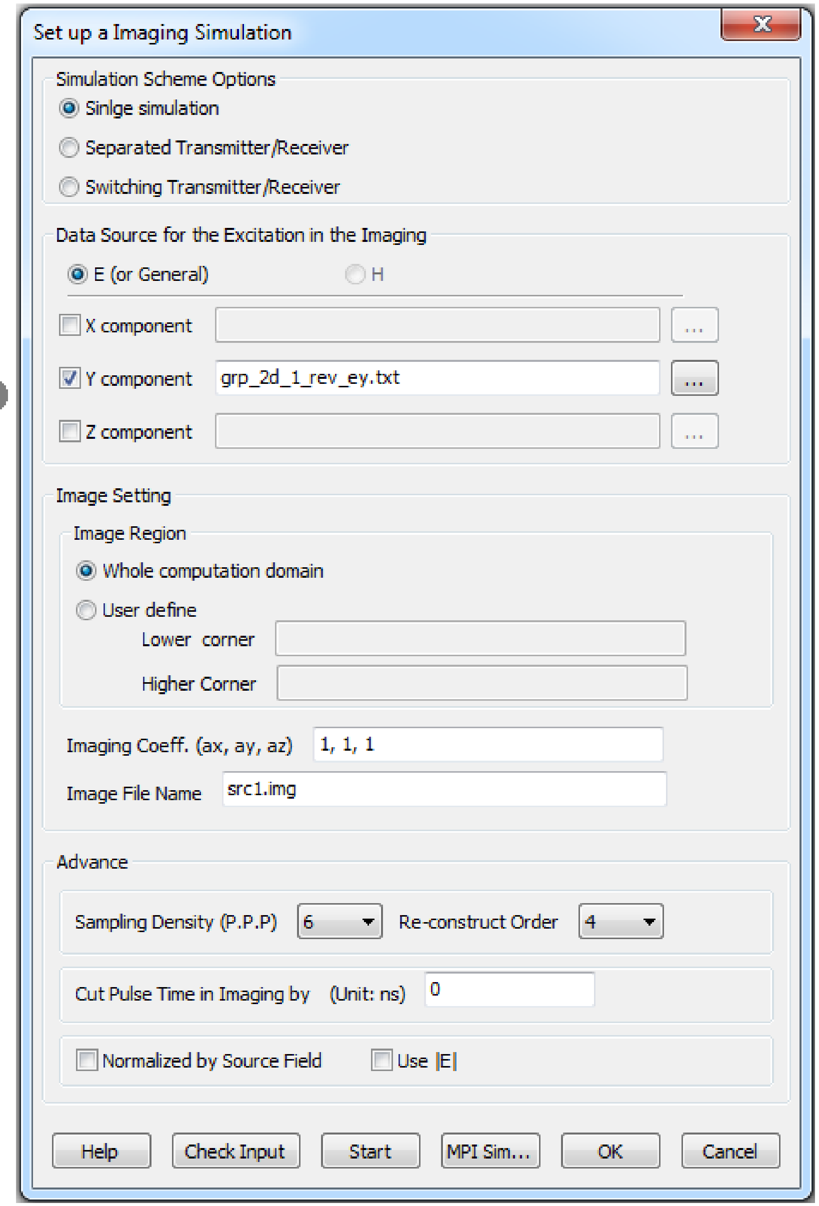
Imaging process by this case

- We have signals on 19 receivers as the measurement from the real case.
  - these signals can be obtained from our EM simulation tools, as the setup in the previous page.

- For imaging, we assume we only know
  - two layered background
  - the original source to generate the 19 measured signals on 19 receivers
  - 19 measured signals on 19 receivers

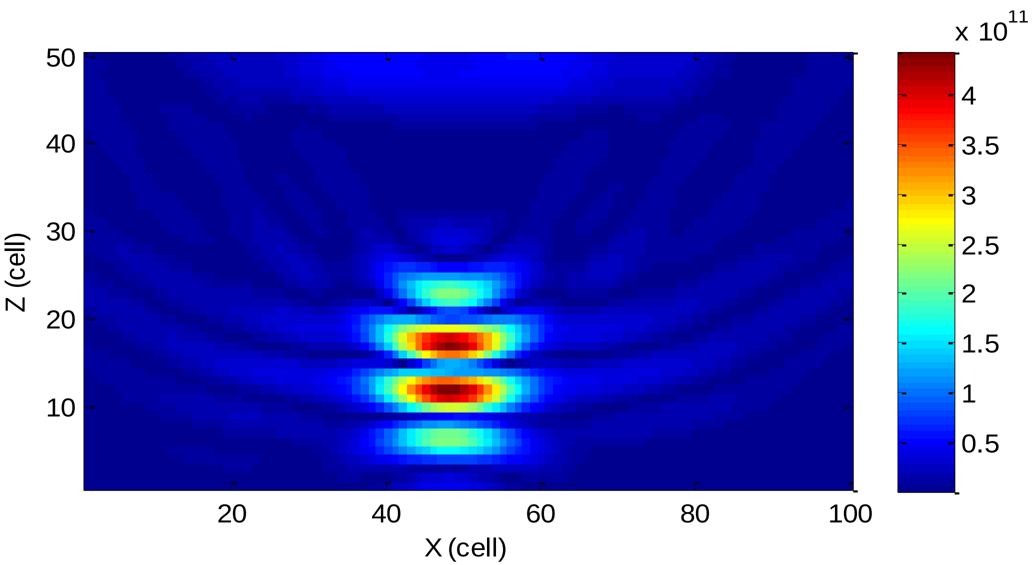
  - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.


19 receivers, which will use the 19 measurements in imaging procedure
Air top
X
Y
source
Ground is sand with ε_r=2

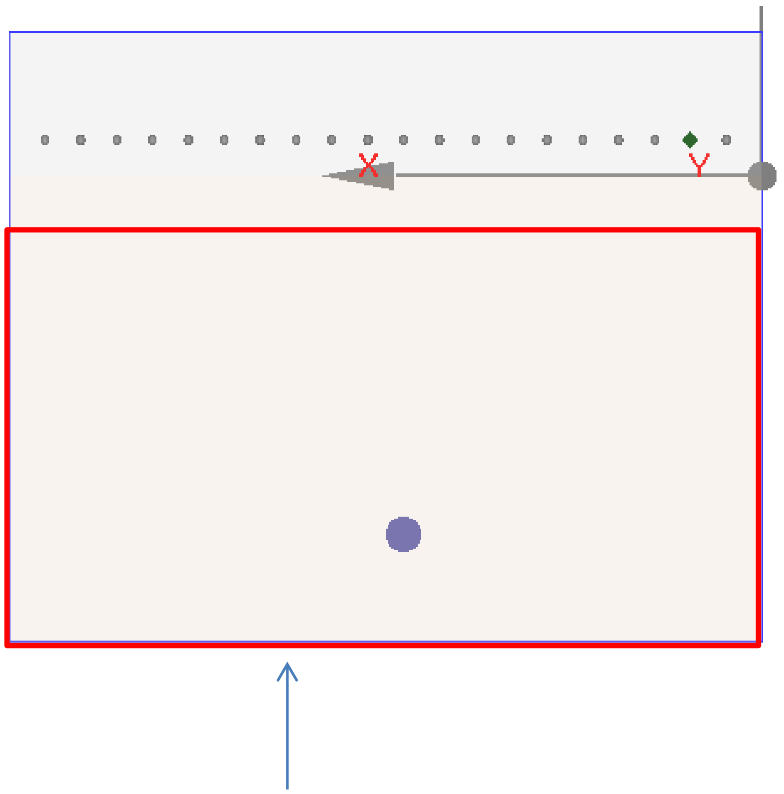

Set up a Imaging Simulation
Simulation Scheme Options
Sinlge simulation
Separated Transmitter/Receiver
Switching Transmitter/Receiver
Data Source for the Excitation in the Imaging
E (or General)
H
X component
Y component
grp_2d_1_rev_ey.txt
Z component
Image Setting
Image Region
Whole computation domain
User define
Lower corner
Higher Corner
Imaging Coeff. (ax, ay, az)
1, 1, 1
Image File Name
src1.img
Advance
Sampling Density (P.P.P)
6
Re-construct Order
4
Cut Pulse Time in Imaging by (Unit: ns)
0
Normalized by Source Field
Use |E|
Help
Check Input
Start
MPI Sim...
OK
Cancel

Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

WCT EM-IMG result



Ground True Case



Note: here, we use cell as displaying unit, not meter.

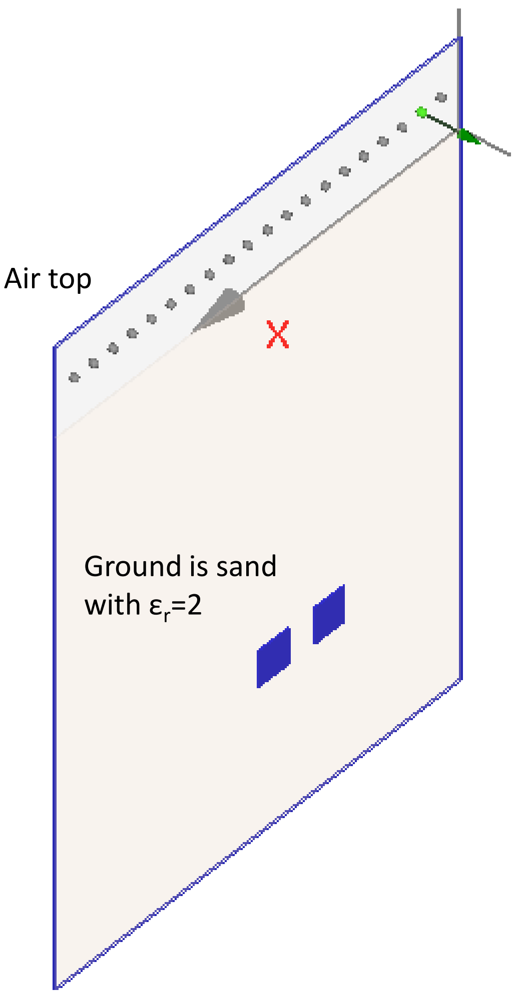
Approximated displaying region in the simulation case

Case II : Pure 2D Imaging Two objects with f_{max}=6 GHz

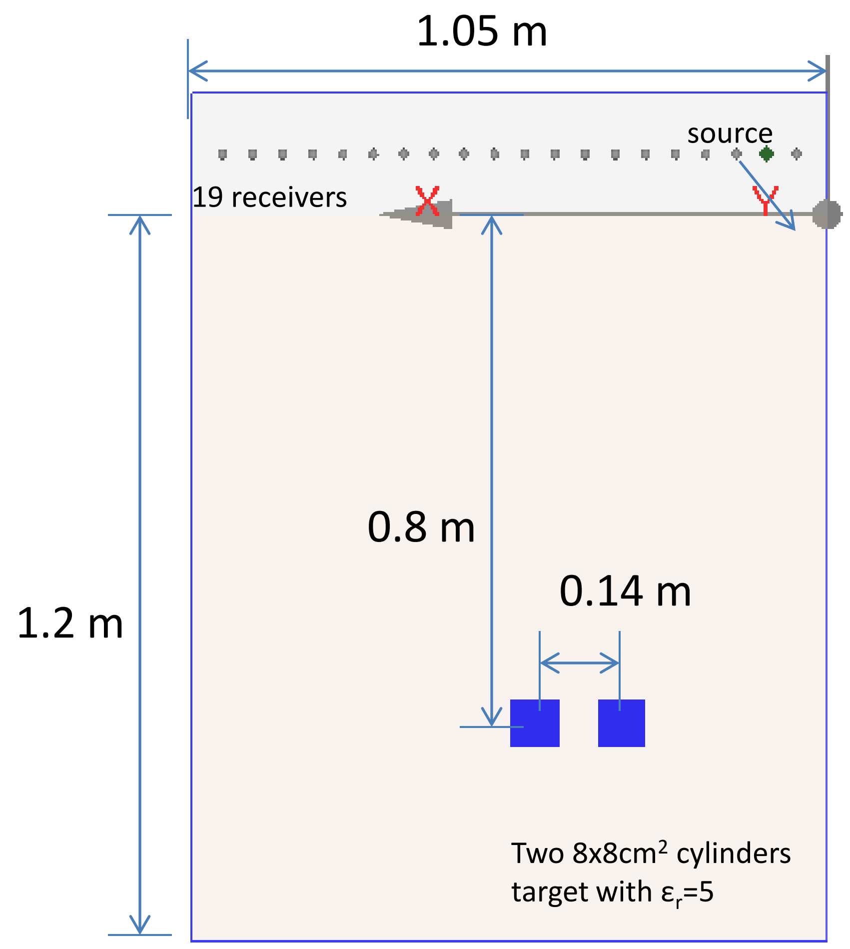
(note: This case is similar to the case I, but with higher frequency, with more targets. Scheme I with multiple cases.)

- Freq: f_{max}=6 GHz ($f_c \approx 2$ GHz)
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are two 8x8 cm^2 and ε_r=5 rectangular cylinder with a center-center distance of 14 cm
- Signal on receiver: from WCT EM solver
- 19 receivers with a distance as 0.05 m
- 1 line sources

Angle View

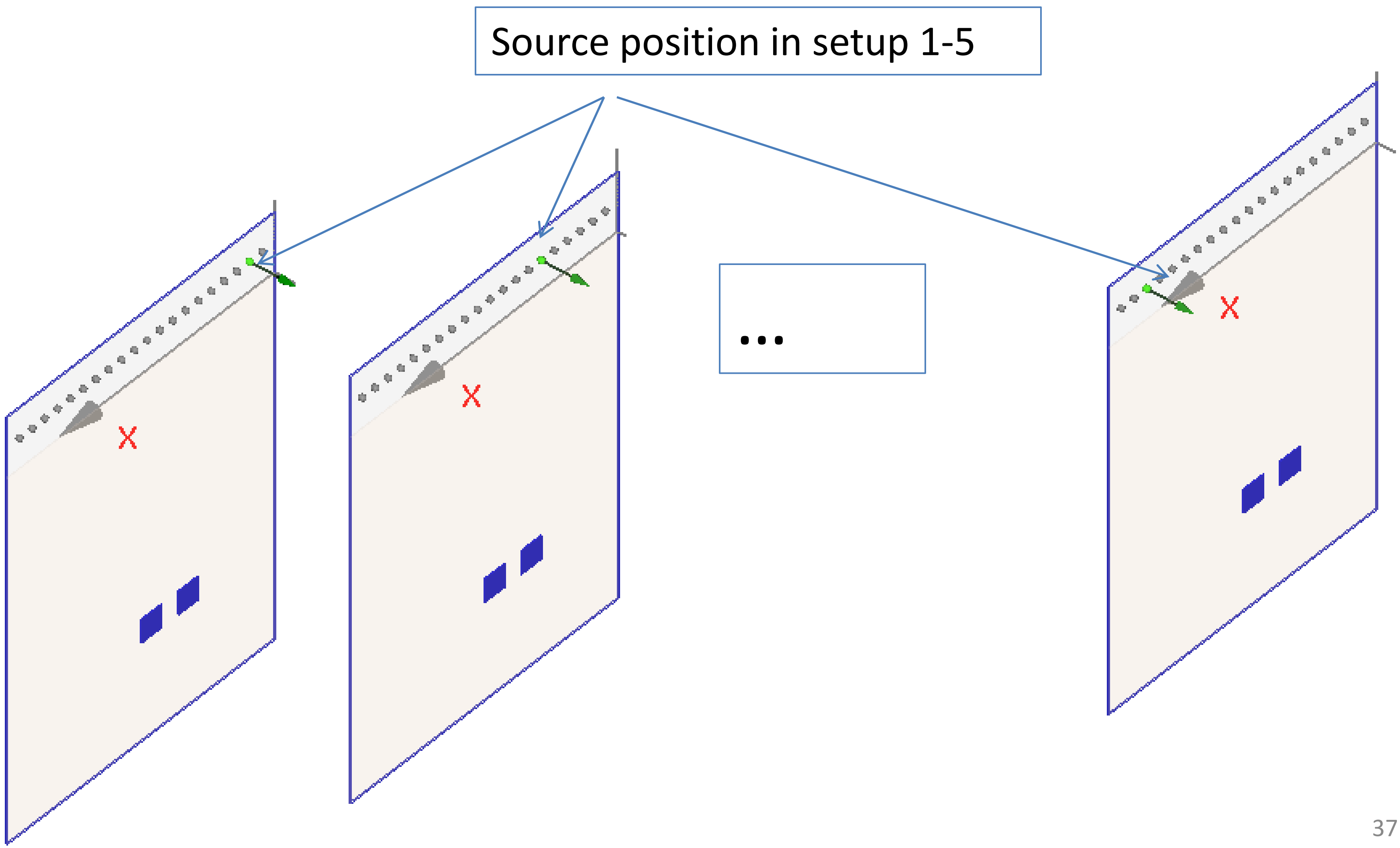


Front View



(note: here, in order simulate the line source in a 3D model, we use 3 Y dipole with Y direction periodic B.C. to represent a Y direction line source, and 3 point receiver as a line receiver.)

5 Forward Simulations to Obtain Measured Signal (Synthetic Data)

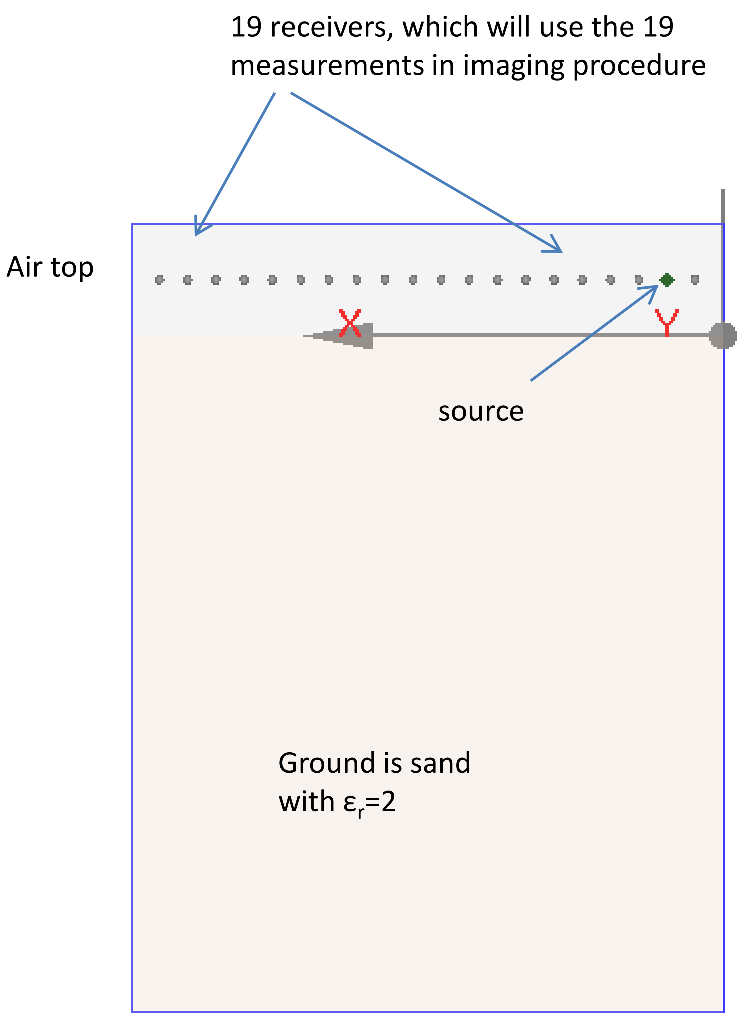


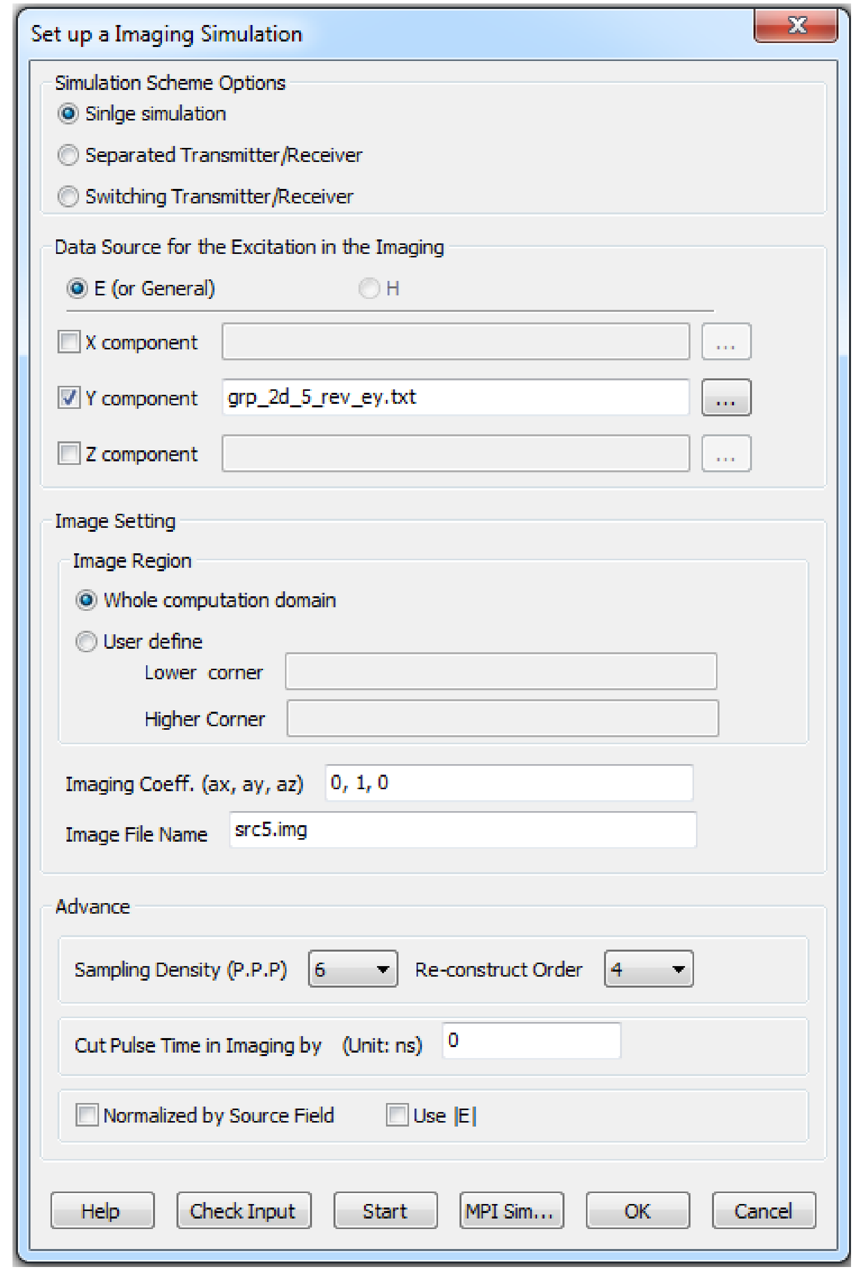
Imaging process by this case

- We have signals on 19 receivers as the measurement from the real case.
  - these signals can be obtained from our EM simulation tools, as the setup in the previous page.

- For imaging, we assume we only know
  - two layered background
  - the original source to generate the 19 measured signals on 19 receivers
  - 19 measured signals on 19 receivers

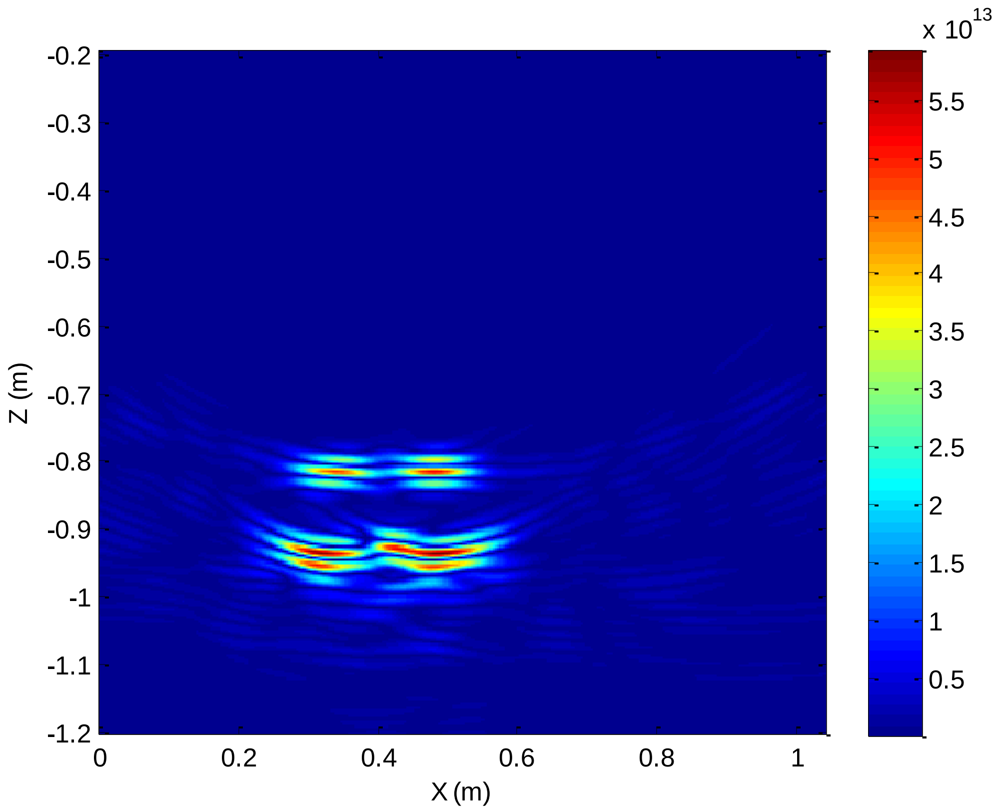
  - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.


19 receivers, which will use the 19 measurements in imaging procedure
Air top
X
Y
source
Ground is sand with ε_r=2

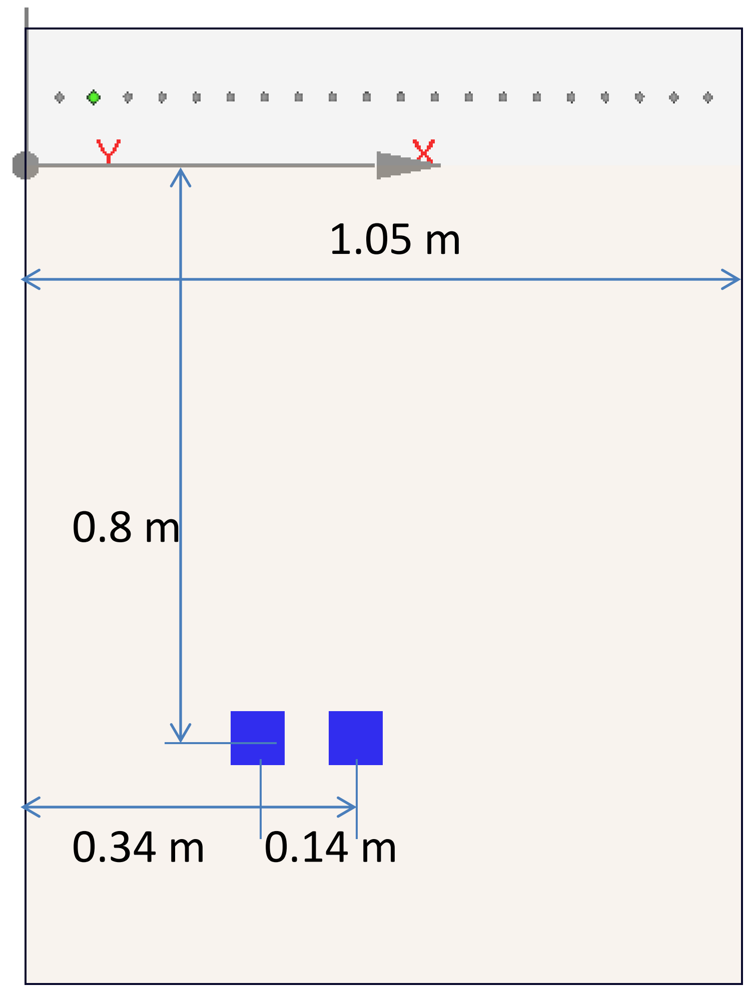

Set up a Imaging Simulation
Simulation Scheme Options
Sinlge simulation
Separated Transmitter/Receiver
Switching Transmitter/Receiver
Data Source for the Excitation in the Imaging
E (or General)
H
X component
Y component
grp_2d_5_rev_ey.txt
Z component
Image Setting
Image Region
Whole computation domain
User define
Lower corner
Higher Corner
Imaging Coeff. (ax, ay, az)
0, 1, 0
Image File Name
src5.img
Advance
Sampling Density (P.P.P)
6
Re-construct Order
4
Cut Pulse Time in Imaging by (Unit: ns)
0
Normalized by Source Field
Use |E|
Help
Check Input
Start
MPI Sim...
OK
Cancel

Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

WCT EM-IMG result



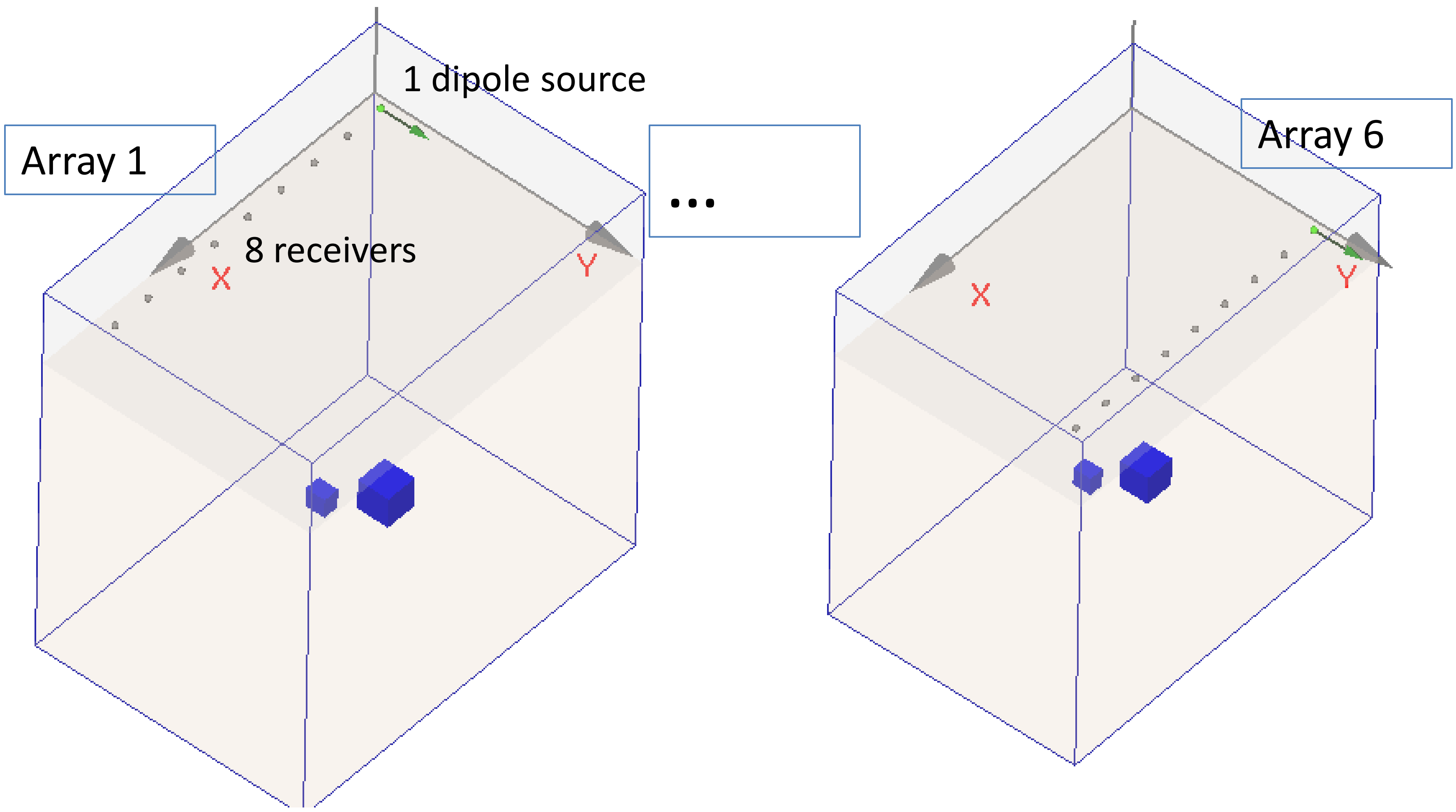
Ground True Setup



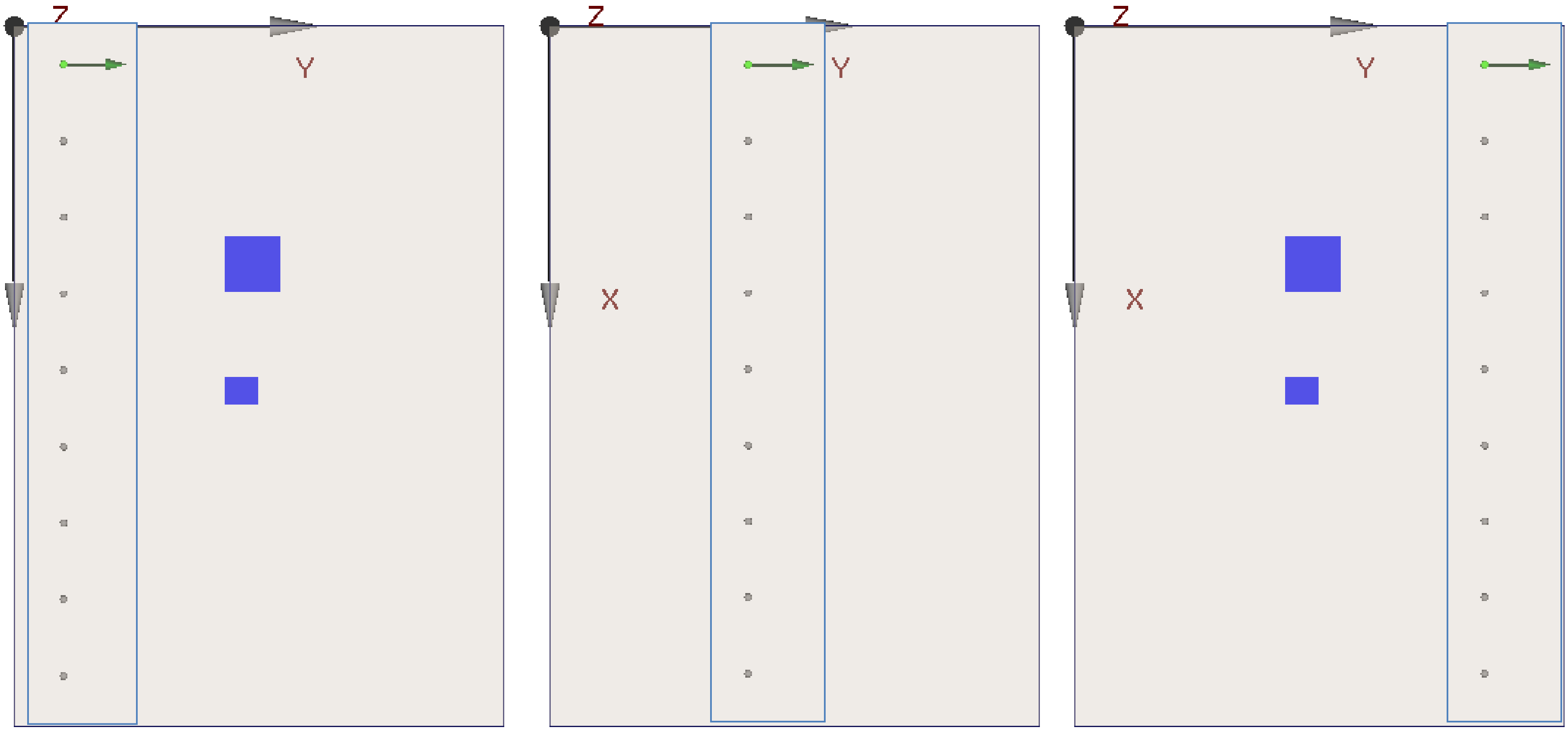
Case III : 3D Imaging Two objects with f_{max}=5.5 GHz

(note: This case uses scheme I with multiple cases.)

- Freq: f_{max}=5.5 GHz ($f_c \approx$ 1.6 GHz)
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are a 8x8x8 cm^3 and a 4x5x5 cm^3 box, two objects have a ε_r=5
- Signal on receiver: from WCT EM solver
- Using 6 “transmitter + receiver array” to imaging, each array has
  - 8 receivers with a distance as 0.1 m
  - 1 dipole source
- Only use Ey field to imaging (ax,ay,az)=(0,1,0)

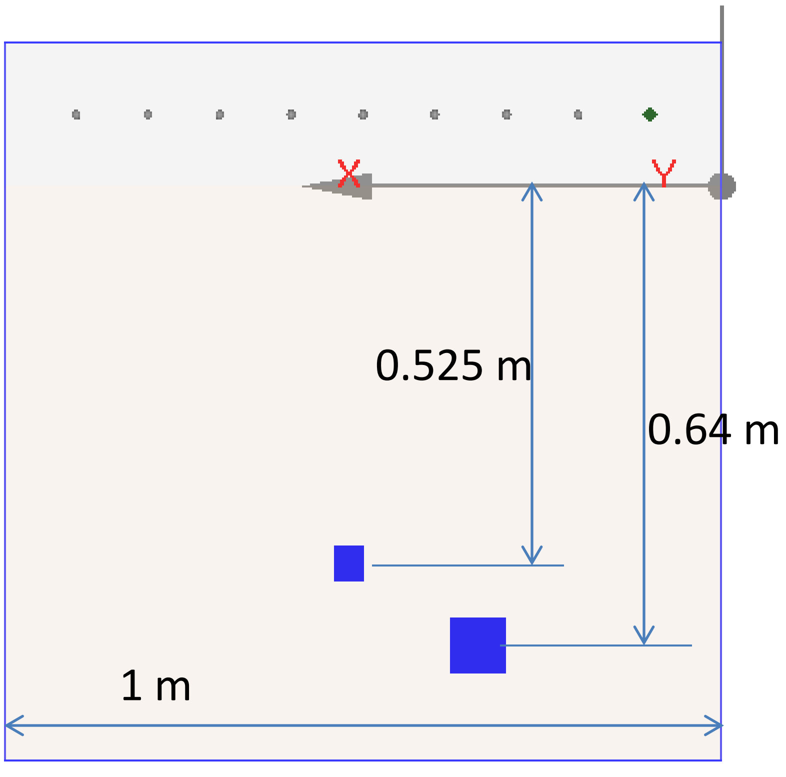

Array 1
1 dipole source
8 receivers
X
Y
...
Array 6
X
Y

Top view

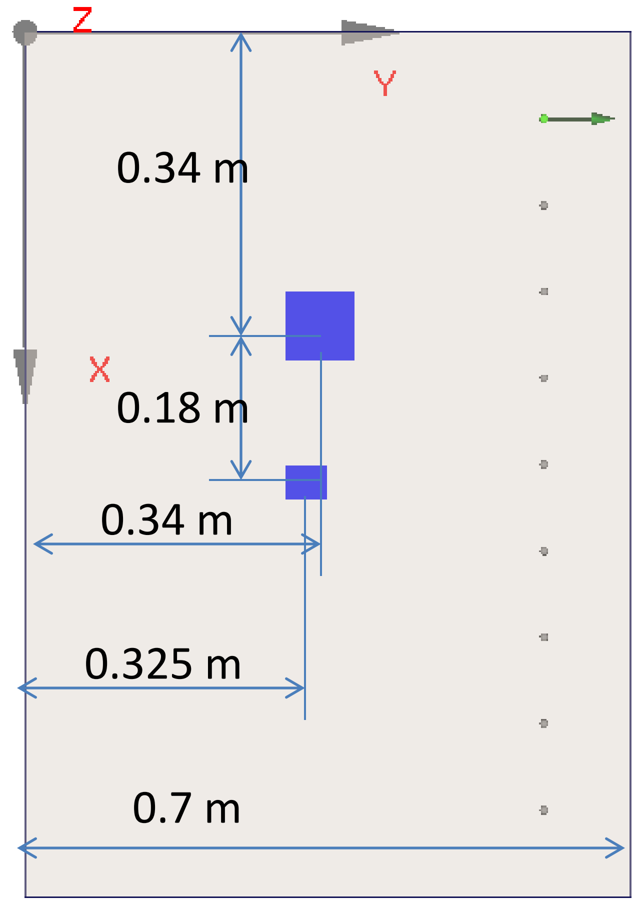


Array 1 … Array 3 … Array 6

Size view

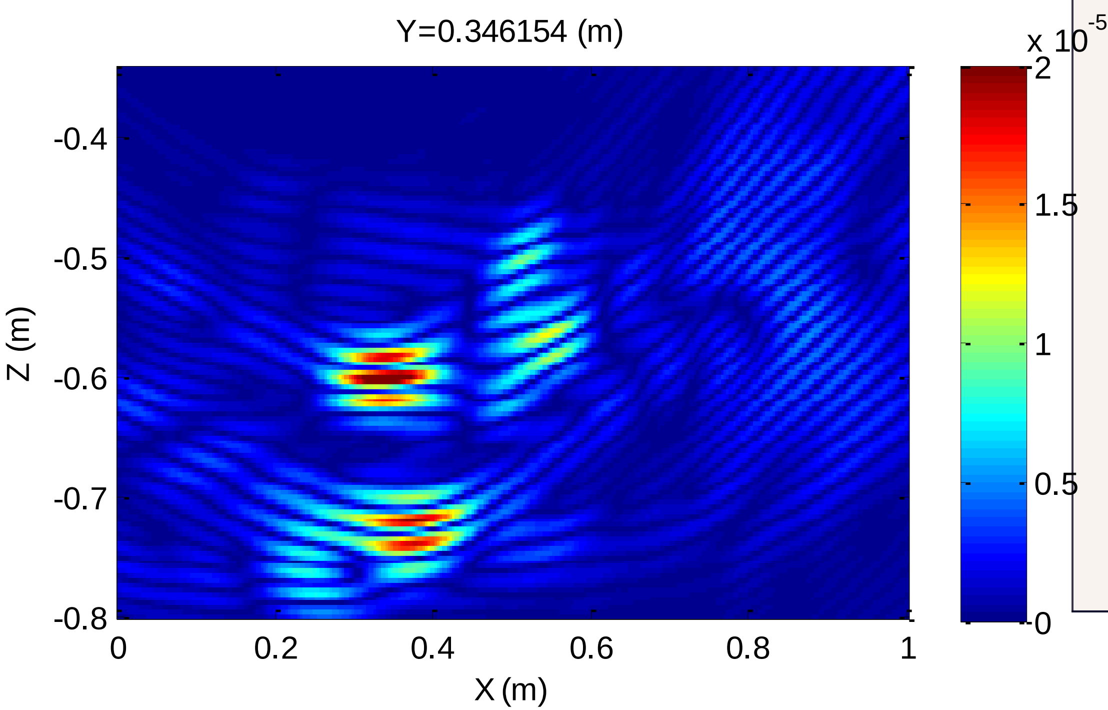


Top view

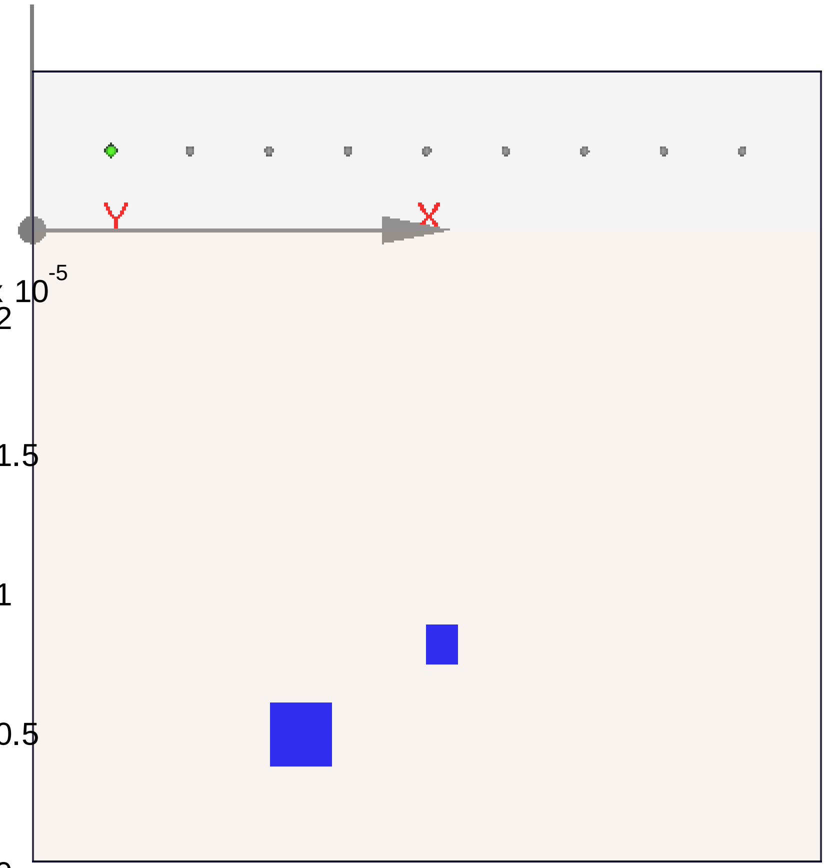


Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

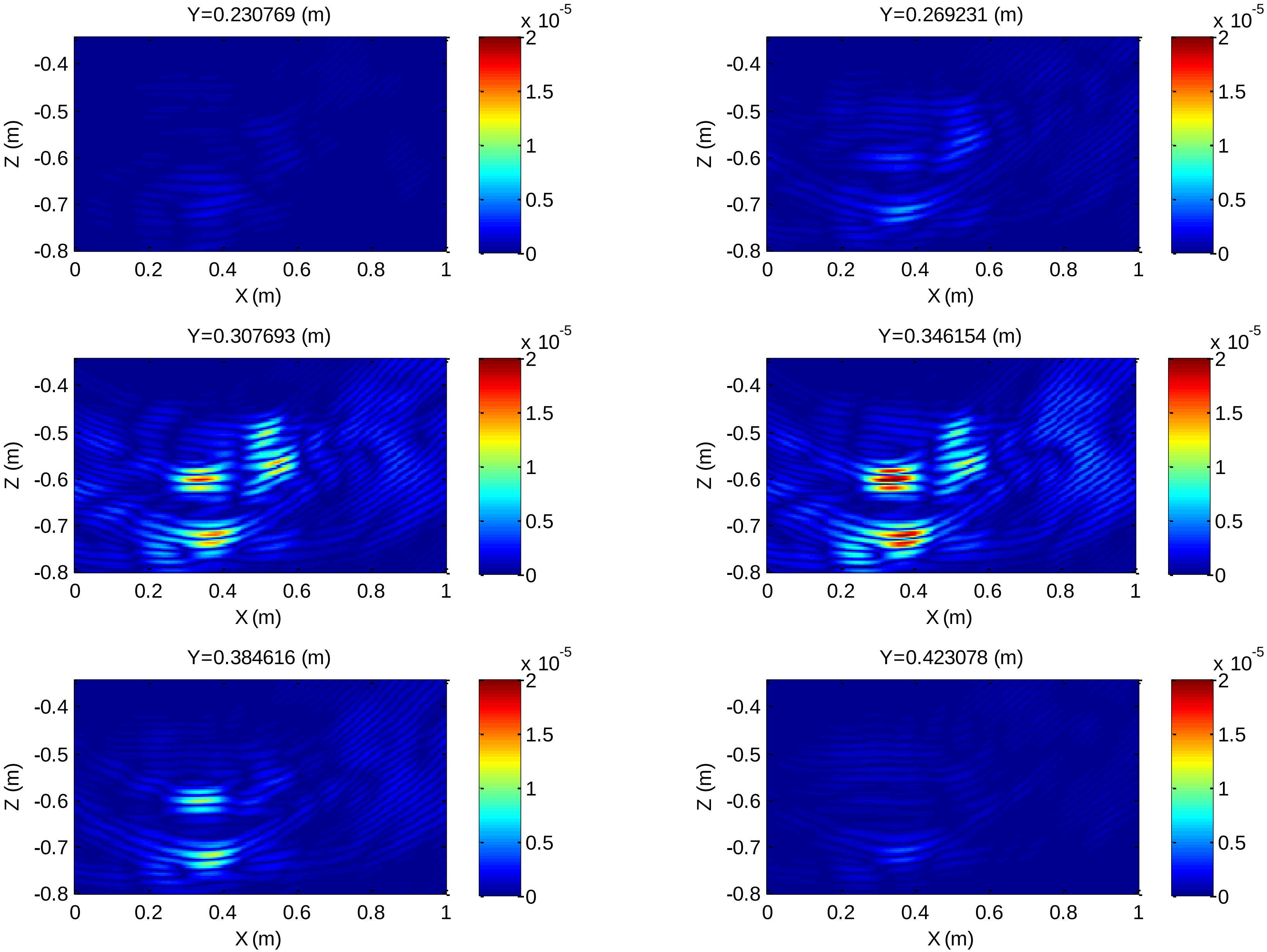
WCT EM-IMG result



Ground True Setup



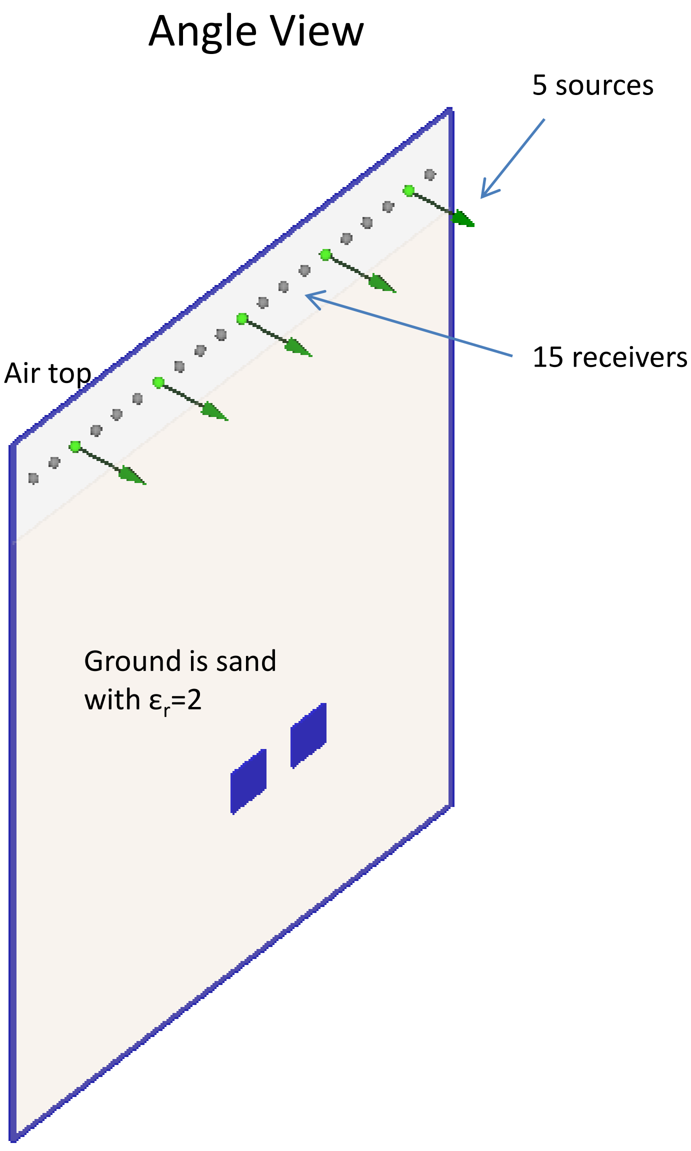
More Slides along Y axis

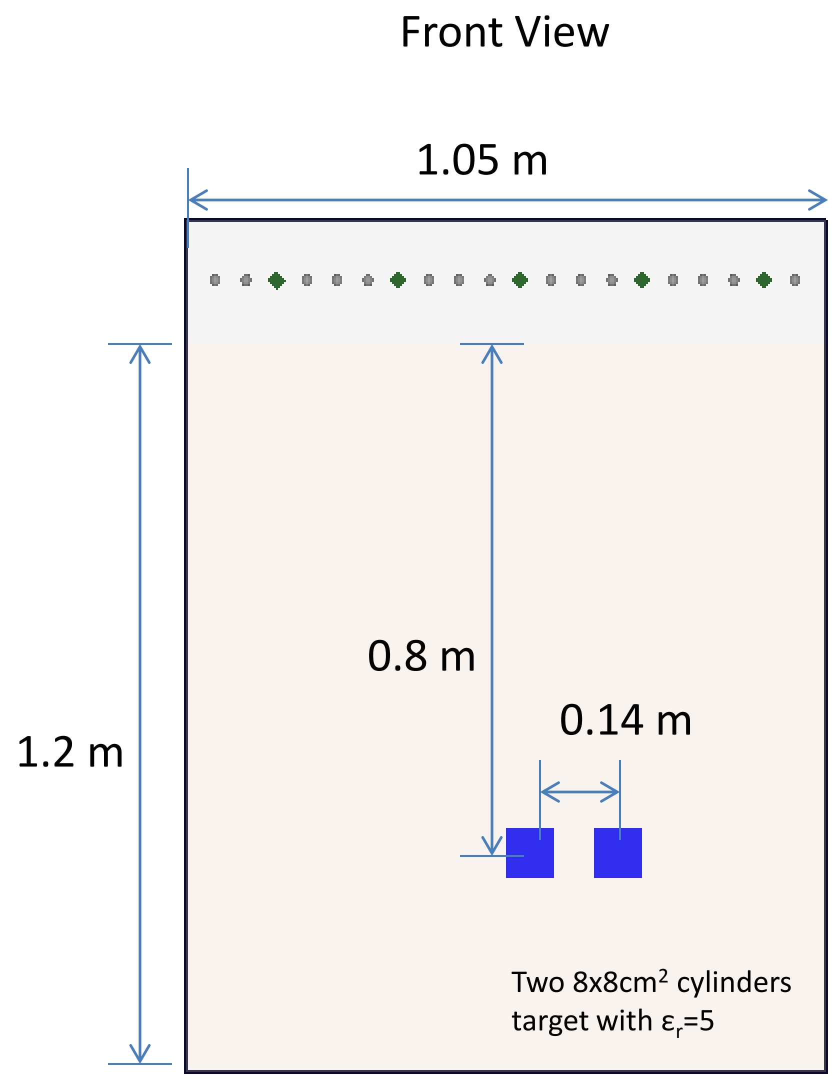


Case IV : Pseudo 2D Imaging
Two objects with f_{max}=6 GHz, Scheme II

(note: Except source & receiver, this case is same as case III, two targets in a two-layers environment. The change is there are not 3 dipole sources to work as a line source, a single dipole source with periodic boundary condition is used to make the single source working similarly to a line source. With this change, we can use scheme II run this case in one click.)

- Freq: f_{max}=6 GHz ($f_c \approx 2$ GHz)
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are two 8x8 cm^2 and ε_r=5 rectangular cylinder with a center-center distance of 14 cm
- Signal on receiver: from WCT EM solver
- A receiver array with15 receivers
- A transmitter array with 5 transmitters


Angle View
5 sources
15 receivers
Air top
Ground is sand
with ε_r=2

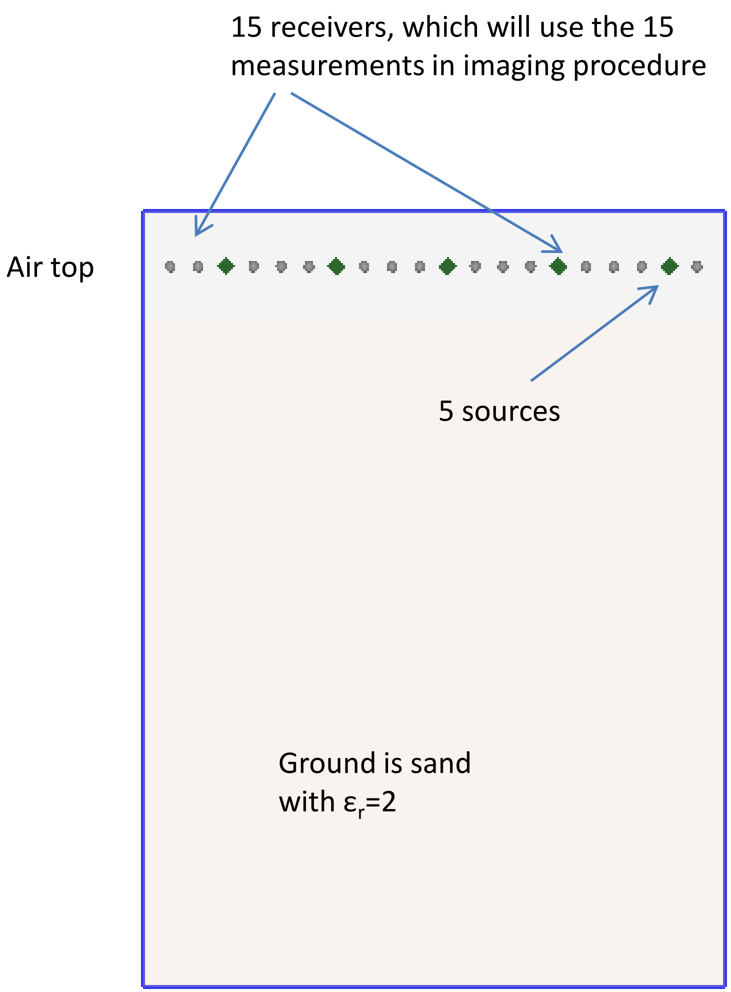

Front View
1.05 m
0.8 m
0.14 m
1.2 m
Two 8x8cm^2 cylinders
target with ε_r=5

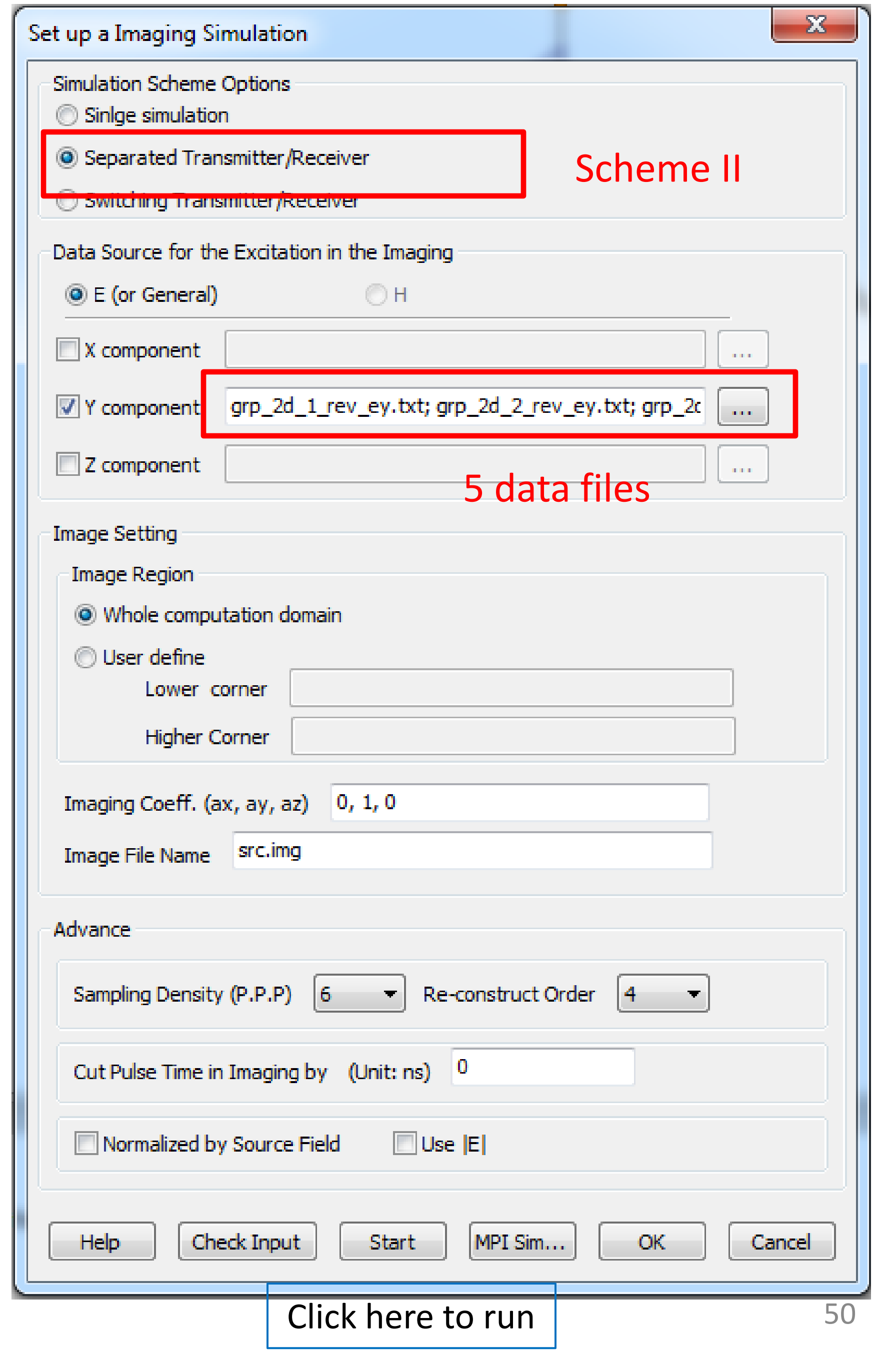
Imaging process by this case

- We have signals on 15 receivers as the measurement from the real case for each excitation.
    - these signals can be obtained from our EM simulation tools.

- For imaging, we assume we only know
    - two layered background
    - one source generates 15 measured signals on 15 receivers. These 15 traces are stored in one file.
    - there are 5 data files for these 5 sources.

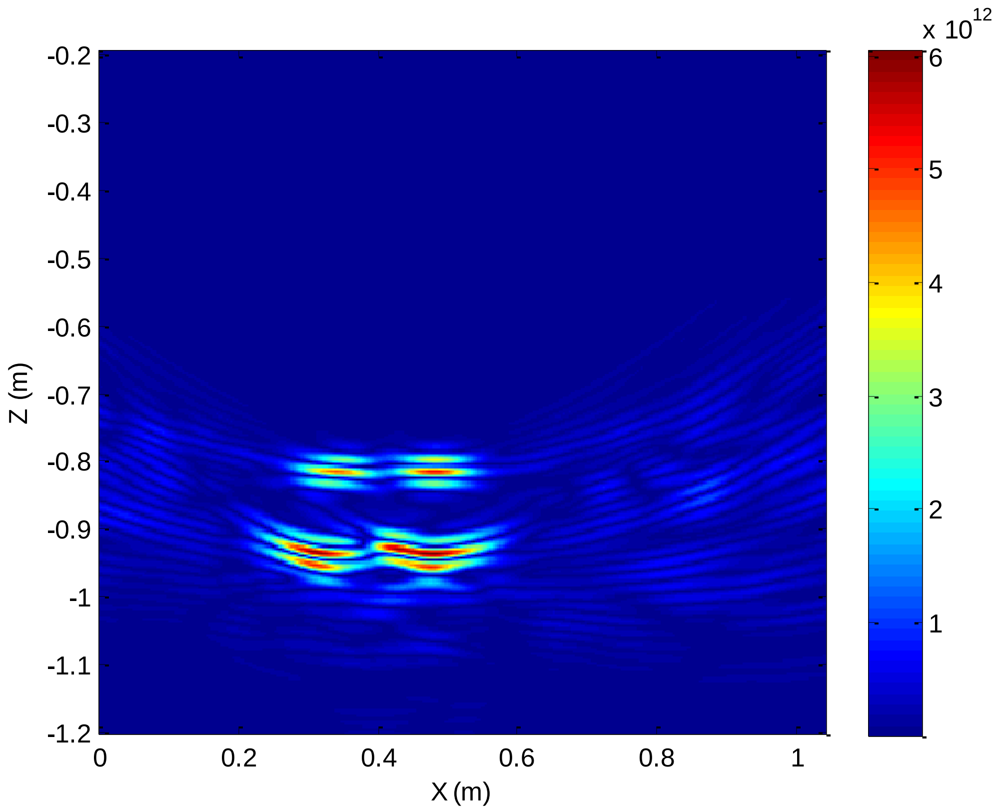
    - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.


15 receivers, which will use the 15 measurements in imaging procedure
Air top
5 sources
Ground is sand with ε_r=2

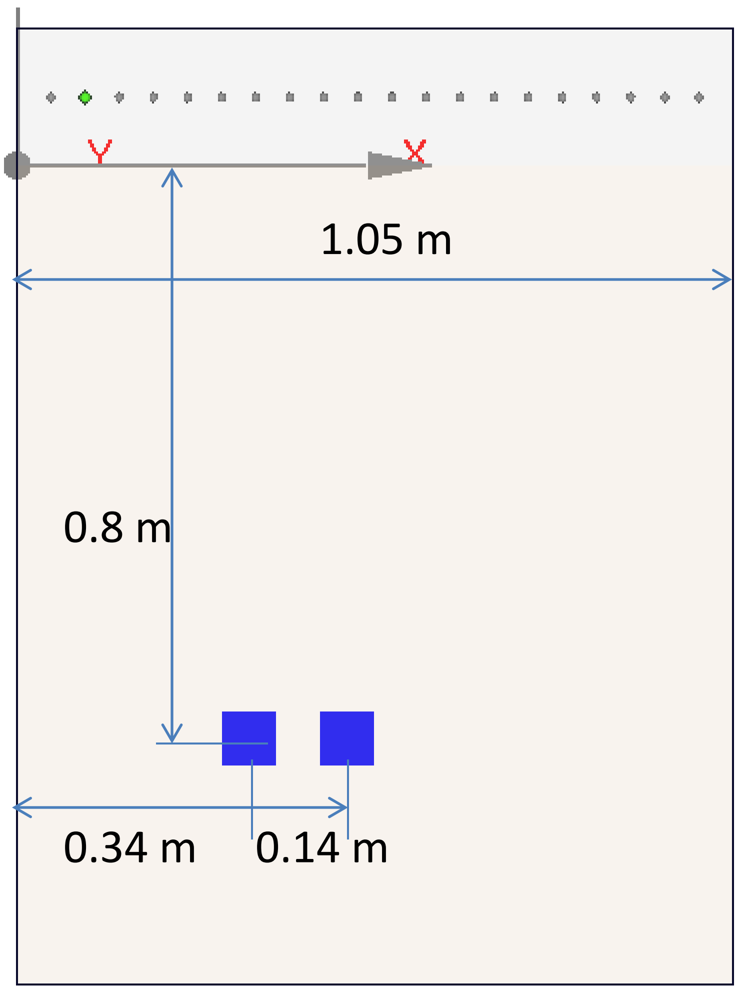

Set up a Imaging Simulation
Simulation Scheme Options
Sinlge simulation
Separated Transmitter/Receiver
Switching Transmitter/Receiver
Scheme II
Data Source for the Excitation in the Imaging
E (or General)
H
X component
Y component
grp_2d_1_rev_ey.txt; grp_2d_2_rev_ey.txt; grp_2c
Z component
5 data files
Image Setting
Image Region
Whole computation domain
User define
Lower corner
Higher Corner
Imaging Coeff. (ax, ay, az)
0, 1, 0
Image File Name
src.img
Advance
Sampling Density (P.P.P)
6
Re-construct Order
4
Cut Pulse Time in Imaging by (Unit: ns)
0
Normalized by Source Field
Use |E|
Help
Check Input
Start
MPI Sim...
OK
Cancel
Click here to run

Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

WCT EM-IMG result



Ground True Setup

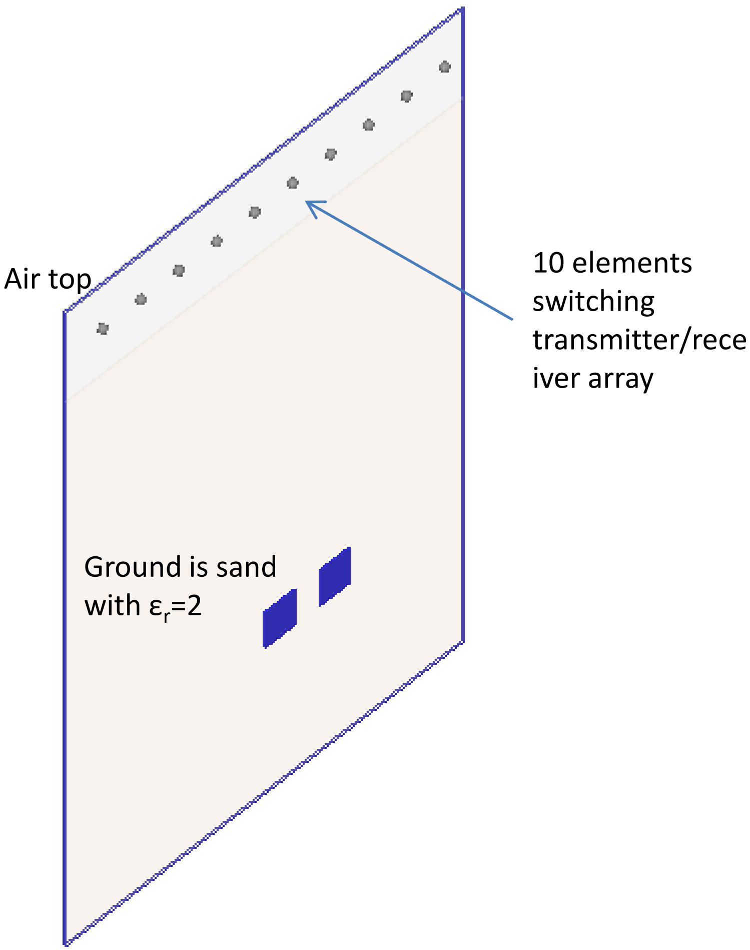


Case V : Pseudo 2D Imaging
Two objects with f_{max}=6 GHz, Scheme III

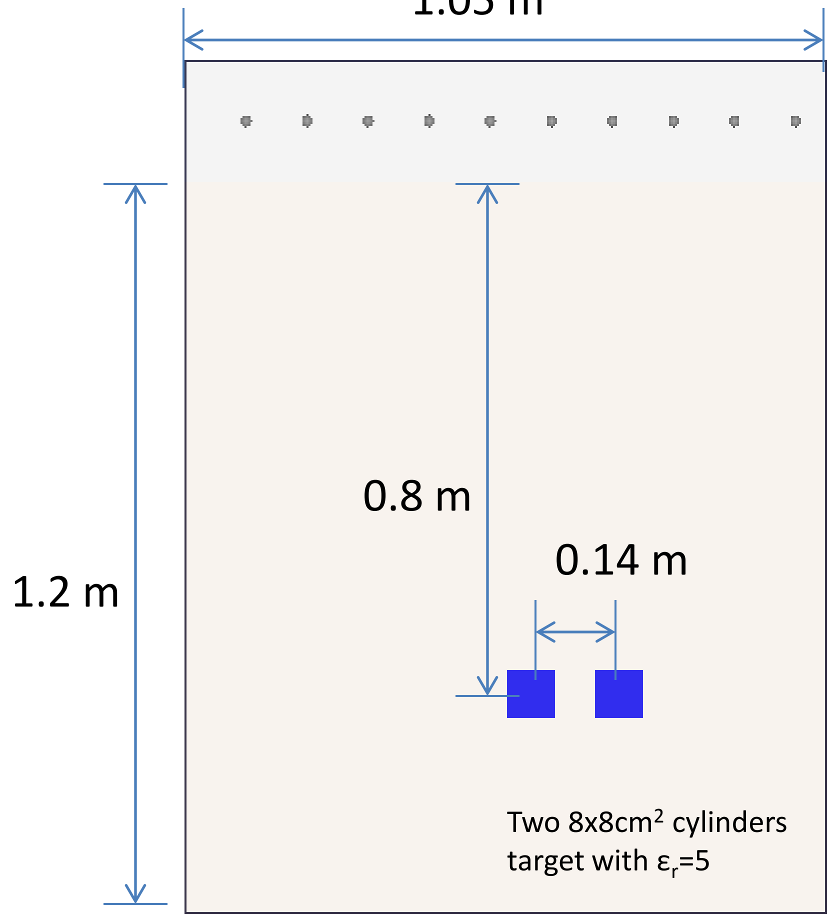
(note: Except source & receiver, this case is the same as case III & V, two targets in a two-layers environment. We will use scheme III run this case in one click.)

- Freq: f_{max}=6 GHz ($f_c \approx$ 2 GHz)
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are two 8x8 cm^2 and ε_r=5 rectangular cylinder with a center-center distance of 14 cm
- Signal on receiver: from WCT EM solver
- A switching transmitter /receiver array with10 elements.

Angle View



Front View

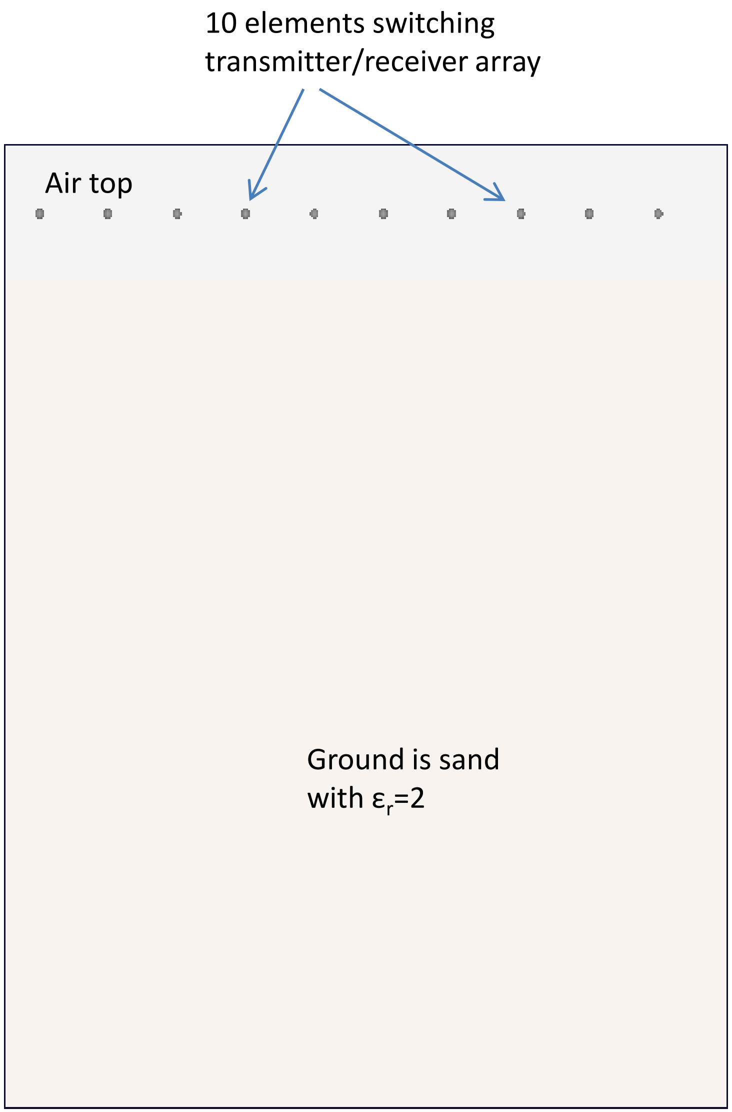


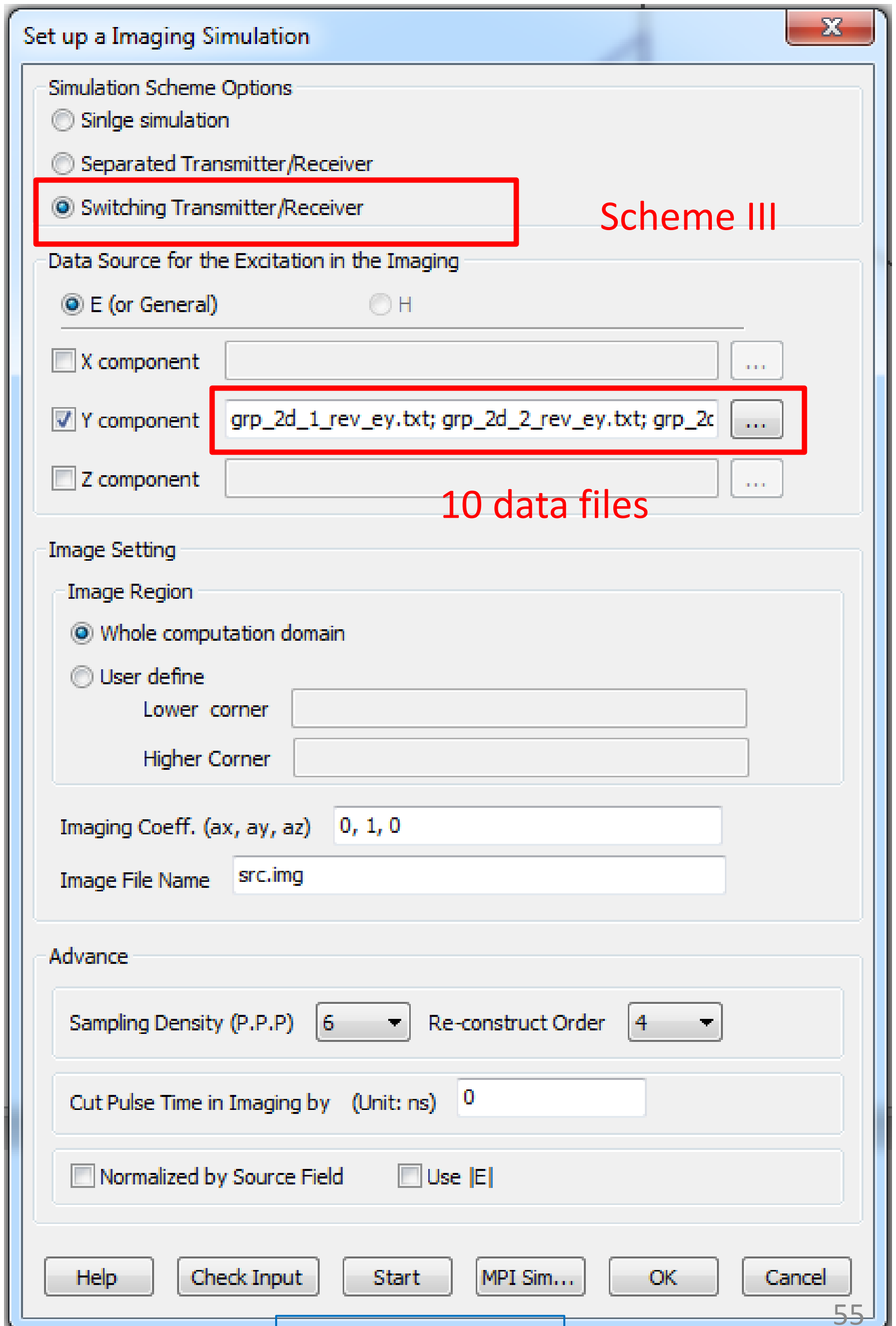
Imaging process by this case

- We have signals on 9(=10 elements – 1 working source) receivers as the measurement from the real case for each excitation.
  - these signals can be obtained from our EM simulation tools.

- For imaging, we assume we only know
  - two layered background
  - one source generates 9 measured signals on 9 receivers. These 9 traces are stored in one file.
  - there are 10 data files for 10 sources (each element will be switched to transmitter mode).

  - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.

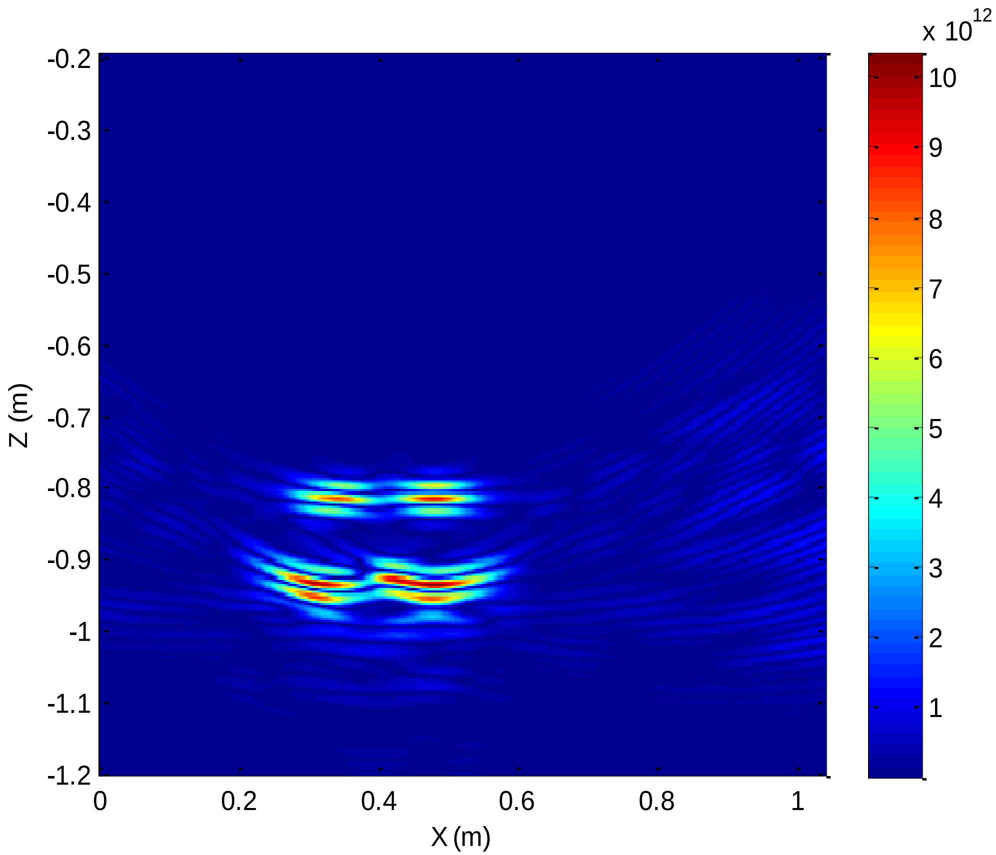




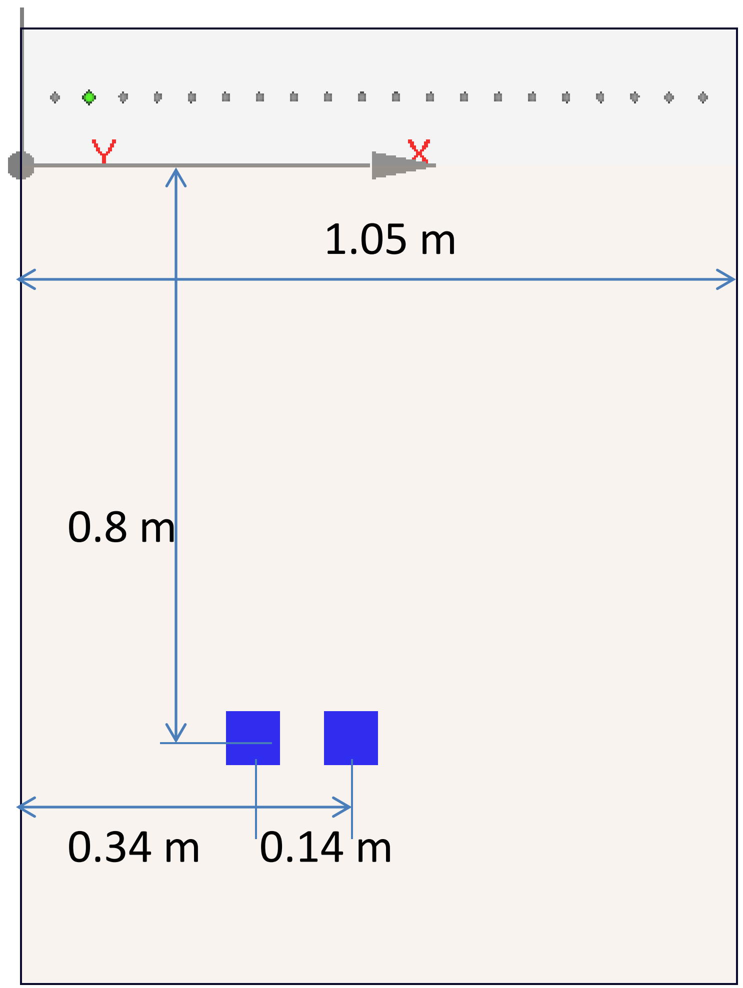
Click here to run

Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

WCT EM-IMG result

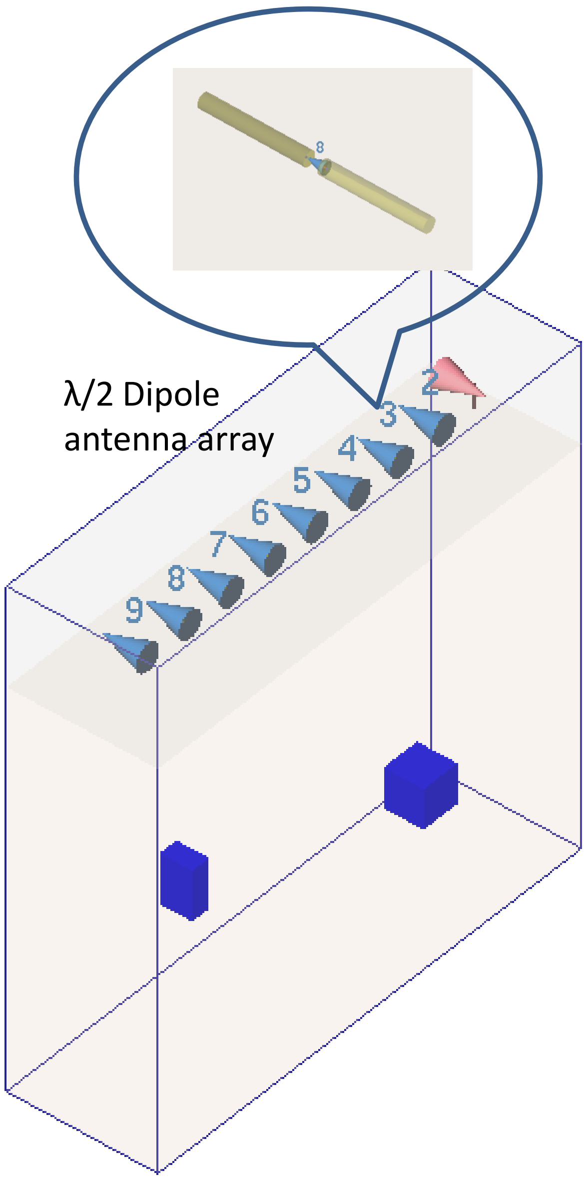


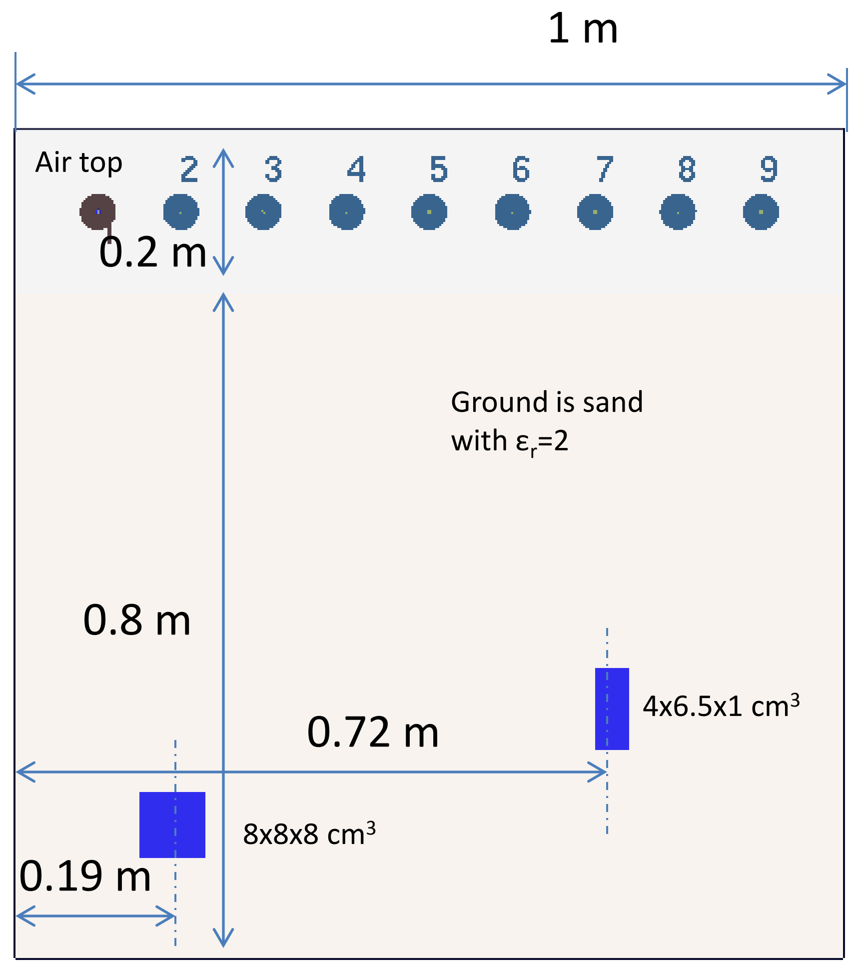
Ground True Setup



Case VI : 3D Imaging with λ/2 dipole Antenna Two objects, Scheme III

- Freq: f_{max}=5.5 GHz
- λ/2 dipole Antenna length: 6.4 cm; design freq: 2.34 GHz
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are two rectangular object with ε_r=5
- Signal on receiver: from WCT EM solver
- A switching transmitter /receiver array with 9 elements.


λ/2 Dipole
antenna array
2
3
4
5
6
7
8
9

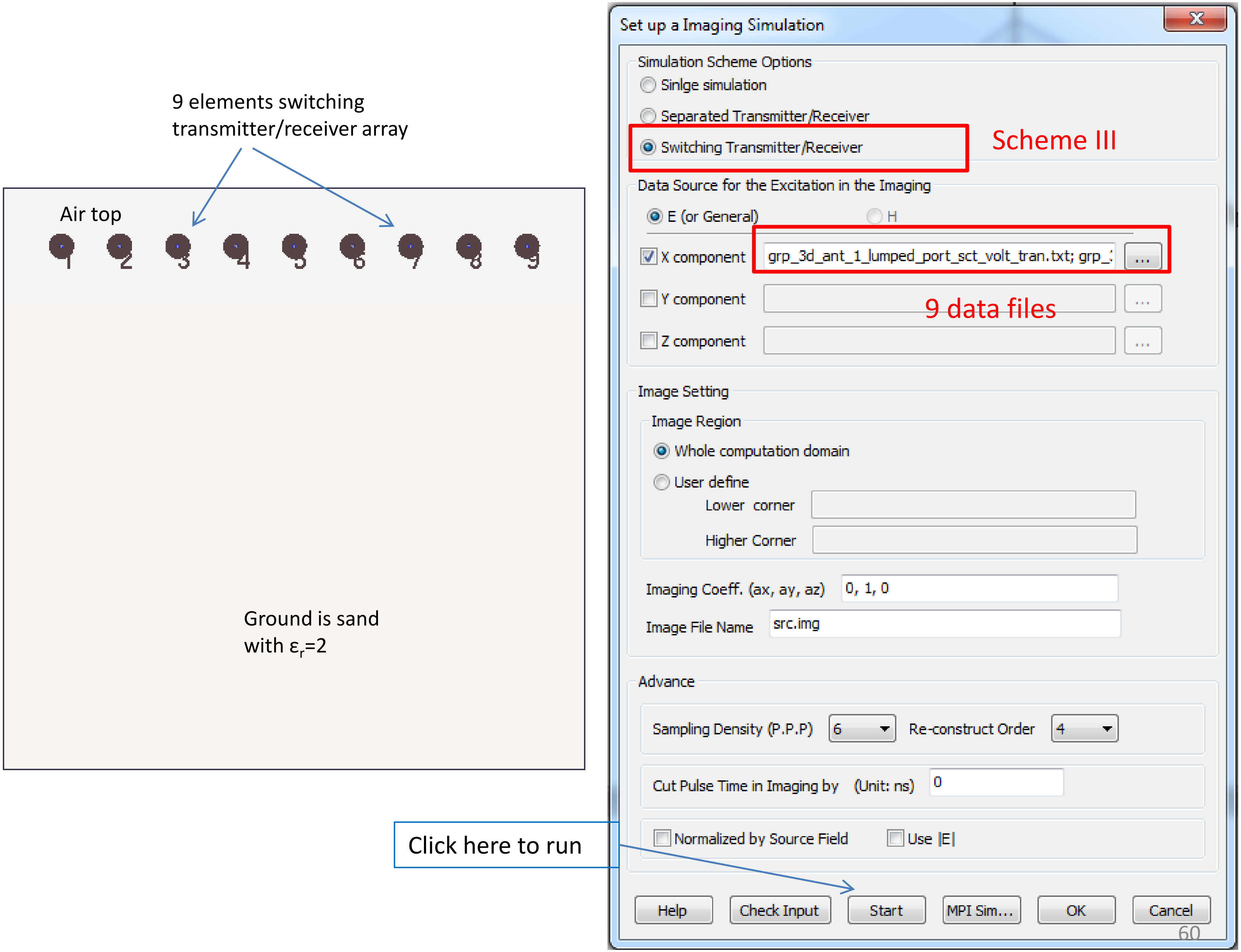

1 m
Air top
2
3
4
5
6
7
8
9
0.2 m
Ground is sand
with ε_r=2
0.8 m
4x6.5x1 cm^3
0.72 m
8x8x8 cm^3
0.19 m

Imaging process by this case

- We have signals on all 9 antennas as the measurement from the real case for each excitation.
  - these signals can be obtained from our EM simulation tools.

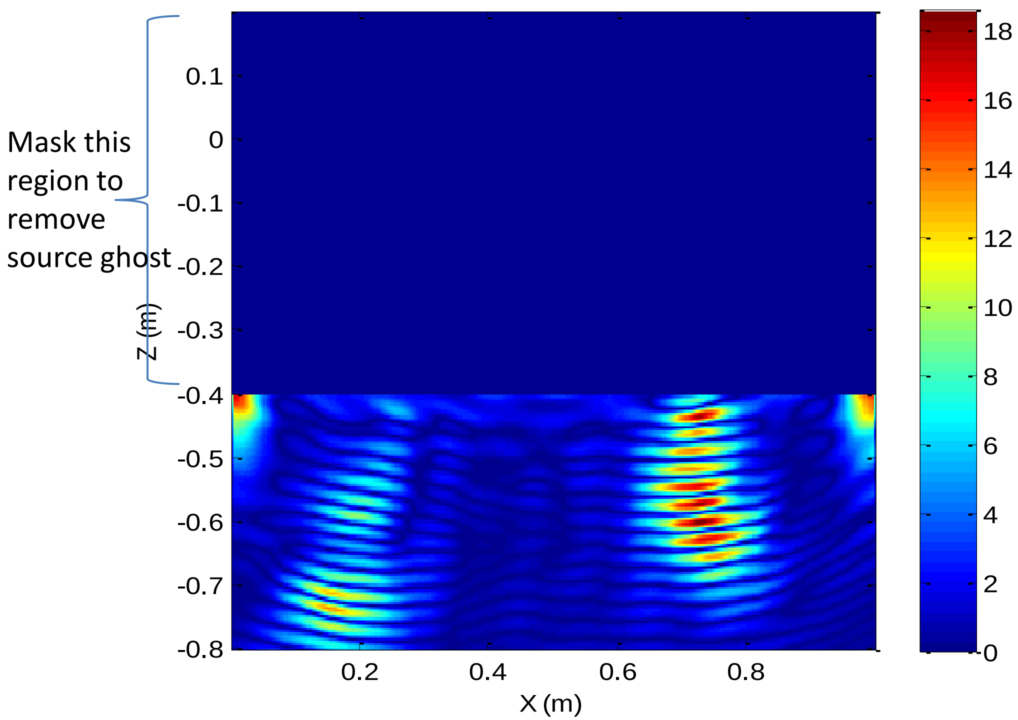
- For imaging, we assume we only know
  - two layered background
  - one source antenna generates 9 measured signals on 9 antennas (including the source antenna). These 9 traces are stored in one file.
    - in a WCT EM simulation, assuming we use lumped port to excite and receive signal on antenna, the signal data file should be "xxx_lumped_port_sct_volt_tran.txt" (xxx is project name) under folder "xxx_res\lump_ports\"
  - there are 9 data files for 9 sources (each element will be switched to transmitter mode).

  - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.

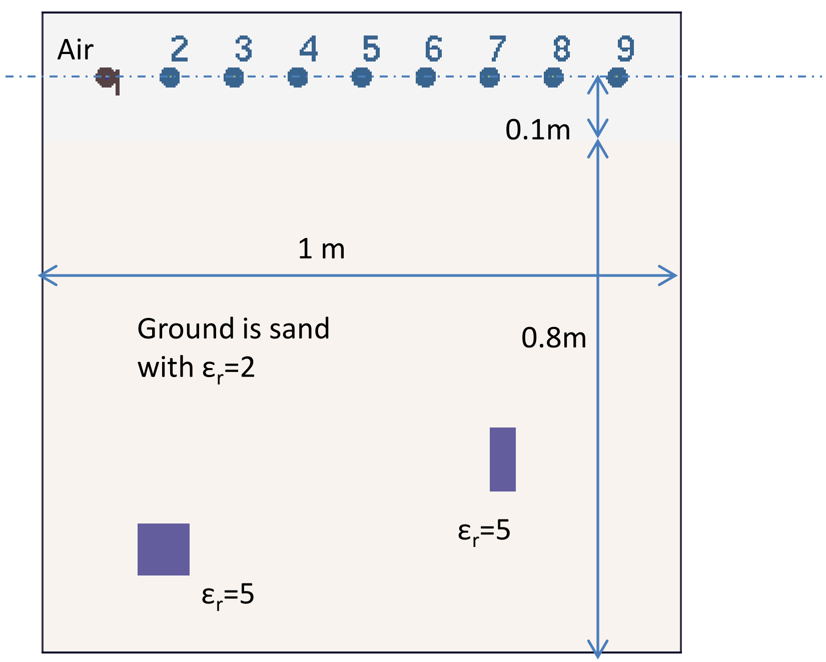

9 elements switching transmitter/receiver array
Air top
1 2 3 4 5 6 7 8 9
Ground is sand with ε_r=2
Click here to run
Set up a Imaging Simulation
Simulation Scheme Options
Sinlge simulation
Separated Transmitter/Receiver
Switching Transmitter/Receiver
Scheme III
Data Source for the Excitation in the Imaging
E (or General)
H
X component
grp_3d_ant_1_lumped_port_sct_volt_tran.txt; grp_
Y component
Z component
9 data files
Image Setting
Image Region
Whole computation domain
User define
Lower corner
Higher Corner
Imaging Coeff. (ax, ay, az)
0, 1, 0
Image File Name
src.img
Advance
Sampling Density (P.P.P)
6
Re-construct Order
4
Cut Pulse Time in Imaging by (Unit: ns)
0
Normalized by Source Field
Use |E|
Help
Check Input
Start
MPI Sim...
OK
Cancel

Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

WCT EM-IMG result

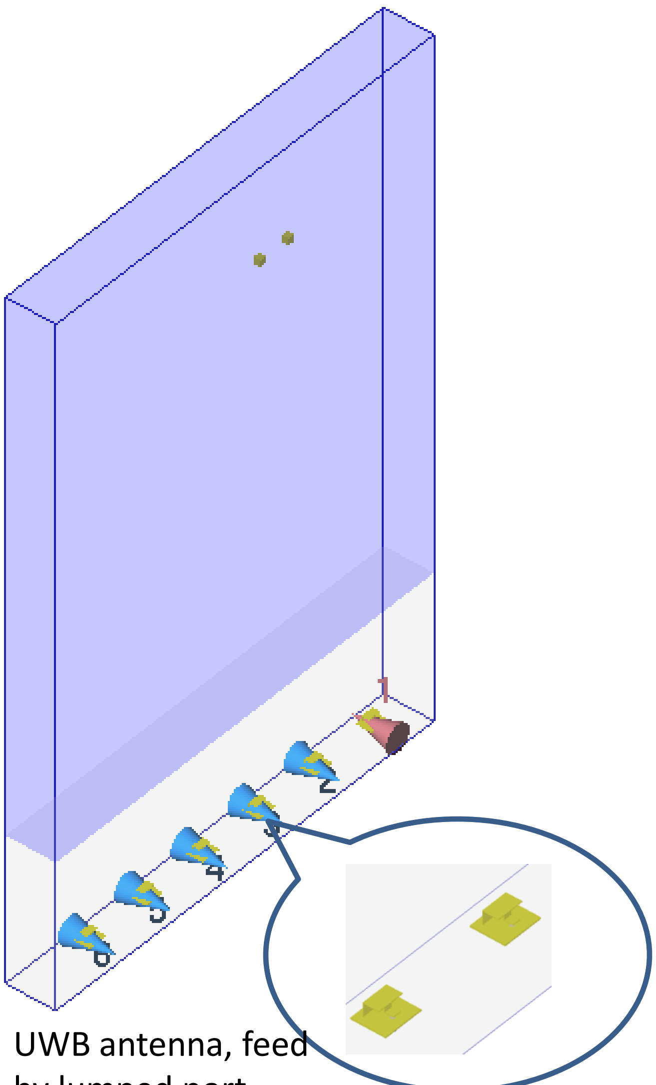


Ground True Setup

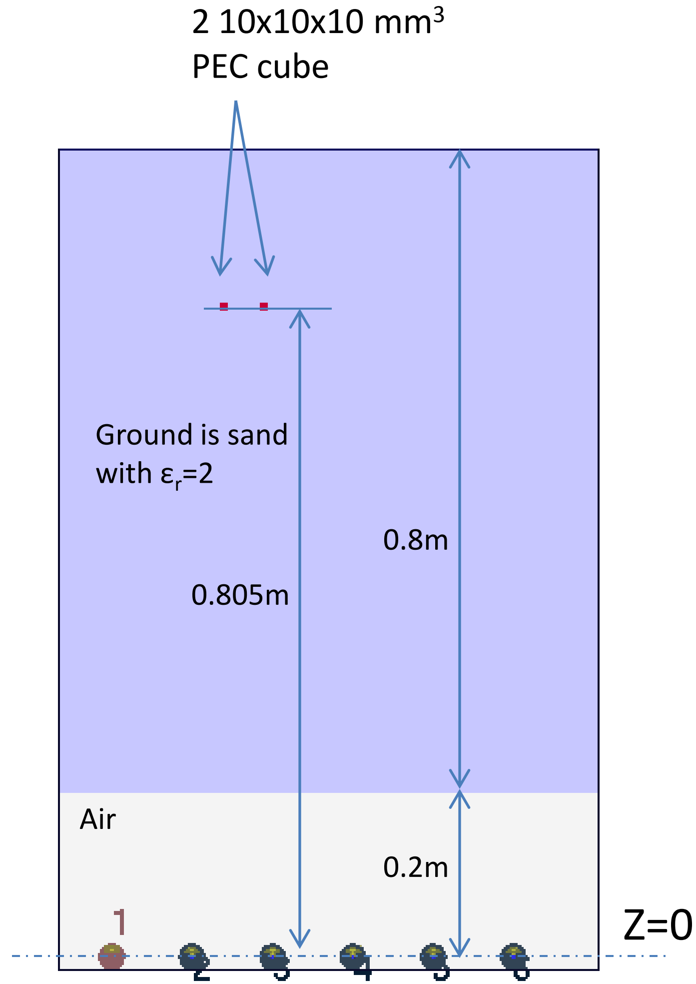


Case VII : 3D Imaging with UWB Antenna Two PEC objects, Scheme III

- Freq: f_{max}=7 GHz
- UWB Antenna size: ≈3x2.5x2 cm; design bandwidth: 3-10 GHz
- Two layers background: top is air, bottom is sand with ε_r=2
- Targets are two 1x1x1 cm^3 PEC object with a distance of 5 cm
- Signal on receiver: from WCT EM solver
- A switching transmitter /receiver array with 6 elements.



UWB antenna, feed by lumped port



Imaging process by this case

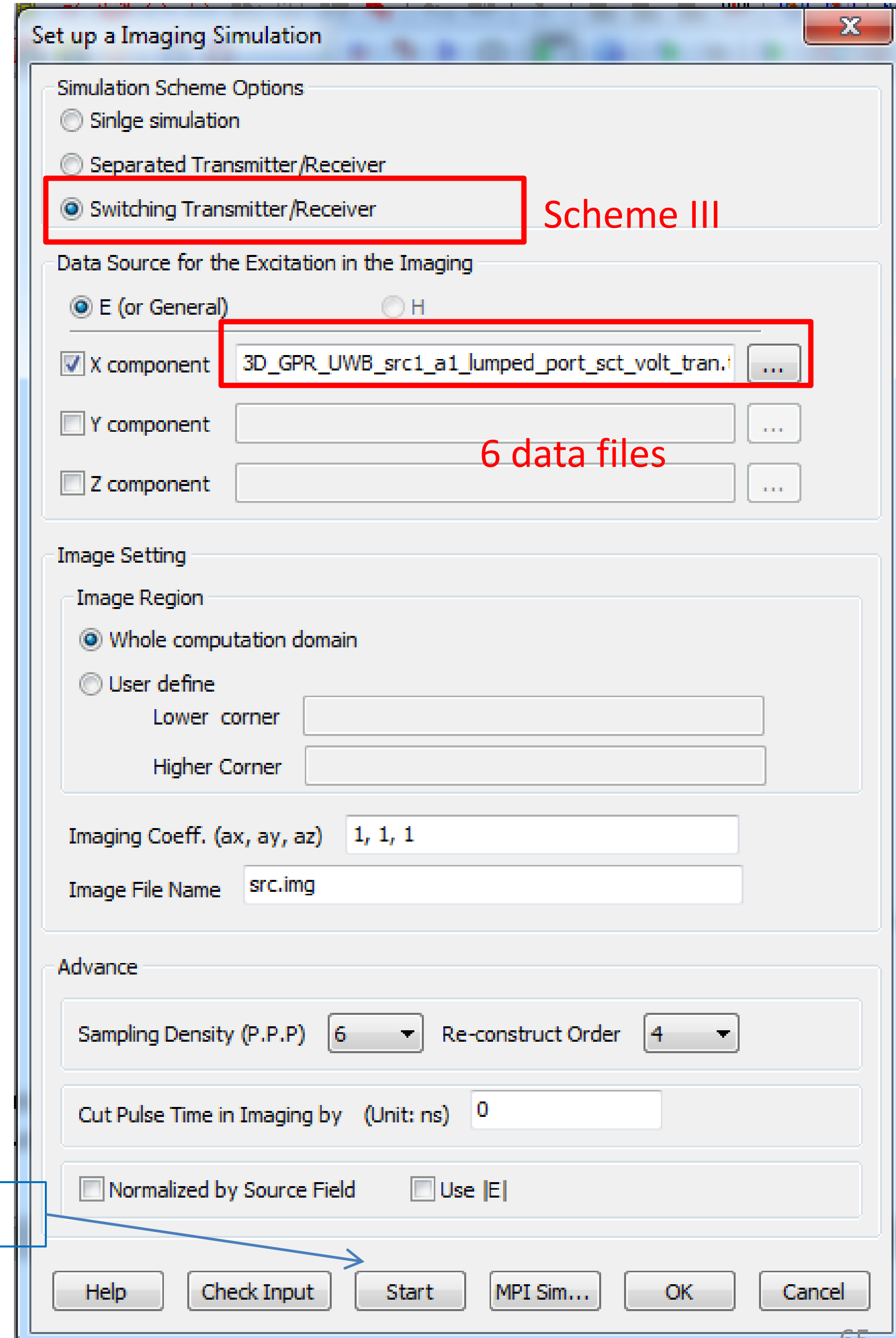
- We have signals on all 6 antennas as the measurement from the real case for each excitation.
  - these signals can be obtained from our EM simulation tools.

- For imaging, we assume we only know
  - two layered background
  - one source antenna generates 6 measured signals on 6 antennas (including the source antenna). These 9 traces are stored in one file.
    - in a WCT EM simulation, assuming we use lumped port to excite and receive signal on antenna, the signal data file should be "xxx_***lumped_port_sct_volt_tran***.txt" (xxx is project name) under folder "xxx_res\lump_ports\"
  - there are 6 data files for 6 sources (each element will be switched to transmitter mode).

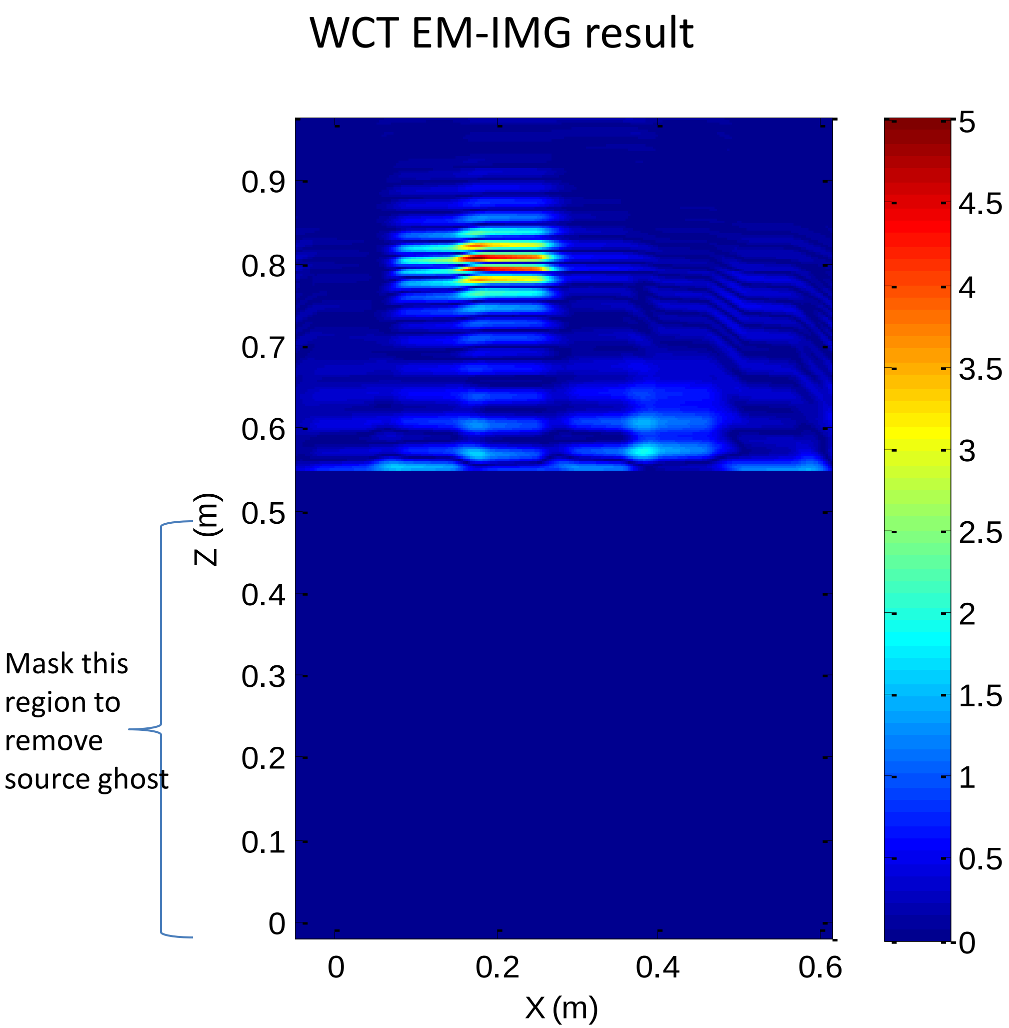
  - Then, we use WCT EM-IMG package to imaging with above knowledge, as shown in the next page figure.

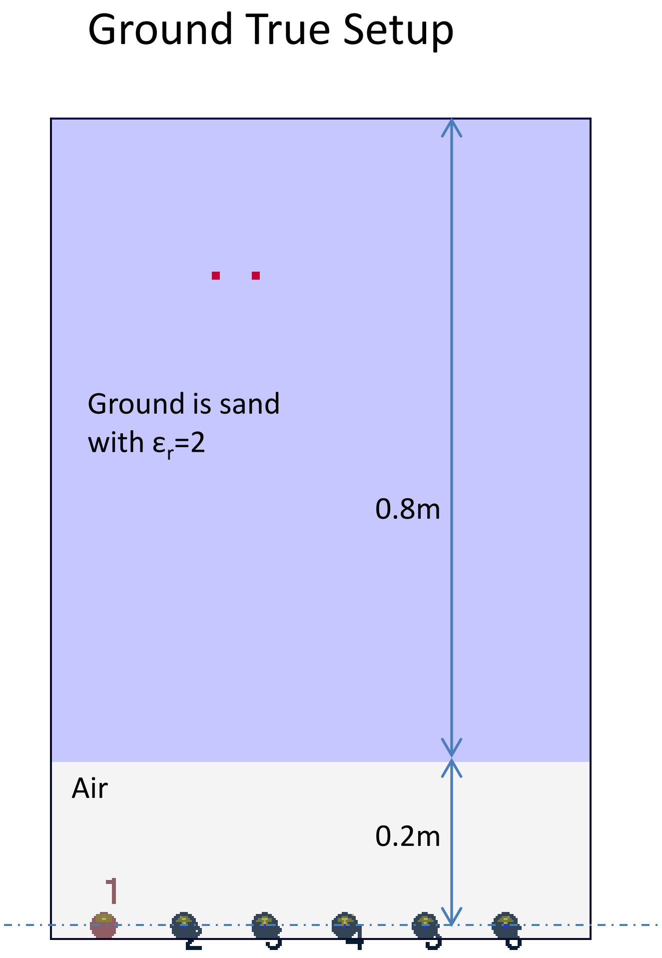
6 elements switching transmitter/receiver array

Click here to run



Here, it is the image from WCT EM-IMG simulation. The right figure is the ground true of the case for comparison purpose.

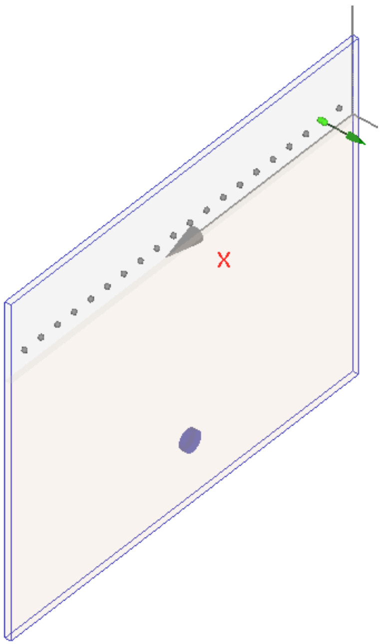


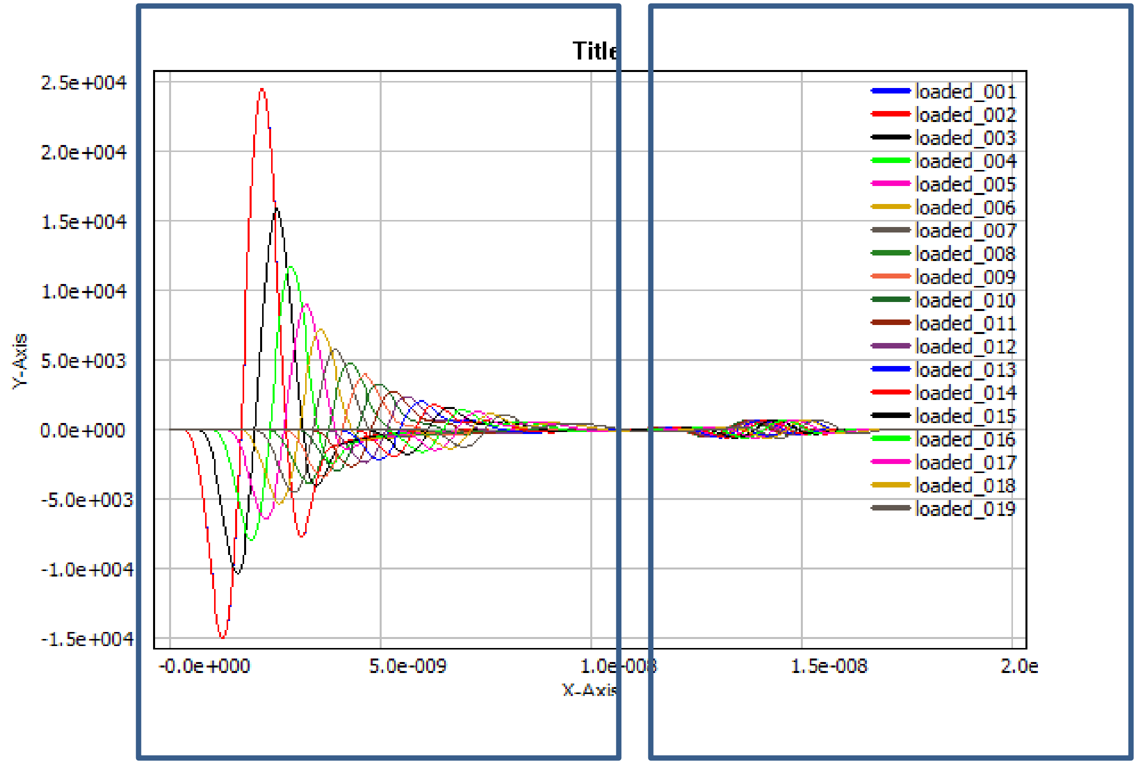


Case VIII : Imaging with Adjusted Signal

- From case I to VII, all displayed images are a partial space which cut off the source region, this is due to the direct wave from source to receiver is too strong compared to the scattered signal.
  - This will produce a much strong focus on source & receiver compared to the focus on the target.
    - In order to see the target from final image, we need to cut the source region off.

The signal on the receiver for case I, source 1



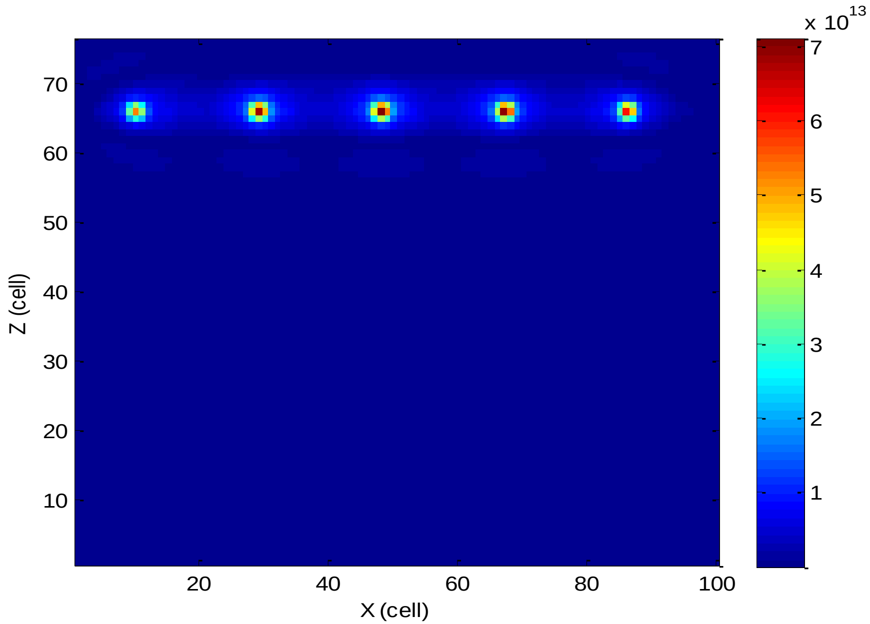


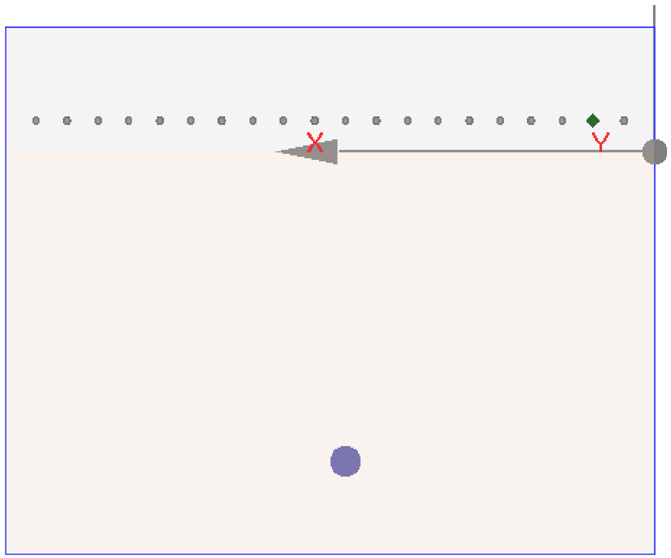
Direct wave

Scattered wave

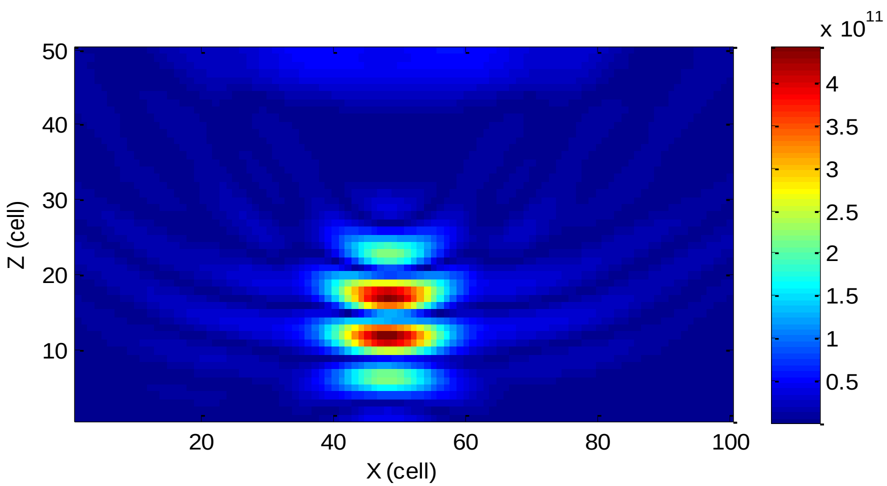
It is very clear that direct wave is much larger than scattered wave.

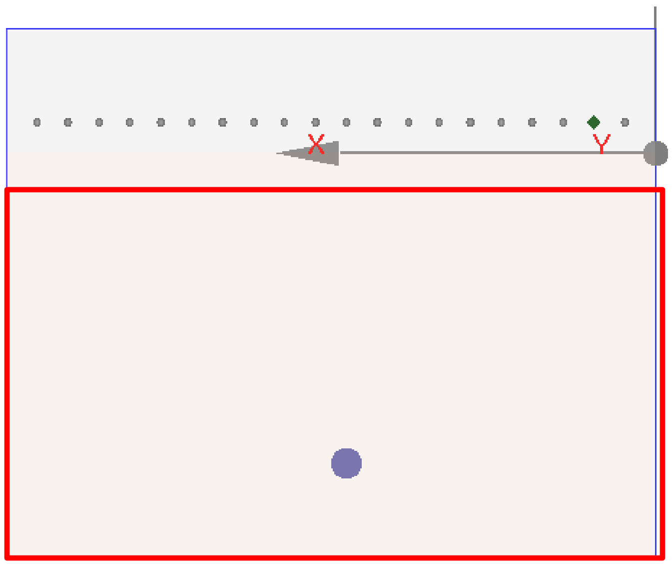
If show all space of case I, we can see 5 sources only



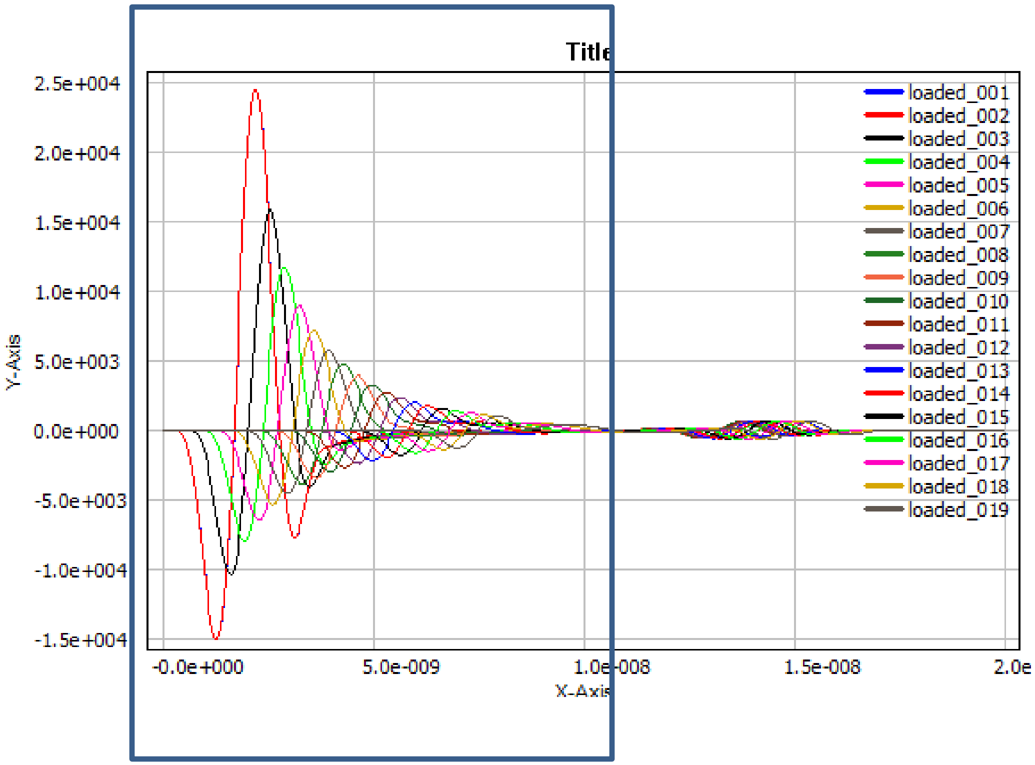


In order to see the focus on target, need to remove source region

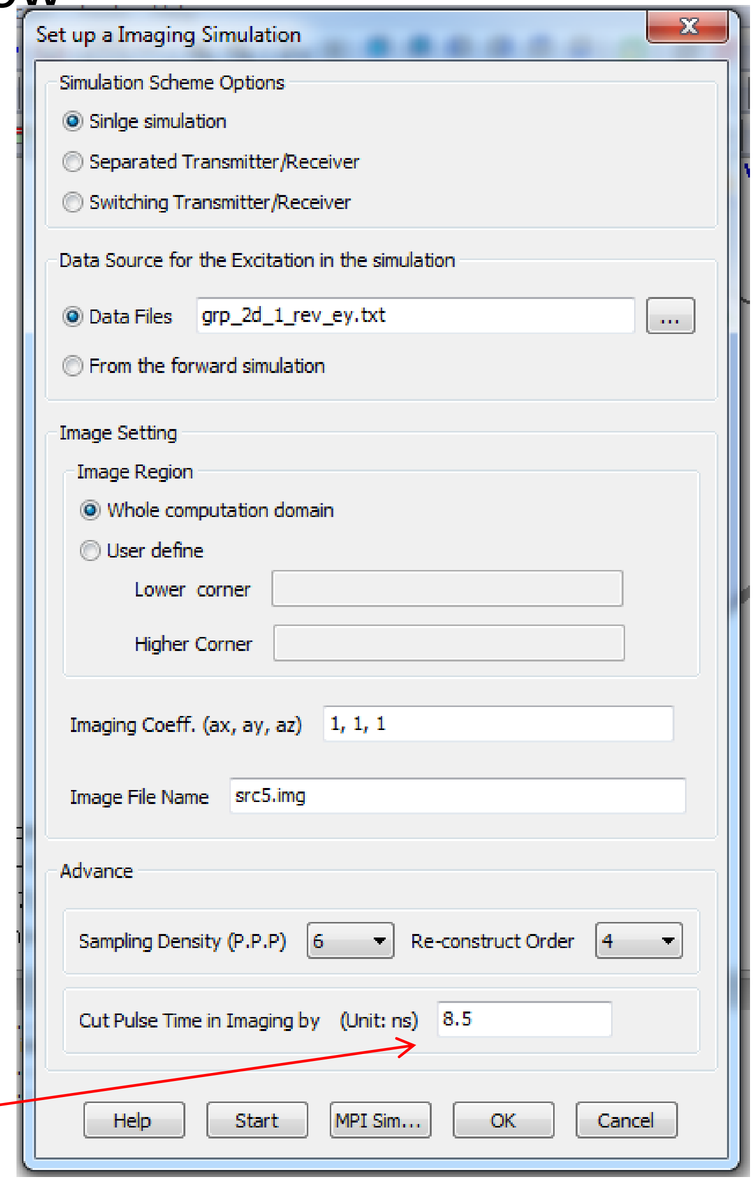




Method A. Adjust signal by directly cutting the time window

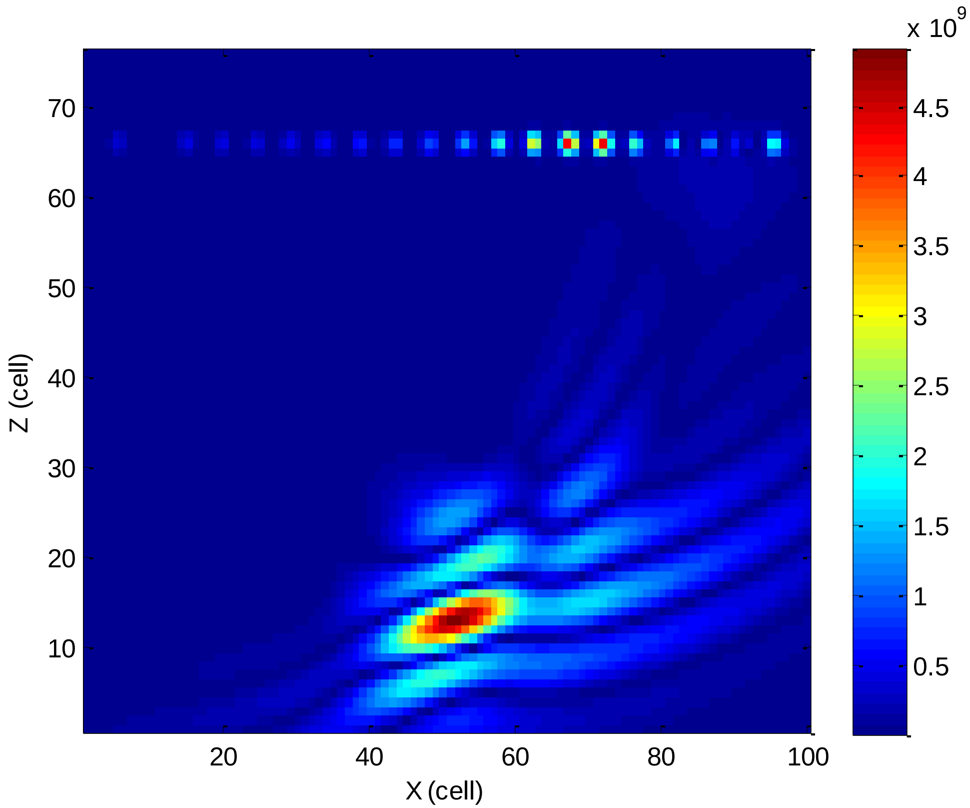


Direct wave



Here, in Imaging setting, we can let the solver directly skip the beginning 8.5 ns to skip the direct wave.

Following figure is one image from the source 1 of case I.

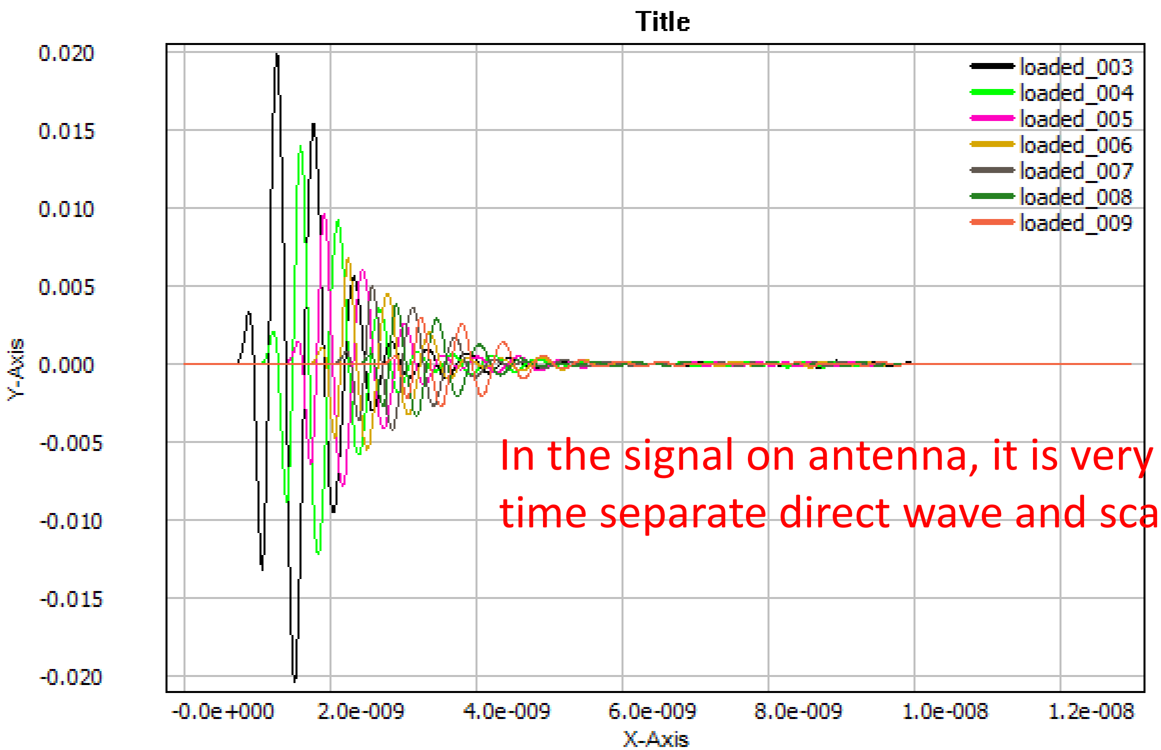


We can see the transmitter/receiver array in whole space, but compared to the target, it is not very strong. So, we can display the image for whole space.

Method B. Manually remove directly wave from measurement

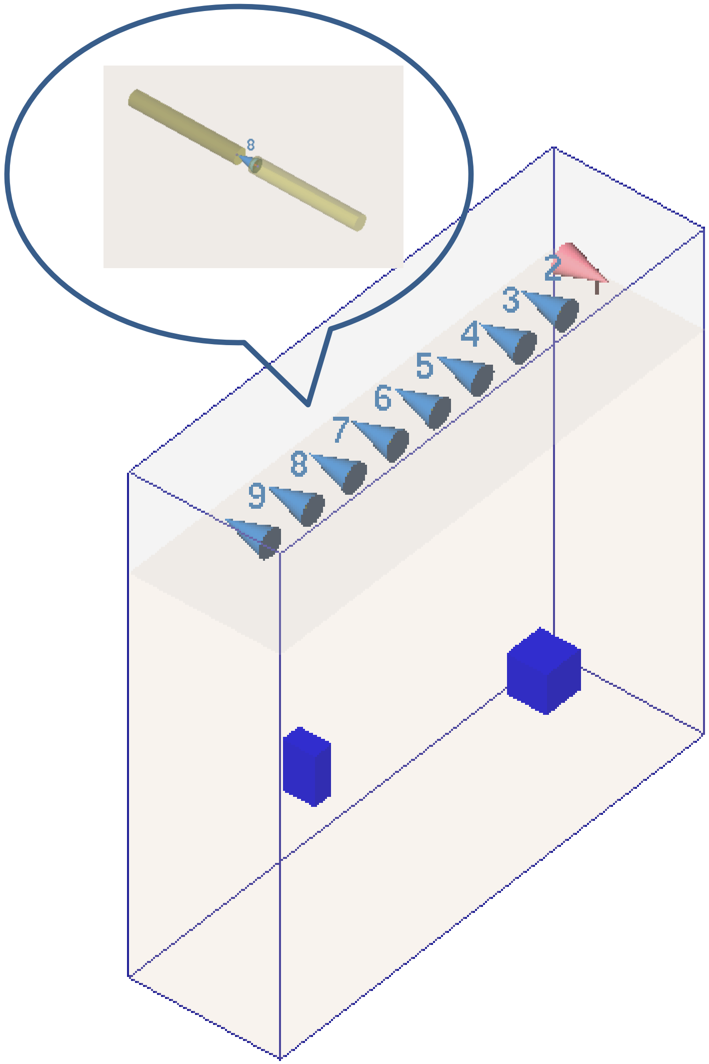
In case VI, we use real antenna to imaging. However, due to the bandwidth of antenna, direct wave is hard to clearly separated from measurement, as following figure.

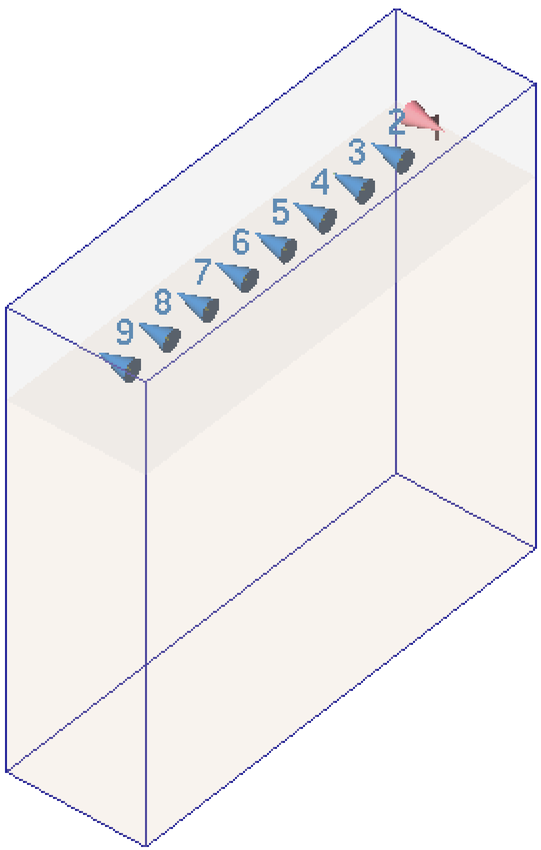
The measurement on antenna



In the signal on antenna, it is very hard to know a good time separate direct wave and scattered wave

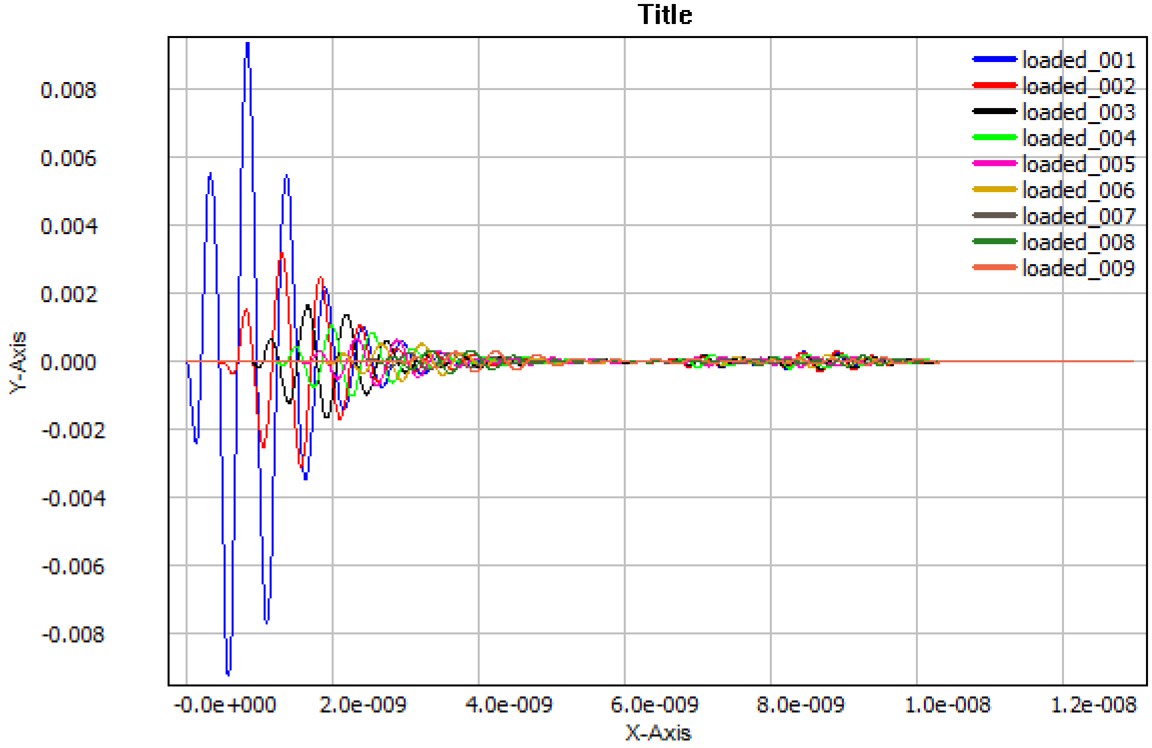
If we say left setup can get the measurement, and right setup can get the direct wave from transmitter to receiver (without the target).



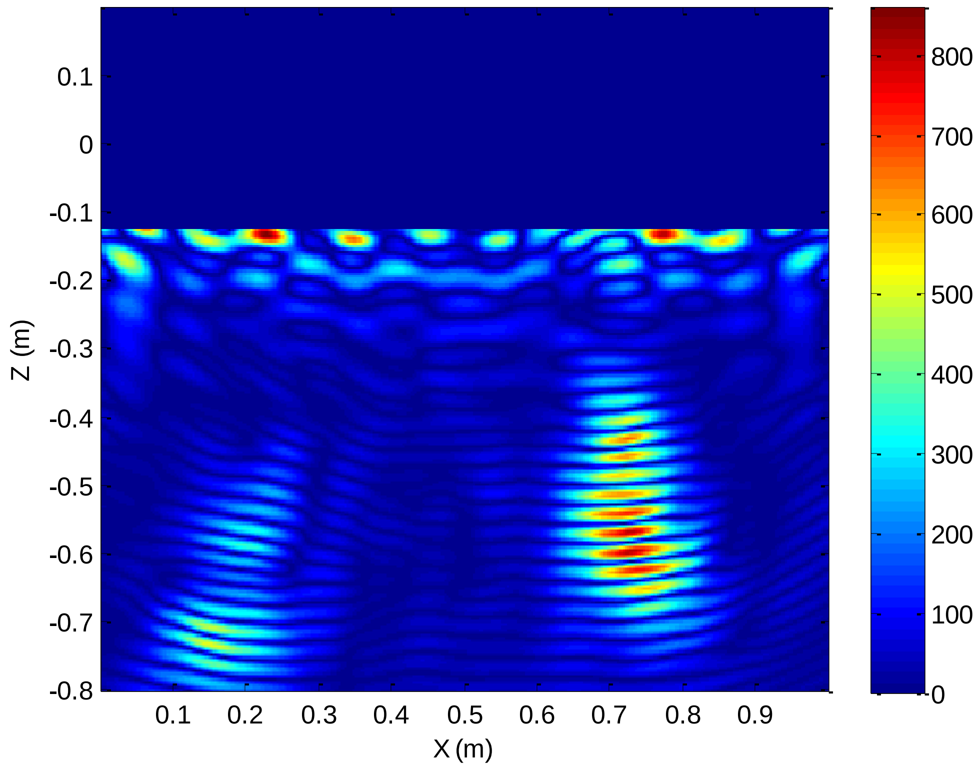


We can subtract two kinds of signal to get the scattering. Maybe due to real situation, noise or, simulation solver's error (due to setup is different), exist.

Following is one example for case VI, transmitter 1's signal, processed by subtracting direct wave.



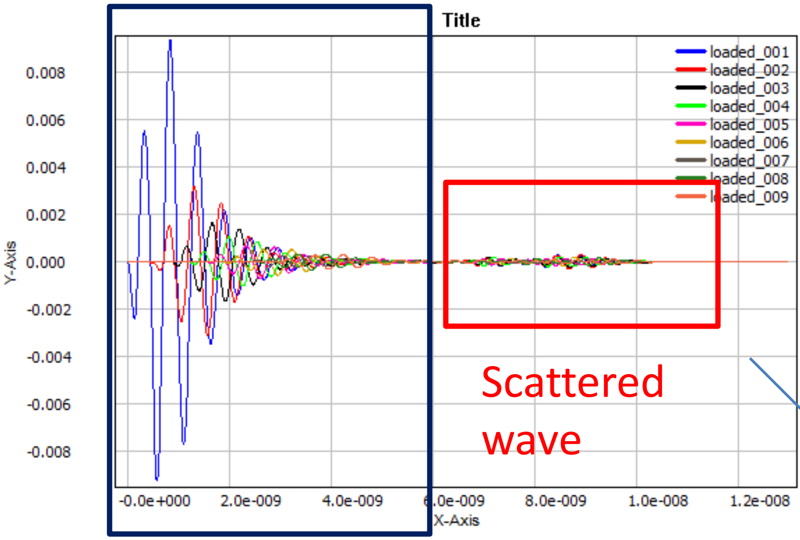
As can be seen, the relative magnitude of scattered wave become much more stronger.



As can be seen, compared to case VI, we can imaging a bigger space.

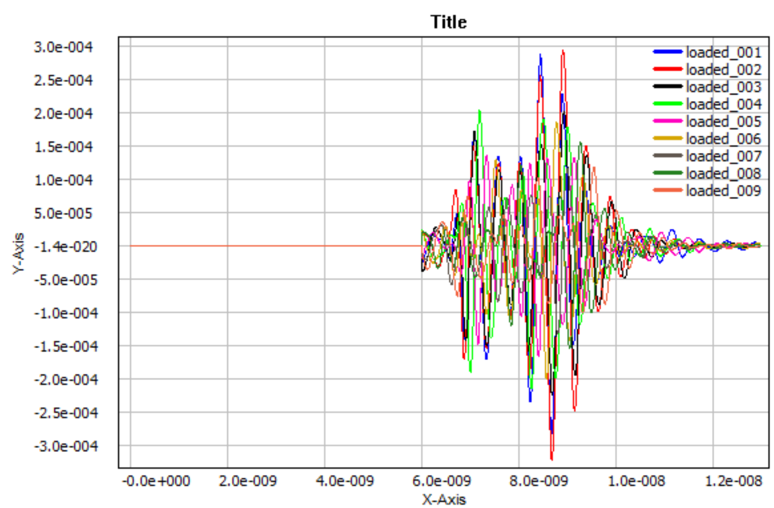
Method C. Manually remove directly wave from measurement with more adjustment

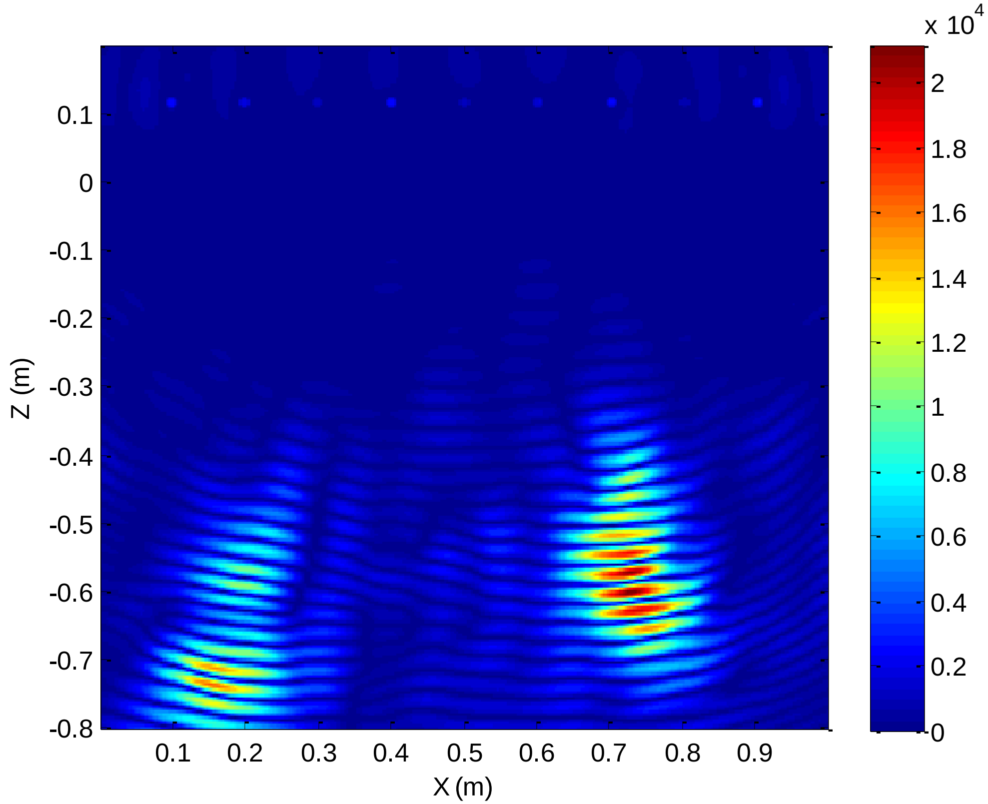
In method B, after direct wave subtraction, the relative magnitude of scattered wave become much larger. Meanwhile, the real time range of scattered wave become more clear. Therefore, we can use more adjustment to manually remove the noise outside the time range of scattered wave – set them as 0.



Set the signal in this time range as 0.

After processing





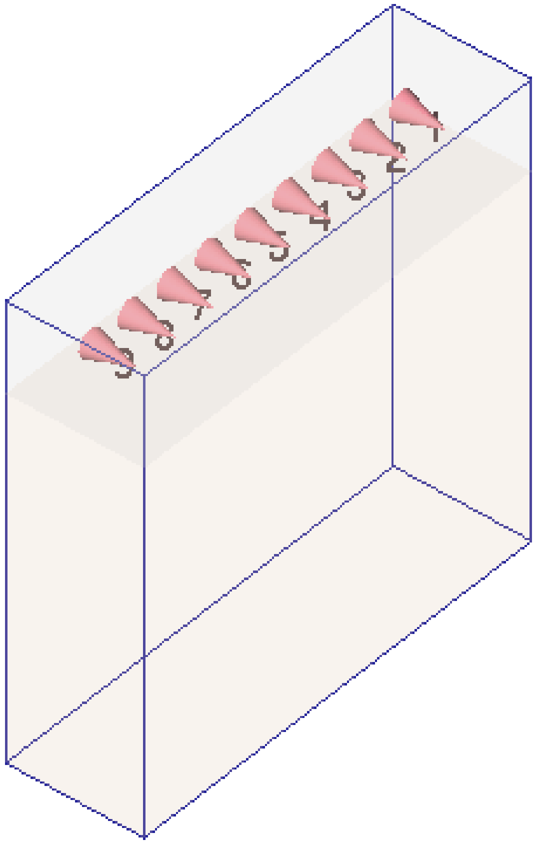
We can see the transmitter/receiver array in whole space, but compared to the target, it is not very strong. So, we can display the image for whole space.

Imaging performance comparison [1]

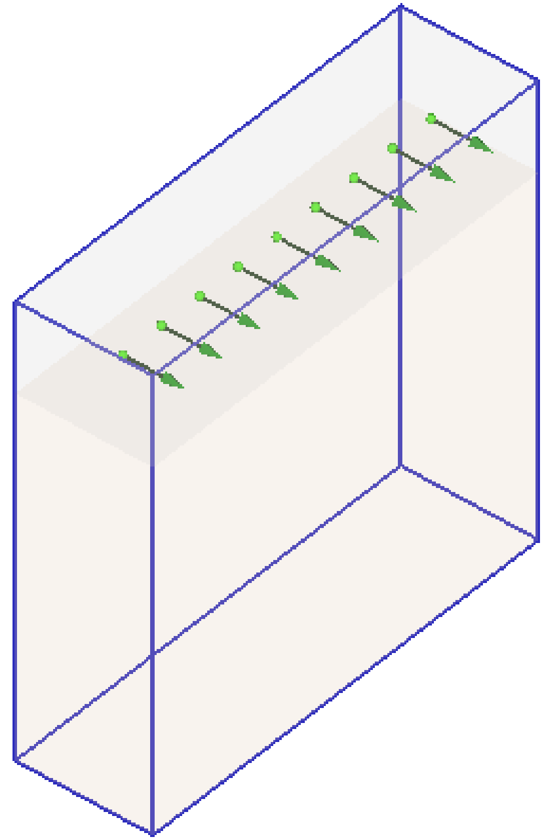
Ideal Point Dipole vs. Half Wavelength Dipole Antenna

- All signal used in imaging are the antenna port's voltage on half wavelength dipole antenna
- We compare the images from two imaging process
  - One is case VI, use the same half wavelength dipole antenna to imaging
  - In another method, we replace the half wavelength dipole antenna by ideal point dipole with the same polarization. The ideal dipole is at the antenna center. And the ideal point dipole will use the signal on the antenna at the same position.

Imaging Method I, use 9 λ/2 dipole antennas

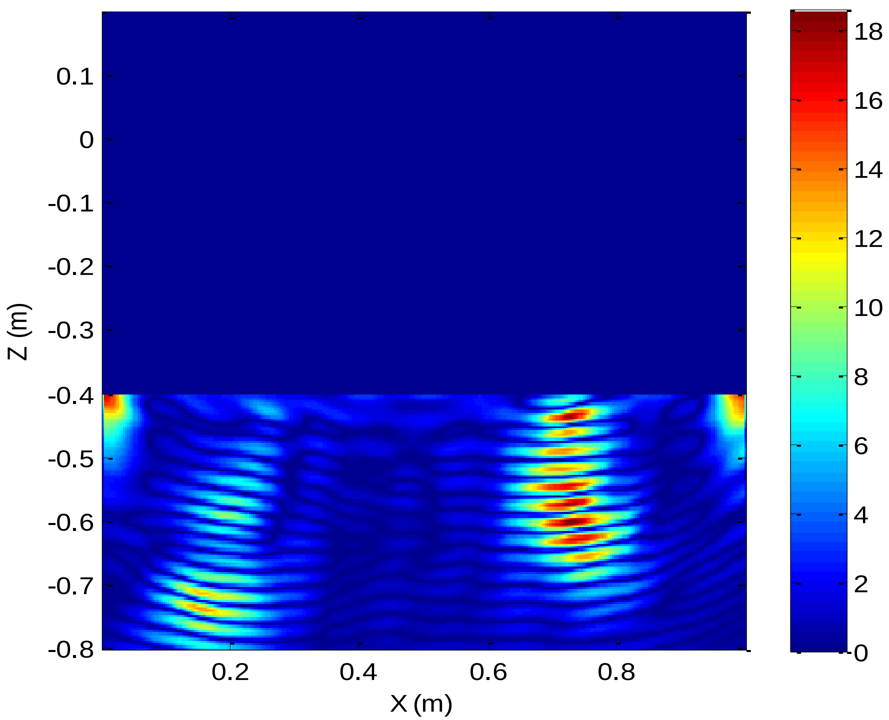


Imaging Method I, use 9 ideal point dipole

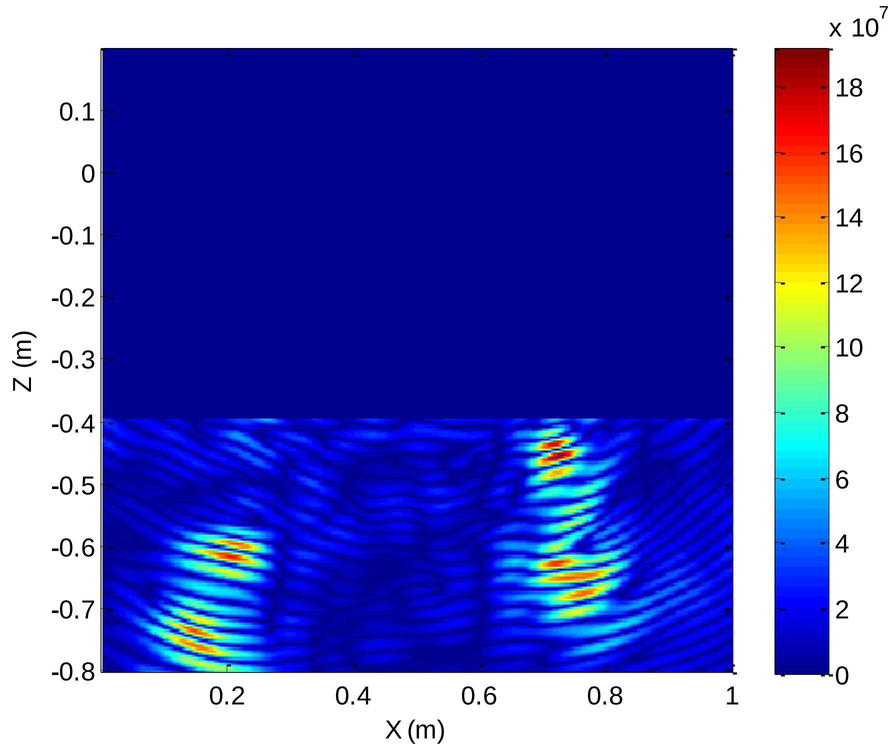


- Two methods use the same signal to imaging
    - One thing need to mention is, for ideal point dipole setup, due to it will use ideal dipole/receiver configuration, the trace number in each data file will be 8 instead of 9. But the trace number in the scattered voltage data file from antenna simulation is 9. Therefore, we need to remove the trace on source antenna. As the matlab code “make_signal.m” in demo package.

Antenna Imaging Result



Ideal Dipole Imaging Result



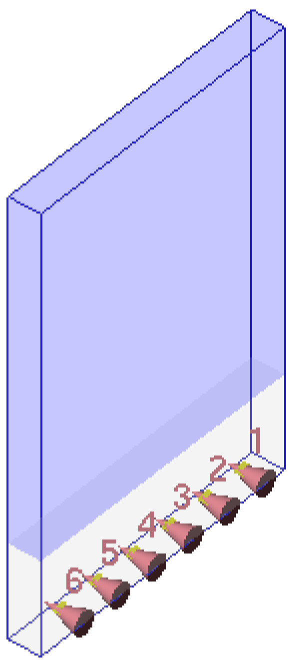
- As can be seen, two methods both can locating the target correctly. However, imaging from ideal dipole is more clear than that from λ/2 dipole antennas.

Imaging performance comparison [2]

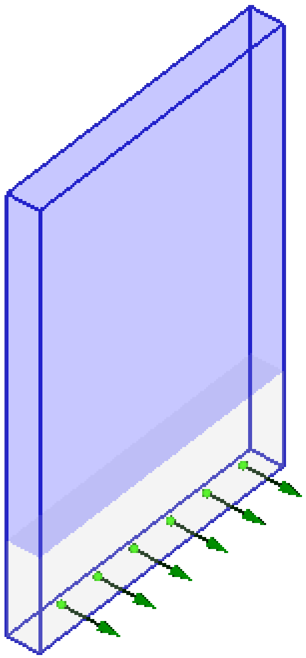
Ideal Point Dipole vs. Ultra Wideband Antenna

- All signal used in imaging are the antenna port's voltage on ultra wideband antenna
- We compare the images from two imaging process
  - One is case VII, use the same ultra wideband antenna to imaging
  - In another method, we replace the ultra wideband antenna by ideal point dipole. Due to size of ultra wideband antenna, and the aperture and the polarization is not fully compatible with ideal point dipole. We place Y dipole at the ultra wideband antenna canter. And the ideal point dipole will use the signal on the antenna at the same position.

Imaging Method I, use 6 UWB antennas

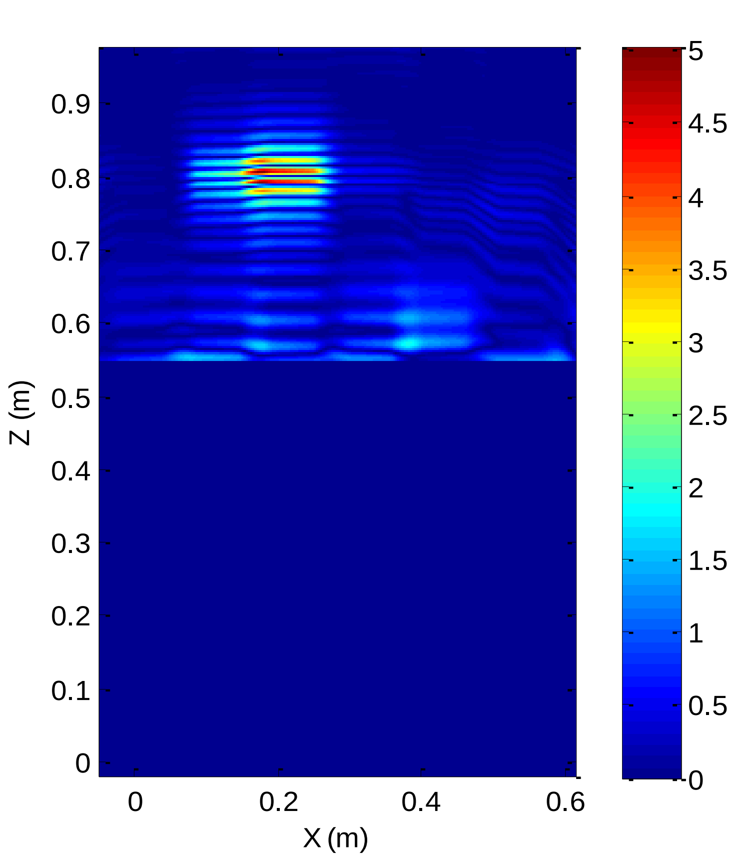


Imaging Method I, use 6 ideal point dipole

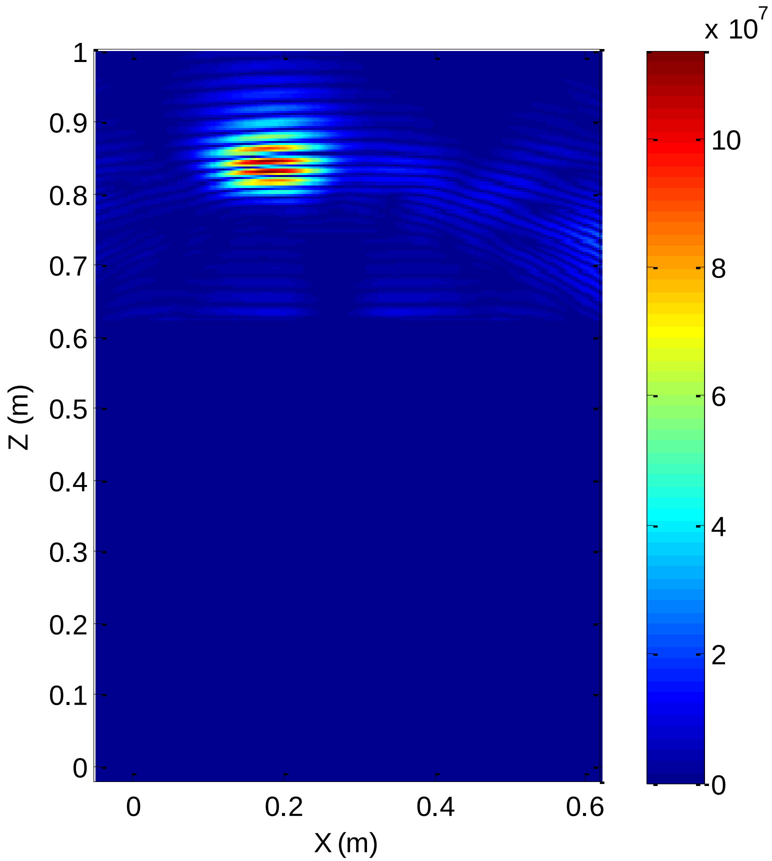


- Two methods use the same signal to imaging
    - One thing need to mention is, for ideal point dipole setup, due to it will use ideal dipole/receiver configuration, the trace number in each data file will be 5 instead of 6. But the trace number in the scattered voltage data file from antenna simulation is 6. Therefore, we need to remove the trace on source antenna. As the matlab code “make_signal.m” in demo package.

Antenna Imaging Result



Ideal Dipole Imaging Result



- As can be seen, imaging from ideal dipole has a better focus than that from UWB antennas. However, the center of focus from ideal dipole is not very correct, about 0.84 m. It is different from the real target Z position 0.805 m. As comparison, the focus from UWB antenna imaging is correct.

Some Thought on Imaging Process

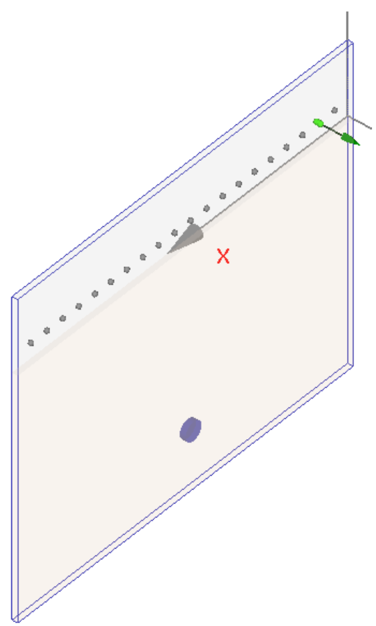
- We can always use ideal point dipole to replace real antenna to imaging.
- However, if there is mismatch between two kinds of transmitters, including band width, radiation pattern, aperture, replacement by ideal point dipole will introduce error.
- In order to get more accurate imaging, it is recommended to real antenna to imaging, if the computational cost is not too high.

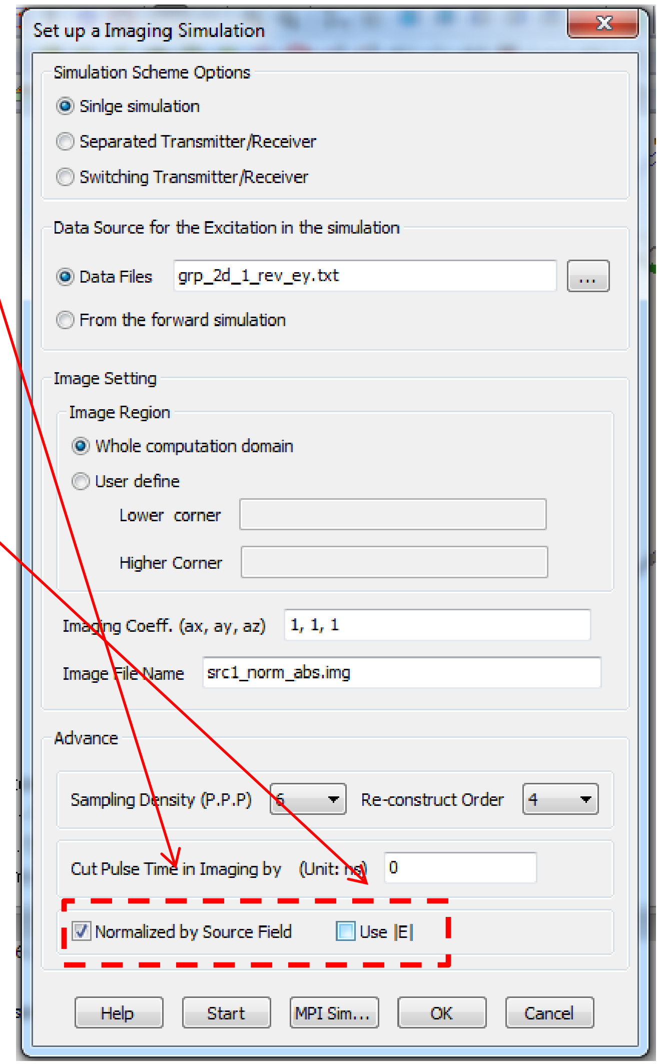
Advanced Functionality

1. Imaging Normalization by Source Field
   - ➢ This functionality can shift down the values of image and enhance the contrast of the weak signal

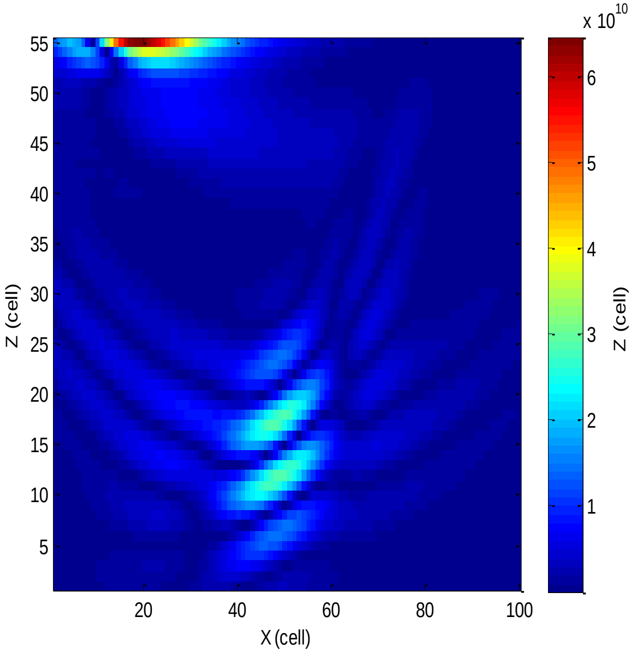
2. Using E field magnitude to imaging
   - ➢ This functionality can produce a image with all values > 0. It can also enhance the contrast of the weak signal

We will compare the images with different functions by the case in the right figure.

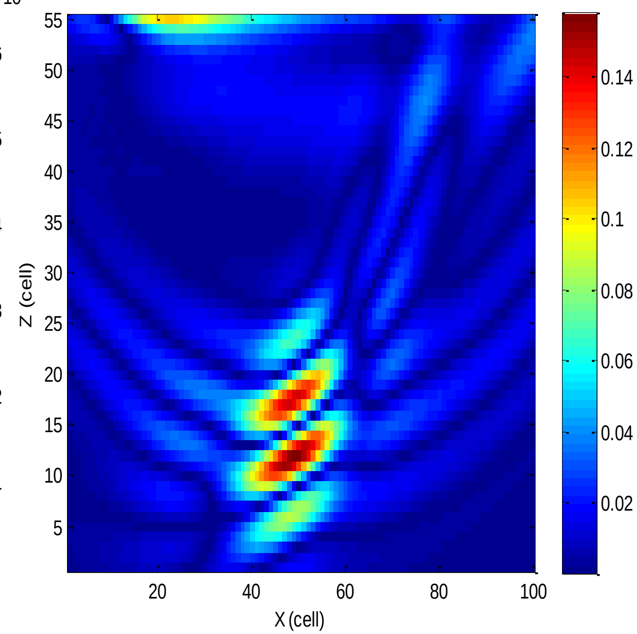




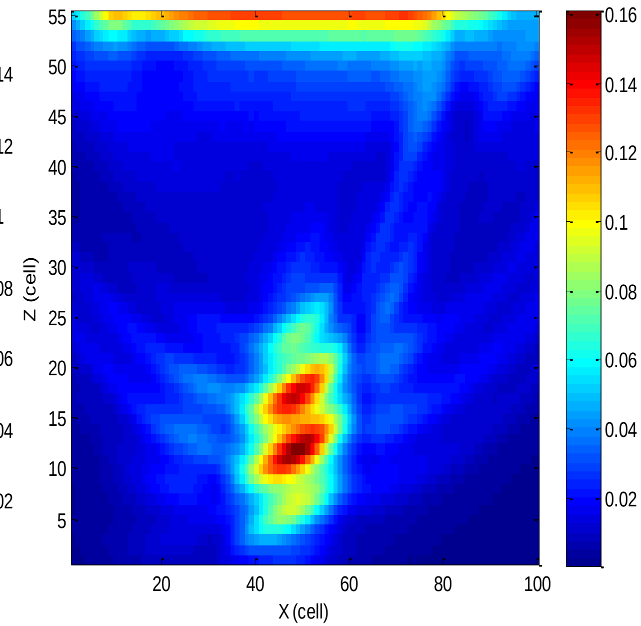
Use E field to imaging without normalization



Use E field to imaging with normalization



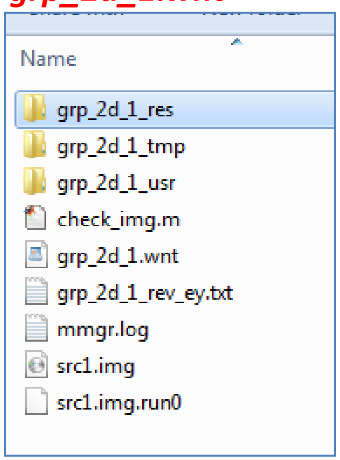
Use |E| to imaging with normalization



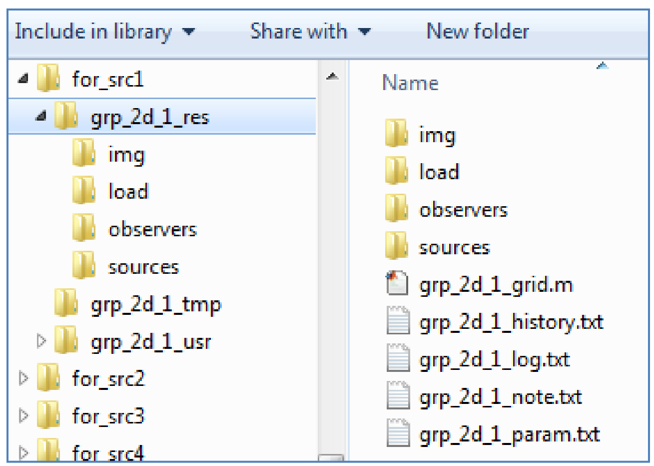
Result Displaying in WCT GUI

In the new release version, WCT imaging solver will generate the image result in sub-folder: xxxx/xxxx_res/img, as following

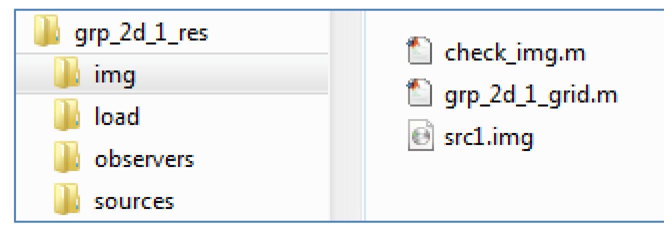
Project folder for case:
grp_2d_1.wnt



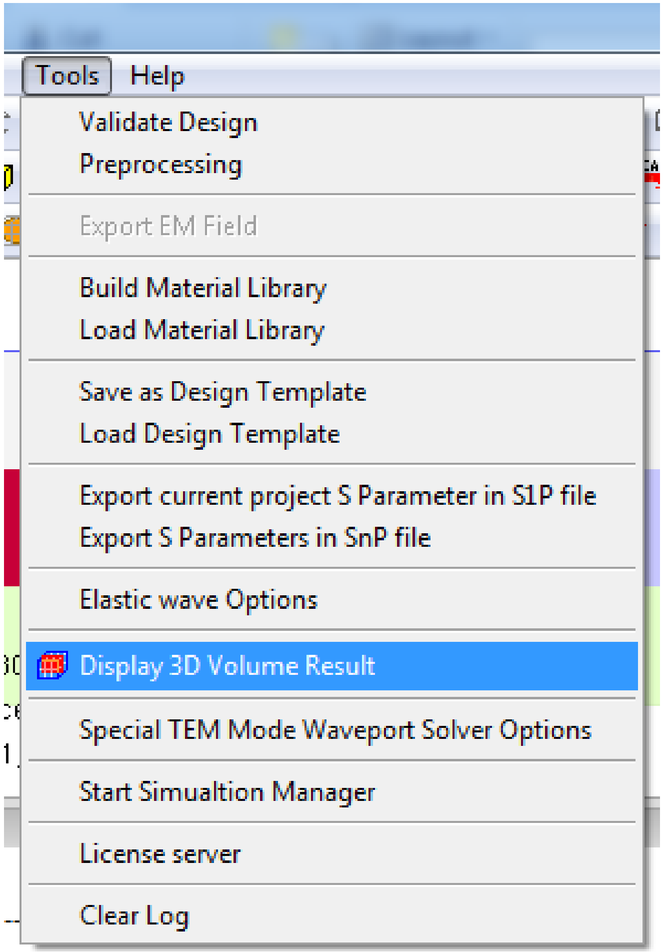
Result root folder



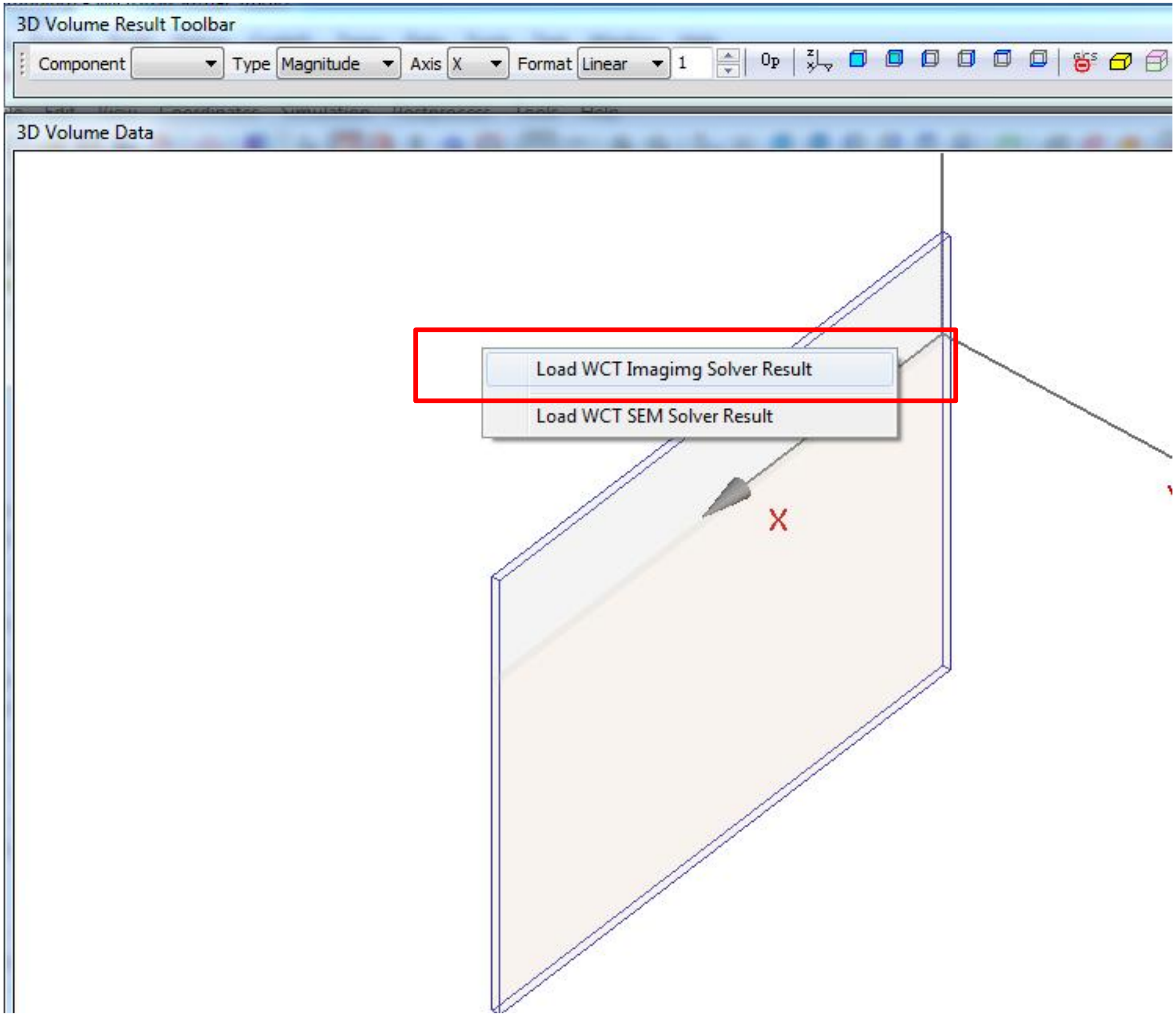
Sub-folder for "img" and the result data file

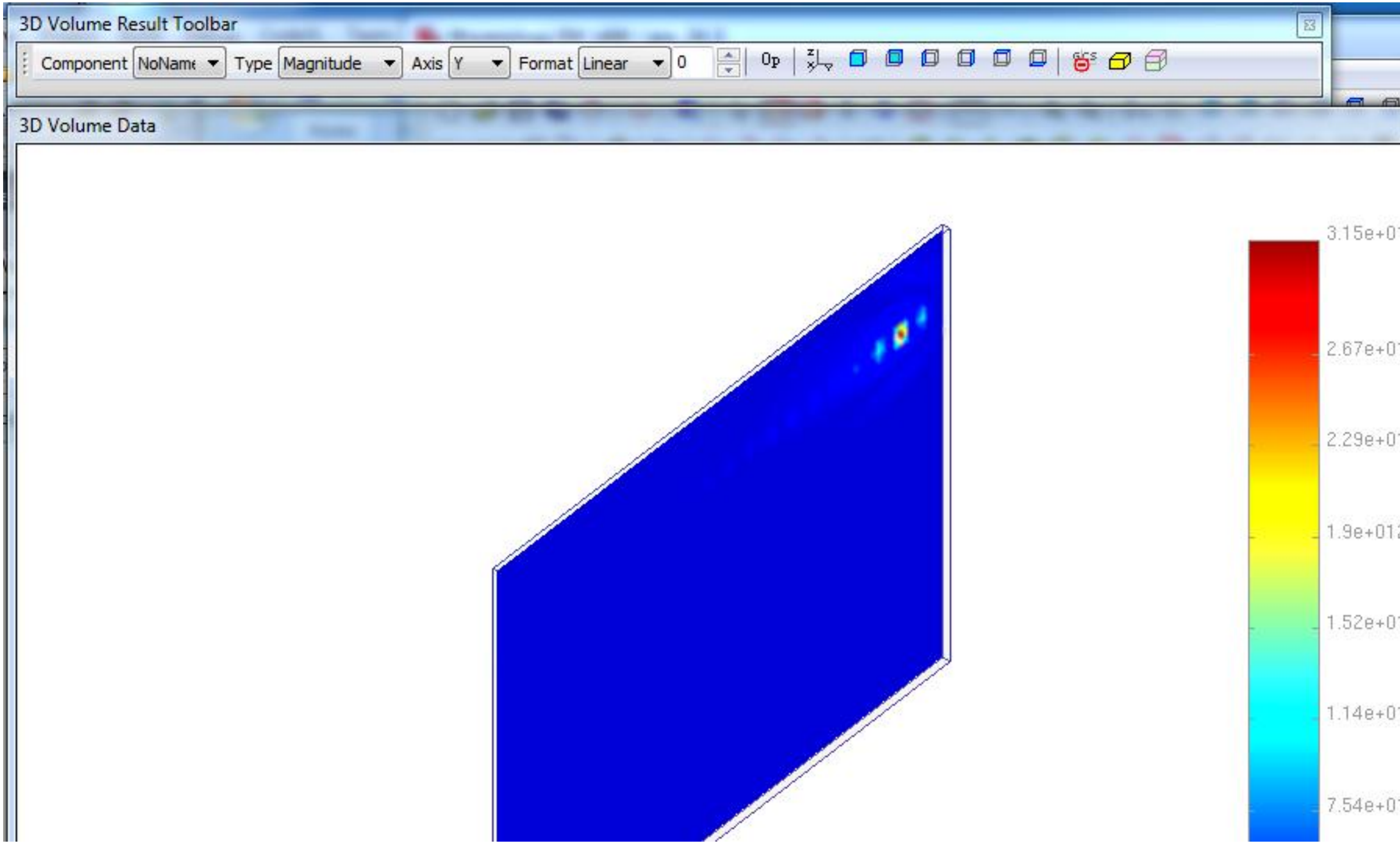


Then, use this menu

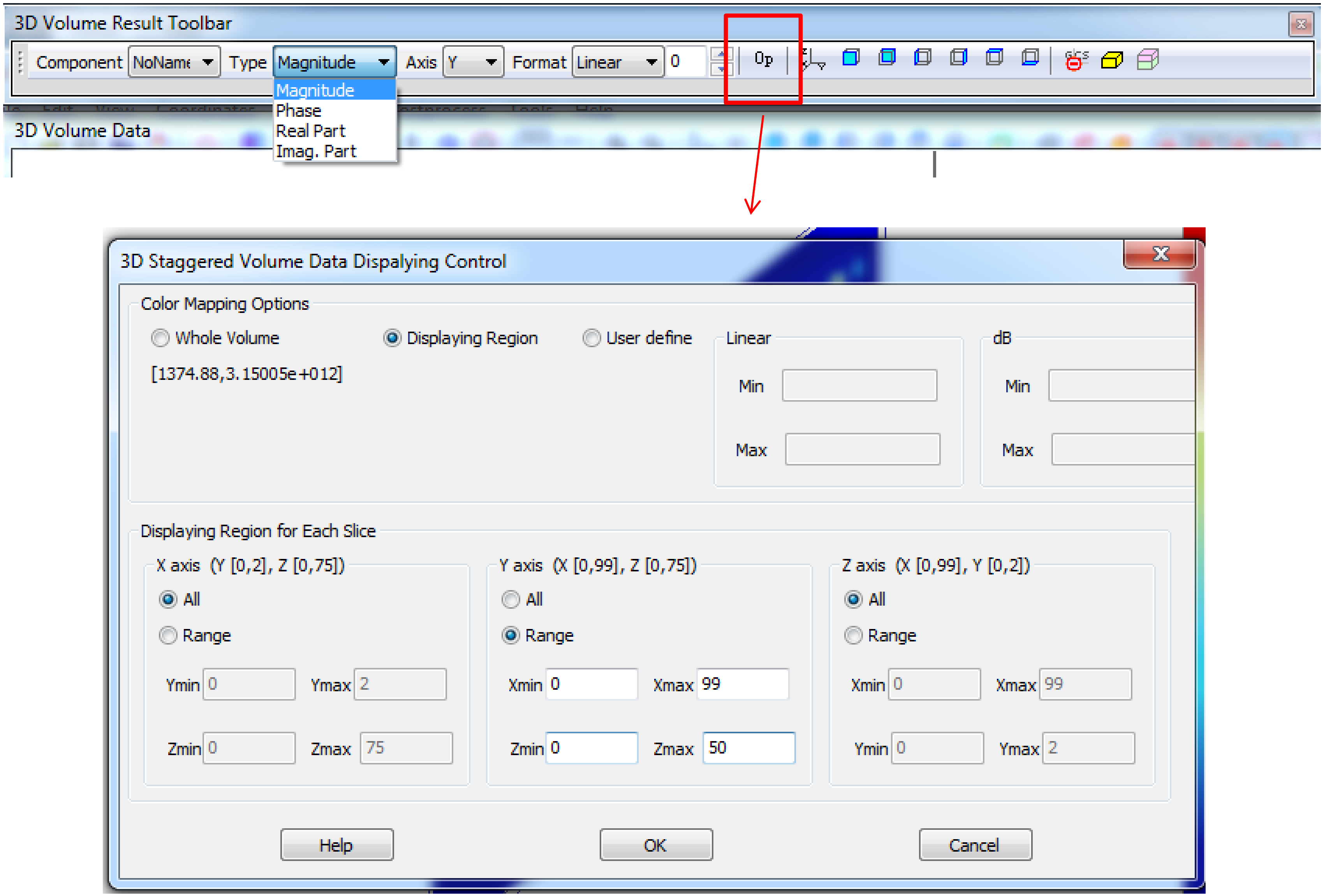


In the new canvas, right click mouse to popup a menu to load the image

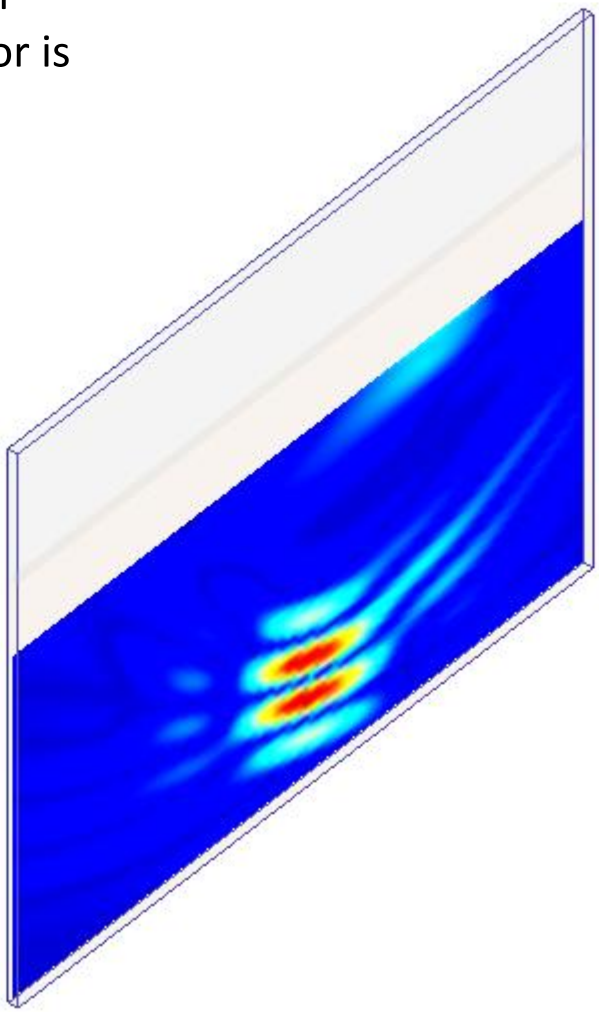



3D Volume Result Toolbar
Component
NoName
Type
Magnitude
Axis
Y
Format
Linear
0
3D Volume Data
3.15e+012
2.67e+012
2.29e+012
1.9e+012
1.52e+012
1.14e+012
7.54e+011

The toolbar has many options to control different components, displaying type, etc.



Following is the figure for half Z space and the color is clampped to local values

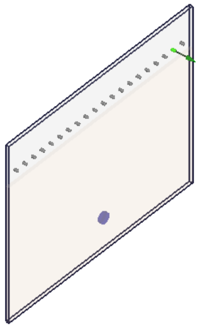


Tutorial/Demo Package

- In this package, there are 6 case groups
  - Small size 2D GPR case with fmax=1 GHz. This is for fast demo purpose. All cases in this group can be run in a short time.
  - Big size 2D GPR case with fmax=6 GHz. This is for the demo of accuracy purpose.
  - 3D GPR case with fmax=5.5 GHz, using ideal point dipole
  - 3D GPR imagine with real antenna
    - One case use half wavelength dipole antenna
    - Another use UWB antenna
  - How to improve imaging area with adjusted signal
    - Ideal dipole with directly signal cut
    - Half wavelength dipole antenna
      - Direct wave subtraction
      - Direct wave subtraction and more adjustment
  - The imaging performance comparison between ideal dipole and real antenna
    - One is Ideal Point Dipole vs. Half Wavelength Dipole Antenna
    - Another is Ideal Point Dipole vs. Ultra Wideband Antenna

[1] Group:small_2d_gpr_1GHz

- 2D_multiple_run: pure 2D case with line source & receiver
  - Scheme I, with multiple cases
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation
    - The receiver signal is in each case’s “project_name_ res/ observers/ project_name _rev_ey.txt” (if we use Ey component)
  - Folder “RTM” has all cases that use the signals comes from “Forward_to_get_measurement” .
    - We already copy the signal “project_name _rev_ey.txt” from the forward simulation to the imaging proejct’s root folder, and define it as the data file in imaging.
    - Each sub-folder has a matlab code “check_img.m” to check the image for each case
  - In the root folder, a matlab code “check_img.m” merge all images from multiple cases and get the final result

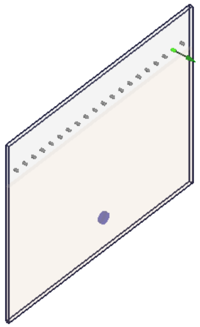


Cont.

- psd_2d_multiple_run: pseudo 2D case with dipole source & point receiver
  - Scheme I, with multiple cases
  - The file system is the same as “2D_multiple_run”

- psd_2d_seq: pseudo 2D case with dipole source & point receiver
  - Scheme II
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation
  - Folder “RTM”
    - Sub-folder “all_in_one” is the single case using scheme II.
      - » There is a matlab code “check_img.m” to check the image.
    - Sub-folder “for_srcx” is for verifying each excitation in the case “all_in_one” .

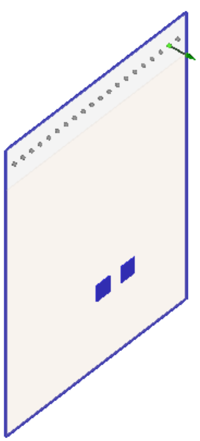
- psd_2d_switch: pseudo 2D case with dipole source & point receiver
  - Scheme III
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation
  - Folder “RTM”
    - Sub-folder “all_in_one” is the single case using scheme III.
      - » There is a matlab code “check_img.m” to check the image.
    - Sub-folder “for_srcx” is for verifying each excitation in the case “all_in_one” .



[2] Group: big_2d_gpr_6GHz

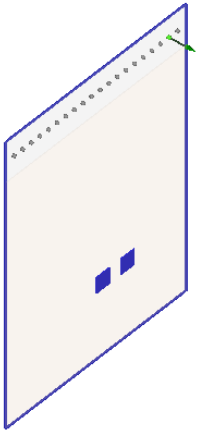
– pure_2D_gpr : pure 2D case with line source & receiver
  - Scheme I, with multiple cases
  - Folder "Forward_to_get_measurement" is the simulations to provide the signals in the backward simulation
    – The receiver signal is in each case's "project_name_ res/ observers/ project_name _rev_ey.txt" (if we use Ey component)
  - Folder "RTM" has all cases that use the signals comes from "Forward_to_get_measurement" .
    – We already copy the signal "project_name _rev_ey.txt" from the forward simulation to the imaging proejct's root folder, and define it as the data file in imaging.
    – Each sub-folder has a matlab code "check_img.m" to check the image for each case
  - In the root folder, a matlab code "check_img.m" merge all images from multiple cases and get the final result

– pseduo_2D_gpr_multi_run: pseudo 2D case with dipole source & point receiver
  - Scheme I, with multiple cases
  - All sub-folder has the same meaning as "pure_2D_gpr"



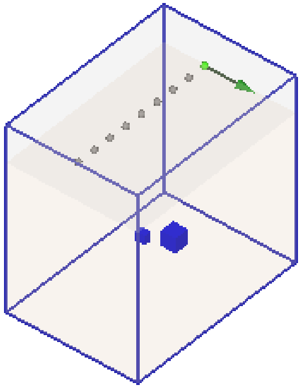
- pseduo_2D_gpr_seq_src: pseudo 2D case with dipole source & point receiver
  - Scheme II
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation
  - Folder “RTM”
    - Sub-folder “all_in_one” is the single case using scheme II.
      - There is a matlab code “check_img.m” to check the image.

- pseduo_2D_gpr_switch_tr: pseudo 2D case with dipole source & point receiver
  - Scheme III
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation
  - Folder “RTM”
    - Sub-folder “all_in_one” is the single case using scheme III.
      - There is a matlab code “check_img.m” to check the image.

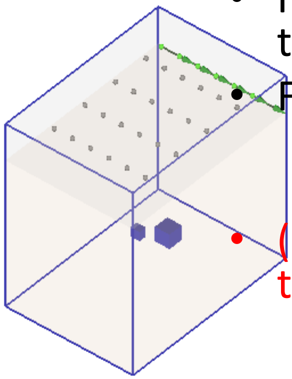


[3] Group: 3d_gpr_5.5GHz

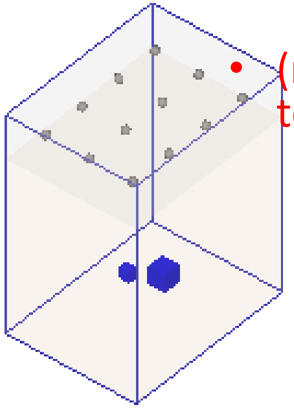
- 3D_gpr_multiple_run : 3D case dipole source & point receiver
  - Scheme I, with multiple cases
  - Folder "Forward_to_get_measurement" is the simulations to provide the signals in the backward simulation
    - The receiver signal is in each case's "project_name_ res/ observers/ project_name _rev_ey.txt" (if we use Ey component)
  - Folder "RTM" has all cases that use the signals comes from "Forward_to_get_measurement" .
    - We already copy the signal "project_name _rev_ey.txt" from the forward simulation to the imaging proejct's root folder, and define it as the data file in imaging.
    - Each sub-folder has a matlab code "check_img.m" to check the image for each case
  - In the root folder, a matlab code "check_img.m" merge all images from multiple cases and get the final result



- 3D_gpr_seq_src : 3D case with dipole source & point receiver
  - Scheme II
  - Folder "Forward_to_get_measurement" is the simulations to provide the signals in the backward simulation
  - Folder "RTM"
    - Sub-folder "all_in_one" is the single case using scheme II.
      - There is a matlab code "check_img.m" to check the image.
  - (note: this case is for demo how to use scheme II in a 3D imaging purpose only. Due to the T/R array is not dense enough, the imaging result is not very good)

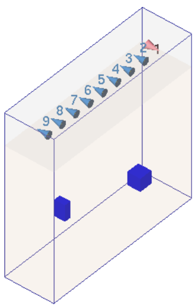


- 3D_gpr_switch_tr : 3D case with dipole source & point receiver
  - Scheme III
  - Folder "Forward_to_get_measurement" is the simulations to provide the signals in the backward simulation
  - Folder "RTM"
    - Sub-folder "all_in_one" is the single case using scheme III.
      - There is a matlab code "check_img.m" to check the image.
  - (note: this case is for demo how to use scheme III in a 3D imaging purpose only. Due to the T/R array is not dense enough, the imaging result is not very good)

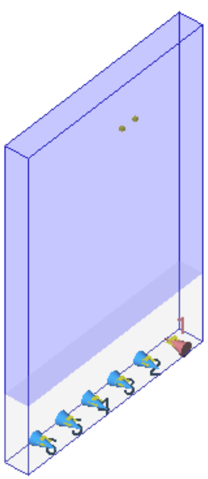


[4] Group: Antenna

– half_wavelength_dipole : 3D imaging case with λ/2 dipole antennas
  - Scheme III
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation. The cases in this folder can be used to verified antenna performance also.
  - Folder “RTM”
    – Sub-folder “all_in_one” is the single case using scheme II.
      » There is a matlab code “check_img.m” to check the image.

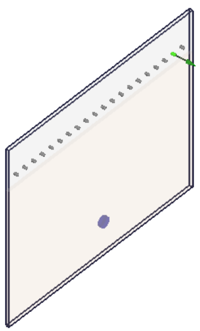


– UWB : 3D imaging case with ultra-wide band antennas
  - Scheme III
  - Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation. The cases in this folder can be used to verified antenna performance also.
  - Folder “RTM”
    – Sub-folder “all_in_one” is the single case using scheme III.
      » There is a matlab code “check_img.m” to check the image.



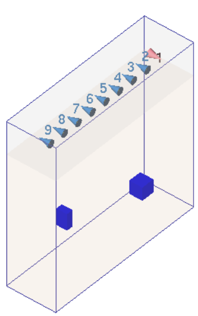
[5] Group: Adjust-Signal

– Ideal_point_dipole : 2D imaging case with ideal point dipole



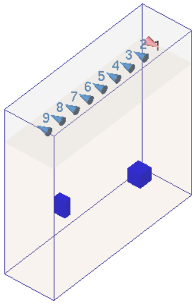
- Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation.
- Folder “RTM”
  – Sub-folder “for_src1” is the single case to demo how to use GUI to isolate direct wave from scattered wave without additional operation.
    » There is a matlab code “check_img.m” to check the image.

– half_wavelength_dipole : 3D imaging case with λ/2 dipole antennas and pre-processing on signal



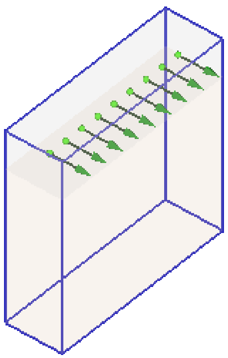
- Folder “Forward_to_get_inc” is the simulations to obtain the direct wave that will be used in signal pre-processing.
- Folder “Forward_to_get_measurement” is the simulations to provide the signals in the backward simulation.

- half_wavelength_dipole : 3D imaging case with λ/2 dipole antennas and pre-processing on signal
  - Folder “RTM_sct_signal_only” is the imaging by direct wave sub-traction only
    - The file “grp_3d_ant_x_lumped_port_sct_volt_tran.txt” is the measurement, “grp_3d_ant_x_lumped_port_sct_volt_tran_inc.txt” is the direct wave signal on port. “make_sct.m” is the matlab code to use above files to generate scattered signal on ports, as “sct_x_volt_tran.txt”
  - Folder “RTM_sct_signal_adjust2” is the imaging by direct wave sub-traction and with more signal adjustment
    - The file “grp_3d_ant_x_lumped_port_sct_volt_tran.txt” is the measurement, “grp_3d_ant_x_lumped_port_sct_volt_tran_inc.txt” is the direct wave signal on port. “make_sct.m” is the matlab code to use above files to generate scattered signal on ports, as “sct_x_volt_tran.txt”

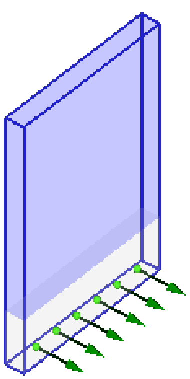


[6] Group: Antenna vs. Ideal Dipole

- ideal_dipole_with_dipole_signal : Imaging by ideal point dipole with signal from λ/2 dipole antenna
  - Folder "RTM"



    - Sub-folder "all_in_one" is the case to demo how to imaging by ideal point dipole with signal from λ/2 dipole antenna.
      - » matlab code "make_signal.m" to convert 9 antenna transient signals to 8 receiver transient signals.
      - » matlab code "check_img.m" to check the image.
- ideal_dipole_with_uwb_signal : Imaging by ideal point dipole with signal from UWB antenna
  - Folder "RTM"



    - Sub-folder "all_in_one" is the case to demo how to imaging by ideal point dipole with signal from UWB antenna.
      - » matlab code "make_signal.m" to convert 6 antenna transient signals to 5 receiver transient signals.
      - » matlab code "check_img.m" to check the image.

END