FreeCAD to OpenEMS export plugin tutorial - Planar filter design

Software used:

- Qucs 0.0.19 - https://sourceforge.net/projects/qucs/
- FreeCAD 0.19 - https://www.freecadweb.org/downloads.php
- FreeCAD to OpenEMS Export Plugin – this is done by me, Lubomir Jagos - https://github.com/LubomirJagos/FreeCAD-OpenEMS-Export
- Qucs-Rflayout
  - https://github.com/thomaslepoix/Qucs-RFlayout/blob/master/doc/tutorials/openems.md
  - https://github.com/thomaslepoix/Qucs-RFlayout/releases/tag/2.0.0
  - for Windows I used .zip one where are binaries - https://github.com/thomaslepoix/Qucs-RFlayout/releases/download/2.0.0/qucsrflayout-2.0.0-x86_64.zip

Qucs Filter Design

Use Qucs to design filter as on picture below.

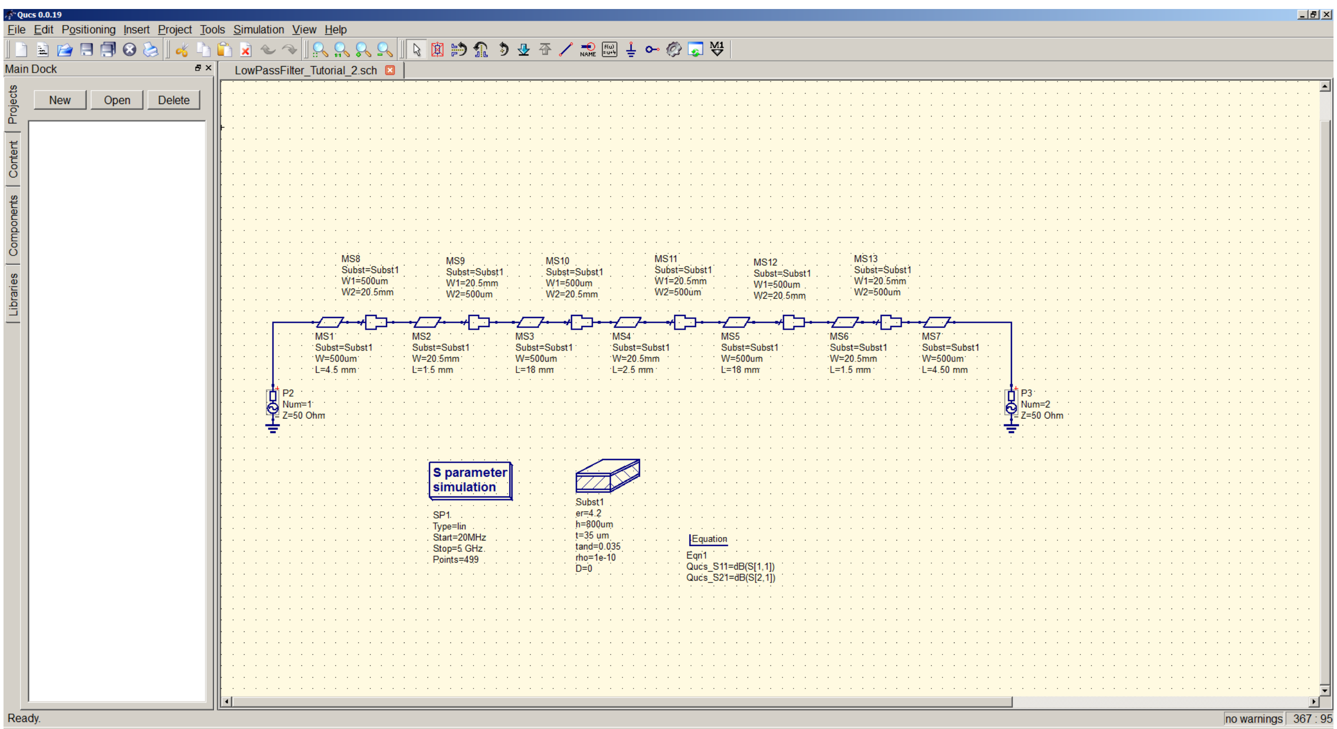


Figure 1: QUCS microstrip filter initial design

Simulate circuit to get some referent result which should be similar to simulation from openEMS. Result of this simulation is on picture below.

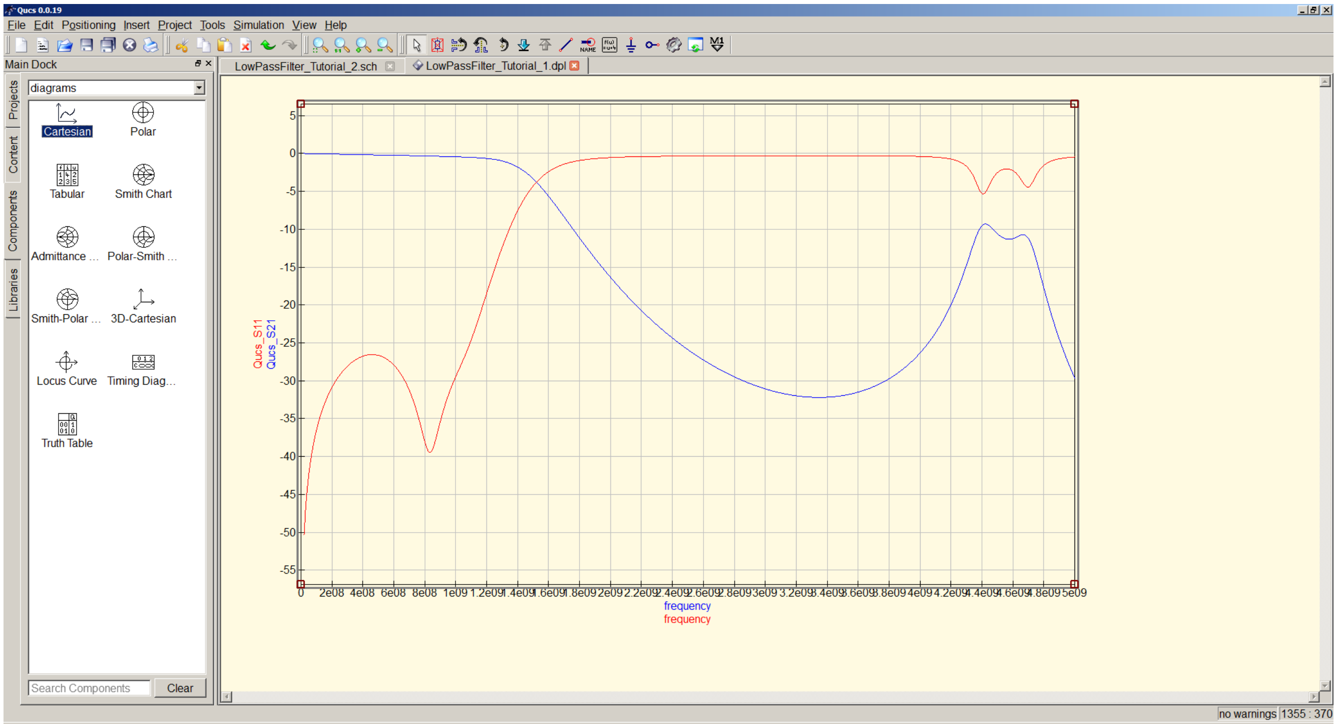


Figure 2: QUCS microstrip simulation S11, S21 results

QUCS to KiCAD to FreeCAD conversion

Now we have initial filter design and simulation and need to get it into FreeCAD somehow. For this I used small application to convert Qucs schematic into PCB layout for KiCAD.

To make QucsRFLayout working properly path to Qucs binaries must be set in SYSTEM PATH, because it's calling Qucs and if it's not set there is ERROR.

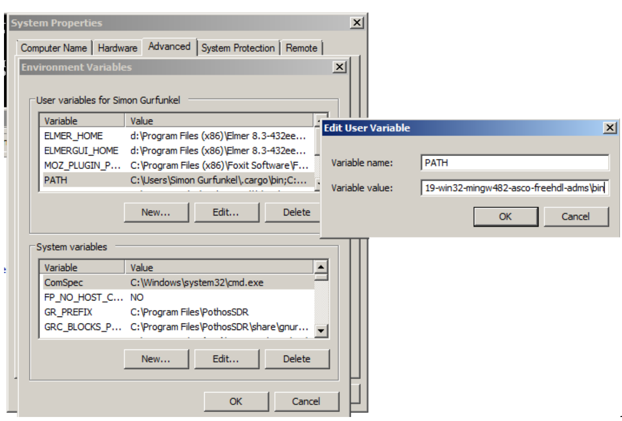


Figure 3: Setting path to Qucs binary into system PATH variable in Windows

Run QucsRFlayout and point it into your qucs file with filter design, read it and then export as KiCAD PCB.

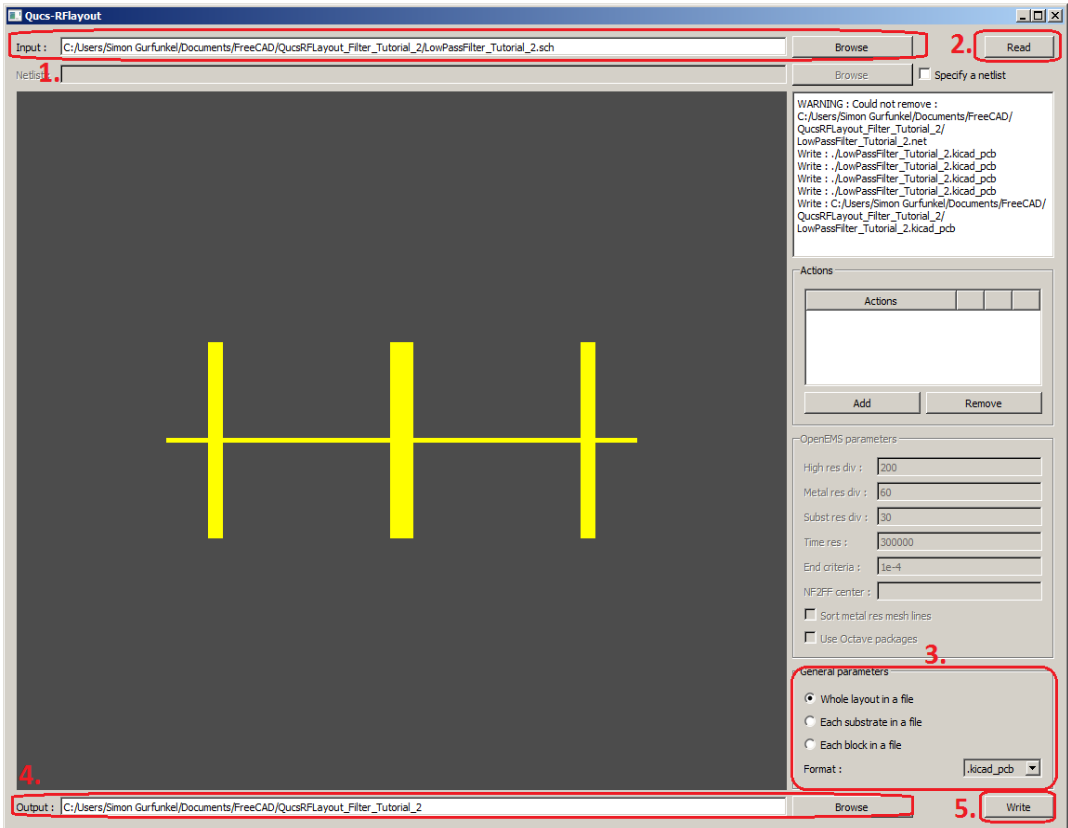


Figure 4: QucsRFlayout export microstrip filter as KiCAD PCB

After succesfull export open file in KiCAD PCB editor.

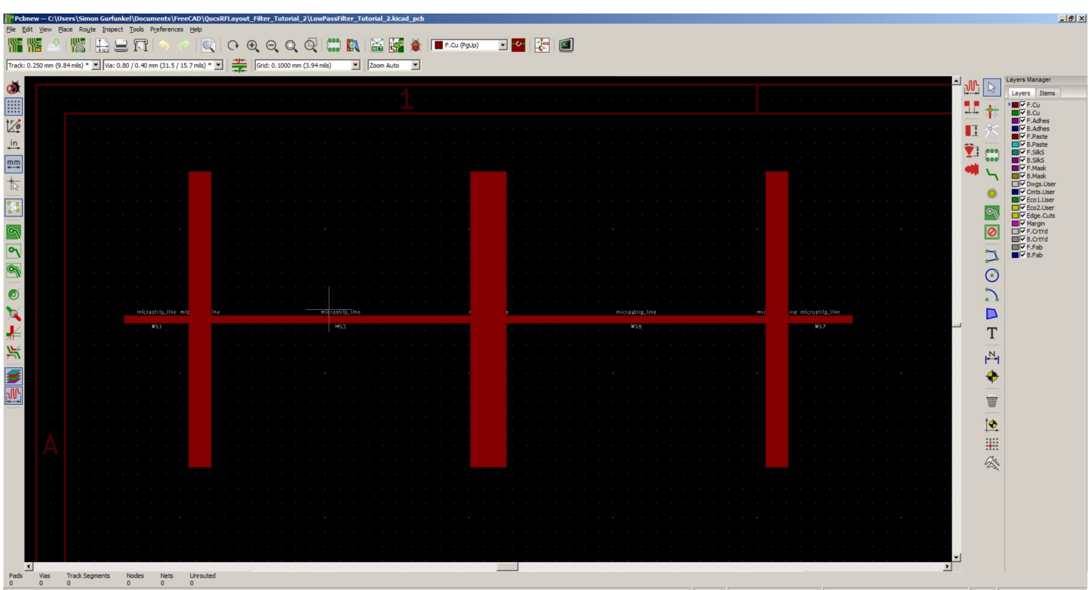


Figure 5: Exported PCB design from Qucs in KiCAD PCB editor

Now export PCB copper layer as SVG to be possible to load it into FreeCAD properly.

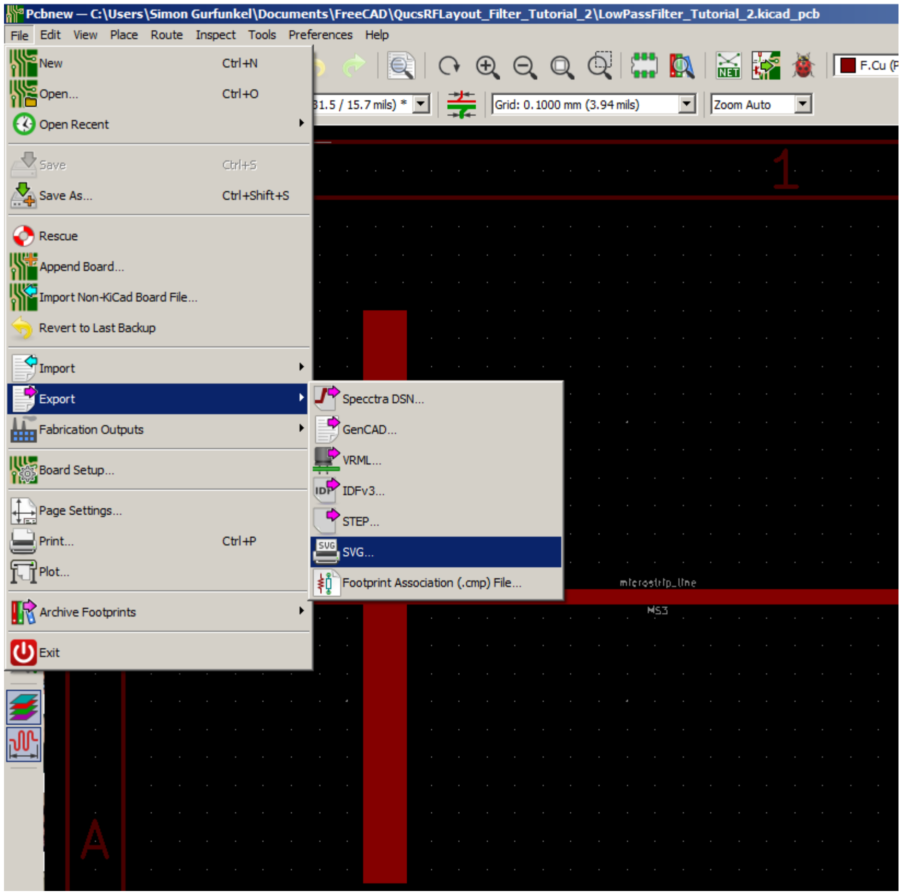


Figure 6: Export KiCAD copper layer as SVG

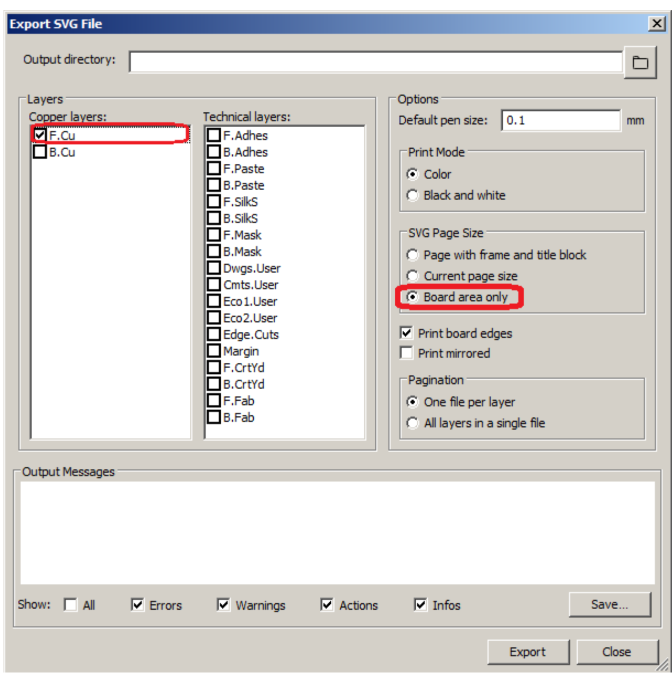


Figure 7: Export just copper layer to SVG file

Open FreeCAD and create new document. Then import planar filter SVG file.

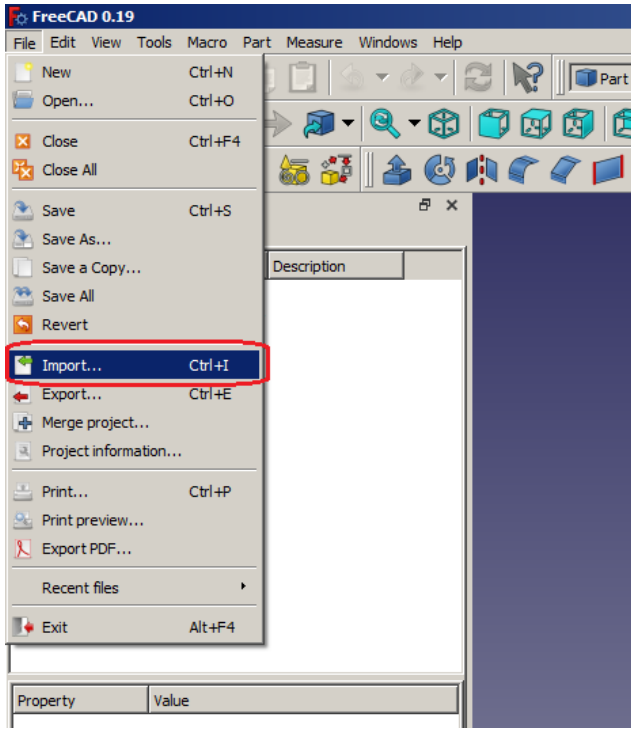


Figure 8: Importing SVG into FreeCAD

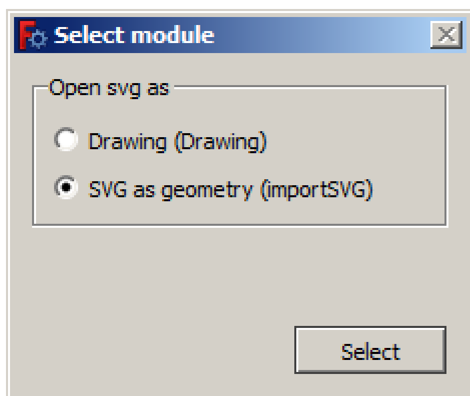


Figure 9: Importing SVG into FreeCAD as SVG

If there is some message about resolution just confirm it or whatever, I haven't pay attention to this I needed to get curves into FreeCAD be imported.

You should got copper layout imported in FreeCAD view, on my monitor it looks like on picture below. Each rectangle part of filter is imported as open path, next steps will convert these paths into faces and whole filter model will be created inside FreeCAD.

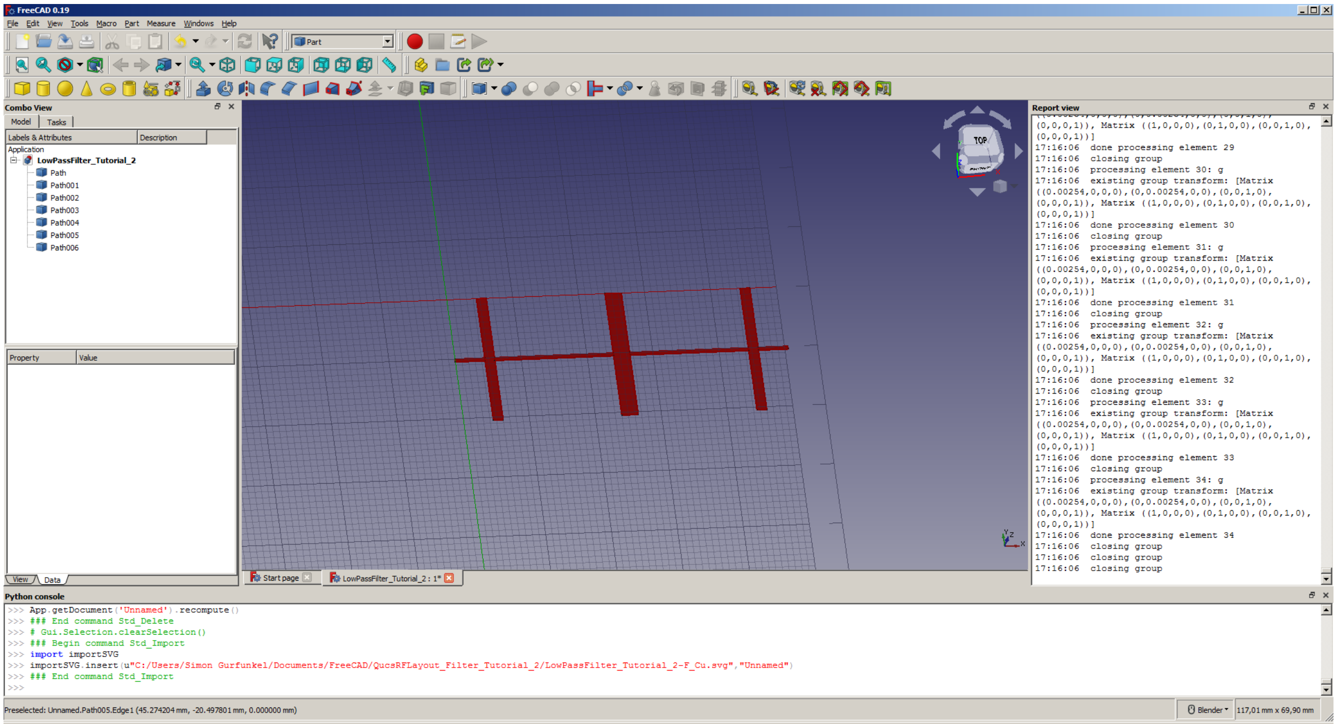


Figure 10: Copper layout imported in FreeCAD, SVG is imported as open path into FreeCAD.

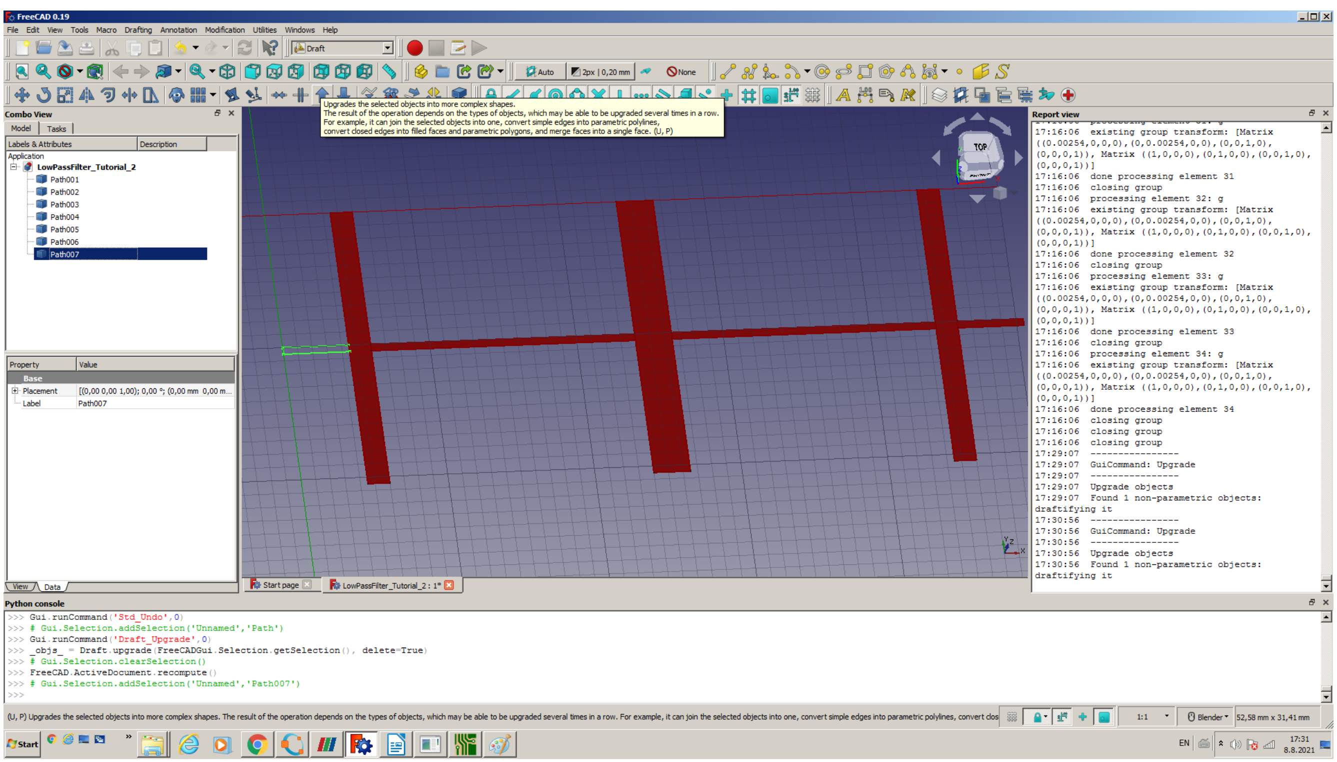


Figure 11: Second Upgrade operation needed to convert path into face in FreeCAD

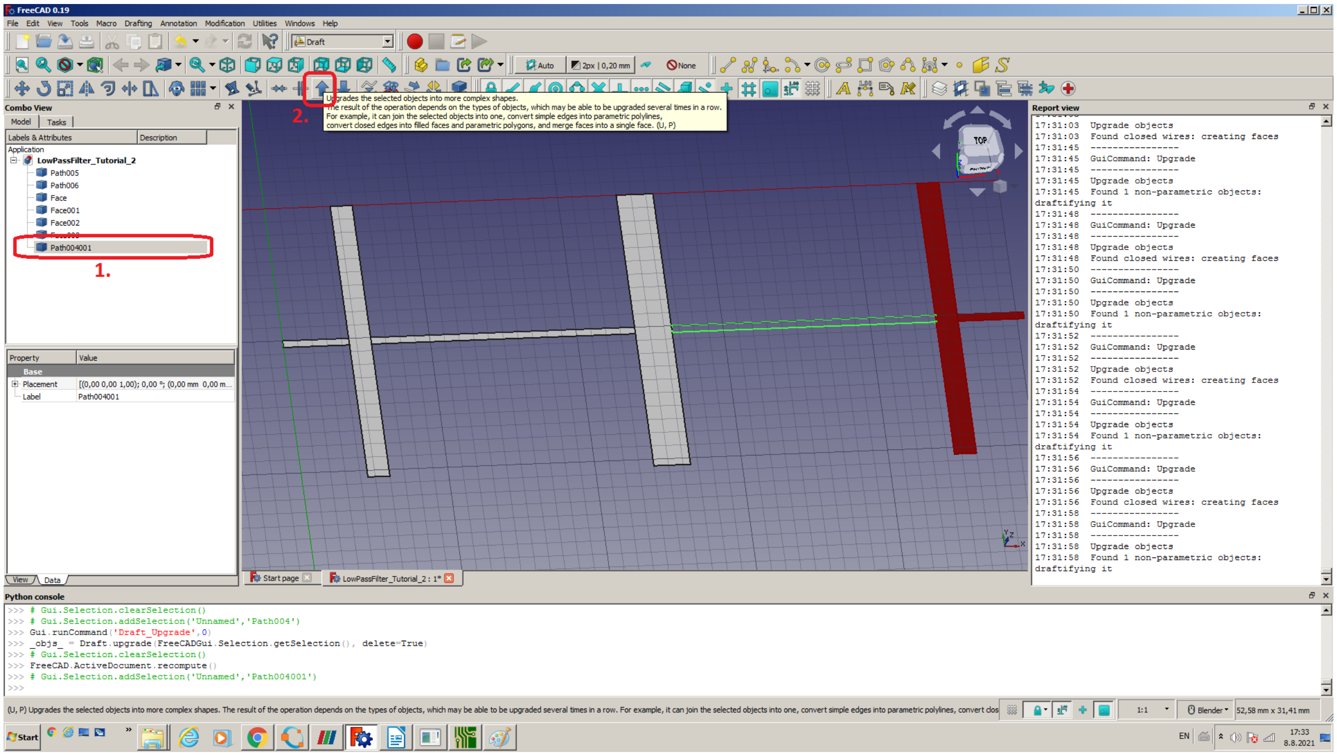


Figure 12: Repeat Upgrade process in Draft view for every path in document to convert all to faces

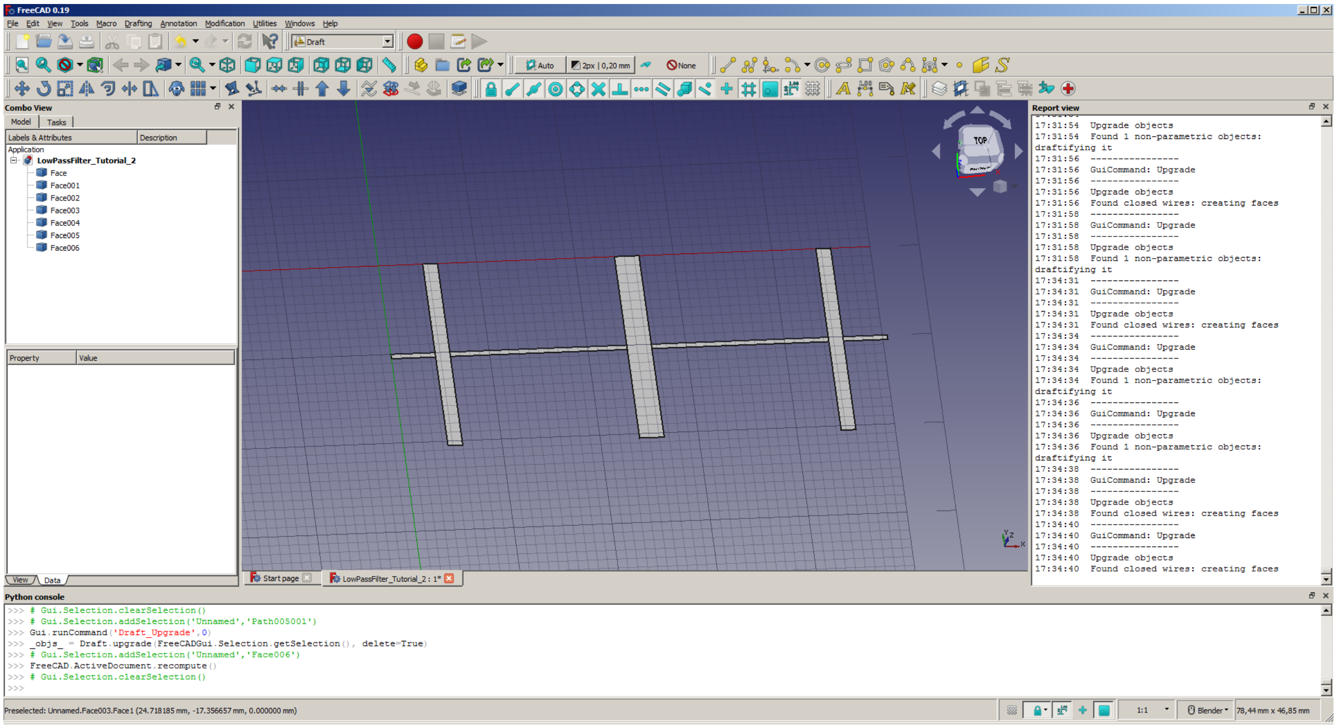


Figure 13: All path converted into closed paths and after to faces, this is how it should looks like

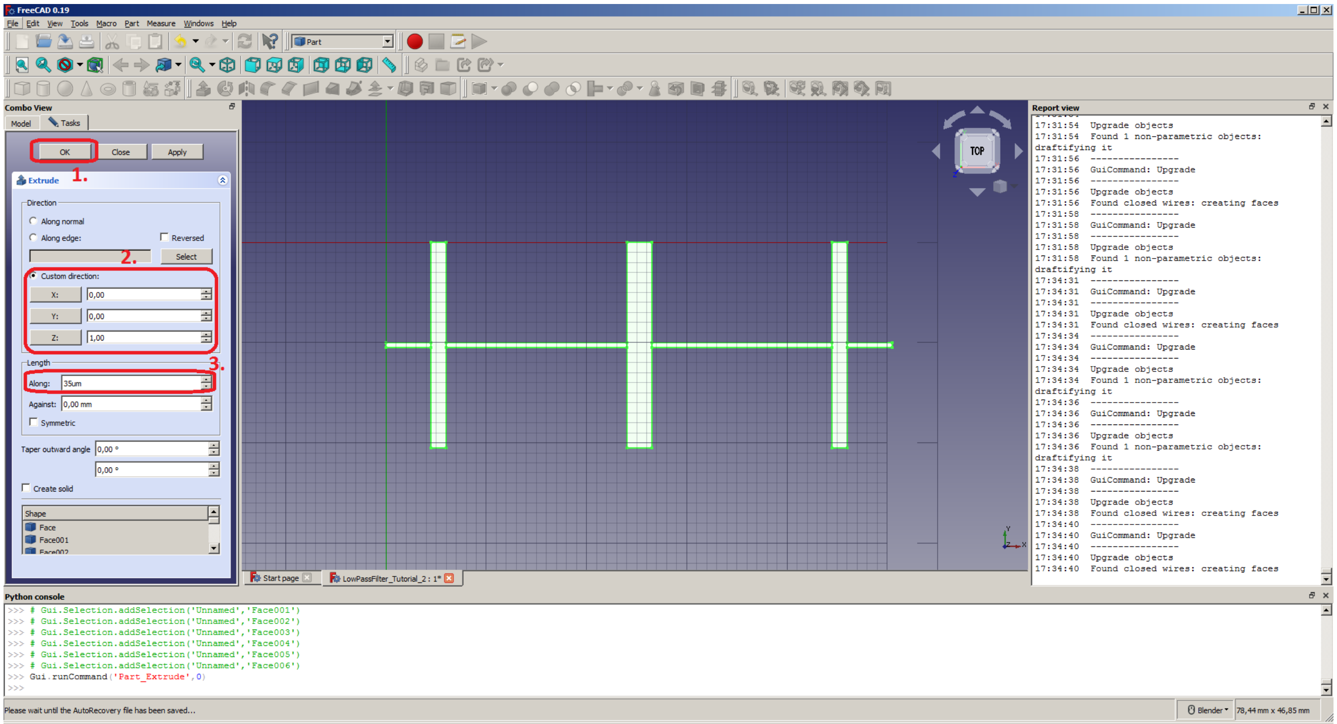


Figure 14: Extruding copper layer of filter to 35um same as it is in reality

Modelling filter in FreeCAD

Now we have imported filter copper layer into FreeCAD and extruded it into real copper layer with 35um thickness. Now we have to model rest of the filter how it will looks like in real to be able crete openEMS simulation using FreeCAD to OpenEMS Export Plugin.

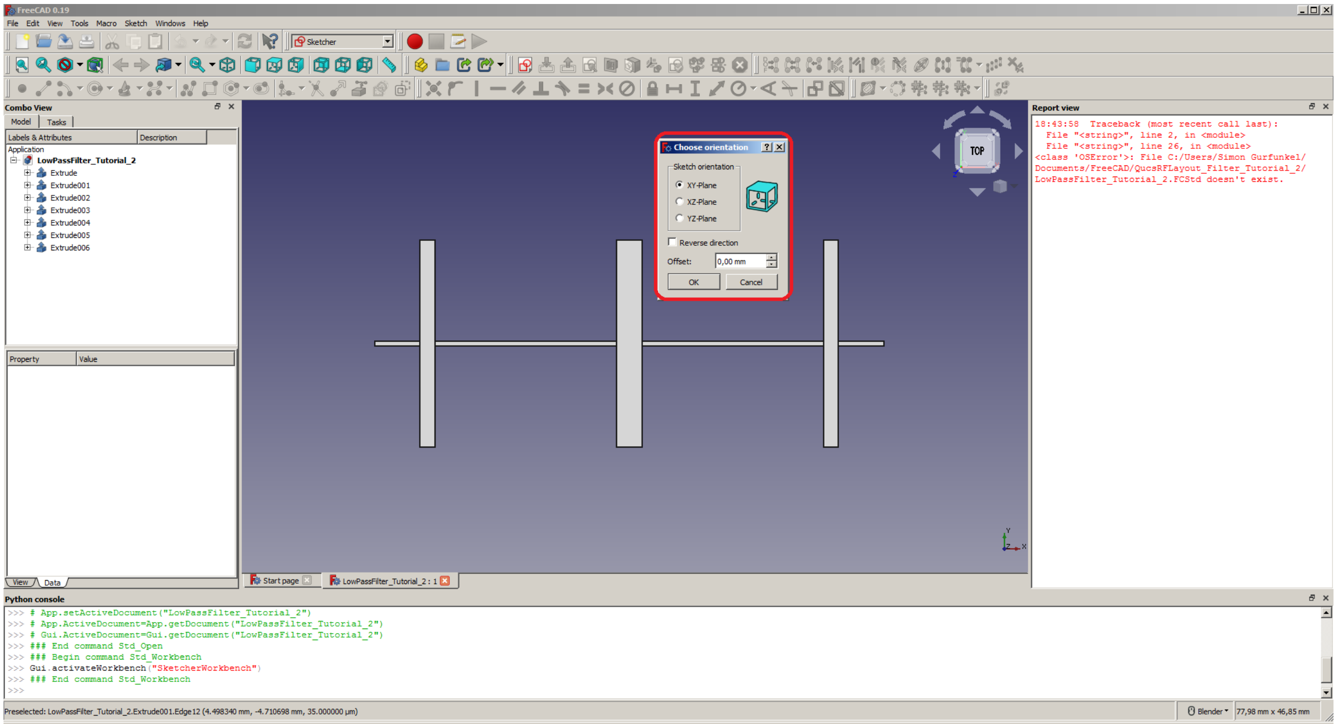
So what left to us:

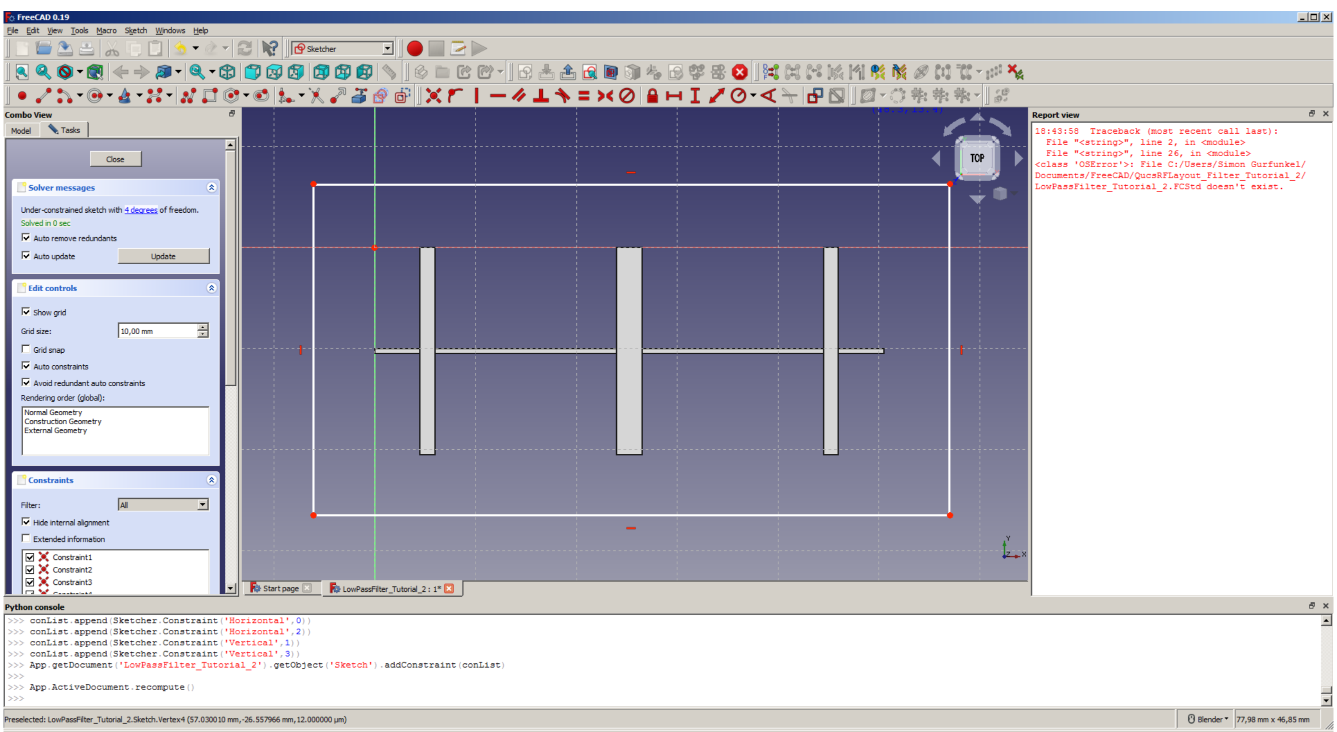
1. create PCB model including substrate and gnd
2. create input and output port
3. create air model around filter to get right simulation results
4. setup export plugin

Modelling planar filter in FreeCAD

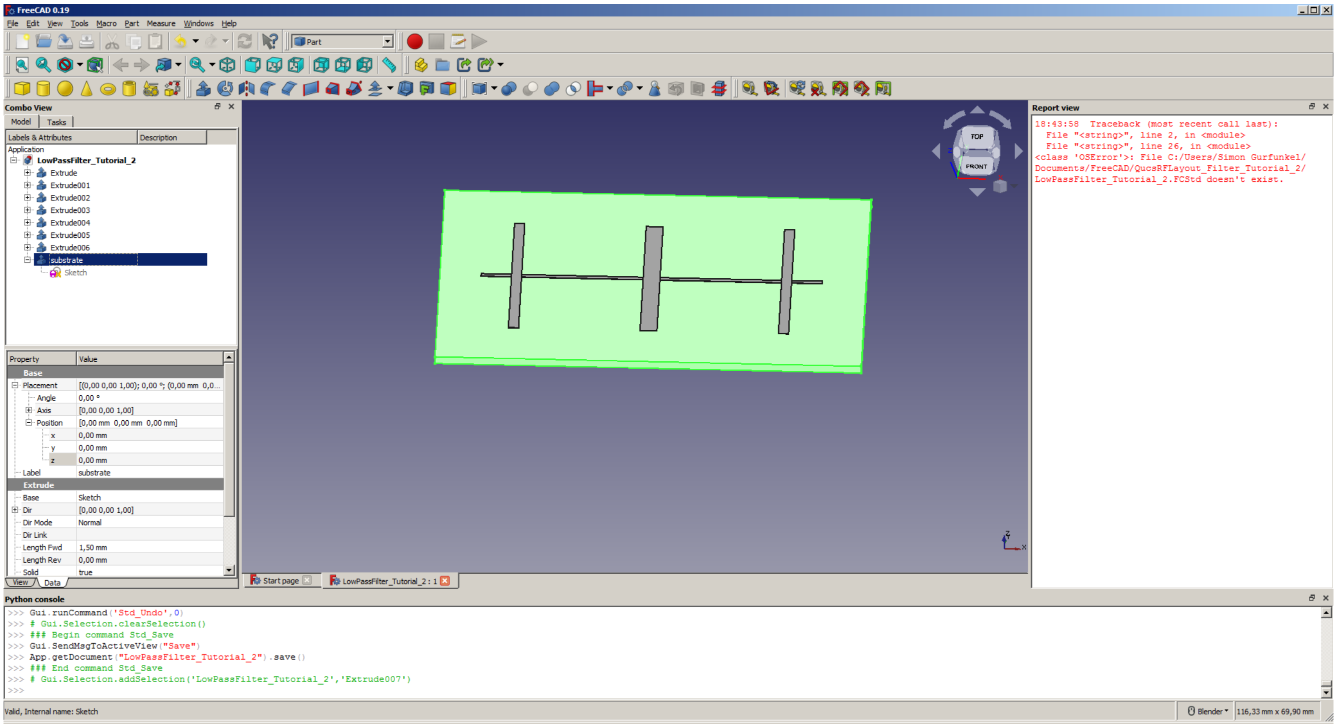
Now we have successfully imported planar filter designed in Qucs into FreeCAD and convert copper layer to FreeCAD object so we can start to create real model.

First we model substrate, so create rectangle around copper layer using sketch.

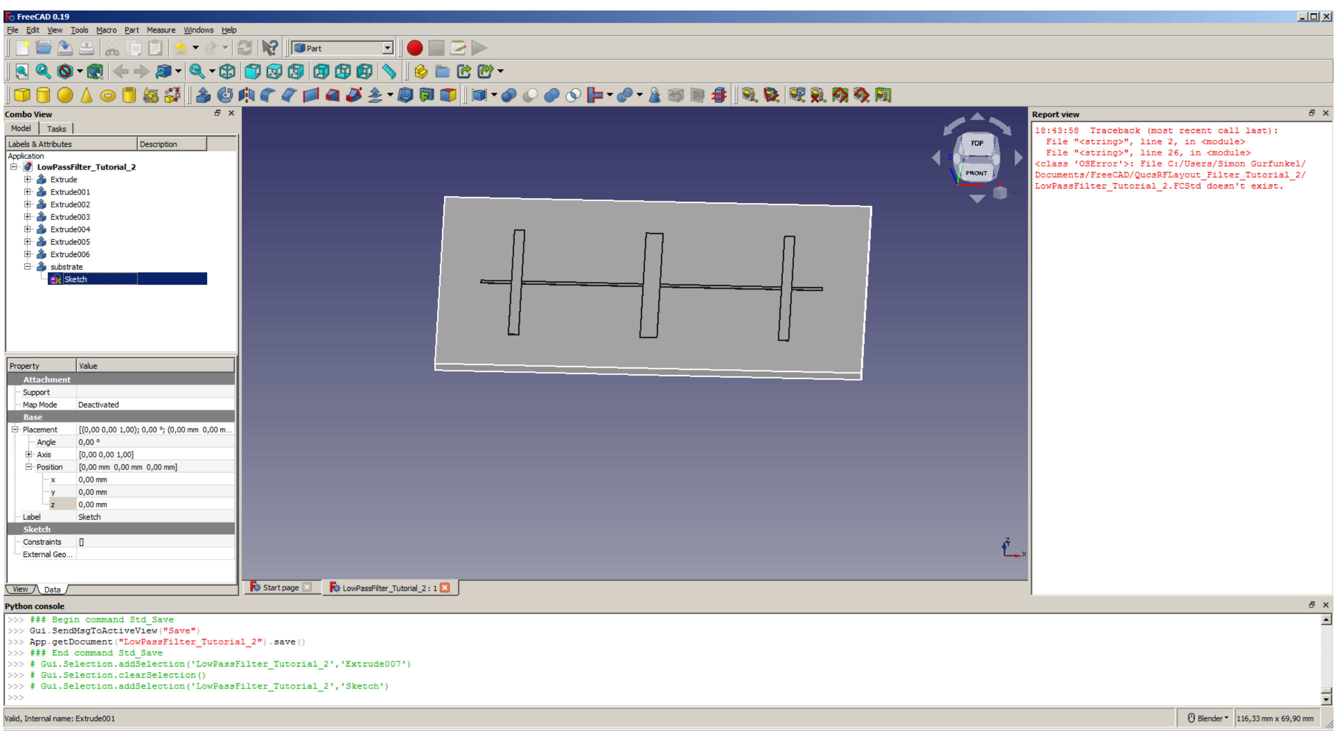




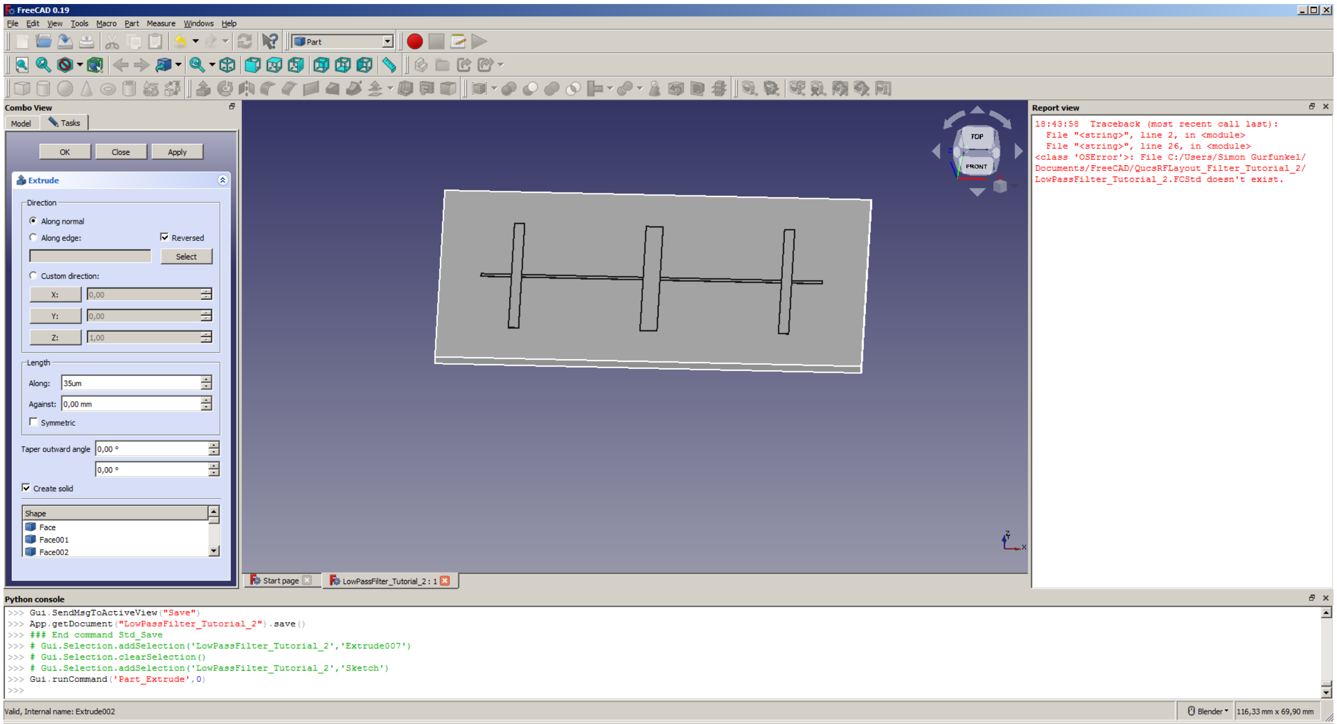
Then extrude sketch in Z direction but reverse it to create substrate with thickness 1.5mm and rename extruded object as substrate.



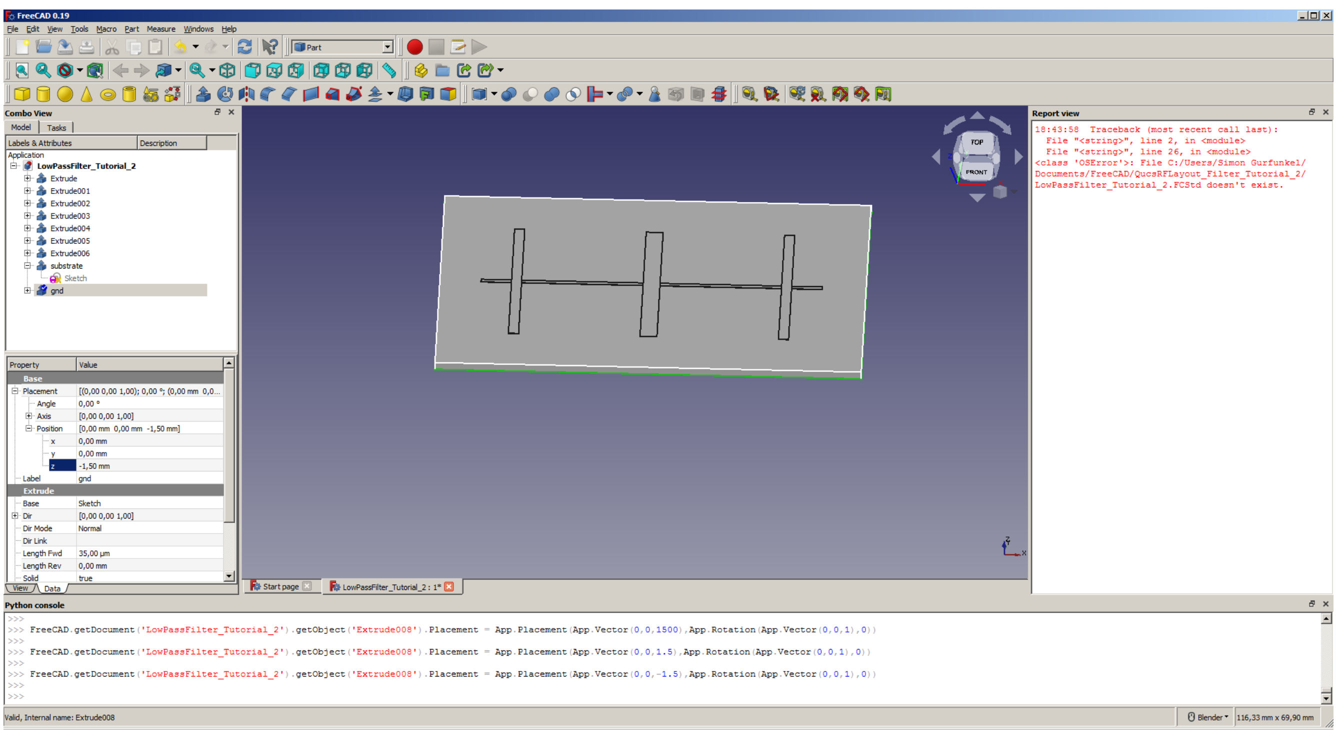
We will use sketch for substrate to create ground plate. Select sketch located in model treeview under substrate and again choose extrude tool.



Set parameters as on picture below, extrusion length to 35um which represent ground copper layer and reversed direction.

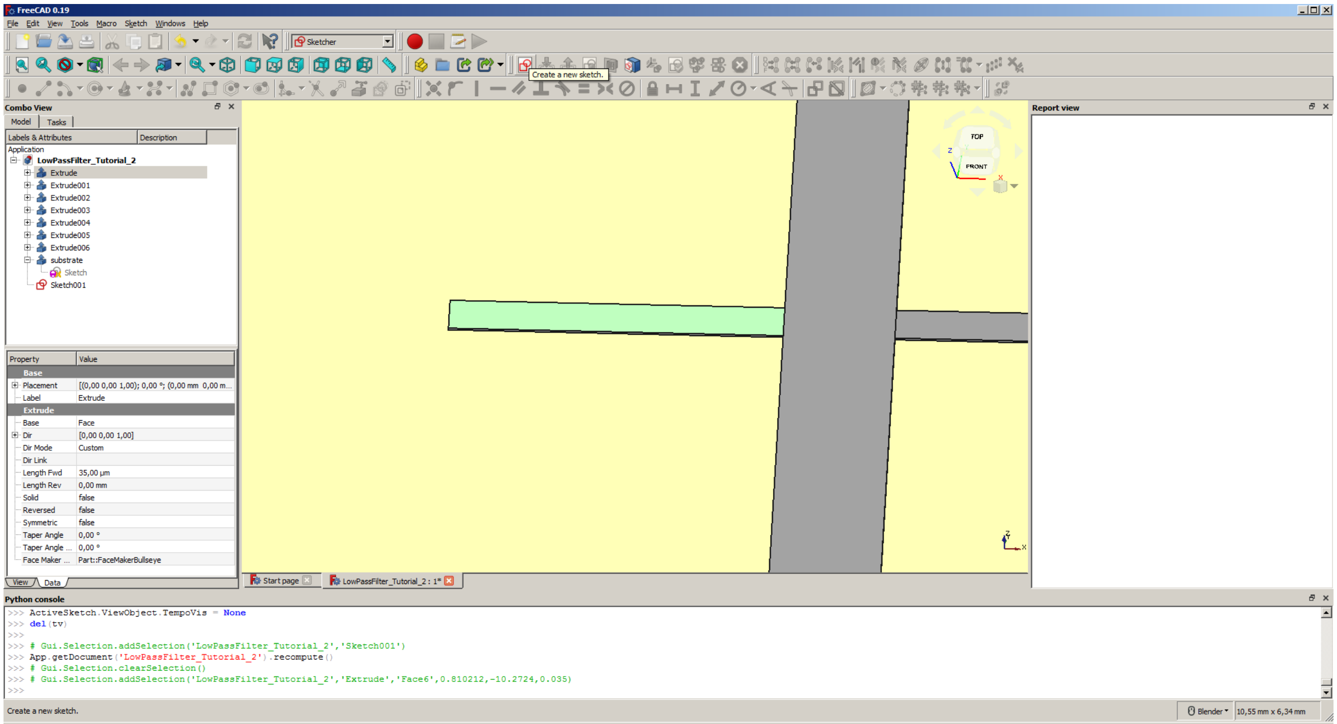


Now renamed extruded object to name gnd and set its position as -1.5mm to move it below substrate.

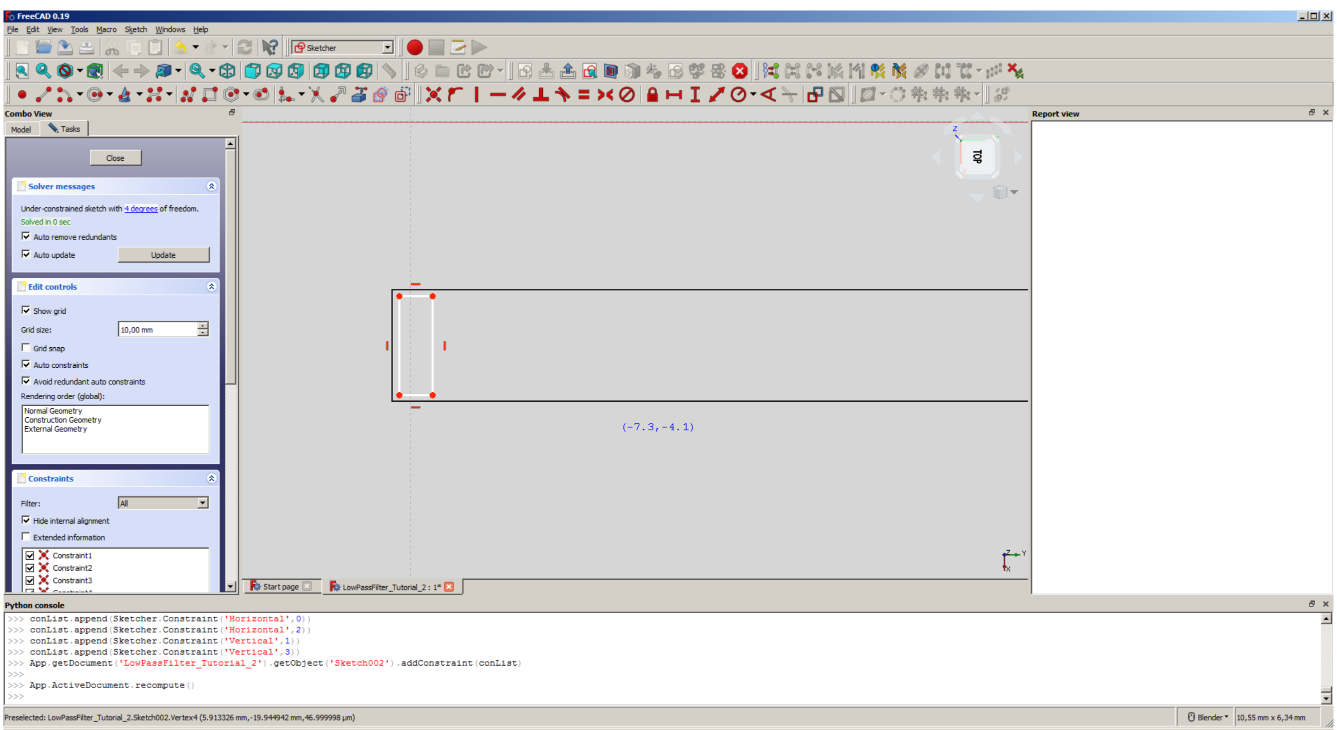


At this point we have planar filter model already ready. We must create input and output port which will be made using two boxes, one in left filter part and second in right part.

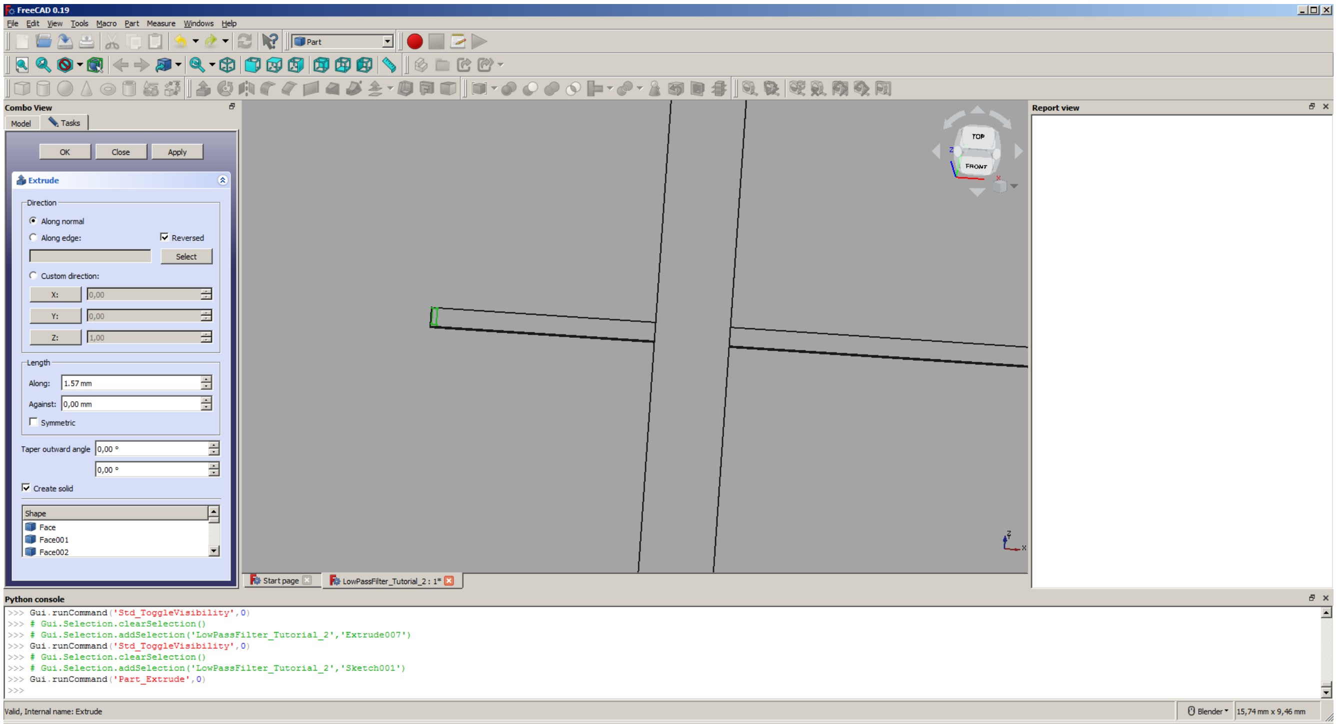
Select left filter copper face and from sketcher choose create sketch as shown below.



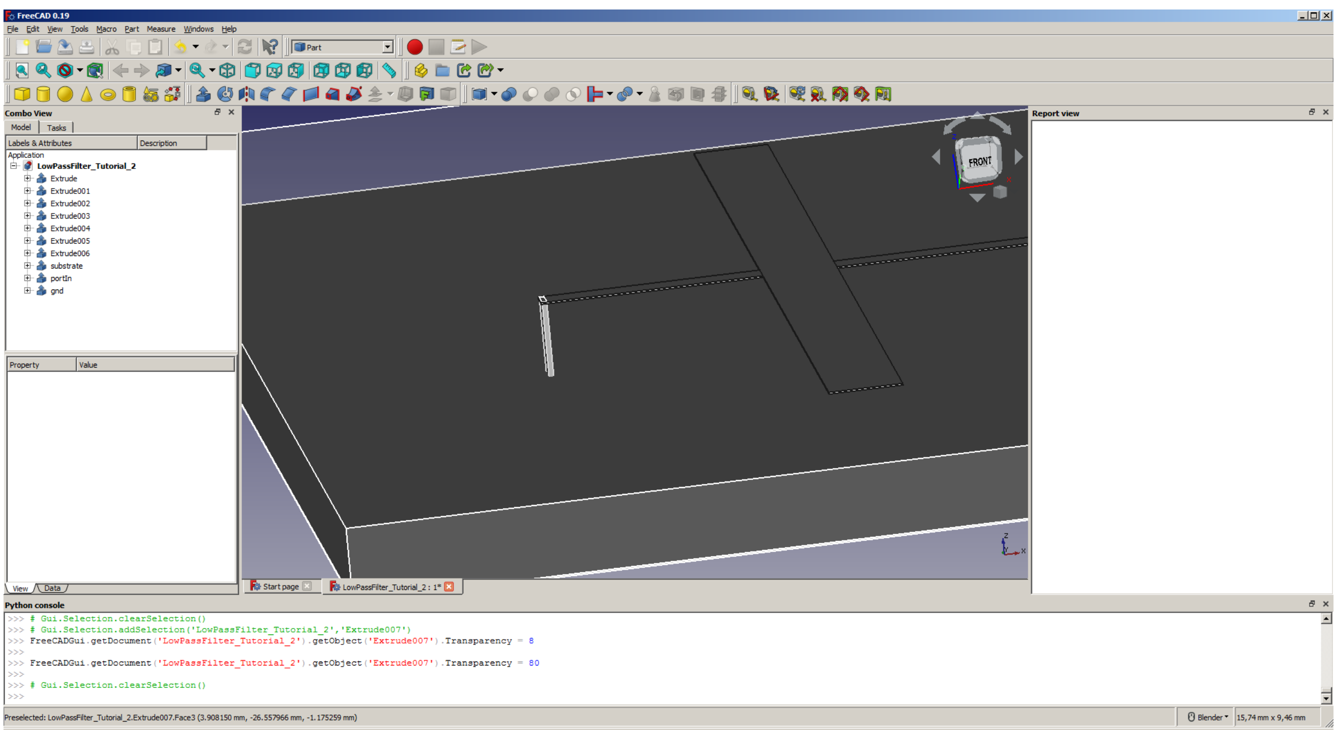
Draw rectangle, it will be input port for our simulation. You don’t have to really care about its dimensions, there would be later defined just one line going through this inpt port.



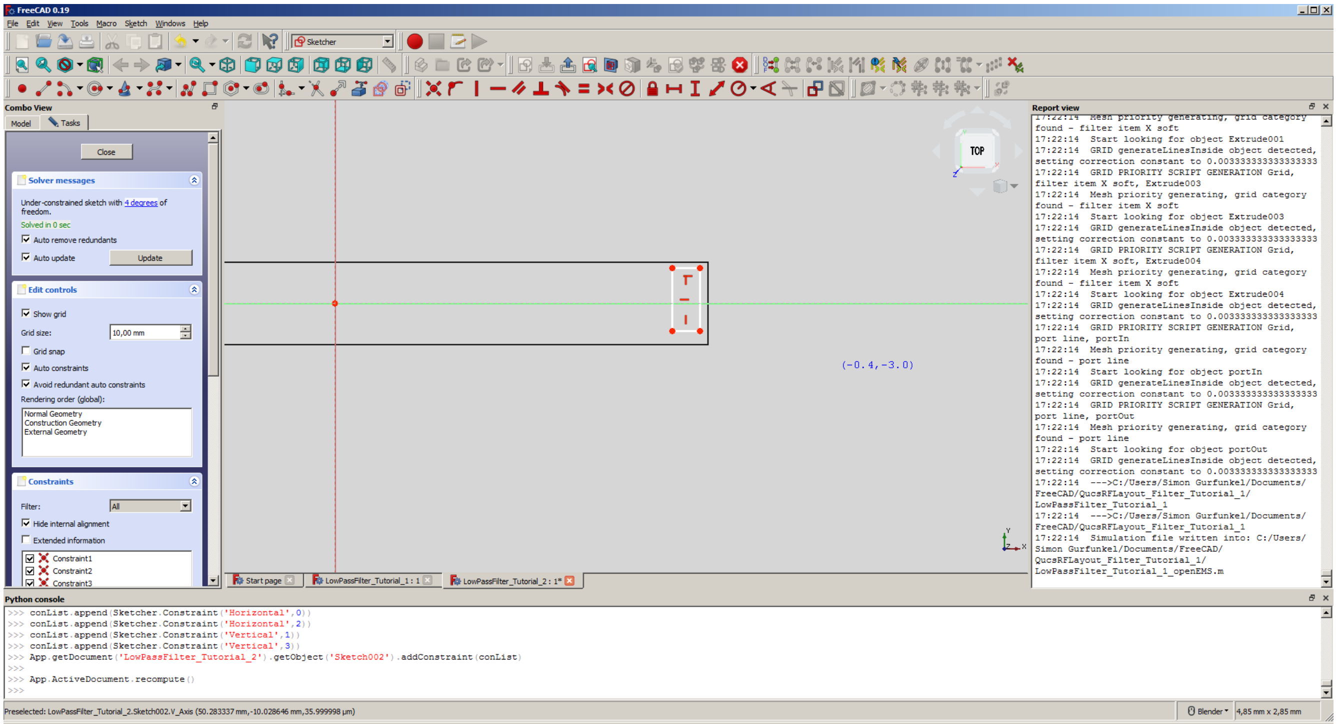
Now extrude box in reversed direction for 1.57mm (that’s 1.5mm for substrate and 2*35um for top copper filter part and gnd plate).



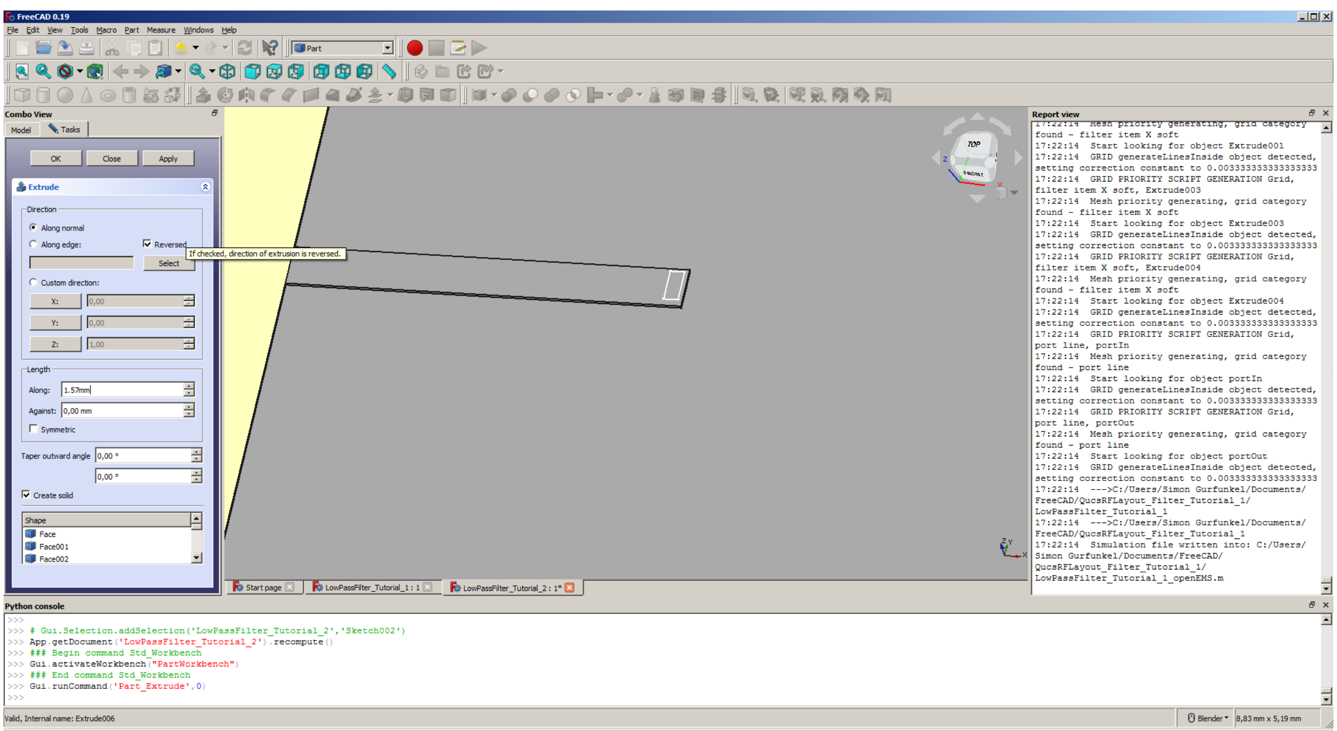
Now your model should looks like this.



Let’s draw second output port for filter. Select top face on right part of filter and same way draw rectangle on top.



Then change for Part tool, select sketch in object explorer and extrude it in reversed dircetion for 1.57mm (again 1.5mm for substrate 2*35um for two copper layers filter one and ground plate) as shown below.



Now rename objects in object window to some reasonable names as shown below for later easier simulation setting.

So now filter is prepared for meshing. There would be also needed add some space around it but first look how mesh in openEMS is setup for better understaning how to define air around filter and how to setup grid.

Grid setup in openEMS

OpenEMS uses rectangular grid for simulation, that means that user defines x, y, z coords and therefore for each coordination x, y, z is generated one grid line.

In reality suppose that we defined grid coords as follows:

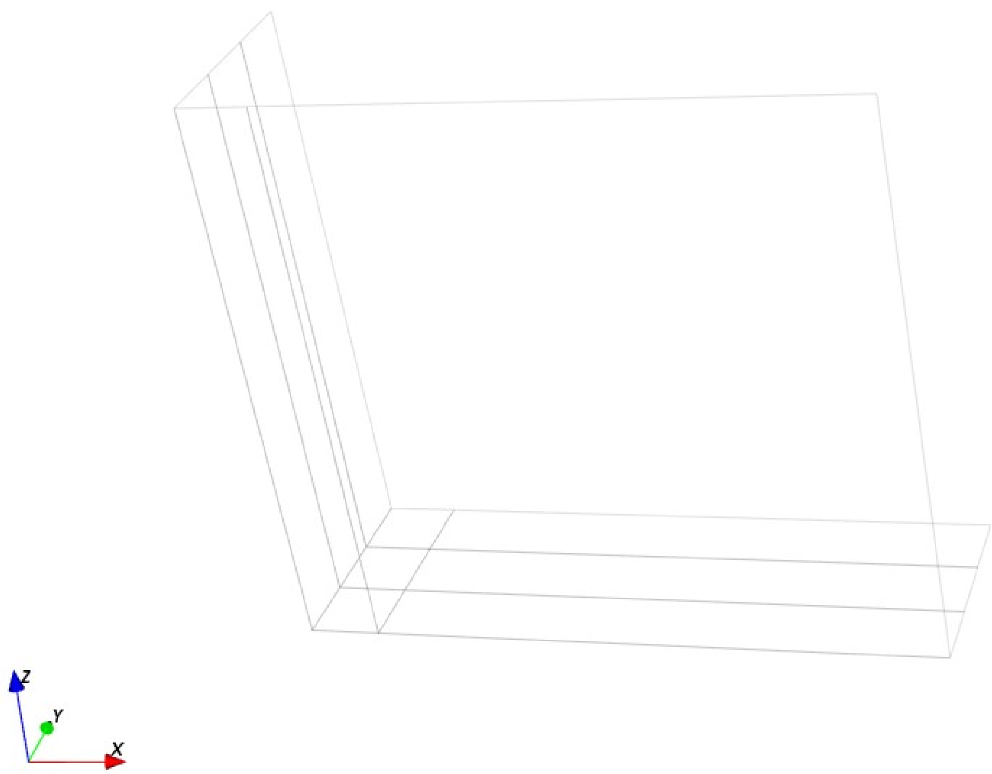
mesh.x = [1 2 10]

mesh.y = [5 6 7 8]

mesh.z = [9 17]

In this case there will be generated in openEMS grid lines as follow:

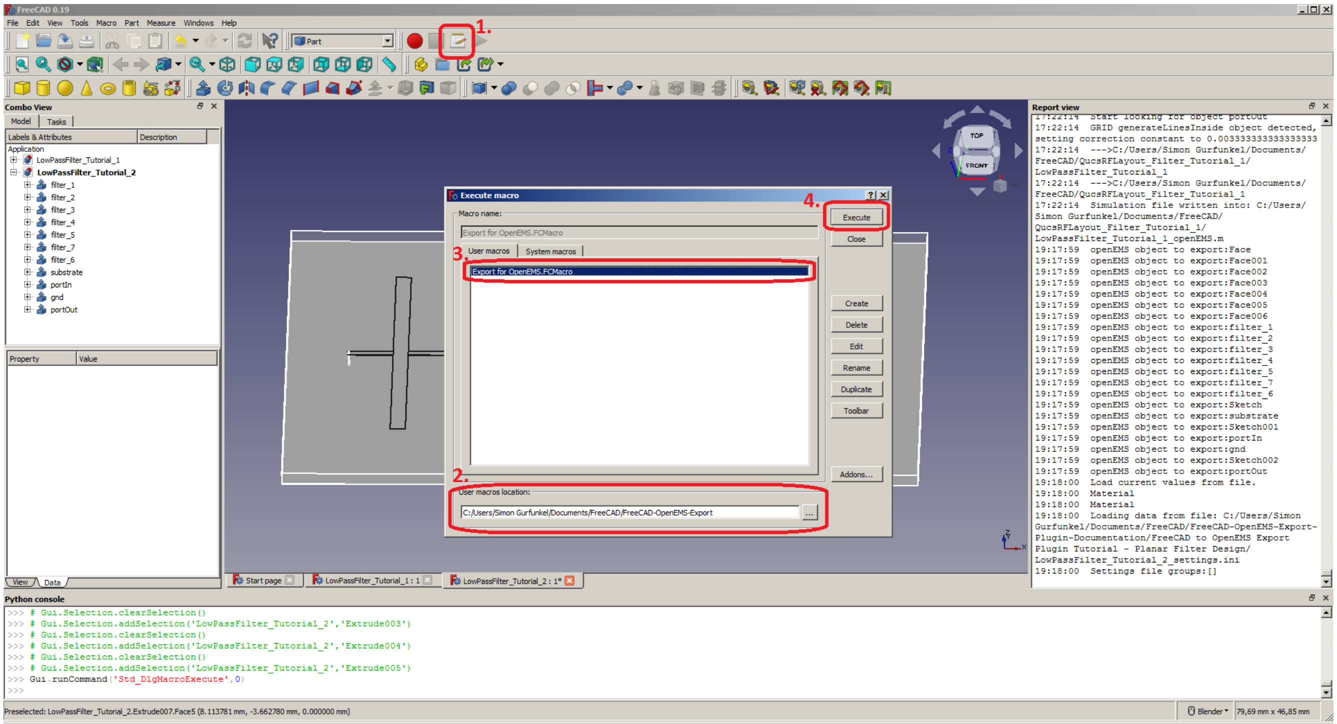
in XY plane will be 4 lines in X direction at coords [1 2 3 4] and 4 lines in Y direction at [5 6 7 8] there would be two XY planes one at coord 9 in z direction and one at 10 as shown on picture below



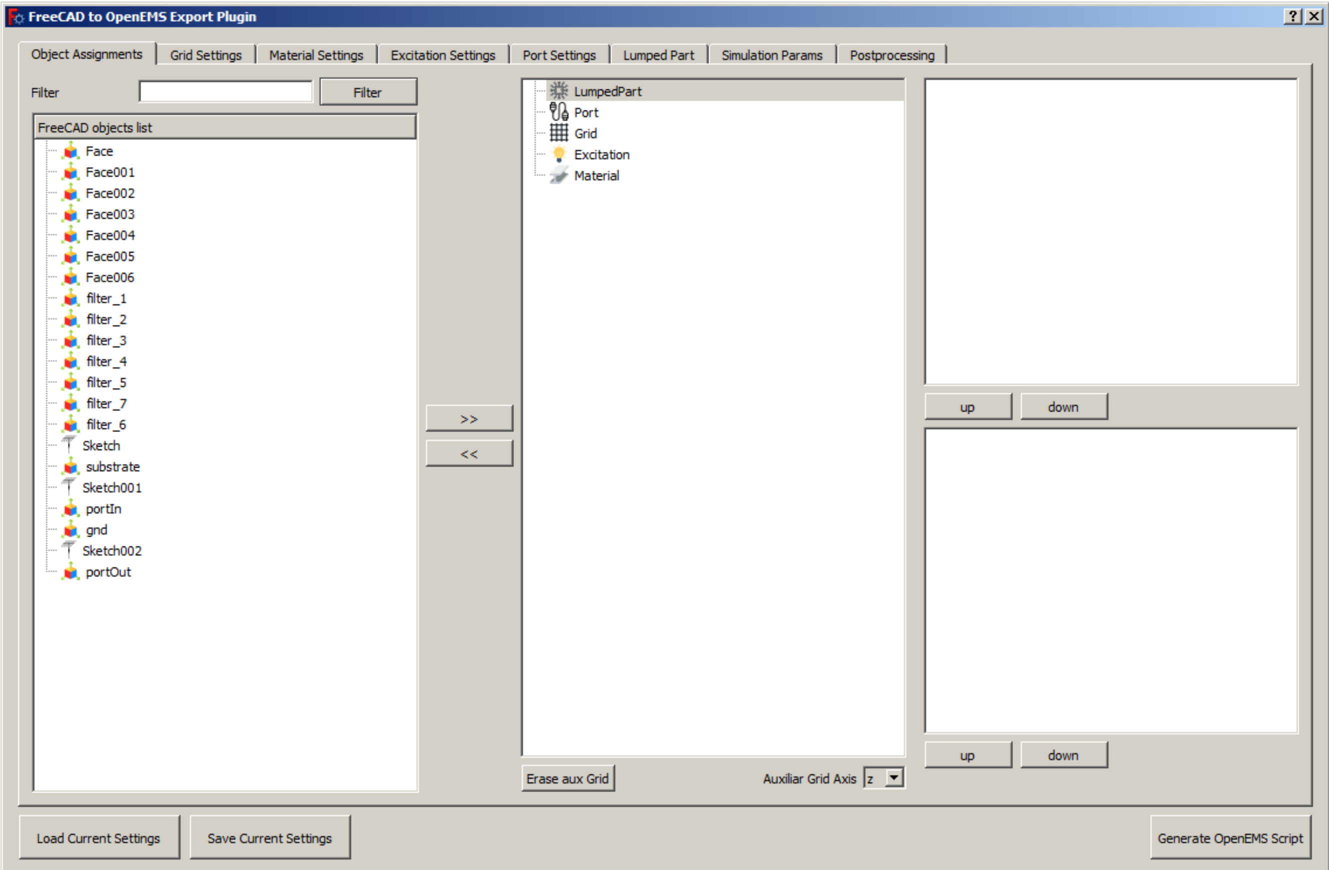
For now in plugin to export simulation script there are implemented two main features to setup grid right, setting grid at fixed distance on selected object or setting line count in each direction for selected object. This is enough to simulate basic planar filters. Now start with simulation setting.

Setting openEMS simulation using FreeCAD plugin

Run FreeCAD to OpenEMS Export plugin, click on running macros, setup path to folder with downloaded plugin and execute macro.



Main window for export plugin should appear.

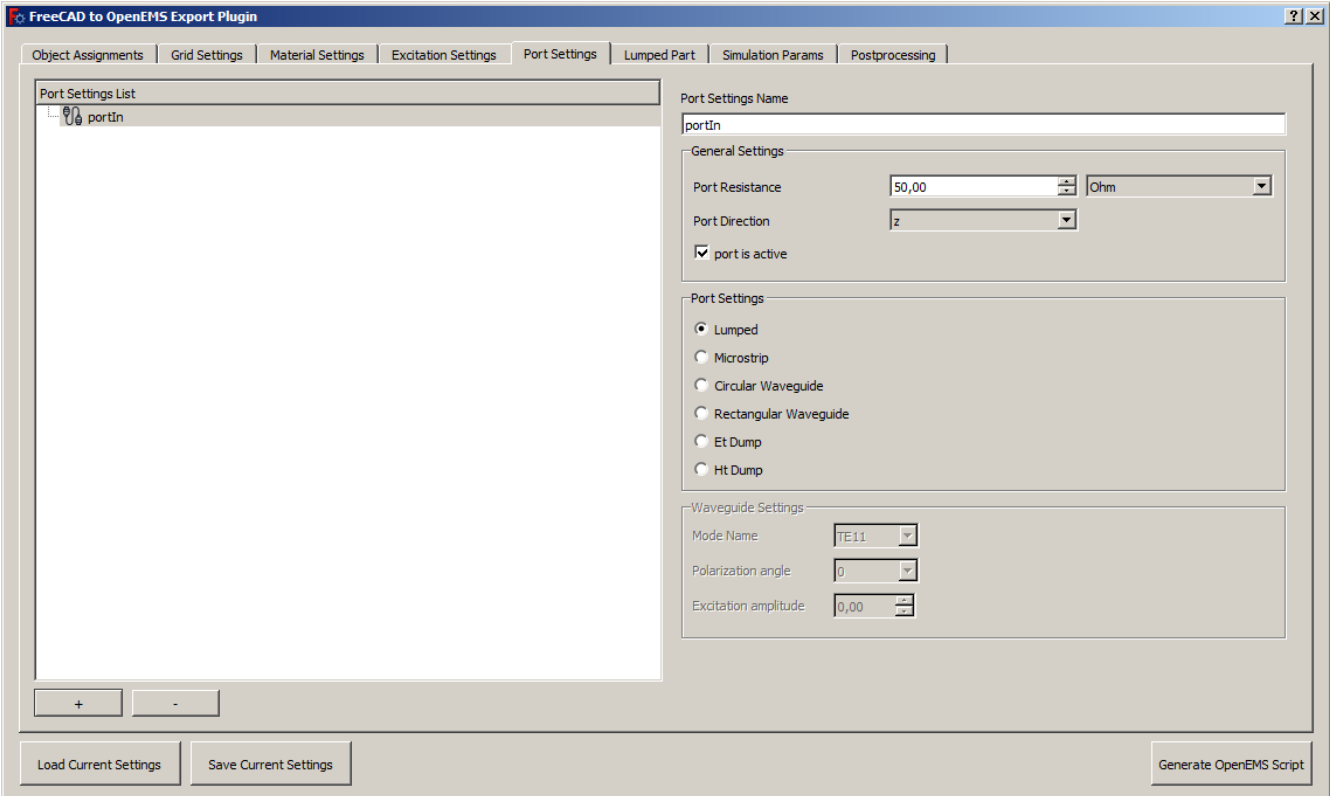


Basic idea for this plugin is, that in left part are listed all objects from FreeCAD that means all object even nested from Combo View, they have different icons, one is for objects and second (antenna icon) is for sketches.

Idea to for setting simulation is that you define all categories in right part (Lumped Ports, Ports, Grid, Excitation and Material) under each category assign one FreeCAD object and then hit button Generate OpenEMS Script. After this, simulation script and all needed files would be exported from FreeCAD and you just run simulation in Octave to get results.

So let start with port definition. We will define one input active port (it will be excited by settings in Excitation category) and one passive output port to sense filter transmission S21.

Also to get nice electric field picture in time we will define Et Dump port what we add as plane into FreeCAD model later.


FreeCAD to OpenEMS Export Plugin
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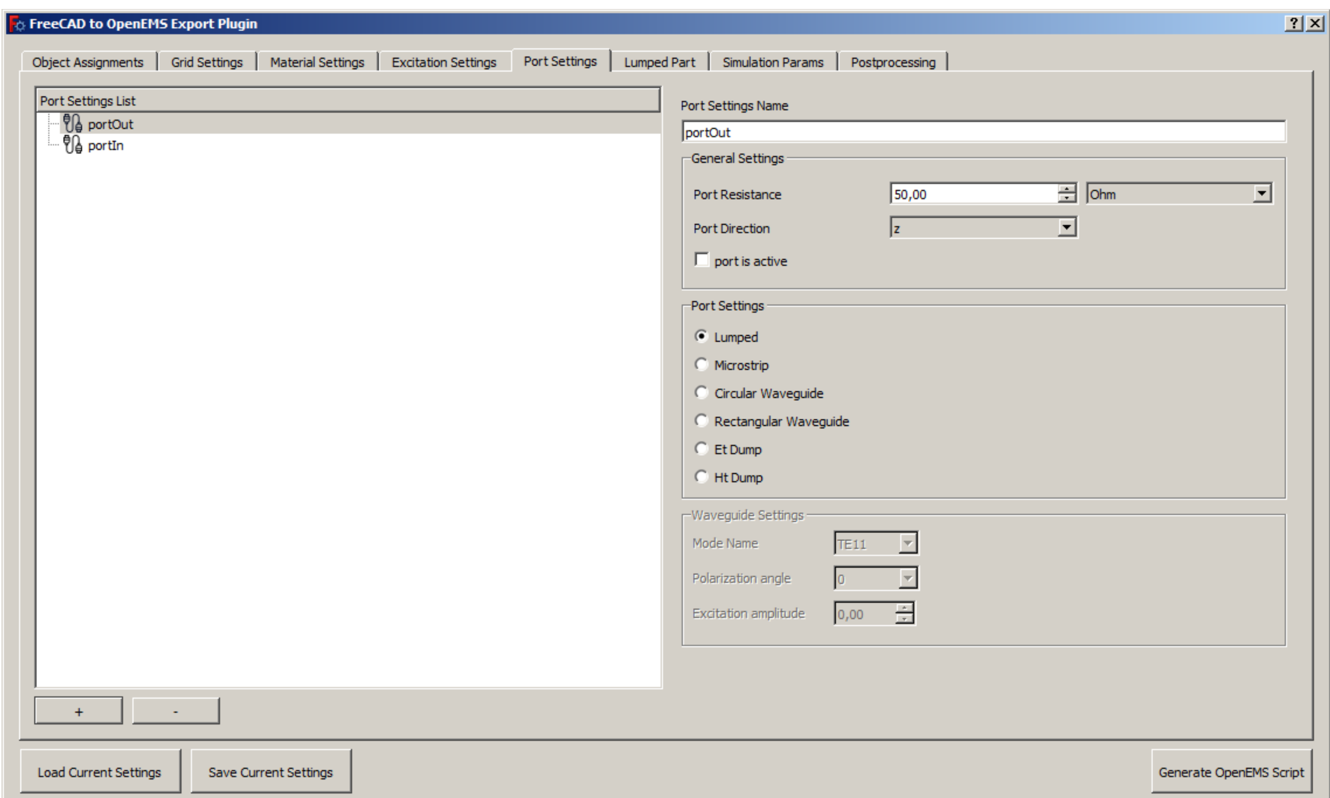
Grid Settings
Material Settings
Excitation Settings
Port Settings
Lumped Part
Simulation Params
Postprocessing
Port Settings List
portIn
Port Settings Name
portIn
General Settings
Port Resistance
50,00
Ohm
Port Direction
z
port is active
Port Settings
Lumped
Microstrip
Circular Waveguide
Rectangular Waveguide
Et Dump
Ht Dump
Waveguide Settings
Mode Name
TE11
Polarization angle
0
Excitation amplitude
0,00
+
-
Load Current Settings
Save Current Settings
Generate OpenEMS Script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Ohm
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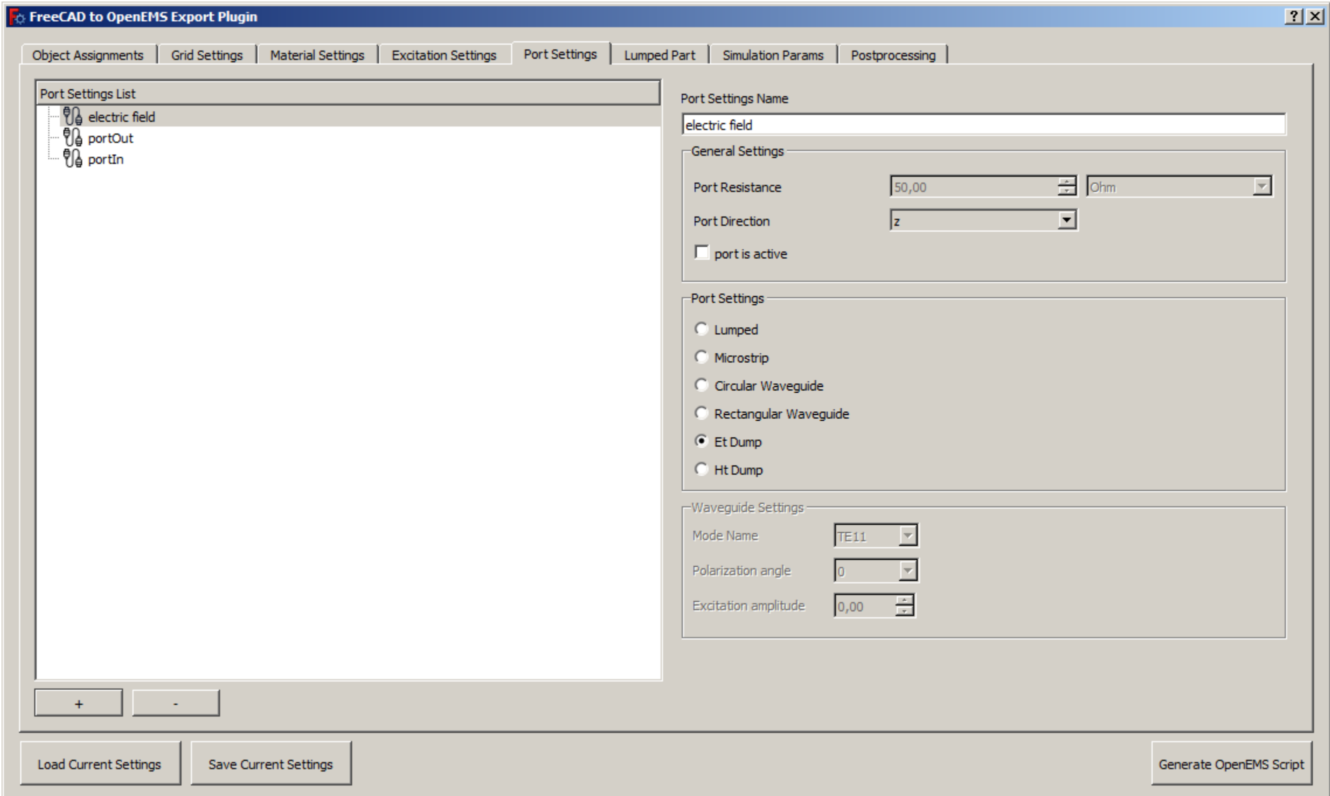
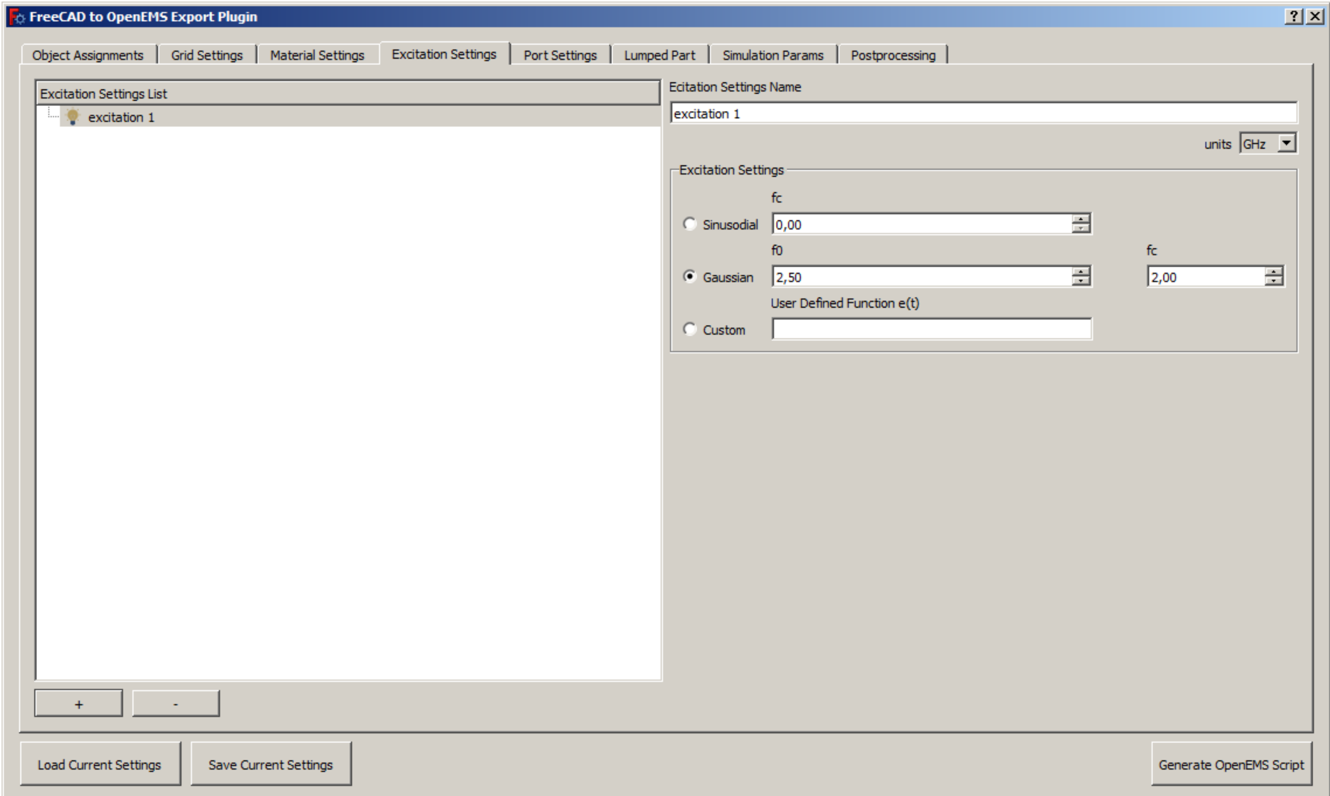
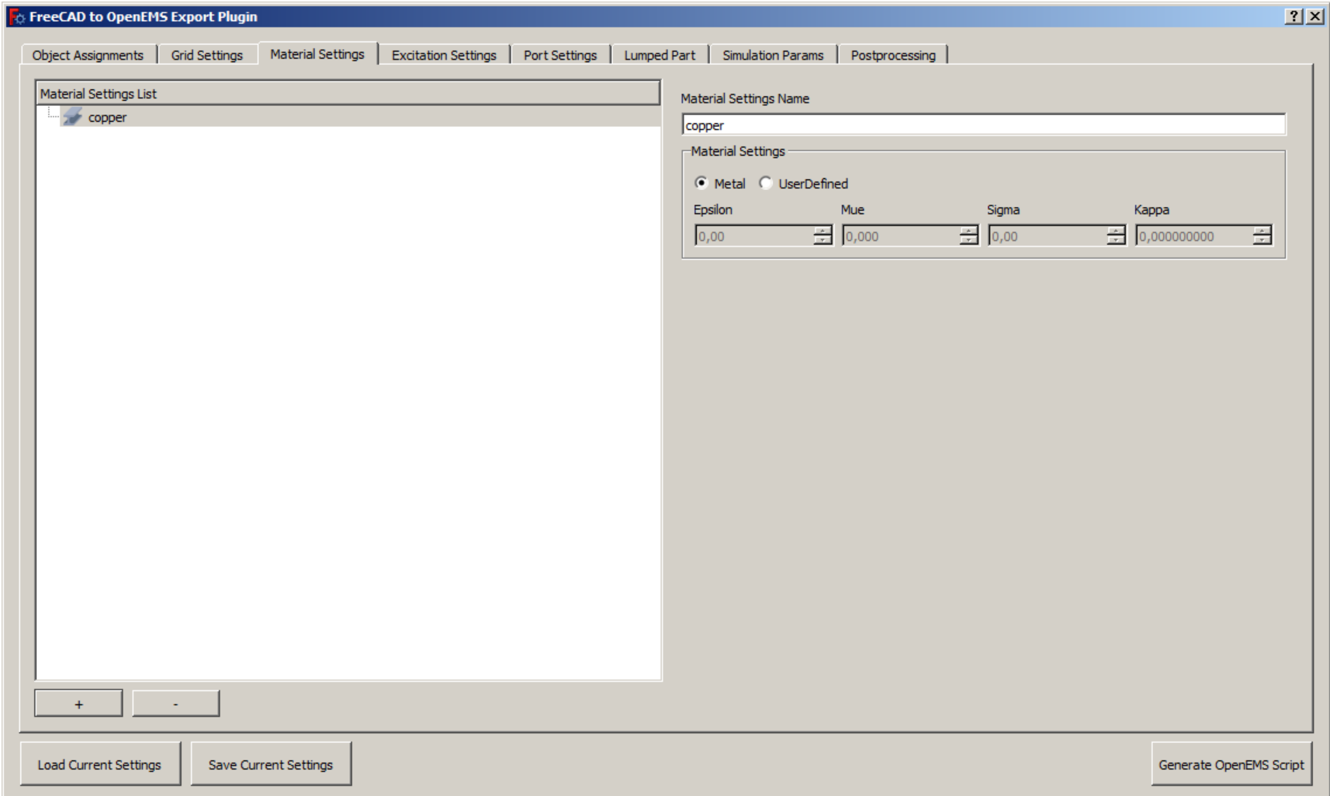


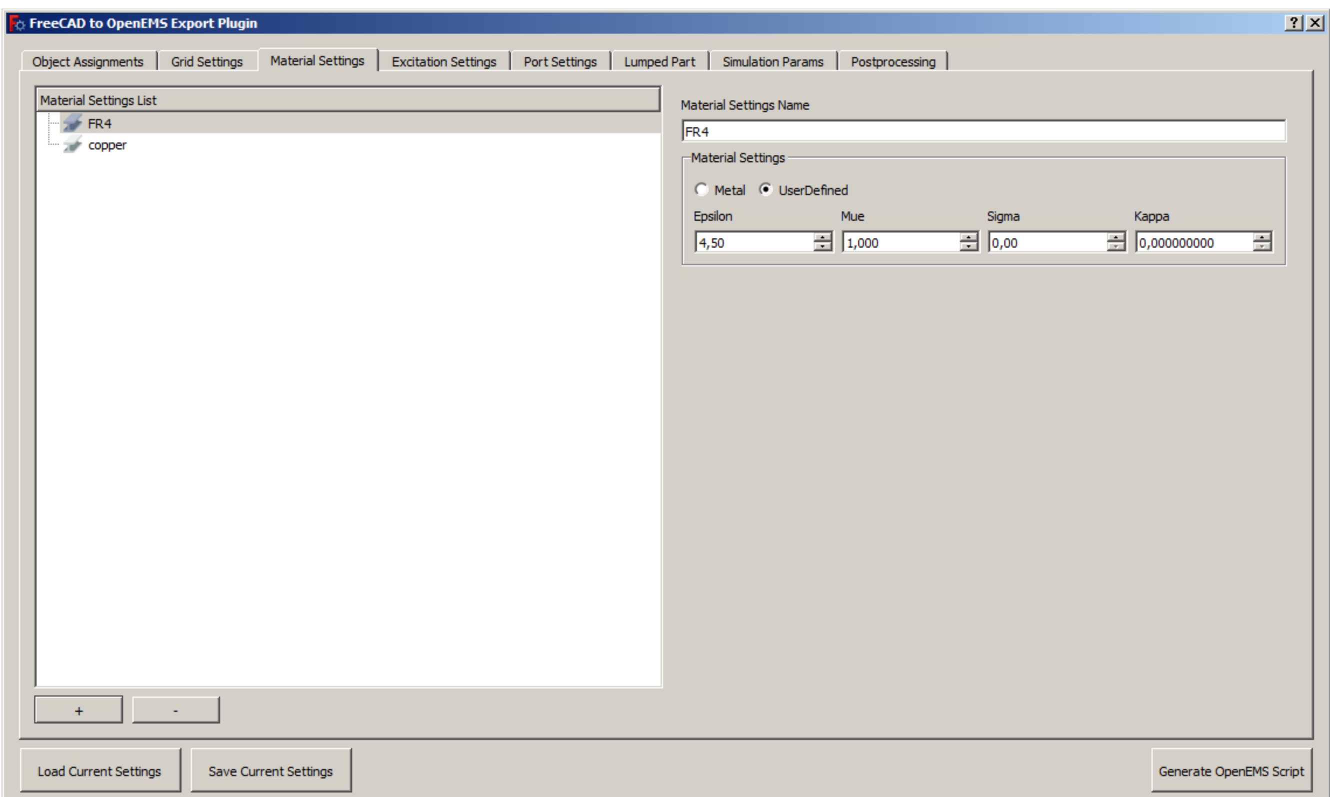
Now let's define excitation for our model. There could be just one excitation in current plugin version. We are going to inspect filter S21 in range 500MHz to 4.5GHz so for this simulation we will define gaussian impulse with fc = 2.5GHz and f0 = 2GHz, don't forget to change units from Hz to GHz in right top corner.



Ok, now let’s define material of some objects in our simulation. Let’s start with copper.



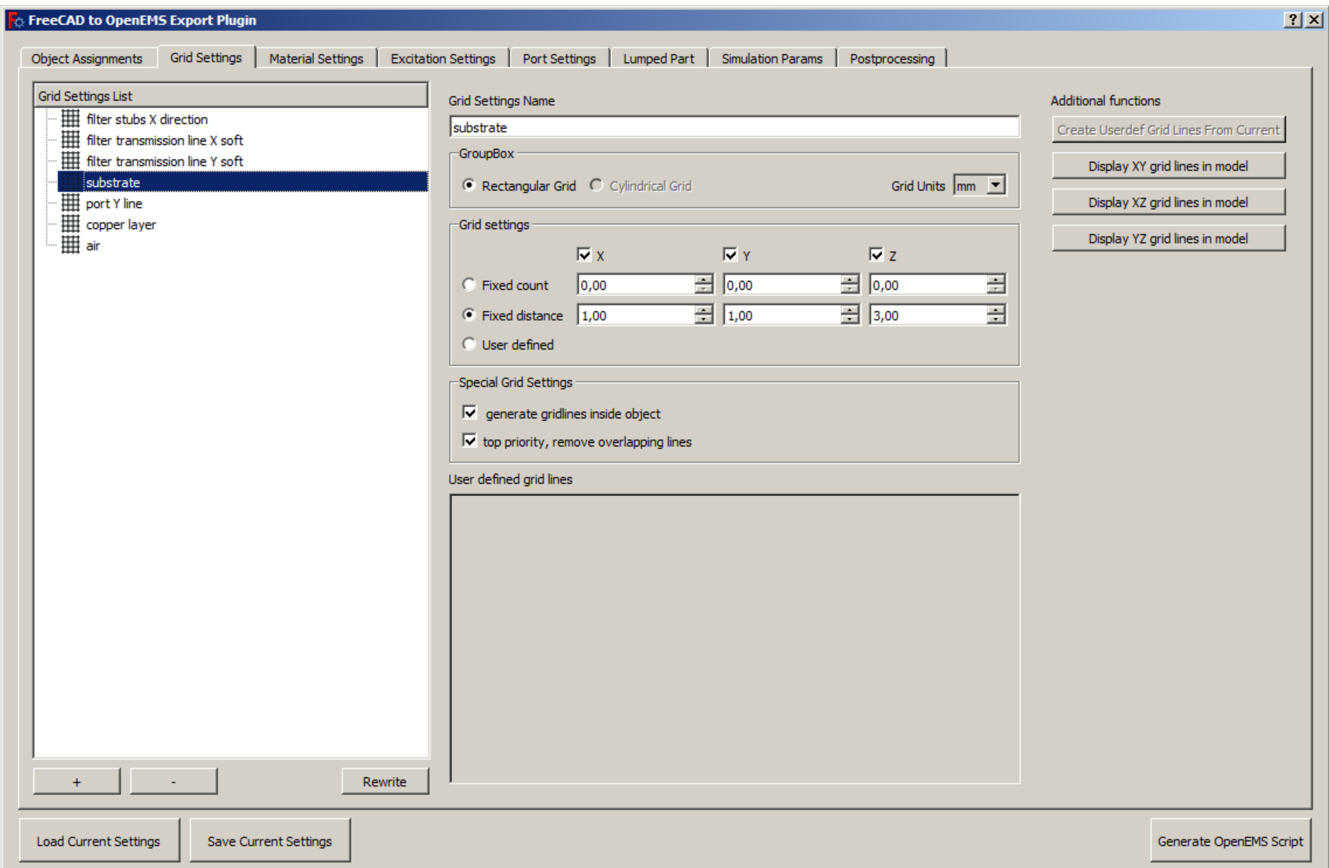
Continue with FR4, it’s relative permitivity is 4.5 and relative permeability is 1.

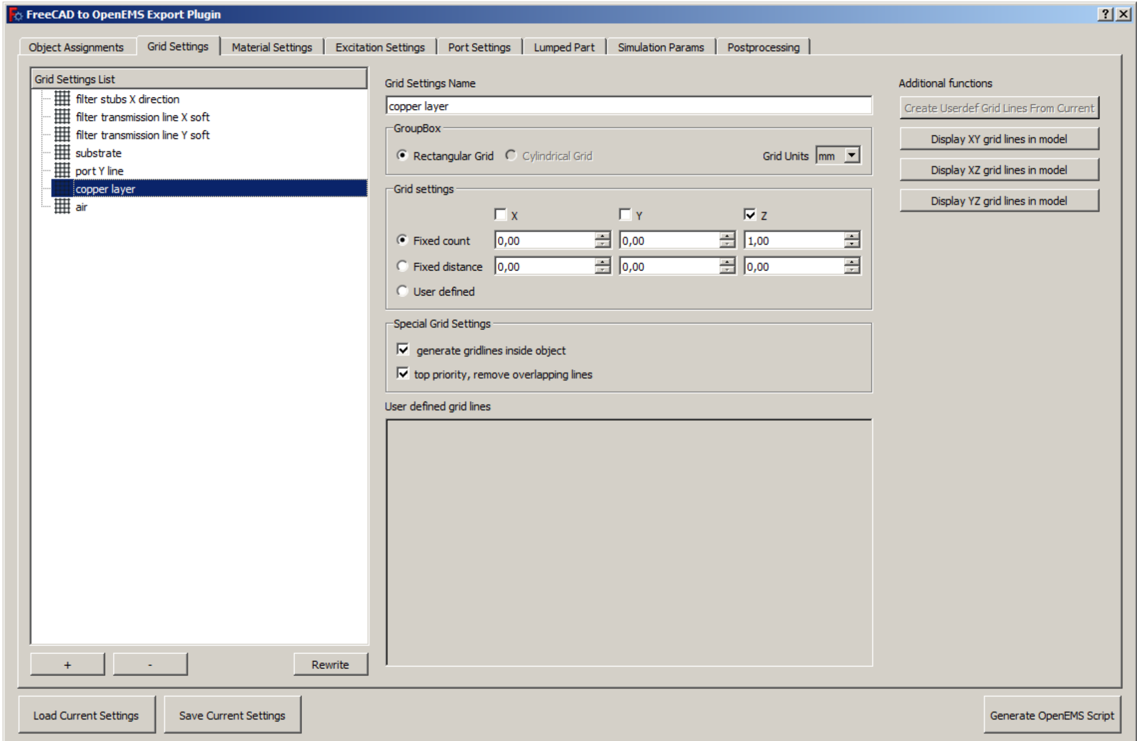


Last thing what we need is to create grid rules to properly mesh our model. First think how we want to mesh our object:

- subtrate doesn't has to be meshed realy soft, we need at least 3 lines in Z ax
- filter copper part compose from transmission line in Y direction and stubs in X direction, these should be meshed soft
- there should be at least one line in Y direction for ports to have some mesh intersection on ports
- we need some coarse mesh around whole structure to have boundaries far away from our structure, this will be coarse mesh for air

Now we define some categories for grid which fulfill all conditions mentioned above. Definition for all these conditions is on pictures below.

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Lumped Part
Simulation Params
Postprocessing
Grid Settings List
filter stubs X direction
filter transmission line X soft
filter transmission line Y soft
substrate
port Y line
copper layer
air
Grid Settings Name
copper layer
GroupBox
Rectangular Grid
Cylindrical Grid
Grid Units
mm
Grid settings
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User defined
Special Grid Settings
generate gridlines inside object
top priority, remove overlapping lines
User defined grid lines
Additional functions
Create Userdef Grid Lines From Current
Display XY grid lines in model
Display XZ grid lines in model
Display YZ grid lines in model
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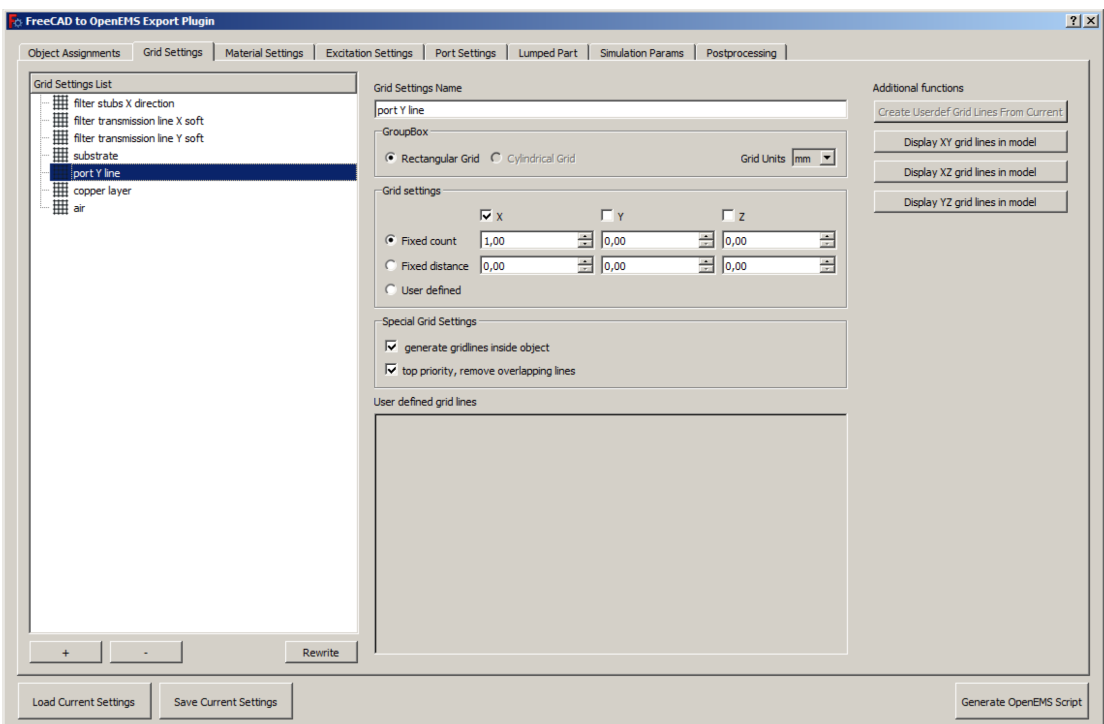
Load Current Settings
Save Current Settings
Generate OpenEMS Script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Grid settings
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Fixed count
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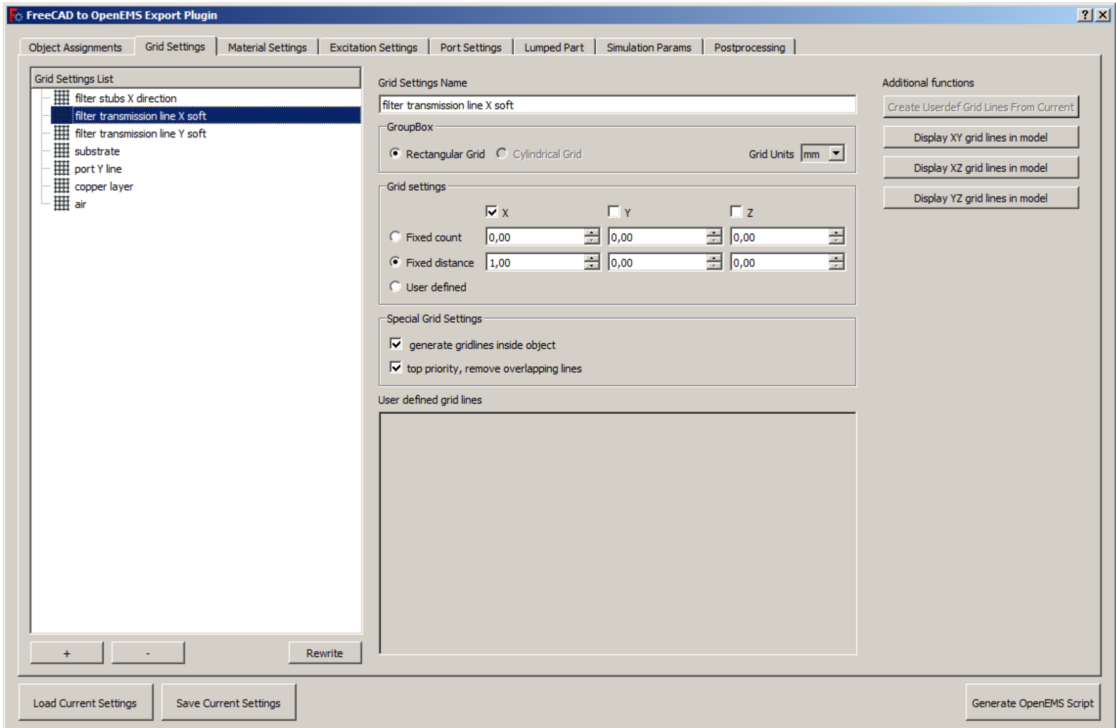
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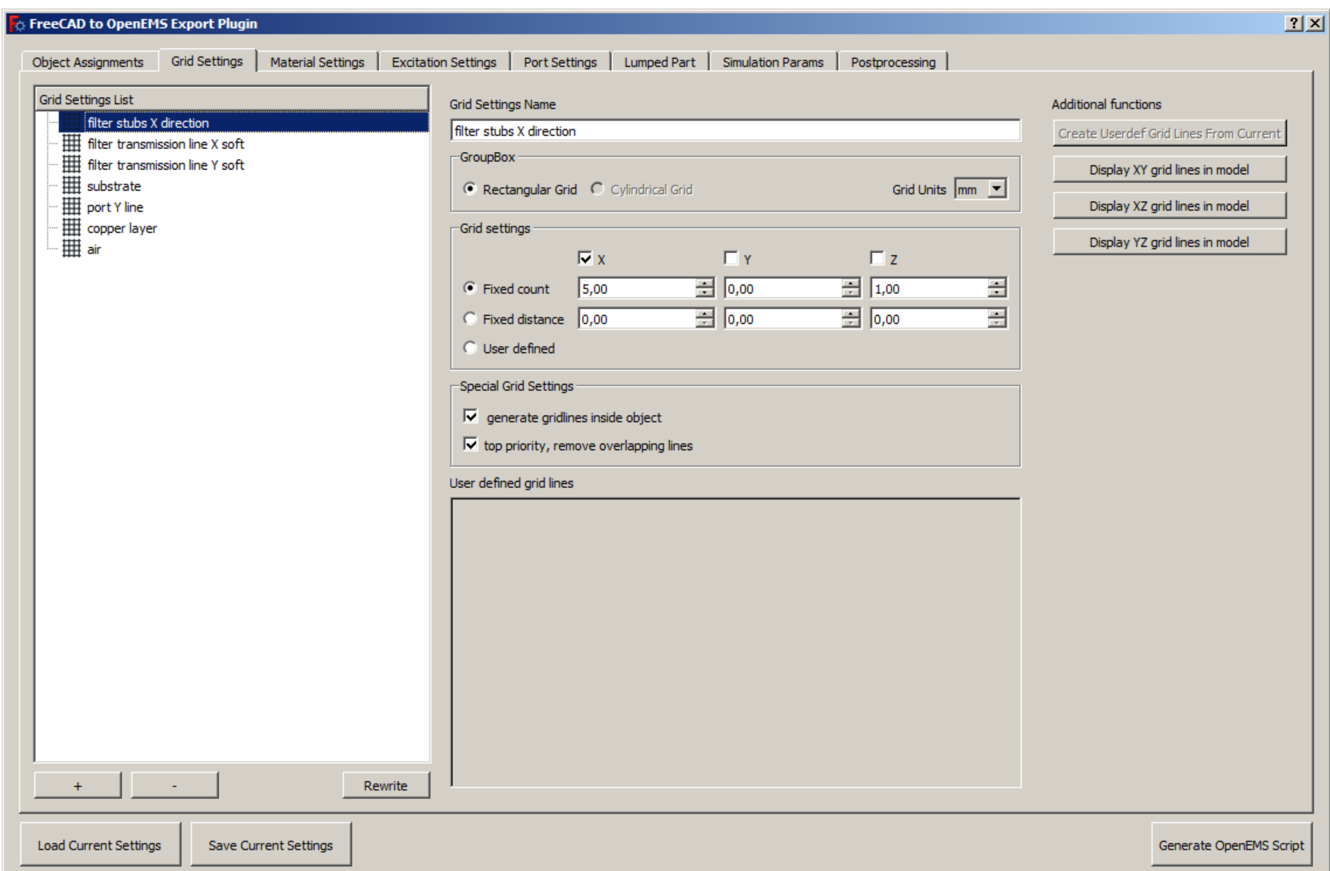
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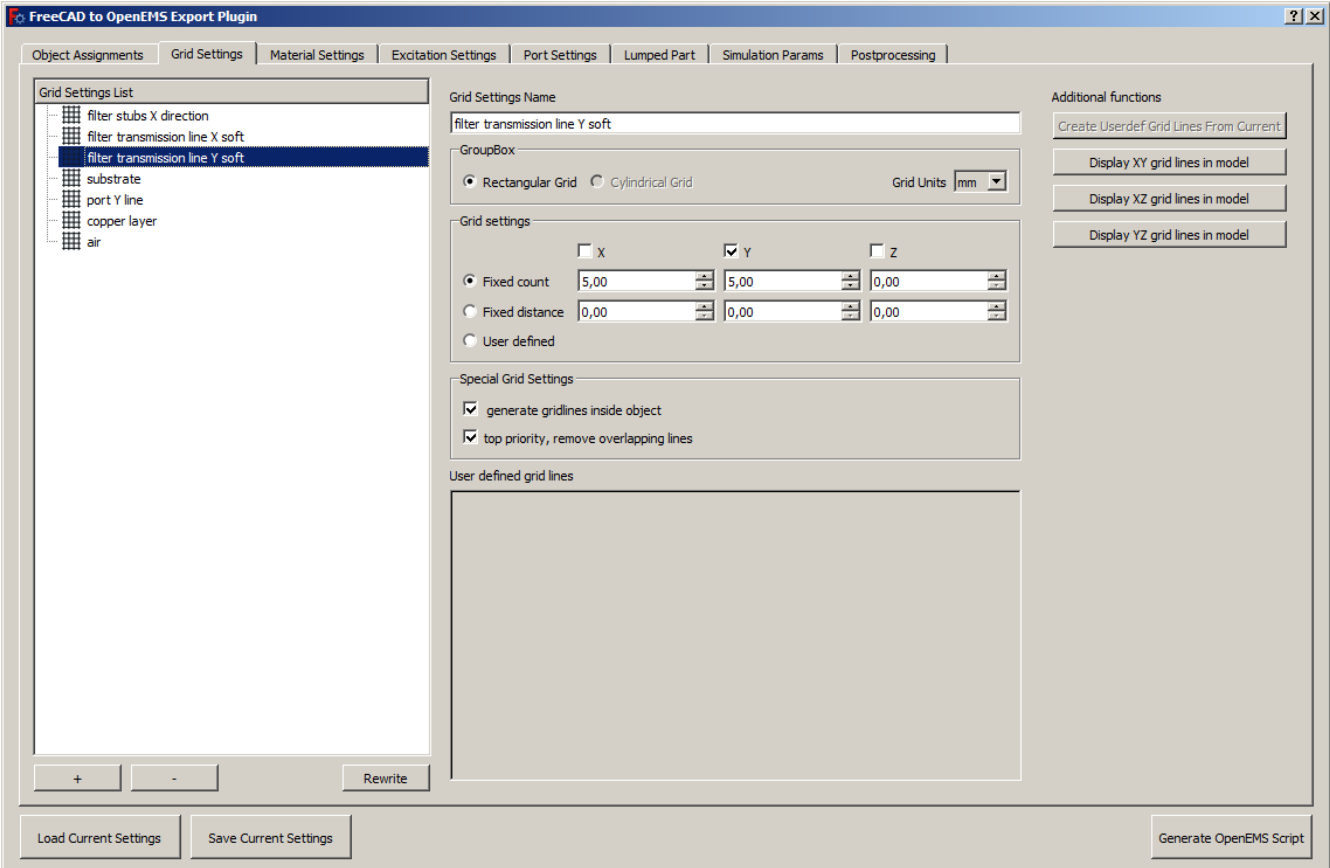

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filter transmission line Y soft
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port Y line
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Grid Settings Name
filter transmission line Y soft
GroupBox
Rectangular Grid
Cylindrical Grid
Grid Units
mm
Grid settings
X
Y
Z
Fixed count
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Fixed distance
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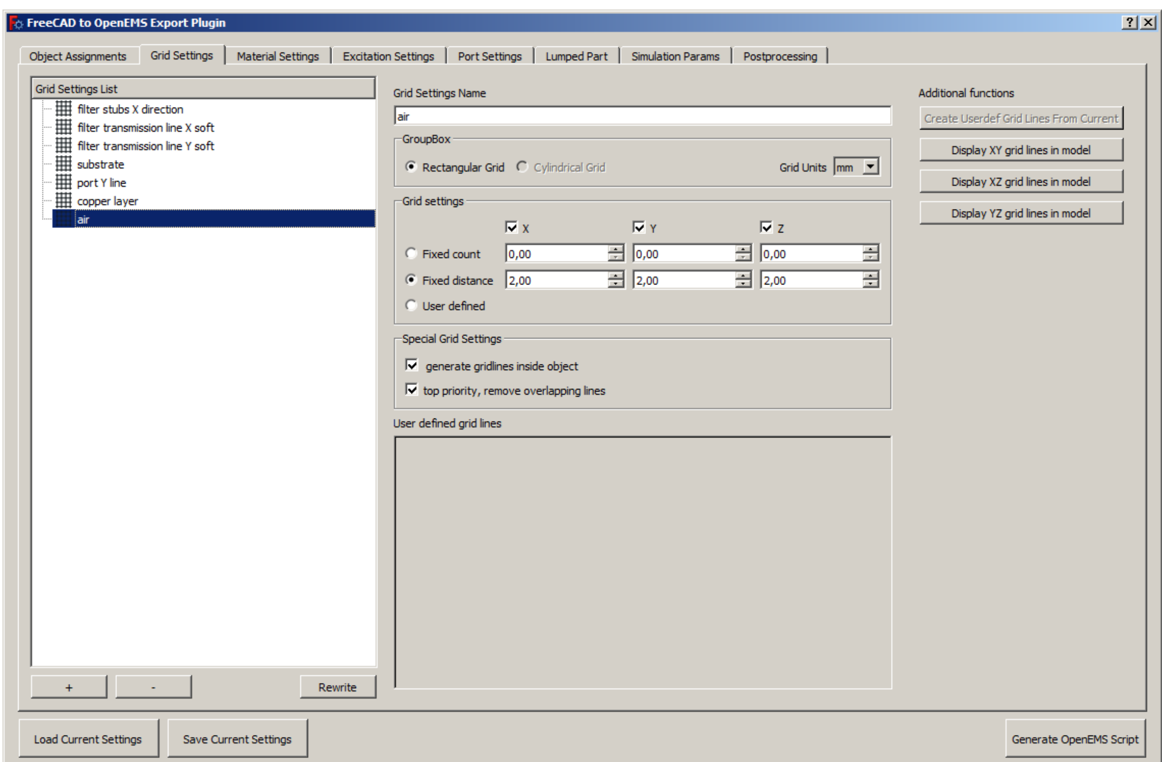
Save Current Settings
Generate OpenEMS Script

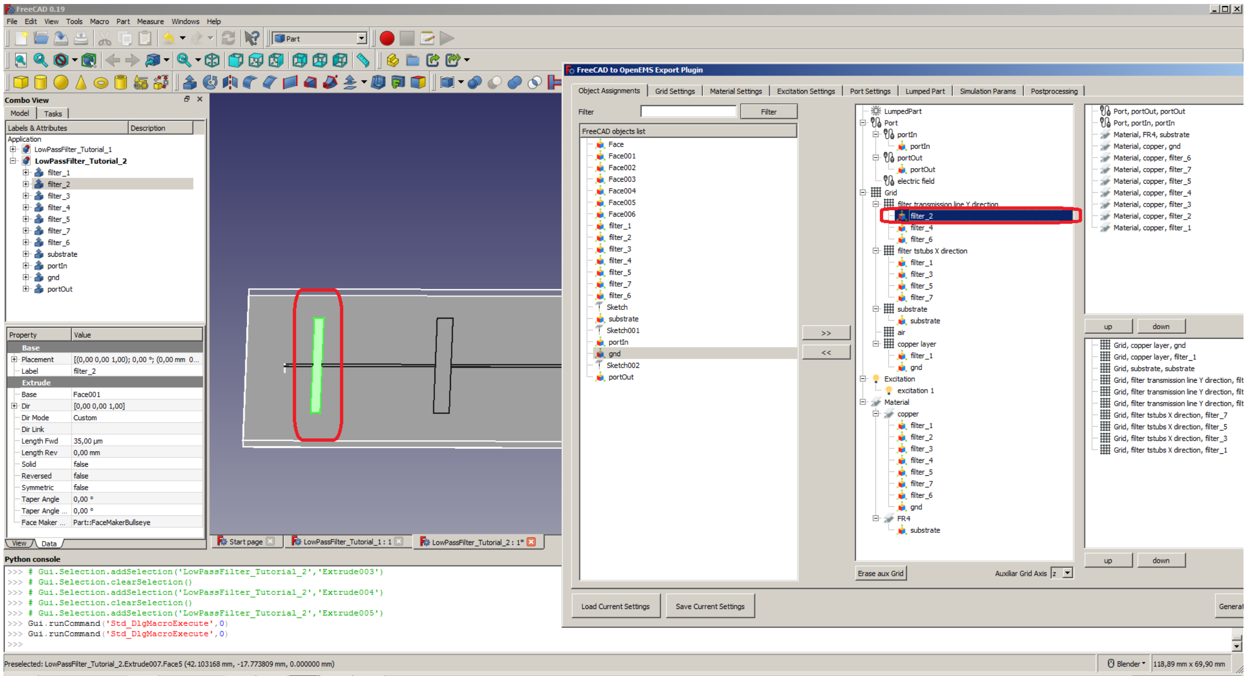


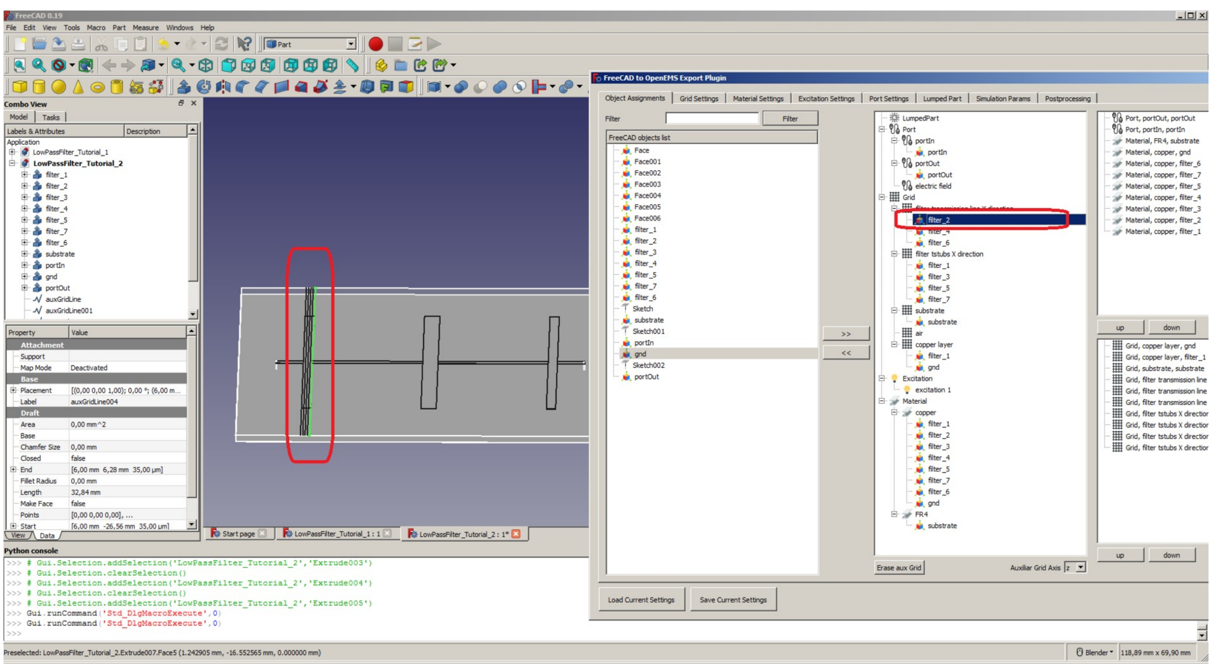
FreeCAD to OpenEMS Export Plugin
Object Assignments
Grid Settings
Material Settings
Excitation Settings
Port Settings
Lumped Part
Simulation Params
Postprocessing
Grid Settings List
filter stubs X direction
filter transmission line X soft
filter transmission line Y soft
substrate
port Y line
copper layer
air
Grid Settings Name
air
GroupBox
Rectangular Grid
Cylindrical Grid
Grid Units
mm
Grid settings
X
Y
Z
Fixed count
0,00
0,00
0,00
Fixed distance
2,00
2,00
2,00
User defined
Special Grid Settings
generate gridlines inside object
top priority, remove overlapping lines
User defined grid lines
Additional functions
Create Userdef Grid Lines From Current
Display XY grid lines in model
Display XZ grid lines in model
Display YZ grid lines in model
+
-
Rewrite
Load Current Settings
Save Current Settings
Generate OpenEMS Script

At this point we defined all needed categories and now assign objects under each category. Change for “Object Assignment” tab and use buttons “>>” and “<<” to move objects from left list to right list. Always click on category, then for object and then for button “>>” to get result as shown below.

When object is assigned in right column and you select it, it will be highlighted in FreeCAD window.

If you double click by mouse on object grid lines appears in FreeCAD window, you can erase them using button in bottom part “Erase Grid”.



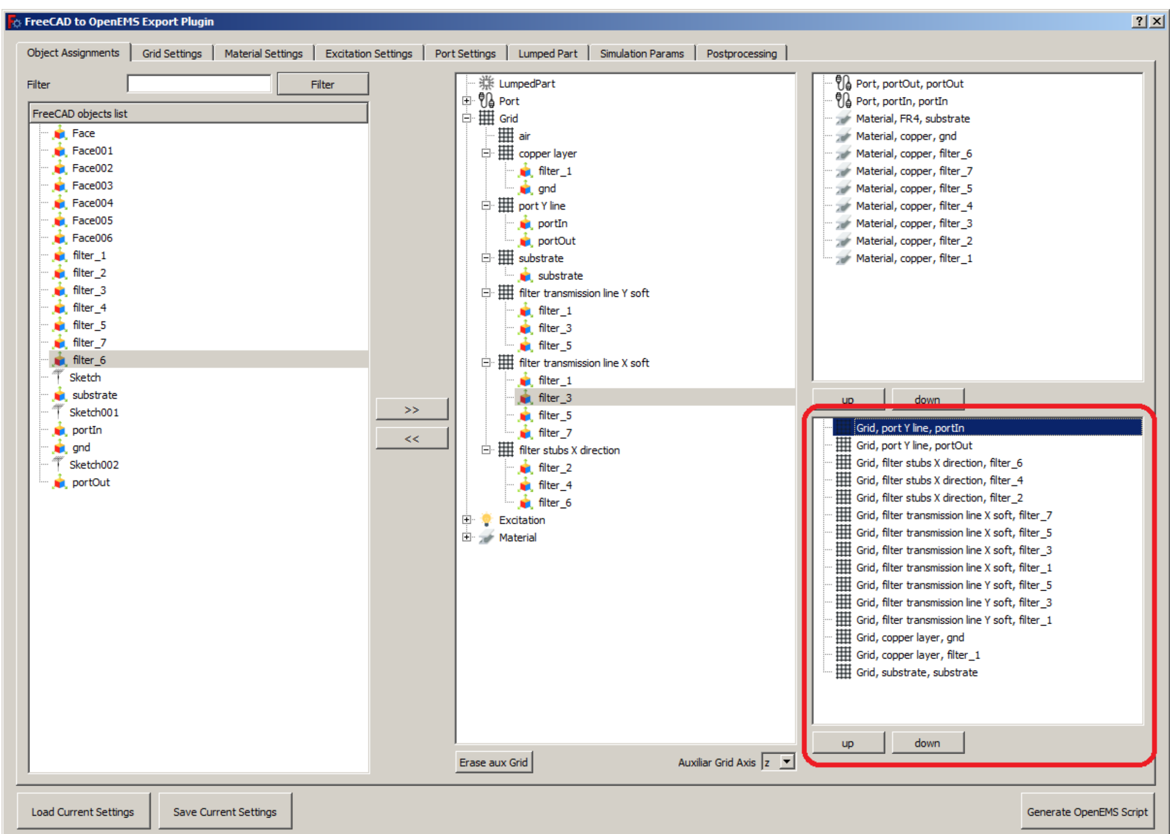


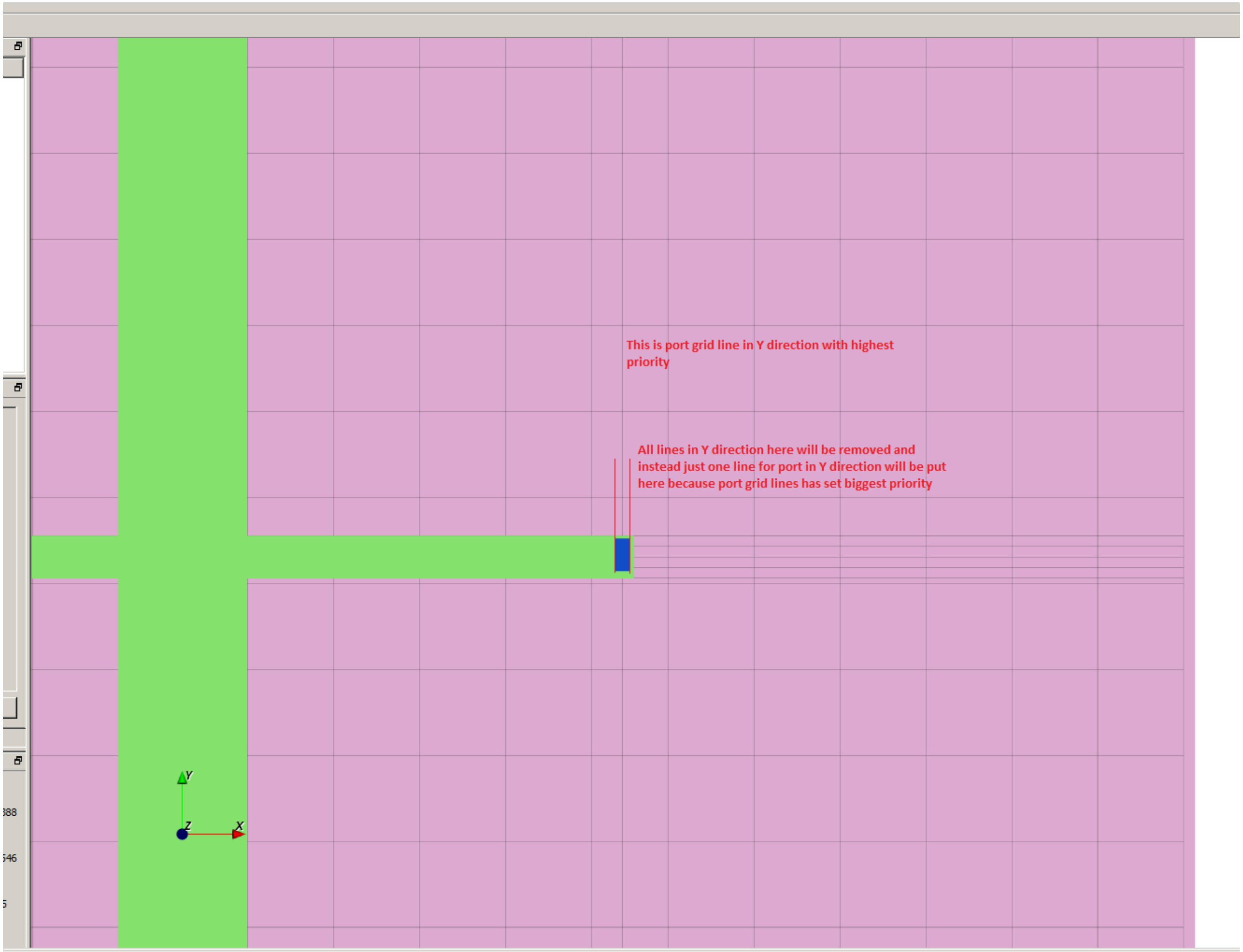
To properly generate grid we have to also choose right grid order in object assignment tab. Because we set top priority lines, overlap existing lines, it means that grid objects which are at top they removed lines which are defined in it space, so let's say there is set mesh for substrate which is defined in x, y, z so there are grid lines with uniform spacing. If some line is in space let's say at ax y in space of transmission line which is going from left to right this line would be removed and there would be placed lines for transmission line, because transmission line has higher priority.

In octave script this is generated like followed:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% MESH PRIORITY - filter transmission line X soft - filter_1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
mesh.x(mesh.x >= 0.003333333333333333 & mesh.x <= 4.495006666666668) = [];    %this remove grid line in space of transmission line
mesh.x = [mesh.x (0.003333333333333333:1.0:4.495006666666668) + 0];
CSX = DefineRectGrid(CSX, 0.001, mesh);
```

So grid priorities should be setup as on image below. For example the most priority have port grid lines in Y direction, that means that in every case if there would be already defined lines from substrate or from transmission lines in Y direction which can cause that lines will be too close to each other they will be removed and instead there would be just one grid line generated in Y direction which intersect port and other in port width will be removed.

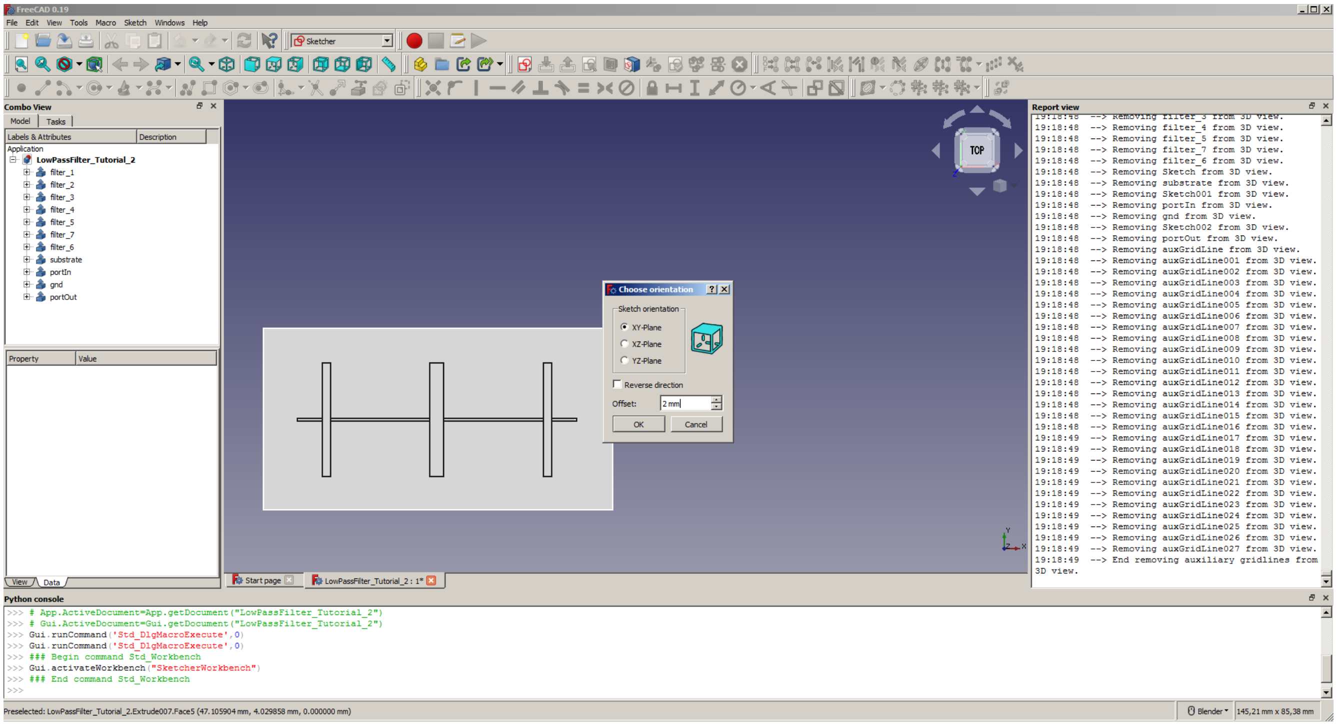


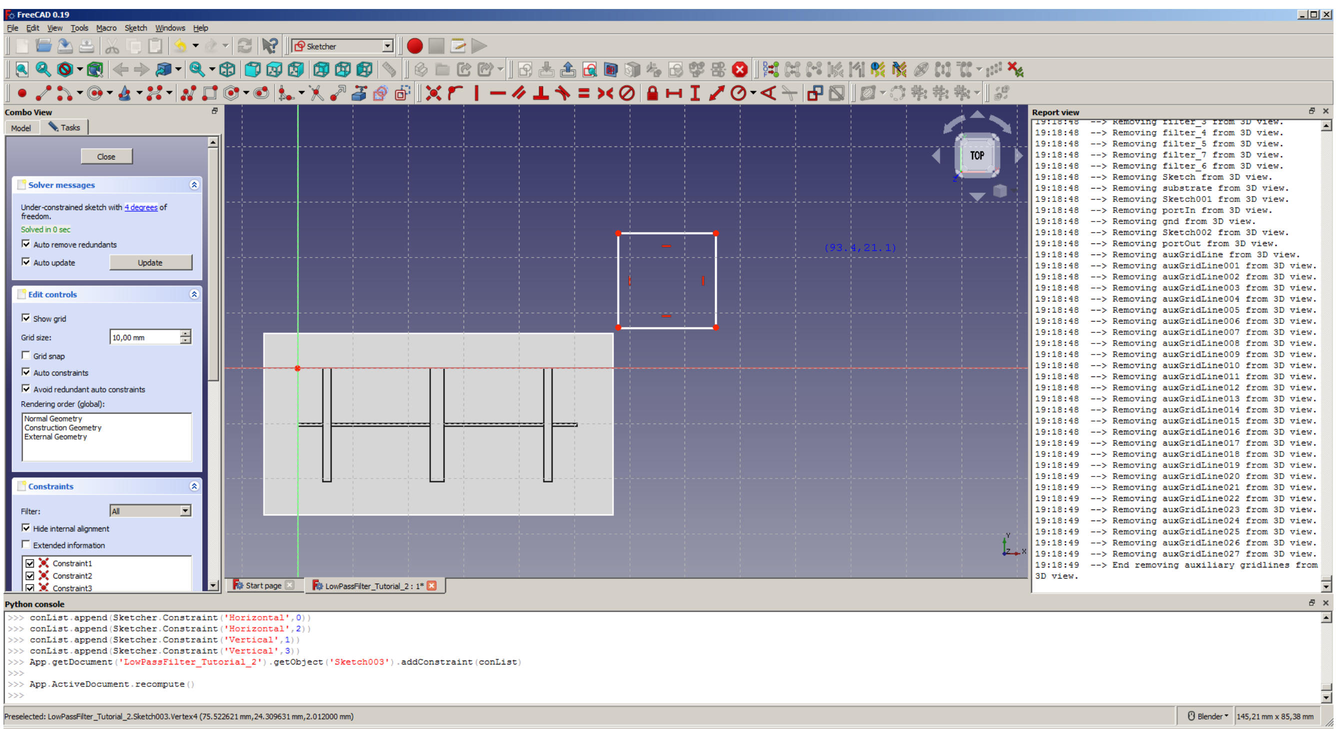


Now we set mesh for our filter structure, we set grid for substrate, copper layers and filter itself in XY plane. To create right simulation we have to also create filter surrounding, that means to add some air and define boundaries for our simulation.

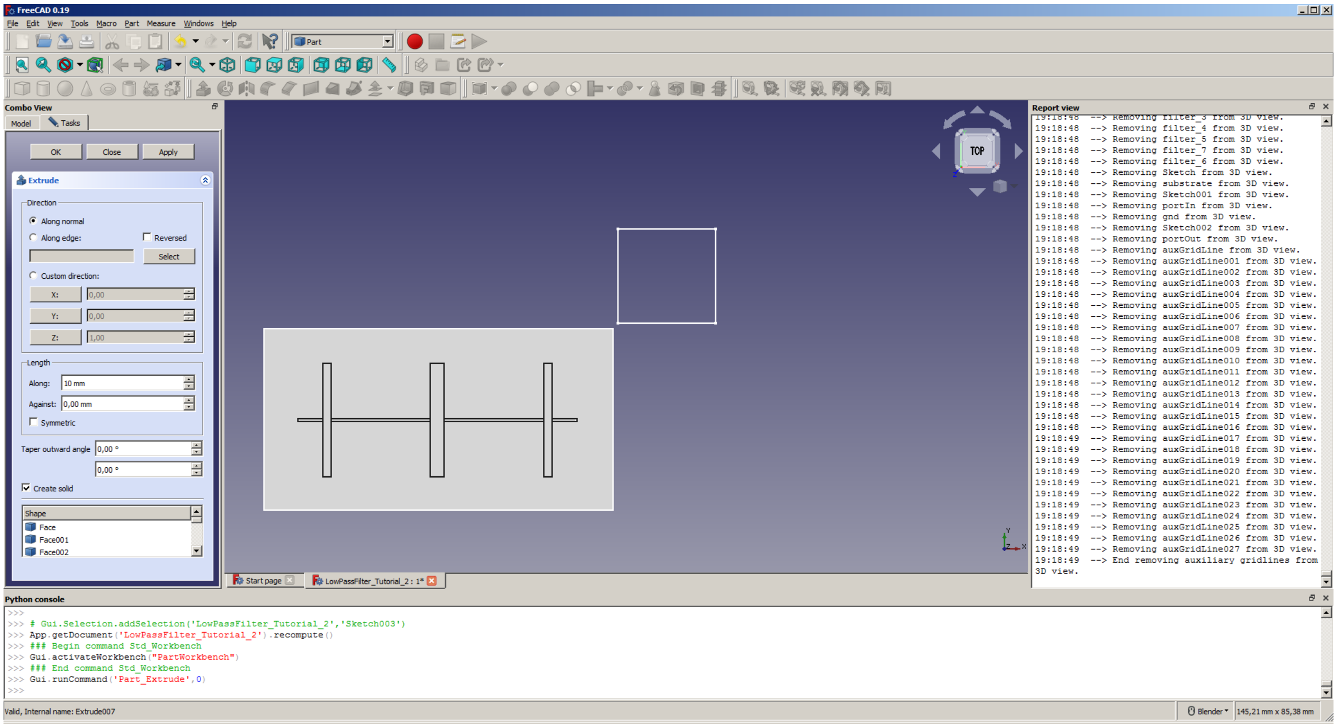
Let's continue by adding some air around our filter. As was shown how gridlines are set in plugin air wouldn't be added as continous box around whole filter, but instead we need to add air which has relative permitivity 1 and relative permeability 1 around structure. For this we add two boxes to topmost right corner and bottom left corner around filter as will be shown on pictures below.

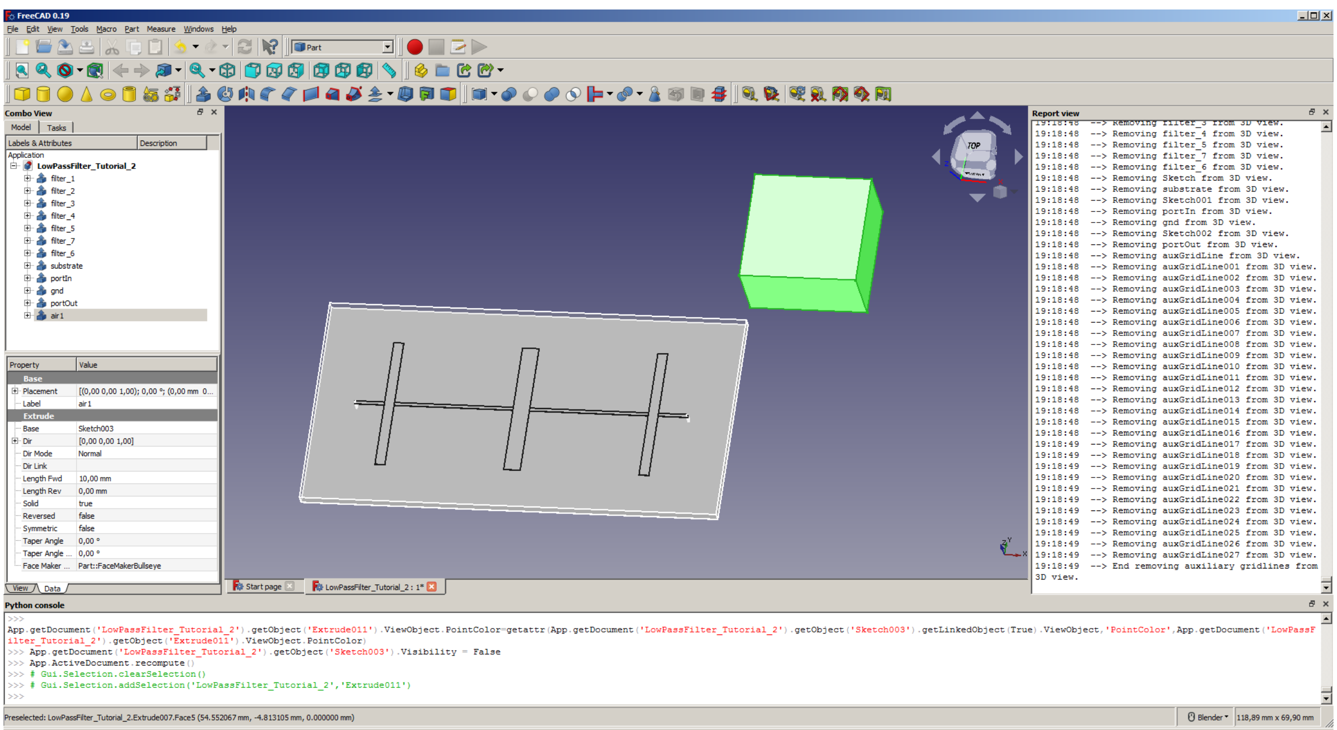
First we add right top box which should be above filter structure, so we create sketch in XY plane 2mm above base.



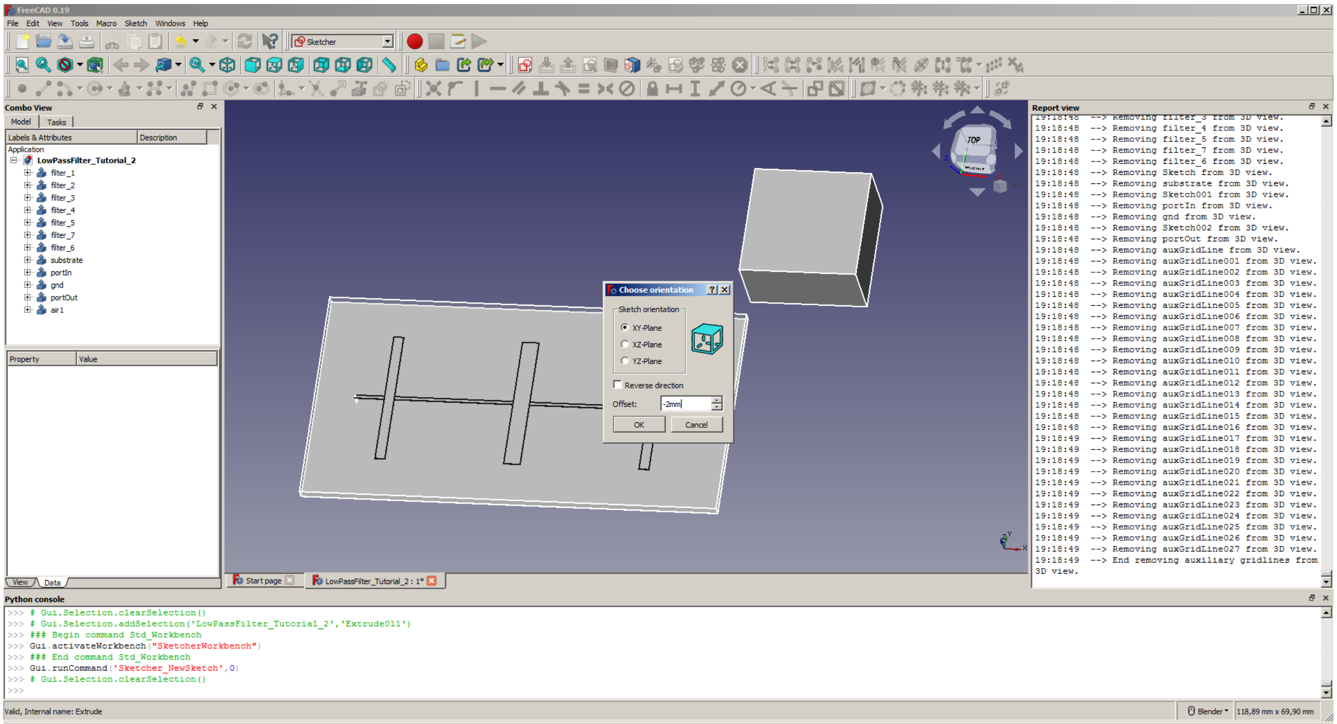


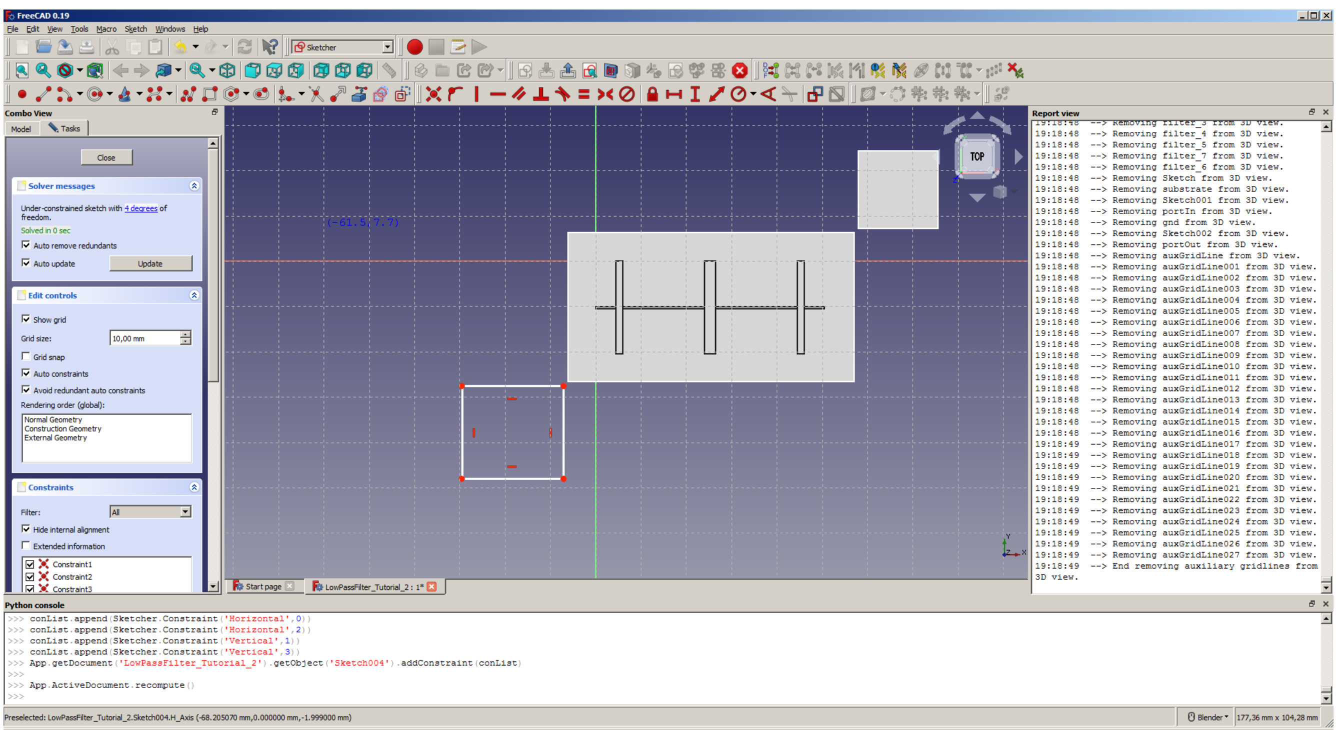
Then extrude air box for 10mm in normal direction as shown below and rename it as air1.

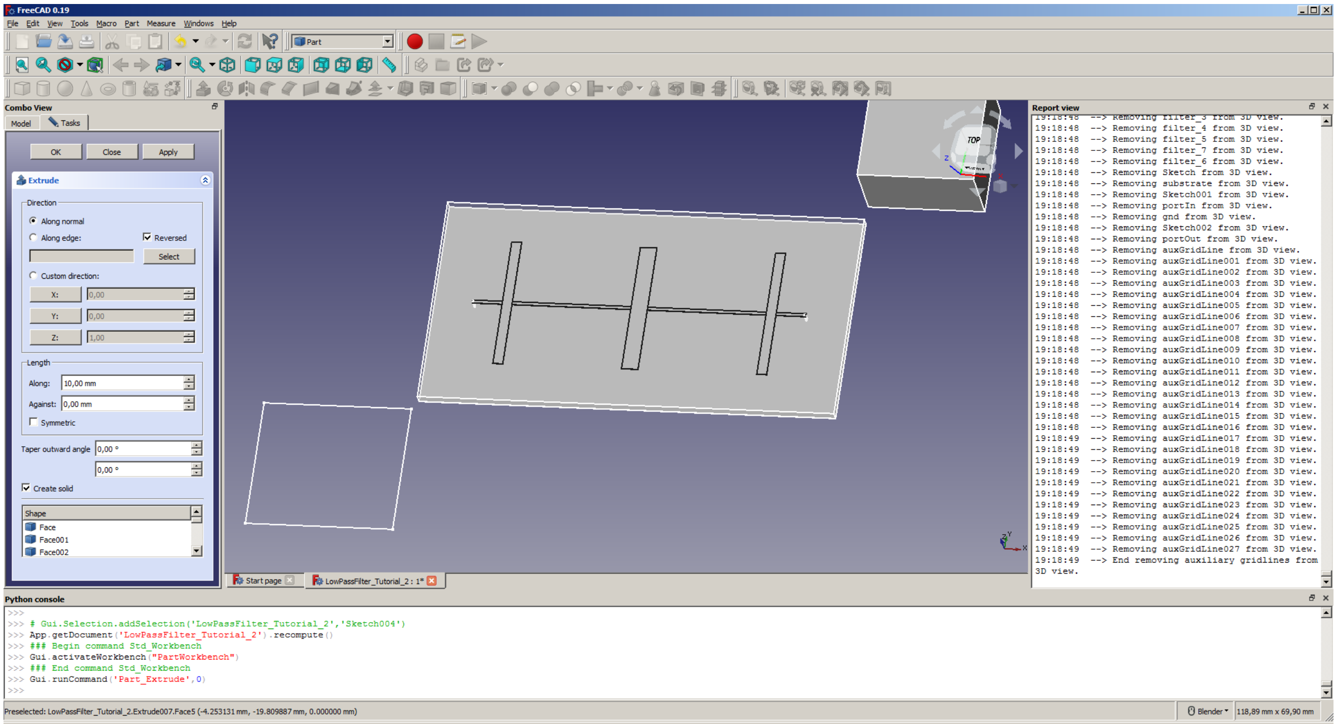


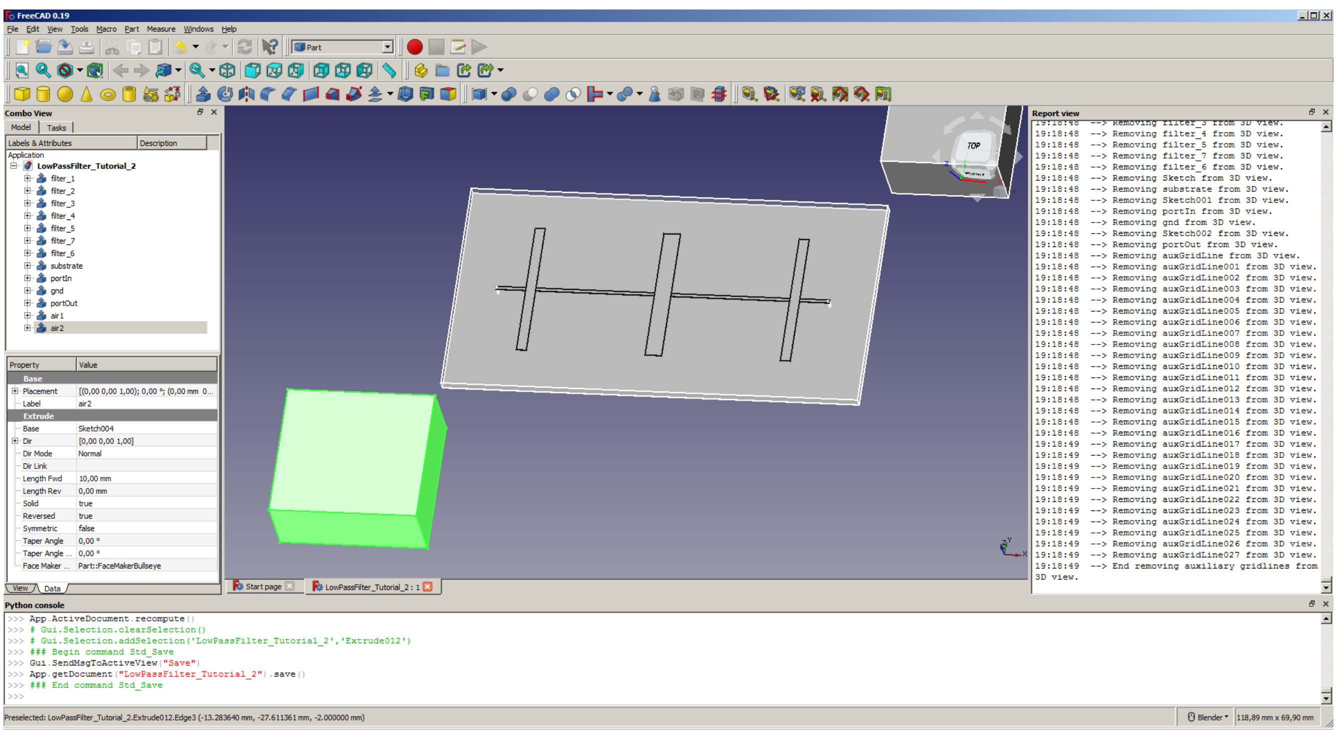


Repeat same steps for bottom left air box. This time sketch will be -2mm relative to base.

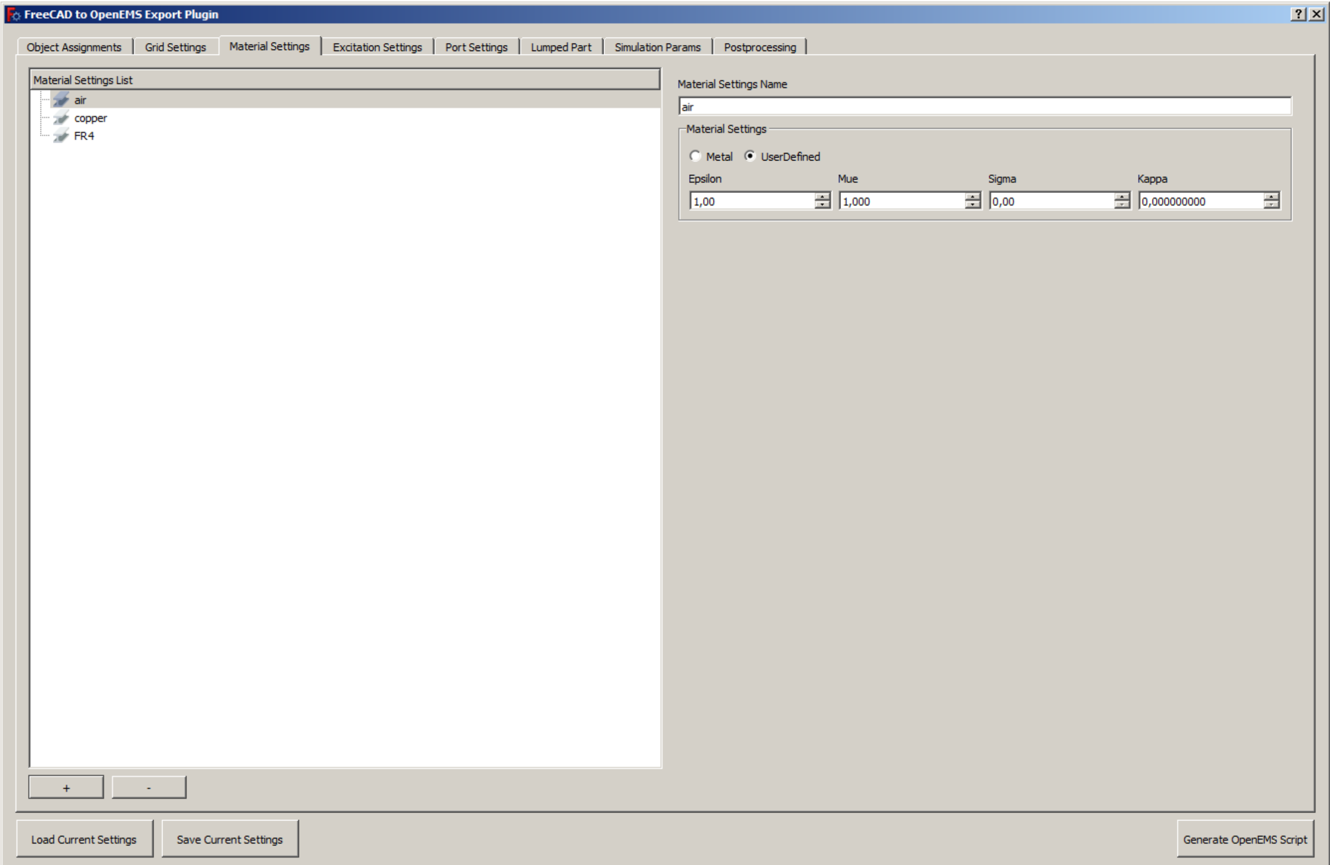




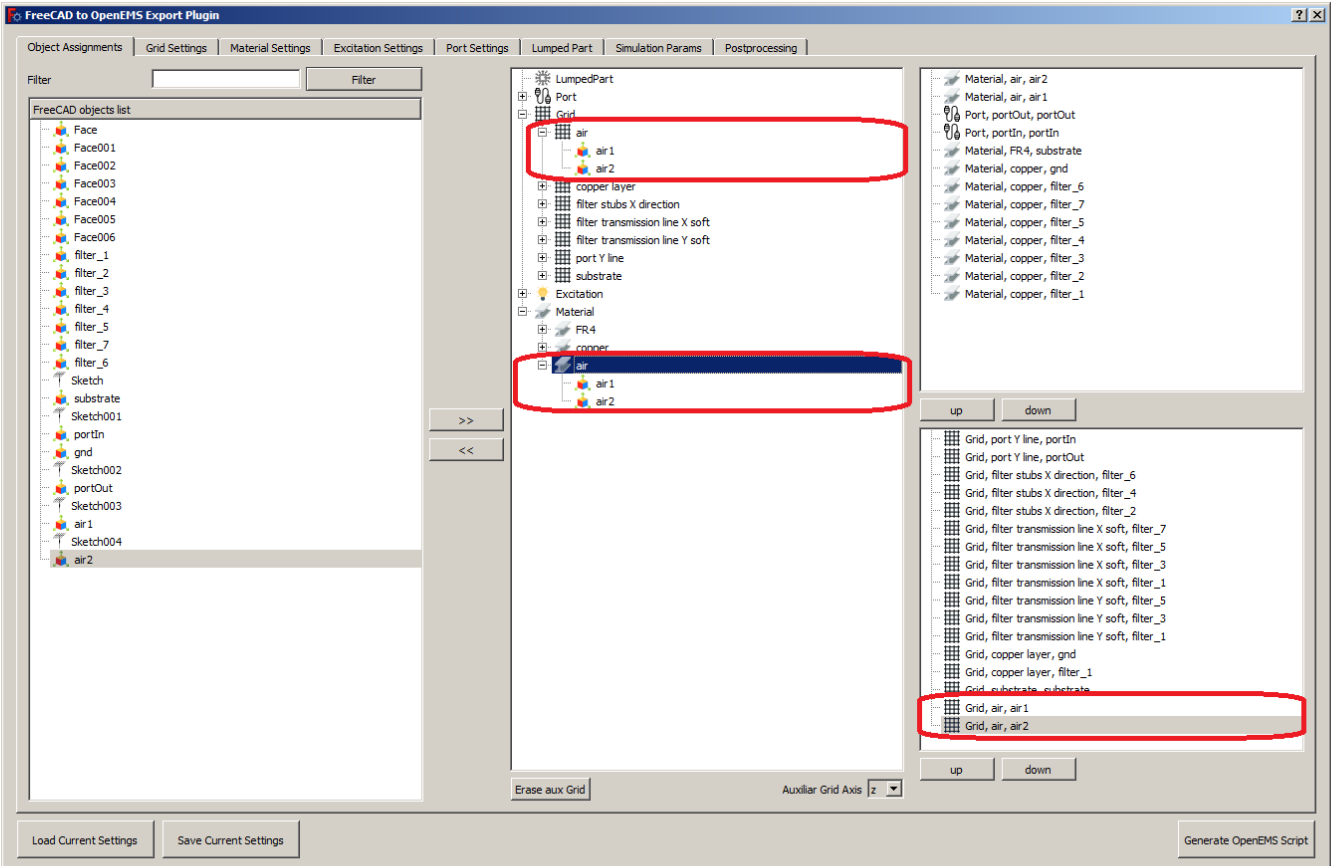




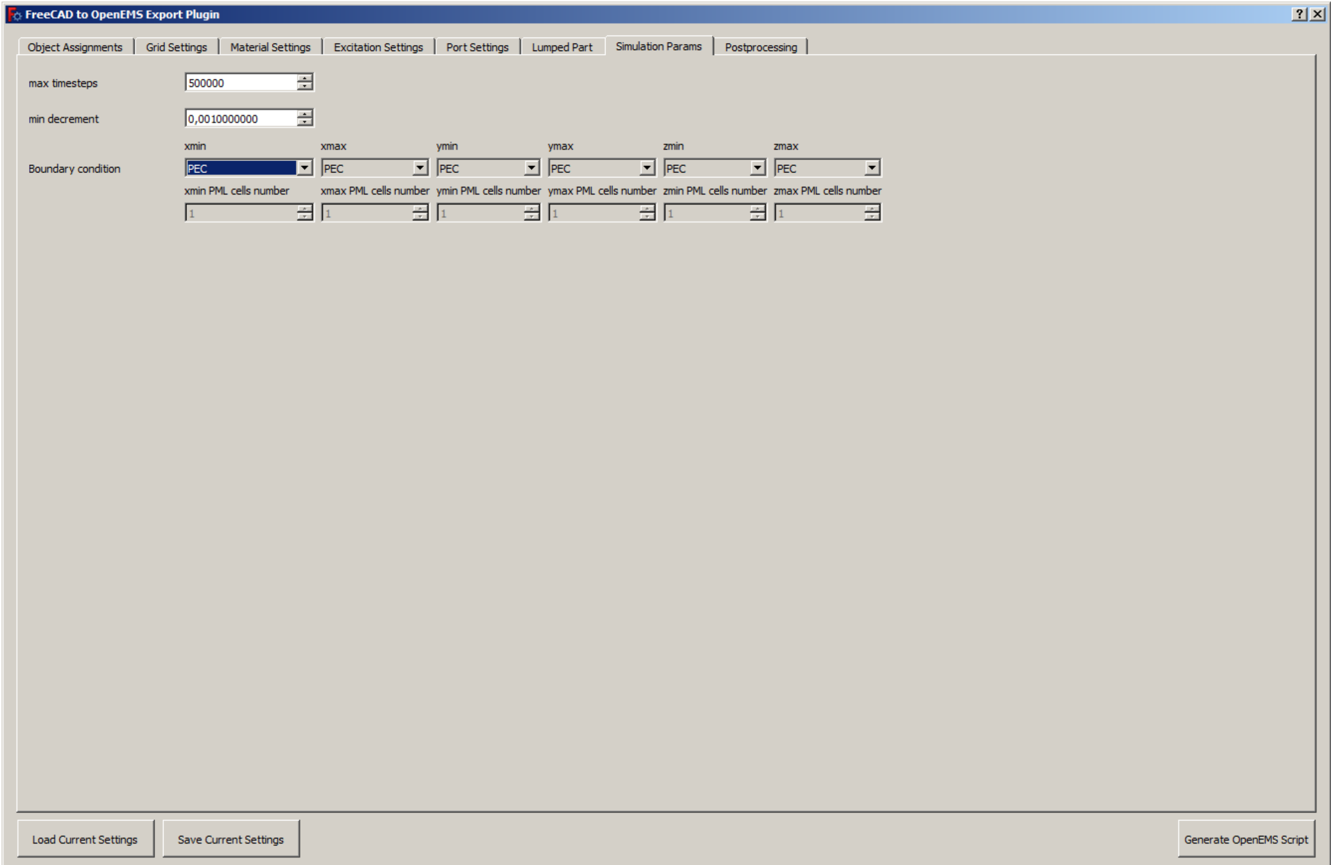
Now add air as material with relative permeability 1 and realtive permitivity 1 as shown below.



Assign air structures under grid settings for air, to air material and also move grid in grid priority to the bottom to have lowerst priority. Because boxes are in corner and their lines are not overlapping nothing this settings for priority has no effect but just to be sure make it.

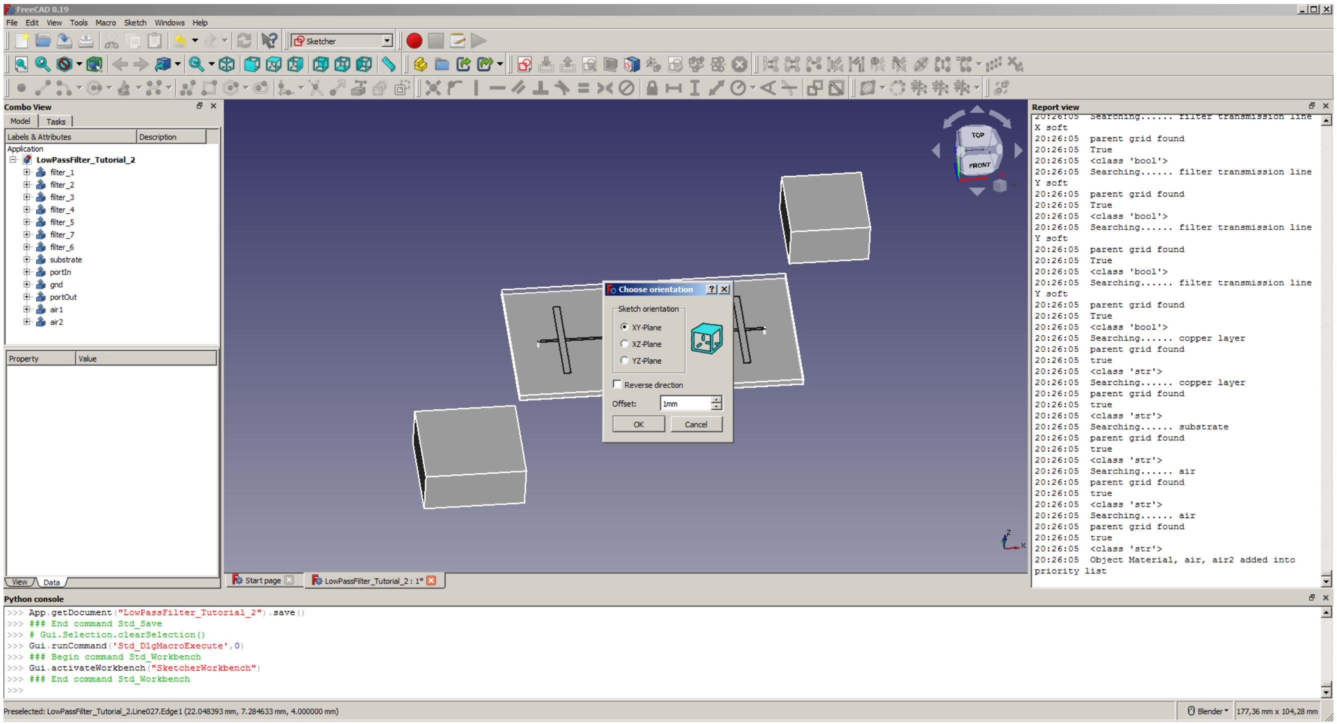


Now let's set simulation params. Set them as shown below, max timestamps to 500 000 what means that simulation make this amount of steps maximum even if it will not reach critera 0,001 what means -30dB for energy in simulation, there is gaussian impulse at input and during simulation this energy is disipated in structure and is decreasing, if there is higher decrease of energy than -30dB since beginning of simulation simulation is stopped, otherwise it will be stopped after reaching 500 000 time steps. Also boundaries are set to be PEC around whole simulation box, it's box around whole structure, that's also reason why we put air structures there how we put them to create boundaries far enough from base structure to not intervene with structure.

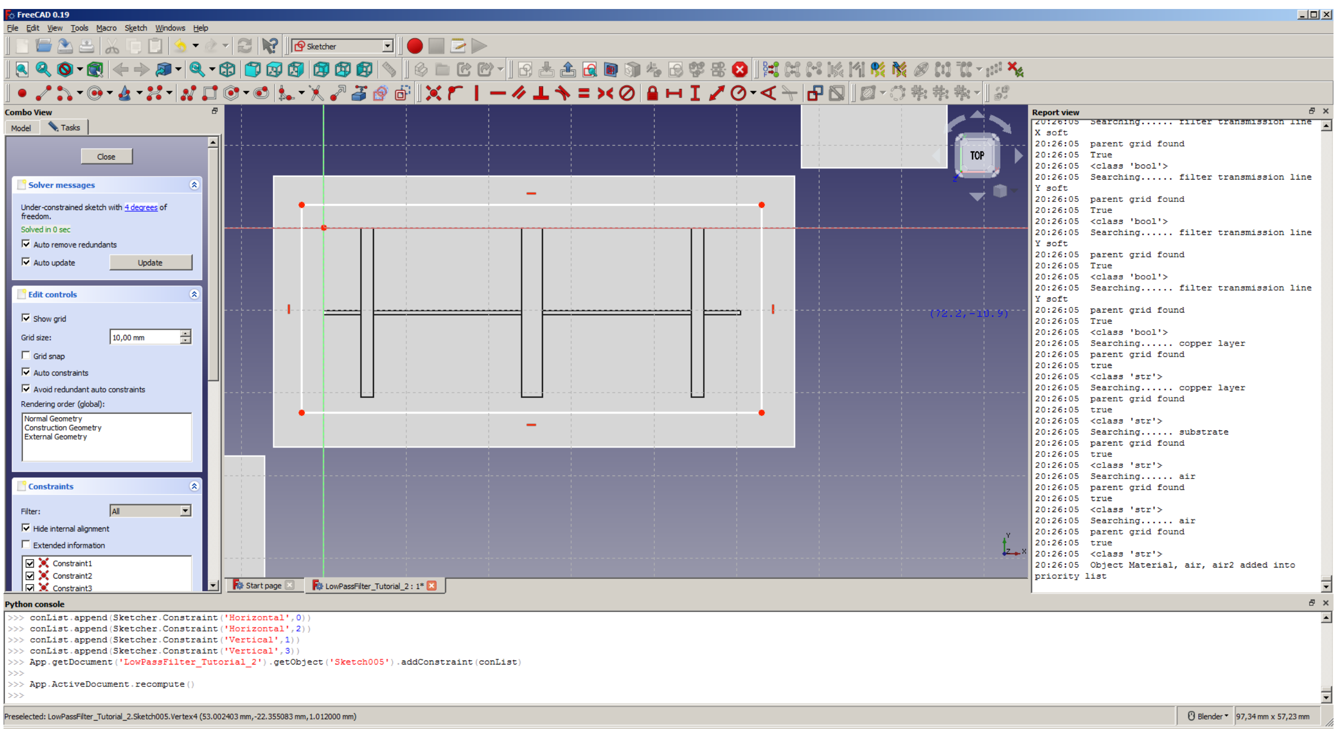


Go for postprocessing tab and hit button “Write Draw S21 Script” which generate octave script to display S21 and S11 param for simulation results. Uncheck option “Generate just simulation preview” to create script which also perform simulation and try to solve it.

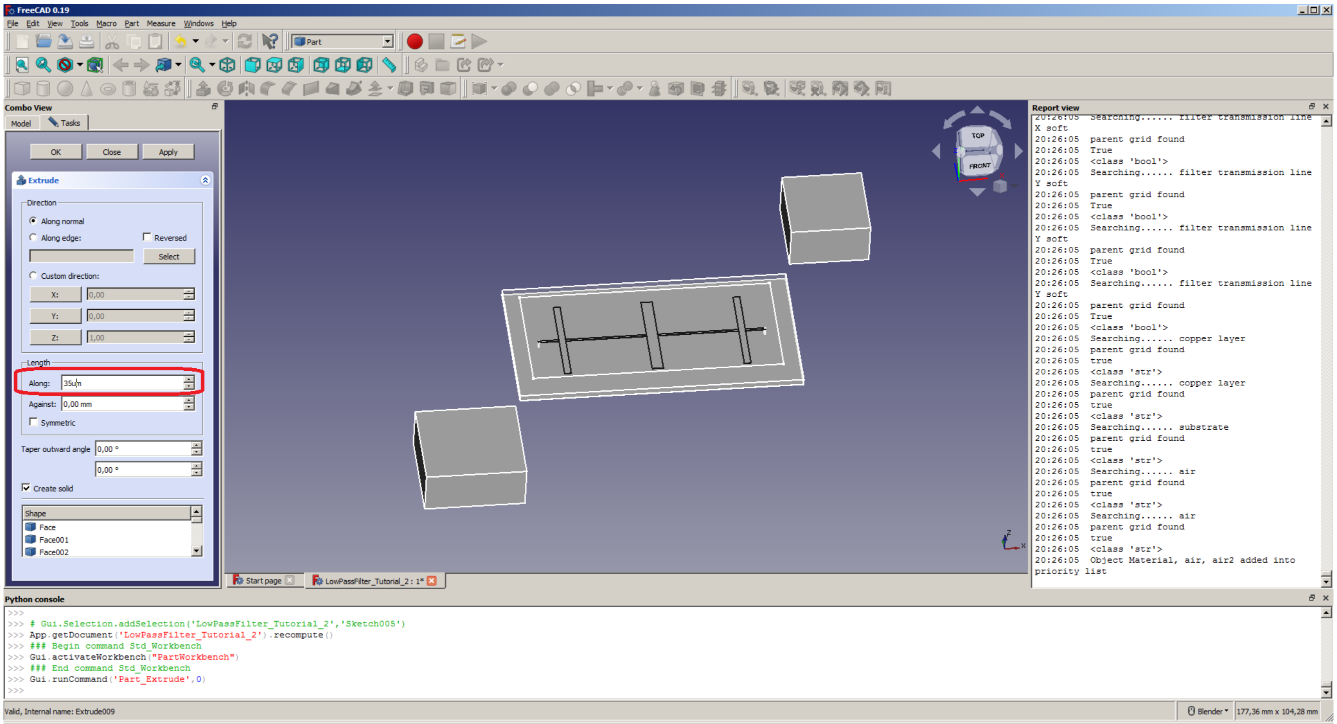
Last additional thing we are missing but is optional to shown nice animation how energy is floating in our structure is to add por plane for electric field. Let’s suppose we are sensing electric field in our simulation in plane above 1mm of our structure. So create sketch above 1mm of our filter and extrude it, there will be just one layer of gridlines in middle so gird settings for it will be same as for copper.



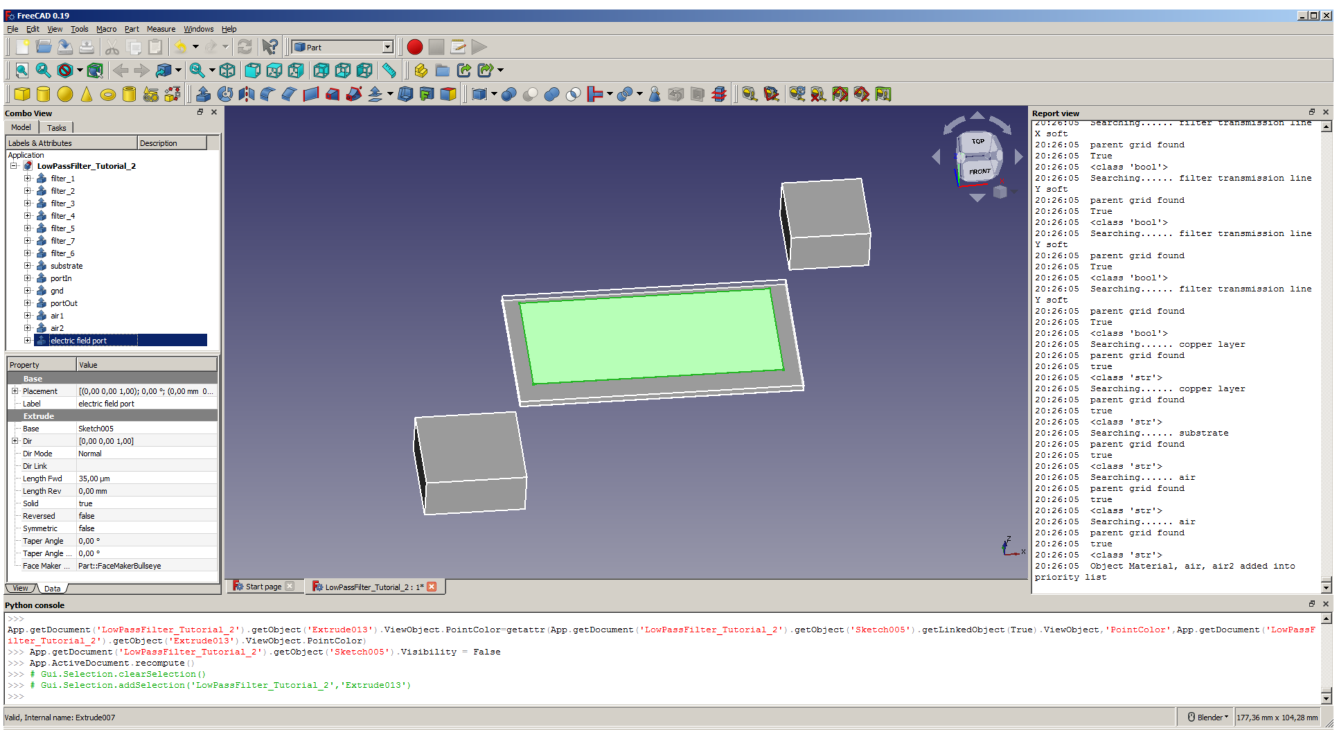
FreeCAD 0.19
File Edit View Tools Macro Sketch Windows Help
Sketcher
Combo View
Model
Tasks
Labels & Attributes
Description
Application
LowPassFilter_Tutorial_2
filter_1
filter_2
filter_3
filter_4
filter_5
filter_7
filter_6
substrate
portIn
gnd
portOut
air1
air2
Property
Value
View
Data
Choose orientation
Sketch orientation
XY-Plane
XZ-Plane
YZ-Plane
Reverse direction
Offset:
1mm
OK
Cancel
Start page
LowPassFilter_Tutorial_2 : 1*
Report view
Python console
>>> App.getDocument("LowPassFilter_Tutorial_2").save()
>>> ### End command Std_Save
>>> # Gui.Selection.clearSelection()
>>> Gui.runCommand('Std_DlgMacroExecute',0)
>>> ### Begin command Std_Workbench
>>> Gui.activateWorkbench("SketcherWorkbench")
>>> ### End command Std_Workbench
Preselected: LowPassFilter_Tutorial_2.Line027.Edge1 (22.048393 mm, 7.284633 mm, 4.000000 mm)
Blender
177,36 mm x 104,28 mm



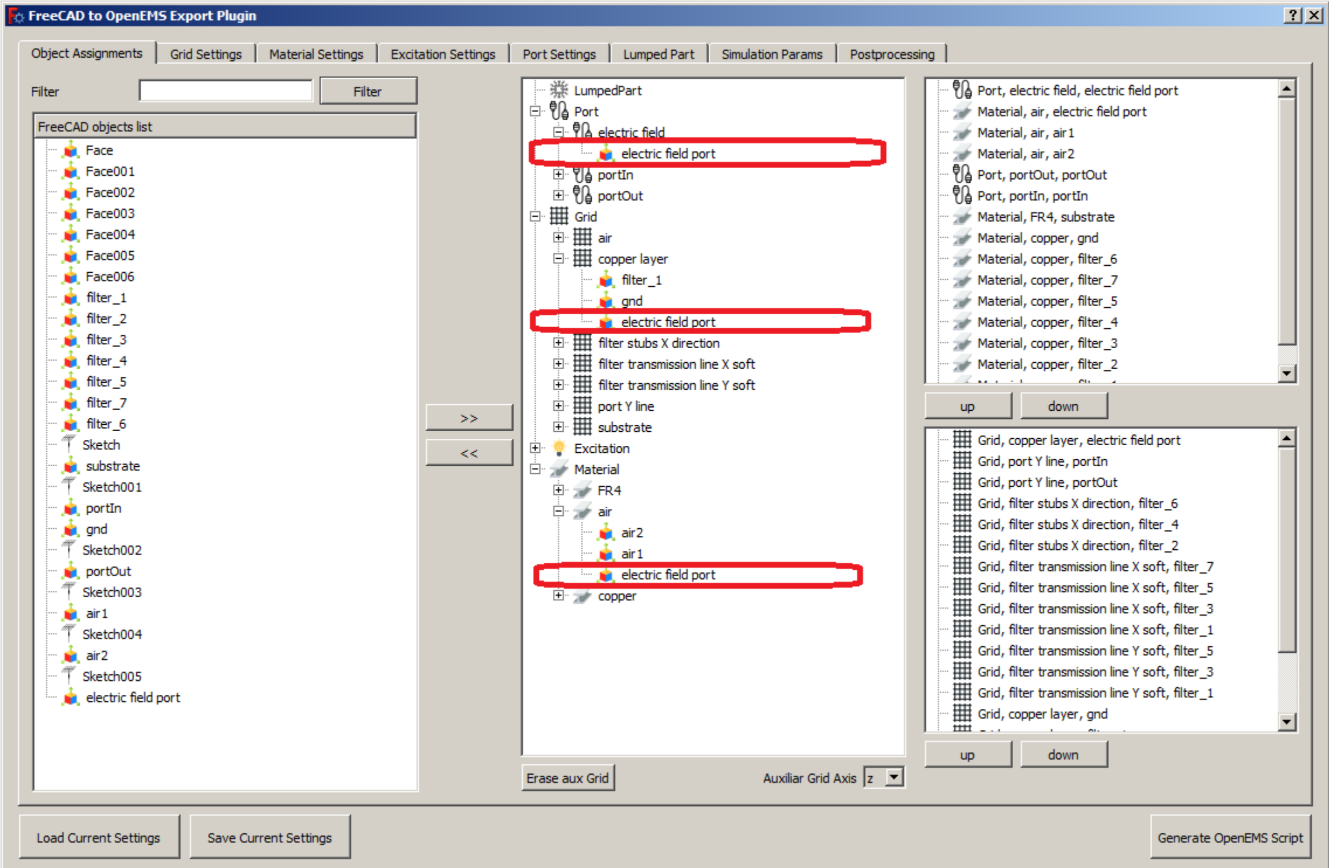
FreeCAD 0.19
File Edit View Tools Macro Sketch Windows Help
Sketcher
Combo View
Model
Tasks
Close
Solver messages
Under-constrained sketch with 4 degrees of freedom.
Solved in 0 sec
Auto remove redundants
Auto update
Update
Edit controls
Show grid
Grid size:
10,00 mm
Grid snap
Auto constraints
Avoid redundant auto constraints
Rendering order (global):
Normal Geometry
Construction Geometry
External Geometry
Constraints
Filter:
All
Hide internal alignment
Extended information
Constraint1
Constraint2
Constraint3
TOP
Start page
LowPassFilter_Tutorial_2 : 1*
Report view
Python console
>>> conList.append(Sketcher.Constraint('Horizontal',0))
>>> conList.append(Sketcher.Constraint('Horizontal',2))
>>> conList.append(Sketcher.Constraint('Vertical',1))
>>> conList.append(Sketcher.Constraint('Vertical',3))
>>> App.getDocument('LowPassFilter_Tutorial_2').getObject('Sketch005').addConstraint(conList)
>>> App.ActiveDocument.recompute()
Preselected: LowPassFilter_Tutorial_2.Sketch005.Vertex4 (53.002403 mm,-22.355083 mm,1.012000 mm)
Blender
97,34 mm x 57,23 mm

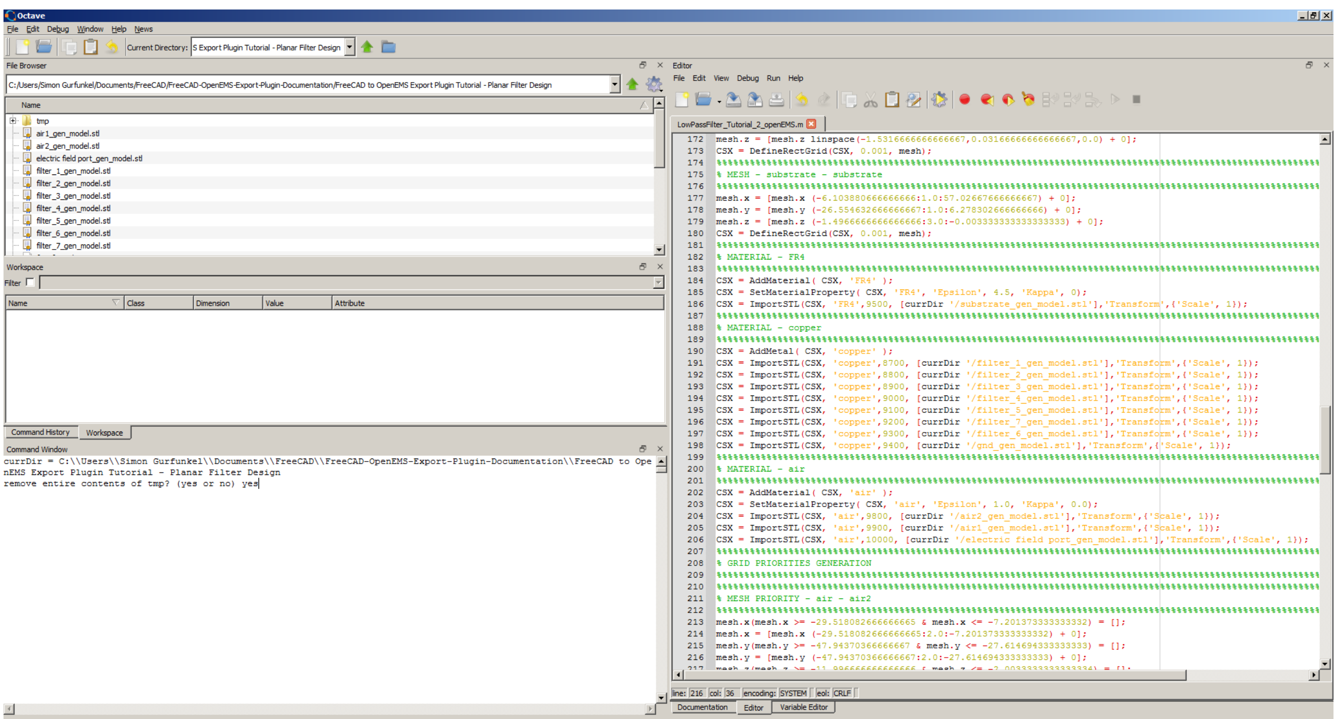


FreeCAD 0.19
Combo View
Extrude
Length
Along: 35um
Report view
Python console

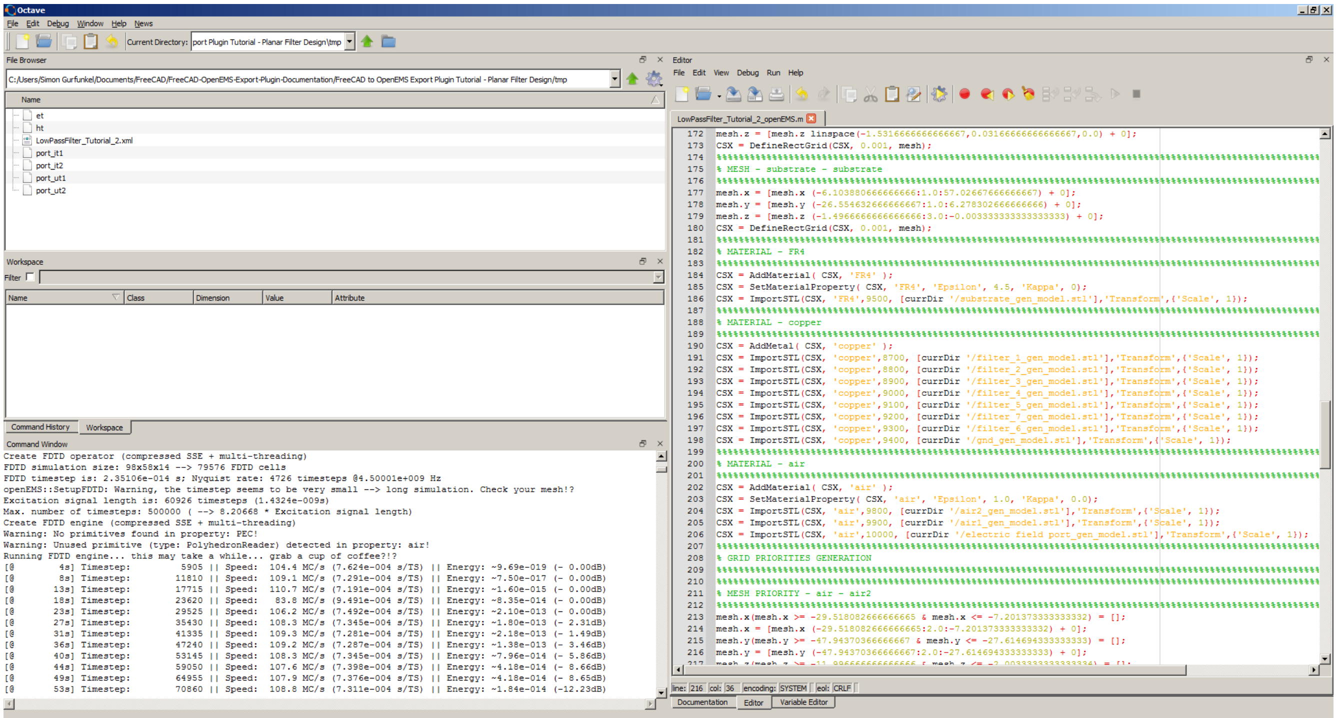


FreeCAD 0.19
Combo View
LowPassFilter_Tutorial_2
electric field port
Report view
Python console

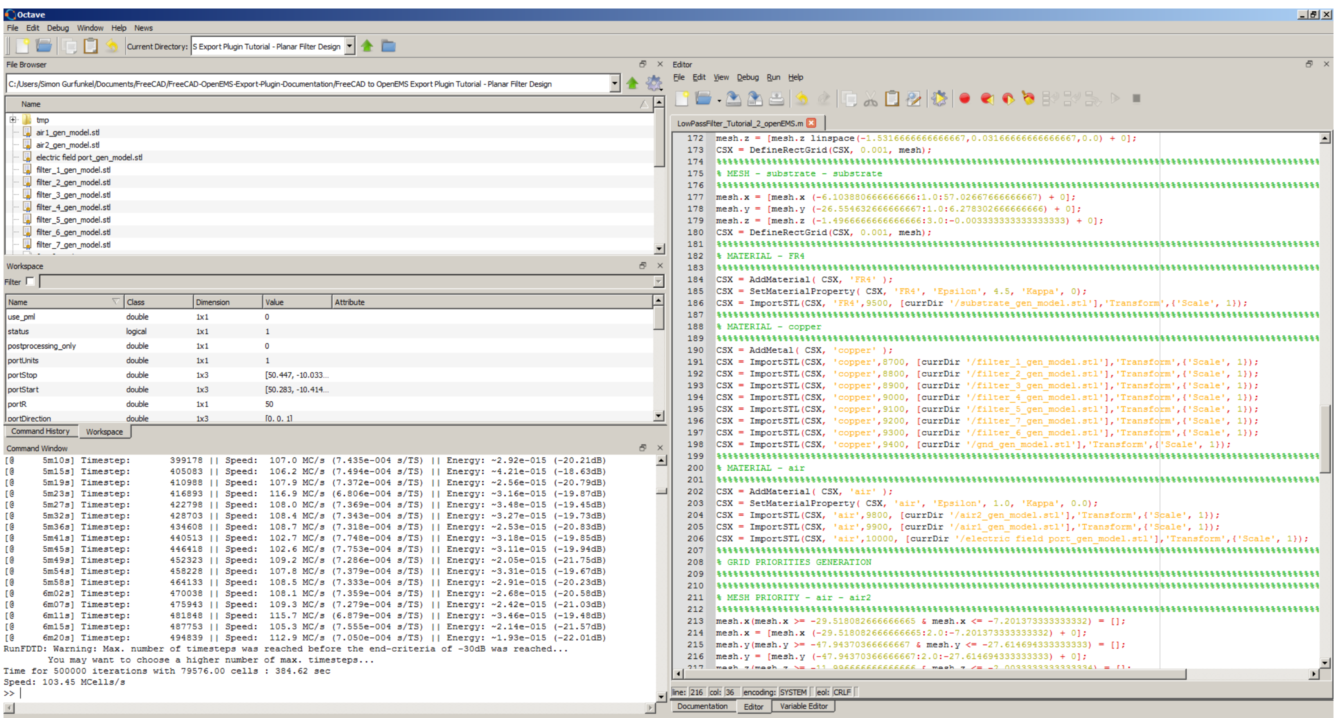




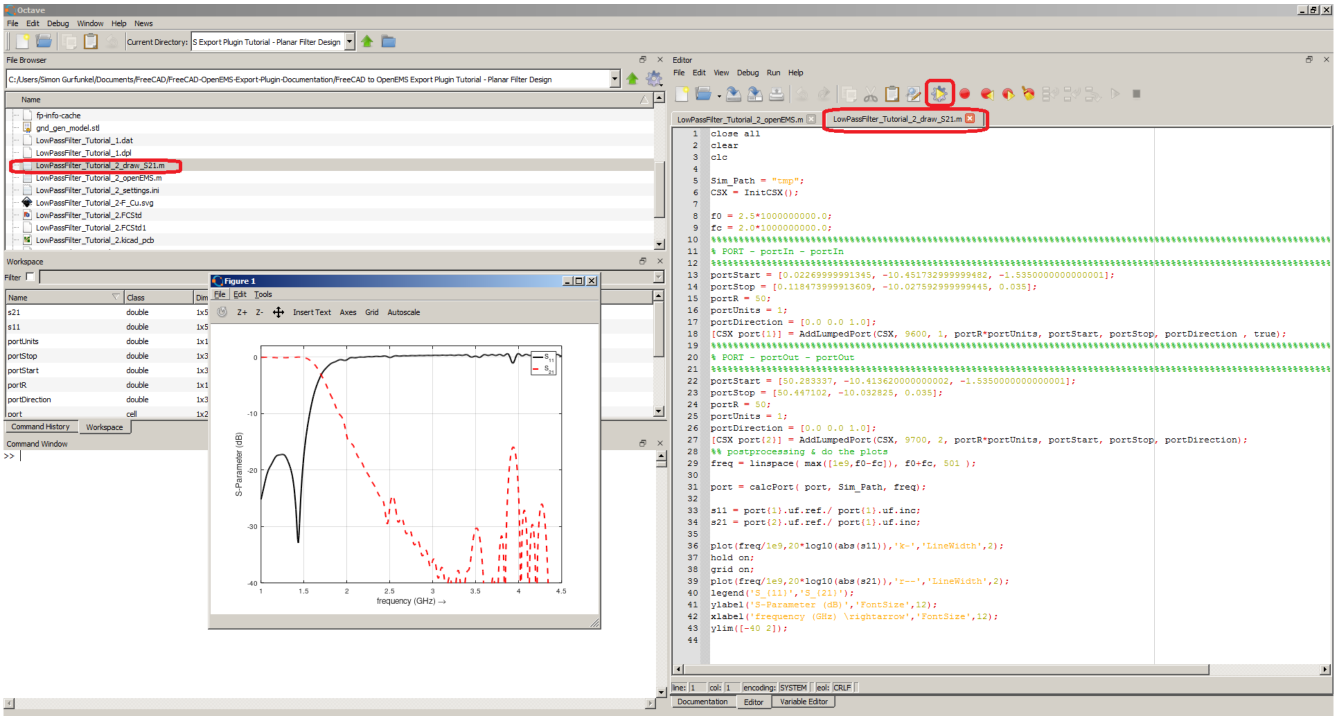
You can see how energy is decreasing during simulation.



Simulation end, maximum timesteps reached before meeting energy dispersion -30dB.



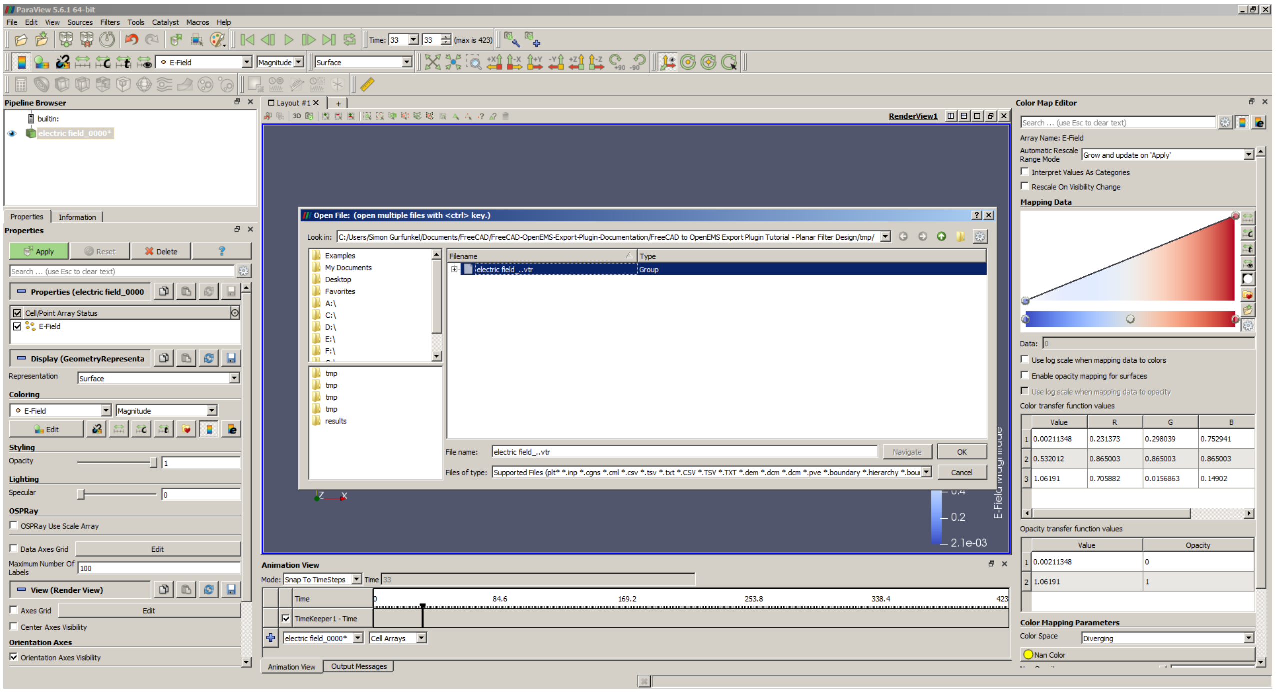
Runing generated script to display simulation results.



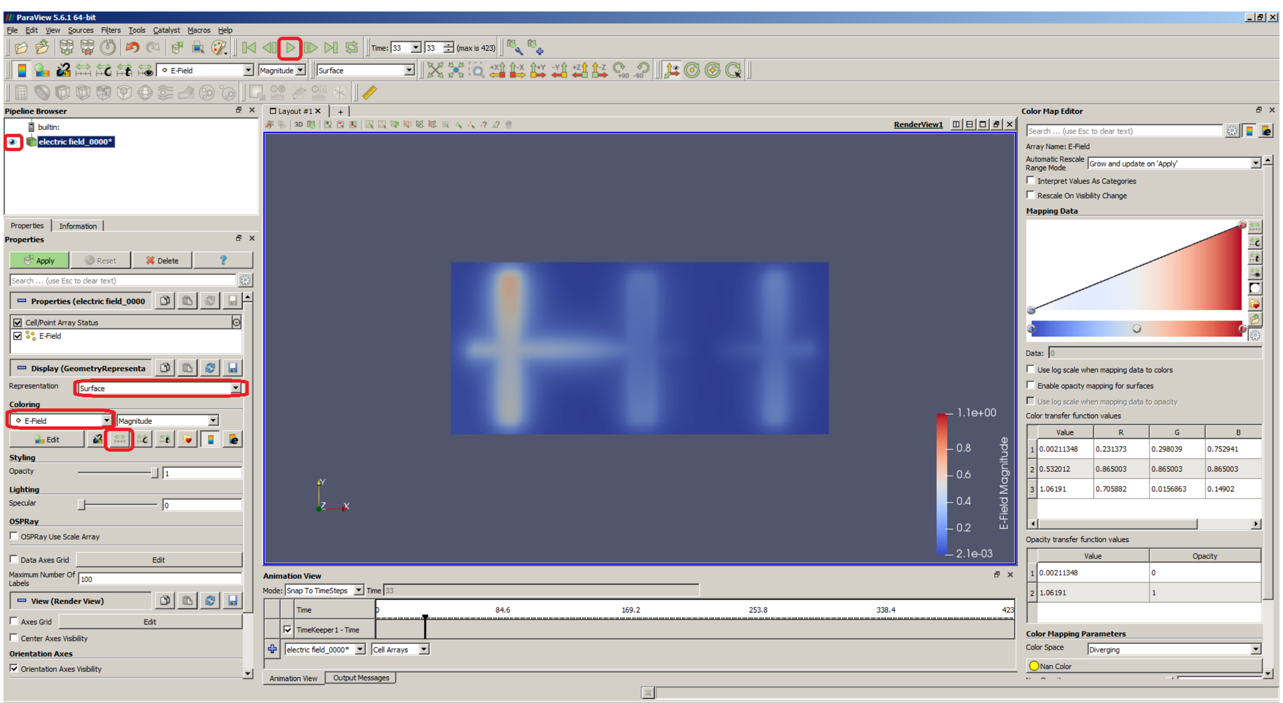
Octave
File Edit Debug Window Help News
Current Directory: S Export Plugin Tutorial - Planar Filter Design
File Browser
C:/Users/Simon Gurfunkel/Documents/FreeCAD/FreeCAD-OpenEMS-Export-Plugin-Documentation/FreeCAD to OpenEMS Export Plugin Tutorial - Planar Filter Design
Name
fp-info-cache
gnd_gen_model.stl
LowPassFilter_Tutorial_1.dat
LowPassFilter_Tutorial_1.dpl
LowPassFilter_Tutorial_2_draw_S21.m
LowPassFilter_Tutorial_2_openEMS.m
LowPassFilter_Tutorial_2_settings.ini
LowPassFilter_Tutorial_2-F_Cu.svg
LowPassFilter_Tutorial_2.FCStd
LowPassFilter_Tutorial_2.FCStd1
LowPassFilter_Tutorial_2.kicad_pcb
Workspace
Filter
Name Class Dim
s21 double 1x5
s11 double 1x5
portUnits double 1x1
portStop double 1x3
portStart double 1x3
portR double 1x1
portDirection double 1x3
port cell 1x2
Command History Workspace
Command Window
Figure 1
File Edit Tools
Z+ Z- Insert Text Axes Grid Autoscale
S-Parameter (dB)
frequency (GHz) →
0 -10 -20 -30 -40
1 1.5 2 2.5 3 3.5 4 4.5
Editor
File Edit View Debug Run Help
LowPassFilter_Tutorial_2_openEMS.m
LowPassFilter_Tutorial_2_draw_S21.m
close all
clear
clc
Sim_Path = "tmp";
CSX = InitCSX();
f0 = 2.5*1000000000.0;
fc = 2.0*1000000000.0;
%%
% PORT - portIn - portIn
%%
portStart = [0.02269999991345, -10.451732999999482, -1.5350000000000001];
portStop = [0.118473999913609, -10.027592999999445, 0.035];
portR = 50;
portUnits = 1;
portDirection = [0.0 0.0 1.0];
[CSX port{1}] = AddLumpedPort(CSX, 9600, 1, portR*portUnits, portStart, portStop, portDirection , true);
%%
% PORT - portOut - portOut
%%
portStart = [50.283337, -10.413620000000002, -1.5350000000000001];
portStop = [50.447102, -10.032825, 0.035];
portR = 50;
portUnits = 1;
portDirection = [0.0 0.0 1.0];
[CSX port{2}] = AddLumpedPort(CSX, 9700, 2, portR*portUnits, portStart, portStop, portDirection);
%% postprocessing & do the plots
freq = linspace(max([1e9,f0-fc]), f0+fc, 501);
port = calcPort(port, Sim_Path, freq);
s11 = port{1}.uf.ref./ port{1}.uf.inc;
s21 = port{2}.uf.ref./ port{1}.uf.inc;
plot(freq/1e9,20*log10(abs(s11)),'k-','LineWidth',2);
hold on;
grid on;
plot(freq/1e9,20*log10(abs(s21)),'r--','LineWidth',2);
legend('S_{11}','S_{21}');
ylabel('S-Parameter (dB)','FontSize',12);
xlabel('frequency (GHz) \rightarrow','FontSize',12);
ylim([-40 2]);
line: 1 col: 1 encoding: SYSTEM eol: CRLF
Documentation Editor Variable Editor

Using paraview to shown electrical field in time

Open simulation results in Paraview to display animation of electric field evolution during time.



Set paraview settings as on picture below. If you see just red rectangle use button to set average scale based on current frame, this button is below Coloring cattegory highlihted on picture.



And that's all, that's your first simulation using whole open source toolchain.