Transmission lines and electromagnetic waves
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Lecture – 26
Octave Simulation of Perpendicular Polarisation – II

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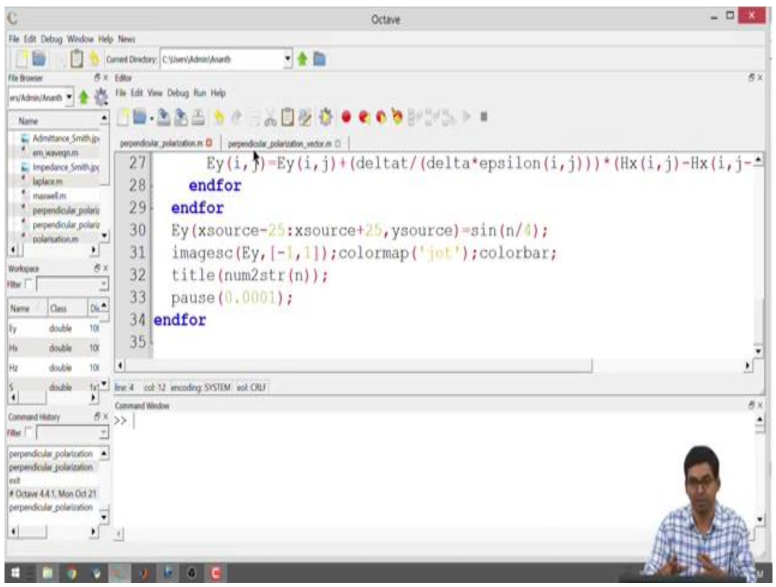

We will get started right. So, the objective today is to make a slightly faster program than what we had written yesterday. Using the same concepts as what we had seen for transmission lines and we use vector updates. We are going to do the first a the the vector updates first and then we are going to see some use cases, we are going to put some interface, we are going to put some multiple interfaces, we are going to plot we are plotting only the electric field, we are also going to see how Hx Hz look like we have also updated them.

So, there are a variety of things that we will be changing in the code once we have a fully working code that is reasonably first ok.

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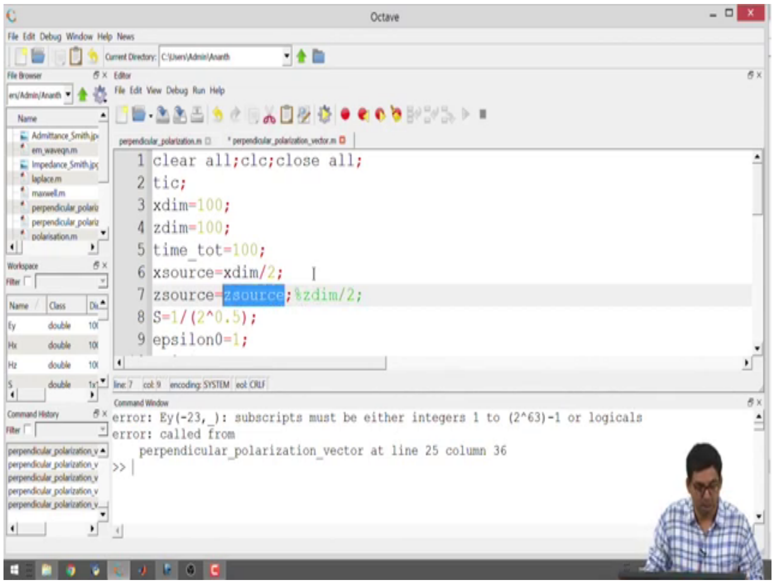

So, I will go ahead and open a new program. I have this program here for reference right now.

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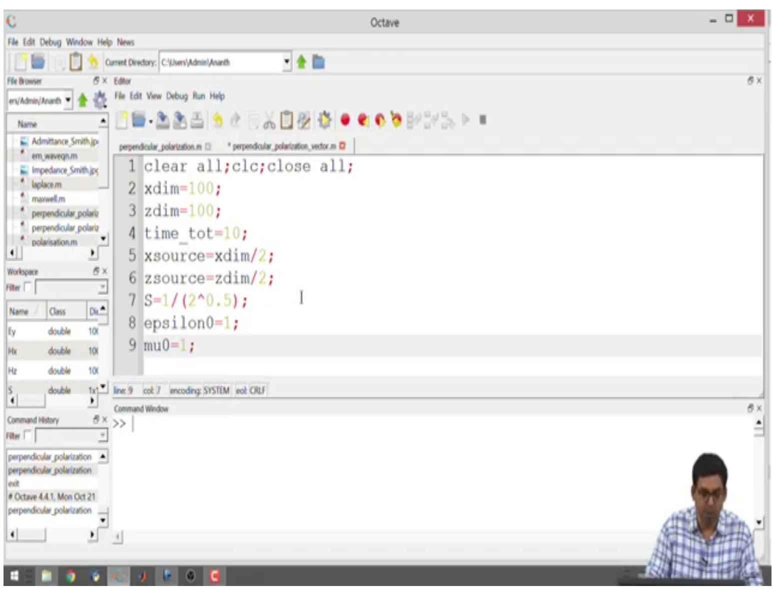

The initialization section will remain the same all right now the less i will go ahead and type it right. So, I will use the same dimensions of the space 100 by 100 space units ok. So, yesterday some people have confused about ydim all right, it's just the y axis of this monitor all right, but just to clarify that confusion will also use xdim right may not we will use zdim. So, that confusion is gone, we are plotting the exact plane right.

The total time for which we will run the simulation, we will keep adjusting this as we go forward. Initially, I will keep it at 10. The reason is I want to check whether the program works correctly. After that I will increase the amount of time right. And I will have the same variables for x source. So, I will be having a point source at the center of the space right.

Yesterday, I used ydim right. Now, I am just using zdim, so that you do not have that confusion going between the x y axis of this monitor and the program. One more aspect that we had seen yesterday was a right the calculation of delta t had some new once associated with it, we had used something known as a current stability factor. We did not go into a lot of details because that is an advanced topic, but for the 2 D case you have to take care of this number all right and the number here is 1 by square root 2 all right in the case of vacuum.

So, we will just keep that number in the code. Remember the objective of these lectures is not to go deep into the computational aspects of electromagnetic at all. It is just to give you a working example to start with, so that at the end of the course you have a set of programs using which you will be able to manipulate things and go on. Also it will form a strong base for the advanced level courses all right. Where you will have the basic skeleton then you can go deeper into each and every aspect of the code and start learning more from it right.

So once again we are using relative as you know units. So, what we are trying to do here is we are setting the permittivity and permeability of vacuum to 1. Just like yesterday, which means that the velocity in free space or vacuum will be considered as 1 and everything else will be considered with respect to the velocity in air right this is done. So, that you do not have approximation errors while doing some updates because it is a very tiny number all right you do not have any 0 errors coming into the picture. Similarly mu0 is equal to 1 ok.

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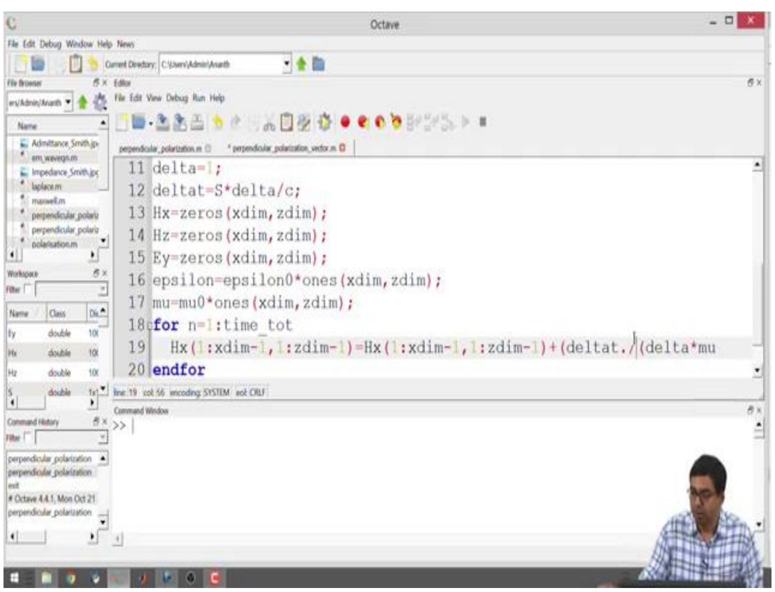

Consequently, a velocity becomes equal to 1 in vacuum at least right ok. Space steps in both x and z directions are set to 1. The only thing that remains is calculation of delta t ok so, that is s times this is the only change that we had made right. Delta t calculation had to be taken into a you know a it has to take into account the distance traveled by the wave in a diagonal direction in a 2 D grid all right.

So, the distance is multiplied S times delta divided by c ok. Now, we just need to initialize some variables Hx Hz Ey Hx we sought with all zeros ok. You are just using xdim comma zdim. If you did happen to use the same initialization as yesterday, you have to continue with the same variable names there are no problems with that all. Hz same electric field y direction. So, we are considering perpendicular polarization.

So, another thing that we want to do today for which we did not have enough time in the last lecture is want to change permittivity in different regions and we want to closely analyze what is happening at least visually. We know that when we have a single interface, we are going to experience some reflection and the reflection is going to have a reflection coefficient that is angle dependent because you had $Cos\theta_t$ $Cos\theta_i$ coming into the picture for the reflection coefficients. You also had a transmission coefficient that was also angle dependent all right.

So, we would like to be able to see if not everything, at least for the normal incidents case what does the visual picture look like. When you have a you know waves going traveling forward and then hitting the interface coming backward what happens to the region in between we need to see a few of these aspects. And then we have to see if by using this program I can open up a new topic for discussion in the following weeks ok.

So, I want to be able to have the freedom to change epsilon at different places. So, epsilon has to be a matrix whose dimension is xdim comma zdim this space. So, I will be able to address epsilon at each and every point right. So, I am going to have epsilon 0 multiplied with once of xdim comma zdim. So, as of now, the epsilon matrix will have all ones at all the spaces later on I would change the epsilon at specific coordinates ok. Similarly, I will be having mu to be mu naught times ones of xdim comma zdim ok.

Now the initialization part is over. This is identical to the code that we had yesterday, except that instead of ydim I am just using zdim. So, the people do not get confused at all still in the exact plane ok. Now, we had a giant time loop. So, I will write a for loop right n equal to 2 to time total.

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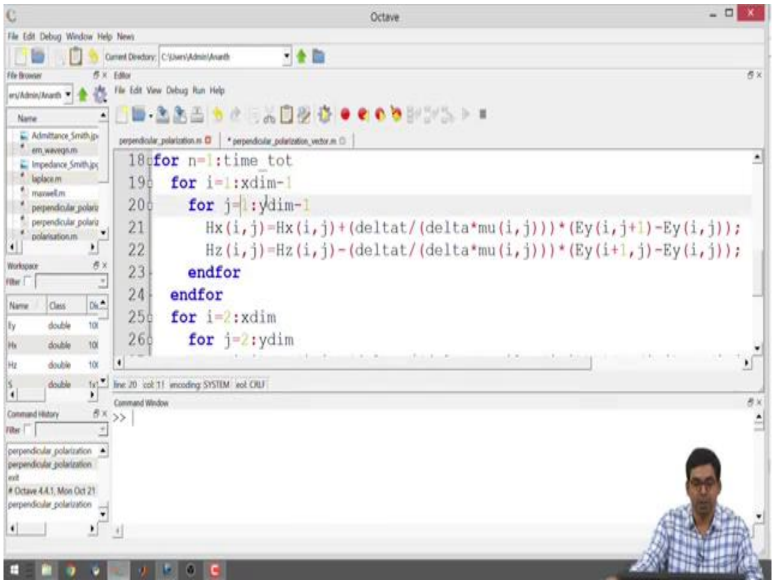

So, for all instances of time I want to make use of the different forms of the Maxwell's equations for this particular polarization configuration and I want to create some updates for the electric field and the magnetic field right.

So, yesterday we had to use two for loops, one loop was going for the magnetic field calculation. Another far loop for the electric field calculation. This is simply because for the magnetic field calculation we had used a forward difference for the spatial derivative of electric field all right. So, the limits are different when you take forward differences. So, you have to go from 1 to xdim minus 1 1 to ydim minus 1.

Whereas, when you were calculating the electric field update, we were using backward difference for the magnetic field. So, we needed to have 2 for loops all right. And what we are doing today is we are still sticking to that all right, but the objective is to remove this for loops and use vector updates all right ok. We are still going to continue to use forward and backward differences, but we are just doing it by vector updates ok.

So, all I want to do is remove for loops alright and I want to incorporate this i equal to 1 to xdim minus 1 j equal to 1 to xdim minus 1 extra into this part over here all right. Wherever, I have array indices and remove the for loops internally octave will take care of calculating them by distributing them in a better more efficient way than a for loop which is a serial calculation right. So, we go back to the program ok. So, I look at the first line of what I had yesterday, I had Hx of i comma j all right.

So, I had Hx of i comma j equal to Hx of i comma j right, but this i and j were being defined in the loop all right. So, I varied from 1 to xdim minus 1 j varied from 1 to xdim minus 1. So, all I need to do in my code now is I need to stop using i and j and directly use the definition of i and j from the for loop. So, I will just go ahead and replace i with 1 colon xdim minus 1 and replace j with 1 colon zdim minus 1 right. Again 1 colon xdim minus 1 and j will look like 1 colon zdim minus 1.

So, all we are doing is from the previous program, we are removing the for loops and the definition of i and j right. We are going to plug it in directly into the update itself. So, suppose I have a comma j, I will be replaced with 1 comma 1 colon xdim minus 1 j will be replaced with 1 colon zdim minus 1.

Suppose, I had i plus 1 it means that you will take the lower limit which is 1 add 1 to it it will become 2 and the upper limit xdim minus 1 you will add 1 to it it becomes xdim all right. So, wherever you have i plus 1 you will substitute for the lower and upper limit, do the algebraic operation and then put them back in the code all right. So, there is no big change over here, but will go over it systematically at least for the first update over here right.

So, I have plus delta t ok ok. Now compare to the program yesterday. Yesterday, we had delta t divided by delta times mu of i comma j ok. Remember that when we are executing something inside this for loop this delta t is a single number according to our definition delta is a single number. So, it is 1 a for delta alright and it will be S multiplied by delta divided by c. S was 1 over root 2. So, it is a single number which will be substituted here mu of i comma j is a single number ok. Now since we are doing this slightly differently now because we do not have a loop, we want to be explicit by using this dot operator in front of division multiplication just means that.

Whenever you are going to a mu's now going to be a matrix, mu of i comma j will be like mu going from 1 colon xdim minus 1 comma 1 colon zdim minus 1 you have to pick up specific elements and multiply it at that instant of time. So, in order to tell that we are going to be using an array it is better to use dot slash. It just means that every element of the array will be multiplied with this number all right.

It would not attempt to perform matrix multiplication or matrix division. Remember matrix multiplication would be like you take a row and multiply with the column of the second matrix and then you fill up the first element we do not want to do that ok. So, in order to say that take the corresponding elements and multiply them or take the corresponding elements and divide them you can use the dot operator right.

So, I want to be clear. So, I just use the dot slash. So, far delta t is a number delta is also a number, but mu is going to be a matrix and according to the program I had was mu of i comma j all right. So, i is replaced with 1 colon xdim minus 1, j is replaced with 1 colon zdim minus 1.

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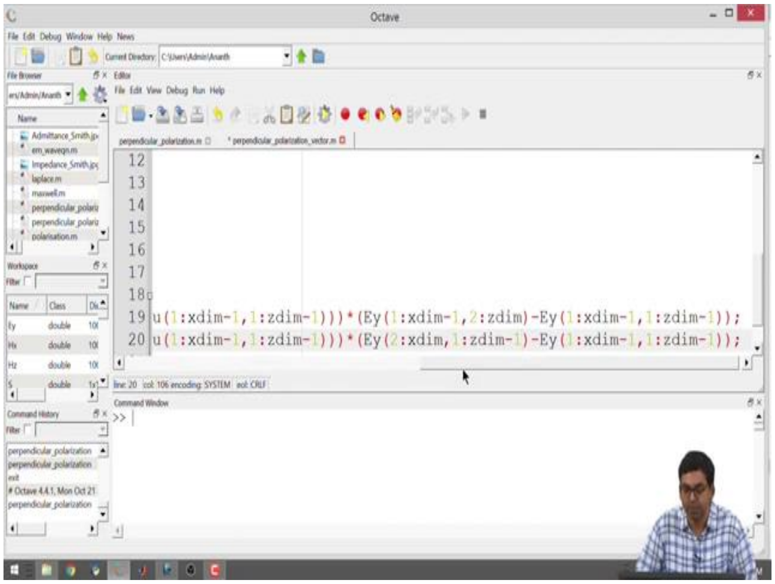

So, I will close this entire term and then it was multiplied with the derivative of E right. yes, go backward and I will keep this part here. So, I had Ey i comma j plus 1 minus Ey i a i comma j. So, all I need to do is I need to use the same thing instead of i. I will use 1 comma xdim minus 1 j plus 1 we will look like 2 comma zdim all right. So, I need to substitute for again Ey of i comma j. So, I will go ahead. Ey of i comma j plus 1 becomes 1 colon xdim minus 1 comma 2 colon xdim i comma j plus 1 ok. So, 2 colon xdim minus E y.

Student : (Refer Time: 15:26) 2 colon zdim (Refer Time: 15:29).

Ah 2 colon zdim I think I made a mistake good ok. Towards the end I place a semicolon I will just wait for everybody to catch up with the code ok. So, now, I will proceed for Hz ok which is in the same loop right.

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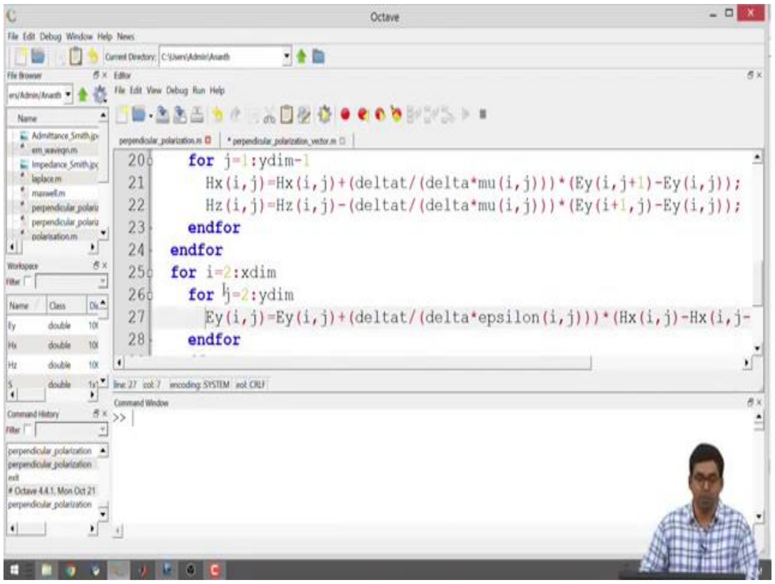

So, I will go ahead for the next slide and I will insert a new line for Hz. So, if I look I have Hz of i comma j is equal to Hz of i comma j minus something. So, I will systematically go Hz of i comma j looks like 1 colon xdim minus 1 comma 1 colon zdim minus 1 is equal to Hz of i comma j plus some update terms. So, it is minus delta t divided by delta.

So, what I will do here is I will just copy from the previous line ok. This coefficient ok I will just copy from the previous line because it is identical ok. This part is identical alright and I need to have i plus 1 comma j for the electric field minus Ey of i comma j. So, I am going to go back to the program. Once again I would just go into copy paste from the previous line and then manipulate it.

So, I had i plus 1 1 comma j. So, i plus 1 will make it 2 to xdim and 1 comma z 1 colon zdim minus 1 for z and the last term is anyway Ey of i comma j. So, it remains the same ok. Now, we have another loop for calculating the electric fields in the prior lecture, we are going to remove that the extent of the loop was going from 2 to xdim and 2 to ydim all right.

Now, all we have to do is replace i and j with 2 to xdim and 2 to ydim. So, we will have another line for E y. So, I will just take Ey of i comma j plus something till here, I will copy it I will paste it start replacing things ok. So, I have a comma j, but comma j now the definition is 2 to xdim 2 to ydim all right.

So, it is different from the previous loop. So, we have to be a little careful. So, it is looking like 2 to xdim. So, I will put that as j is 2 to zdim all right is equal to Ey of 2 colon xdim ok plus I have some coefficient for the derivative of the magnetic field.

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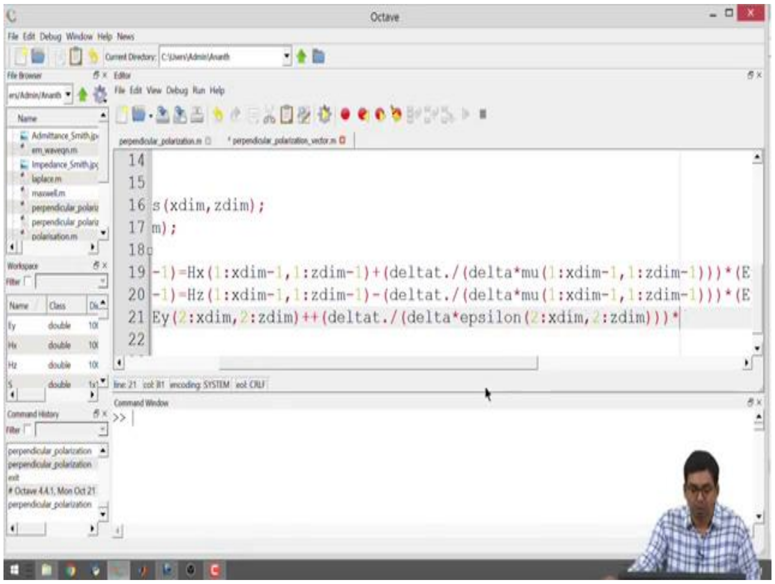

So, previously I had delta t divided by delta times mu of i comma j. Now, I have a similar form I just have delta t divided by delta looking identical to the prior updates instead of mu I am having epsilon of i comma j all right that is all. So, I can go back to my program from the previous lines, I could copy this coefficient based on the current line and make some adjustments ok. So, instead of mu I had epsilon and instead of i comma j previously i comma j was 1 colon xdim minus 1. So, I have to make it 2 to xdim and I have to make it 2 to zdim all right.

These are some 2 changes that you will have to make: 1 is you will have to change your mu to epsilon and the other one is changing the i comma j definition all right. Once you have this then the remaining part, we will have to fix its going to be a long equation, but all right. So, I have Hx of i comma j right. So, I will start with this 2 colon xdim i comma j will make it 2 colon zdim ok minus Hx of i comma j minus 1.

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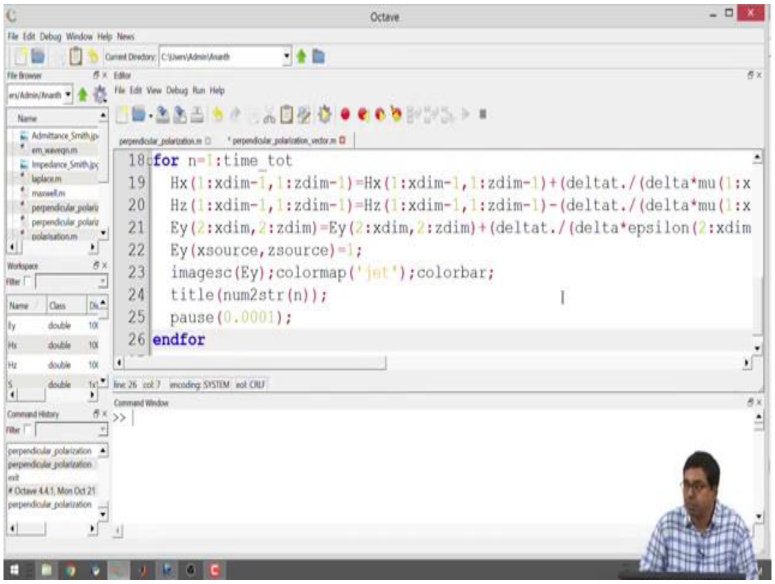

So, I am just going to take this part. We have to put a minus sign and Hx of i comma j minus 1, we will make it 1 colon zdim minus 1 ok just then I have Hz of i comma j.

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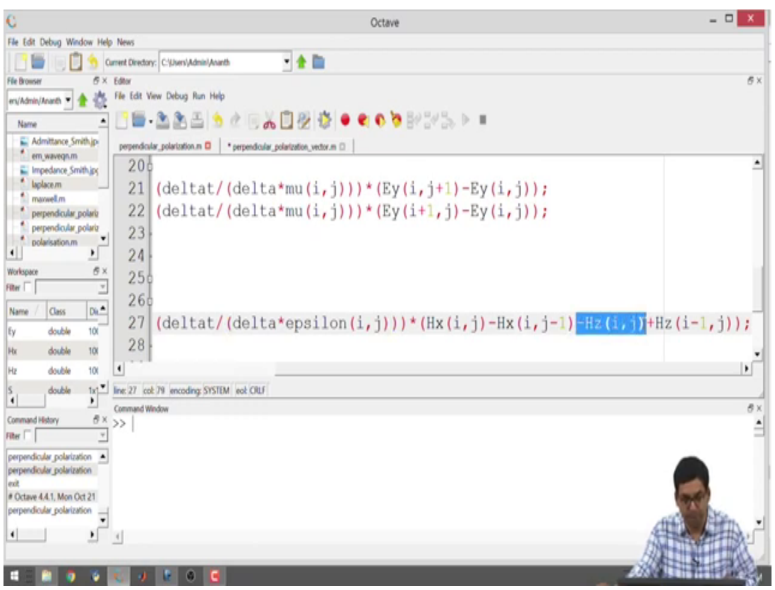

So, it is minus Hz i comma j. So, I will just copy this part. So, instead of I once again I put 2 colon xdim instead of j I put 2 colon xdim.

Student : Sir.

Yeah that is it and the last term is some plus Hz i minus one j. So, I will just use instead of i minus 1 I will have 1 colon xdim minus 1 and j will look like 2 colon zdim just check with the bracket closes ok.

Student: (Refer Time: 23:23).

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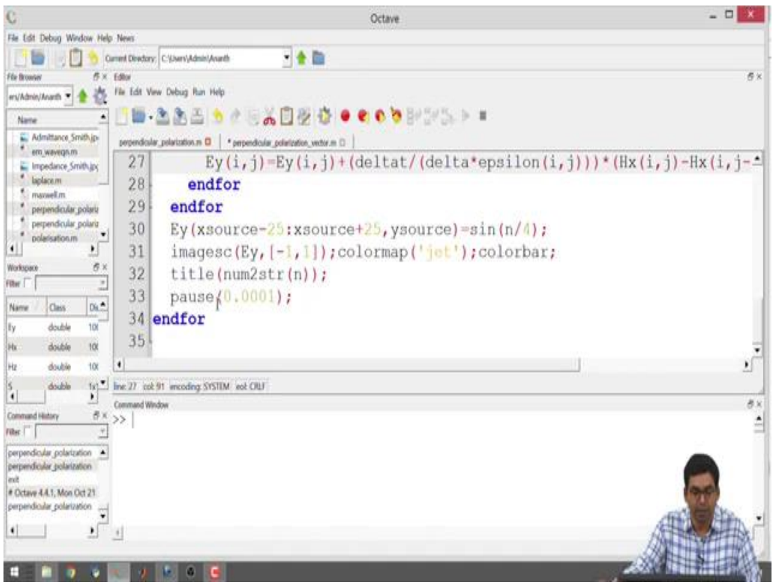

All right.

So, now we have finished creating the updates for all the quantities all we need to do is set a source and make some plot comments ok. So, we will set a source at x source comma y source as we wish right. So, I will be having Ey at x source comma z source is equal to 1. So, right at the middle you will be having a source being set to 1 and then some plots ok.

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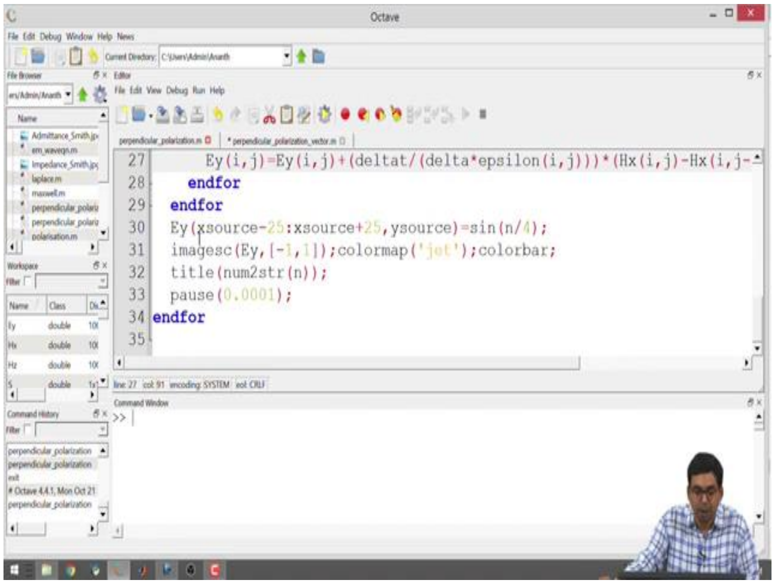

So, I am just going to all right.

Student: (Refer Time: 24:13).

I will just do images c of Eye color map will be z and I want the color bar to be present right

Student: Ey plus plus 2 times (Refer Time: 24:31).

E y what?

Student: Ey that is 2 delta plus plus 2 (Refer Time: 24:37).

Hm ok good ok. I will also give it a title just like in the previous class right num 2 s t r of n. So, I just want to know which time step it is showing me the plot for and then as usual we will have a pause command. So, that we can see the plot right ok. So, now, we are done and now, you can see that the code looks a little bit more simpler, you can clearly understand that there are 3 lines for doing essentially the Curl equation update. The remaining are just definitions of quantities; plot commands extra right.

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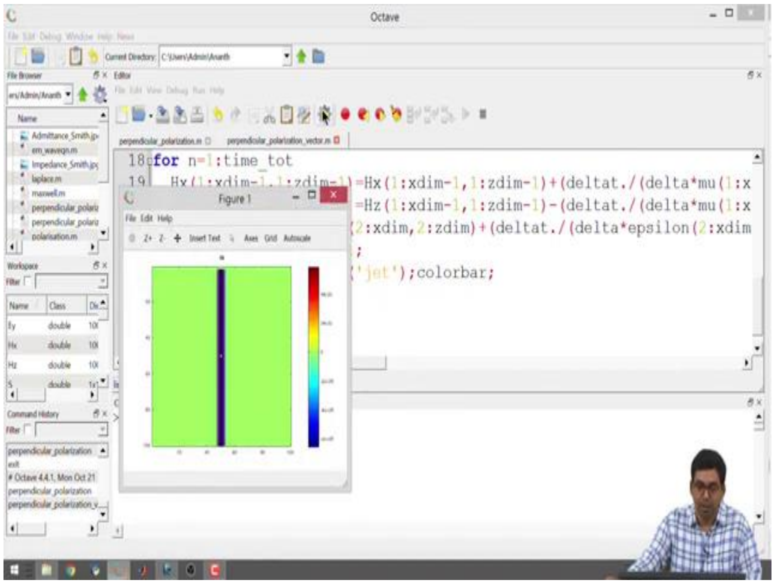

So, it is a much cleaner code. Let us try to run it and see whether we are getting something right or something is not all right. So, I am having an error somewhere ok. So, ok I think I understand what is going on. There is a tiny error that can be easily fixed all right.

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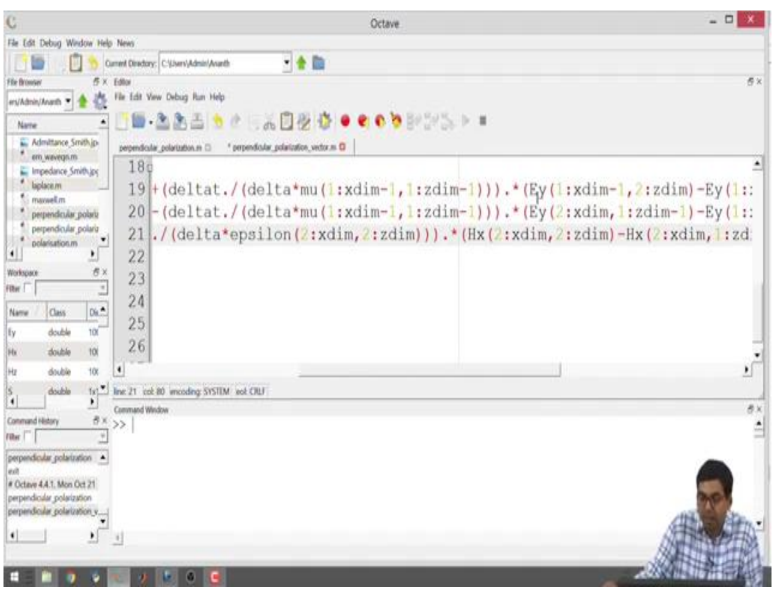

I think when we are dealing with the mu and epsilon doing this inside this and then we are multiplying it with Ey all right and then Hx we have to be a little careful. I think we have to say that it has to be an element twice multiplication again all right.

So, just the error is very tiny it can be fixed. In the first line update for Hx after the delta t by delta mu calculation instead of this multiplication sign just put a dot in front of it. It's attempting to do matrix multiplication there right. Same way in the second line of code place a dot here third line of code place a dot here that is the error

It is attempting to do matrix multiplication there whereas, we need individual element twice multiplication ok. Just go ahead and run this now all right there we go ok.

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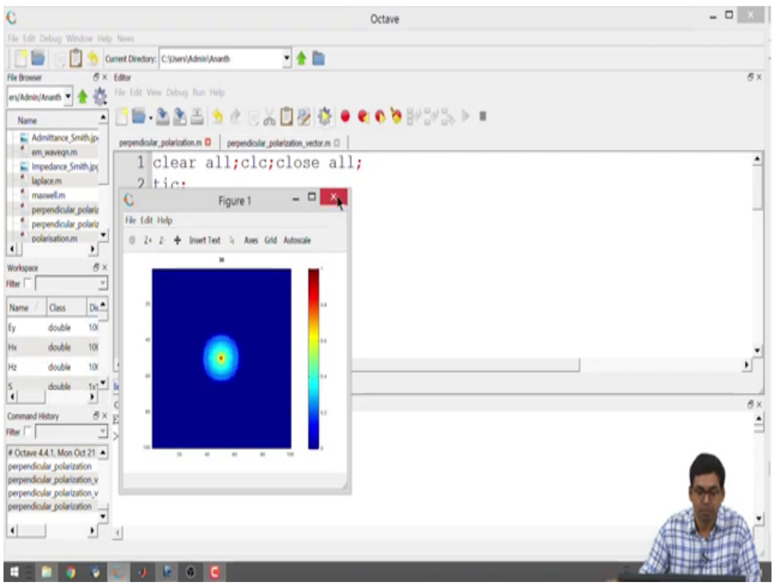

So, now, I have a code that runs right. Now, I would like to just get a feeling for the code that we had before and the code that we have now. So, I am just going to take the prior code and make the time total equal to say 20 ok.

And I am going to keep x source as xdim by 2 ydim by 2 extra. I am going to be having a similar source. I will not give any additional parameter ok 0 0 0 1 ok. So, I have identical codes. All I just want to do is I want to just get a feeling for the amount of time it takes to do all this all right.

So, I will put a tic command here and at the end of the code 1 have a toc all right. So, I will go ahead and run this code first. This is just for our information ok. It is about 17 seconds ok with the for loop. Let us just have a look at what is happening with this. So, I had once again a tic the toc and I think the number of steps was 20.

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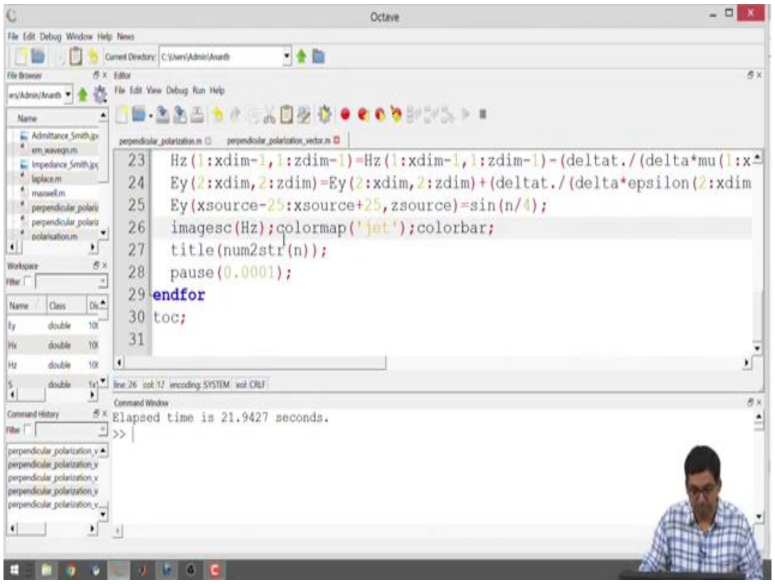

. So, hardly three and half seconds. So, you get a tremendous uh update speed over here. So, it is that is why we spend this much time because it is a 6 times speed up just by changing the loops all right. This makes it a little bit more convenient for the stuff we are going to try in the class right.

So, the first thing that we can do now is start to put a source which is slightly different and yesterday, we talked about how to make a plane wave source. Now, we are having a circular wave front that is going all the way. So, yesterday one of the things that we were doing is we were using this x source minus 25 to x source plus 25 ok. If I make this change over here, I will have a bunch of points ok.

Student: (Refer Time: 29:23).

I will have a bunch of points acting as a source no longer is a point source right.

Student: (Refer Time: 29:39).

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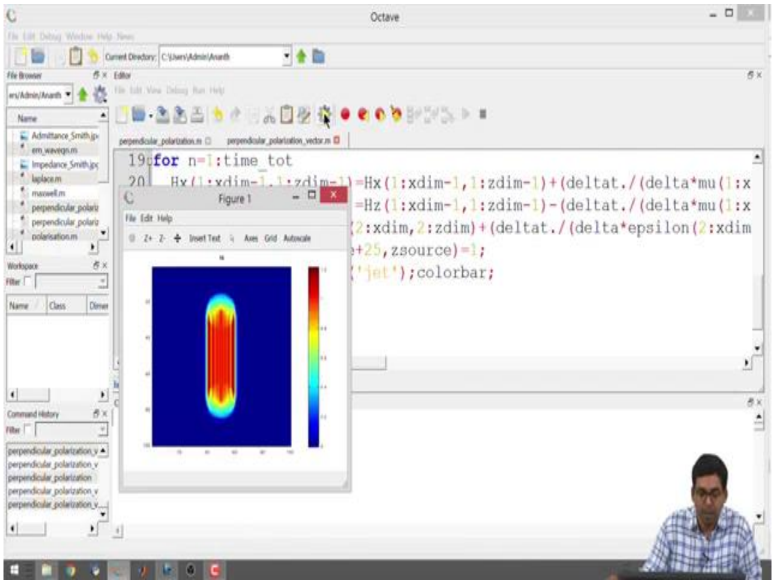

I am going to run this code again. Now, I have I can create some wave front that looks flat at least in these directions. You cannot prevent the electromagnetic field from doing this. It's normal for it to do this because there is nothing restricting it from going in a collimated manner at all alright.

So, you are creating some wave fronts over here which looks flat all right. So, you could always try to play with this right. One of the things that we can start doing now is starting to put some different material interfaces.

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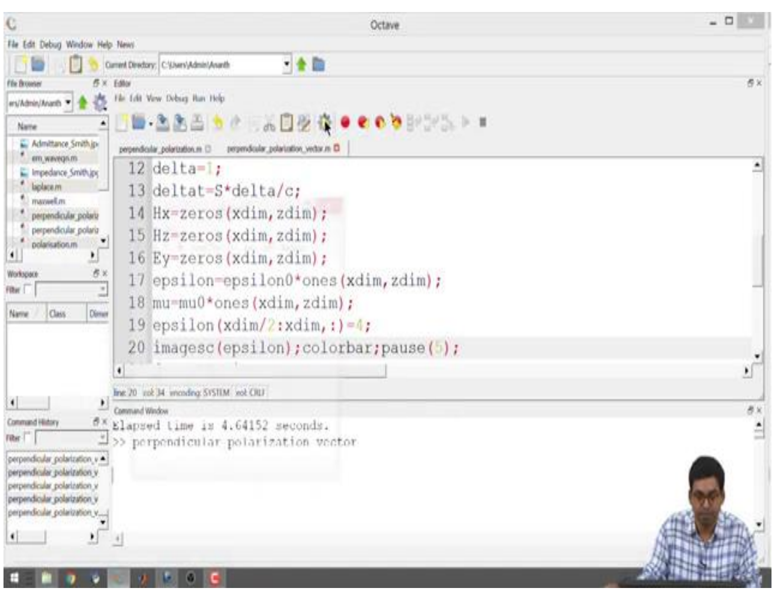

So, what I will do is just before the for loop ok. I will just make epsilon all right in some positions to be 4 all right. Currently epsilon is 1 in some other positions I would like to make the epsilon 4 times. So, that a 1 by square root epsilon mu in those times becomes a you know half all right. So, you will half the velocity all right and ah, we will see the consequences of what is happening there. So, I will just make it a s

o, let us say that I have a wave I have plotted let us see xdim by 2 colon xdim comma colon ok. So, all I have done here is epsilon for x values going from xdim by 2 to xdim. For all values of z are going to be equal to 4 right it takes some time to visualize what exactly we have written over here. So, what I will do here is for you to visualize what has happened, I will just pause briefly and then I will maybe show you know the plot for epsilon itself.

So, I will just do an imagesc of an epsilon and pause, maybe you know. I do not know the unit of pause comments I am assuming it is seconds, but we will try and see right ok.

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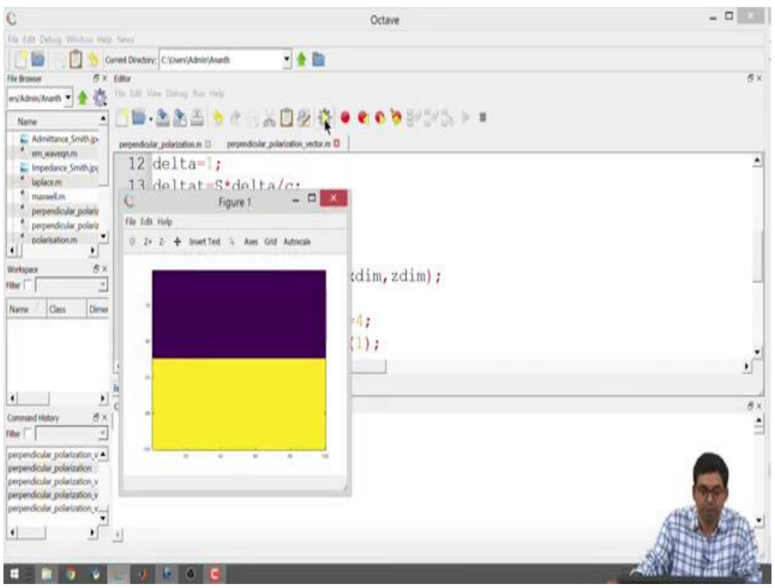

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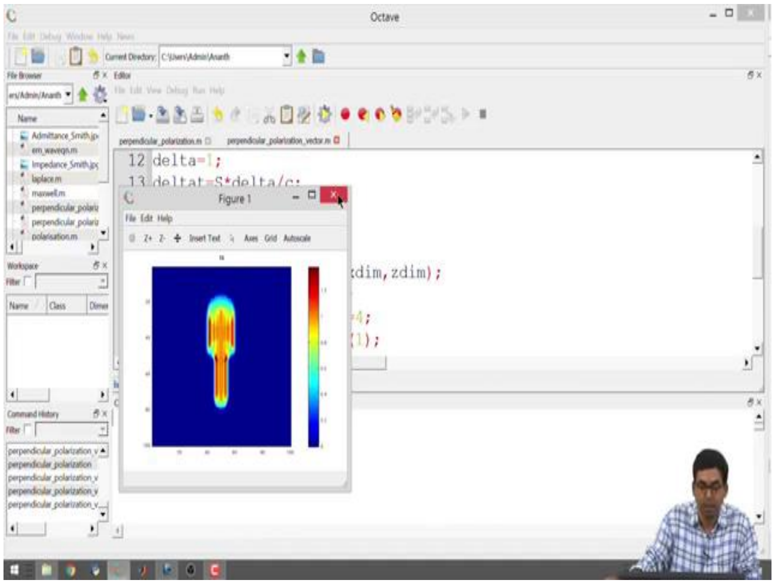

So, that is how it looks right ok. Go for it. I will do it once again right. So, where you have plotted epsilon it looks like this, we wanted it the other way around because now, we are having a source that is going in both of them, but that is fine we are getting a comparison anyway right. The other thing that would have been useful here is having a color bar. So, I know what is right and maybe increase the pause to 5. So, that I can read what is in the color bar ok.

So, yellow is 4 right and the black region is 1. So, I can quickly notice that in the bottom half the velocity is a smaller as expected all right and one could also take a look and see whether it S approximately half right you can always do that comparison and see ok. So, I can see that the velocity is different.

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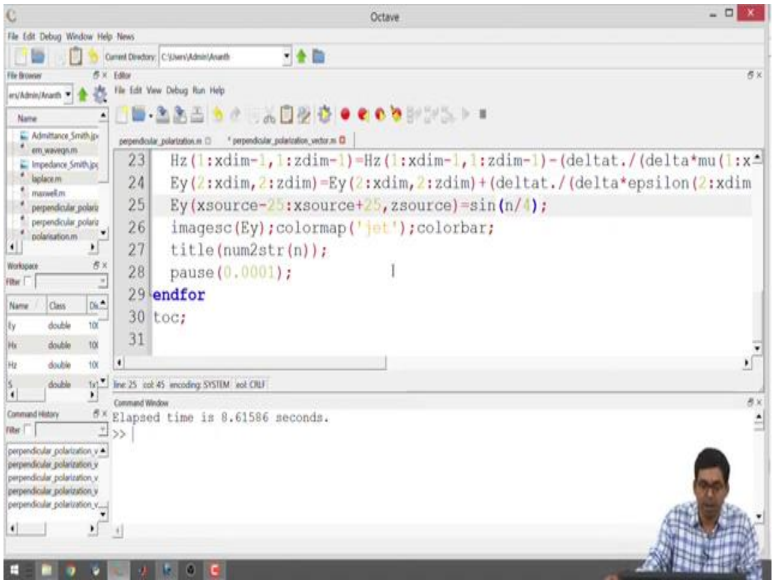

Now, at this stage what I would like to do is, I would like to change the source a little bit to not be just like 1 and I would like to change it to a sinusoidal source of some n by 4 ok. And I would like to allow it to run for a longer amount of total time. So, total time just making it 100.

Student: (Refer Time: 33:12).

Ok.

Student: (Refer Time: 33:14).

So, all I have done now is I have changed the source to sin of n divided by 4 and the time total I have made it 100 because I want to see for a longer amount of time what is happening. I am just running this right ok.

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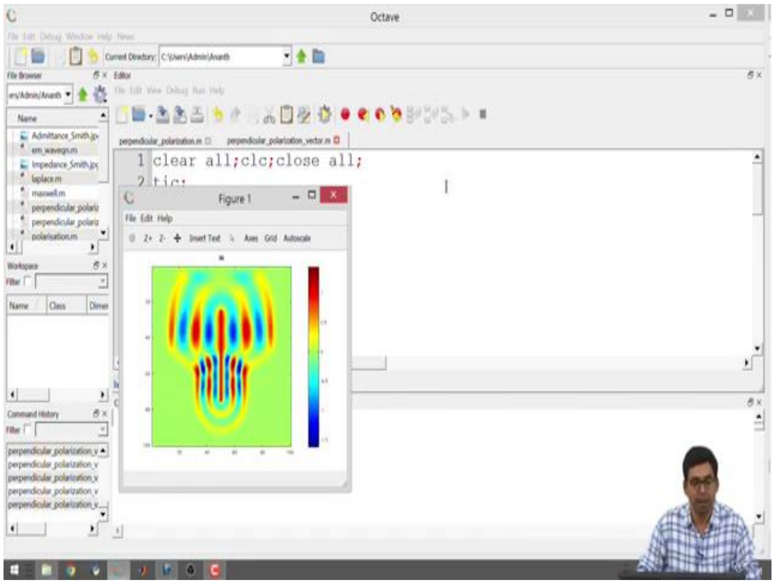

Previously, when I had a constant E source I noticed that the velocity of travel was smaller, but now I am also seeing that the wavelength in one medium is much smaller than the wavelength in the other medium.

So, the effect of permittivity is two things: one it affects your velocity and the other one it affects your wavelength all right. So, higher permittivity is going to be the wavelength lower is going to be the velocity of travel ok. So, this is the conclusion that one could make all right

Whoever in the course, we had seen slightly different scenarios. So, I will just push the source to some one side because having a source right in the middle is good for the program, but when we had seen something in the class, we had a source on one side and we had an interface on the other side extra. So, what I will do is. I will make it look slightly different ok I will go to the definition of epsilon where we had modified it ok.

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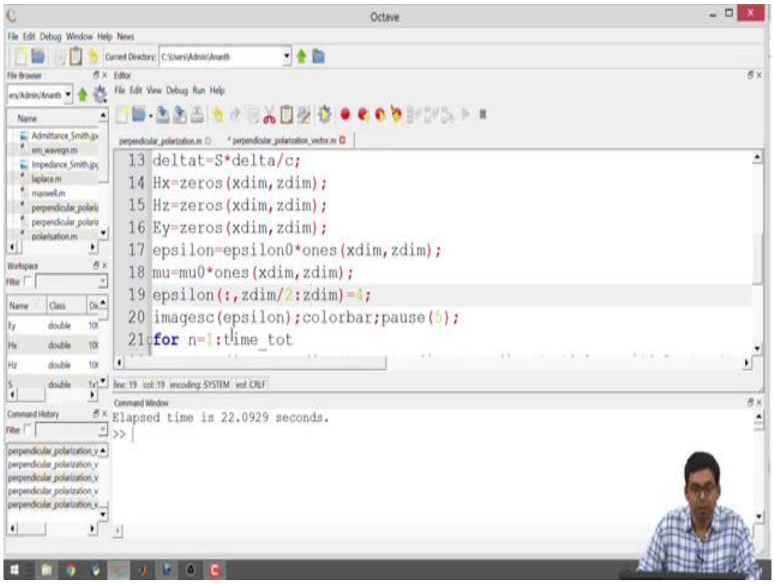

So, I will just change it to the other orientation. So, visually it's easier for us to see what is going on right. So, I just made an epsilon of the colon comma. I mean zdim by 2 to zdim. So, I just rotated the permittivity profile 90 degrees ok ok.

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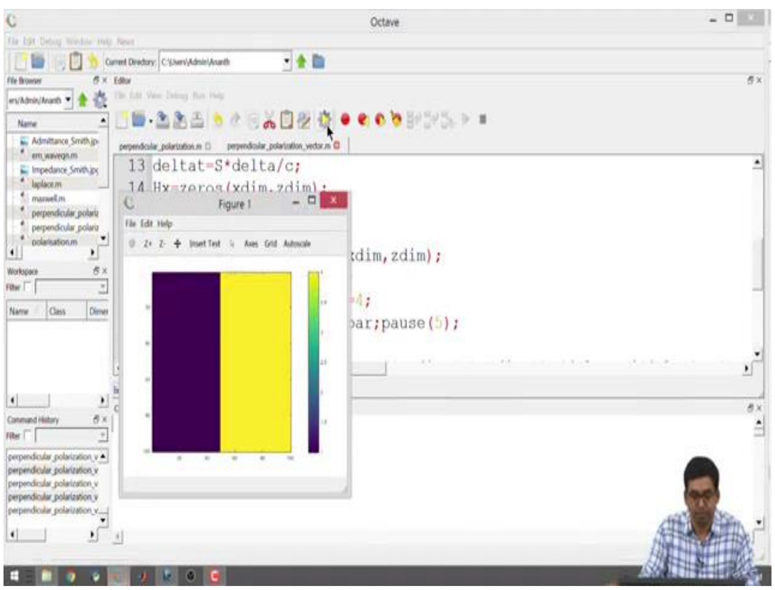

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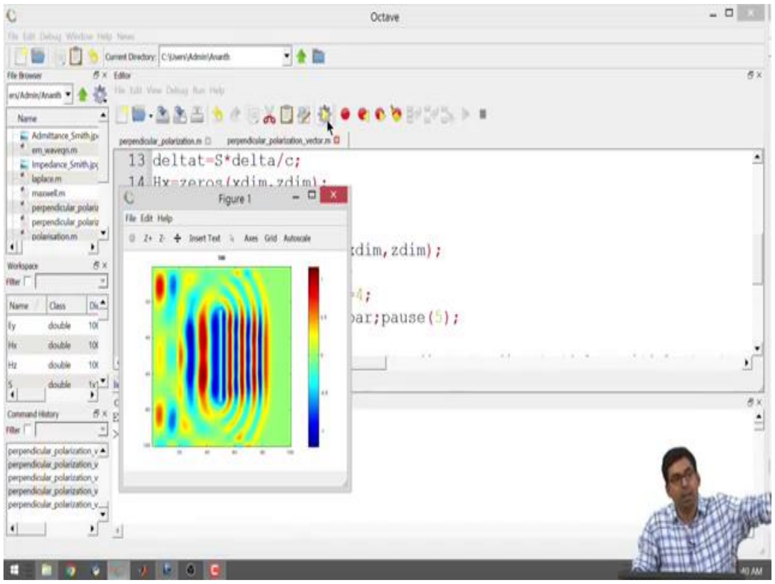

So, this is good now, we have the source being placed as a line exactly on the interface all right. So, we are having some amount of electric field going this way, some amount of electric field going this way and it is clear that on the left hand side it already reached the left side boundary, it's getting reflected from there and it is forming some patterns all right. These patterns are interference patterns.

That is happening because you have a forward wave that is going and hitting the interface and because of the reflection coefficient being 1 it's becoming it's getting reflected and you are having some interference. So, the concept is very similar to that of your transmission line, you had a forward, you had a backward wave. Only thing is the visualization part previously, we had graph like visualization parts because you are taking one line along this horizontal part and then you are visualizing it in transmission lines.

Now, you are doing it in 2 dimensions and it is a little bit tougher to do this mentally, but at least now you have something to see right. Now, we have concentrated on Ey for the sake of completeness why do not we have a look at the other quantities that we have spent time in writing the update equations Hx and Hz right. So, first I will just make this imagesc of Hx right and let us observe what is happening.

This is what He seems to look like. If you are careful you can go back and make some different analysis you can see the amount of Ey one side amount of Ey on the other side and see his Hx lower on one side compared to the other side is the magnitude of H a x different in different slides why is it so, you could make all that analysis, but this is what He seems to look like right.

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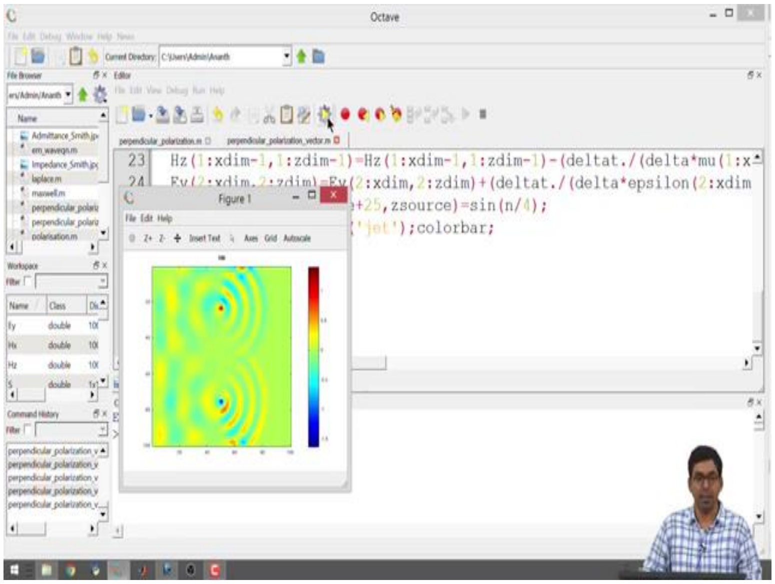

If I want to take now Hz looks completely different right. Normally just by looking at Maxwell's equations, it would not have been possible for you to visualize that Hz would look like this right. So, generally it is very tough to visualize these equations unless you write a program and actually start drawing inferences and the other thing that we also want to stress is it is not enough.

If you give a plot of one quantity say electric field alone because if you were see the magnetic field and another component it looks very very different and it in some many students will find is also a non inductive why is this happening, but this is exactly the solution to the Maxwell's equation we have not done anything at all.

We just put a source and allowed the equations to solve for the fields at different points and different times, but this is what it looks like, but I do not think anybody would have visualized that this is how the magnetic fields would have looked like. So, there are two things whenever you are sharing your results with other people, it will make a lot of sense to give them all components whatever you are if you are dealing with perpendicular polarization you have to deal with Ey Hx Hz.

So, that person gets a clear idea of what you are talking about. Also Ey and Hx looked similar they are not the same they looked similar all right, but Hz looks very different all right. So, we have to look at all these quantities and then only make some analysis all right.

So, this is one thing right. Now, we will extend this program a little bit more. I will move the source a little bit to the left side all right. So, I will just make it x source alright looking like you know 1 or 2 add all right all right z source can be the same I will just want to see what happens oh maybe I add an array out of bounds error ah. We will just make z source ok z source is equal to 2 ok because right now I do not have an idea which is x which is z.

So, I will figure it out as I go forward right just run it I will just figure it out as a go ok again we are plotting. So, the correct place where I want it is not the quantity that I want to plot. So, I will go ahead right. So, I will plot Ey ok

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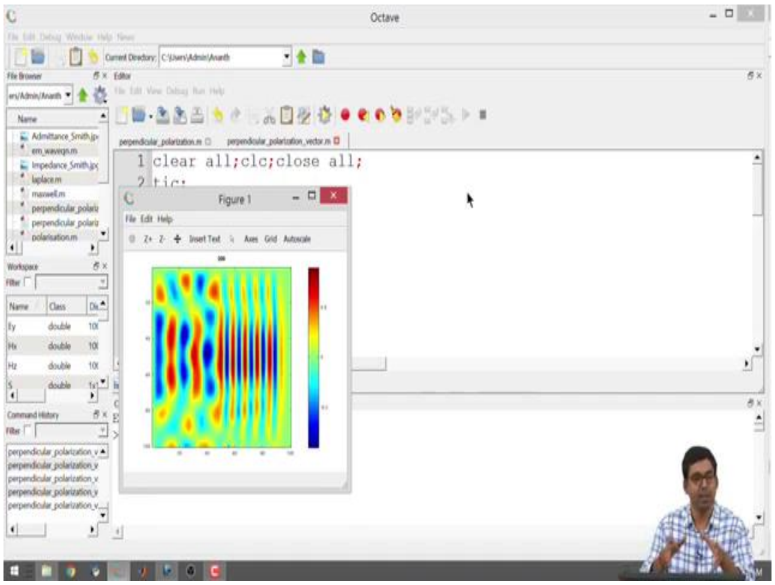

So, now I have created some decent looking plane wave fronts they are travelling from the vacuum they are hitting an interface some portion of it is getting reflected right I think it will run it for longer amounts of time. So, I will just make this time total to be 200 ok.

So, I am having a plane wave coming from the left side and hitting the interface creates an interference pattern or a standing wave pattern on the left side. A portion of it is transmitted to the left side. So, we know that the consequence of going to a denser medium is having smaller wavelength in the medium and the speed of travel is also going to be lesser in the second medium, but you can always see on the left side all right it looks very messy because of the interference patterns that you have.

So, this is a good starting point all right in order to visualize very cleanly, it may be a good idea to kill some reflections happening from the boundaries see all these happened because you had the wave going from the interface going and hitting the left hand side boundary alright and then bouncing back right.

Suppose we found a way to kill any wave that goes from here right to the interface to not come back then this would look like a cleaner way all right. So, manipulation of boundaries is very important. So, in the case of transmission lines, we had made use of what is known as observing boundary conditions. One could extend the same concept thus. So, people use these conditions just to have a cleaner visualization without multiple interference in the first medium right.

So, you could observe boundary conditions over here, we will look at that little later because now it is an overkill right. Now, you have normal incidence alright if you were to look at what is the transmission reflection coefficient in a clean simulation. We will be able to find out its n 1 minus n 2 by n 1 plus n 2 are you know ah.

Eta 1 minus eta 2 by eta 1 plus eta 2 is a formula that we should be able to verify at least with this program. In order to create plane waves going at an angle all you need to do is define a source at different x y coordinates equal to some sign something. So, how normally people do it is they will create a set of x y coordinates. So, they first they will just say that ok I want a line at 45 degrees to acts as a source

So, we will just say y equal to m x plus c m is going to be equal to 1 for 45 degrees constant is just depending on where you want to place the source you know along the vertical directions. So, you can always start at 0 does not matter. And then you will calculate x is equal to say going from 1 to 25 y will be equal to m times x right you will create one vector over there then you will take Ey at these positions x comma y is equal to 1 then you can create some slanted source you can control the angle all that right.

So, you can do that you will be able to observe total internal reflection extra all right, but the only problem here is I am having 100by 100special steps, when you start putting tilted sources you also have to take into account that your simulation area should be large enough.

So, that the plane wave has enough space to go and actually hit the interface right in the wave we have set up. If we keep a source at the bottom, it may actually just reach the edge of the interface at the end of the simulation. So, you need to know to create larger I will leave that to you over a period of time you will get confidence and you will be able to do these manipulations.

But what else can we do with this which can lead to more interesting things in the later classes ok. Now, we have two materials with two different refractive indices all right and we have already talked about reflections, we also talked about total internal reflection. What if I created a medium which is say higher permittivity in the middle lower permittivity on the top and in the bottom that is I will have air in the top air in the bottom and I will have a layer of material with permittivity equal to 4 in the middle all right.

So, we are just making slightly different configurations. So, what I am going to do now is I am going to change my epsilon to look like that ok.

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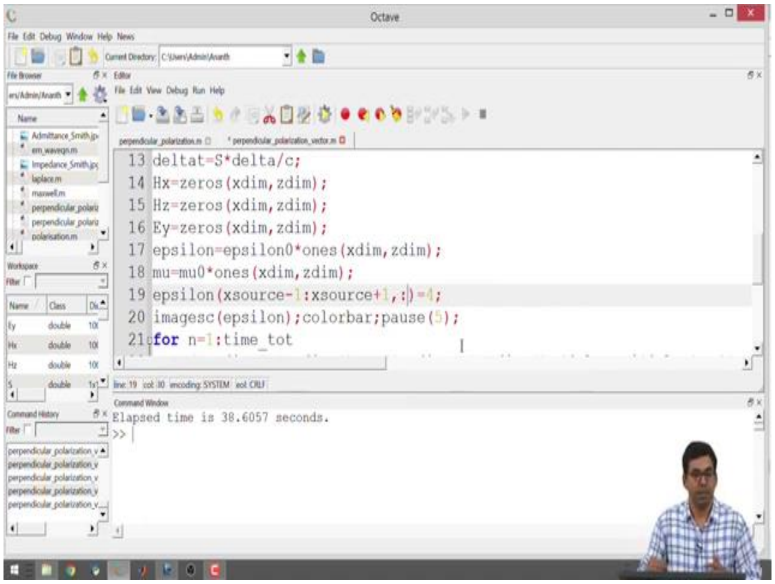

So, I had left half right half extra. So, I am just going to make it just going to I will just make it even smaller x source minus 1 to x source plus 1. Make this colon let me just a reduce the amount of time because I want to see the permittivity profile that I am doing I will just make it 2 times step a all right. Now this is what I am doing now I just want to verify ok all right. So, I have a horizontal stripe of permittivity 4 all right and I have a large source there. I want to create a slightly smaller source. Why don't you make the source to not go so big all right.

So, I am having x source minus 25 to x source plus 25 I will just make it x source minus 1 to x source plus 1 right. That is all I think I have a decent program to begin with I will just start with 20 times steps to check if everything is ok ok seems ok.

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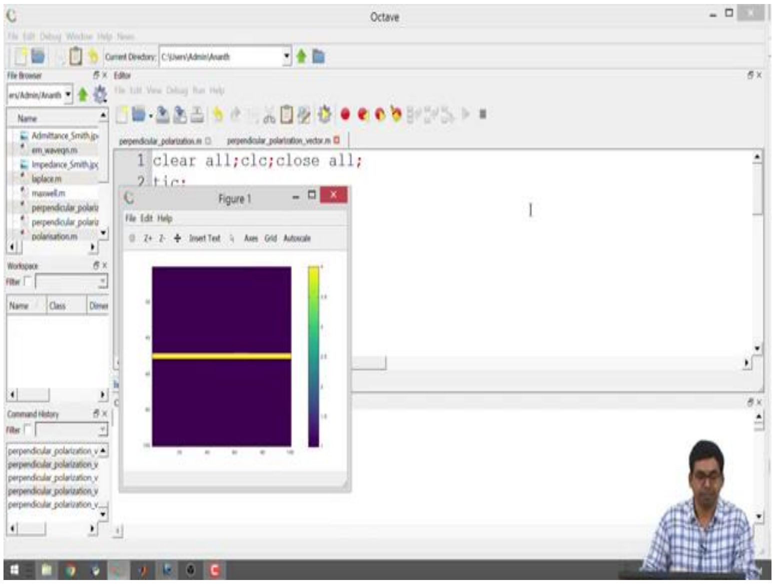

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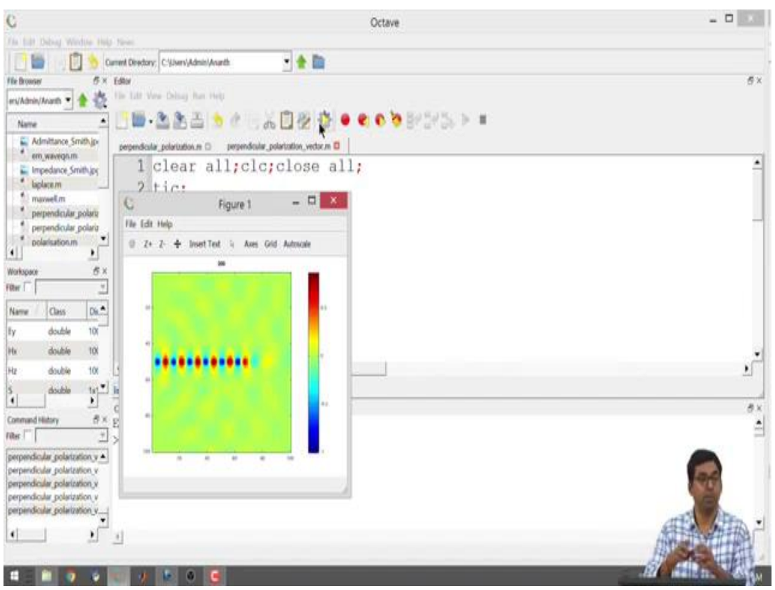

So, I will go ahead and run this for a longer amount of time, make it 200 then let us see what happens. So, we are able to observe that when we had a simple profile with the point source all right, we had vacuum everywhere and a point source was giving out circular wave fronts and the wave fronts were spreading everywhere in the spatial domain.

Now, I place this strip of higher permittivity in between the vacuum and I launched an electromagnetic wave one side I am seeing that most of the electric field is actually within that stripe ok. I guess now you know where we are going to go for the next classes right. We are going to talk about wave guides all right.

So, we are talking about this is the simplest form of modeling wave guide. So, we are having a glass waveguide. You can say that permittivity is 4. So, piece of glass placed in vacuum and you lost a source and it turned out to be a guided wave medium all right. So, it takes it you can also make it look like you know arbitrary shapes using a program you can modify epsilon in the way you want all right and you can start creating know patterns and observing what is happening right so, but that is a general direction, however, there is a detail.

Here we are talking about a specific kind of wave guide called dielectric dielectric waveguide that is you are having a dielectric region surrounded by to dielectrics, but we are going to learn about the extreme case, we are going to talk about metal dielectric interfaces all right first because we will talk about parallel plate waveguide rectangular waveguides first to understand. Dielectric waveguides we will see towards the end of the lectures or if you run out of time then you can also read it on your own, but from the point of view of simulation this is the simplest way of doing it all right.

So, you can imagine this region to be the core of a fiber and the outer region to be just vacuum right. You can also replace the index of the outside region to be slightly lower and see what happens. Already you can create any profile of permittivity and observe. So now, you have a tool all right, all you need to do is go back and manipulate and play and see what you can do with it. So, I will stop here and we will meet in the next class.