Antennas
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Module - 10
Lecture – 47
Horn Antennas-III

Hello and welcome to today's lecture on horn antennas. In fact, in the last few lectures we have been talking about horn antenna. So, we started with the rectangular wave guide and we saw that if the rectangular wave guide is like this that e field is perpendicular going like this, and the e field goes form the maxima at the center and at goes towards 0 so in fact, this plane here is H-plane and this plane here is E-plane. So, if we expand the whole thing in E-plane it is known as E-plane sectoral horn and if we expand in this particular direction then it is H-plane sectoral horn antenna. And then we talked about pyramidal horn antenna in which what actually happens that we expand in this direction as well as in this direction.

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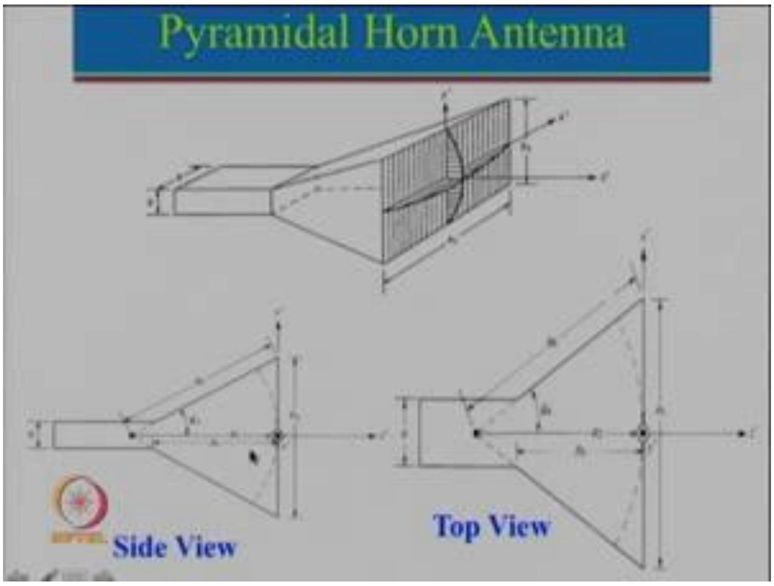

So, let us continue from there. So, we had seen that this is a pyramidal horn antenna and that was the side view and the top view.

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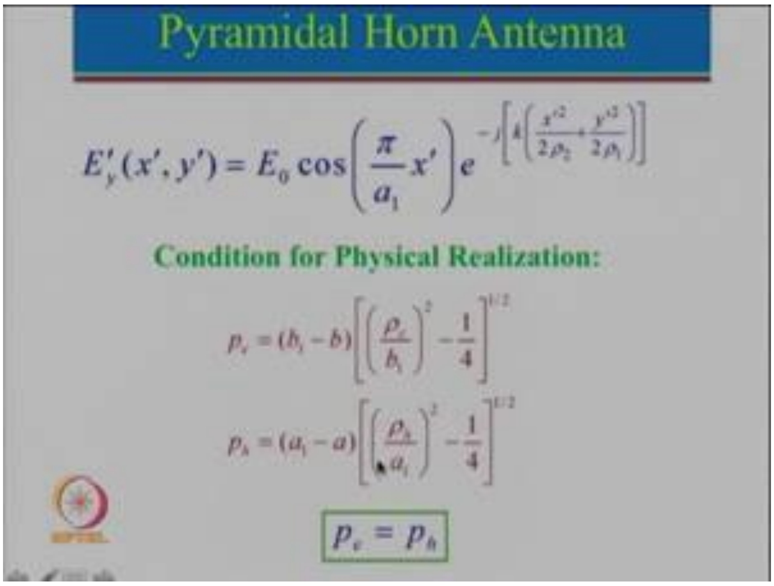

And then from here we had also seen that the amplitude variation will be given by this cosine function, where if x dash is equal to 0 which is at the center field will be maximum, and at the edge x dash will be a 1 by 2. So, that will be cos pi by 2 will be equal to 0. And in the terms of phase, the phase terms will be actually summation of both the phase terms in the E-plane as well as in the H-plane. So, the phase error will be much larger. And condition for physical realization actually there is only 1, and that is rho e should be equal to rho h and the values of rho e and rho h can be obtained from the parameter dimension.

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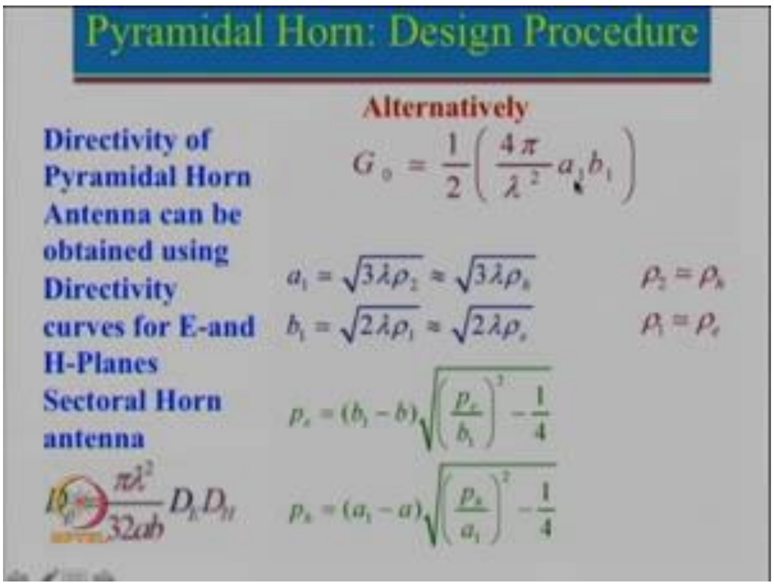

And then we had actually seen that the gain of the pyramidal horn antenna which has been taken as this particular term which is a 4 pi area divided by lambda square that is in normal directive expression, and area is here aperture area which is equal to a 1 times b 1.

Efficiency has been taken equal to 0.5, and I want to mention that we will just look into the design given in this particular book of Balanis, but; however, we will tell you what things can be done so that we can improve the efficiency to even 70 percent or 80 percent. So, now, we will continue from here. So, we had seen that for optimum horn antenna dimension a 1 is given by this expression, b 1 is given by this expression which was approximated to this particular expression. This expression is only good if the aperture dimensions a 1 and b 1 are relatively small. Only in that case this approximation is valid. And then by using these equations I had mention that by combining these equations, one can actually get a equation something like this here. Where if you notice this is actually even they looks like a x or it is psi.

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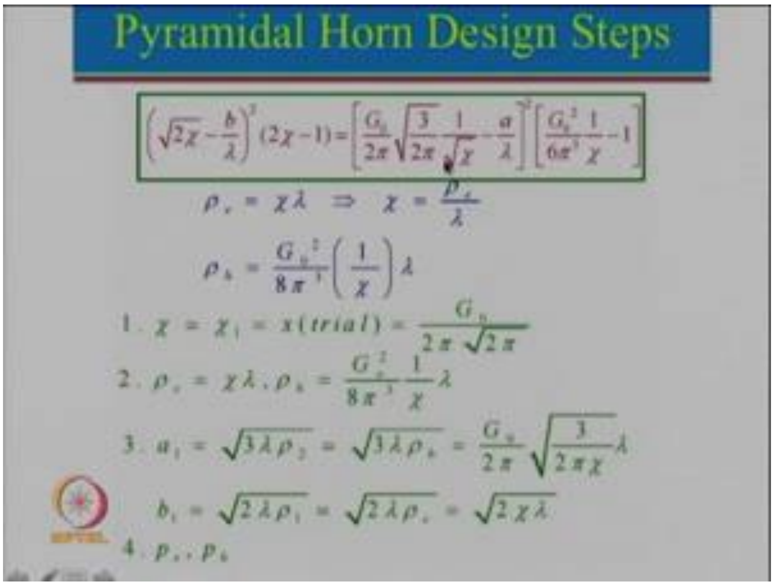

So, psi here is everything on the left hand side is in the numerator, and psi this side here is in the denominator. And these things have been obtained simply by combining the previous equations. So, if you combine these equations you will get this expression over here, and where we can actually see that rho e is given by this expression, and once we solve this equation for x or psi then we can find out rho e and all the other parameters.

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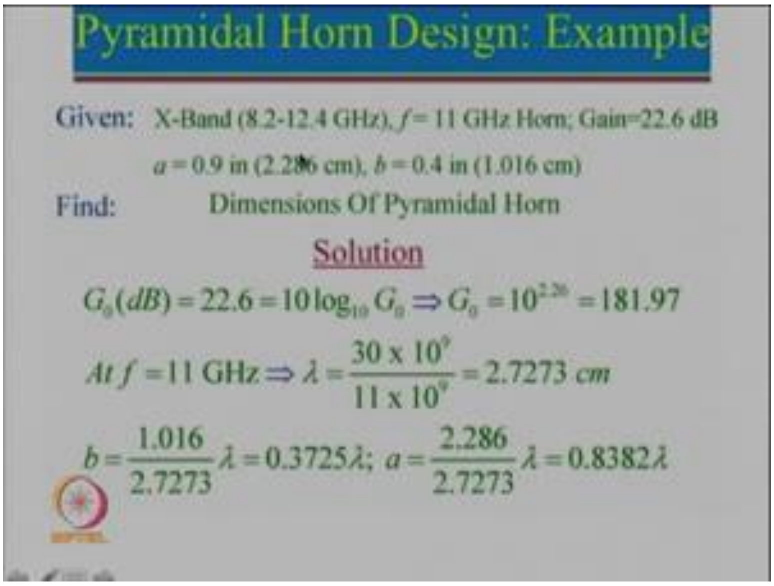

So, we actually just shown you this particular example. This example is again given in the Balanis book. So, here x band antenna is to be designed at poor that the first step is to choose the proper x band wave guide. Because that desired frequency at which antenna is to be designed this 11 gigahertz and the gain is 22 point 6 dB.

So, corresponding to this frequency we need to find the wave guide. And this particular wave guide has been chosen because this actually works in the frequency range from 8 .2 to 12.4 and these are the wave guide dimensions that is this actually wave guide is w r 90. And as I had mention w r 90, that 9 0 really implies 0.90 inches. So, a here is 0.9 inch and then b is 0.4. So, from here we can actually do that design procedure starts like this. So, first where the given value of the gain you find out the numeric value and then for the given frequency f we find out what is lambda, and then b is written in the terms of lambda as well as a is written in terms of lambda.

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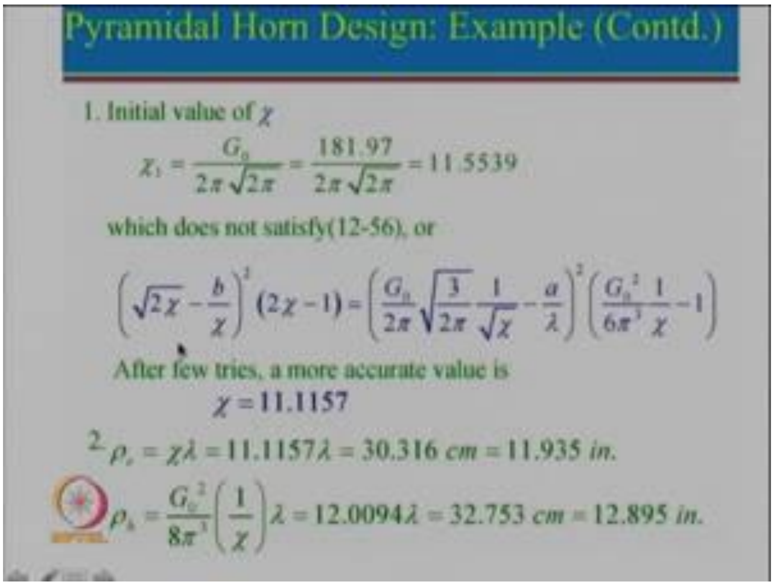

And then this is the initial guess, if we use this particular guess as we will see solution is relatively close, but for given value of g 0. So, the psi value is given by 1.5539.

Now, if you substitute this value of psi in this particular equation we will actually see that left hand side is greater than in the right hand side. So; that means, this psi value has to be decrease. So, if this is decrease this LHS will decrease and this will increase. So, after a few iterations if you do a properly iterations will be less, but you can see that the psi value is about 11.11. If you compare with this here it is within 4 percent error, which is fairly good starting point. And if you use this starting point then we can arrive to the solution quickly. And then once psi is known or we can say x is known then we can find out all the other parameters like rho e rho h and then a 1 b 1 and other dimensions and that completes that design.

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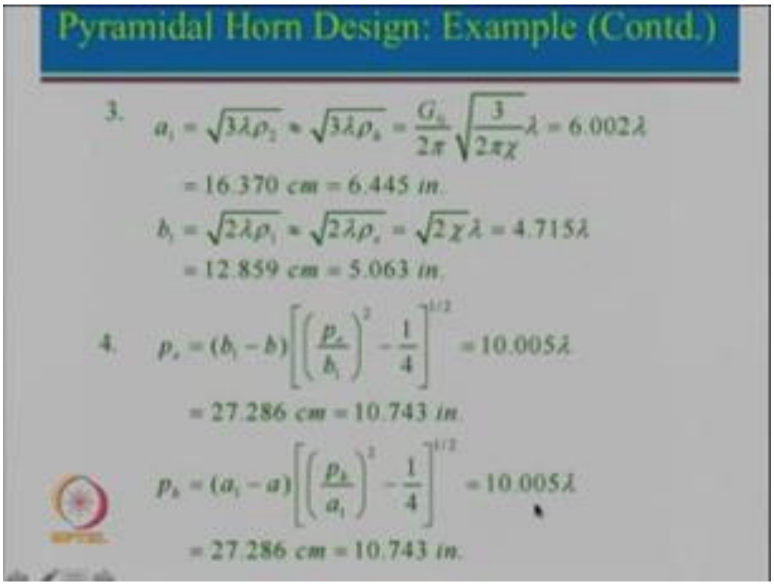

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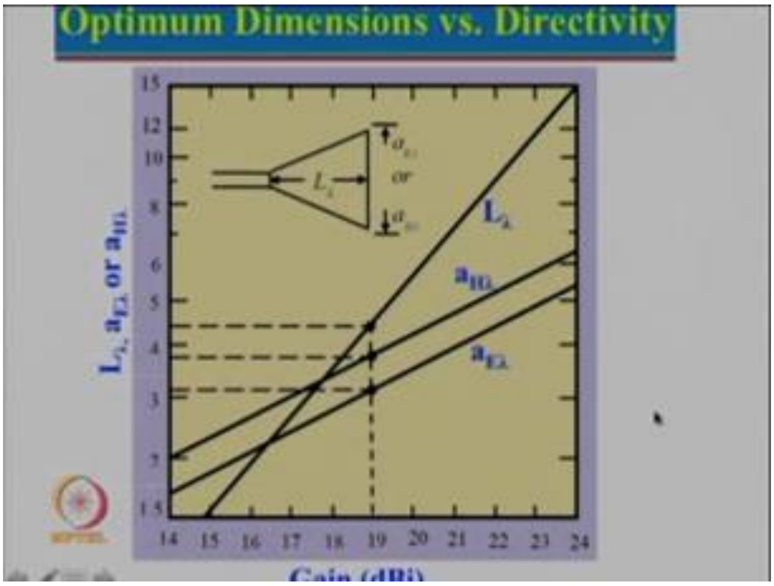

Now, one thing is you can do all of these equations or there is an alternate way very fast way and this particular curve is given in the cross book. It is actually always a very good idea that you read different books you read different journals so that you can get the things quickly. So, with this particular books says that this is the plot here which is gain plot is over here and all the other dimensions are shown in this particular direction here. So, for example, we want to design antenna let say at 19 dB gain, all you need to do it is we draw the line vertically. So, corresponding to this you find out what is the value of L lambda which is the distance from here to here, which we have also given the nomenclature this is the known as the neck of the horn antenna this is the mouth of the horn antenna.

So, or you can say this is aperture and this is the joint. So, this distance is given by the term over here and correspondingly a H lambda a E lambda or just you tell you these a H lambda a E lambda basically are shown in this particular book, but whereas we have taken these as a 1 and b 1. So, just you need to do that correction, and then you can see that we can get this particular values and that actually completes a design.

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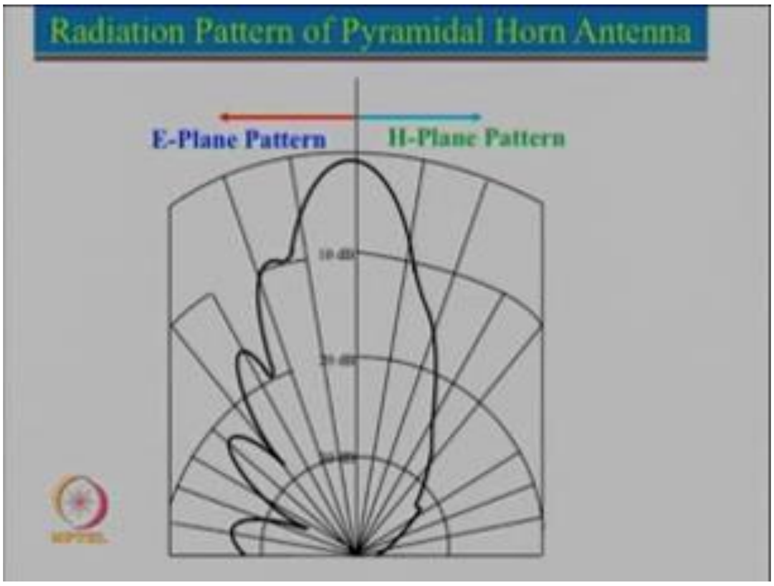

And if you look at the result of these things here now, here is a 1 of the radiation pattern of pyramidal horn what it shows here that this part here shows the H-plane, but this will be symmetrical in this side. Just to save the space only half the portion is shown here and this is the E-plane pattern which is shown over here. Now let just see little more carefully if you look at this E-plane pattern you can see that there is a fairly visible shoulder over here which is at the level of around minus 10 dB.

Now, this is happening mainly because of the large phase error, you can also see that the null directions are not very sharp whereas if you recall for error theory when we talked about the space factor concept. So, for uniform field distribution this should have been generally somewhere here around a minus 13 dB or so, if the phase error was negligible. So, because of the high phase error this radiation pattern is not very good, it has a larger side globe level. And you can see that for this entire particular range over here the value is about minus 10 dB below. 10 dB below means 1 percent power.

So, you can see that all this directions power is radiating which is not really the desired power. Now let just look at the H-plane pattern, where H-plane pattern where we had seen that there is a cosine distribution along H-plane and for cosine distribution, if we apply that array theory there should have been somewhere side globe level would have been close to minus 22 dB or so, but now because of the phase error, one can see that whereas, no sharp null at all. All you we see here is these are the shoulders which are coming up here again this problem is mainly because of the large phase error and because of the large phase error only the efficiency of the horn antenna taken in these design examples is only about 50 percent and some books do we take as 60 percent.

But however, if we take better antenna design then we can get efficiency of 70 to 80 percent also. So, I would like to mention that from here when we read all of these things and I just want to mention when about 10 years back I have started my own company Wilcom technologies private limited which is an IIT Bombay incubated company. And we had design several antennas and we get these antennas to the telecom operators and other people. And then they actually ask have you calibrated these things using standard gain horn antenna and in fact, we had not done that, but we knew that our things are correct, we even told them that we have done lots of other micro step antennas we know how to do the gain calculation, but no they wanted everything to be calibrated against standard gain horn antenna. And then I went through the internet and saw, most of these standard gain horn antennas we saw the prices are approximately 1 lakh or so.

And I did not want to spend so, much money and since I have been teaching horn antenna since 19 you can say 1993 94. So, I felt why since I have been teaching why not at design my own horn antenna. And then when I wanted to manufacture the horn antenna I realize that lot of these things which we have discussed now, they talk about the phase error they talk about aperture dimensions wave guide dimension, but they really do not give too much detail about how to feed, what should be the feed dimension, what should be the feed location and other thing. So, then we real decided that let us do something more carefully and let see what all we can do. So, it was basically that a need and that is why they always say you know when there is a need then only you start looking into the thing.

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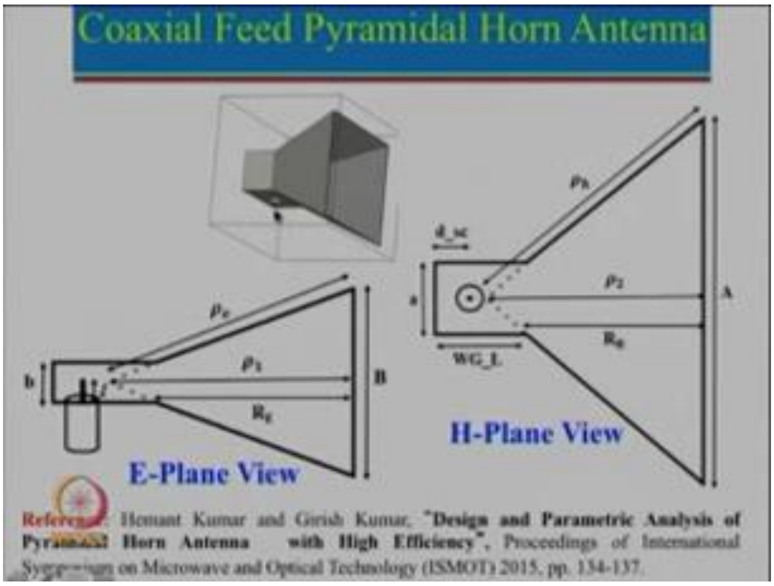

So, after that we decided let just do some simulation and experimental work. So, here is a horn antenna. You can actually see that this is the where we are feeding the horn antenna. You can actually see the side view from here, but can actually see this dimension v over here and this is where we are feeding it. And if you look from the top we will actually see only the coaxial feed over here. So, now, what is important that what should be the height of this particular feed, what should be the diameter of this particular feed, and what should be location of this particular feed, with respect to the shorting position.

So, I will just tell you quickly we will open the suspense right now and then we will show you what all is happening. So, after doing all of these that is what we really realized that this is really nothing, but a monopole antenna. And we know that how to design monopole antenna and this monopole antenna sees a large ground to plane. So, we know that for monopole antenna if you change the length frequency we will change if you change the diameter, bandwidth will change. And then comes the next part that what should be the location. So, since this is a shorting post here. So, if this is a short and if this is lambda g by 4 distance then this short will act as an open circuit. So, there will be no loading, on this particular probe at this particular point; however, if this distance varies there will be some loading on this particular probe and impedance will change.

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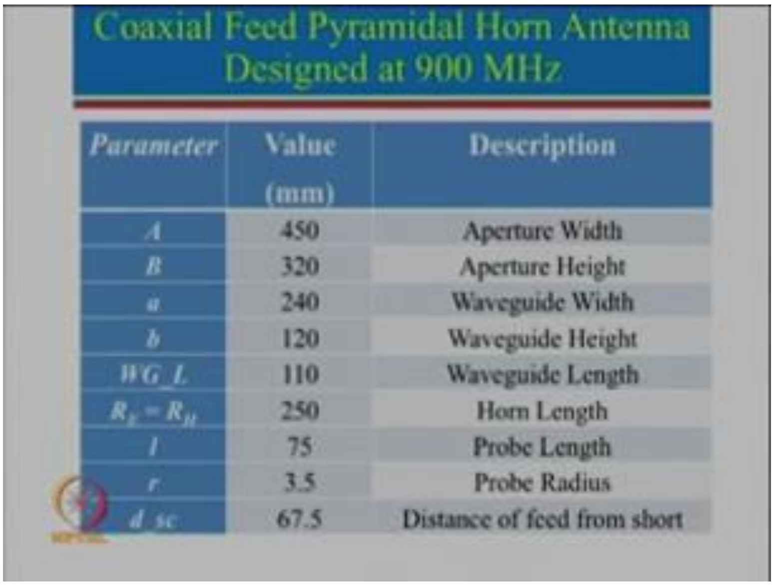

So, now after giving you the suspense now let see how the values change. So, we actually designed antenna at around 900 antenna megahertz. There was a reason because we were designing antennas at CDMA band as well as GSM 900 which covers from 820 megahertz to 960 megahertz. And hence we chose this particular design as our first design. So, I am just giving the basic parameters here, but we will show you the parametric study of different parameter. So, just to tell you here, probe length is around 75 mm and one can actually see that at 900 megahertz wavelength is 33 centimeter half of that will be slightly more than 80 mm. So, we took slightly less than that to account for the diameter effect.

Then this is the radiance which is 3.5 mm and this is equal to 7 mm diameter. Then we have taken the wave guide dimensions has a is 240. So, that we have a cut of frequency lower than this value here and this is the b value. And these are the aperture dimensions' capital A and capital B we have been writing as small a 1 and b 1 which is really here capital A and B. And this is the horn length which is from you can say from the net to the mouth which is about 250 mm. So, now, let see one by one what are the effects of the different parameter.

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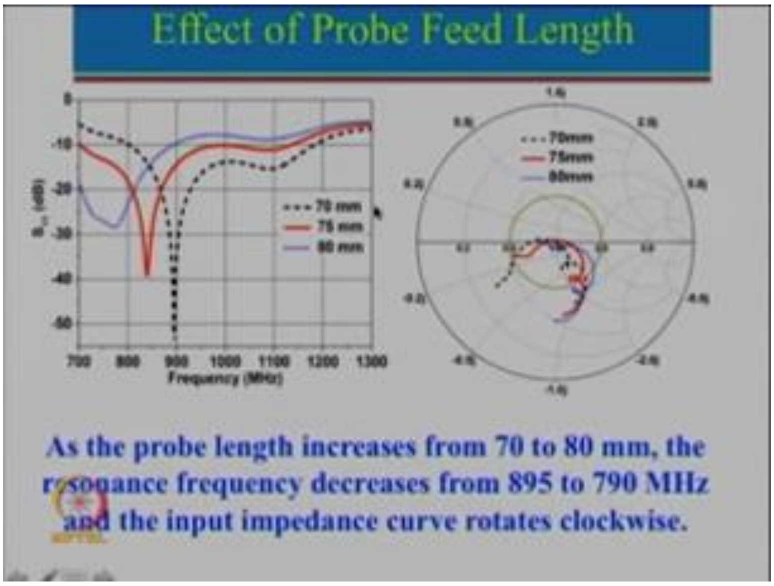

So, the first effect is the effect of the probe feed length. So, here what you can see the S 1 1 plot as well as the impedance plot for 3 values of the probe feed length and these are 70 mm 75 80 mm. So, one can actually see that this is the plot for 70 this is the plot for 75 80. So, as one can see that if we increase the probe length from 70 to 80 which is what I have written here. Then what will happen if we increase the probe length then resonance frequency decreases. So, one can see that the resonance frequency decrease from about 895 to 790 megahertz. This is actually straight forward in the sense that if we can even see that approximately L 1 f 1 is equal to L 2 f 2. So, if you increase the length frequency will reduce and as for as the smith chart is plot is concerned, basically as we change the dimension what we can see that the impedance plot is basically rotating.

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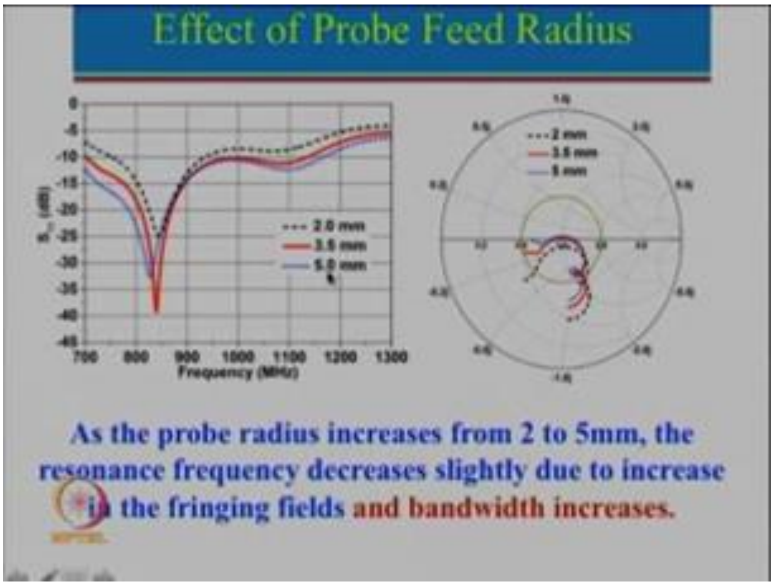

What we can see here is that the input impedance curve is rotating clockwise. Now let see the effect of the probe radius. Now as we change the probe radius and you can see here that different 3 values are there. So, radius is 2 mm 3.5 mm 5 mm. So, if you increase the radius. So, what do we expect if we increase the radius in general you can say that fringing fields will increase and that will reduce the frequencies slightly. So, one can actually see that from here to here, to here frequency is reduced slightly; however, the major effect of this is that if we increase the radius bandwidth increases.

One can actually see that if this is S 11 which is line here is minus 10 dB. So, you see that this is the bandwidth corresponding to the radius which is 2 mm and if we increase the radius you can see now that the bandwidth has increase and if we increase the radius further one can actually see that the band width has increased further. And there is a small effective change in the radius on the impedance plot.

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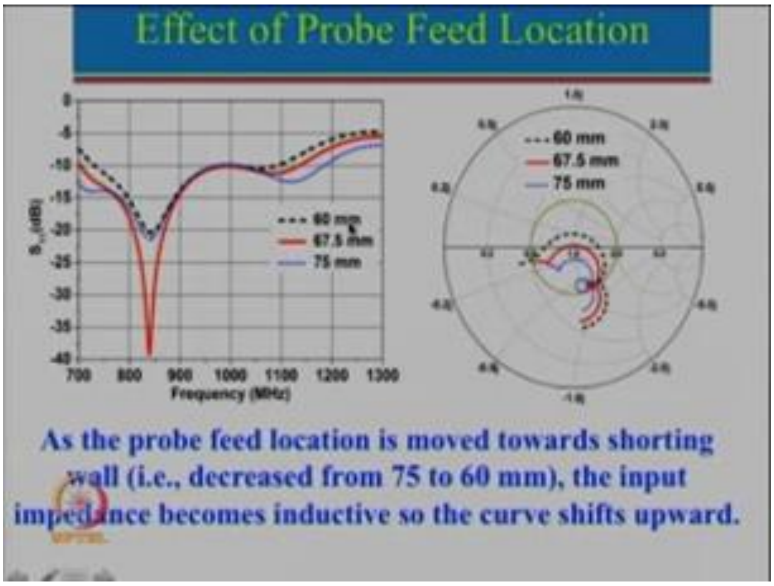

Then let just look at the effect of the probe feed location. So, what we have shown here for 3 different values of the probe feed location. And this is 60 67.5 75. Now these are approximately equal to lambda g by 4 at the desired frequency. Now one can actually see that by changing the probe feed location you can see the change in the frequency actually speaking there is no change in the frequency; however, there is a significant change in the impedance plot. What one can see that if this distance is small? If this distance is small now one can just go back look at the figure. If this distance is small then this impedance looking from here recalled transmission line, where transmission line we know if this length is less than lambda by 4 then this input impedance becomes inductive. And if the length is more than lambda by 4 input impedance here will be capacitive.

So, that impedance will do the loading effect, and one can actually now see. So, for shorter distance one can actually see for shorter distance input impedance will be inductive. So, one can actually see the shift along the inductive region. In fact, this particular concept can be used to optimize the feed location, so that we can get a proper impedance matching with the feed probe.

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And then now let see the effect of the horn length. So, here aperture dimensions are fixed as before I mentioned I will just go back here. So, the aperture dimensions are 450 by 320. And what we are showing you is the effect of this particular horn length change.

So, one can actually see for the fix aperture as we increase the horn length, one can actually see the frequency efficiency has been shown for 2 different values of the frequency. These are basically you can say close to the 2 bandage frequencies. So, one can actually see that at lower frequency efficiency somewhere here and this frequency efficiency is poor. And as we increase the horn length you can see that the efficiency is increasing. Now if you use that concept of the optimum pyramidal horn antenna which will actually give us a very poor efficiency that will correspond to somewhere over here corresponding to this horn length.

However, if we increase the horn length, and one can see that if the horn length is greater than 150 mm which is over here if we choose this here you can see that this efficiency is greater than 72 percent. So, anywhere around there and then if we actually take the horn length greater than 250 mm which is somewhere over here then we can see that efficiency is close to 80 percent.

Now, here we can actually see there is a no point in keep on increasing the horn length to even 450 or so, you can see that efficiency is relative constant. So, after certain point there is a no increase in the efficiency; that means, that the phase error after this is relatively very small, but this much phase error is acceptable for a decent frequency. So, one needs to choose some of these parameter so that is why I do not over emphasis that you do all those optimum calculations and do all of those things. So, basically what you do that you try to use the horn antenna with the relatively lower phase error. In fact, I did mention and that earlier that what we had seen that in the books they mentioned, for E-plane you can actually take maximum phase error as 90 degrees, and in the H-plane you can take phase error up to about one 35 degrees. I do not recommend this at all. I suggest that for E-plane maximum error you should plan to take is about 45-degree phase error.

So, choose the length and dimensions accordingly. Similarly, for H-plane you can take phase error between 45 degrees to 90 degrees, but lower the phase error better will be the efficiency.

So, yes we read lot of good things in the book, but the thing is when these things were written those days we did not have these sophisticated software tool. So, many of these things were done analytically or they had done some approximations to derive or they had use these analytical expressions to come to the result; however, those days because of the lack of the sophisticated computer simulations and software. So, now, we have all these tools. So, utilize these tools. So, do not take everything what is there in the book as the final thing. The books actually give us the guiding thing they give us the theory you read those theory, understand the concept and then apply your logical and analytical ability, to improve upon the performance of the antenna. And also please remember whatever is your application you need to do optimization according to that particular application.

Sometimes you may have a restriction on the length; sometimes you may have a restriction on the aperture. So, you need to look at what are the restrictions where you need to put and then also many times you have to see that you would like to get a very good reflection coefficient. If you are feeding very high power or you need to see that I need a better efficiency. So, it all depends upon what is the actual requirement. So, do not think that that everything given in the book is the final word, you should read the books understand and I always encourage the people to read the books because like when I wrote a book on broad man micro strip antenna it took me about 2 years to write that books. And also I put my 20 years of experience in writing their books.

Similarly, like books written by Kraus or Balanis and other people. These people have put decades of their experiences in a writing these books. So, we should read these things and also I strongly recommend that you should read the journal papers also, because in the journals you will always see the latest things happening around the world.

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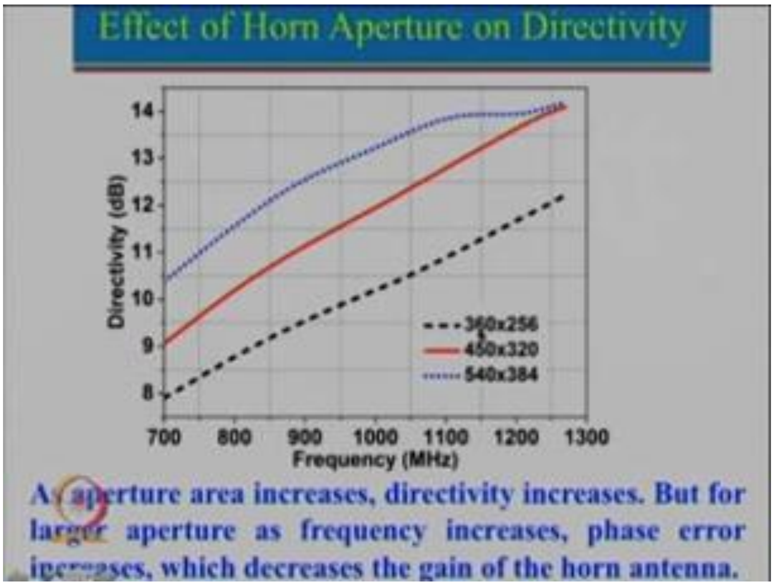

So, with that let us go to the next part that is let us now look at the effect of the horn aperture on the directivity. So, here what we have done we have kept the length fix and the aperture dimensions are increasing. You can see that 360 450 540, but what we have done aspect ratio has been kept constant.

So, in this particular case you can see that when this is the dimension that is the directivity curve here. If we increase the aperture dimension we can see that the directivity is increasing, but when we increase the aperture further you can actually see yes in the beginning it is increasing, but towards this point here if you see at this point the directivity is actually same for these 2 aperture. And if the directivity is same for these 2 aperture then why take a larger size.

So, what is the reason why directive as started because, the reason for this is that our length was fixed and if the length is fixed. And if we keep on increasing the aperture area then phase errors starts increasing. So, this is now for a simple practice for you people. Take these dimension the length is given to you which is 250 mm calculate what is the phase error for different frequency values, and we will know that why directivity is decreasing at this particular level here.

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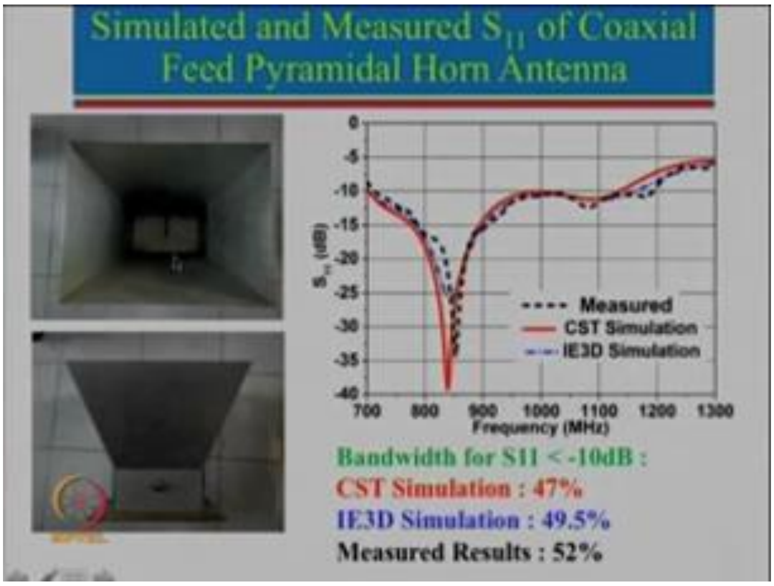

So, based on these dimension then we actually did the fabrication. So, here is the fabricated antenna picture you can see that this is the coaxial feed over here. This is the another view from taken from the front. You can see that that this is the probe length over here these are the aperture dimension.

So, we have done the simulation using IE3D also we have done simulation using CST microwave studios software also. And then we have done the measurement also. So, you can see that the results are in reasonably good agreement, and the bandwidth for this minus 10 dB is almost close to about 50 percent.

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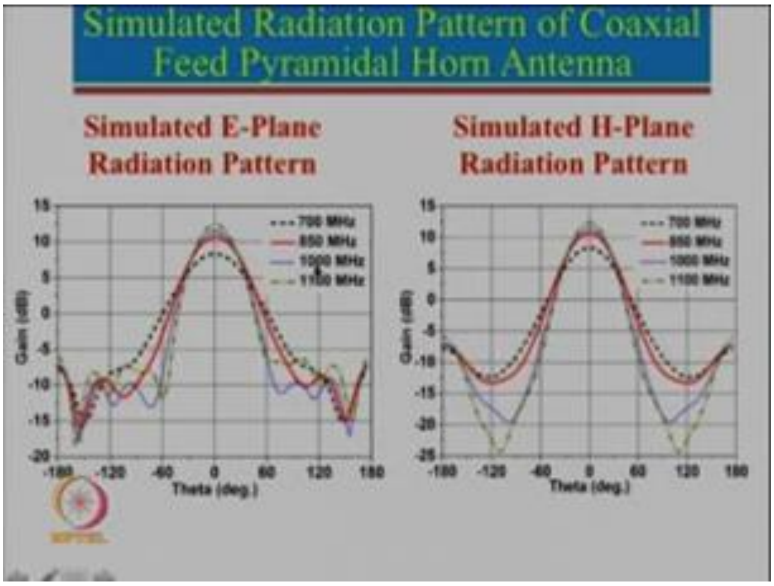

And let just also look at the radiation pattern. You can see the radiation pattern E-plane as well as H-plane, and here is the frequency value 700 850. We can see frequency is increasing, and this is the gain plot. You can see the gain is slightly increasing. So, that is a reason because aperture is fixed frequency is increasing and we know that the directivity is given by 4 pi a by lambda square. So, if the frequency is increasing lambda will reduce hence gain will increase.

Now, here you can since see that the side globe levels are fairly low, because the antenna which we have designed that has the relatively very good efficiency greater than 70 percent. So, phase error is less hence our patterns are also relatively good. So, we will conclude the todays lecture here. So, what we saw today, pyramidal horn antenna, we looked in to the typical designed equations given and how we can do the design; however, as I said those optimum design which are given in the books they assume efficiency of 50 percent or maximum 60 percent. So, hence those are not really the optimum dimension because they have given the design for larger phase error. Whereas, then after that we gave you the parametric study of what should be the location of the feed point.

What should be the diameter, what should be the length and we have given these dimension for a given frequency and you can do the frequencies scaling. In fact, after using these 900 megahertz we also designed another horn antenna at 1800 hundred megahertz. And the results were very similar as we had shown you for this particular case here. So, we strongly recommend that do not take phase error more than 45 degrees where E-plane and for H-plane some relaxation is there 5 degrees to up to absolute maximum is 90 degrees. And then we also showed you what are the experimental results which were in good agreement with the simulated result.

So, in the next lecture, we look in to horn antennas and many other things. So, with that bye, we will see you next time.