

Wi-Fi Hand Penetration

A comparison of 2.4 and 5 GHz Wi-Fi signals ability to penetrate a user's hand

Outline

- Problem and Basic Settings
- Import Geometries and Add Materials
- Prepare the Grid
- Adding Antenna Signal
- Boundary Conditions and Data Collection
- Running and Analyzing Results

Problem and Basic Settings

A situation that most people encounter on a daily basis, is a small antenna situated in their hand.

Some simple questions:

How do the signals from these antennas interact with the hand?

Which frequencies are blocked by the hand?



Problem and Basic Settings

We can simulate a similar situation to a cell phone antenna in VSim.

- Most cell phones communicate with ~850Mhz signals
- Wi-fi enabled devices use 2.4 or 5 Ghz signals

It's advertised that the 5 GHz signals from a wi-fi device have higher speeds at the cost of range and signal strength.

We can test that here in VSim.

Problem and Basic Settings

To get started:

Open a new simulation and check the basic settings:

Length units = m

Dimensionality = 3

Coordinate System = Cartesian

Field Solver = Electromagnetic

These settings should be the default values

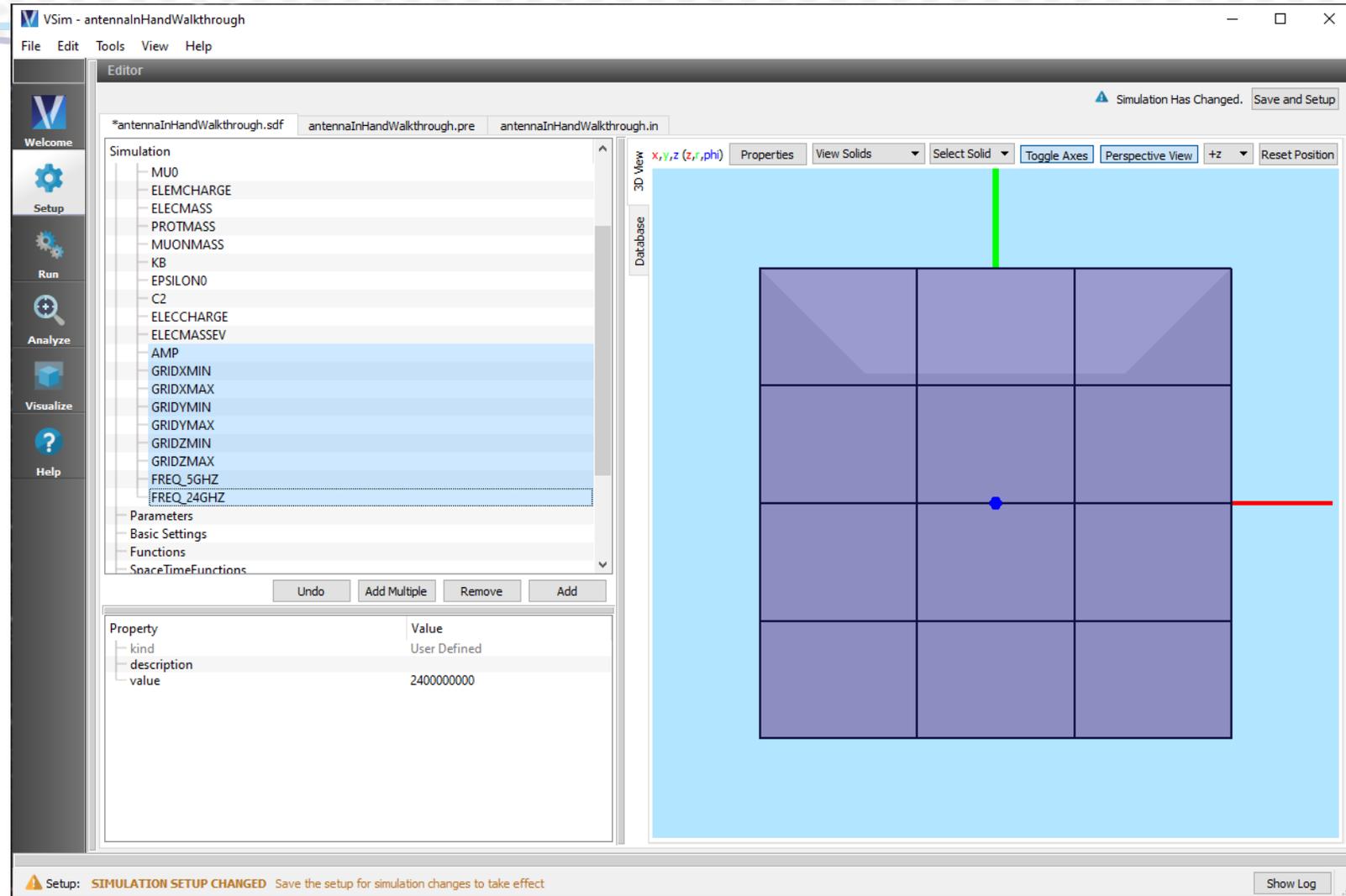
The screenshot shows the VSim software interface for a simulation named 'antennaInHandWalkthrough'. The 'Editor' window displays a tree view of simulation settings, with 'Basic Settings' selected. Below the tree is a table of properties and their values. The '3D View' window shows a 3D model of a grid structure with a blue dot in the center and a red horizontal line extending to the right. The status bar at the bottom indicates 'Setup: COMPLETED' and 'Click run to continue'.

Property	Value
surface meshing tolerance	0.5
cfl number	0.95
time step	0.0
number of steps	100
steps between dumps	20
dump in groups of	1
precision	double
length unit	meter
use GPU (if found)	false
verbosity	information
dimensionality	3
grid spacing	uniform
restore geometries	False
MPI decomposition	default
PEC	solid
coordinate system	cartesian
field solver	electromagnetic
background permittivity	1.0
dielectric solver	point permittivity
Cerenkov filter	none
periodic directions	no periodicity
particles	no particles
collisions framework	no collisions
moving window	no moving window

Constants and Parameters

For most simulations it is useful to define many constants and parameters to allow for more flexibility and easier adjustments

Some of the constants can be seen in the figure on the right. All of their values can be found in the example

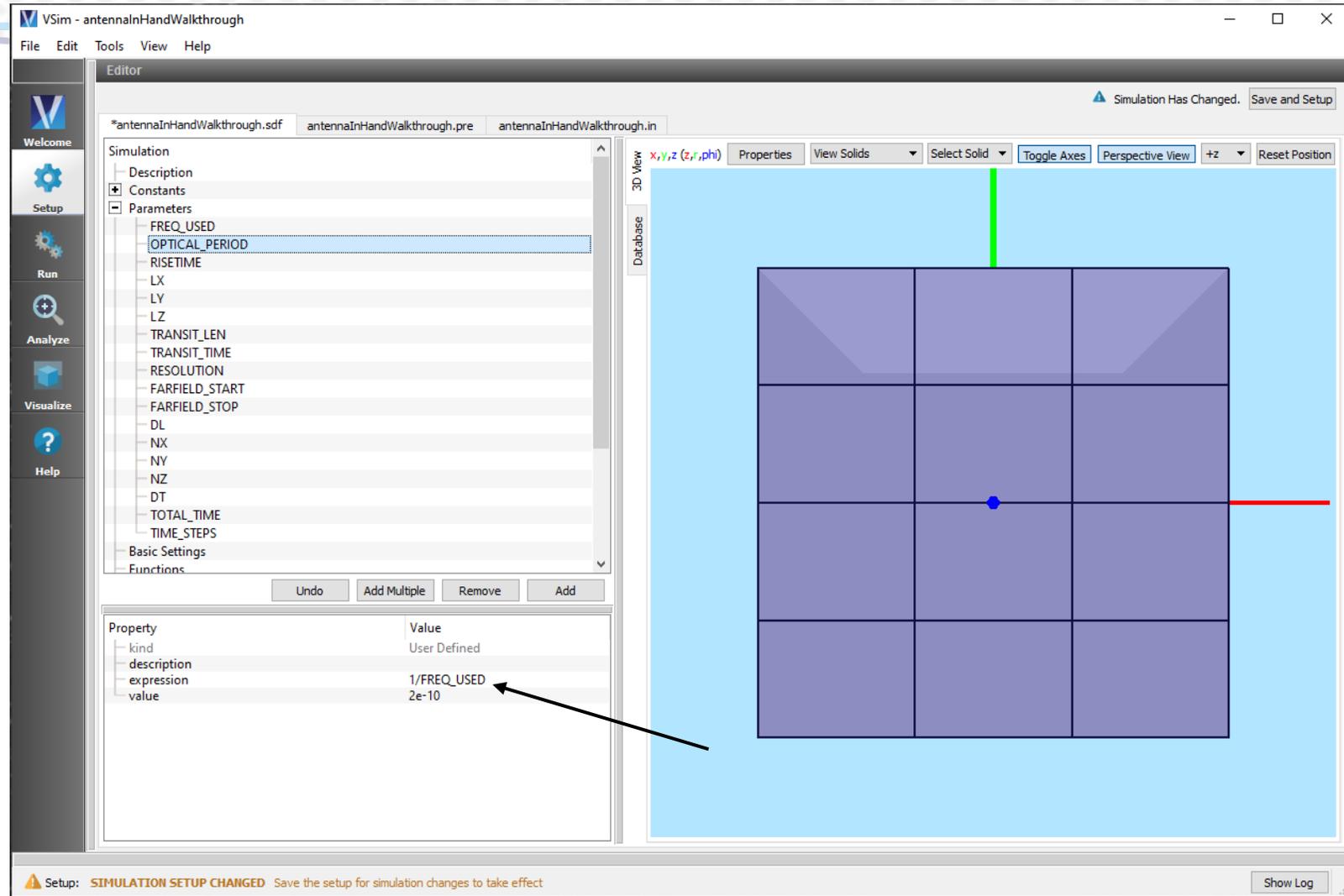


Constants and Parameters

Parameters are similar to constants although they can vary based on constants and other parameters

Some of the parameters can be seen in this figure on the right.

All of constants and parameters will be used to streamline and simplify our setup process.

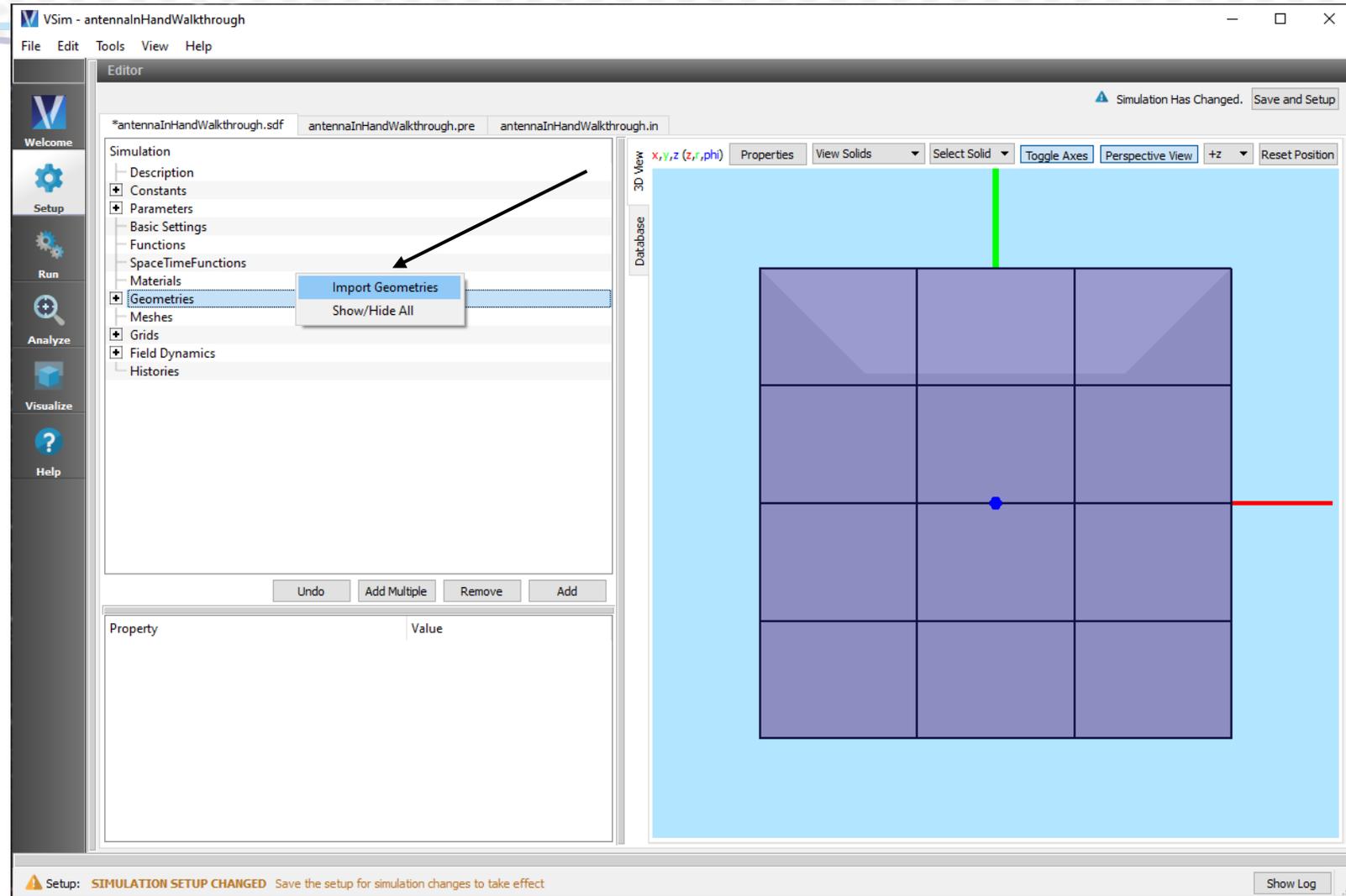


Geometries

With all of the constants and parameters taken care of, we can create and import the geometries for the simulation.

We will be using an imported “.stl” file of a hand and several primitive objects to replicate things like bones in the hand.

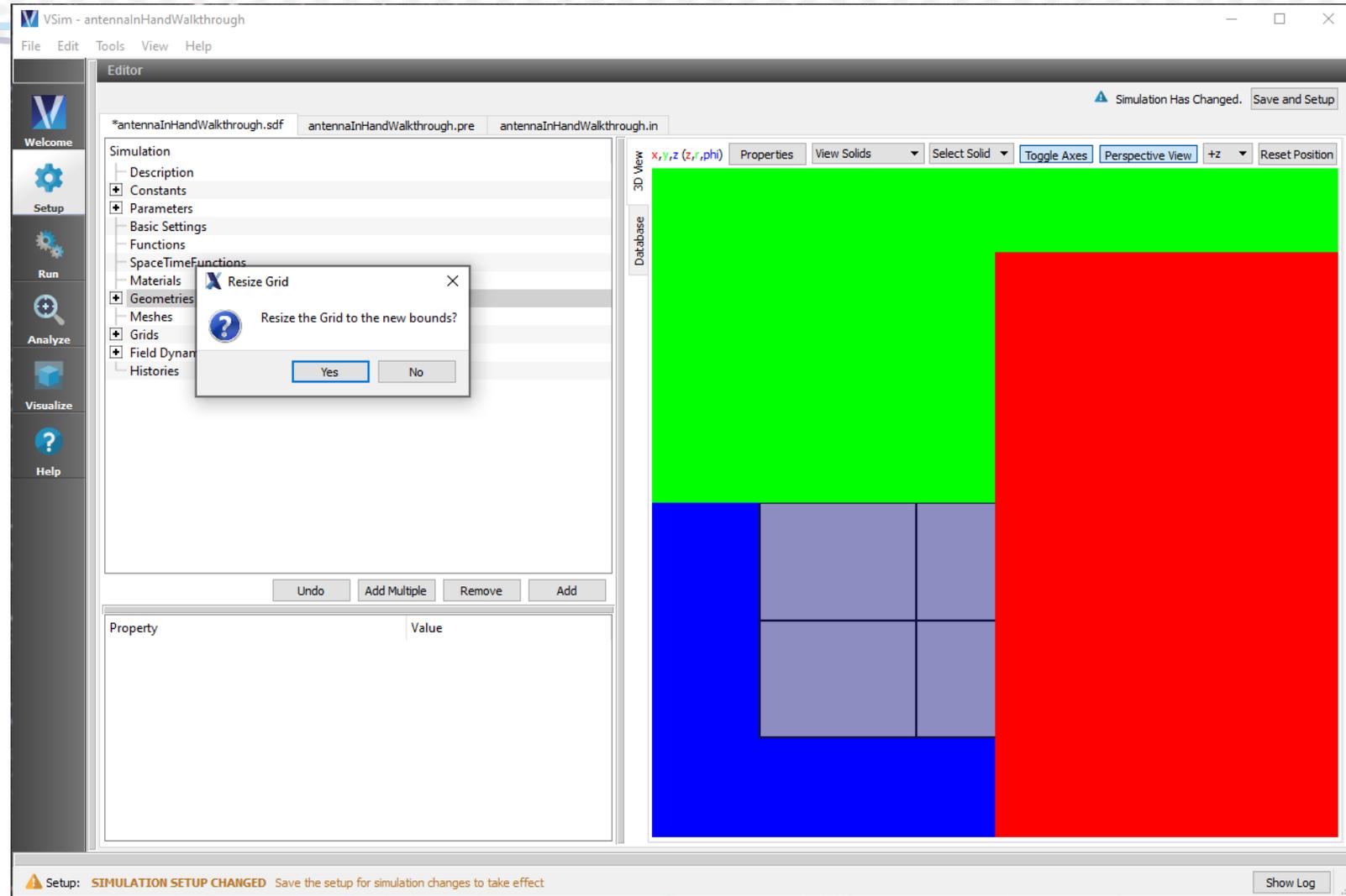
To import the hand geometry, right click on “Geometries” and select “Import Geometries”



Geometries

Navigate to the “Hand.stl” file and select open.

VSIm will ask if you want to resize the grid.
This a good idea to get a good starting point for the grid size, although we will be modifying the grid size later.



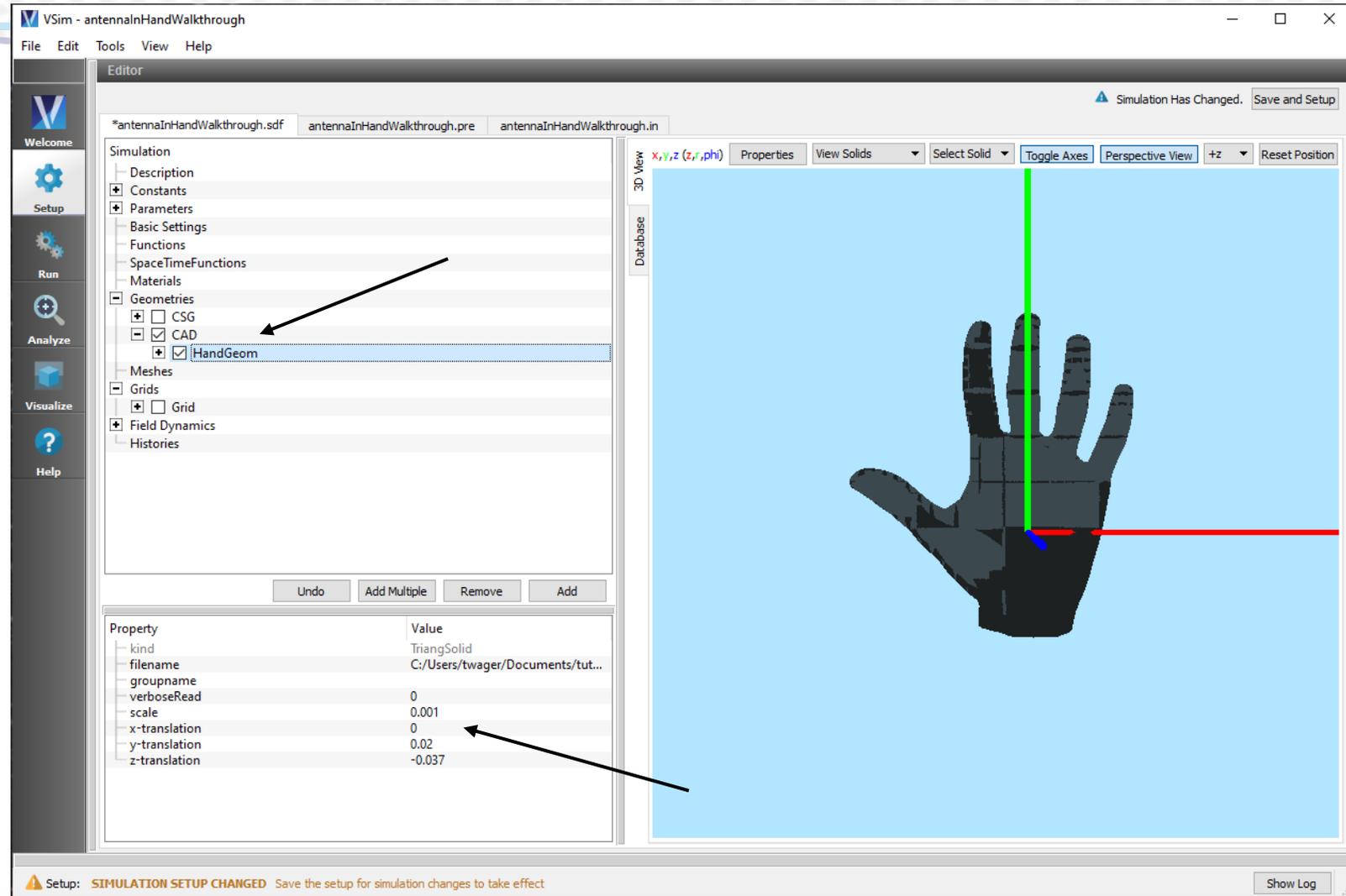
Geometries

With the hand imported and the grid resized, we can start to see our simulation coming together.

Before we move on though, we need to scale the size of the hand.

The hand was designed using mm as the units. We can change the scale of the hand to 0.001 to account for this.

We also want to translate the hand so the origin is in the palm.



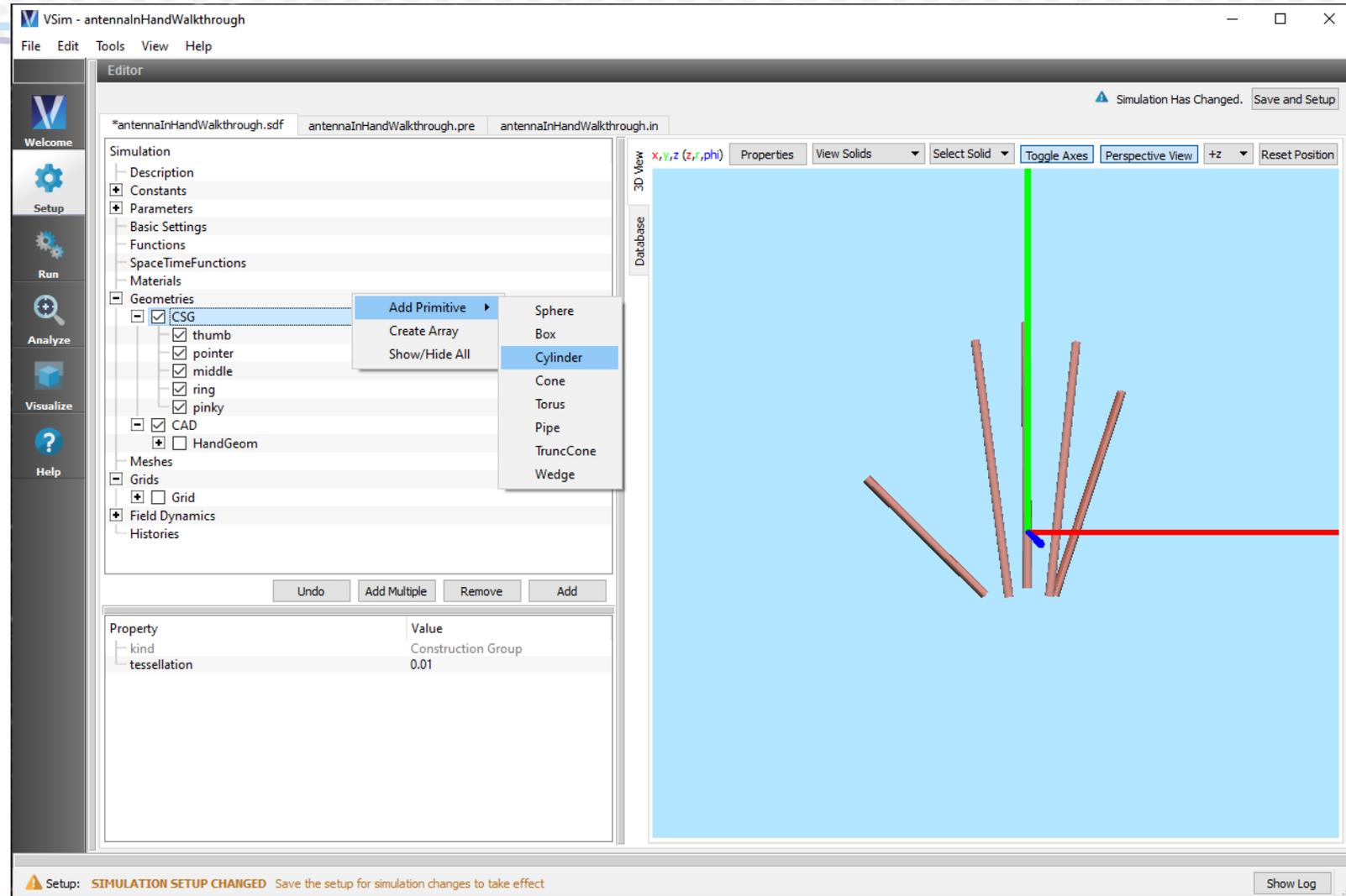
Geometries

Next we need to add bones to our hand.

To do this we can add 5 simple cylinders to the hand.

Right click on "CSG" in the tree view and select "Cylinder" under "Add Primitive".

Each of the parameters used for each hand can be found in the example.



Materials

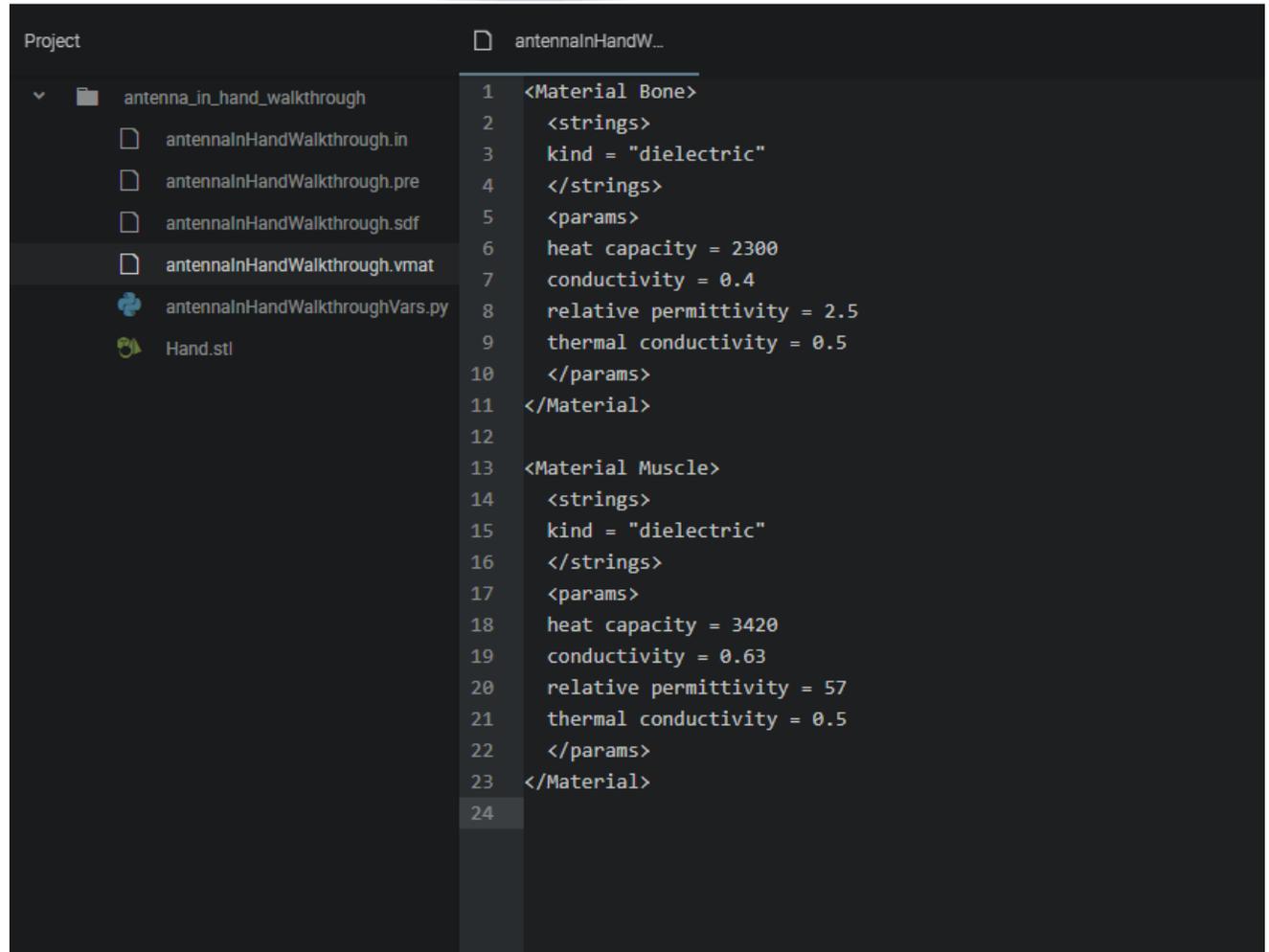
Finally we need to add materials to our hand.

Unfortunately, bone and muscle are not included materials in VSim so we need to add them as custom materials.

To do this, we create a “.vmat” file and import it into our simulation

The “.vmat” file should look like the figure on the right.

You can now right click on “Materials” in the tree, select “Import Materials” and open this file.



```
Project
└─ antenna_in_hand_walkthrough
   └─ antennaInHandWalkthrough.in
      antennaInHandWalkthrough.pre
      antennaInHandWalkthrough.sdf
      antennaInHandWalkthrough.vmat
      antennaInHandWalkthroughVars.py
      Hand.stl

antennaInHandW...
1 <Material Bone>
2   <strings>
3     kind = "dielectric"
4   </strings>
5   <params>
6     heat capacity = 2300
7     conductivity = 0.4
8     relative permittivity = 2.5
9     thermal conductivity = 0.5
10  </params>
11 </Material>
12
13 <Material Muscle>
14   <strings>
15     kind = "dielectric"
16   </strings>
17   <params>
18     heat capacity = 3420
19     conductivity = 0.63
20     relative permittivity = 57
21     thermal conductivity = 0.5
22   </params>
23 </Material>
24
```

Materials

Now the materials will appear in the database tab on the right side of the setup window.

Select the bone and muscle material and select "Add To Simulation"

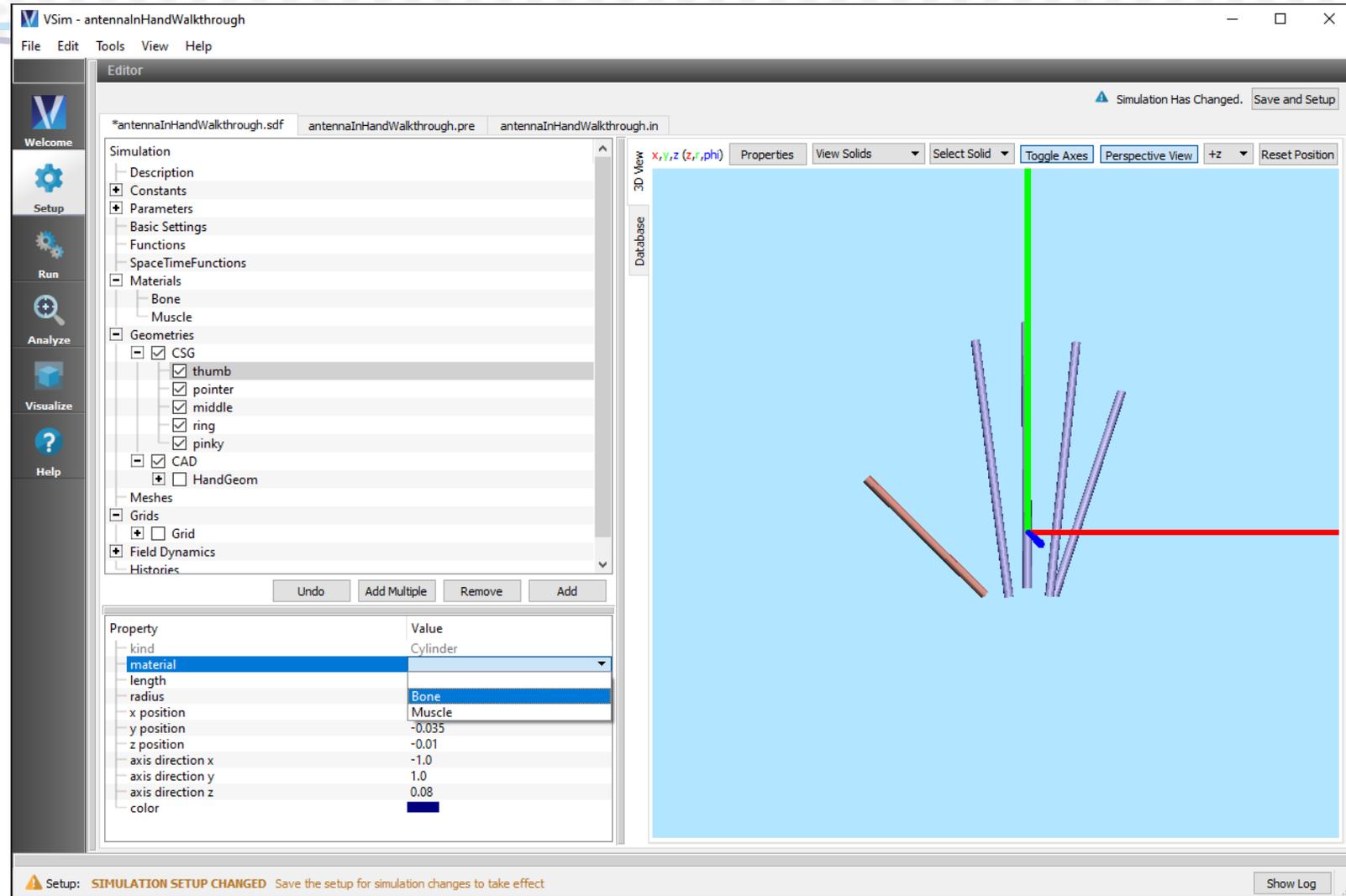
The screenshot shows the VSim software interface with the following components:

- Editor:** A tree view on the left showing simulation settings. The 'Materials' folder is expanded, showing 'Bone' and 'Muscle' materials. A black arrow points from the 'Materials' folder to the 'Bone' material.
- Database:** A table on the right showing the materials database. A black arrow points from the 'Bone' material in the tree to the 'Bone' row in the table. Another black arrow points from the 'Muscle' material in the tree to the 'Muscle' row in the table.
- Table:** A table with the following data:

Name	kind	heat capacity	conductivity	lative permittivi	ermal conductivi
Bone	dielectric	2300	0.4	2.5	0.5
Muscle	dielectric	3420	0.63	57	0.5
- Status Bar:** A message at the bottom reads: "Setup: SIMULATION SETUP CHANGED Save the setup for simulation changes to take effect".

Materials

To apply the materials to the hand cylinder, simply select the geometry of interest and under material choose the appropriate material.

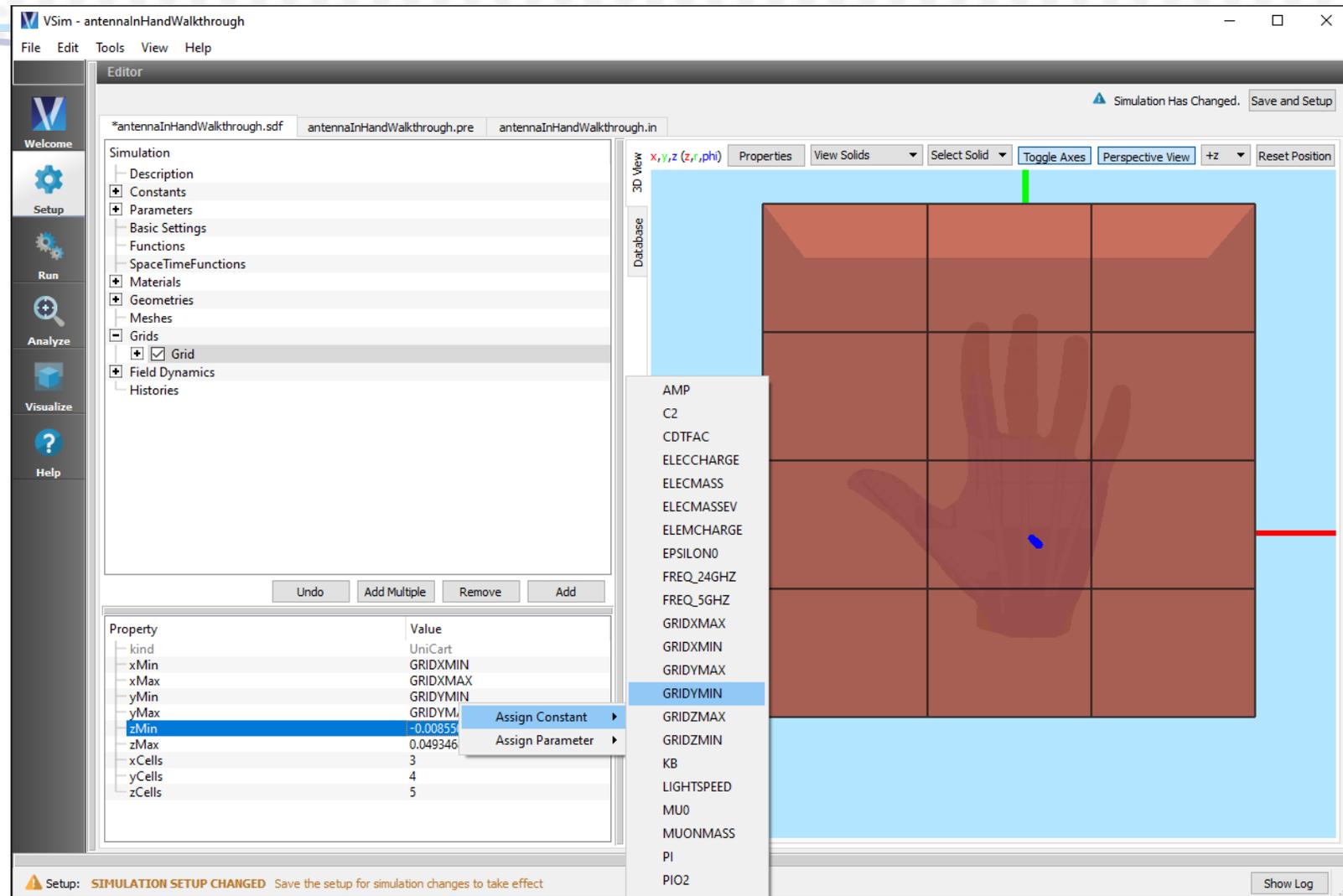


Simulation Grid

For a successful simulation, we need to make sure our grid encompasses the entire region.

This can be done using the constants that were set earlier.

With the “Grid” selected, right click the values of each property and select the appropriate constant.

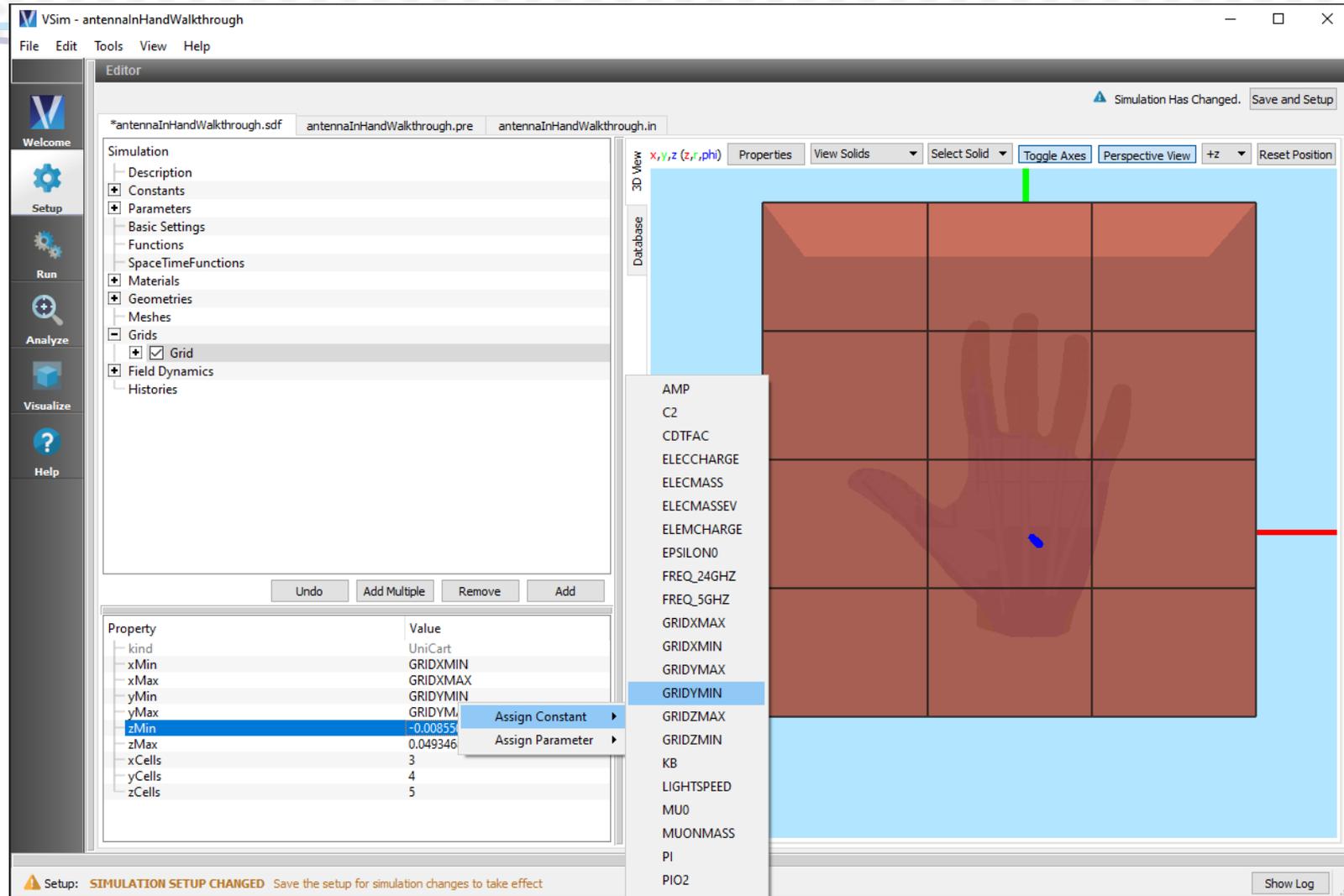


Simulation Grid

The values for NX, NY, NZ were chosen by setting the parameter RESOLUTION

RESOLUTION is the length that can be resolved by the simulation so:

$$NX = \frac{GRIDXMAX - GRIDXMIN}{RESOLUTION}$$



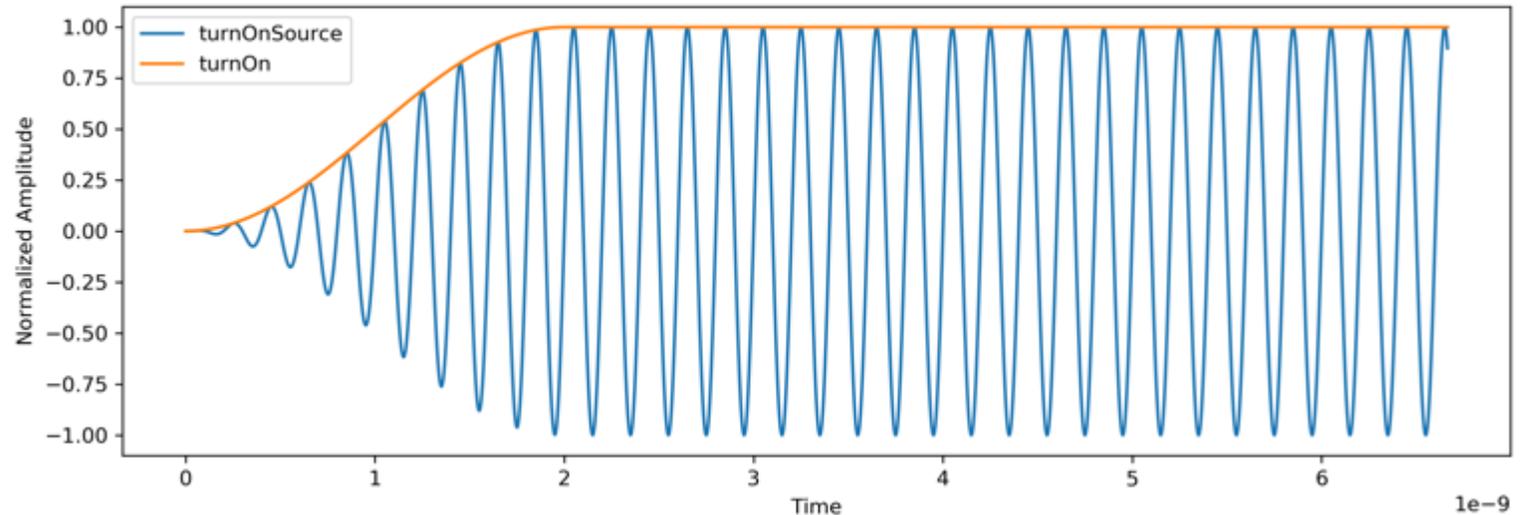
Antenna Signal

To create the current source of the signal, we need to define a few SpaceTimeFunctions

source: Simple sin wave at the frequency of interest (FREQ_USED)

turnOn: A \sin^2 function that allows the signal to slowly ramp up in time

turnOnSource: the two signals multiplied together.



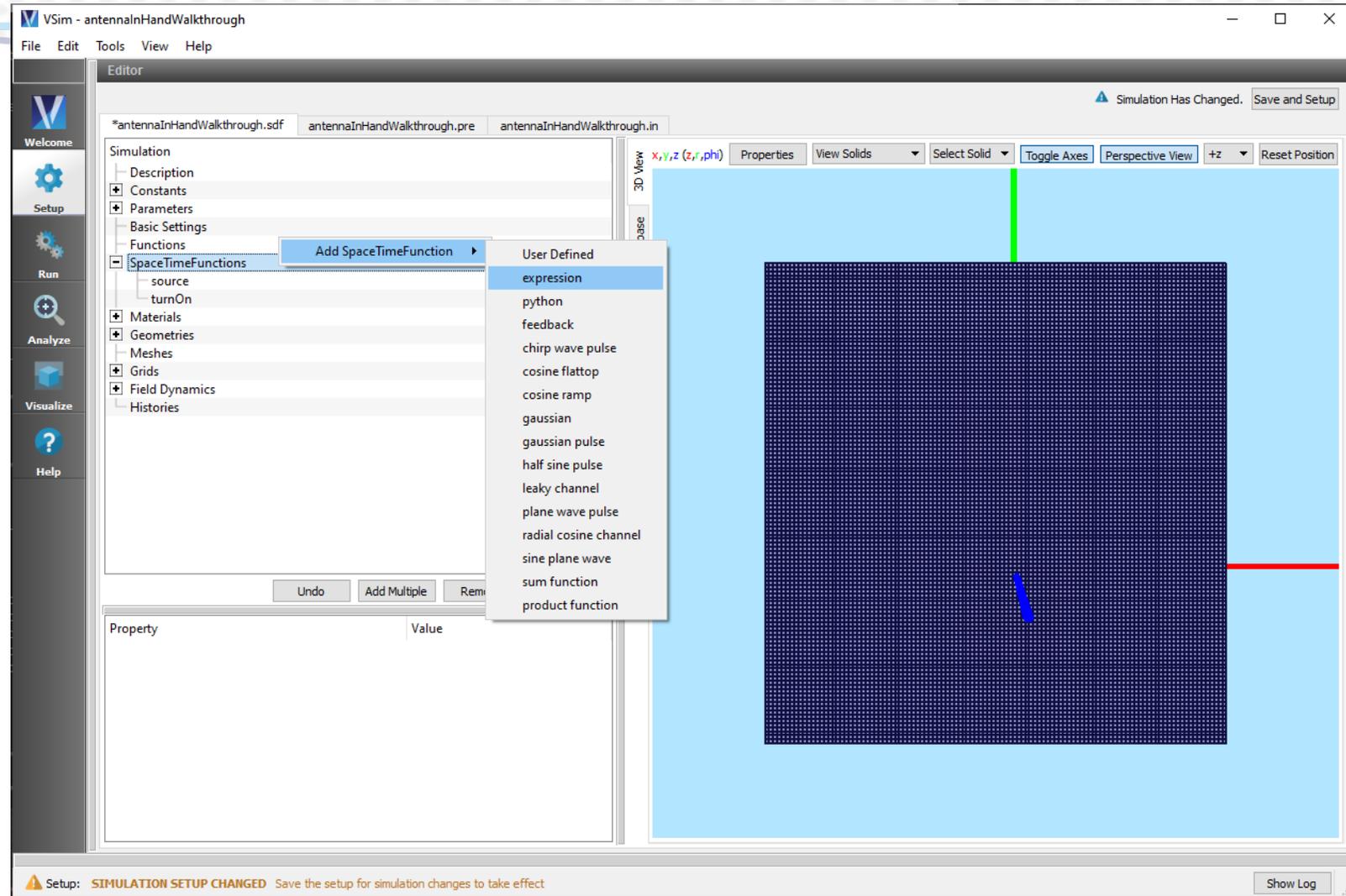
Plot of the antenna current over time. This has a RISETIME of 10 periods.

Antenna Signal

These functions can be added by right clicking "SpaceTimeFunctions" and selecting expression.

For example the source function would take the following form

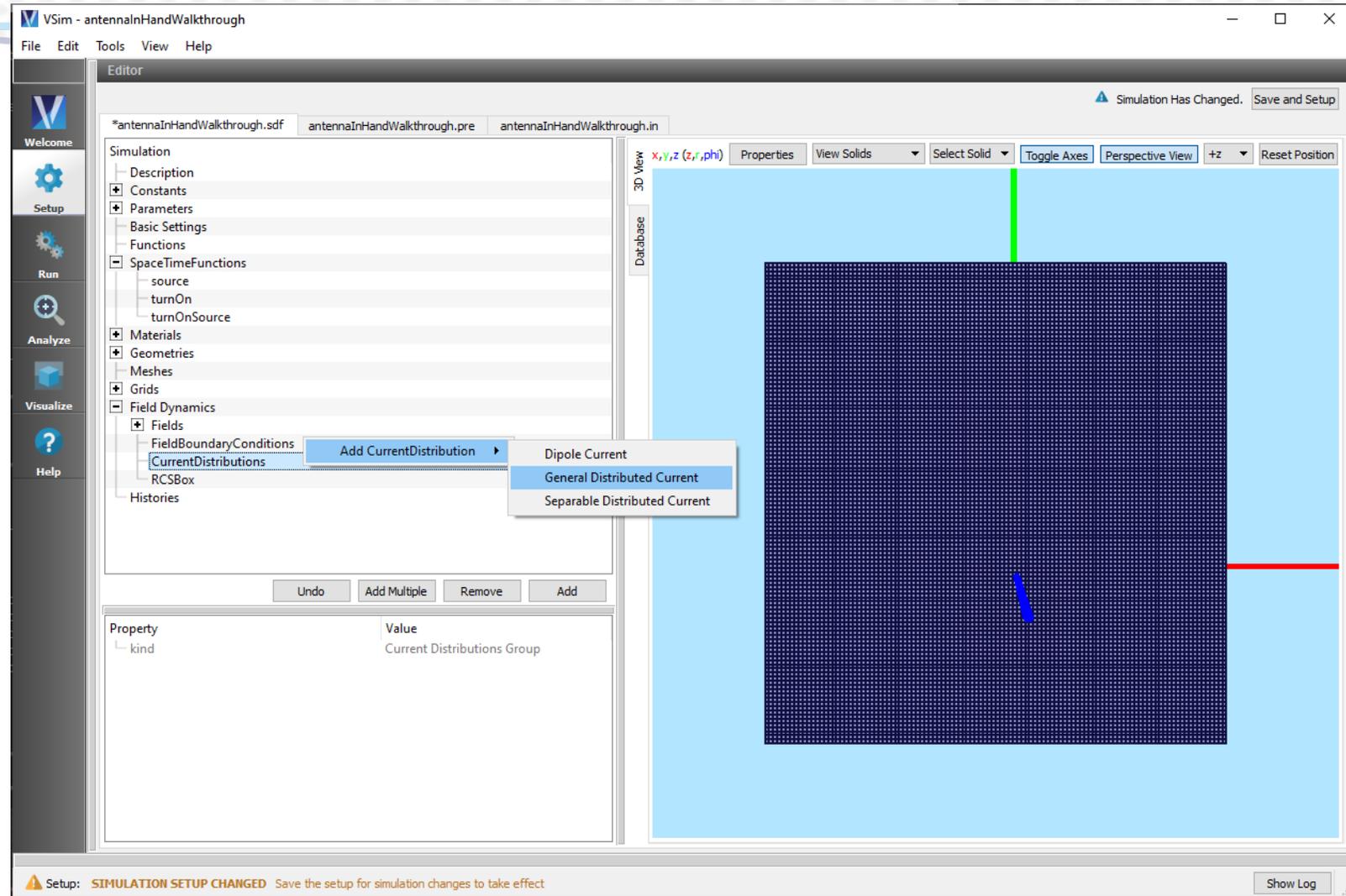
$$AMP * \sin(2 * PI * FREQ_USED * t)$$



Antenna Signal

Lastly, we need to apply this signal to a region in the palm of the hand.

For this we can navigate to “Field Dynamics” and right click “CurrentDistributions” to add a “General Distributed Current” to the simulation.



Antenna Signal

We can give this new current distribution the parameters given in the example

We can also apply our antenna signal to the y component of the antenna.

The screenshot shows the VSim software interface for a simulation named 'antennaInHandWalkthrough'. The left sidebar contains navigation icons for Welcome, Setup, Run, Analyze, Visualize, and Help. The main window is divided into several panels:

- Editor:** A tree view showing the simulation hierarchy. The 'generalDistributedCurrent0' component is selected under 'CurrentDistributions'.
- Properties:** A table showing the properties of the selected component. The 'J1(x, y, z, t)' property is highlighted, and a context menu is open over it with 'Assign SpaceTimeFunction' selected. A sub-menu is also open, showing 'turnOnSource' selected.
- 3D View:** A 3D rendering of a hand-shaped antenna model in a blue environment. A black arrow points from the 'turnOnSource' option in the sub-menu to the antenna model.

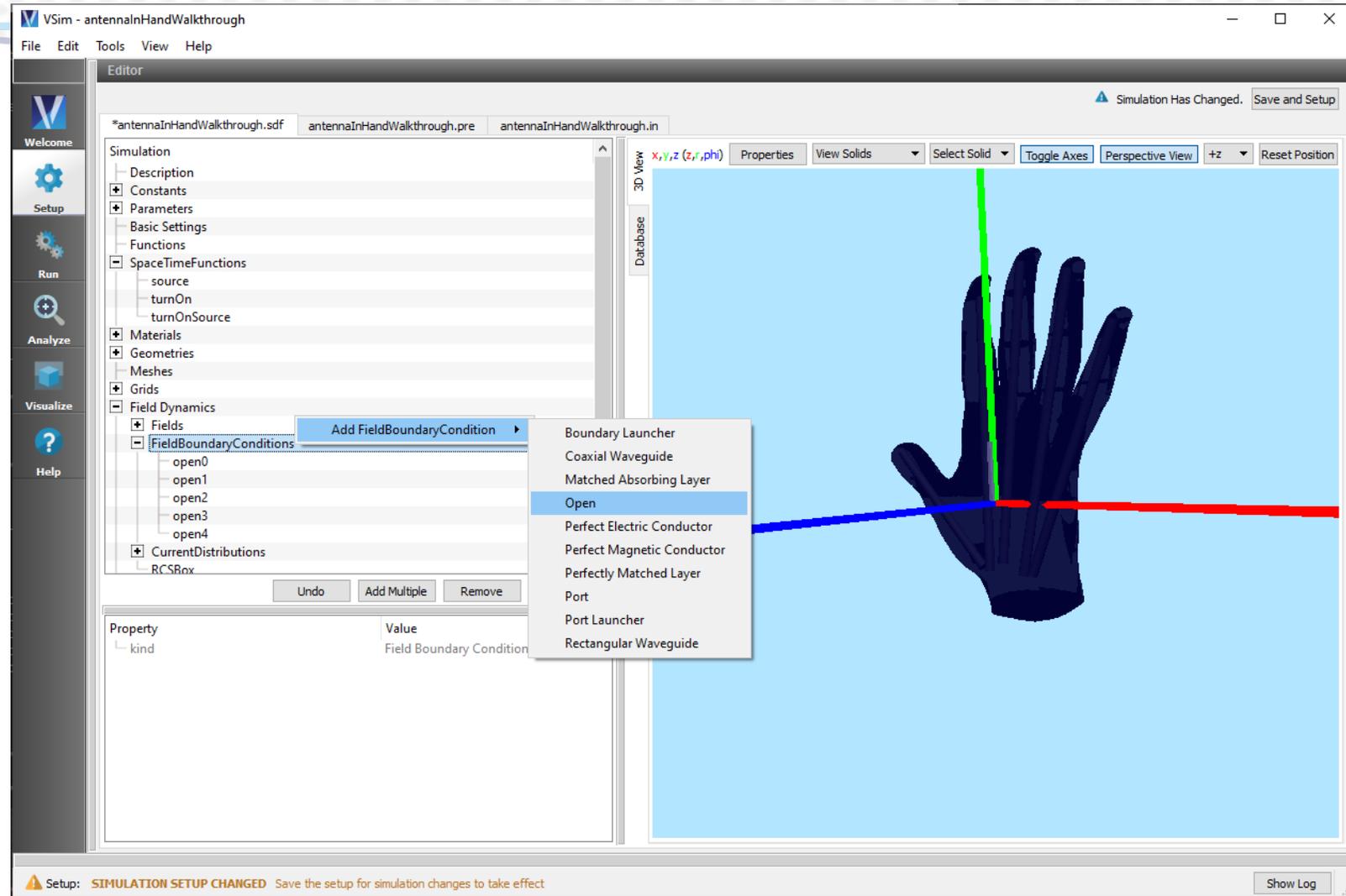
Property	Value
kind	General Distributed Current
description	
J0(x, y, z, t)	0.0
J1(x, y, z, t)	0.0
J2(x, y, z, t)	0.0
volume	cartesian 3d slab
xMin	-0.001
xMax	0.001
yMin	0.0
yMax	0.03
zMin	0.001
zMax	0.003

Boundary Conditions

Finally we need to add boundary conditions to our simulation

In this case we want all 6 boundaries of the simulation to be “open”

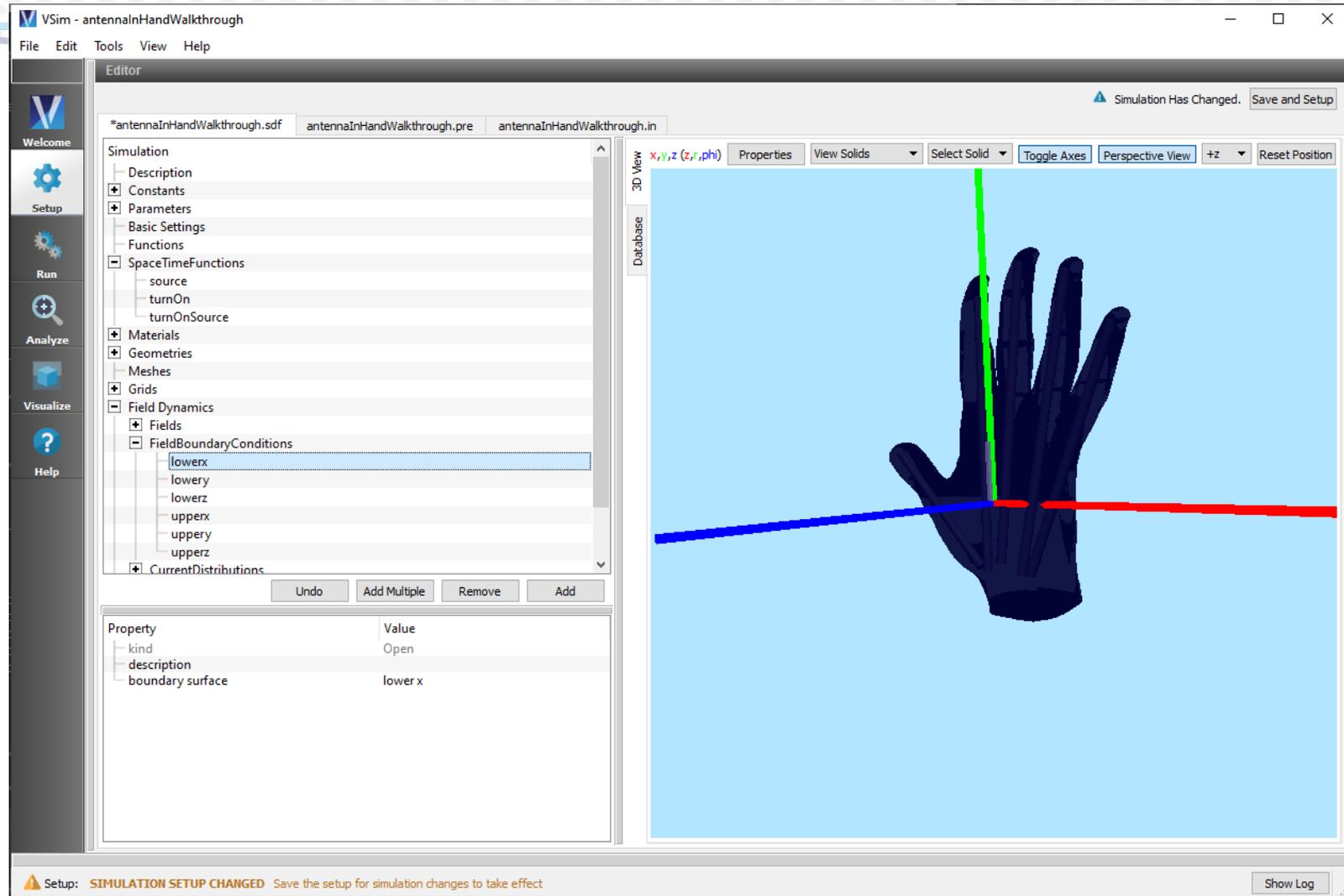
To do this, under “Field Dynamics” right click “FieldBoundaryConditions” and add 6 “Open” field boundary conditions



Boundary Conditions

Select all 6 possible boundaries:

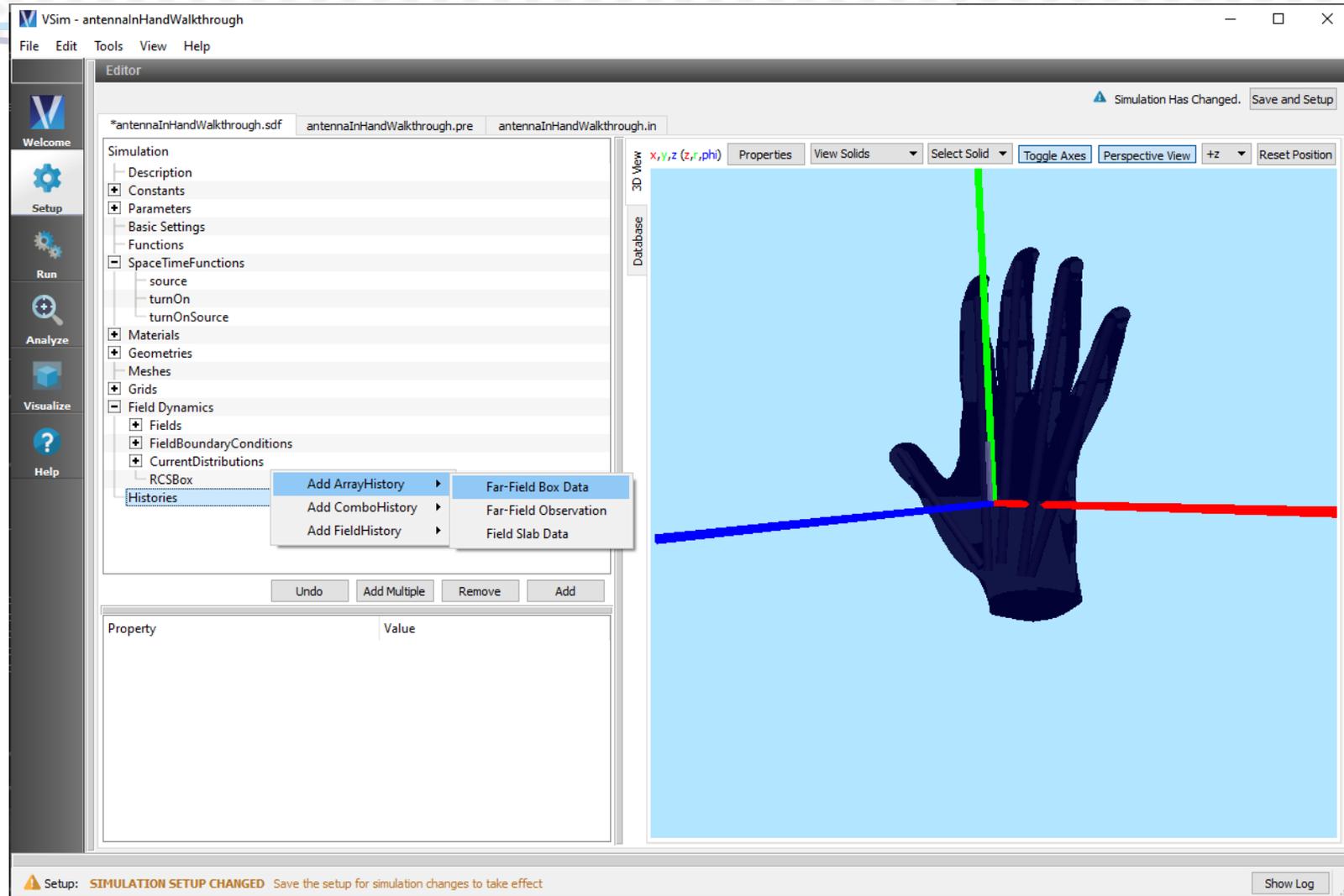
- Lower x
- Lower y
- Lower z
- Upper x
- Upper y
- Upper z



Far Field Box

Lastly, because we are interested in the far field behavior of the antenna, we should include a “Far-Field Box Data”

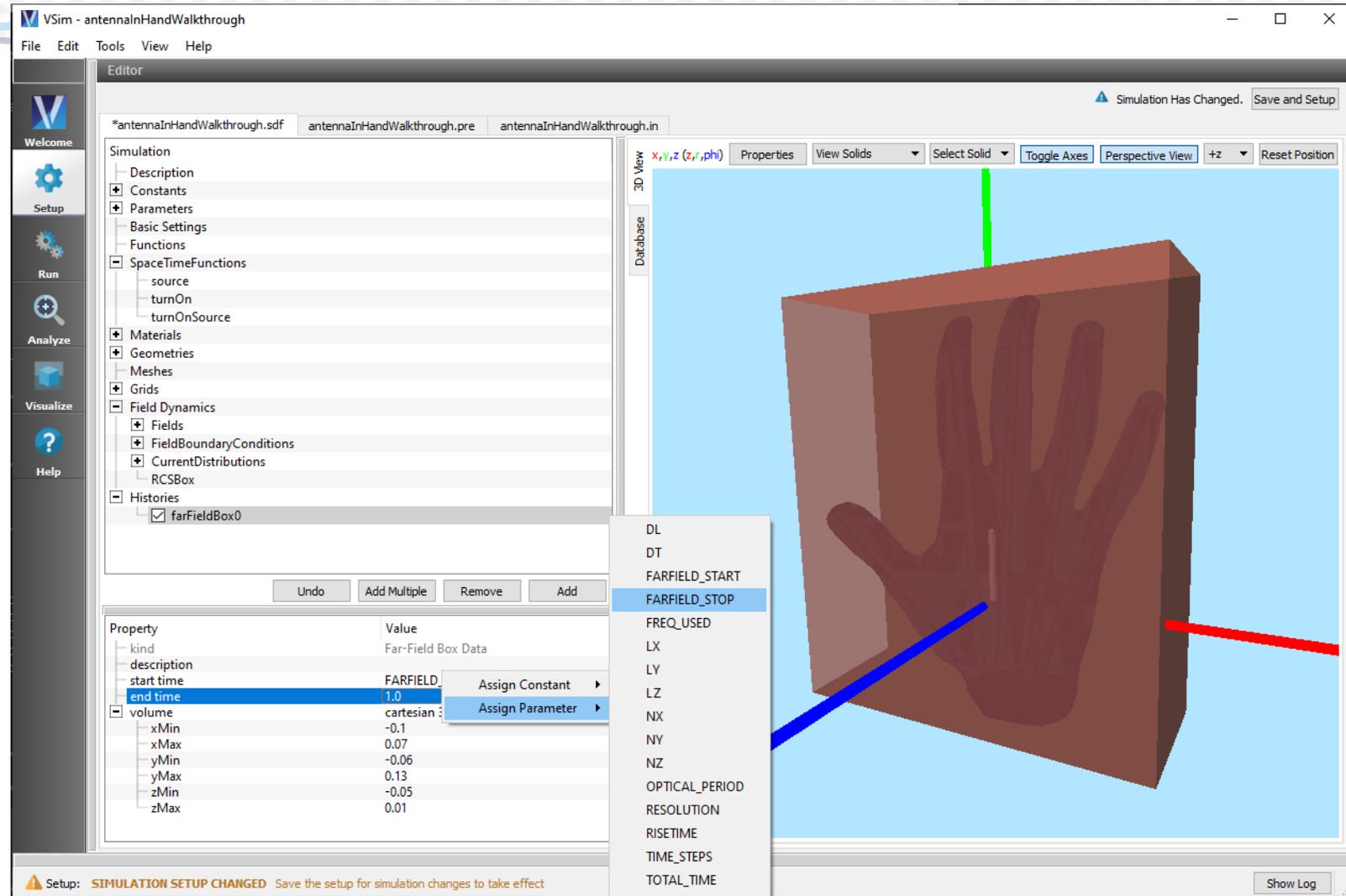
This can be done by right clicking “Histories” then choosing “Far-Field Box Data” under “Add ArrayHistory”



Far Field Box

Under volume select “cartesian 3d slab” and select values that encompass the hand

For the start and end time, we can assign our parameters defined earlier.



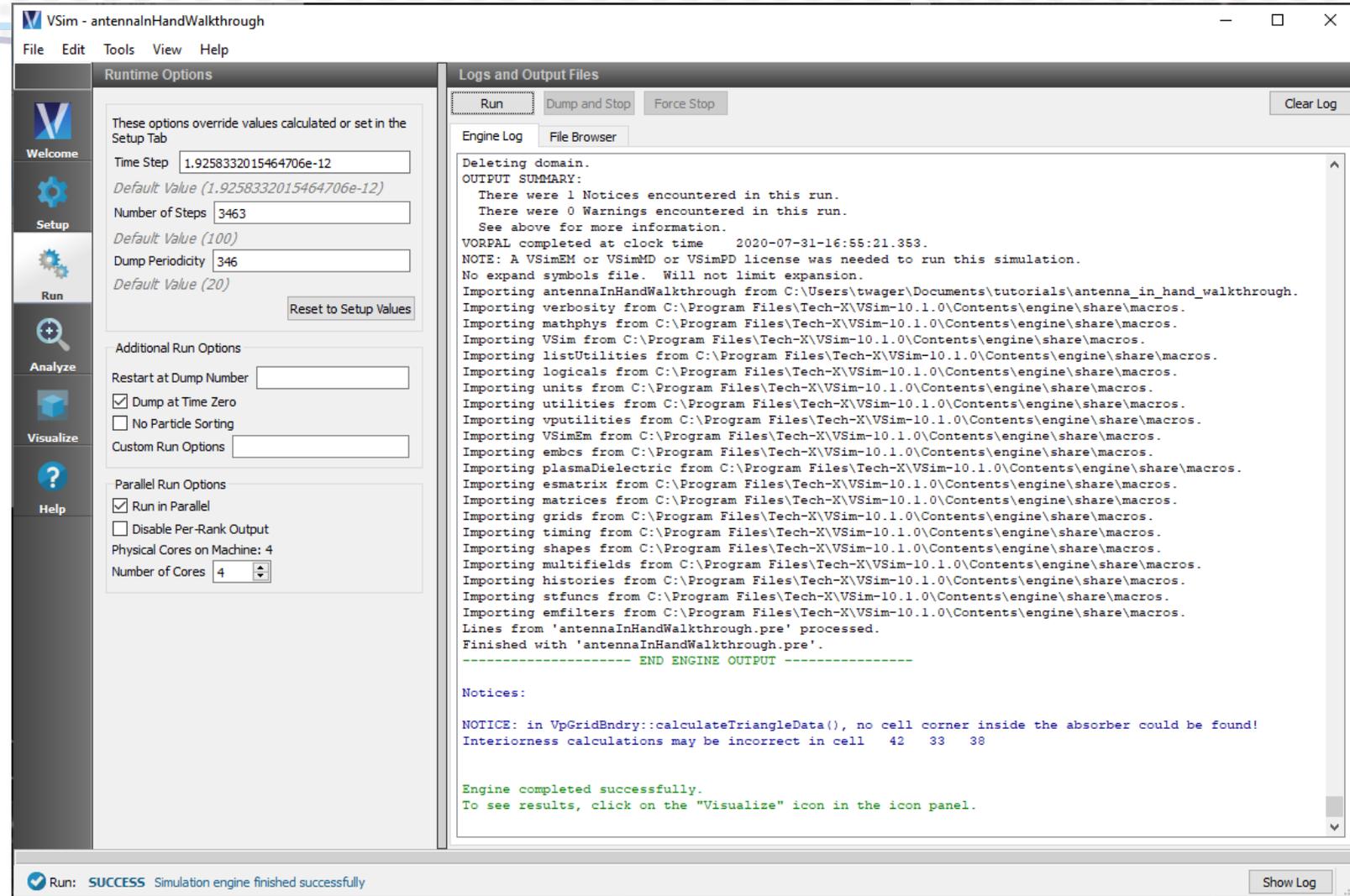
Running

Now select the “Run icon on the far left of the screen as save the setup if needed.

Set the number of steps to the value under the parameter “TIME_STEPS”

Choose a value of “Dump Periodicity” that makes sense for you. This example used about 1/10 the number of time steps to get about 10 dumps

And finally select “Run”



The screenshot shows the VSIM software interface. The left sidebar has the 'Run' button selected. The 'Runtime Options' panel shows the following settings:

- Time Step: 1.9258332015464706e-12 (Default Value: 1.9258332015464706e-12)
- Number of Steps: 3463 (Default Value: 100)
- Dump Periodicity: 346 (Default Value: 20)
- Reset to Setup Values button
- Additional Run Options: Restart at Dump Number (empty), Dump at Time Zero (checked), No Particle Sorting (unchecked), Custom Run Options (empty)
- Parallel Run Options: Run in Parallel (checked), Disable Per-Rank Output (unchecked), Physical Cores on Machine: 4, Number of Cores: 4

The 'Logs and Output Files' window shows the following output:

```
Deleting domain.
OUTPUT SUMMARY:
  There were 1 Notices encountered in this run.
  There were 0 Warnings encountered in this run.
  See above for more information.
VORPAL completed at clock time 2020-07-31-16:55:21.353.
NOTE: A VSIMEM or VSIMMD or VSIMPD license was needed to run this simulation.
No expand symbols file. Will not limit expansion.
Importing antennaInHandWalkthrough from C:\Users\twager\Documents\tutorials\antenna_in_hand_walkthrough.
Importing verbosity from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing mathphys from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing VSIM from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing listUtilities from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing logicals from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing units from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing utilities from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing vutilities from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing VSIMem from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing embcs from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing plasmaDielectric from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing esmatrix from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing matrices from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing grids from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing timing from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing shapes from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing multifields from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing histories from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing stfuncs from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Importing emfilters from C:\Program Files\Tech-X\VSIM-10.1.0\Contents\engine\share\macros.
Lines from 'antennaInHandWalkthrough.pre' processed.
Finished with 'antennaInHandWalkthrough.pre'.
----- END ENGINE OUTPUT -----

Notices:
NOTICE: in VpGridBndry::calculateTriangleData(), no cell corner inside the absorber could be found!
Interioriness calculations may be incorrect in cell 42 33 38

Engine completed successfully.
To see results, click on the "Visualize" icon in the icon panel.
```

The status bar at the bottom shows: Run: SUCCESS Simulation engine finished successfully

Visualization

One way to visualize this data is to select the following data:

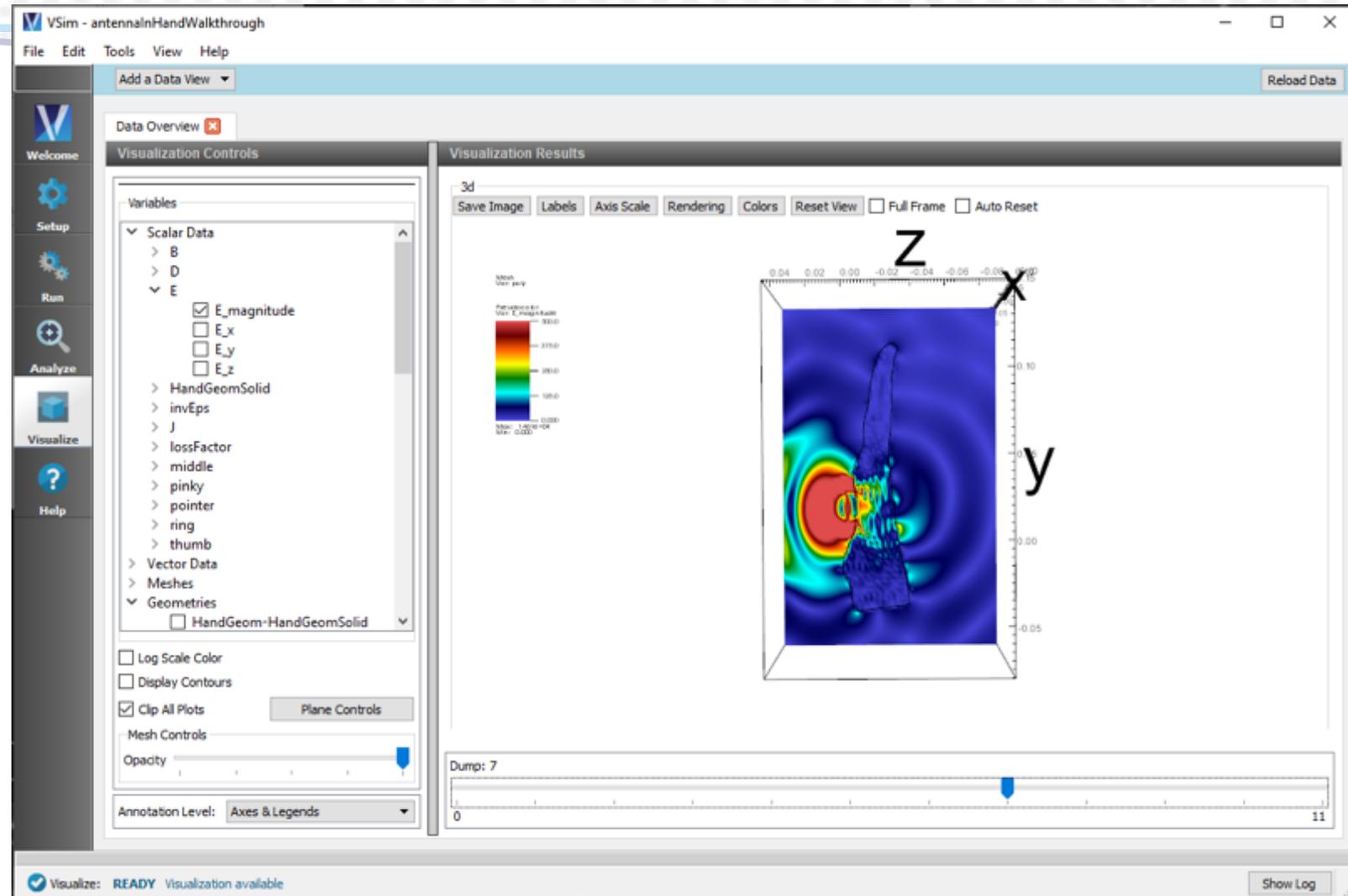
Scalar data -> E Magnitude

Geometries -> poly (HandGeomSolid)

And take a cross section of the data by selecting “Clip All Plots” in the lower left panel.

Clicking the “Colors” icon along the top of the page we can set the maximum of the color scale to be around 500.

We can then scroll through the dumps and observe how the signal penetrates the hand.



Visualization

Another visualization we can do is create a far field analysis using the “computeFarFieldFromKirchhoffBox” analyzer.

The screenshot displays the VSim software interface for the 'antennaInHandWalkthrough' project. The 'Analysis Controls' panel on the left lists various analyzers, with 'computeFarFieldFromKirchhoffBox.py' selected. The 'Analysis Results' panel on the right shows the configuration for this analyzer, including simulation name, field label, far field radius, number of periods, frequency, incident field, number of theta and phi points, and zero direction vectors. The 'Outputs' section shows the results of the analysis, including field lower and upper bounds, finished loop over counts, and a successful completion message.

```
computeFarFieldFromKirchhoffBox.py | Analyze | Stop | Clear Output
```

simulationName: antennaInHandWalkthrough
fieldLabel: E
farFieldRadius: 10
numPeriods: 0.25
numFarFieldTimes: 2
frequency: 2.4e9
incidentField:
numTheta: 60
numPhi: 120
zeroThetaDirection: (0,0,1)
zeroPhiDirection: (1,0,0)

Outputs

```
TxsYeeFarFieldField::readFieldHistory#5:fieldLowerBounds:  
[10,105,25]  
TxsYeeFarField::readFieldHistory#5:fieldUpperBounds:  
[96,107,55]  
Finished loop over: 2 far point times.  
TxsYeeFarFieldField::readFieldHistory#5:fieldLowerBounds:  
[10,10,24]  
TxsYeeFarField::readFieldHistory#5:fieldUpperBounds:  
[96,106,26]  
Finished loop over: 2 far point times.  
TxsYeeFarFieldField::readFieldHistory#5:fieldLowerBounds:  
[10,10,54]  
TxsYeeFarField::readFieldHistory#5:fieldUpperBounds:  
[96,106,56]  
Finished loop over: 2 far point times.  
Writing Ez  
Writing antennaInHandWalkthrough_farE_0.vsh5  
Writing antennaInHandWalkthrough_farE_1.vsh5  
Beginning least-squares analysis  
farFieldDt = 5.208333333333334e-11  
simulationDt = 3.6590830829384264e-12  
Reading antennaInHandWalkthrough_farE_0.vsh5  
Reading antennaInHandWalkthrough_farE_1.vsh5  
areaTotal = 12.5664, E2total = 1.03721, sin2Avg = 0.66659  
Writing history file, antennaInHandWalkthrough_PdB14RCS.vsh5.  
History file, antennaInHandWalkthrough_PdB14RCS.vsh5, written.  
-----  
Analysis completed successfully
```

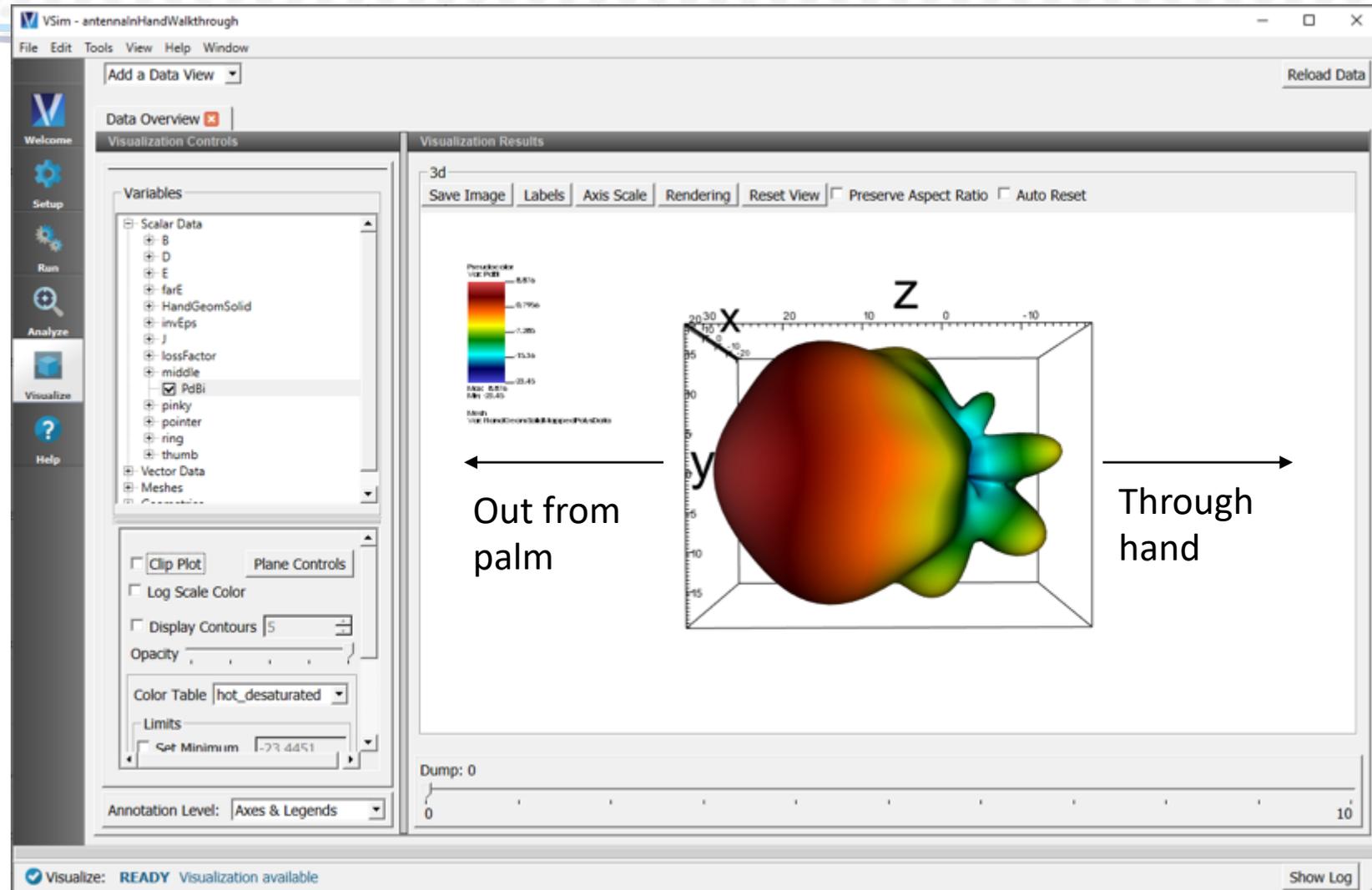
Analyze: ANALYZER SUCCESS Analyzer finished successfully.. Show Log

Visualization

Back on the visualize page, reload the data in the top right of the window.

Turn off the E Magnitude data and uncheck the "Clip All Plots"

You should obtain a picture that look similar to the one here.

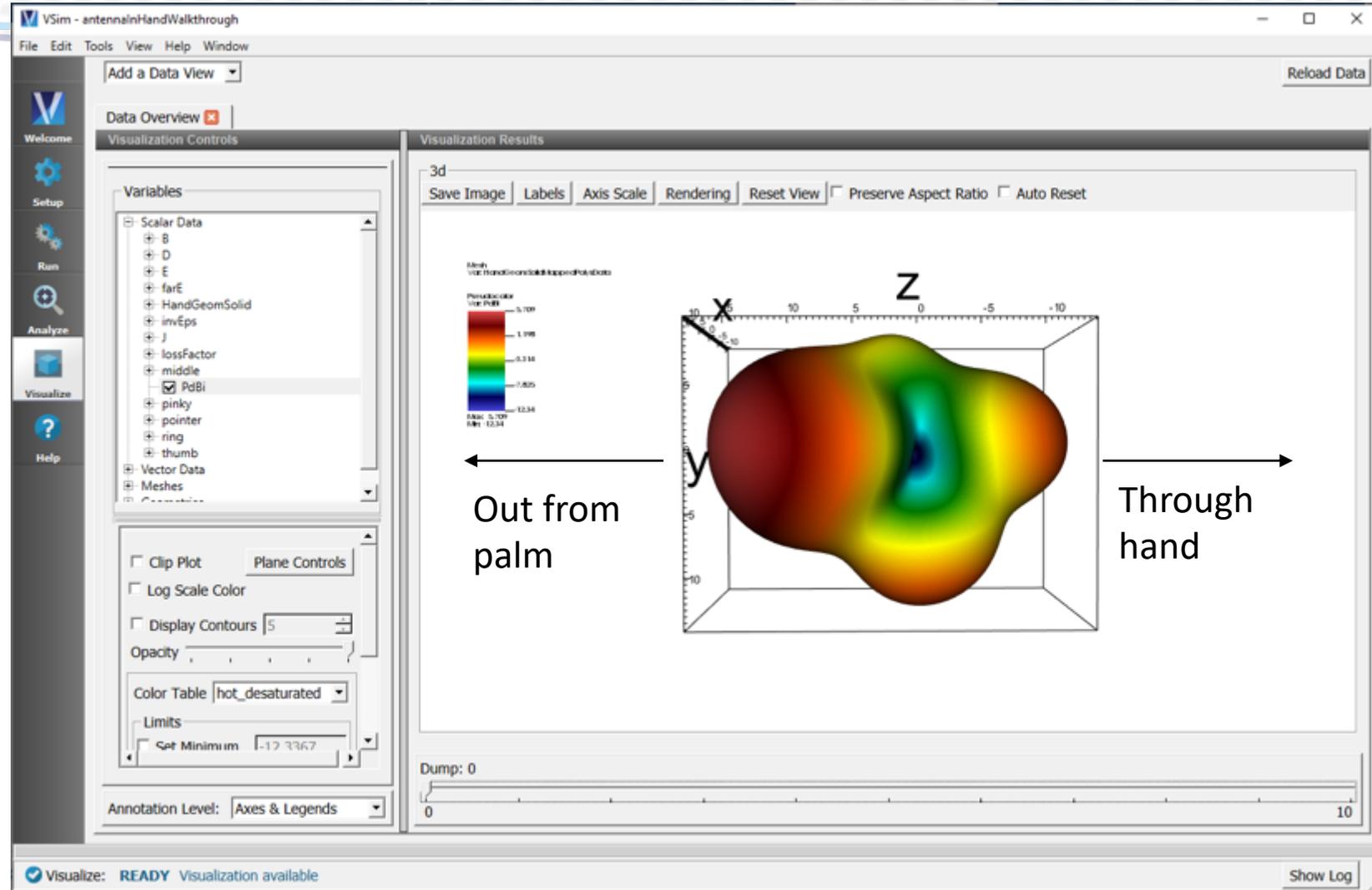


Answering our Question

Finally let's test the assertion that 2.4GHz signals have better "range" by comparing how the fields travel through the hand compared to the 5GHz signal.

Because we prepared our simulation using constants and parameters, we can simply change the parameter `FREQ_USED` to the `FREQ_24GHZ` constant and rerun our simulation.

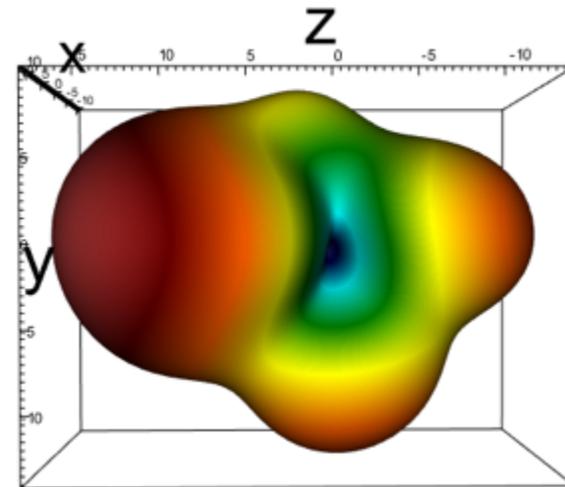
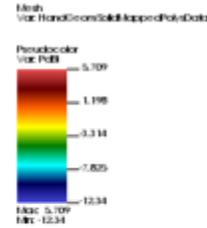
The same analysis should yield the following far field



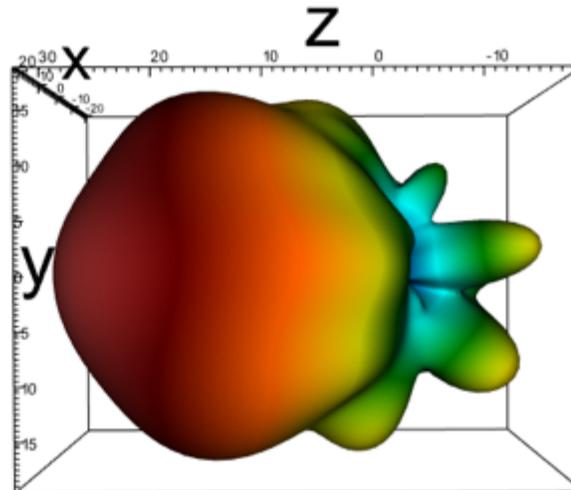
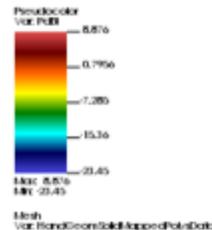
Answering our Question

Comparing these two far field results, it is clear to see that the 2.4GHz signal (top) actually does have a more uniform distribution of the signal and clearly penetrates the hand more effectively.

Although the relative strength of the signal is much less than the one highly directional lobe of the 5GHz signal.



2.4 GHz



5 GHz