Neural Science for Engineers
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Lecture - 38
COMSOL Brain Electrical Stimulation Demo

Welcome to the next session of numerical simulation with the Neuroscience for Engineers. In the earlier session we talked about different biomedical applications which can be used in a broad range of applications that we studied. Now, we want to focus specifically on Electrical Stimulation of Brain.

So, here what you see over here is the brain or the complete head, along with the skull and the tissue. And we are going to provide a stimulation at a particular region. So, this is the place where we are going to give the stimulation, and this is the ground where we are going to withdraw the stimulation.

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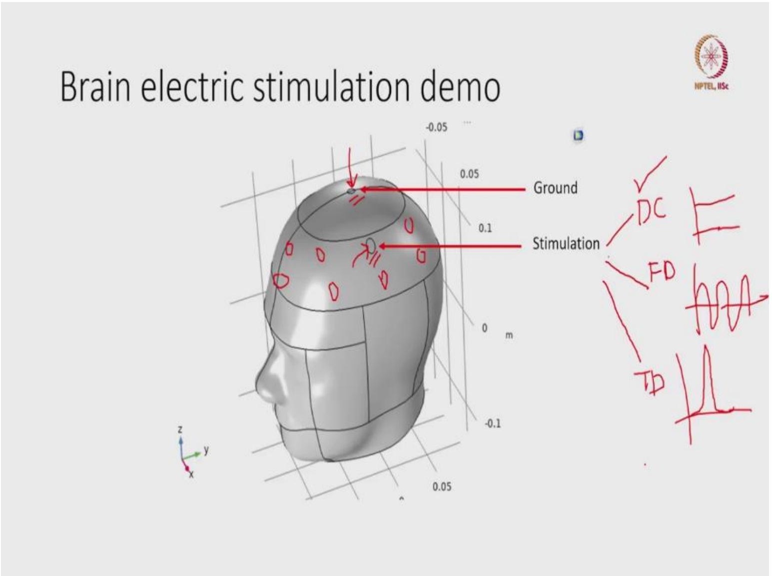

In an actual prototype there is not just a single stimulation, but there is an arrangement of various positions of the stimulation. But in our example, we are going to start with simple. So, we are going to only use this as the stimulation area and this as a ground region.

So, let us see how you can do that in COMSOL. So, again the simulation could be various. So, you just start with DC that is a kind of a DC signal that you can maybe a 10 millivolt or so. Or you can do a frequency domain that is a certain frequency you can stimulate with. Or you can do a time domain stimulation, that is you can give a certain impulse or a kind of a Gaussian impulse, Gaussian pulse a very short duration of time to see how this stimulation is going to affect the tissues within the brain.

So, we are going to start with the DC and see how you can do a DC stimulation first and approach to a frequency domain and time domains are on the similar lines.

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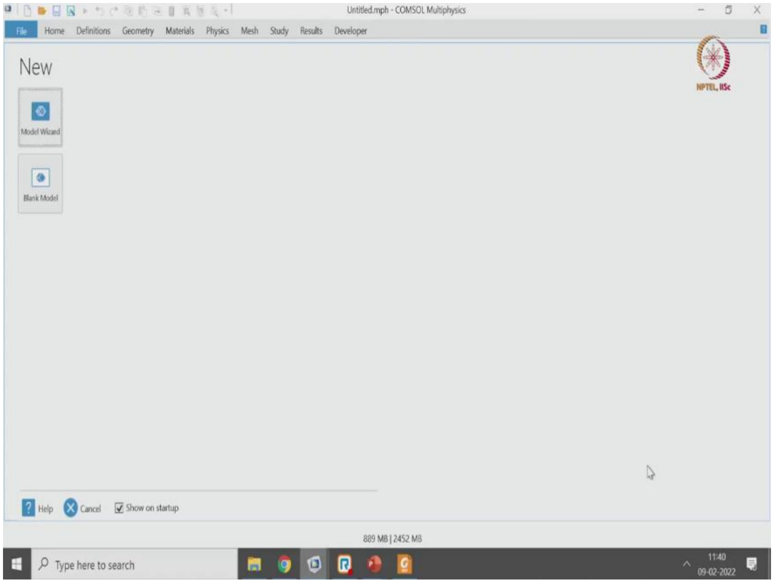

So, let me go and start the stimulation. So, this is the first thing that you see once you open COMSOL, you just need to go to file new. And then there are two options, one of them is Model Wizard and this is the best thing to use Model Wizard instead of going to Blank Model.

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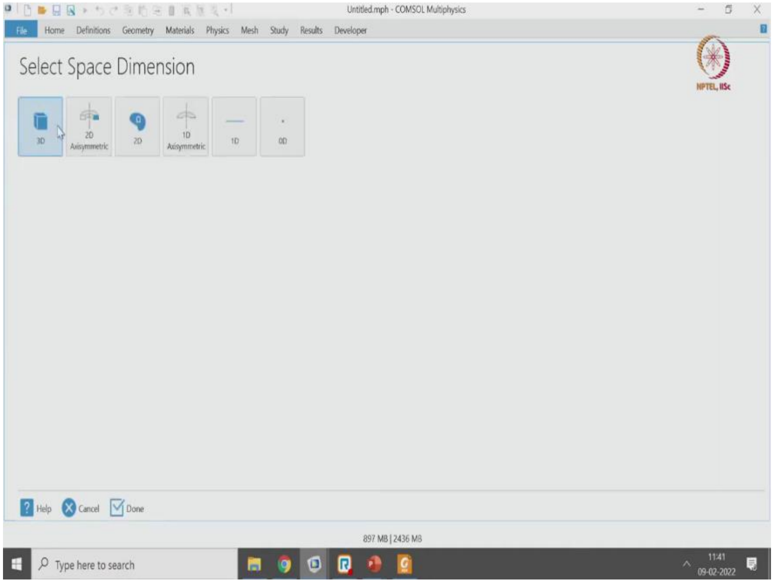

So, once you click on Model Wizard there are different options of dimensions that you can choose from. For example, you can choose a 3D simulation you can do a 2D axisymmetry, you can do a 2D, 1D axisymmetry, 1D or 0D. Our simulation that you can see over here is 3D simulation. So, we are going to choose 3 dimensions.

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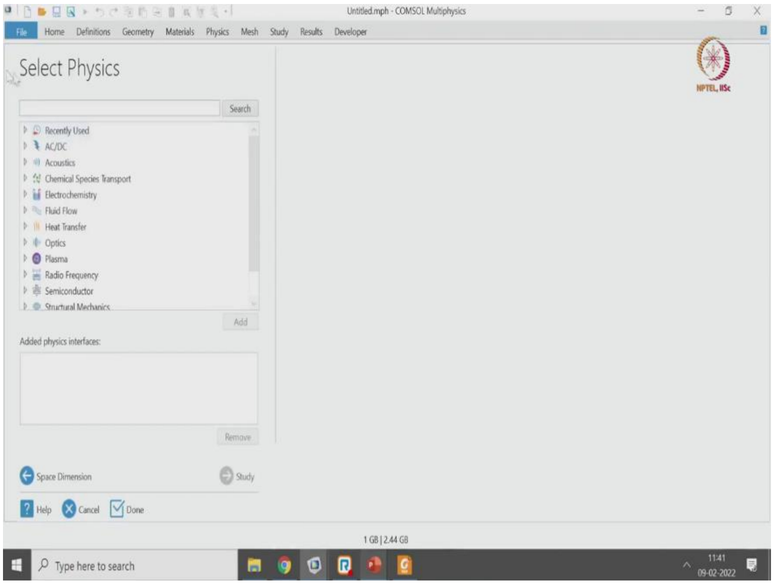

So, once you select the dimension it is asking to select the physics. So, over here coming back to this figure over here, you can see that we are going to give a voltage as an excitation or current per se. So, the physics that we are going to solve is a flow of current within the tissue and this all requires only the, if you go into the AC, DC module.

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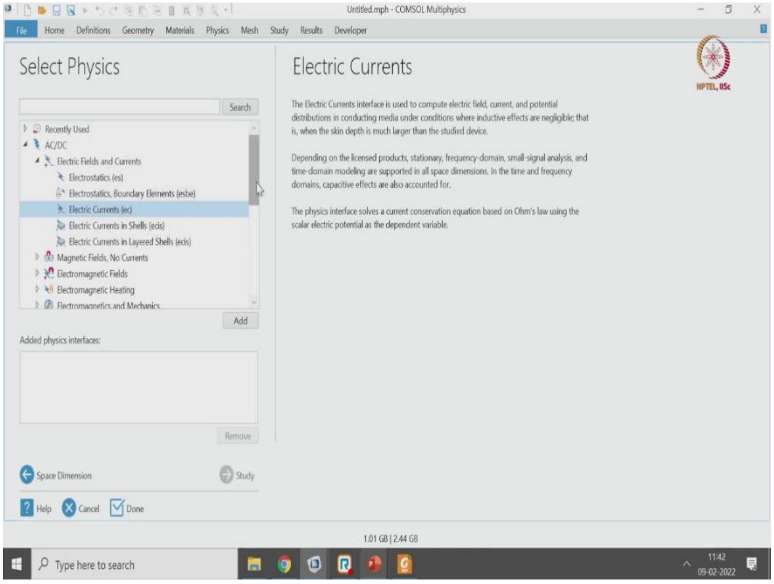

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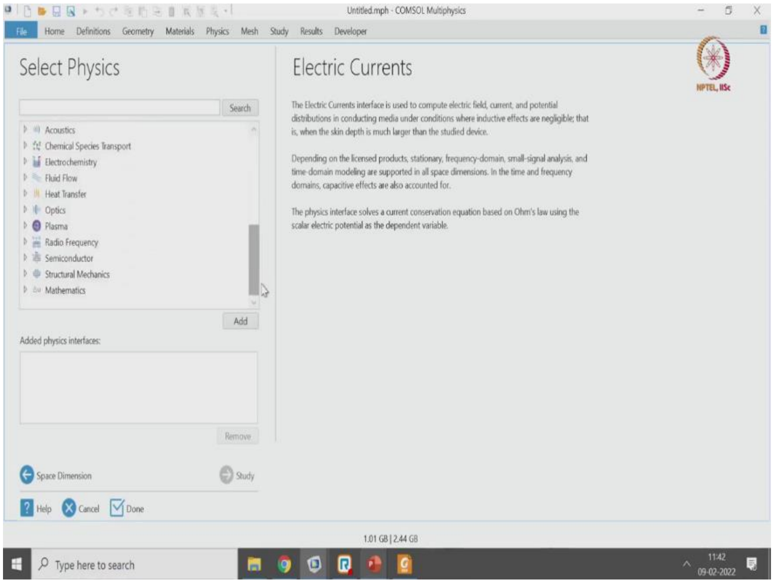

And it will go into the Electrical Fields and Current and this option known as Electrical Current interface. So, this is the only interface that is required in this case. Having said that there are also other physics that you may be interested in at a later point.

So, I am just showing you all these modules. As of now I will just go to Electric Currents, and I click on that, and I click on Study.

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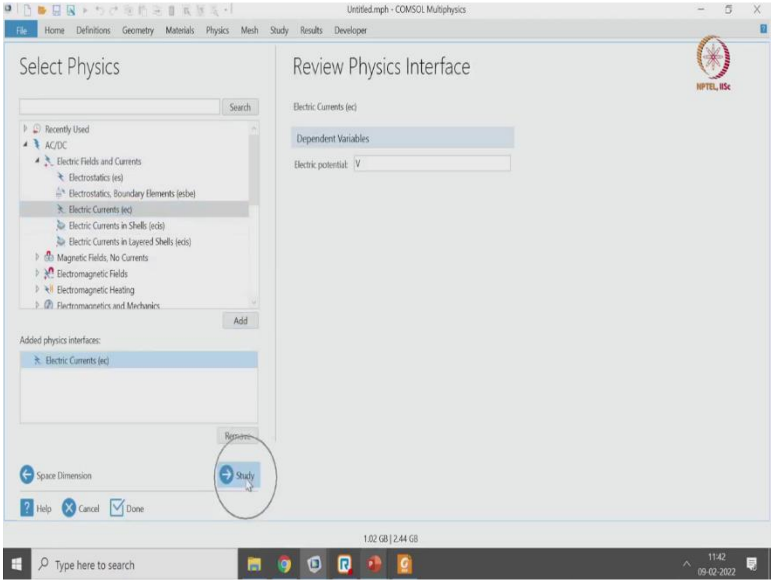

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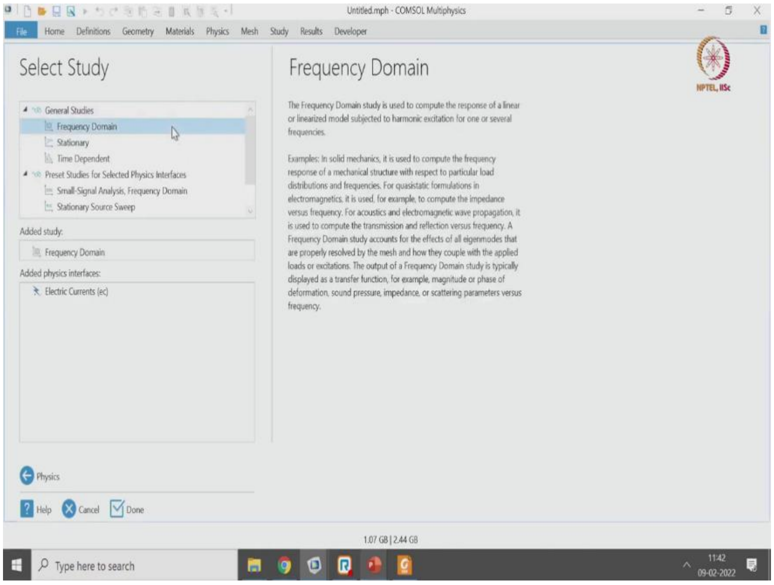

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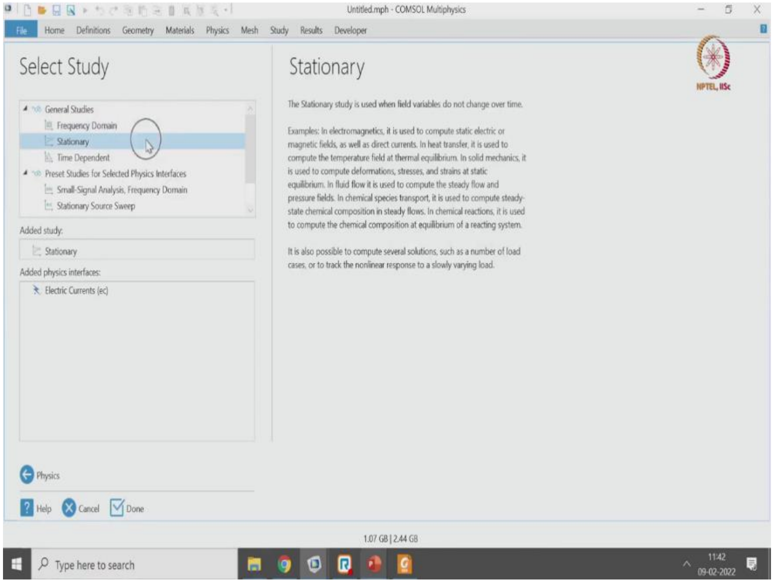

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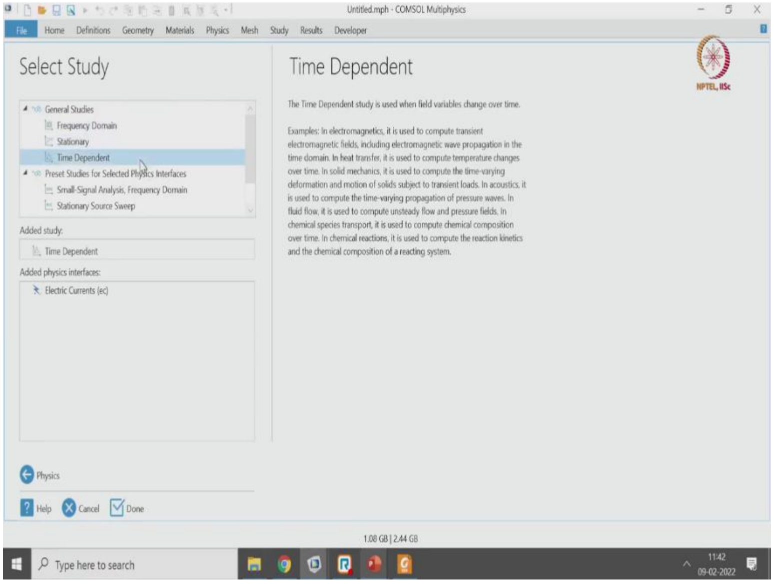

Then the tool is asking me of which kind of study that I want to perform. Whether we want to do a Frequency Domain study that is a harmonic as an input, or it is a Stationary study or it would be a stationary means a direct current that is a DC study. Or you can also see it is a steady state study; that is a, at time t equal to infinity what it would be? Or it I can do a Time Dependent study where I need to mention the time scales of the model.

There are also different options such a Small-Signal Analysis that is you can have both a DC bias along with the frequency domain signal. And you can do a source sweep and there are different like Eigen frequency analysis, but we are not interested to do those as of now. We are interested do only study state analysis, that is a DC analysis it is case of a static analysis. So, I just select Stationary and click on Done.

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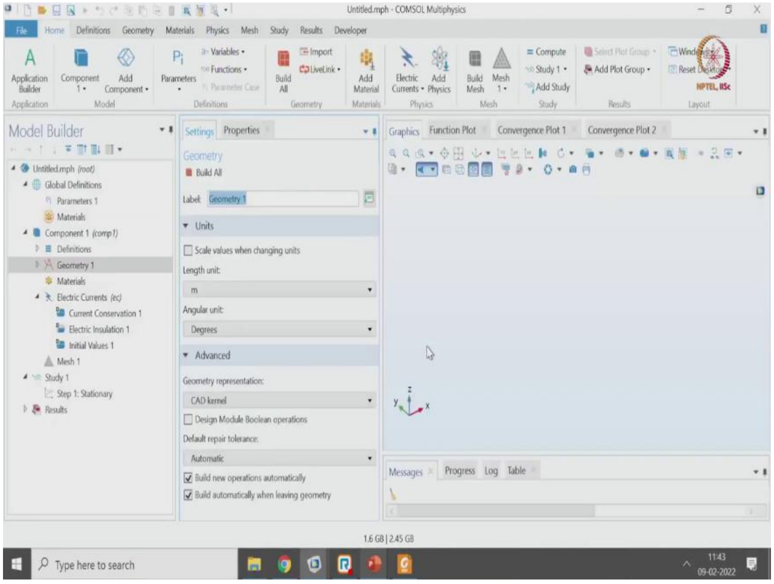

So, that is it, now I come to the main page or main interface of COMSOL Multiphysics. So, what you see on the left side is the Model Builder and the approach to in the Model Builder is from top to bottom. So, what you see over here is the first you make the Geometry.

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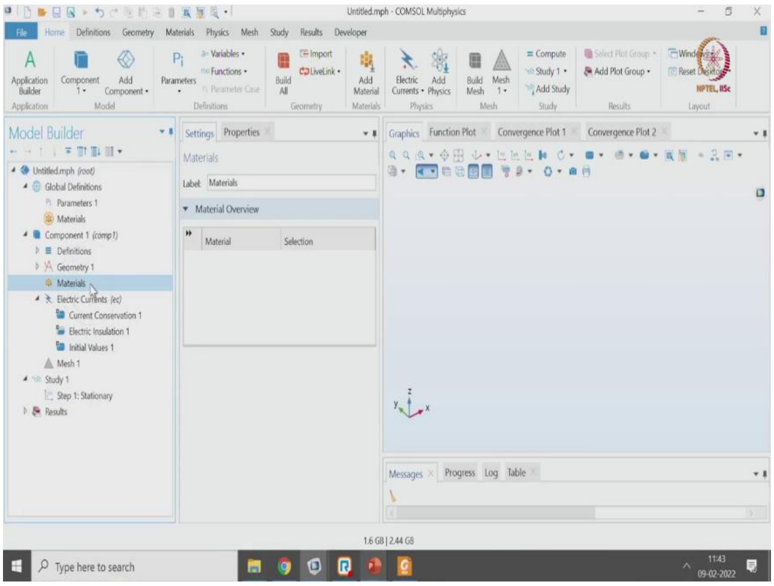

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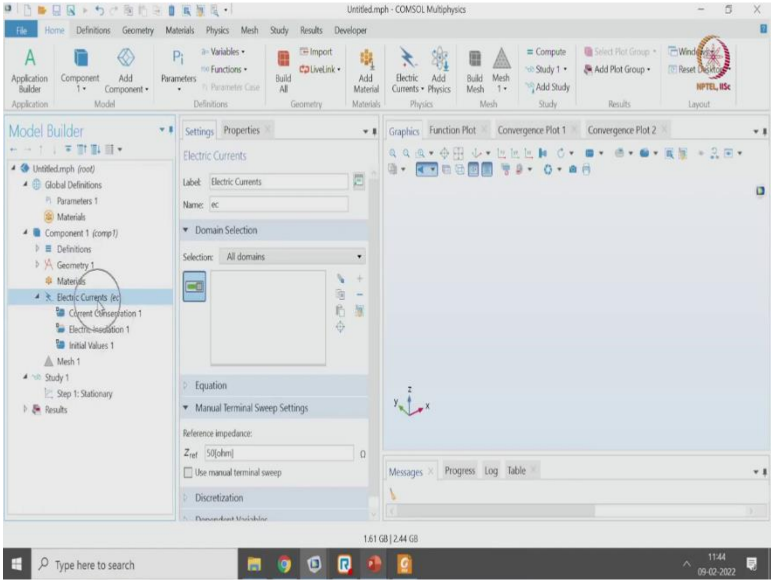

Then you add the Materials, then you apply appropriate physics conditions.

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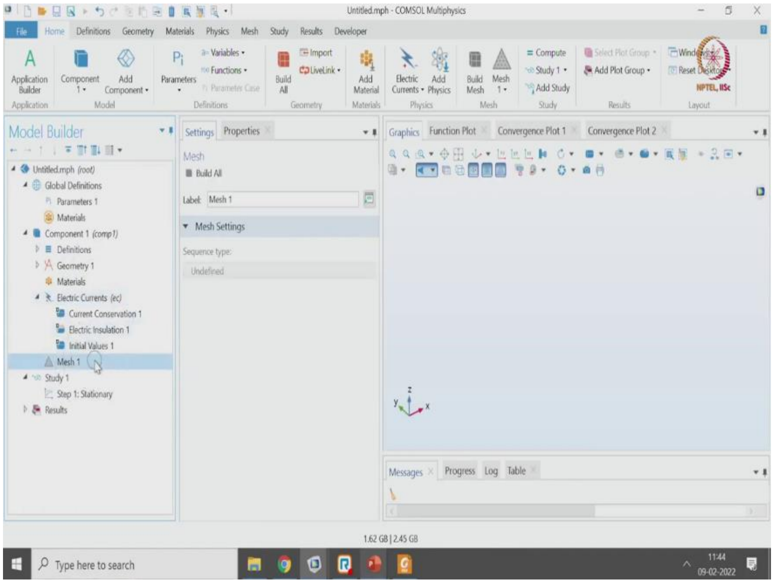

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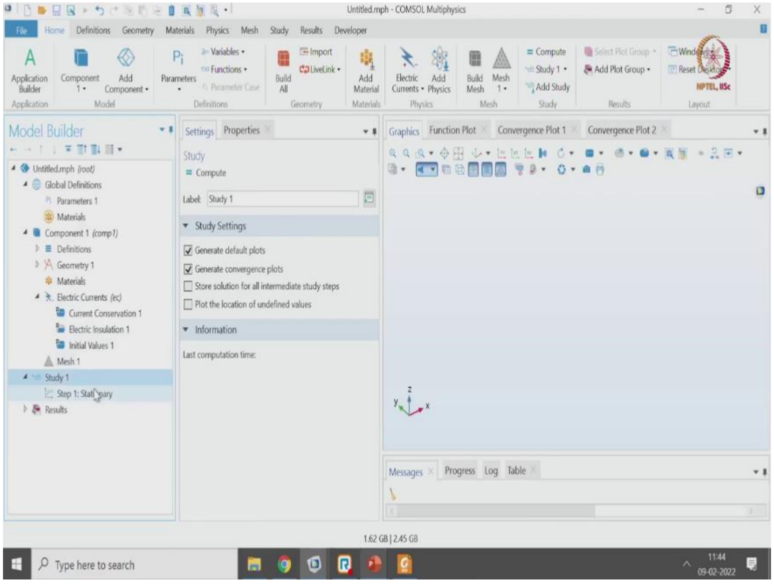

Then you mesh the geometry and then you perform a kind of analysis, let it be a stationary analysis or a frequency domain analysis or a time domain analysis.

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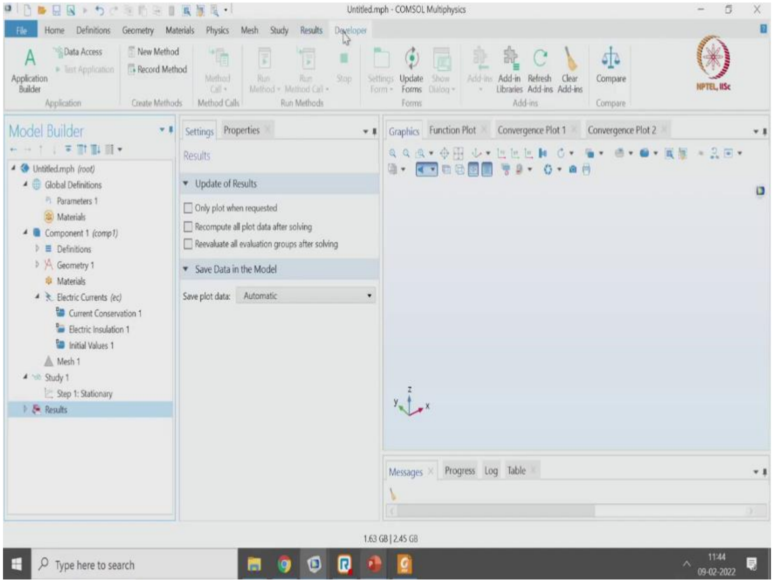

And then finally, you post process the results. So, the approach that you see is from top to bottom in the Model Builder section. The top section is the ribbon pane that you see over here in the top and the approach in the ribbon pane is also the same. That is, you first make the geometry, then add the materials, apply appropriate boundary conditions, mesh the geometry, perform the study, and finally, post process the results.

There is also a developer section over here that you can use to write your own scripts and code and couple it with your model. So, with that let us begin and build this model. So, the first thing is to create the geometry as you can see over here.

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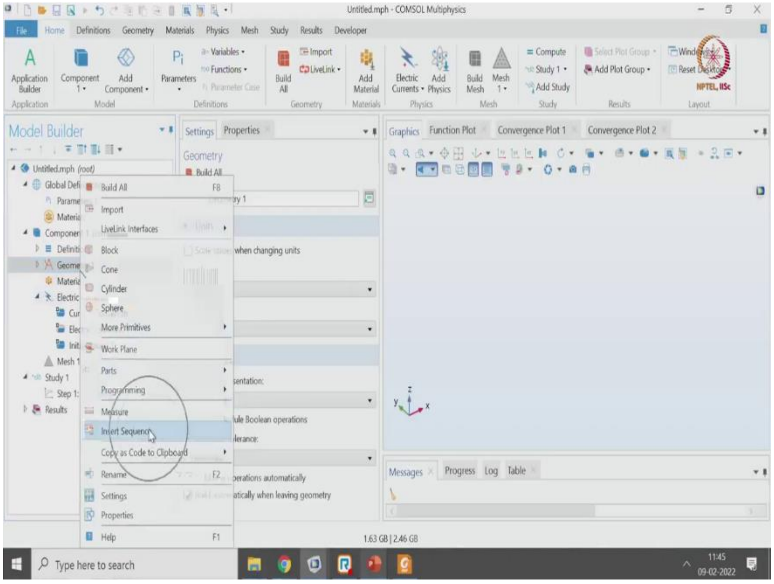

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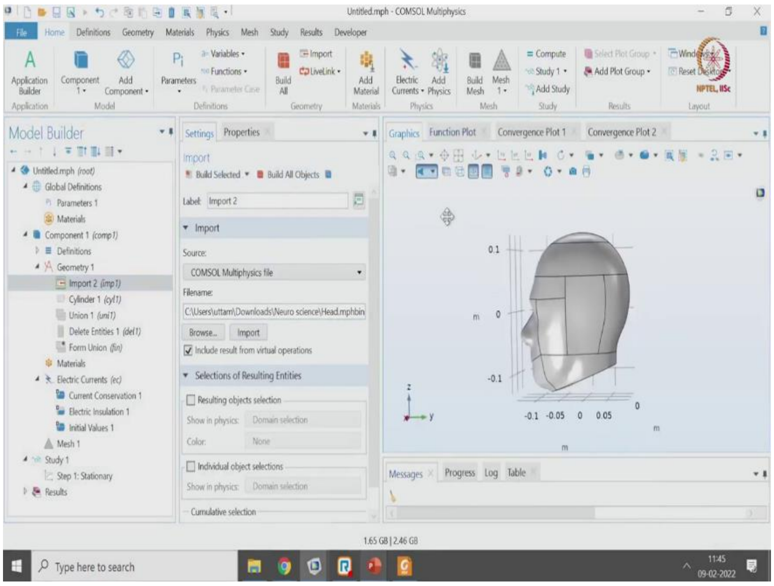

To save the time what I do I have already created it and I can just insert that sequence within this model. These structures could also be available easily if you just go and search in the some of the CAD free sources. Such kind of structure of the of the upper part of the body are easily available. The next is to also import the head body.

So, this is a head part. So, this is first thing I start with importing the structure of the head. So, you can see this is the structure of the head and then this ground is already there over here. So, I do not need to add the surface for the ground, but I want to have one more stimulation over somewhere over here. To do that I can just use the Cylinder for example.

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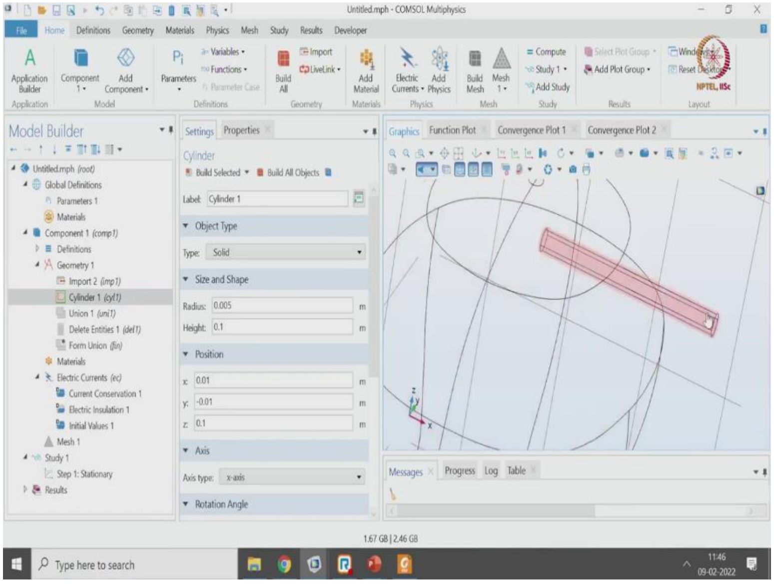

So, I will just use cylinder and just place the cylinder over here, there is also an option of wire frame rendering. So, the cylinder you can see that it is a very elongated cylinder passes through the tissue, but I am interested only to have the intersection of this long cylinder with this tissue. So, only that surface is what I want to introduce. So, I can use a union and delete the domains, this is the operations that I can perform.

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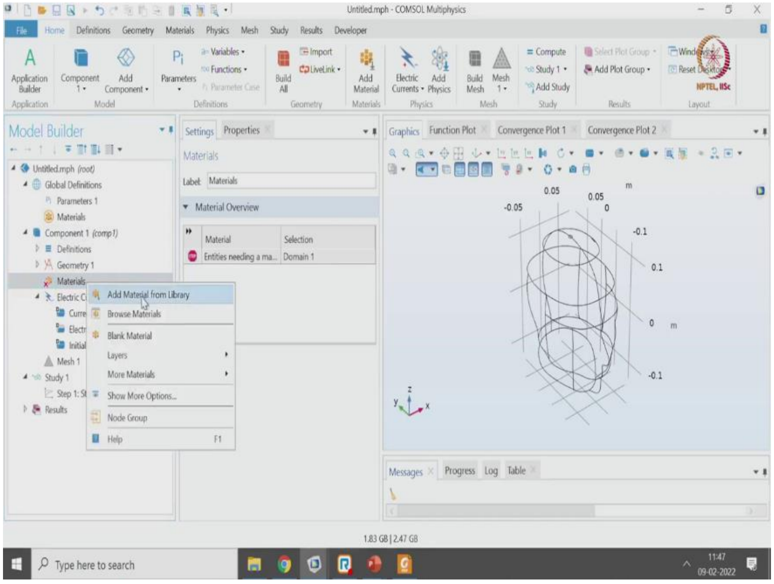

So, such kind of operations can be performed and I what I finally, get is this particular surface and this as this particular surface acting as a stimulus. But it is still not acting as stimulus I have just created this surface as of now.

I need to apply appropriate boundary conditions to act is act it as a stimulation and this is a ground boundary. So, that is it with my geometry part. The next thing is to apply appropriate physics conditions or material conditions to start with. So, one way to apply the materials is just right click on the Materials Apply Materials from Library.

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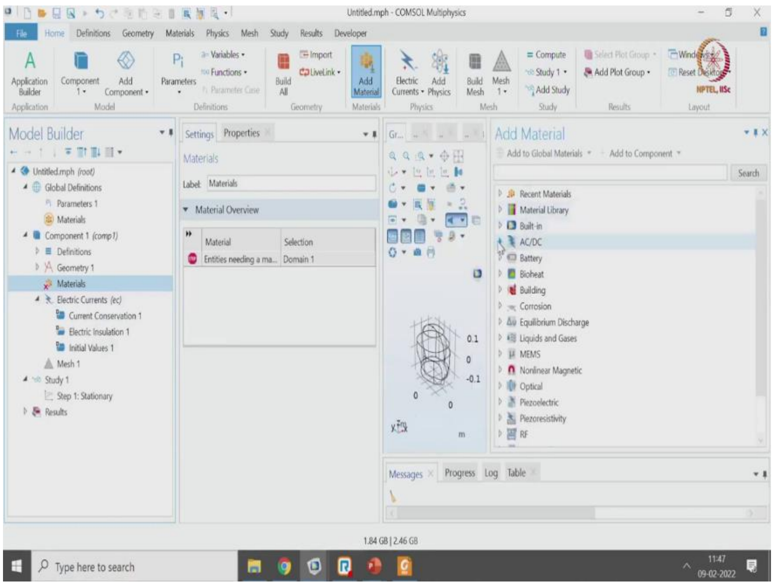

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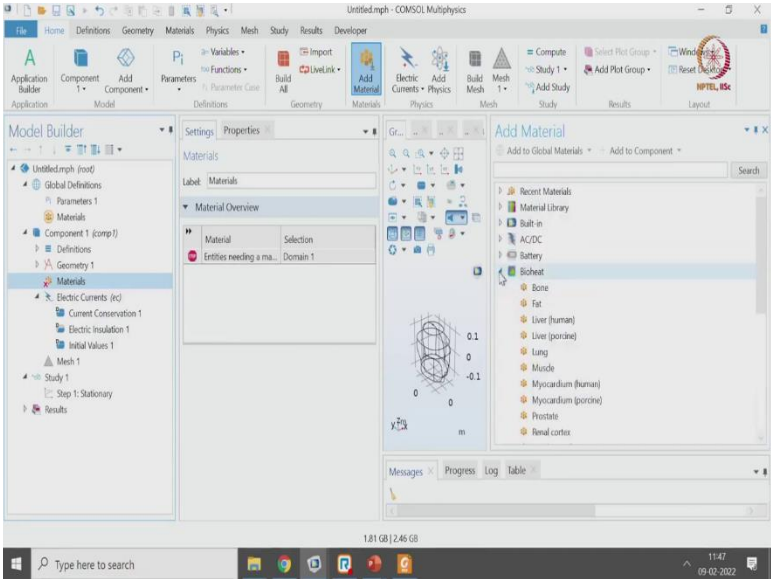

And here you can see there are a lot of materials available within the library of this tool.

So, you have Bioheat and there are a lot of biological tissues available over here. What I am going to do is I am not going to use anyone from here I am going to use my own and to do so we just need to right click on the Materials, add a Blank Material.

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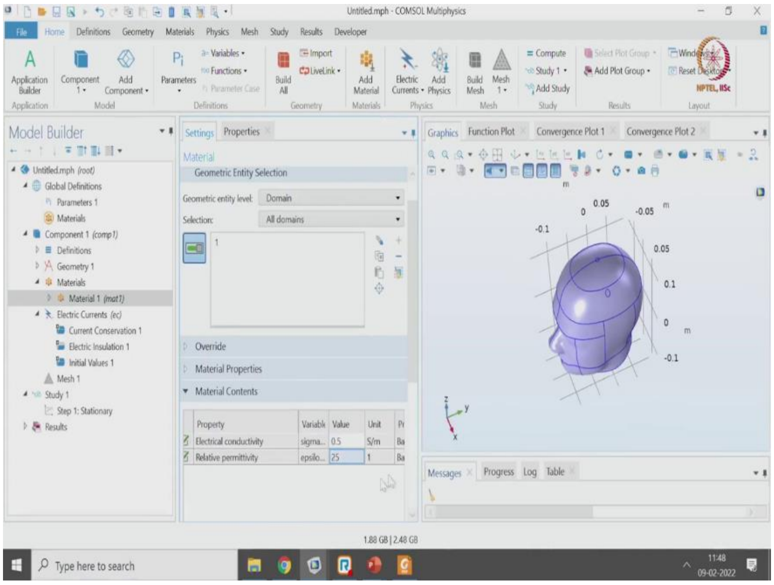

You can see that it is already selected this particular domain over here and the conductivity as a 0.5, I just choose you can introduce your own conductivity and permittivity.

Now, I am doing for a DC excitation, but at a later point you might also be interested to do a frequency domain excitation, that is at different frequency we want to excite. In that case the conductivity as well as the permittivity is not going to be the constant, but it could be a function of the frequency.

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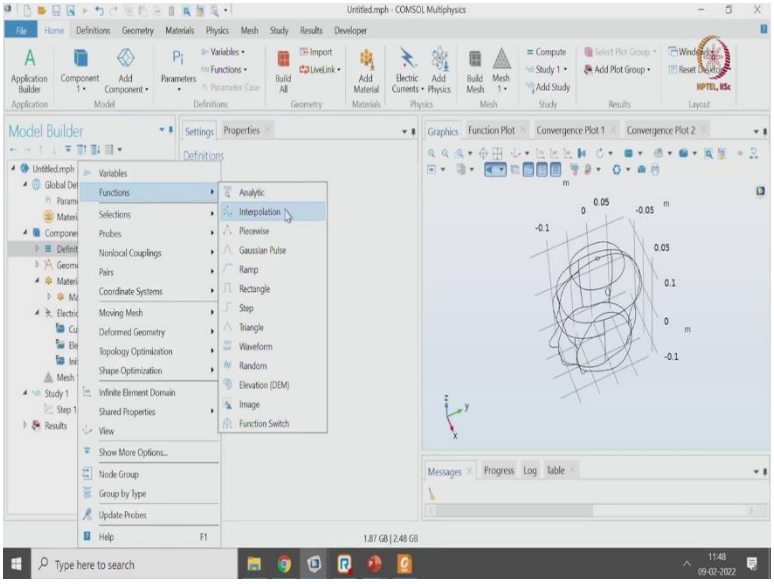

In that case you can use an interpolation function. So, you can just right click on the Definitions, go ahead in the Functions and use an Interpolation function and you can import that text file or dot d data file or dot that file or any other format of the file within this tool. And you can write the name of that interpolation function over here.

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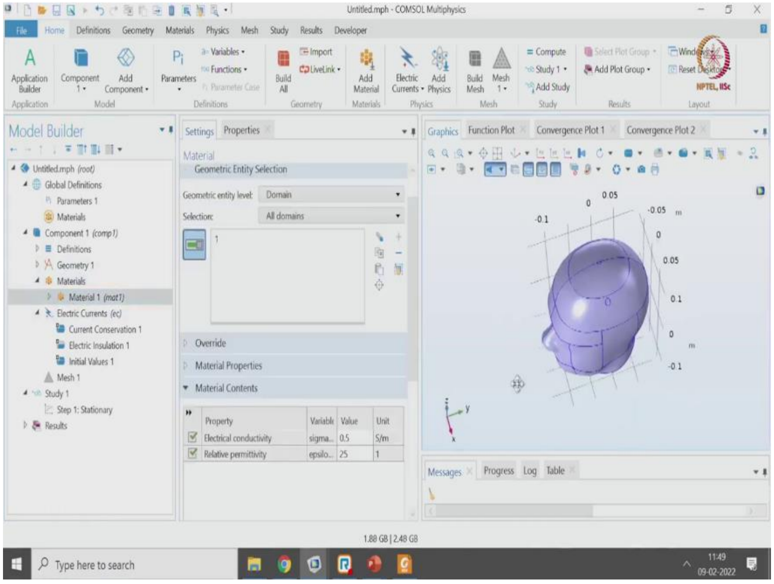

So, you are done with the Material section. So, you applied the appropriate materials and that is what you see in the blue highlighted domain. The next thing is to apply appropriate physics conditions.

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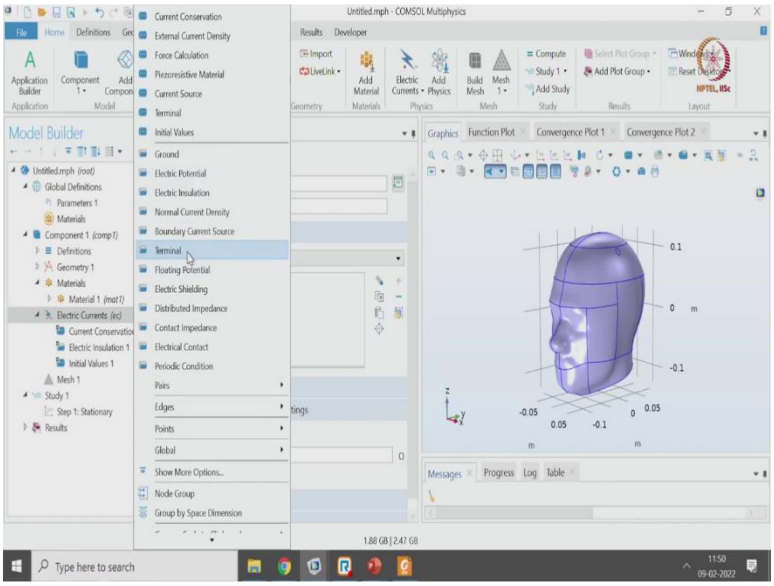

To do so what I do I just right click on Electric Currents, and you can see the complete list of domain conditions. So, you can see this is a cylinder which is fully filled with blue color. So, this is a blue fully filled cylinder which represents domain conditions, and this is cylinders which are half filled which represents boundary conditions ok.

So, we actually need to do a boundary conditions not the domain condition as of now. So, there are different ways to excite, it could be Electric Potential, or it can do a Normal Current Density, Boundary Current Source or Terminal, you have Floating Potential where you want to withdraw the potential that could also be possible. This is the main source condition, so what I will do is I will choose the Electric Potential ok. If you want, you can use Terminal also. So, Terminal is a more robust boundary condition.

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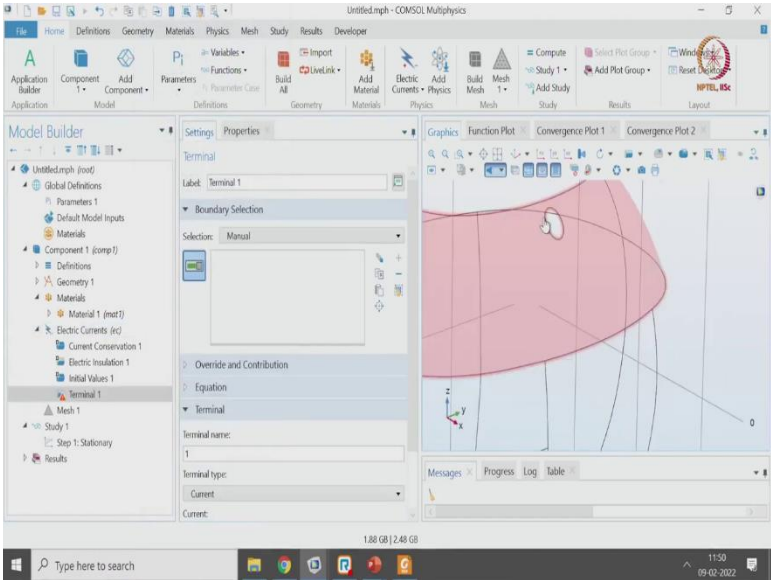

So, just choose Terminal and I go ahead and select this particular boundary over here. So, you can see if I remove the wire from rendering that I have selected this particular region to stimulate this particular region here.

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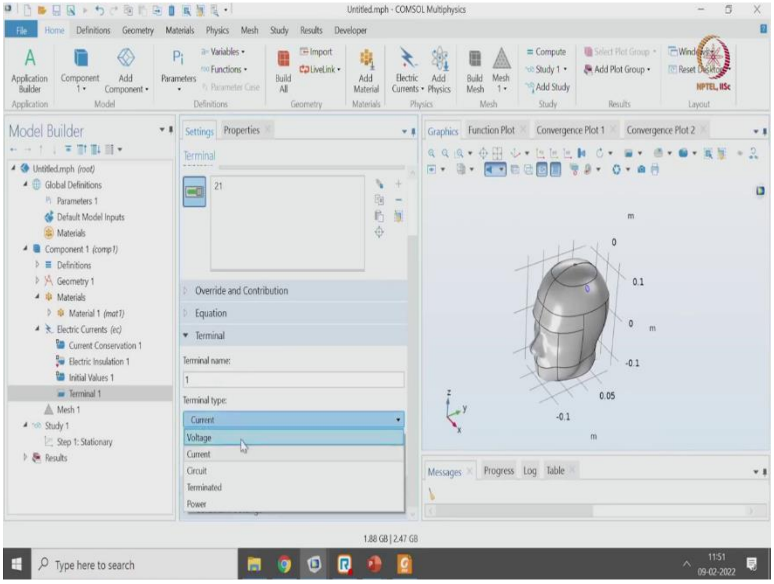

Now, there are different types of excitations that I can use whether it is Current or Voltage or through an external Circuit or a Power. As of now I will use Voltage excitation and I mark it as a V_0 for example, and this V_0 is just showing you unknown variable as of now.

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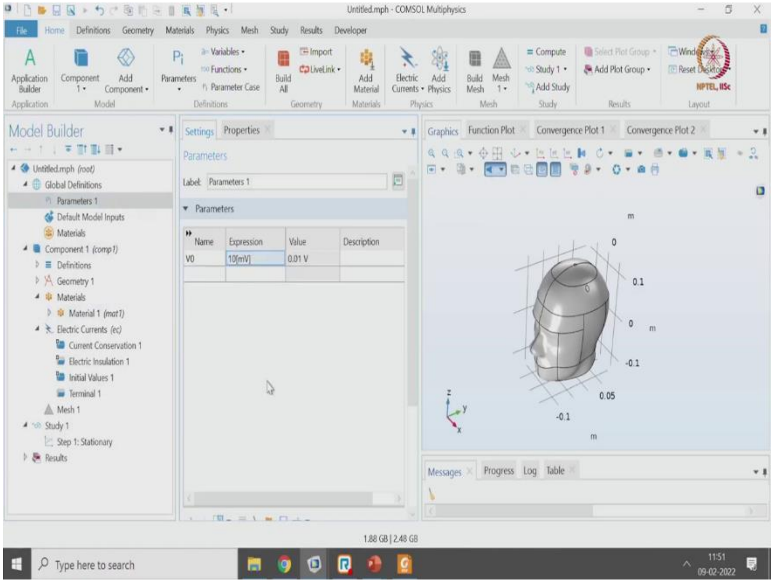

I can go into the parameter section and mark V_0 as maybe 10 millivolts. So, I am marking it as V_0, I also want to see how much current is being withdrawn from this region. So, that is what also is feasible if I define Terminal 1 condition. If I define it as Electric Potential condition, then I cannot quantify the current. So, this is a more robust as what I was saying earlier.

So, Terminal is a more robust boundary condition. I apply a potential over here, now I need to apply ground in the top. So, how do I do it?

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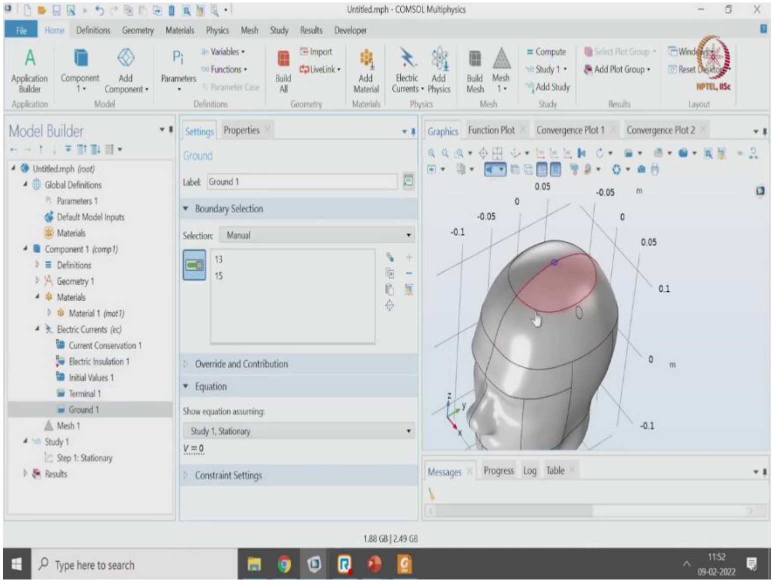

I just right click on the Electrical Current interface, and I choose the Ground boundary condition and apply on the top of the head. So, this actually acts as a Ground condition. So, you can see the equation over here, that is a voltage 0. So, this particular localized resonance of the head actually works as a ground.

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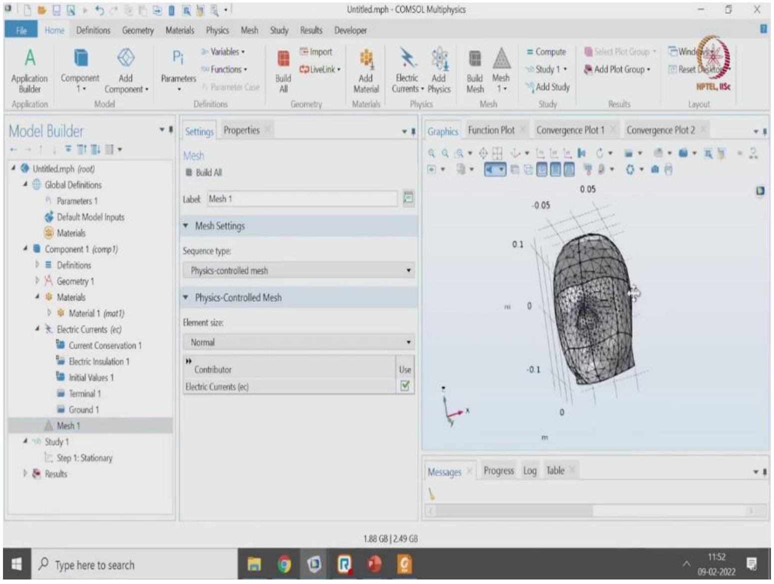

The next thing is the meshing. So, if I go to the Mesh over here, and I click on Build All you can see that this particular geometry has been meshed. Meshing plays a very important role because the geometry that you created is not going to go and be solved in a set of equations in the solvers. But it is the Mesh which is going to be get solved within the by the solvers.

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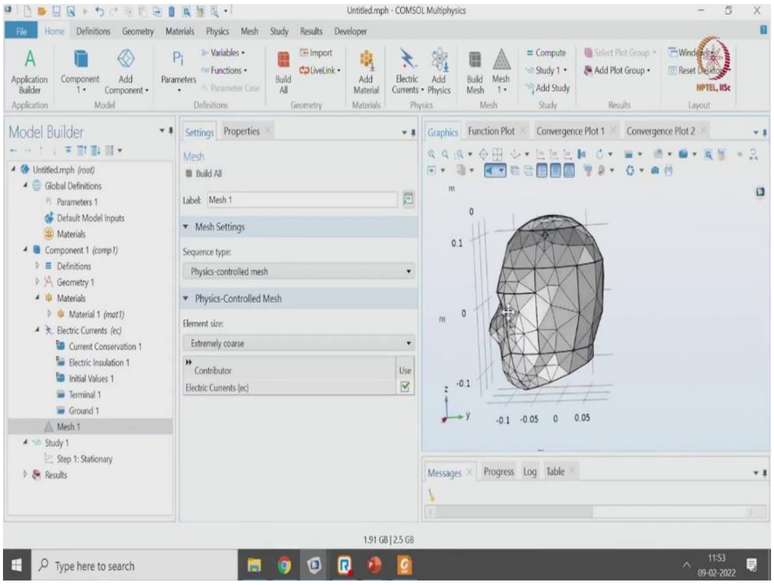

So, here you can see that if you go and make it extremely course Mesh, you can see that it actually deforms the structure or surface of the head. And very pure meshing is being shown over here, you can see even the nose is not that good.

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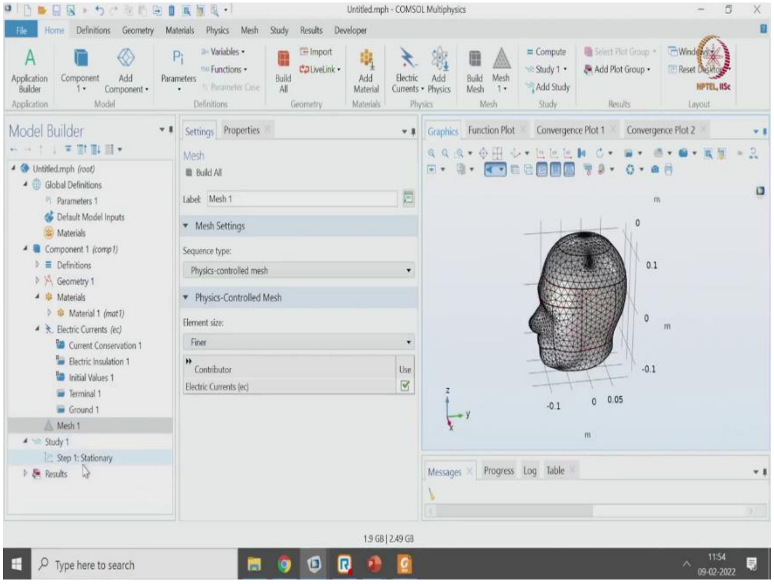

So, you can either go for a Normal mesh or even a little bit Finer or based upon the physics for example, you sometimes need to mesh the geometry.

For example, you are working for very high frequencies in cables ok then there is an effect of skin effect. So, in that case you might need to do a boundary layer mesh, if you are working on a very high frequency like optics or RF applications so in that case you need to resolve the wave that is propagating through the tissue.

So, in that case you need to do a one-fifth of the operating wavelength over the refractive index of the tissues or if it is not a refractive index then if you have permittivity then it would be the denominator would be square root of the permittivity. So, it depends on the physics as well. As of now delete the currents is not that like affect gets affected by the mesh. But the geometry should at least not be getting affected.

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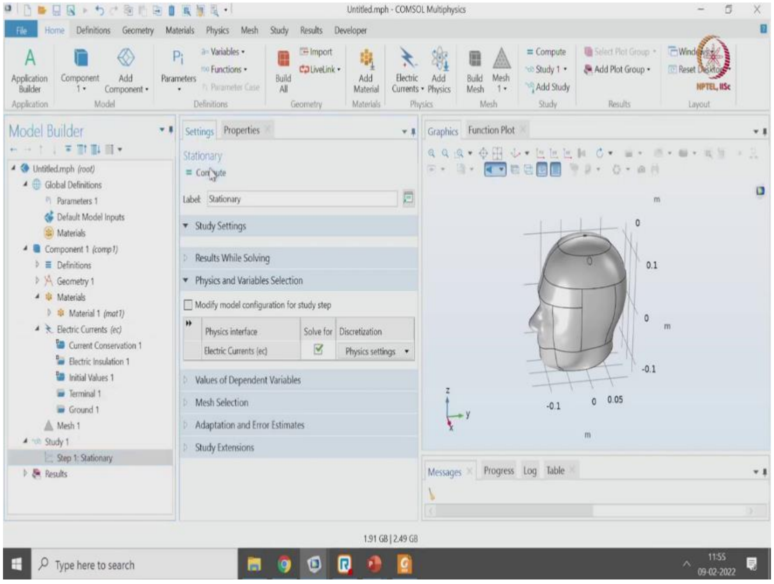

The next is to perform the type of study. So, as of now as I have discussed earlier this is a DC stimulation. So, I just use my Stationary analysis and I click on compute.

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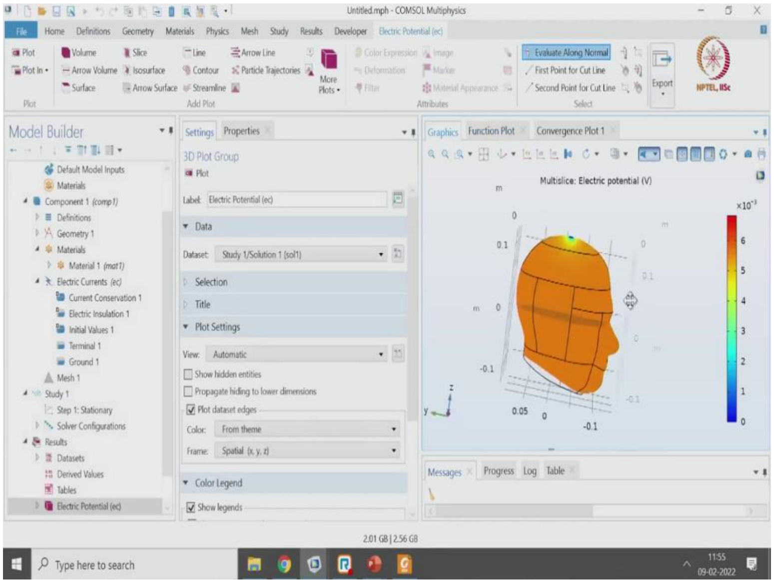

So, here you can see what is happening.

So, the first plot that is getting generated is an Electric Potential plot. So, it shows how the current or the voltage is varying from this place to this place. But I want to see this plot somewhere in this plane. So, there are different ways to create more intuitive images. One of them would be to use data sets.

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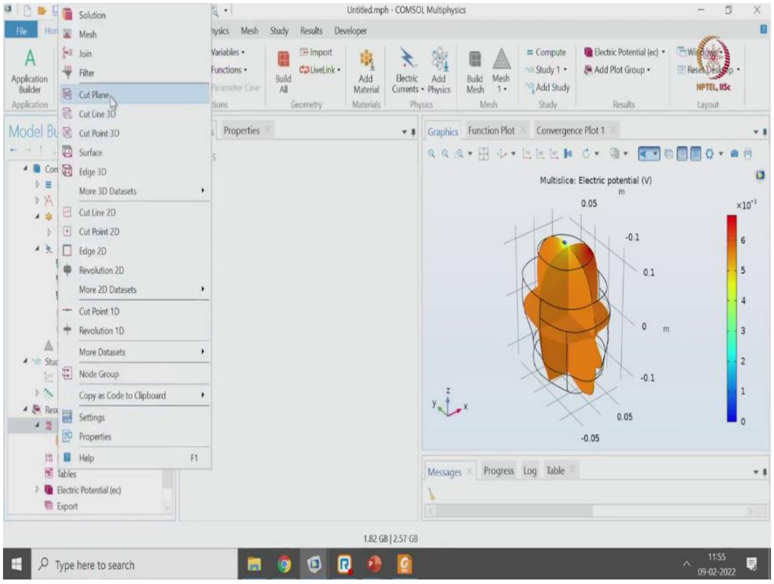

So, I want to create a Cut Plane for example. So, I just right click on the data set, I create a Cut Plane and I want it in the ZX plane. So, along this plane over here. So, I choose the Study 1 Solution of the data set, this is the main data set which has all the solutions. Now, I want to make a subset of this data set into specific regions.

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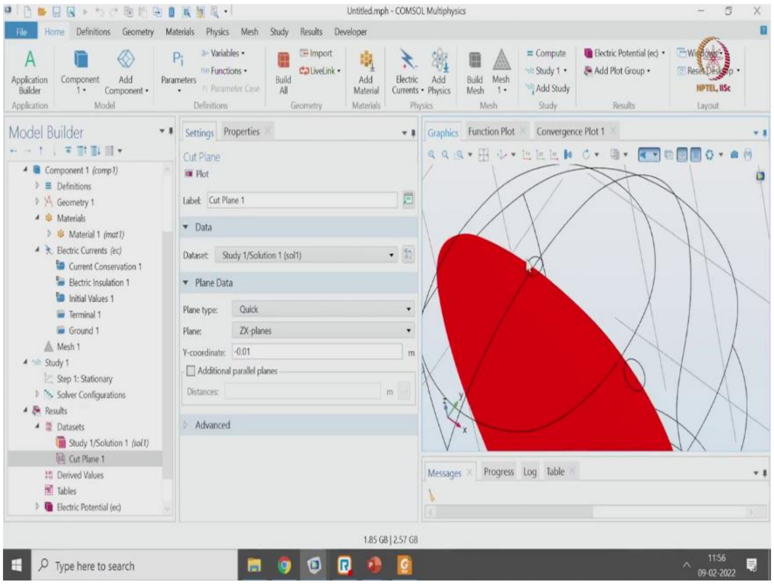

So, I want to choose for example, ZX plane. And I have to click on 0, then it would be Y coordinate 0. So, this is the place that the results are going to get evaluated, but I do not want it to be over here, but little bit on the right side because I want it to get overlapped with this region. So, for example, I will just try to make it little more negative yeah. So, now, we can see that it is overlapping nicely with the stimulation.

I give stimulation over here and this is the ground understood. So, now, what I am going to do is I want to evaluate the electric currents potential all of them in this plane, red plane that you see over here 2D plane.

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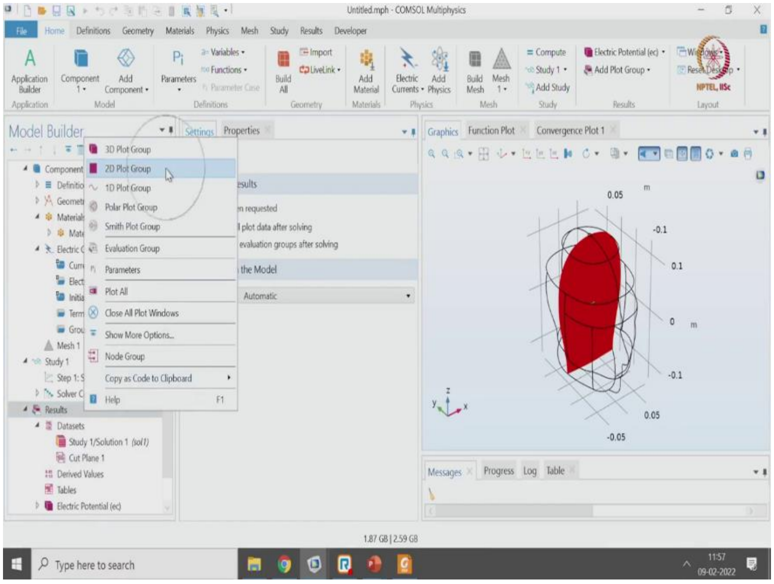

So, Results would also be 2D. To plot the 2D results you can just right click on the Results and there is an option of 2D Plot Group.

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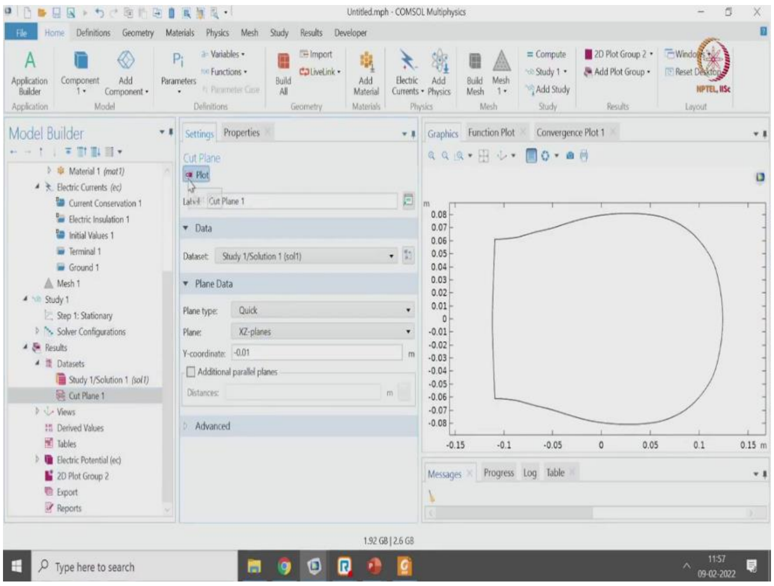

So, now you can see this is actually having a rotation of 90 degrees. So, instead of ZX plane, I can use XZ plane.

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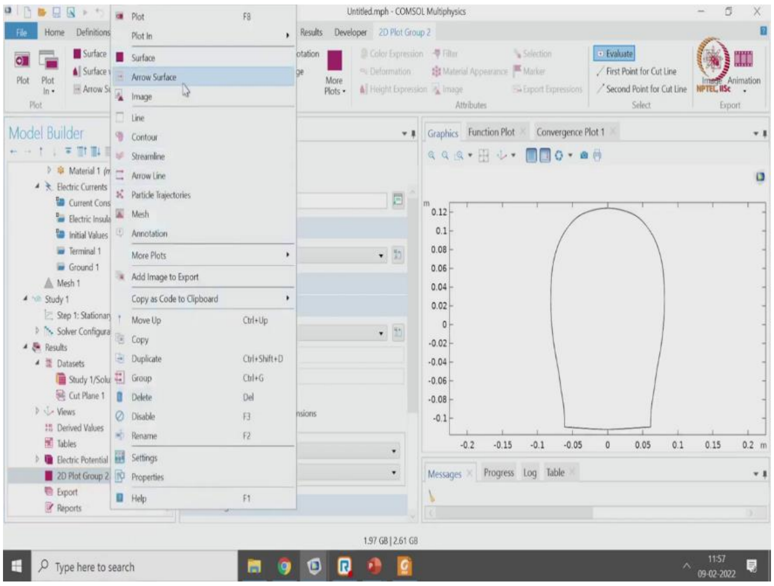

Which is now mixed with more straight kind of a vertical. Now, in this 2D Plot Group what do I need to plot? There are a lot of ways that you want to plot, but the first thing that you should think to yourself is what do you want to plot.

For example, if it is a voltage plot that you want to perform then this scalar quantity. And scalar quantity could be plotted using Surface plots, but if you want to model something or you want to plot something like currents, electric currents which are inherently vector quantities. So, in that case you would require an Arrow Surface plot.

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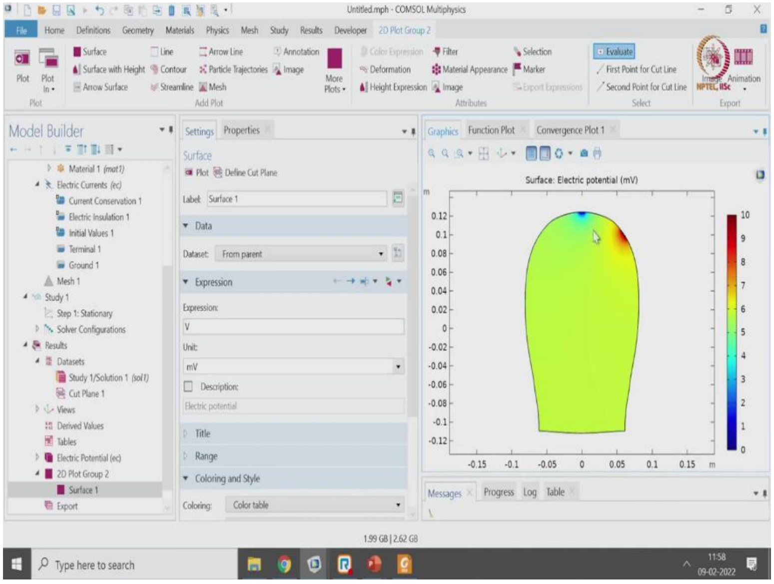

So, let me go and choose the Surface plot to start with and this is the voltage and I make it as millivolt because this is what is going to be.

So, you can see how the voltage is varying from here to here. You can also plot the electrical field. Just right click on the 2D Plot Group, add one more Surface plot and you can just search.

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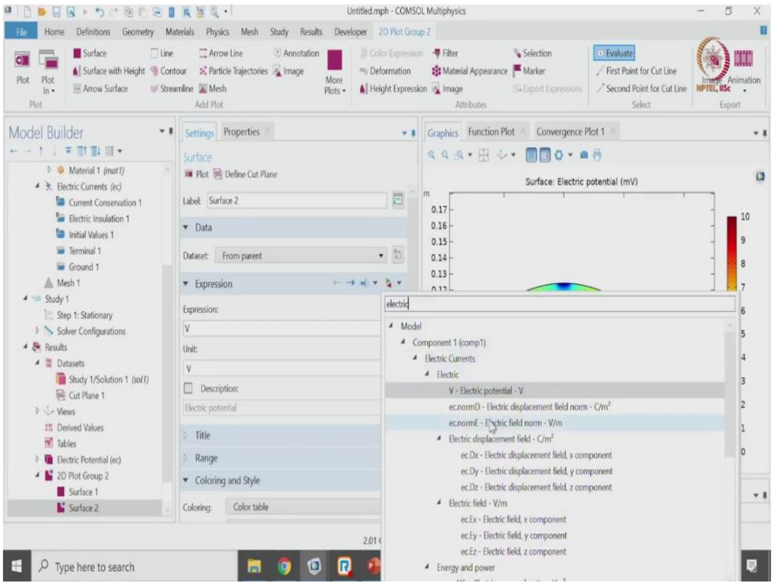

So, if you just come over here, it is a replace expression section over here. Just search for electric field.

So, this you can get an option of ec.normE, this ec.normE is the Electrical field. You can also plot the individual electrical field components that is x y and z components. But as of now, I am going to plot the normalized electrical field that is

$$= \sqrt{x^2 + y^2 + z^2}.$$

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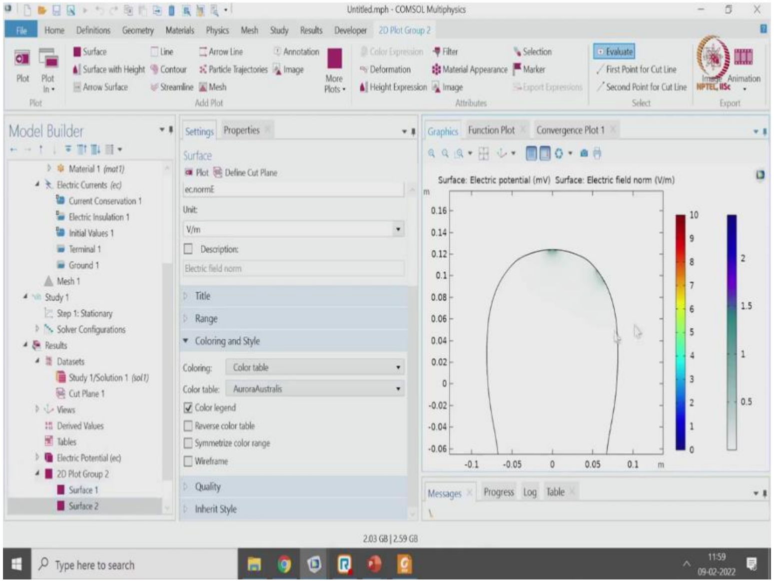

I can make it different color table for example, I can make it AuroraAustralis and plot it ok. So, there are two images which are getting over lapped. So, I will just disable my first surface plot ok and perhaps I will use some other different kinds of ok.

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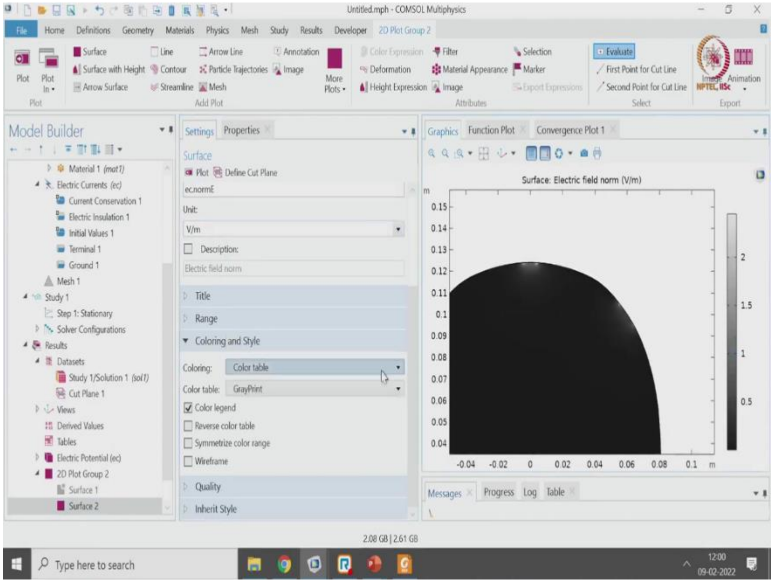

So, now for example, I want to see the how the electrical field is kind of propagating between these two, ok.

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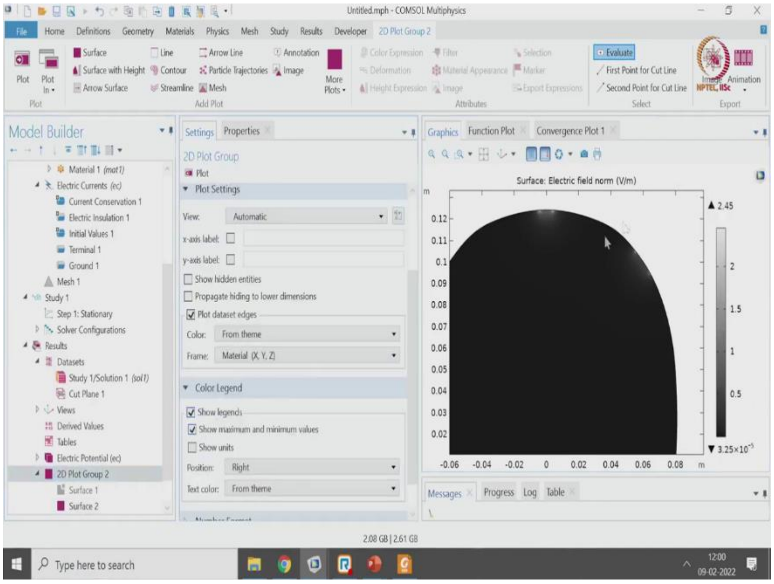

So, here you can see somewhat that the electrical field is high, somewhere over here and here, but I am not visualizing that clear. So, I can just play around with the data range ok.

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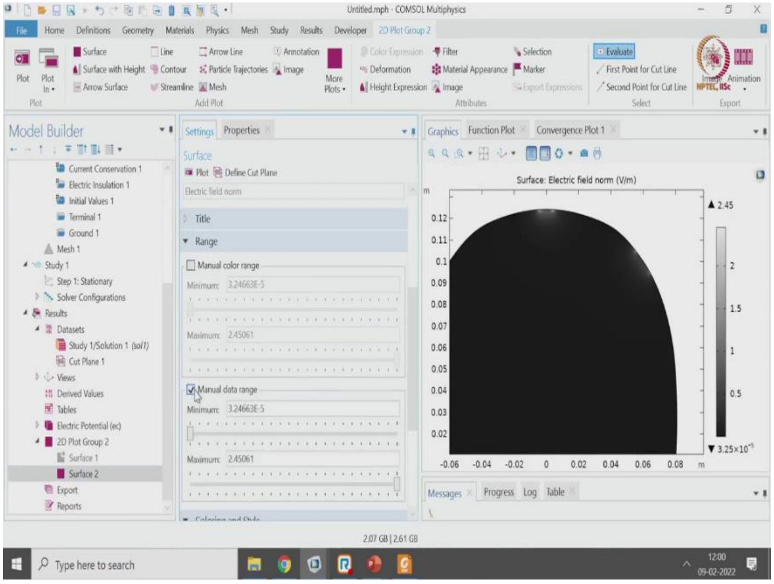

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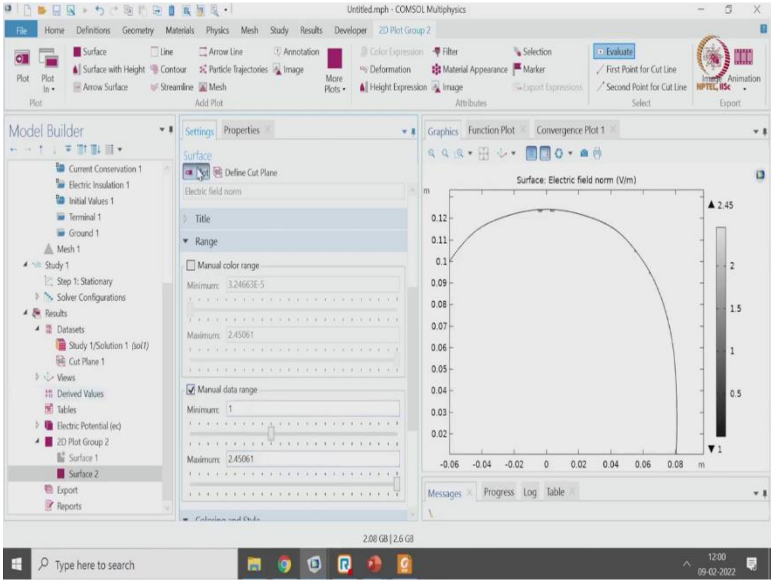

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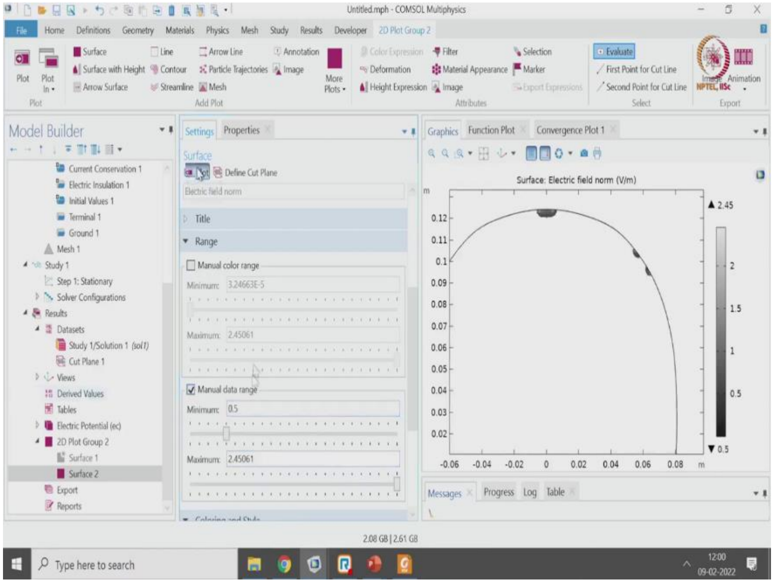

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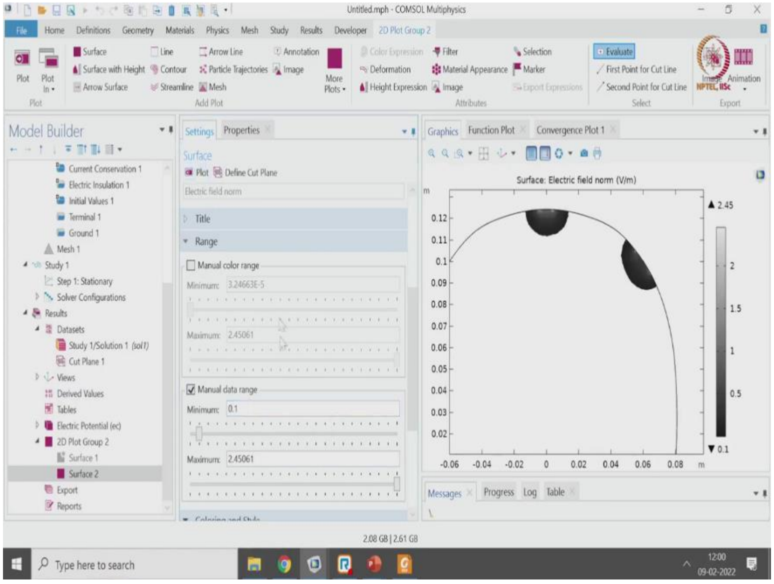

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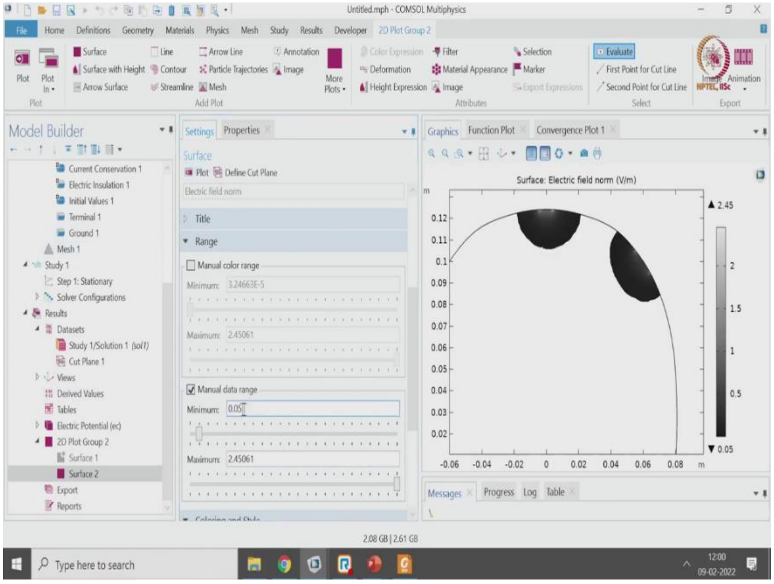

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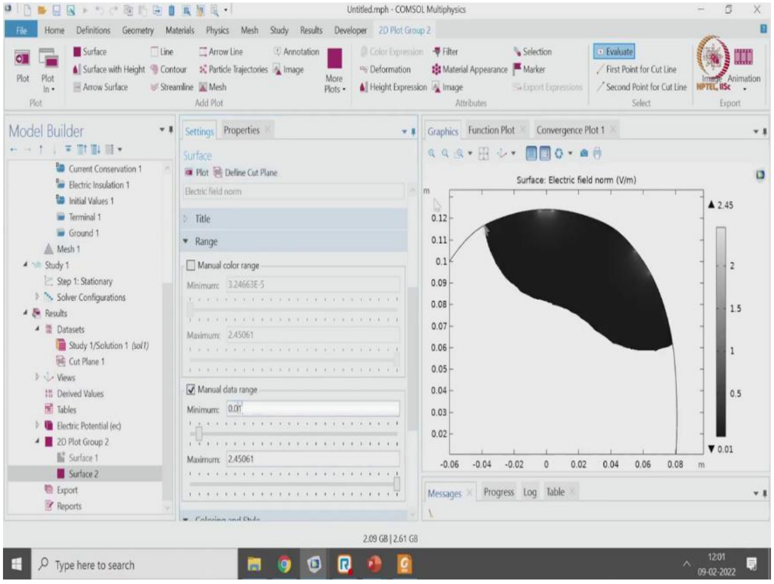

So, I can just play around with that perhaps from maximum to 1 and I can just make it little bit less, I just keep on going little bit less ok.

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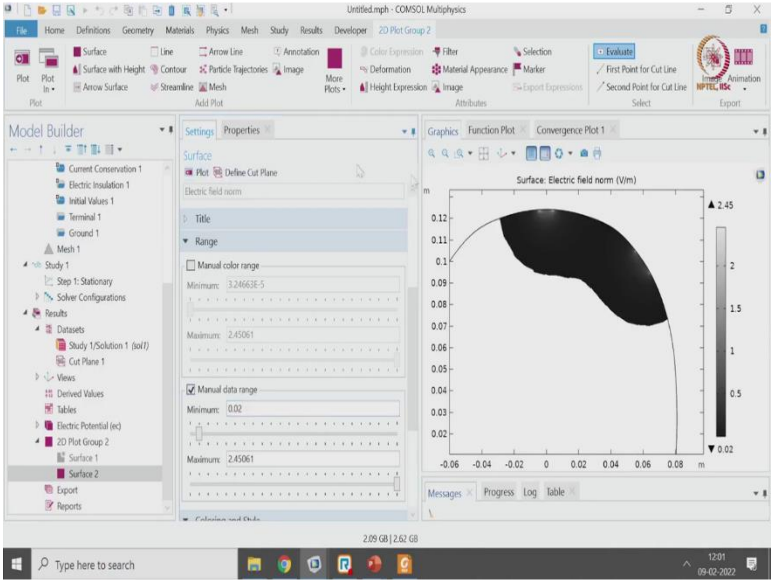

So, here you can see if I have something like this. So, this is the region of electrical field which is at least more than 0.02 volt per meter. I can just choose any other color also.

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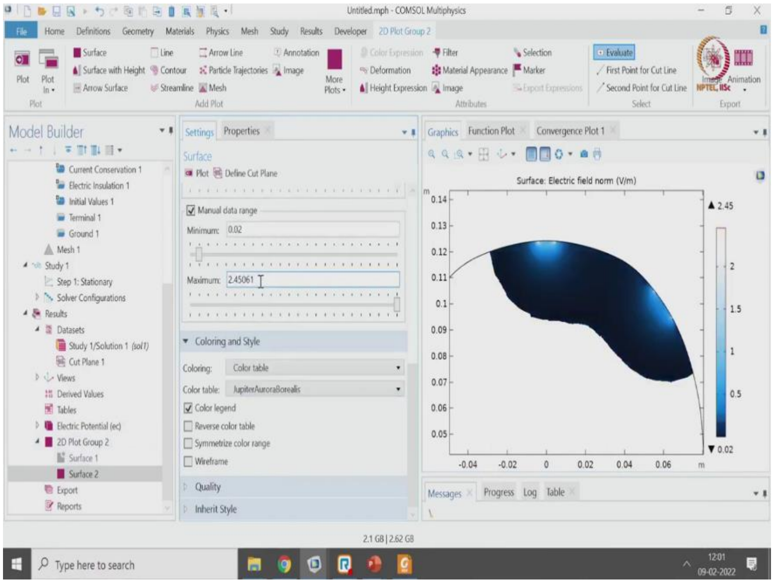

For example, this one is looks better. So, you can see this is the electrical field surface plot definitely little more on these edges of the stimulation because of the discontinuity.

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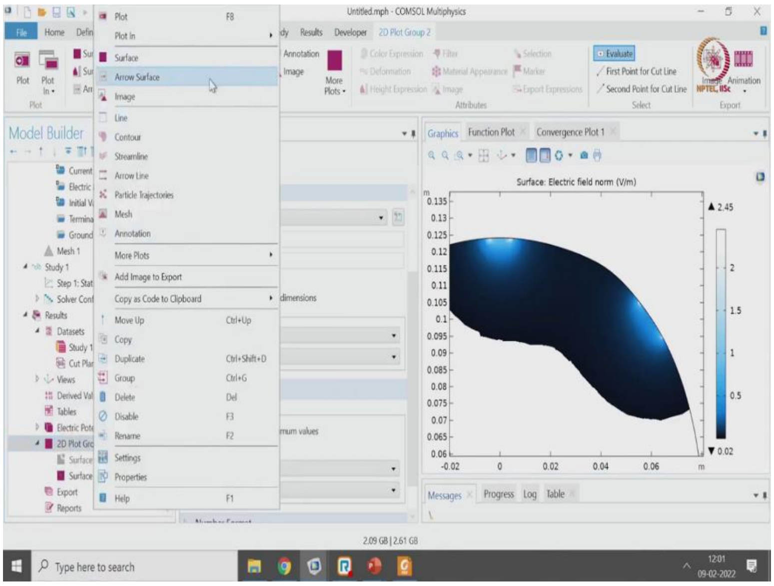

Now, I want to also see the flow of the electrical field. To do that I just right click on the 2D Plot Group, and I click I can use an Arrow Surface plot and again by default it is showing the current. So, let me start with the current not a problem. So, I want to visualize the electrical currents within this profile over here. So, how do I do that? It is already over here color is red, just click on Plot.

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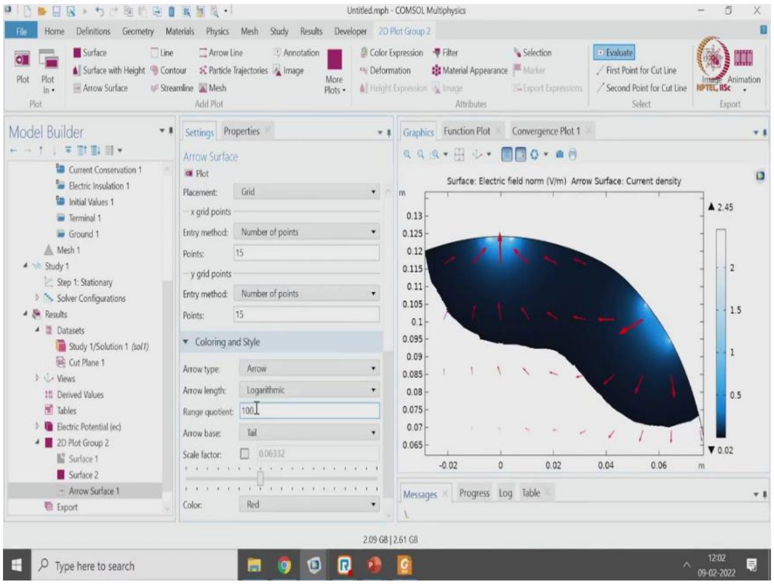

So, here you can see you can visualize the current that is flowing from here and it is coming over here, but it is not that nice. So, what I can do is instead of Proportional I can just choose Logarithmic.

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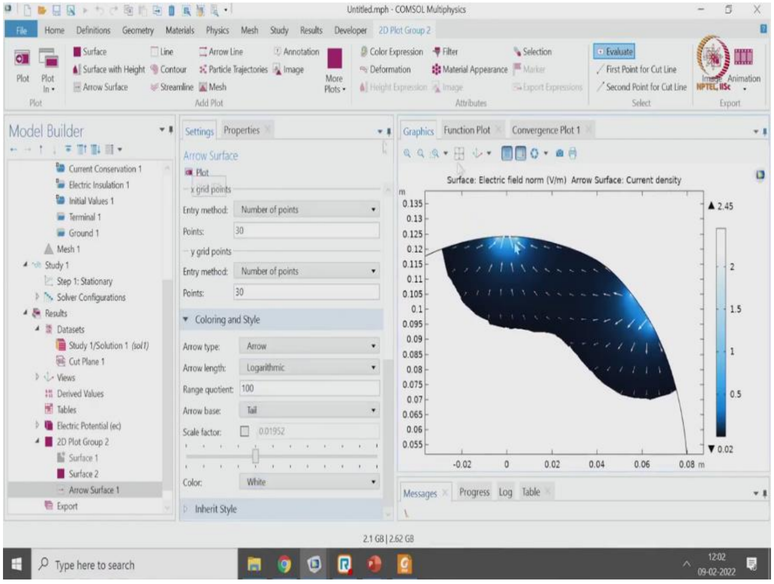

So, Logarithmic plot is what you can see over here I can increase the number of grid points or the number of arrows.

You can see over here I can choose some other colors for example, perhaps white color. So, now, this is looks kind of a better image to see how the stimulation is actually occurring, how much the flow of current is happening over here. You can also plot the electrical field instead of the current.

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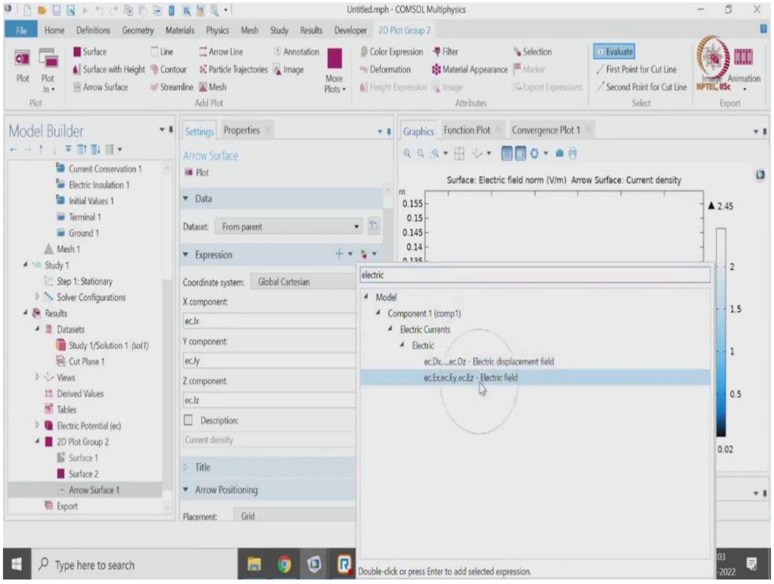

So, you can just change this variable over here and just search for electric field. You just start searching for electric field and you will see these variables over here, Ex, Ey, Ez. Hence just double click on them and click on plot and what you see is very much similar to the current because they are kind of proportional, but the value would be different.

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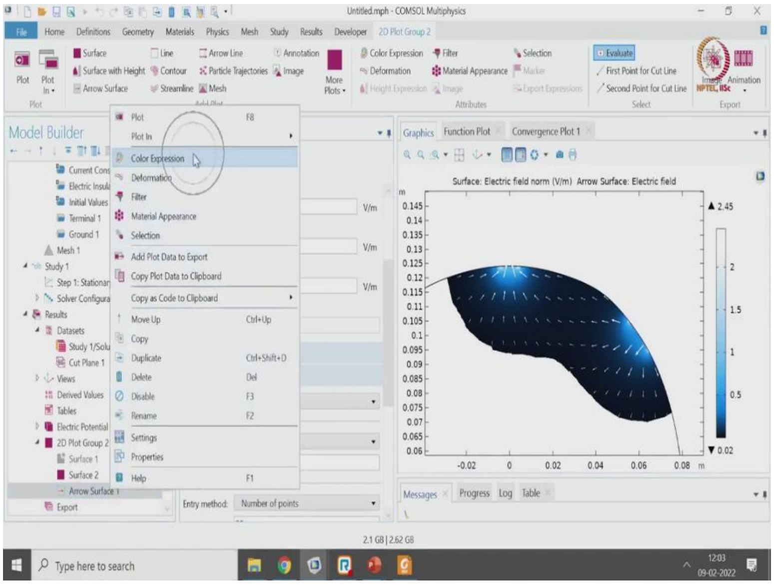

So, what I do I just right click on Arrow Surface, and I click on Color Expression.

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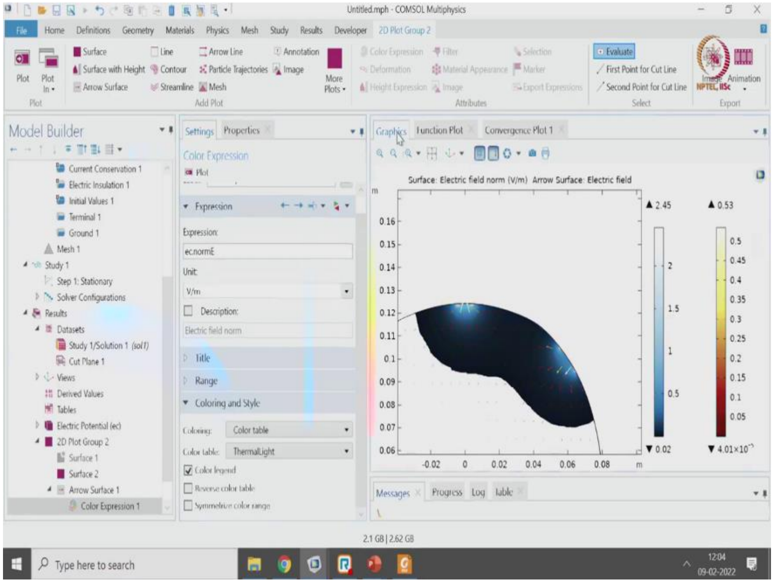

And here I can just write ec.normE and I plot. So, here you can see that I am not just having this electrical field arrows, but along also with the colors ok. So, let me just make check which would be the good color to visualize yeah, perhaps this one.

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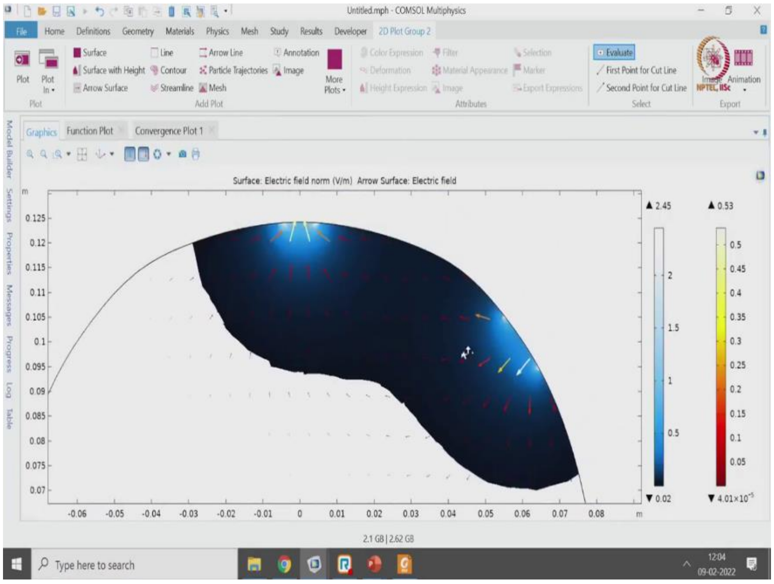

So, here you can visualize that the electrical field is significantly high because this is this legend over here, significantly high over this region over here.

And as you go over here it is little bit high, but in the center, what are the electrical fields comprising of.

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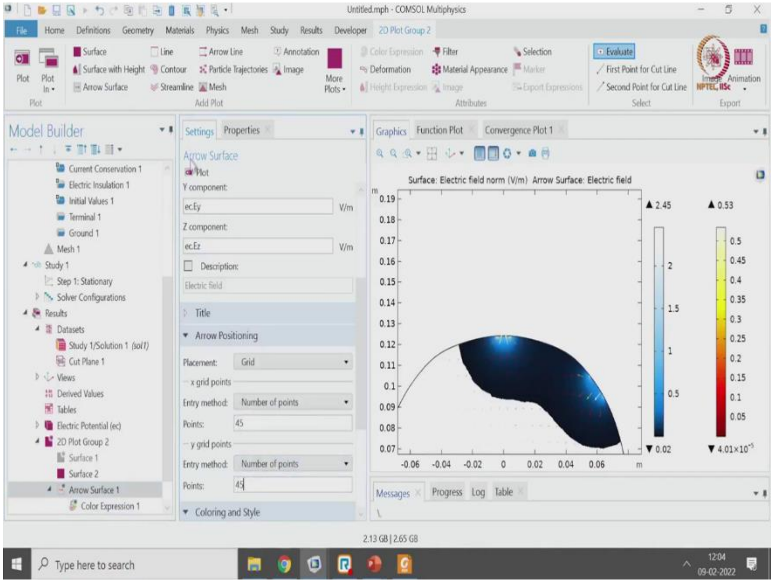

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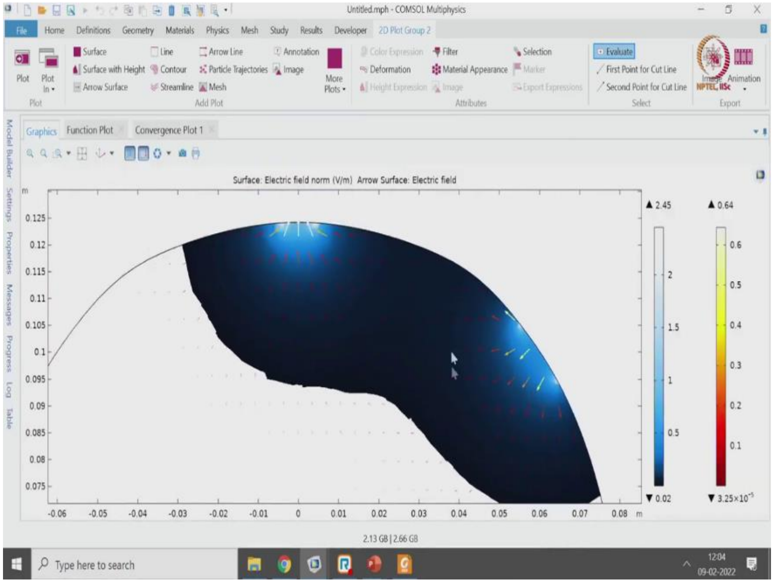

We also increase the number of arrows, maybe perhaps 45 and 45 ok and that gives you a better picture of how the flow of current is happening ok. So, you can also see that the current is also flowing in these regions also ok, looks good.

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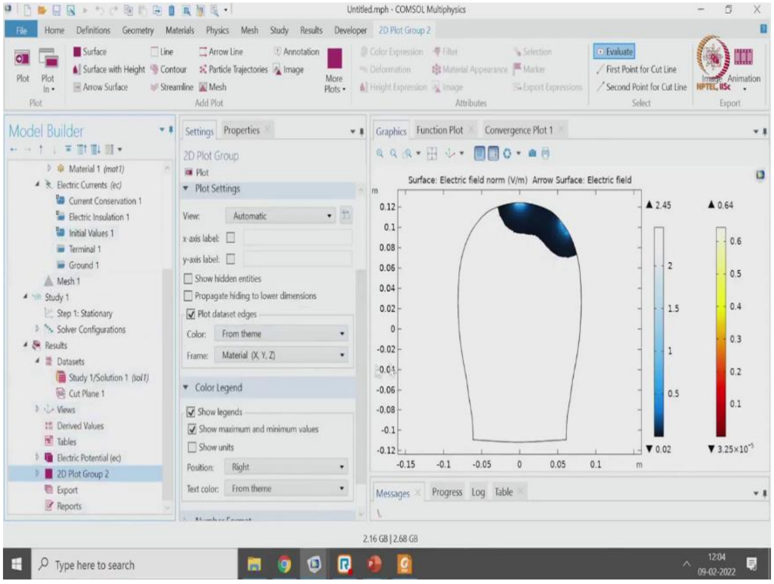

So, this is how you can actually visualize the electrical currents, also the electrical field along with it.

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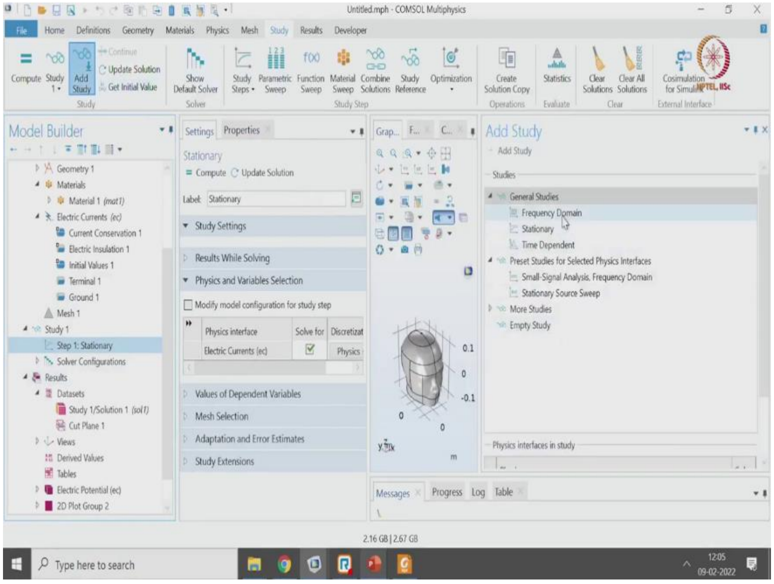

You can also perform not just the DC analysis that I was discussing some time back, but you can also do a frequency domain analysis. To do that it is very simple, just need to go to Study, Add Study and I can just do a Frequency Domain Analysis, just double click on it and then it just asks me about the frequency.

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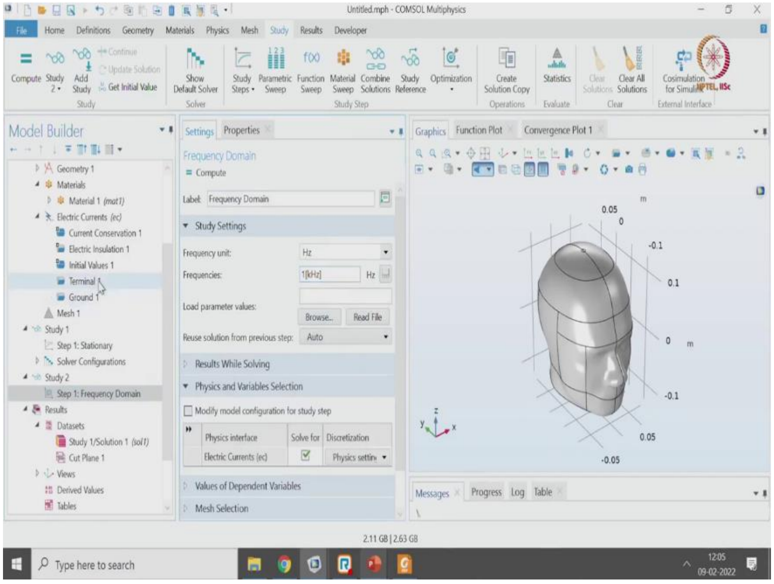

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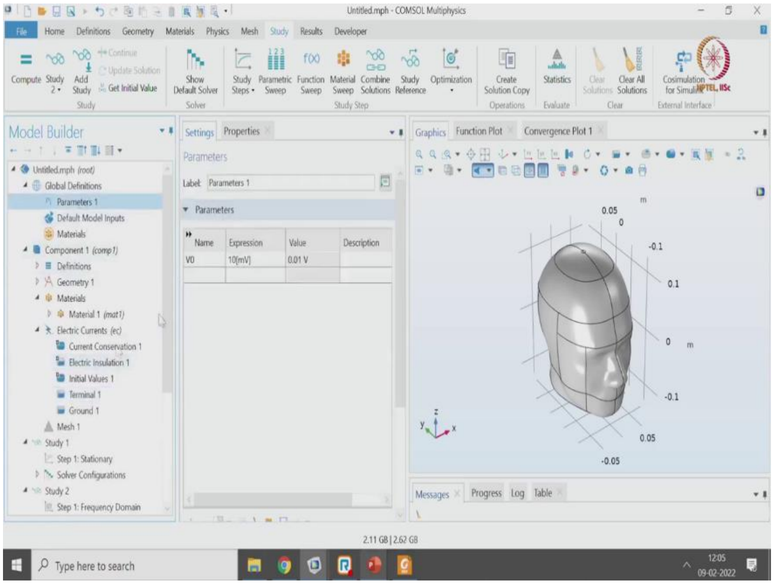

For example, my input frequency is around 1 kilohertz. So, my input is not just V_0 now, that is V_0 which is defined over here this 10 milli volts, but it is now

$$= 10 \times sin(\omega t),$$

where,

$$\omega = 2\pi f$$

and f is 1 kilohertz ok and I click on compute.

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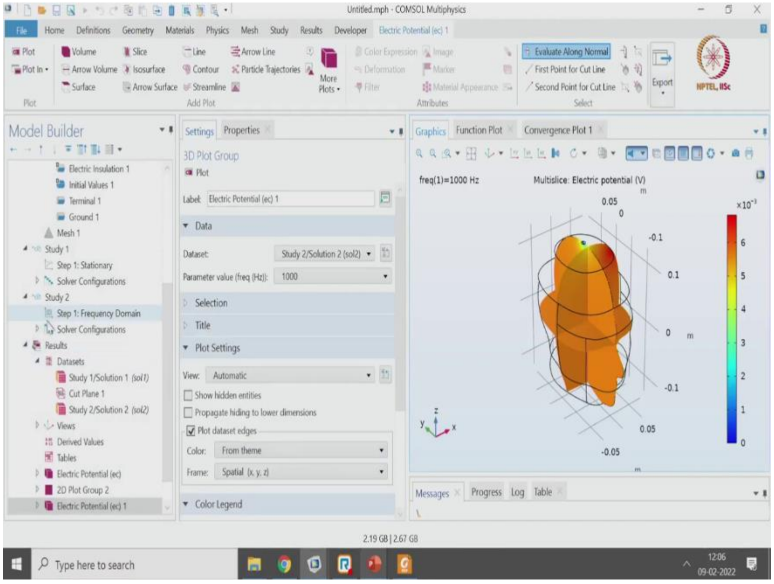

So, that is how simple it is. Once you set up the model just need to add different different studies and you can get the results.

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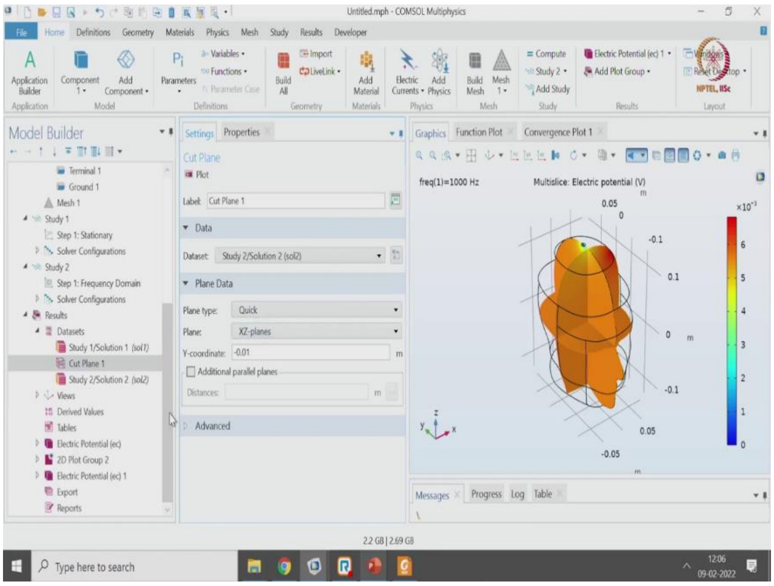

Now, in the Cut Plane instead of Study 1 which is the Stationary analysis or the DC analysis, I will just go ahead and choose the Study 2 that is the Frequency Domain analysis. In this I can now go and see over here, it is showing me a cross over here because it is studying something else.

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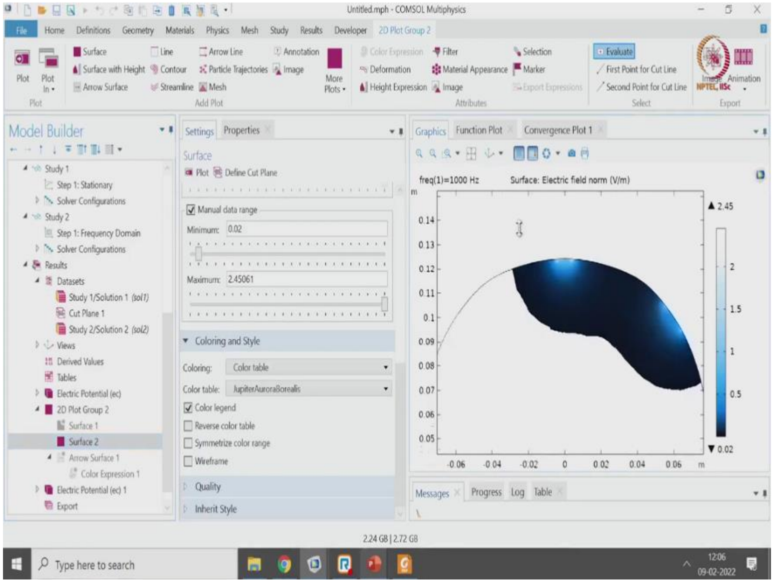

So, yeah in this what we are doing right now is the frequency domain analysis. And the good part of this tool is that with this frequency domain analysis you can do a phase dependent animation.

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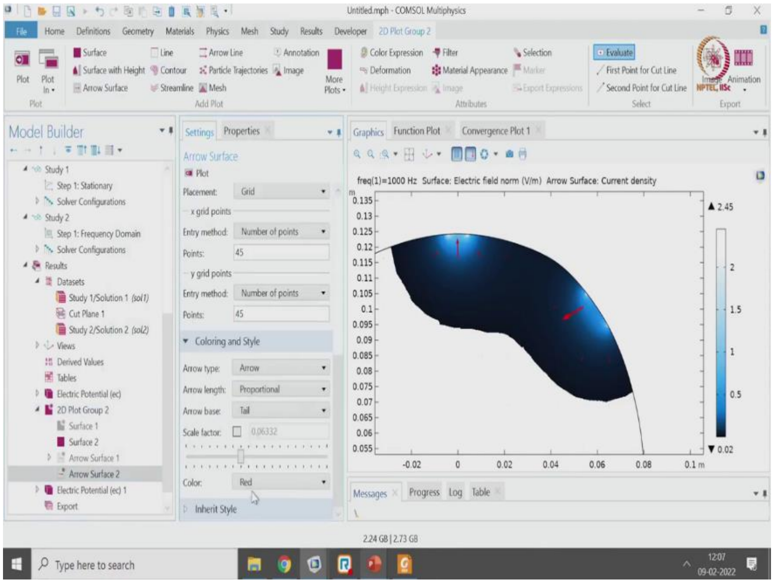

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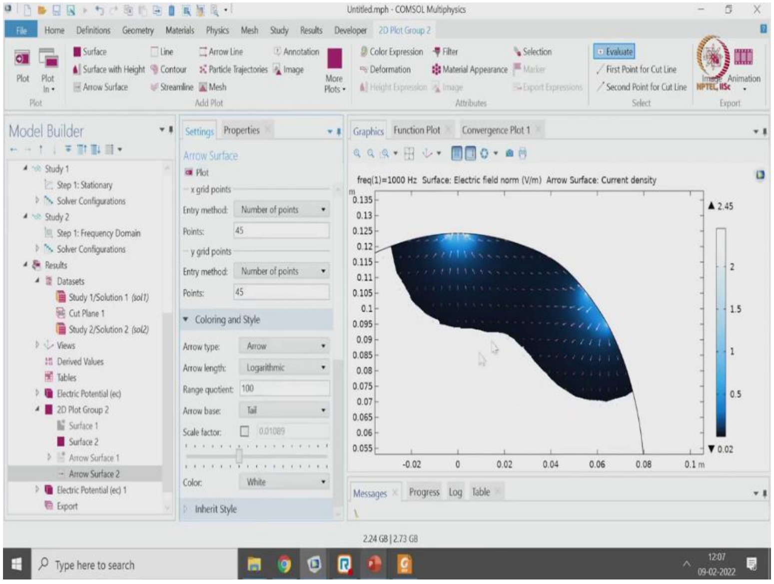

What do I mean by that is if I for example, create a surface plot and I create maybe a 45 45 Logarithmic, yeah perhaps white color. So, you see the current flow as well as the electric potential.

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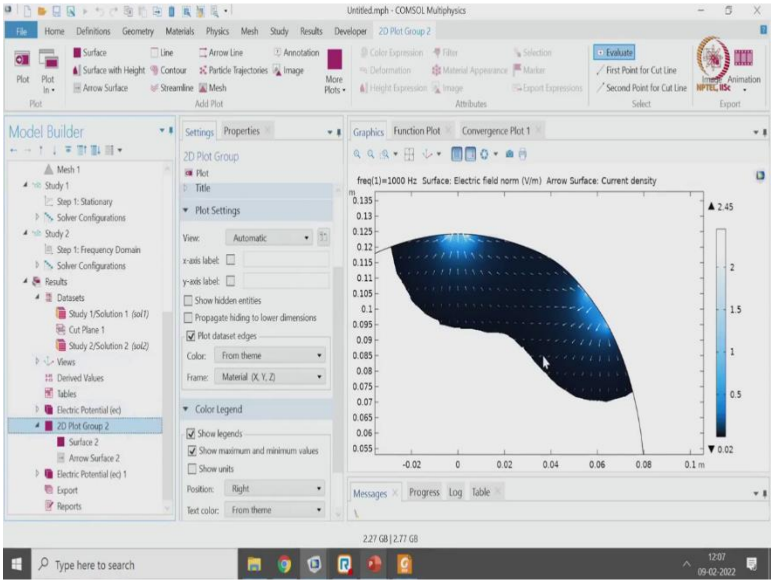

Now, the good part of this tool is that it does the, it solves the frequency domain by solving for different phases. So, it is still a stationary analysis, but it solves at different phases.

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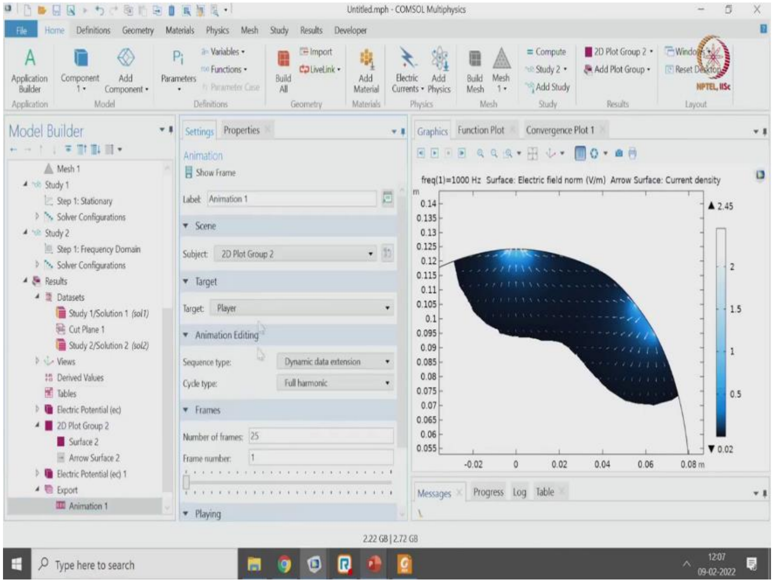

So, phase dependent animation is also possible. So, how do I run that? How do I create an animation? How do I save that animation and use it in my presentation? So, it is very simple. So, I just go to Animation, go to Player and over here instead of Stored solutions I just use the Dynamic data extension and I click on play. So, here you can see how this animation is playing out and I want to play it for infinite time forever perhaps.

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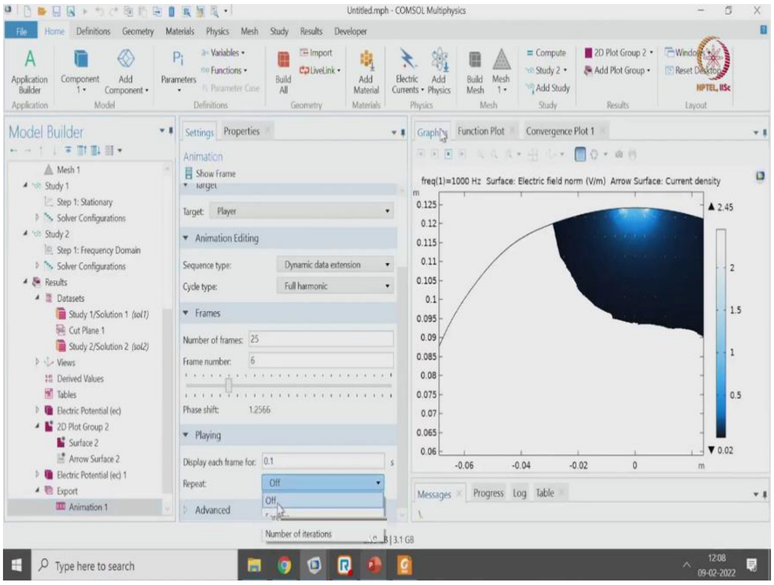

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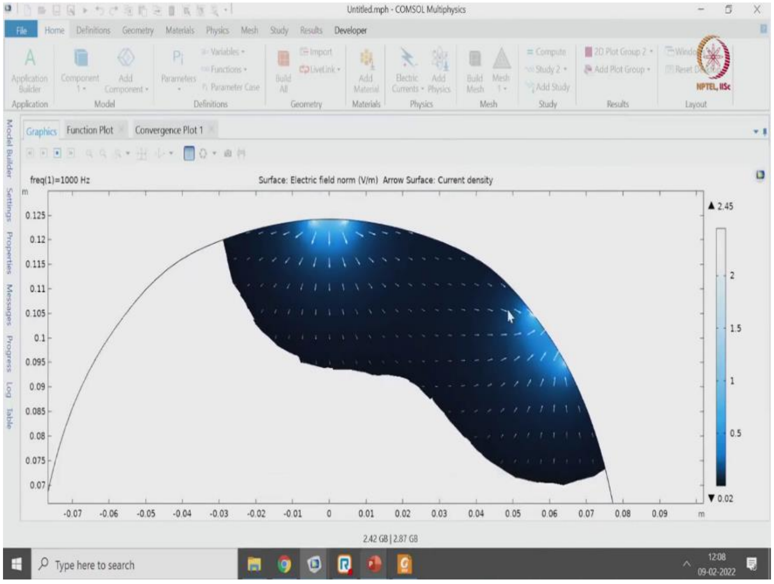

So, you can see how the stimulation is being performed. So, in the if as it is a sine wave it has two cycles. The first cycle is a positive cycle, second cycle is a negative cycle. So, over here you can see that in the positive cycles the current is flowing from here to here and in the negative cycle it is flowing from top to the right side ok. So, here you can see how the stimulation is happening in animation.

Now, the good part is that you can also save this animation in the form of a file and use it in your power point. So, how do I do that?

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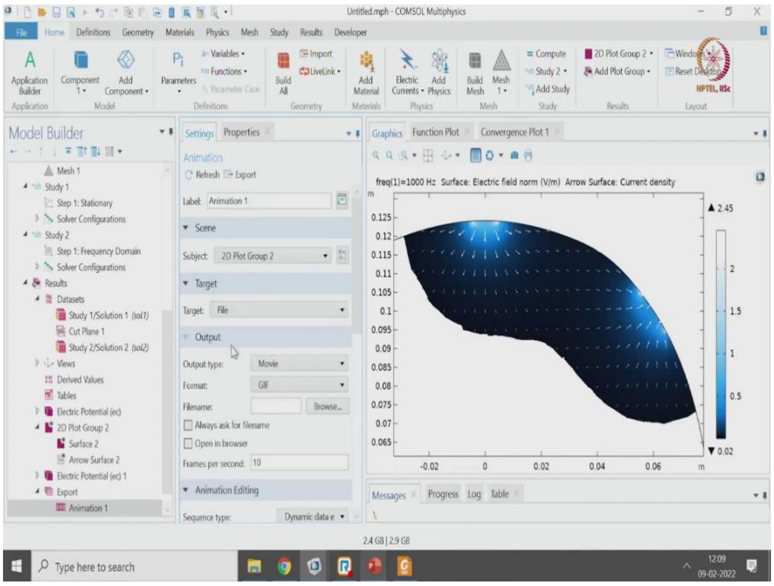

So, and this is very good for showing the results, showing this in a presentation for example. So, instead of target I can use a File and I can use my and that is it, I guess ok yeah. So, I will just keep everything as the default as of now, frames per second I can just make it 5, little bit slow.

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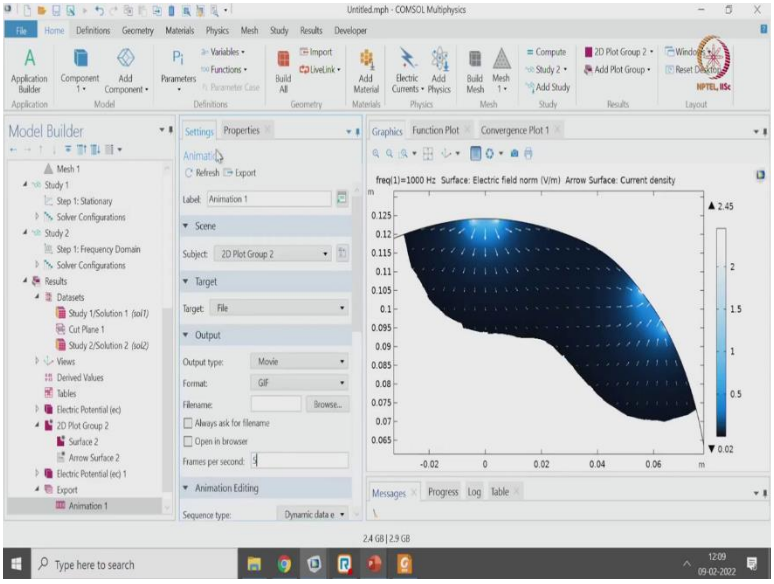

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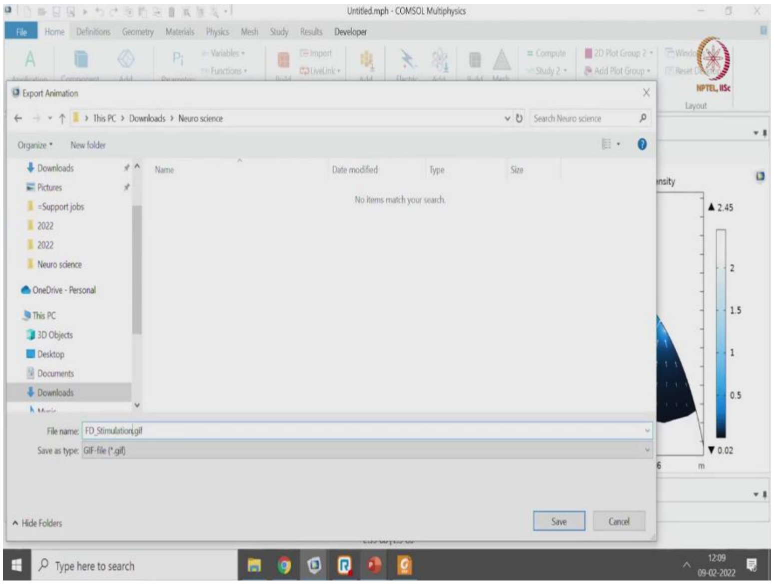

So, FD stands for frequency domain stimulation. So, it has now created that animation it is almost creating this animation. So, meanwhile what I can do is I can just go add a new slide for example.

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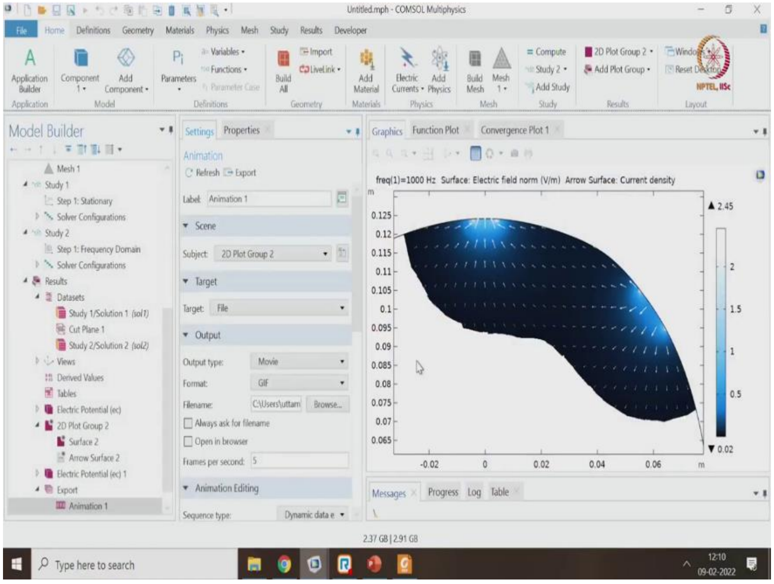

And once it is created, I can just pick and drop that animation into my presentation and this how easy it is to create that animation.

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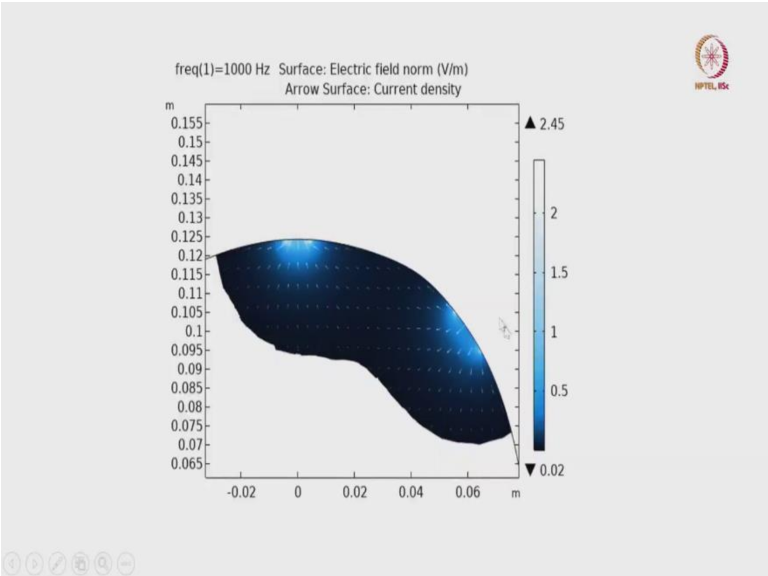

Now, I just go to this animation. Drag and drop over here that is it and I can just go to my full screen, and you can see this animation over here ok. So, it has two cycles, your first cycle this is yeah, the first cycle is this one it goes from here to here and second cycle you can see it goes from here to these positions.

So, that is it, with this session the next session we will talk about multi physics analysis of how you can couple this current that is flowing into the rise in temperature within this tissue. And what are the things that we need to account for this multiphysics analysis in that case.

Thank you.