Transmission lines and electromagnetic waves
Prof. Ananth Krishnan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture – 32
Octave Simulation of Field Pattern of a Parallel Plate Waveguide

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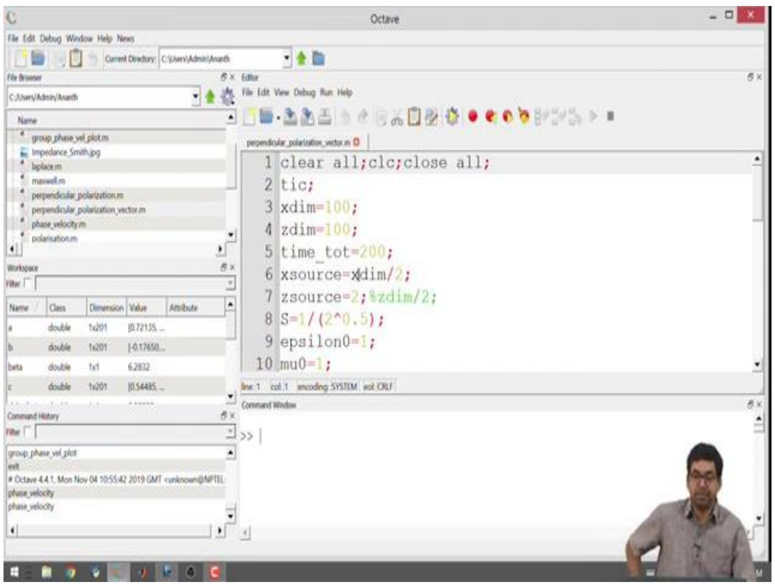

We will get started right. So, the goal today is to modify the programs that we already have all right, to visualize the aspects of the wave guides that we have just analytically solved all right. You need to know how to modify the program in order to see the effect of the waveguide extra right. And in specific since we are dealing with two dimensions' space all right in the case of simulations.

We will see, we will take a look at the parallel plate waveguide case right for the rectangular wave guide you may need to write some three dimensional Maxwell equation code, that will have Ex, Ey, Ez, Hx, Hy, Hz and you will have a you know a solution in all the 3D space and 1 D time then you have to take a slides and solves it is too a hectic all right. So, in this case what we are doing is we are reducing the problem from three dimensions to two dimensions.

First of all, parallel plate a waveguide, you can just draw it as one conductor on the top, one conductor in the bottom filled with some material inside. So, it can be represented in the cross sectional form. So, what we are doing instead of looking at the cross section, we are looking at the longitudinal side all right. We are going to launch from one side and we are going to observe what is going to happen right. For this we had already written a code for perpendicular polarization all right.

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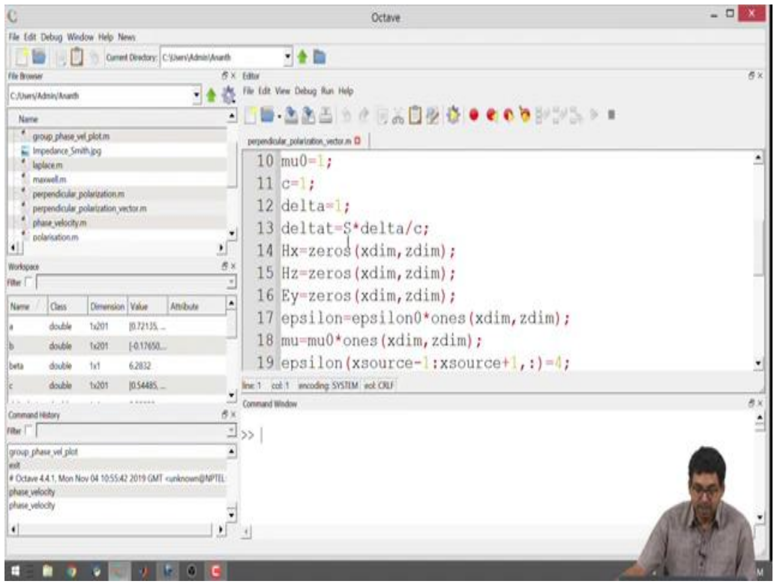

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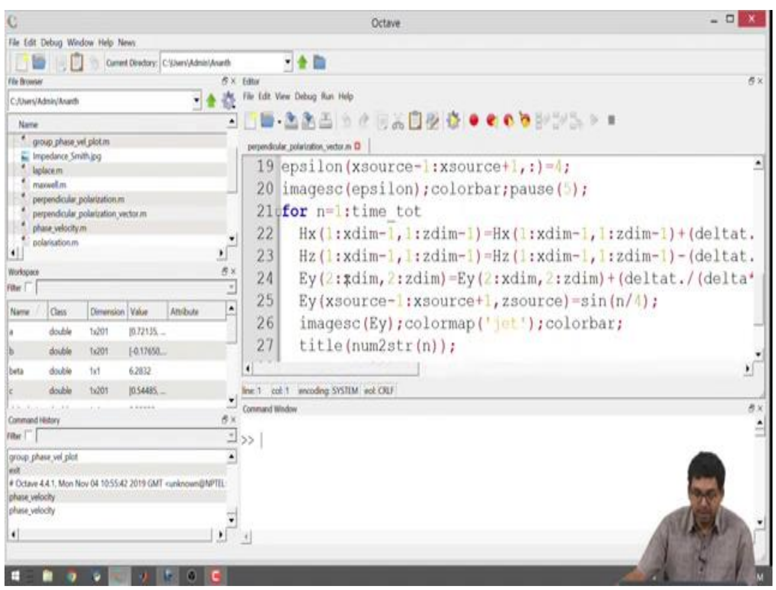

So, I am going to open that code and I am going to start making modifications to plug in the waveguide right ok all right ok.

So, I am going to keep most of the things consistent here all right. The same wave what we had it before I think towards the end we had plugged in another material all right on the right side.

So, we had talked about dielectric interface using this code for perpendicular polarization, what I am doing is I am just getting rid of that particular interface right. Do you have computer? I think maybe and you have this code already with you ok all right ok. I am going to the region in the code so, I am having perpendicular polarization code that we recently wrote.

So, you can open it if you have it right. So, I am just getting rid of this interface because I do not want this dielectric interface I just want a region of vacuum with two plates present inside of it and then I am going to run some experiments on it to corroborate whatever analytically we saw right that is all.

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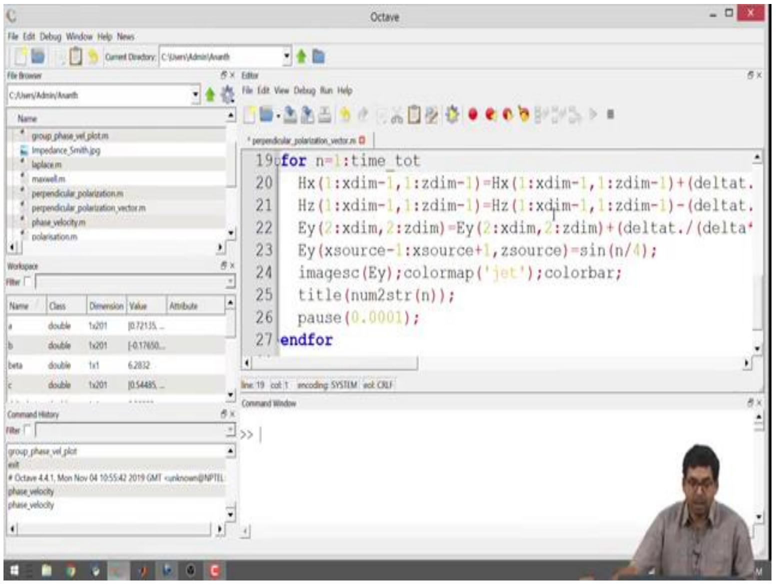

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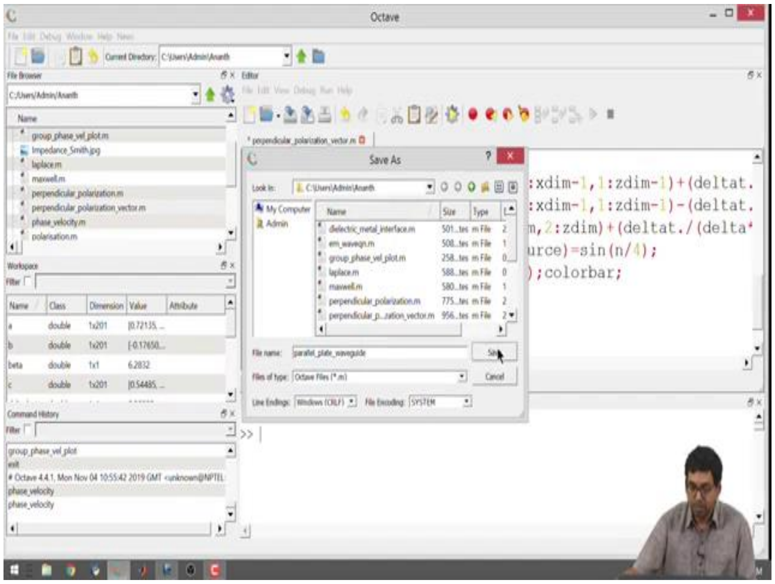

Some getting rid of this right I also do not need a plot of permittivity. So, I will get rid of this and I will save it as a new file ok. Inside we had written the vector update for Hx, Hz, Ey all right and the first step that I will do is make sure that my program first runs and then I will start making modifications. I have removed a couple of lines I will just make sure that my program runs and then I will start making some modifications to it.

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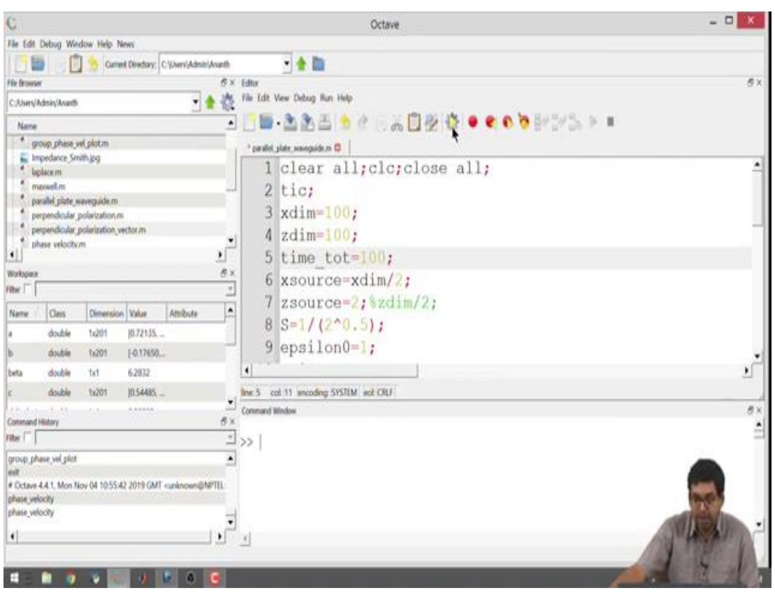

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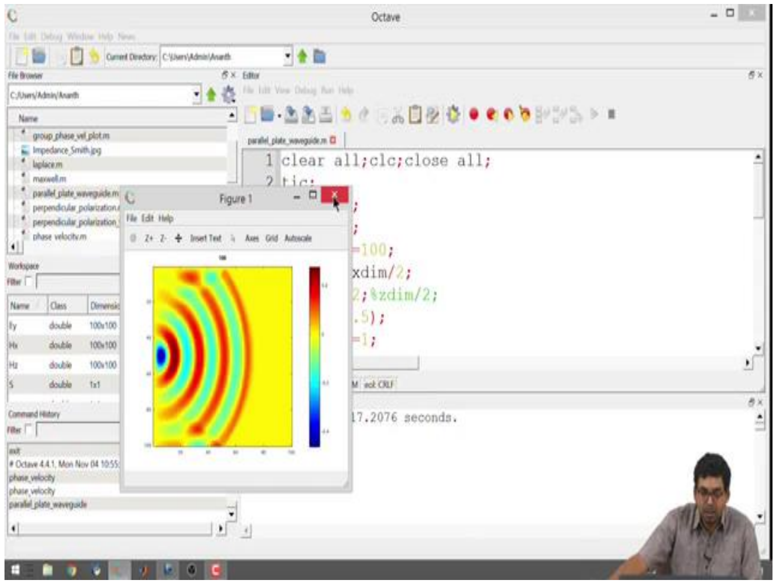

So, I will reduce the amount of time to say 100 time steps, just to check what is happening? ok Seems to be running all right. A few things that I will do very quickly is I want to make sure that my access is not changing with respect to the colors because, it is very wild if your color bar is going to be changing from minus something to plus something for every time step. So, I want to fix that bit to between minus 1 and plus 1 so, that I can make proper inferences right.

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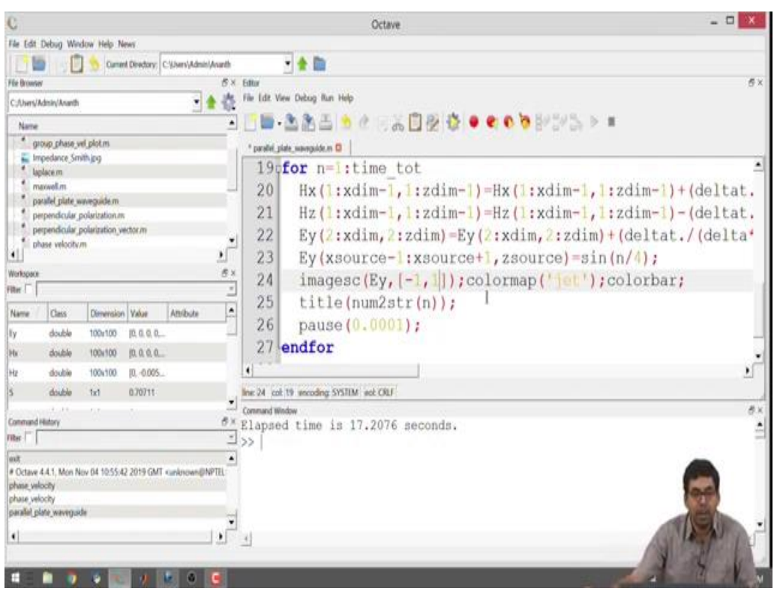

So, in the imagesc command I am just adding a limit of - 1 to + 1 for the color bar that is the first thing that I did right. Now I can start a manipulating this code ok. So, now, we have a code for perpendicular polarization and I want to a create a parallel plate waveguide all right and then start experimenting with the code all right.

So, how do I define a parallel plate wave guide? I know that I need to have two conductors right, the way I tell it to the code that I have two conductors is by making the electric field 0 at specific places. So, I look at the components that I am having in this particular simulation I am having Hx, Hz, Ey ok. So, what I could do is I could just take Ey make it 0 at the places where I want to define the conductor ok. So, what I am doing here is I go inside the for loop ok.

I am just going to say that a you know maybe just before the source right, maybe even after the source does not matter ops right does not matter. So, just around this place so, to be consistent what I will do is I will just do it after I define the source all right.

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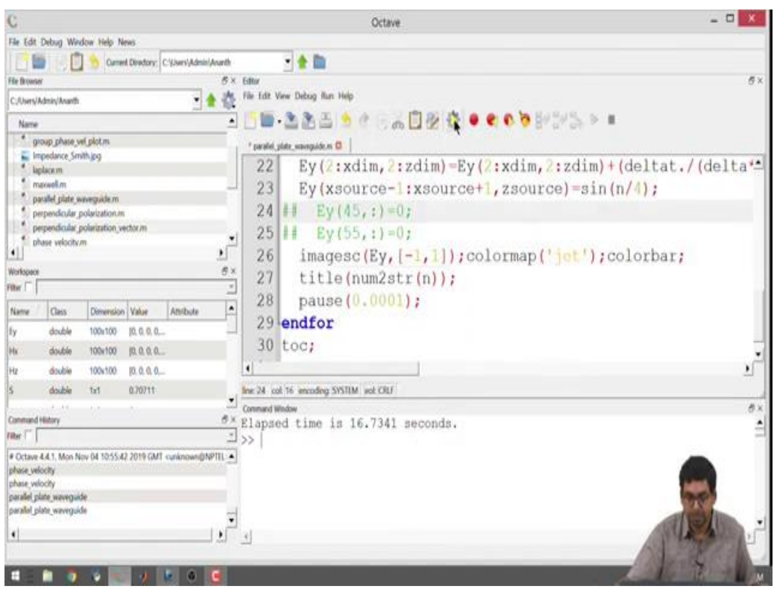

So, I am just going to take some region which let us say that a I am having 100 by 100 space right, 100 points in one dimension, 100 points in another dimension this all right. So, what I will do is I will create something around the middle.

So, I will just do you know maybe 45 right comma colon is equal to 0. So, at x position 45, at all points in y, I have made the electric field manually equal to 0 which means that according to the code I have placed a conductor in this line all right. Now I want to place another line all right. So, I will place it symmetrically on the other side right. So, I will just make it 55 comma colon and I will make that equal to 0 ok.

So, I have x dimension of 100, y dimension of 100, the middle point will be at 50. So, what I have taken is I have taken a line above 5 grid points above 50 grid points below and I have place some two lines where the electric field has been forced to 0. Now the definition of parallel plate waveguide is done all right. Let us run the code and then start making modifications to it and then slowly we will start seeing what is going to happen right ok.

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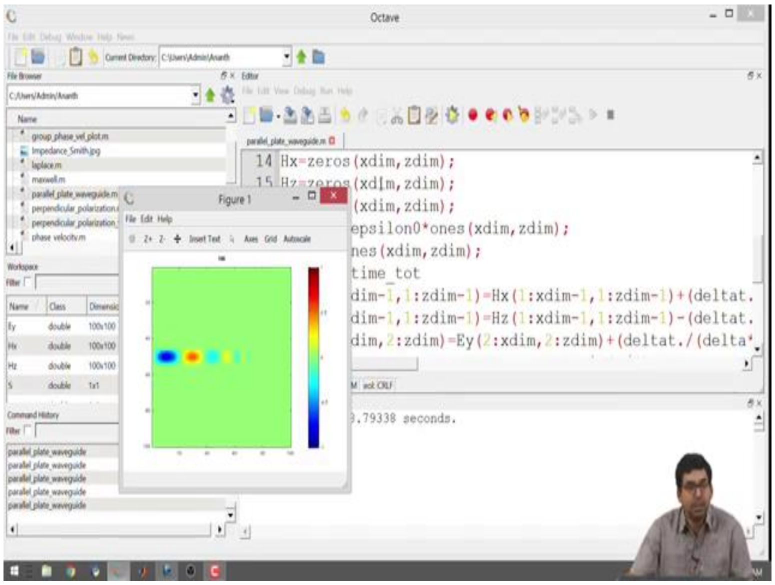

So, I have something, previously when I did not have this course I will just comment this out right and run the same code again.

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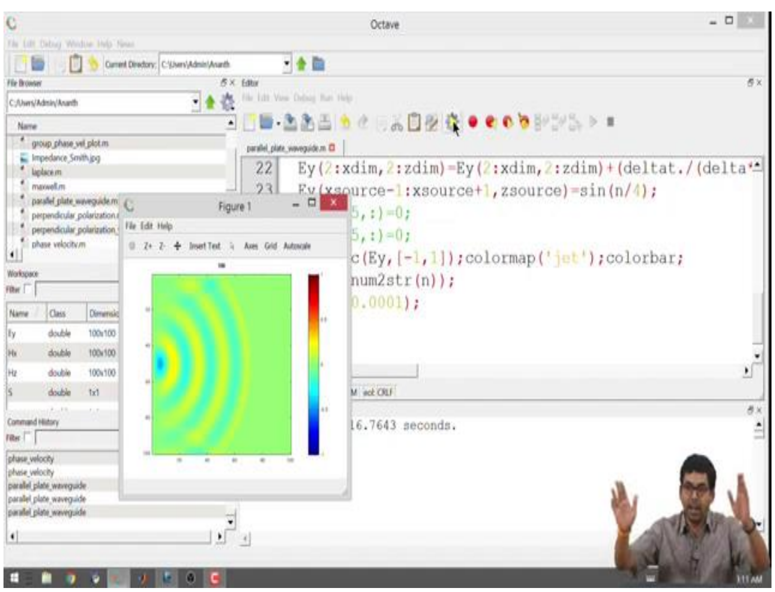

I notice that in both the cases definitely the field patterns are different. So, those two lines are having some effect all right. One of the cases here where the lines are commented I notice that I had a point source on the left side and it is clearly diverging and producing some circular wave fronts all right, where as in the case when I had the two conductors.

I do not have this diverging thing happening all right. I see that something is traveling from left to right so, that gives me hope. Now I will start looking at what is what else is going on right ok. So, also one of the things that I notice is that it is a giving plots for every instant of time. So, I am just going to make it easier for me.

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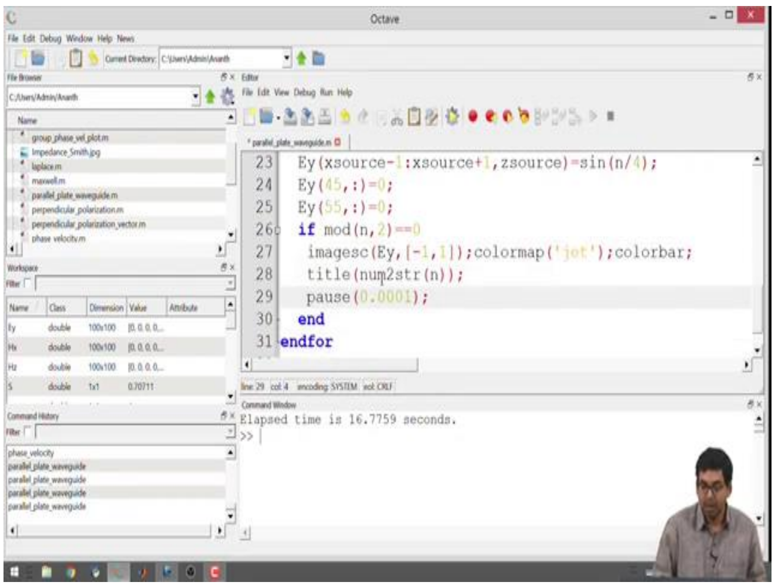

So, I am just going to say that if n a let us say that if modulo n 2. What I have done is, a n is the time loop that we are considering n is equal to 1 to time total, if n is divisible by 2, I am making a plot, that means, for every two time steps I will get one plot that way at least I can have a faster execution of this code all right. So, I will just run it once again to verify right.

So now, I see that there are jumps all right it is going from 40 to 42 right, later on depending upon the need I may change this to you know a lesser number of plots are not right. Another thing that I am noticing here is that a I am having a square region all right when we are talking about waveguides and we are talking about parallel plate I think it has to be clear that one side is longer than the other side then we know which side it is traveling all right. So, I think I will just make that adjustment also.

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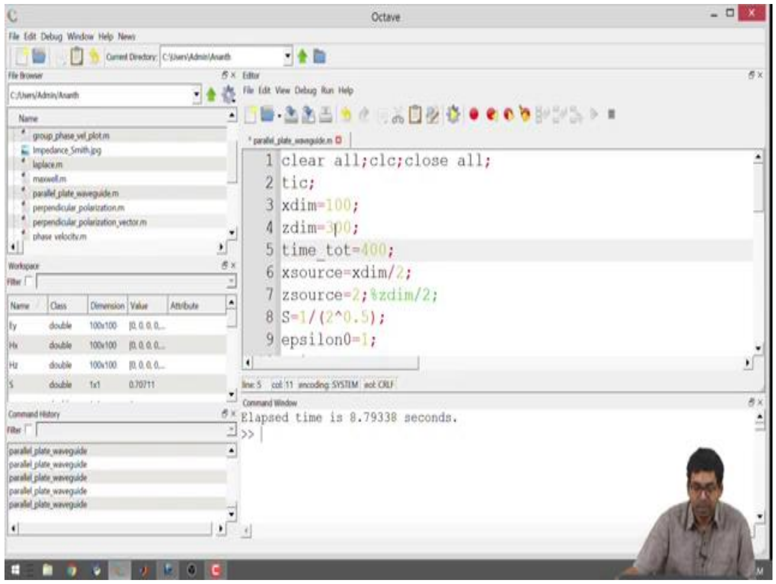

So, I will just make my no zdim to be as I know maybe 2 times or 3 times longer right.

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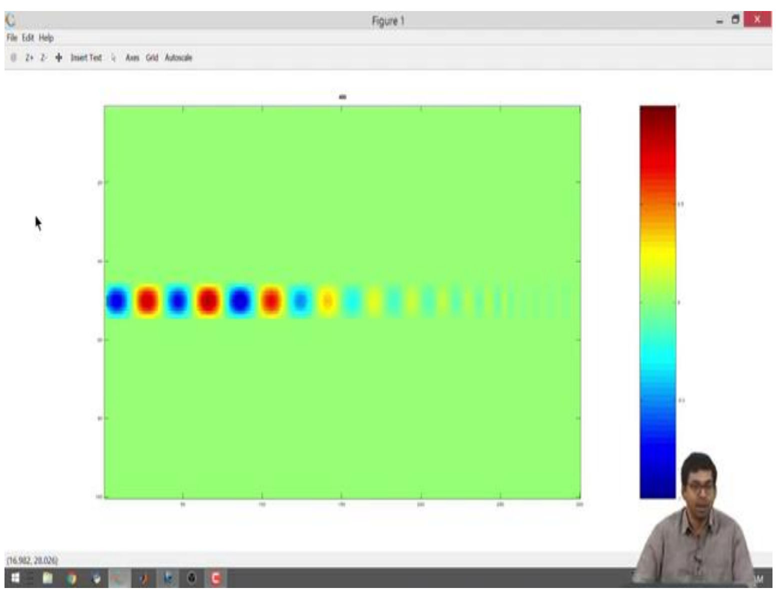

And I will also increase the amount of time to 400 right ok. Now I will maximize this is much better ok. I am having a source on the left hand side and then I am having two plates all right ok. Clearly I am noticing something odd happening over here, that is, I am having a source and as it travels through the wave guide I am noticing that there is an attenuation of some kind all right.

So, first it has to give me a clue that a maybe there exists a cutoff frequency all right for this wave guide and maybe we are close to that cutoff frequency maybe we are just above the cutoff frequency or maybe we are very closely approaching the cutoff frequency right.

So, let us see if by manipulating the frequency of my source, I am able to get a much better well defined propagation right so, that is the first thing that we will do. So, what I will do is I will go ahead and I the source definition I would have use the sino side right. So, I am having sin(n/4) all right. So, this is telling you with respect to the amount of time. So, in order to increase the frequency what I can do is, I can make it sin(n/2) ok. And I am going to run this program again.

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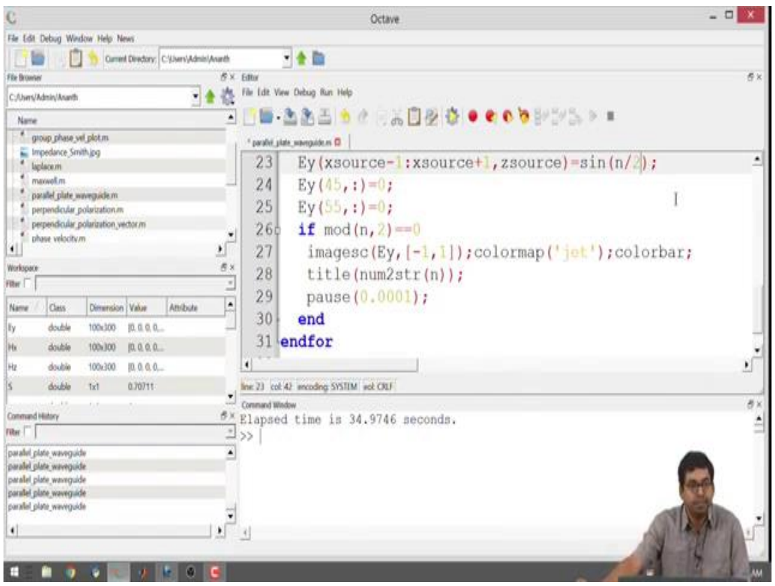

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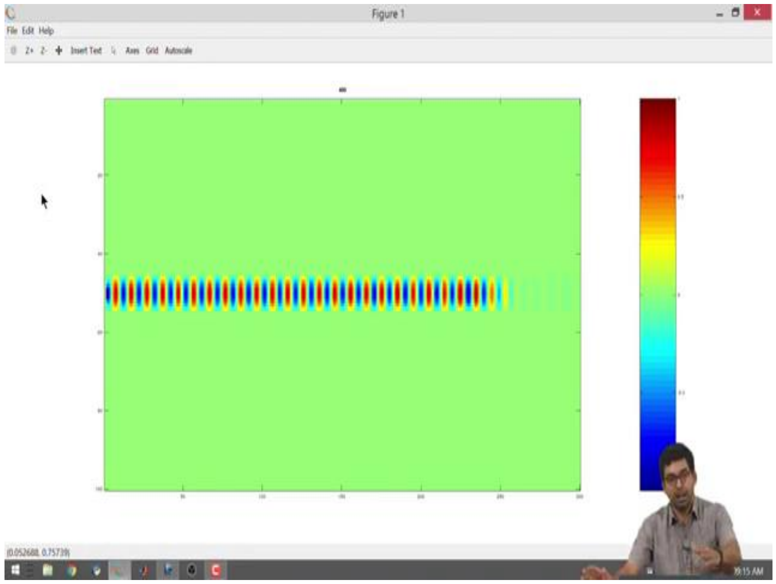

Seems like that fixed it right so, now, we have to verify whether we are right or not. So, we want to go well below the cutoff all right. I have not calculated any cutoff frequency here I am just going to determinate by doing these experiments all right ok. So, it has traveled and I do not see any exponential d k or anything happening over here.

So, it is clearly a you know a guided wave traveling between two plates and it is going from one side to the other side and a I would like to verify if this is truly an issue of the frequency.

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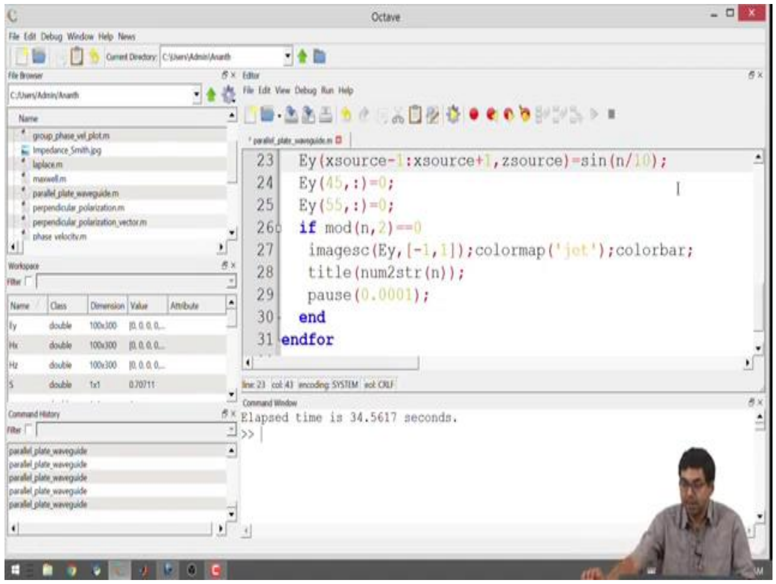

So, what I am going to do is I am going to do the exact opposite I had sin(n/4), made it sin(n/2), I will make it sin(n/10), to just see what happens all right go to the exact opposite direction and see what happens all right.

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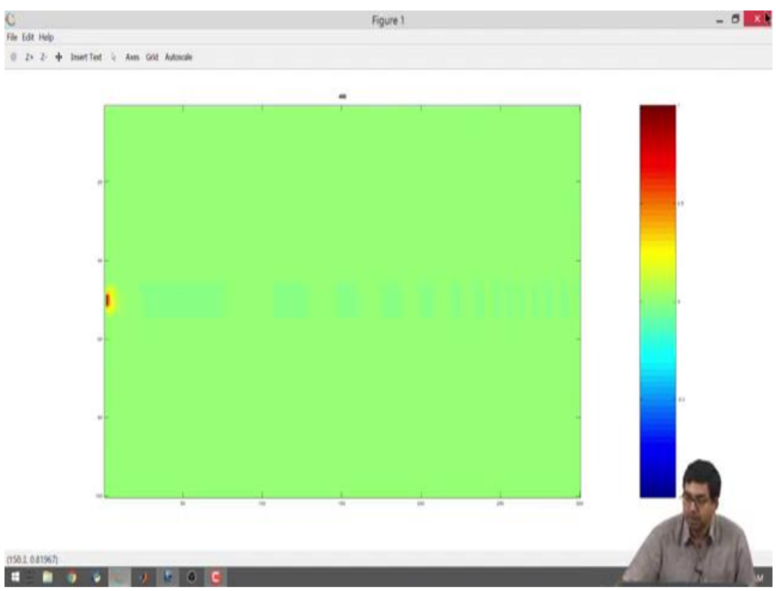

So, is clear that a we are not able to launch electromagnetic fields into it all right. So, first of all the way to visualize cutoff frequency should be clear even if you are not aware of the formula all right. You should be possible for you to take the code just sweep the frequencies of the source and try to get a decent estimate of what your cutoff is going to be right.

Now, I will stop this, then I will go to my theoretical a you know study that we had. If I go back to the notes yeah I would like to see the formula for the cutoff frequency for the parallel plate waveguide.

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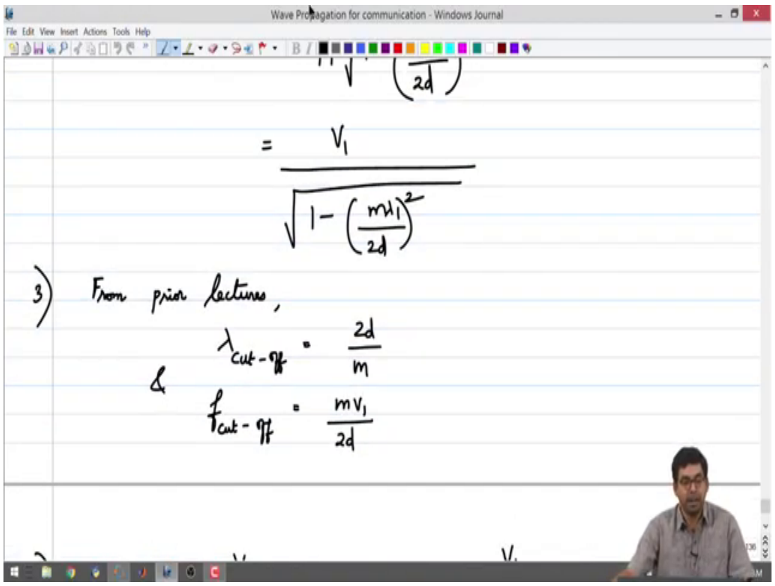

So, I have

$$f_{cut-off} = \frac{mv_1}{2d}$$

all right. Now in this particular case, I have a changed the operating frequency to go higher than say f cutoff extra. But in the program nowhere I have mentioned what mode I want to excite m, I have not given anything all right and the d is a kind of fixed in the way we have written. So, d is the separation between the two plates. So, in one case one plate is at 45th coordinate and the other one is at a 55th coordinate.

So, the you can say that a d in this case is 10 spatial steps all right 10 spatial steps that is good enough. v 1, again we do not notice calculated from whatever epsilon mu and the parameters that we have given so, we do not care. But a now I want to make some sense out of this right. What I look a I mean what I understand from this particular expression here Is that the cutoff frequency inversely a is proportional to the separation right. Which means that if I did increase the separation between the two plates all right, frequencies which were not passed before should start passing ok.

So, your cutoff frequency has to reduce for example, in our case sin(n/2) was passing, n/4 was decaying n/10 was almost not able to pass. Now what happens if I say increase the width or the separation between the two plates right. So, I am going to go ahead and go to the region, I am just going to make it you know 30 and 70 all right.

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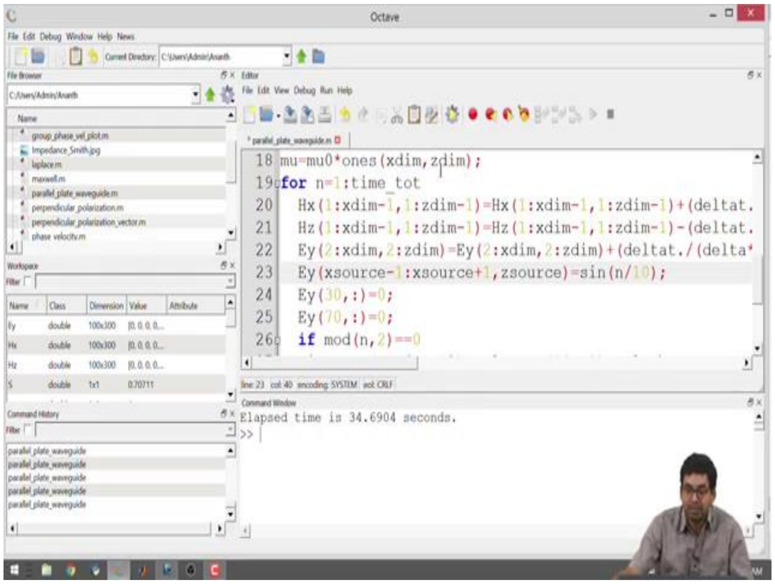

So, the center line is 50th space coordinate. Now I am making my waveguide 30 units on the top 30 units at the bottom. So, I mean no 20 units on the top, 20 units in the bottom so, it has become 40 space unit's separation between the two. Now I want to keep the frequency same at n/10 previously it was not passing I want to see whether it passes now, and whether it has an effect on the cutoff frequency right squared and do it right.

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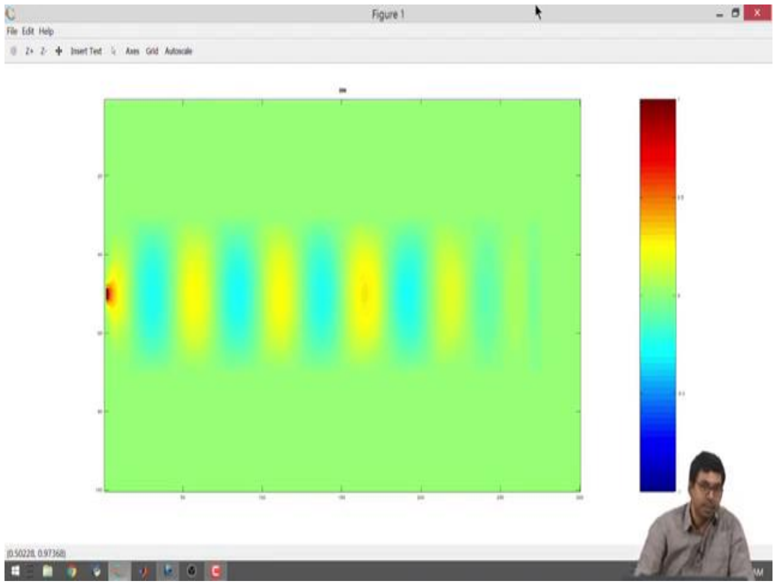

Now, immediately I noticed that I may have to make a modification because the source is defined at a single point, but the waveguide width is large. So, the energy is you know spreading through the area of this waveguide and the intensity of the spots is becoming lesser. This gives us the illusion that maybe something is happening, but what we will do is we will increase the intensity at the point source and then we will start looking at it again right. So, in order to increase the intensity all, you need to do is multiply this with some constants.

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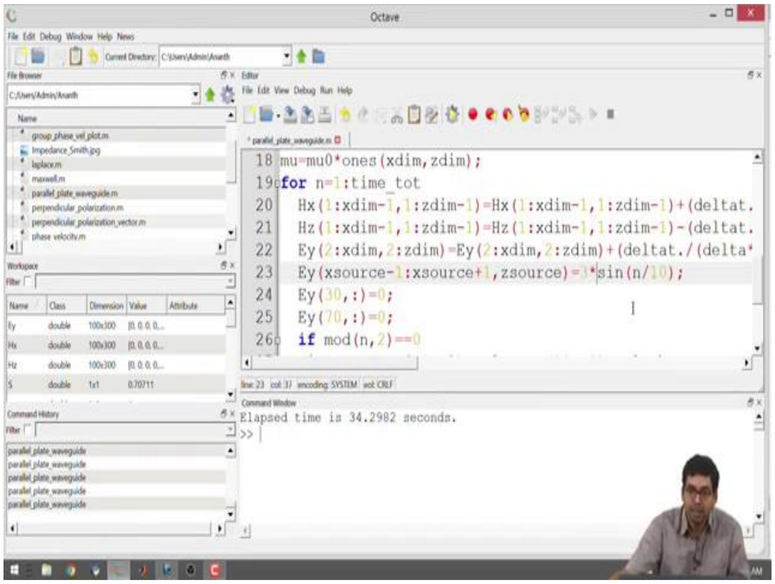

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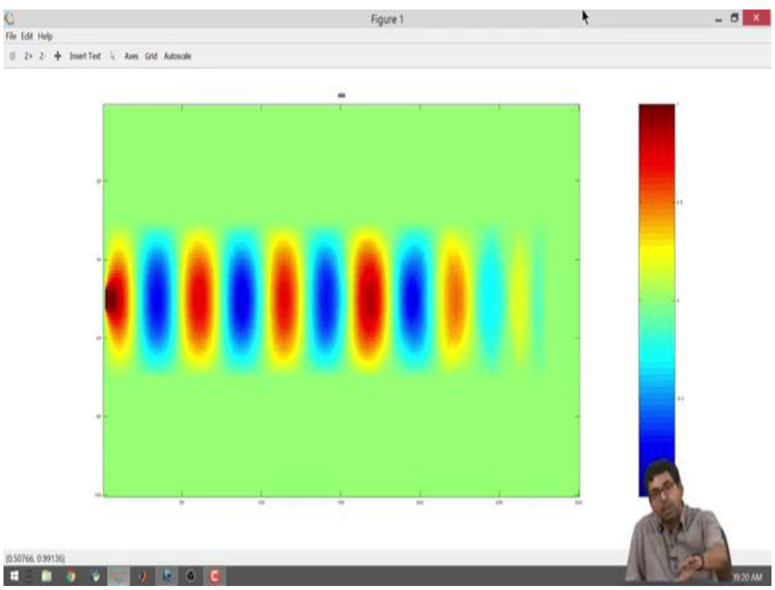

So, I can just put you know 3 times yeah is extra right. So, I will just run this again and then I will try to see what happens ok. Seems like, I am able to launch all right. So, if I change the separation between the two waveguides all right, clearly the cutoff frequency reduced all right, but I have still not said which m I am a you know willing to excite in this waveguide all right.

I am not giving any parameters I have put a source it appears that for this configuration, a particular pattern of electric field is being created all right. Now in this case there are a lot of things happening, let us look at them one by one. First of all, you have a configuration of the waveguide and the source is placed as a point perfectly in the middle of the waveguide all right. Now let us look at that a little bit more carefully right a where is the source ok.

So I have x source - 1 to x source + 1 all that. So, there are there are three points which were emitting. So, what I am going to do is, I am going to fix it to something that I am already aware of. So, a this was between 49 and 51 right. So, I am going to move this I know that the center of the waveguide is at 50.

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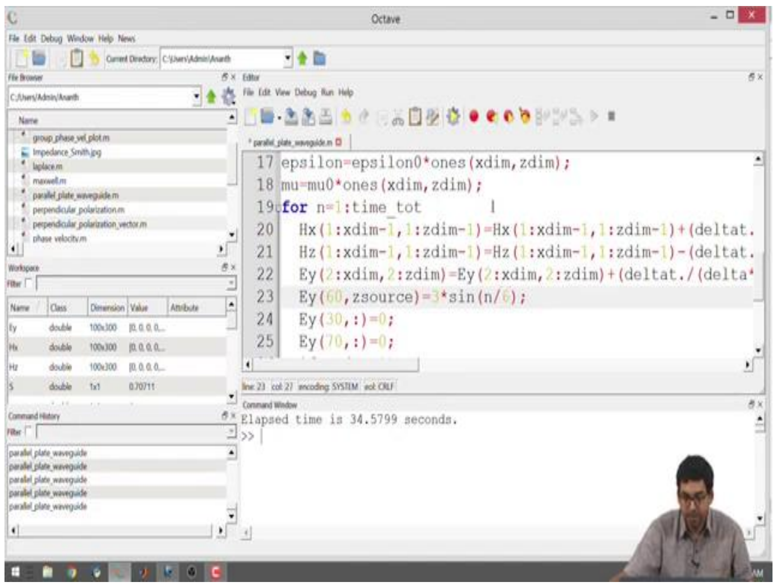

So, I am going to move this to 60 ok. Let me just tell you this again. So, 30 to 70 is the extents of the waveguide 50 is the center of the waveguide. Previously, this point was at 50, now I have moved it to 60 which means that, now it became asymmetric all right with respect to the waveguide all right. So, it is slightly going towards one direction more than the other all right and order to keep my analysis simple I will also no try to increase the frequency to say n/6.

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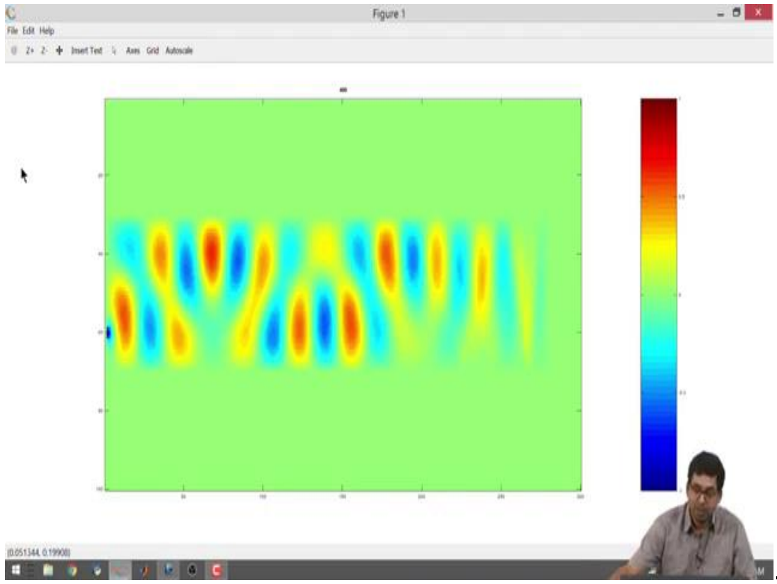

I can notice that the pattern that it produces is the very different than the pattern it was producing when the source was placed right at the center all right. Once again we will do this for a slightly different configuration. I will reduce the waveguide width a little bit because this is overly exaggerated.

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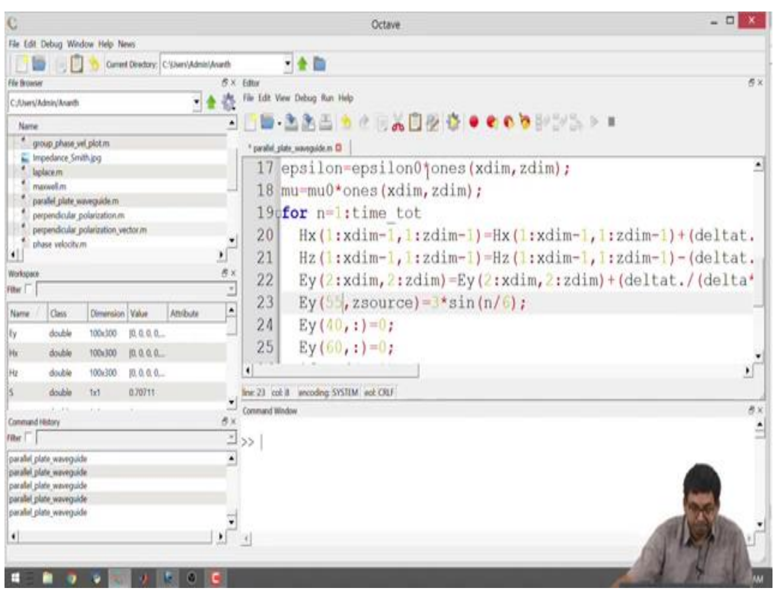

So, I will just make it a little bit shorter all right. So, that I can get my point across right ops I am having it right at the ok.

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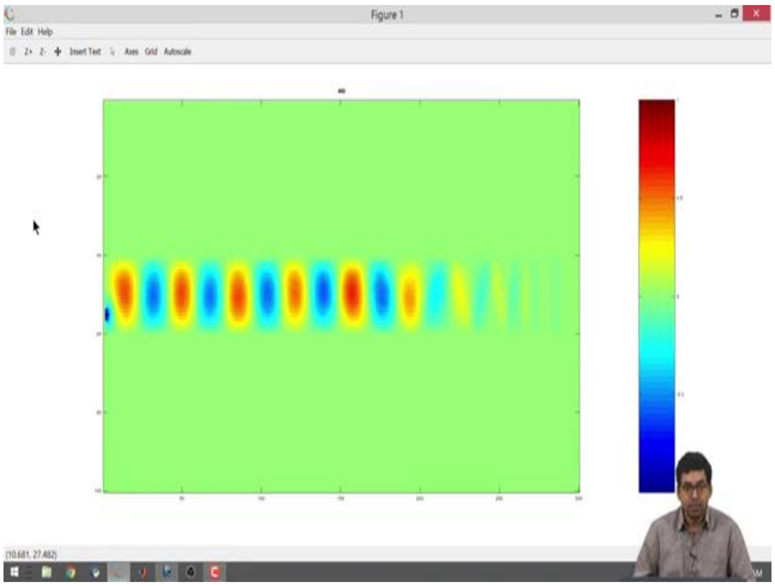

Now, I notice something weird has happened. Previously, when I had the plates to be wider when I kept a source largely asymmetric I started to notice different pattern all right. Now I made the plates go a little closer to each other and I kept the source reasonably asymmetric I would say, but still I notice that the pattern is similar all right. This should tell us something about the way we are making a choice of m in the case of these waveguides all right.

It is telling that first of all when the spacing between the waveguides was very large ok and you have sources of some frequency. Maybe the number of modes that can be supported by the waveguide is higher ok and if the number of mode supported by the waveguide is higher and if your operating frequency is above the cutoff for more than 1 mode then you may be able to excite more than 1 mode all right, that is why we are getting some very different patterns when you move the source from top to bottom of the waveguide make it asymmetric extra.

But if your plates are going to be closer to each other the number of modes that you can excite for a given operating frequency is lesser, maybe it is just 1 in this case right. So, it really does not matter in order to validate this theory, what we will do is we will make the waveguide even narrower and make the source highly asymmetric, that is it is almost touching one of the conductors all right.

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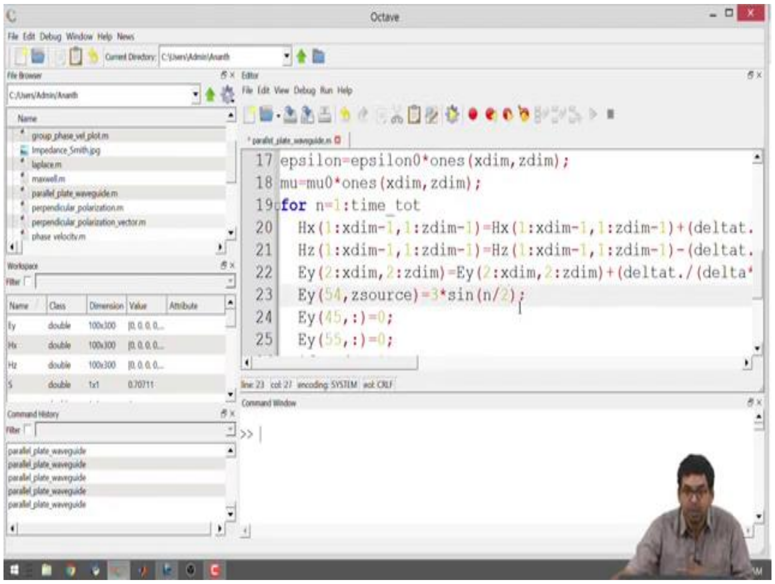

So, what I will do is I will make it 45 to 55 and I am going to put the source at 54th point right. So, now, the sources really not at the center it is close to one of the plates that you are using. So, it is highly a symmetric excitation all right ok.

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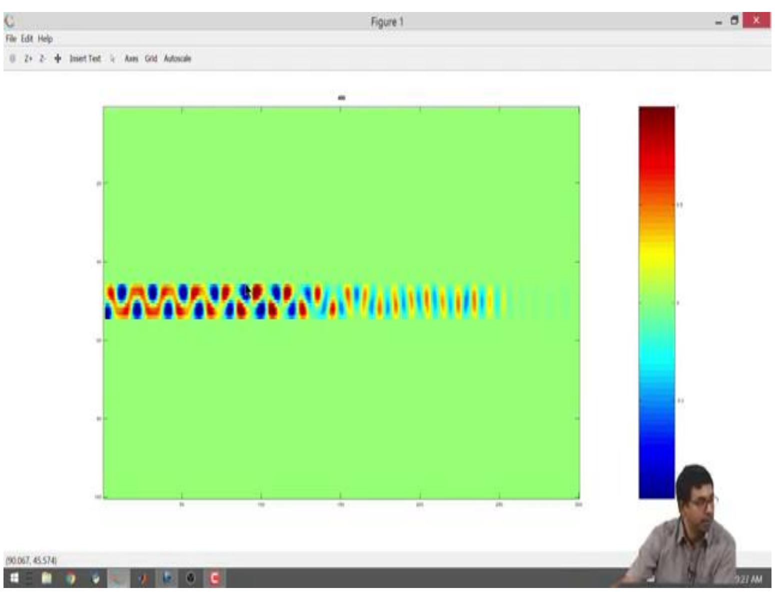

Now I have run into another problem that can be fixed I did not I overlook that problem the frequency all right. Because, I have changed the width all right the operating frequency also has to change maybe clever thing to do is sin(n/2) and then redo this again right all right.

Now I get some propagation, but now there is an issue. sin(n/2) means that you reduce the frequency right you increase the frequency sorry, you increase the frequency. But if you increase the frequency of operation all right you made some adjustments to the width of the waveguide that was valid for the frequency you were using before. Now again for this operating frequency for this separation how many modes are separated has to be recalculated all right.

In this case I can clearly notice that there are multiple patterns which are emanating all right, either it is like this or it is something like this all right, means that this particular waveguide for this particular frequency is still a multimode waveguide all right. So, at this frequency it is still multimode all right.

Student: When pattern also different at right side and left side.

Yeah, but in the it will be like that there will be some beating between them

Student: That the longitude is single mode at the near (Refer Time: 24:25) it is looking like that, but in case at the end certain single mode (Refer Time: 24:31)

Yeah, but there is no direct way to predict at which spatial location at which instant of time you will have which field pattern that is all. They are just it is it is just beating you are having more than one mode, they are beating with each other at different instance. So, now, you saw that towards the end it was single mode if you run it for more time that pattern will change right. So, that is why it is easier for us to operate a waveguide under single mode condition.

So, that you do not have this confusion as to what kind of pattern will be present at what instant of time in what space all right. So, I think the best way is to you know increase the I mean I mean decrease the frequency a little bit of operation all right and see what happens right.

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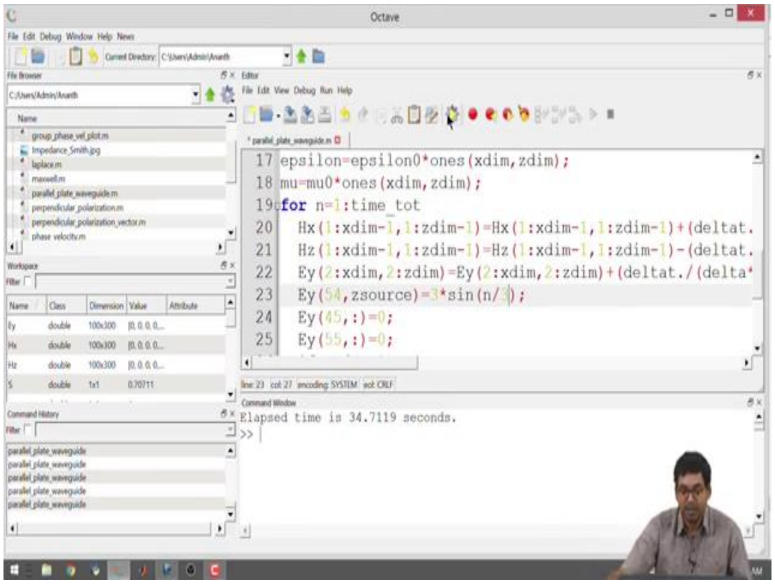

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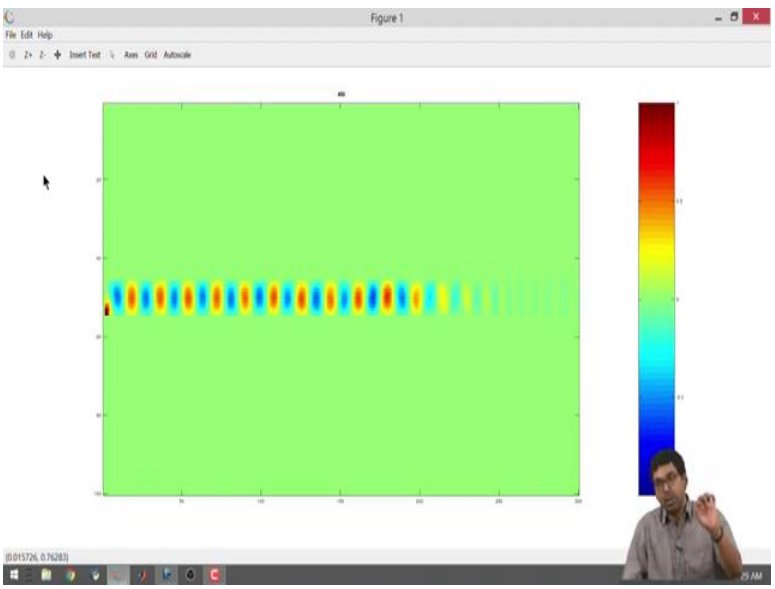

Now it is still a highly asymmetric excitation right, but I have changed the frequency of operation by keeping the waveguide a I mean dimensions fixed all right. What I am noticing here is that a I mean, I am seeing only one kind of pattern emanating between all right. So, it tells that in practice, all right, in practice if you want to excite multiple modes all right, you could do that with a point source that is placed in different locations between this waveguide.

So, maybe if you placed it exactly symmetric, maybe you will get some kind of a pattern, but if you moved it towards one plate or the other plate you may excite the other modes all right. So, we always have this question, what does these multiple modes mean and how do I excite these modes. Usually, a point source gives out a light in all the directions all right.

So, you could use a point source to excite all the modes, but if you want to exaggerate you know the presence of these modes then you can move them in the cross section of the waveguide all right that will give you an exaggeration. But a truly single mode wave guide no matter very you excited right will eventually form a single mode pattern only all right. And in this case it is you know just be adjusting the frequency I was able to get this pattern all right.

The other thing that we can start looking into is right, make it extremely big go back to it 30 to 70. Have a source, that is not a point source. So, far we have been dealing with the point source all right. Also it is worth to notice that suppose you do not have control over your configuration like a point source. For example, if you say that you are waveguide separation is 1 centimeter. Your source needs to be say for example, a millimeter or lesser in size so, that you could consider it as a point source in practice.

Suppose you do not have something like that you have something which produces a collimated electromagnetic wave as the source and that may have some beam width all right. Let us say that we are going to now see the properties of the width of the source on the waveguide let us take a very wide waveguide.

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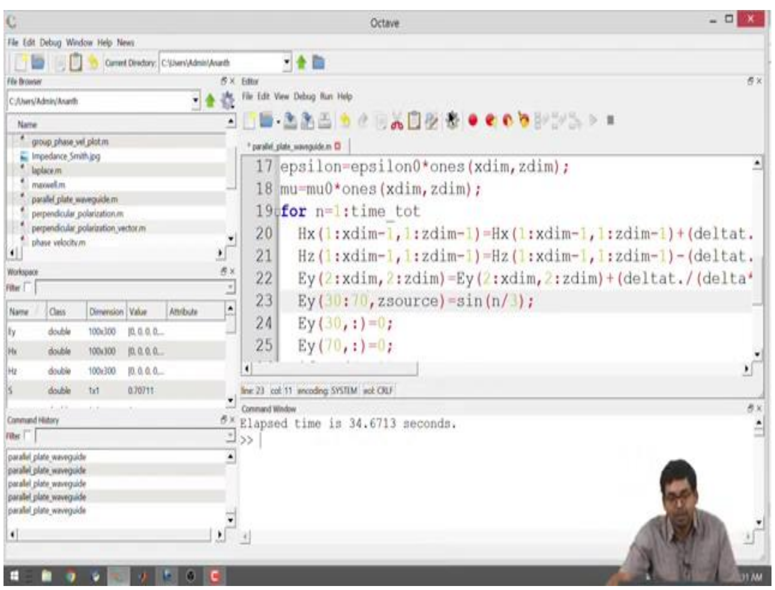

And let us say that from 30 to 70 ok. The entire width of the waveguide, you are having a source that is you are having what is known as a line source instead of a point source and we already know from our previous runs that in line source you will start getting plain wave fronts right and then let us see what the waveguide does to it right.

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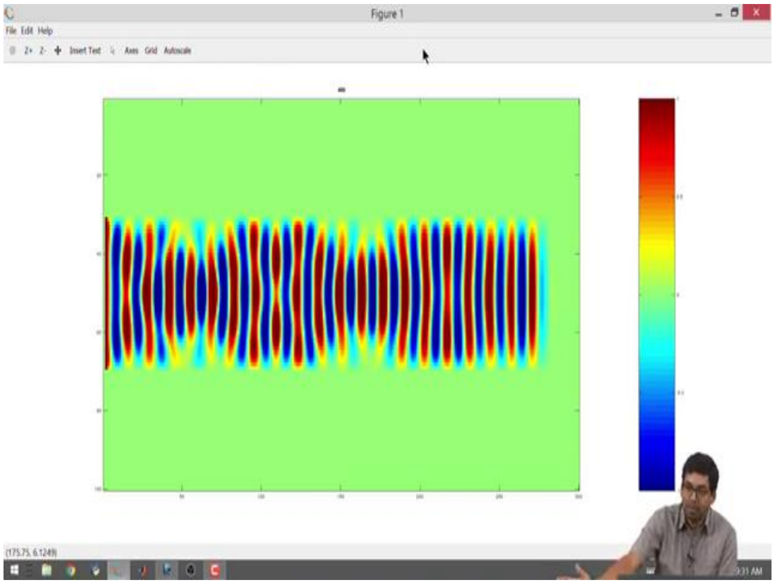

Seems to be ok, seems to be launching like a single mode pattern hard to say because, in between some interference patterns are definitely occurring all right. So, it is hard to say, but seems like it is easier to control this all right.

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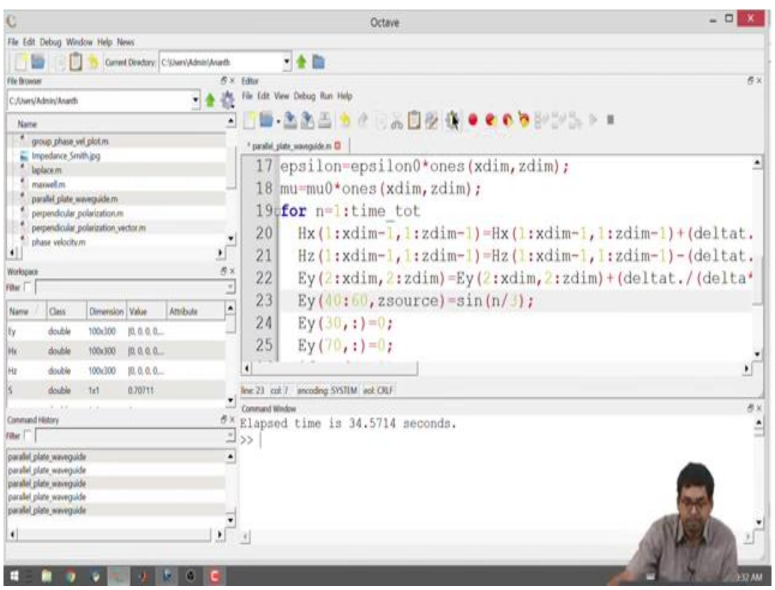

The other thing that we can do is, you know make it a little bit smaller all right.

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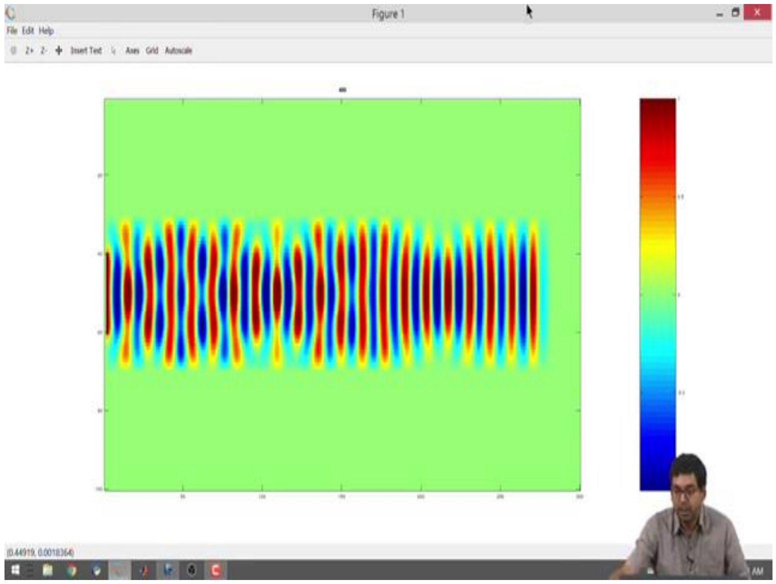

I am just making it a little bit smaller, maybe 40 to 60. Again hard to say, what is going on? It seems like there is propagation, but there are some strange interference patterns which are coming into the picture, I think we will have to reduce it further and let us say that it goes from you know a 40 to 60 so, this will become 45 to 55 right.

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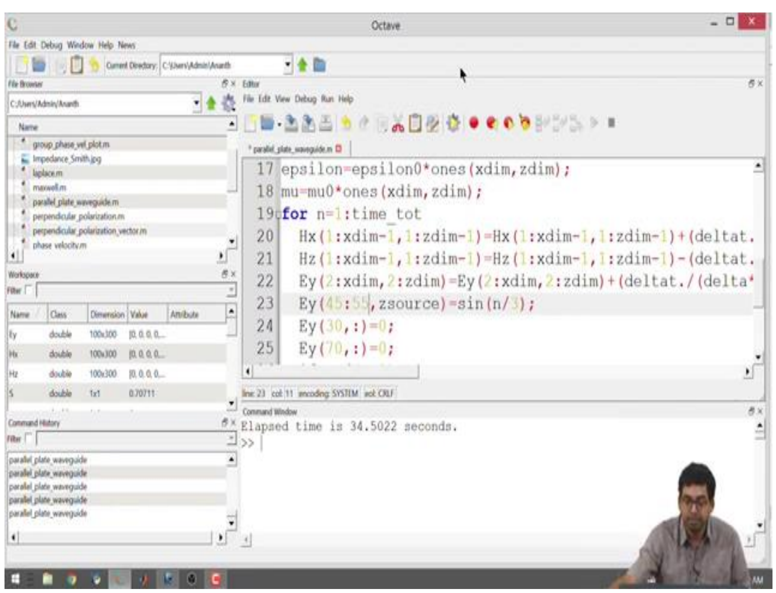

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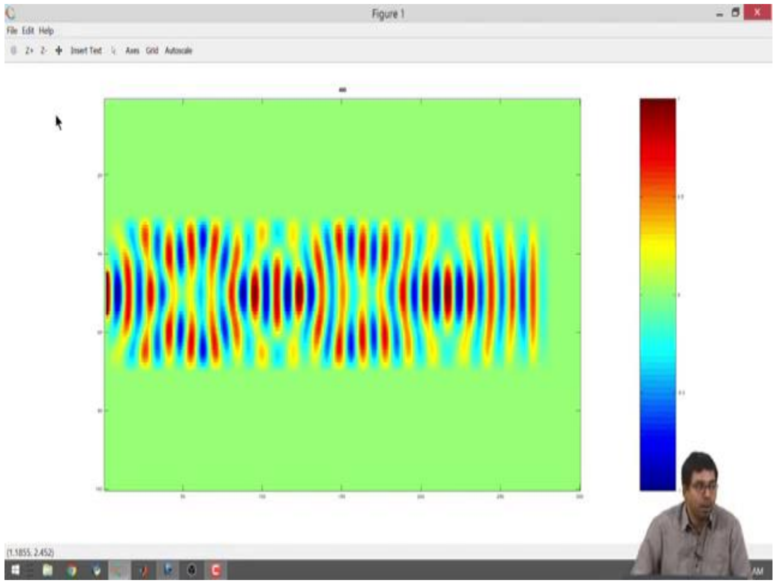

Now, it is possible to say that a you know may be this waveguide is supporting multiple modes and I can see that in some regions it is forming two spots, some regions it is forming one spot extra right. So, clearly the electric field distribution across the cross section is different in different places right and there is some periodicity happening all right.

So, size of your source could also determine how many modes you are exciting probably right. So, in practice in order to avoid all these you know a complications people try to use a source that is as wide as your waveguide ok and also try to make sure that at the frequency of operation whichever frequency you are choosing, at that frequency the waveguide supports only say one mode all right. And the fundamental mode is what you want to operate with in most of the cases. Unless, there is some explicit need to as you know excite the higher order mode. There may be specific application where they want to have you know different mode patterns or different field patterns, unless there is some a requirement like that this is how people would do it right.

So, now, it this part is now very clear all right. Now we will just make a couple more things all right. I had a waveguide going from left to right ok. Now what I am going to do is, I am going to introduce a 90-degree band ok, but I am going to make this an abrupt 90-degree band. So, I am going to launch it from one side right and I am going to abruptly try to see what would happen, if I kept a perfect conductor 90 degrees all right.

So, that I would really know whether it is doing some waveguiding or not. In fact, the essence of waveguiding is I should able to take it from one region guide it to some other region which is not exactly in the line of side right. So, now, we will go ahead and do that, but a we will also remove some of the unnecessary parts I will make the waveguide narrow again all right.

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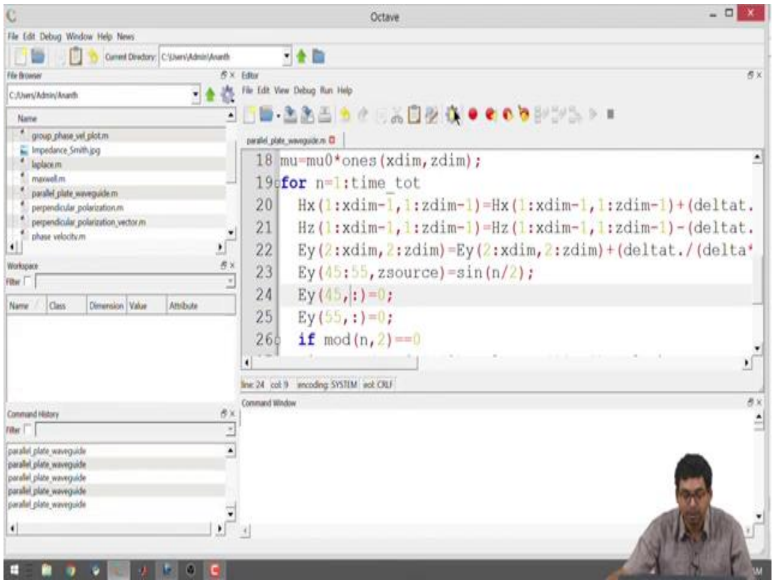

So, it is easy for me right. So, I will make it a between a 45 is what we saw and 55 all right and let the source be as wide as the waveguide and I will also choose a say frequency to operate ok. Now I want to insert two plates. So, originally I had Ey at location 45 for all positions in the other axis to be equal to 0 right.

Now I wanted to go only till the middle let us say right. So, I will just say that you know so, 45 we set the bottom. So, one of the plates has to become a little longer than the other plate because, I am having parallel plates I want to have parallel plates here also. So, one of these plates has to be come longer all right. So, I will just I just do not remember how we were a how the axis was.

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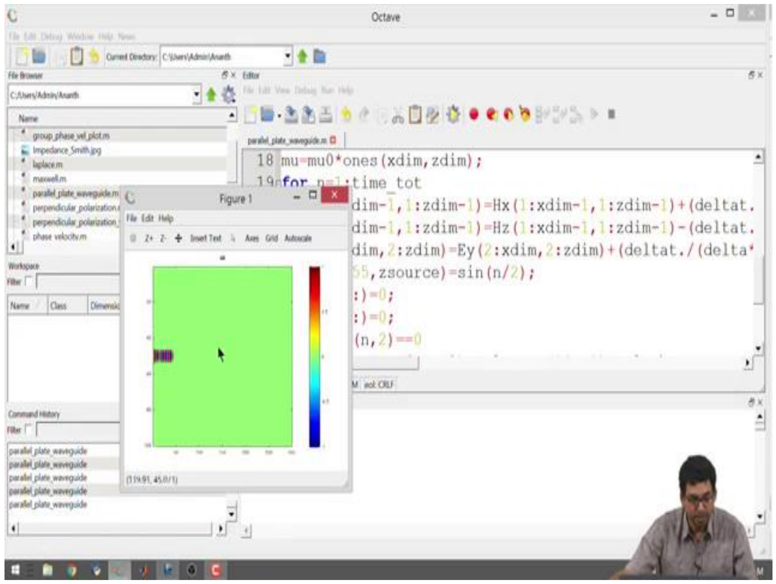

I will just run this and just note down. So, 45 is here ok. So, the 45 plate could be longer right.

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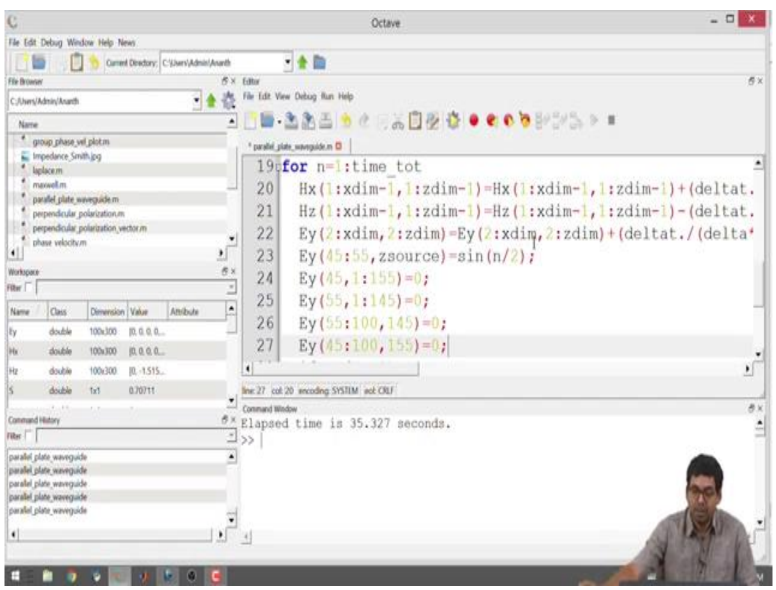

So, this goes from 1, 2 middle point of this was 150. So, 155 ok. Now, I have just made two plates, one plate 10 units longer than the other, which is the width of the waveguide that I have chosen over here right. I will just run to make sure that I am getting something on the other side.

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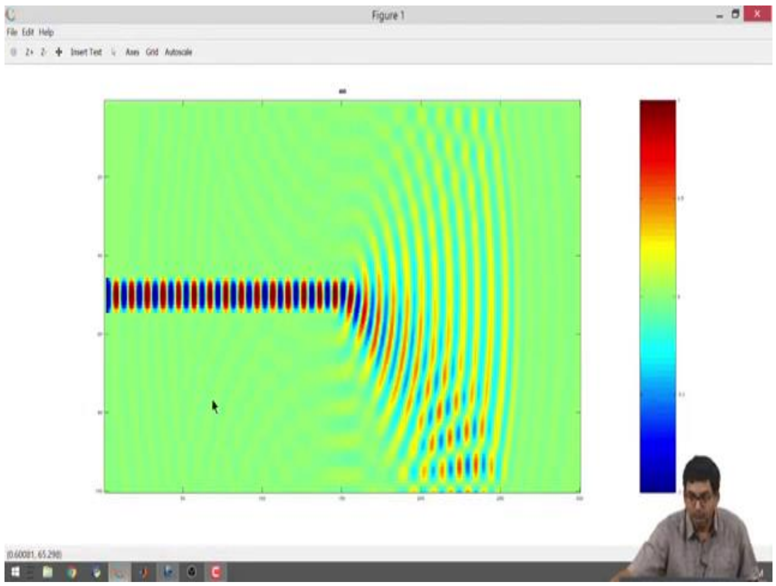

I am not inserted the second pair of plates over here. So, about the center is where should see that something happens it should start exiting the waveguide ok. Because one plate is longer than the other, it is actually directing a lot of the energy to the bottom side.

Now, I want to keep a second pair of plates going from the middle to the bottom and I want to see what is going to happen that is all right ok. So, I will keep the plates once again, I think it is easy of for me for I note down the coordinates. Let me just run this briefly. Just note down the coordinates were I want 55, 145 ok.

So, I am having 55 to 100 ok and I have another plate ok. If they are wrong, I will correct it as we go. I think it is correct 55 colon 100 comma 145, 45 colon 100 seems fine to me ok.

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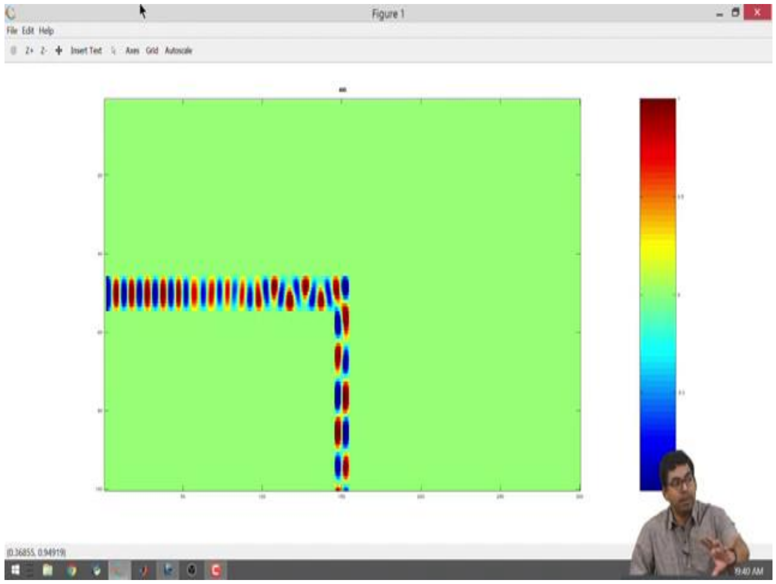

So, now I am going to run this again ok. Now I noticed something that we have not seen or studied about before all right. We have talked about positioning of the source to create different modes, we have also talked about the width of the waveguide that can support difference modes. And in this particular case I had used the line source to excite this parallel plate waveguide, I assumed it to be single mode. But when I inserted a 90 degree bend I notice that the pattern that is coming in this 90-degree bend is very different from the pattern I was getting in the horizontal section and this reminds me of something were clear all right.

It is shows here that you know if I go from one side to the other side on this waveguide, I am having electric filed two spots all right I am having two spots two half cycles I am having. So, this corresponds two m equal 2 all right. And on top of that in order to validate this I also remember that electric filed in one spot is 180 out of shift with respect to the electric field in the other spots. So, clearly one is red and the other one is blue corresponding to positive one and negative one and this clearly tells me that yes I am looking at m equal to 2 spot ok.

So, this means that when you take a waveguide and when you make a bend on it all right you will start seeing the modes that are presents. The second think that you are noticing is that what is more interesting is that we launched and the pattern appeared to be predominately fundamental mode. Fundamental mode had one spot the fundamental mode did not pass through this abrupt 90-degree bend all right. Which means that it may have hit this wall and it is getting reflected back in the horizontal section and it is creating an interference pattern all right.

Whereas the higher order mode all right is actually doing something different than the fundamental mode, may be it is doing multiple bonuses and the way it is travelling is very different from the fundamental mode all right. And it is also clear that when you had an abrupt bend, the higher order mode pass fundamental mode did not pass over here right.

So, these are all some a thinks that we have not studied analytically, but this program now gives you know some starting point to make an experiments with structures and try to see what all things can happen. So, it means that in order for me to do are real experiment ok. I need to have a source, the source could generate you know the source should be of the size of the waveguide all right, in order to excite some clean waves inside of waveguide and in order for me to a dedicate that I am having wave guiding action I could keep a detector on the other side.

But, normally if you keep a source and detectors on the same side, I mean, in line of side it is hard to believe that you are getting the light directly from the source or you're getting it through the waveguide. You will have trouble believing it all right. So, better idea would be to bend waveguide in some way all right. So, that your source and the receiver are not in all of line of side and then actually prove that you are really having wave guiding action all right.

And one of the simpler things one could do is make a 90-degree bend, but it seems that if you make a 90-degree bend all right you are going to be able to measure the intensity, but mode pattern is dependent upon the side of the waveguide again number of mode it supports the frequency of operation extra right. In order to do this once more what we will do is instead of n/2, we will just see if we can do n by 3, all right and just see what happens.

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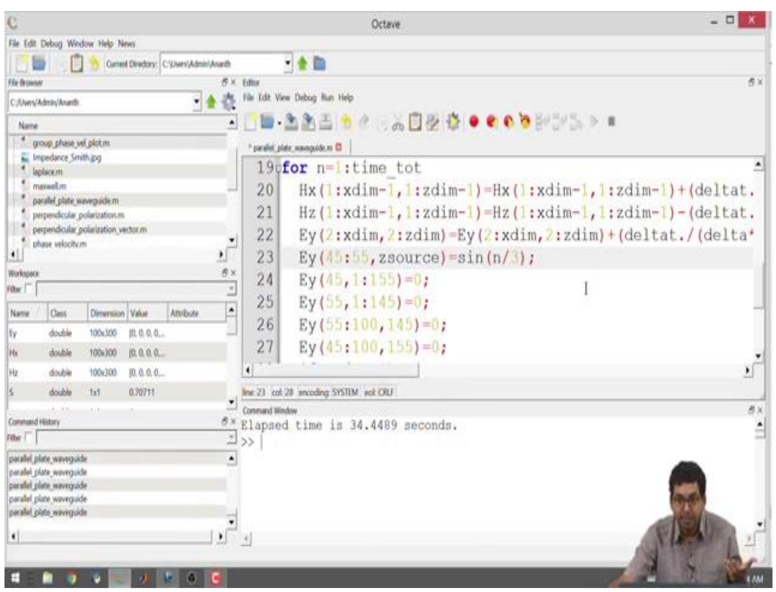

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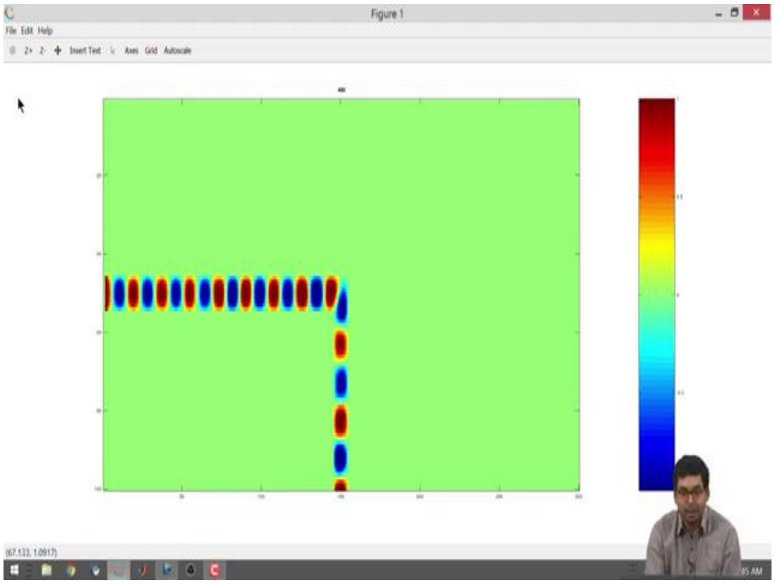

Clearly, this waveguide is single mode right. So, what happened is it went portion of it is started going through to 90-degree bend and did not change the mode configuration. But normally one would say that look it is not very a conclusive thing, only thing you can say is your getting light from this side and it forms a specific mode pattern and the light is coming from the other side, it is forming a specific mode pattern. You cannot conclude that it is a single mode multi-mode all that because may be multiple modes are there and you did not excite or the configuration is such that single mode was dominant and then did not get converted due to several other reasons.

But it is clear that you know the operating frequency, the size of the waveguides, the bend that you have the size of the source, all of these are waves for us to excite and you know probably propagate different kinds of modes in your parallel plate waveguide ok.

So, I things with this 90 degree, think it should be clear that indeed you are seeing some wave guiding action. So, many people make modifications of this, you know you may also choose for example, instead of having a structure like this you may choose put a metal on the right edge of the waveguide. So, it is the very a different case where you have a source, we have a waveguide and then you have metal plate at the edge ok.

So, will be having wave guiding action and end at the edge you are having some complete reflection back. You can push this to one more extremes say that put the source right in the middle of a metallic box ok. It is covered with plate on all four side in the cross section two side this way.

In those case, the energy will not able to leave the box. It will keep on bouncing back and forth, back and forth, back and forth and it will keep on being present in inside the box. So, you can a use the analysis that we had and in several books there are some as you know treatment about cavities resonators extra. These all extensions of the same concepts. So, you start with single interface. Now we had two interfaces and all that all right.

Now, you can go ahead and use the same approach to put metals at the different places and build what is known as cavity resonators extra. You could also study about what is the resonant cavity what is the non resonant cavity all these things. So, we have the frame work, unfortunately, we will not have the time to study each and every component this r f and photonics. But I think that now, you should able to understand that you have the starting point and you can use your imagination to navigate a little bit further.

And another advantage is you have a program all right. You can do any arbitrary nonphysical thing also in a program. You may be able to easily put a source in a middle cover it with a box and see what happens. It may be tougher to do that in an experiment actually all right. So, you have the foundation, I hope that you will make use of it and see what all you can do with it all right we will stop here and next class will continue.