Microwave Theory and Techniques
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Module - 10
Lecture - 50
Horn and Helical Antennas

Hello and welcome to today's lecture on Helical and Horn Antennas. First, I will talk about helical antennas and then I will cover horn antennas. So, helical antenna in general can be realize, if you just take a wire and wrap it around let say a finger like this, so the shape, which is formed is nothing but helical antenna. You may actually say even an inductor looks like that only, which is actually correct. So, you can say even an inductor can act as an helical antenna provided, we take care of certain design specification.

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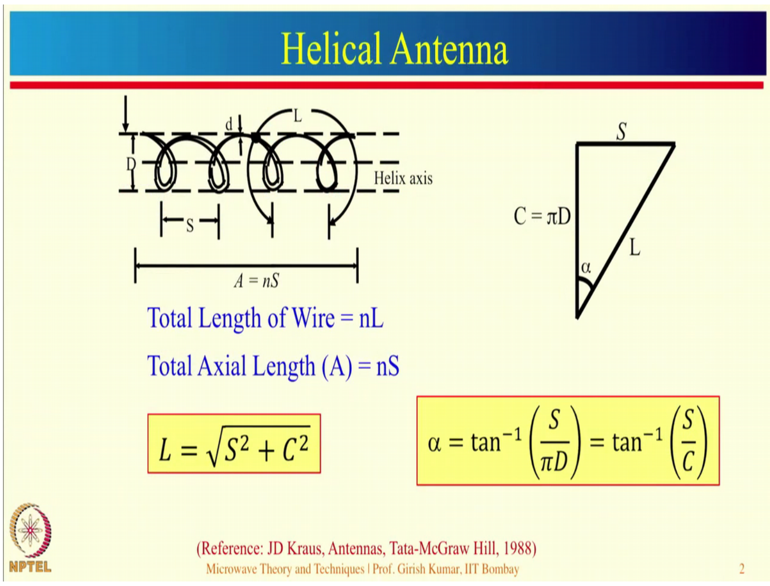

So, let us see, how we can define a helical antenna. So, helical antenna is defined by its diameter D. So, you can see that this is how the helix shape is, so this particular dimension is capital D. Wire diameter is small d. The spacing between each turn is defined by S. So, if there are n turns in an helix, then what will happen, total axial length will be equal to n times spacing between one particular turn.

Now, this particular geometry for a single turn can be represented in this particular fashion, where L is the length of one turn as you can see from here to this particular position. C is equal to pi D, which is circumference of this particular helix. S is the spacing between the elements. So, we can now write that L is nothing but given by this particular expression, which is S square plus C square square root of that. And how we can define angle alpha? We can say that tan alpha will be nothing but equal to S divided by pi D. So, you can see that, this is the expression for alpha tan inverse S by pi D or we can write as tan inverse S by C.

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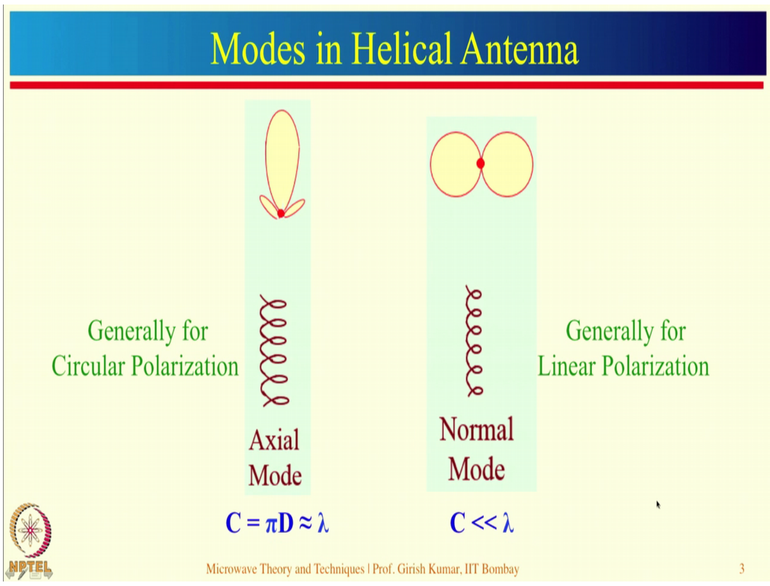

Now, helical antennas in general can be used in two different modes. So, one mode is known as axial mode, where circumference is equal to pi D is approximately equal to lambda. And when we choose this particular dimension and take some other parameters into account, which I will show in the next slide. This is generally designed for circular polarization. The other mode, which is commonly used is normal mode. In this particular case, circumference is much much less then lambda. In fact, we will see later on that typically a normal mode helical length maybe of the order of lambda by 4. And you can see this dimension is much larger just one turn itself is equal to lambda. So, normal mode helical antenna is generally designed for linear polarization. So, first we will talk about axial mode helical antenna.

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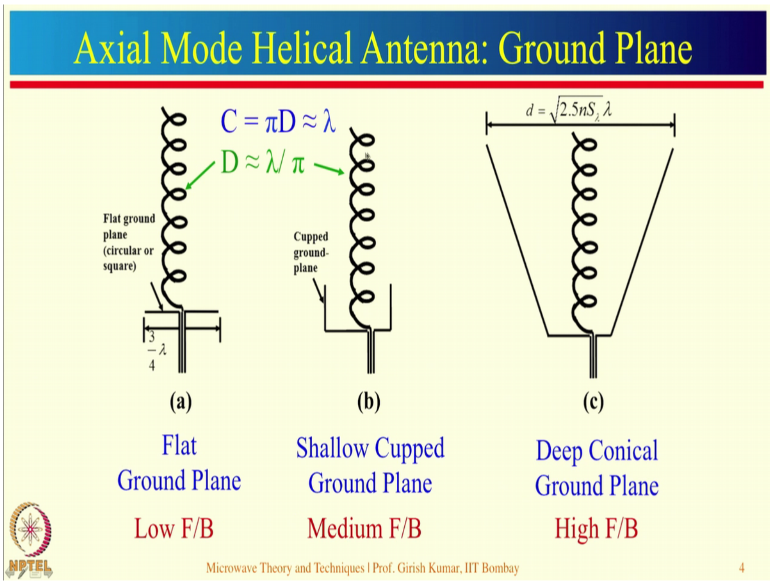

So, axial mode helical antenna as I had mentioned that, it will radiate in this particular direction, which is the axis of the helix. And generally speaking for this particular configuration, radiation is maximum in this particular direction and it is generally designed for circular polarization. Since, we want the radiation to be in this particular direction, we need to have a ground plane over here.

Now, in general let us say C is equal to pi D, which is approximately equal to lambda. So, from here we can say diameter is equal to lambda by pi. You can see that, the ground plane dimensions should be at least three-fourth of lambda, so that the back radiation is reduced. However, you can see there are different shapes of ground plane, which we have used. So, let us see what are the reasons for that. So, when we take a flat ground plane of the dimension, let us say 3 by 4th lambda there still will be considerable back radiation that means, it will have a low front to back ratio, because back radiation is more.

So, to reduce the back radiation, one can use something like a shallow cup shaped ground plane. In this particular case, back radiation is reduced. So, it will have a medium front to back ratio. And for certain applications, where we want back radiation to be as small as possible then one can use something like a glass shape or a bucket shaped ground plane. In this particular you can see that, the back radiation will be very very small. Hence, it will have high front to back ratio and also if the back radiation is reduced that means, gain also will be enhanced slightly.

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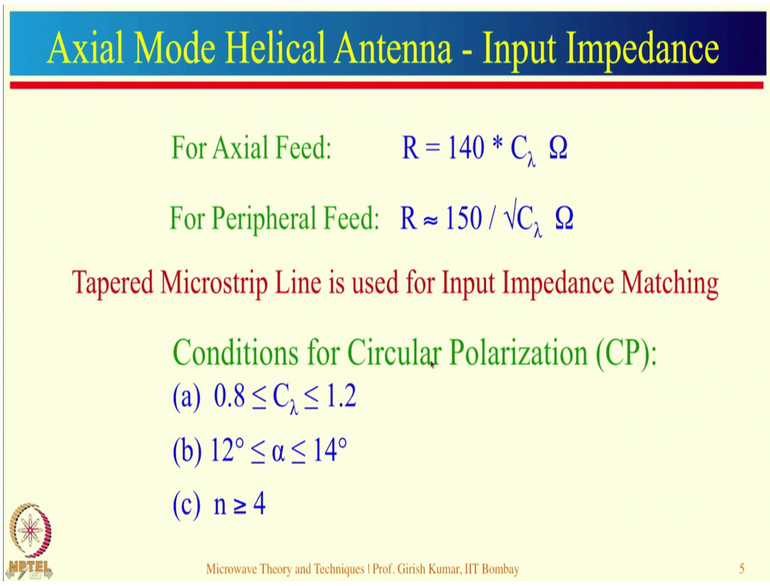

Now, let us see what is the input impedance of axial mode helical antenna, it all depends how we feed. If we feed the helical antenna using this perpendicular thing, that is known as axial feed, then input resistance is given by this particular expression, which is 140 multiplied by C lambda, C lambda here stands for C divided by lambda. If it is fed along the periphery that means, if this is the helix, if you feed like this, in that particular case R is given by this particular expression.

But, generally speaking C lambda is going to be approximately equal to 1. You can see that, if this is 1, it will be 140 ohm. And if this is 1, this will be approximately 150. You can see that the variation in the impedance is not very significant. What about the reactive part? In general reactive part is very small. So, we can neglect the reactive part.

Now, input impedance as you can see that, it will be of the order of 140 to 150 ohm. And if you want to feed with a coaxial feed, which is 50 ohm, then what we need to do, we need to design a tapered micro strip line for input impedance matching. So, one has to design tapered micro strip line, let us say at one end, it can be 140 to 150 ohm. And in this side, it will be 50 ohm typically the length should be taken as about lambda by 2 or you can use two quarter wave transformer to do the impedance matching.

Now, there are three conditions to obtain circular polarization using helical antenna. The condition number one is that C lambda should be between 0.8 to 1.2. If you really look at it, this actually gives bandwidth of approximately 40 percent. So, axial mode helical antenna does gave very large bandwidth. Typical value of alpha should be taken between 12 to 14 degree. And it is recommended that you take n greater than 4.

So, this will also give us decent gain also. As we will see later on, what are the different gain expression? I just want to also mention that the diameter of axial mode helical antenna is not very important, you can take 1 mm also, you can take 5 mm or 10 mm. The performance is very little affected by the diameter of the axial mode helical antenna. However, story will be different, when we talk about normal mode helical antenna.

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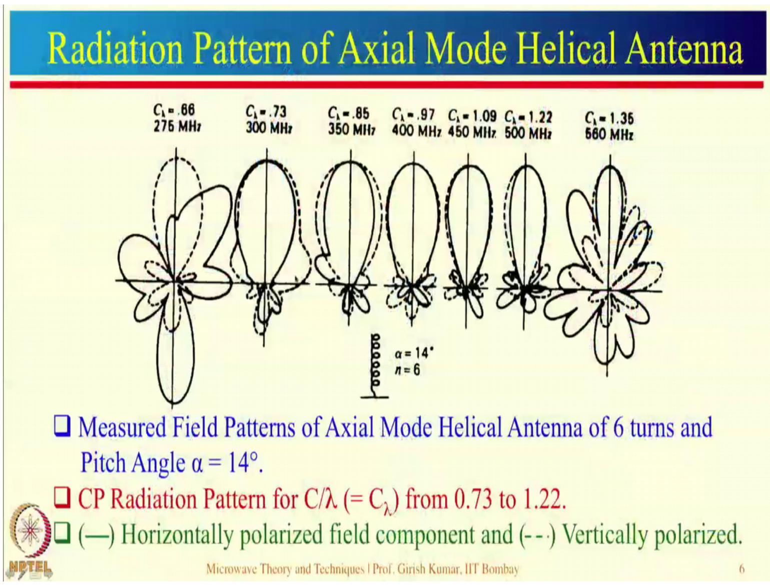

So, let us just take some example. So, here one helical antenna has been designed around 400 megahertz. It has 6 turns pitch angle is alpha equal to 14 degree. So, let us see the response of this particular configuration. So, one can see that C lambda is approximately equal to 1. And what are the plots over here, here solid line shows horizontally polarized component, dotted line shows vertically polarized component. And you can see that, both the components are approximately equal.

And you can see from 0.73 up to 1.22 value of C lambda, variation is very small. As C lambda increases, you can see now the deviation between horizontal and vertical component is much more. Similarly, over here when we go to C lambda 0.66, you can see that there is a very large variation. So, hence for this particular range one can get decent circular polarization.

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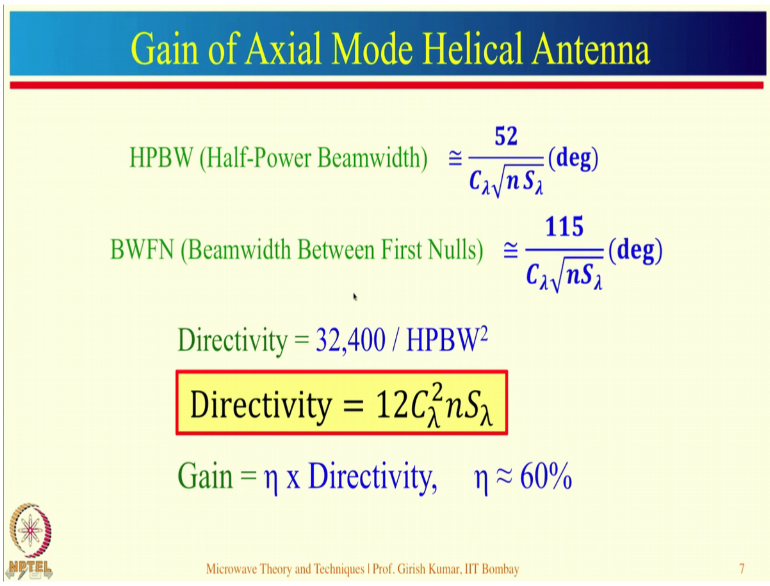

So, let us see, how we can calculate the gain of the axial mode helical antenna. I just want to mention axial mode helical antenna can be approximated as array of n different elements. So, each turn can be represented as one particular antenna, then n different turns will mean that there are n different elements are there. So, one can actually apply the concept of the end fire antenna array. And by using the end fire array concept, we can calculate the half-power beamwidth. So, this is the expression for half-power beamwidth. And this is the expression for beamwidth between first null.

Now, you can see that the factor over here is of the order of 2.25. When I talked about the antenna fundamentals, I had mentioned that for larger array directivity can be approximately found by using this particular expression. So, if we substitute the value of half-power beamwidth, which is given by this particular expression over here, this thing get simplified to 12 C lambda square times n times S lambda. Now, I just want to mention that this is directivity, this is not gain. In fact, in some of the books, they have written directivity as gain, but that is not correct at all. Gain is efficiency multiplied by directivity and typical efficiency of axial mode helical antenna is of the order of 60 percent. So, please apply this particular number to find the gain of the antenna.

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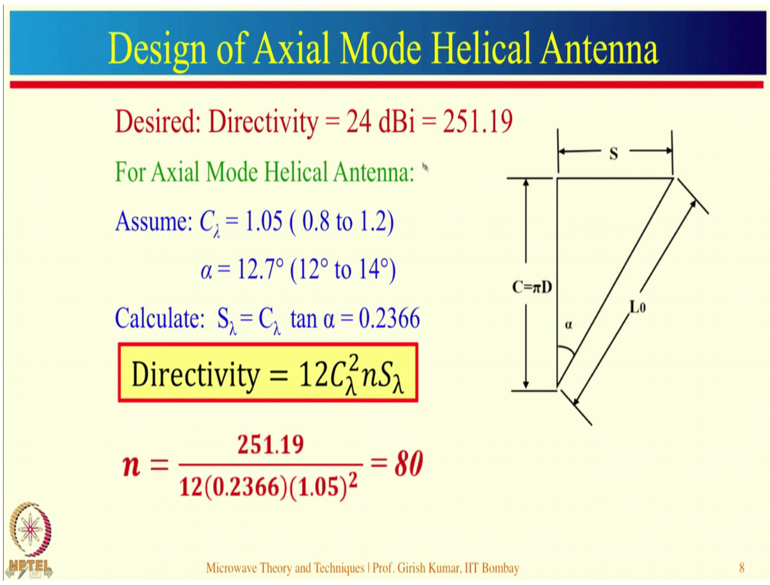

So, let us just take it a design example. So, let us say it is desired that, we want directivity to be equal to 24 dBi. So, the first step is you convert that to its corresponding numeric value. And that can be done this way that, you can just check 10 log of 251 is equal to 24 dB. Now, we want to design for axial mode circularly polarized antenna. So, what we do, we take C lambda between 0.8 to 1.2. So, in this example, we have taken C lambda as 1.05. Alpha should be taken between 12 to 14 degree. So, here it is taken as 12.7 degree.

So, the first step is calculate S lambda, which is given by C lambda tan alpha, so this is the value of S lambda. Now, we know this is the expression for directivity. So, from here, we can find the value of n. So, n will be directivity, which is equal to this value divided by 12, divided by S lambda, divided by C lambda square and that comes out to be 80. So, it requires 80 turns to realize directivity of 24 dBi. So, in general nobody designs helical antenna for 24 dBi gain.

Generally, people realize a helical antenna for 10 dBi or 15 dBi gain. So, you can actually see that you just change this particular number over here. And then correspondingly, you can find the value of n. And here as you can see everything is in the normalized fashion. So, let us say you want to design antenna at 1 gigahertz, that 1 gigahertz lambda will be 30 centimeter. So, from here you can find C lambda is 1.05. So, C will be equal to 1.05 multiplied by 30. So, from there you can calculate the value of d.

And you can take any wire diameter, as I mentioned wire diameter is not very important. And this way, you can realize the axial mode helical antenna.

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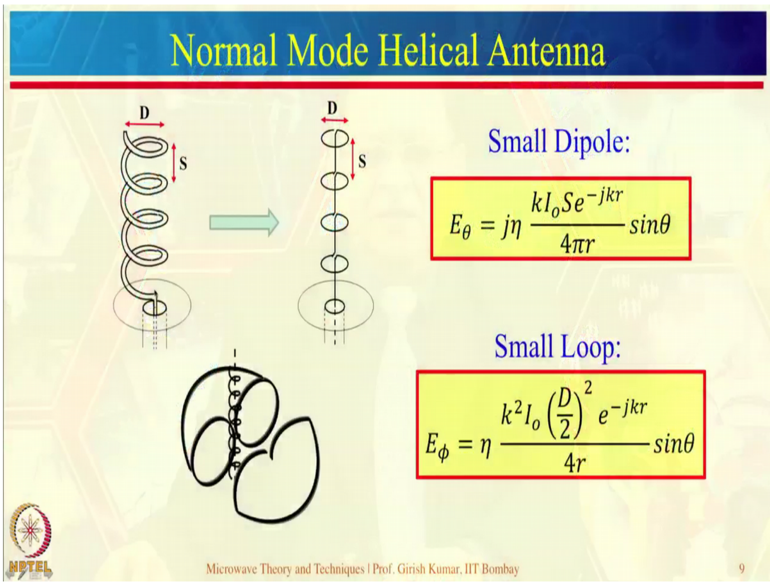

Now, let us talk about normal mode helical antenna. So, here a normal mode helical antenna is shown, as you can see this is the diameter of helix spacing between each turn is given by S, there is no change over here. As far as the configuration is concerned the only difference here is that circumference, which is equal to pi D has to be much smaller than wavelength. So, for the condition, where circumference is much much smaller than wavelength.

This particular normal mode helical antenna can be approximated as, you can see over here one straight line, then a loop antenna, then straight, then a loop antenna, then straight, then loop antenna ok, so that means, this whole particular configuration can be realized in two different components. One component will correspond to one monopole antenna. And then, the other components will consists of multiple n turn loop antenna.

Now, we had seen the radiation pattern expression for small dipole is given by this particular expression. And for small loop, it is given by this particular expression. So, if you look at the sin theta term, so if theta is equal to 0, what will happen, this term will become 0, so that implies 0 radiation in this particular direction. And if theta is equal to 90, sin 90 will be equal to 1 maximum radiation in this particular direction.

In fact, a normal mode helical antenna almost radiates very similar to a monopole antenna. So, what is the difference in case of monopole antenna, we need length of lambda by 4 ok, for extremely large ground plane. Whereas, in case of normal mode helical antenna, we need a lambda by 4 length, this is according to the book little bit later on. So, the same lambda by 4, if we now wrap around, so what will happen, my total height will be reduced.

Let us just take a simple example. Suppose, you want to design antenna at let us a 100 megahertz at 100 megahertz wavelength will be equal to 3 meter. Lambda by 4 will be equal to 75 centimeter and that will be very large. But, if you take the same wire length and wrap it around like this, then the total height can be reduced. You will still get similar radiation pattern.

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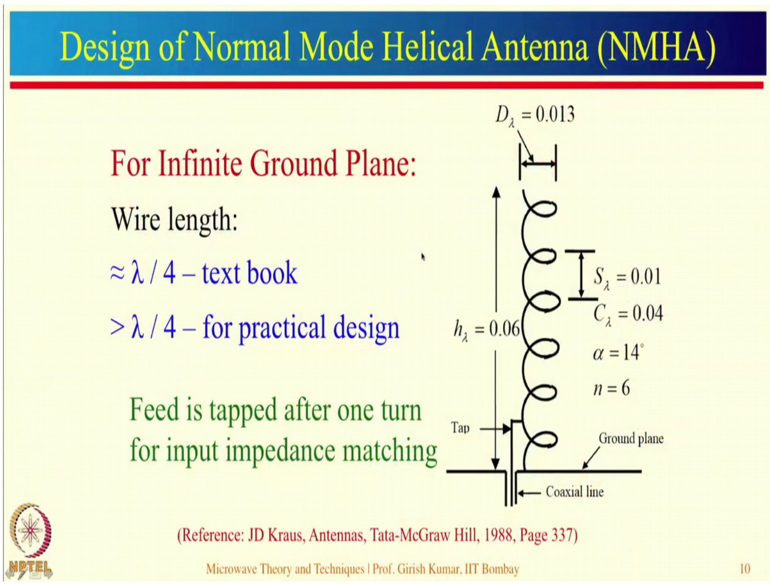

So, let us just take a design example. So, this design example is for infinite ground plane ok. And this particular thing has been taken from the cross book and I have also mentioned page 337. So, let us first see, what this particular example is and then I will tell you what needs to be modified for practical antenna.

So, here what they have done, they have taken C lambda as 0.04. So, D will be nothing but C lambda divided by pi. S lambda is taken as 0.01, so in this particular case, they have taken n equal to 6, alpha equal to 14 degree. So, total height comes out to be 0.06 lambda. You can actually calculate this wire length will come out to be equal to lambda by 4 and you can test that. So, we know that L lambda is nothing but square root of S lambda square plus C lambda square multiply that with n equal to 6, you will get the total wire length as lambda by 4.

Now, how to feed this particular antenna? So, here you can see a tap has been used from the coaxial feed at this particular point. So, this particular tap has been used, so that we can get input impedance matching with 50 ohm. So, why it has been taken over here. So, you can just see that there are 6 turns are there. So, I will just give you approximate concept ok. So, here this is short circuit. So, input impedance will be 0 here, here it is open circuit. So, we can actually just take an approximation as that this is to be matched with free space. The impedance of that is about three 377 ohm.

So, if you take about a tap around one-sixth of that, you can approximately get up 50 ohm impedance matching. So, however this is a very very approximate design. And I also want to mention that this length, which has been taken as lambda by 4 that is a text book design, this is not a correct thing. For practical design, this wire length should always be greater than lambda by 4, there are multiple reasons are there.

First of all, whenever you bent a wire, helical structure is also known as slow wave structure. So, wave gets slow down over here. So, effectively it does not see lambda by 4 length. So, you have to take larger than lambda by 4 length, it can be 0.3 or even 0.4 lambda. But, however that is still true for very very large ground plane. If the ground plane size is very very small, we have seen that this wire length may be as large as 3 lambda by 4 ok. So, please take care, when you are doing a practical design. Again everything is in the normalized fashion.

So, let us say you want to design antenna, let say at 3 gigahertz of wavelength will be 10 centimeter. So, C lambda will be equal to 0.04. So, C will be equal to 0.04 multiplied by lambda, lambda is 10 centimeter. So, you can actually find the value of C and correspondingly you can find the other parameters. Of course, here it is very very important for normal mode helical antenna diameter of the helix plays very very important role. Bandwidth is directly proportional to the diameter of the helix wire. So, if you want a larger bandwidth, please take thicker wire diameter.

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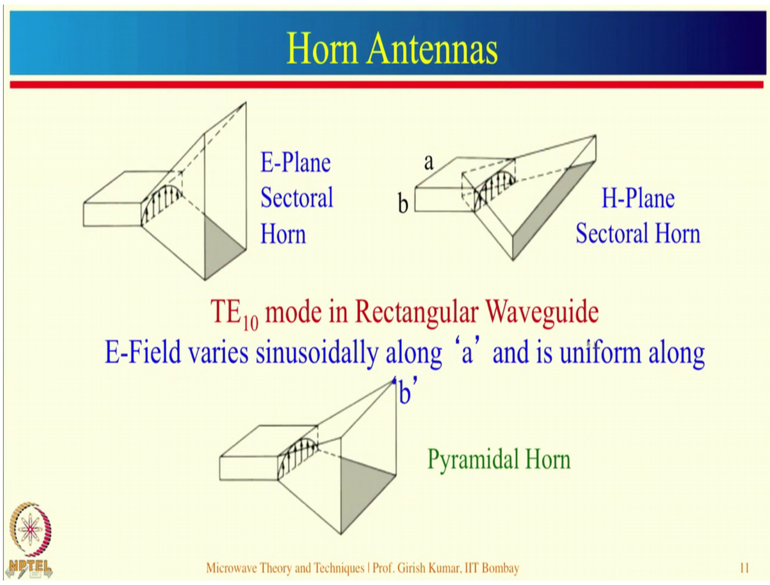

Now, let us talk about horn antennas. So, we will start with simple rectangular waveguide. As you can see here, this is a rectangular waveguide. The dimensions are a and b, we have discussed about this particular thing, when I talked about waveguide. And most of the time horn antennas operate at the fundamental mode of rectangular waveguide, which is TE 10. And for fundamental TE 10 mode, if you recall, 1 implies half wave length variation, 0 implies, no variation.

So, in this particular case, E varies half wave length along this particular dimension. So, this is short circuit, because it is a solid wall. So, short circuit means E will be 0, E will be maximum and the E will go to 0. So, there is a sinusoidal variation along this particular axis and field is uniform along this particular axis. So, if the waveguide is flared, along this particular E-plane, it is known as E-plane sectoral horn antenna. If waveguide is flared in this particular plane, it is known as H-plane sectoral horn antenna. And if the waveguide is flared in both the directions in this as well as this, it is known as pyramidal horn antenna.

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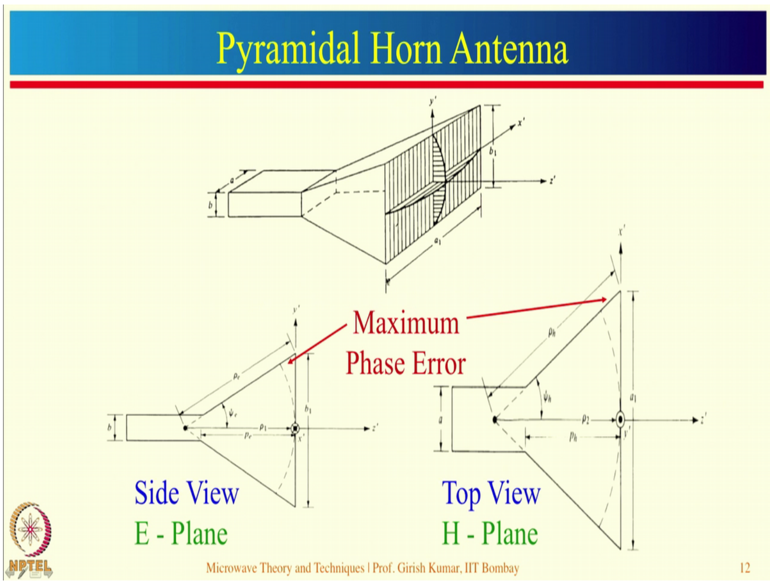

Today, I will talk only about pyramidal horn antenna. As E-plane sectoral horn antenna as well as H-plane sectoral horn antennas are special cases of pyramidal horn antenna. So, let us see the side view of this particular thing overheads. So, if we just look at the side view from here, this almost looks like a E-plane sectoral horn antenna. And if you look from the top, then you can see top view is nothing but similar to H-plane sectoral horn antenna.

So, let us say now the wave is launched in this particular waveguide and these are the boundaries of the pyramidal horn antenna. So, when the wave is launched from here, it will go in this particular fashion, the wave is launched like this. So, as you can see that, there is a large distance between these two points compare to this particular point over here. So, let us take this as a reference point, then one can see that the wave reaching over here will have an dilate phase response.

So, let us take reference as the wave has a phase angle 0 degree, but at this particular point, it may be 10 degree over here, it may be 20 degree, 30 degree and so on. So, maximum phase error will come over here. This is for E-plane sectoral horn, same thing will happen for H-plane sectoral horn antenna. It has been mentioned in the books that for E-plane sectoral horn antenna maximum phase error allowed is 90 degree, whereas for H-plane sectoral horn antenna maximum phase error allowed is 135 degree.

However, I do not think that is a very good idea. Generally, I recommend that you take maximum phase error as 45 degree or so. I will show that particular thing little later on.

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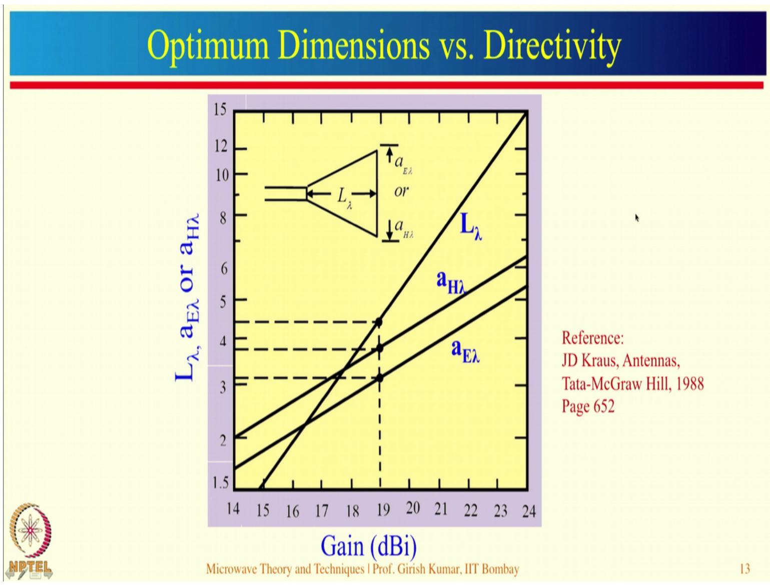

So, let us see how we can find the optimum dimension for given directivity. So, here is the plot gain is given along this particular direction and these are the different dimensions of the horn. So, let us say we want to have a gain of 19 dBi. So, you draw a vertical line, it cuts all these different curves at different points over here. So, here I just want to mention these nomenclatures are slightly different than the nomenclatures had shown in the previous slide.

The reason is different books use different symbol ok, so do not get confused. If you read one book or other book, you should be familiar with the concept symbol can be anything ok. So, this curve again I have taken from the cross book. And the design given over here is for efficiency, approximately equal to 60 percent. And this curve actually makes the design very very simple. So, corresponding to this 19 dBi, just note down the corresponding value of L lambda, a H lambda and a E lambda, your design is actually complete.

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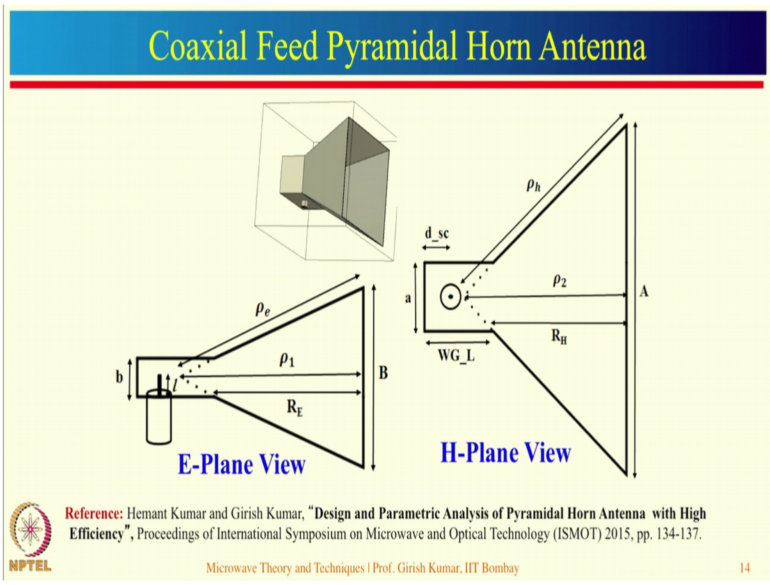

Now, I am going to show you how to practically design a coaxial feed pyramidal horn antenna. So, just to show you here, so here this horn antenna is fed with the coaxial cable over here, you can see that the probe is extended. In fact, I just want to mention that, this probe acts as a monopole antenna. And since, we have a very large ground plane, we can use approximation as length to be equal to lambda by 4.

Now, one can see that this is short circuit. So, if this is short circuit over here, this will do the loading on this particular probe. So, generally what is done, to avoid the loading of this short circuit over here, take this facing as approximately lambda g by 4. So, if you take this spacing as lambda g by 4, what will happen shot will act as open circuit? But, we do not always take this length as lambda g by 4, we may take slightly different value to do the impedance matching with 50 ohm line. So, again this is the side view, this is the E-plane view, this is the top view, which is H-plane view. And these results, which I am going to show, these are written by us only and it appears in this particular symposium preceding.

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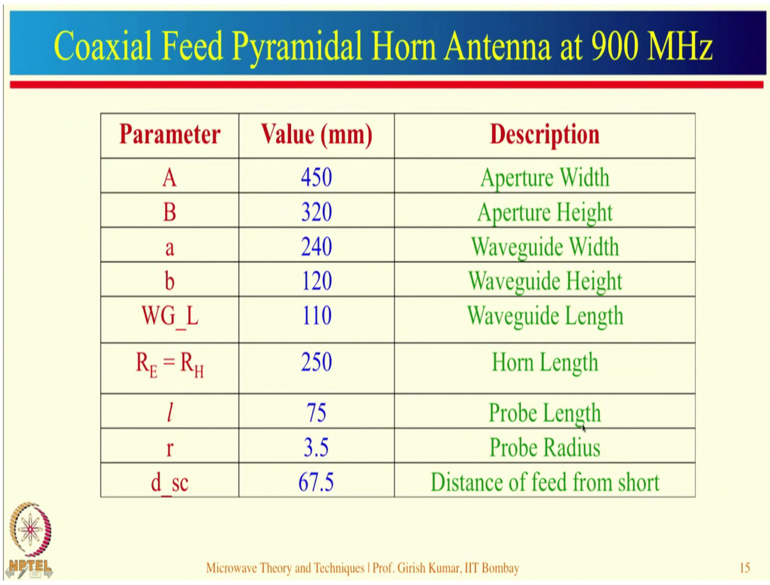

Coaxial Feed Pyramidal Horn Antenna at 900 MHz

Parameter	Value (mm)	Description
A	450	Aperture Width
B	320	Aperture Height
a	240	Waveguide Width
b	120	Waveguide Height
WG_L	110	Waveguide Length
$R_E = R_H$	250	Horn Length
l	75	Probe Length
r	3.5	Probe Radius
d_sc	67.5	Distance of feed from short

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So, we have designed this particular horn antenna at 900 megahertz. So, I will start with the probe length, you can see that this length is approximately equal to lambda by 4. The radius of this has been taken as 3.5 mm that means, the diameter of the probe is about 7 mm. So, we know that bandwidth is proportional to the diameter of the monopole antenna, hence larger diameter is taken. These are the other dimensions.

So, for 900 megahertz waveguide, we have taken a equal to 240 mm, b equal to 120 mm. The flared values of the pyramidal horn antennas are small a becomes capital A, which is 450 mm. Small b becomes capital B, which is equal to 320 mm. And we have taken this particular length R E is equal to R H has been taken as 250 mm, but later on I will show you, what is the effect of this particular dimension.

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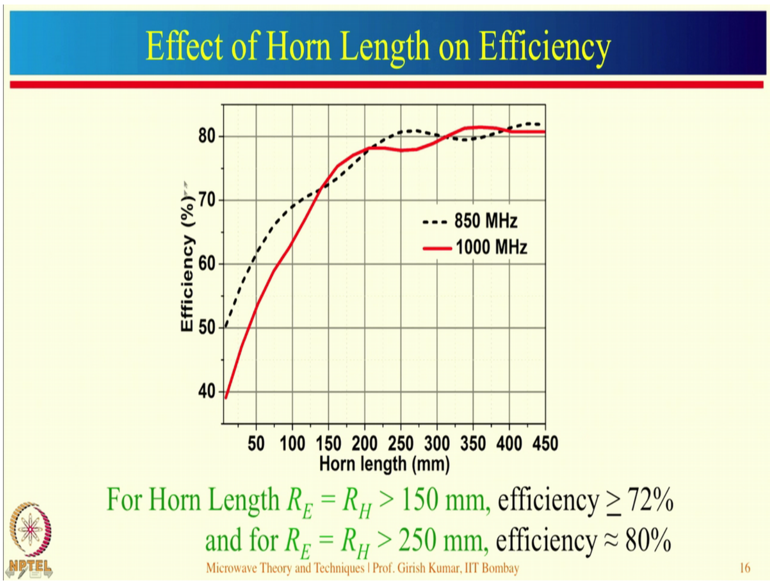

So, this is the efficiency curve versus horn length, which is R E equal to R H. So, let us see, you can see that as this particular length increases, we can see that the efficiency is increasing. Here, we have shown the plot for two different frequencies, 850 megahertz and 1000 megahertz. So, we know that gain increases with increase in frequency. So, let us look at the efficiency curve corresponding to 850 megahertz. One can see that as the horn length increases efficiency increases.

In fact, if you look at different books, for example in the Balani's book, they talk about efficiency of the order of 50 percent. Cross book talks about efficiency of the order of 60 percent. However, you can see here, if R E equal to R H is greater than 150 mm. If you look at this particular line, efficiency is greater than 70 percent. However, if we take R E equal to R H greater than 250 mm, then efficiency is of the order of 80 percent. However, you can see that if you take much larger dimension, there is not much of improvement in the efficiency. So, one should choose the typical efficiency value in this particular region.

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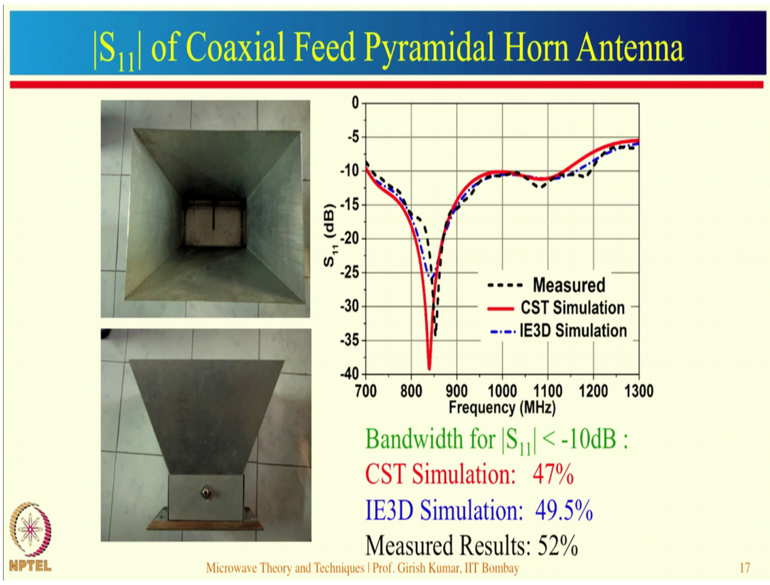

So, let us see what are the results of the designed pyramidal horn antenna. So, there are two views of this particular pyramidal horn antennas, you can actually see there is a coaxial feed over here. And from the side if you see, this is how the coaxial feed is coming out from this particular portion over here. So, for this particular antenna, we have done simulation using IE3D as well as CST software. So, you can see that bandwidth for S11 less than minus 10 db, you actually draw the line like this here ok. So, bandwidth is of the order of 47 percent, 49.5 percent at measured bandwidth is of the order of 52 percent. You can see that, these results are in reasonably good agreement.

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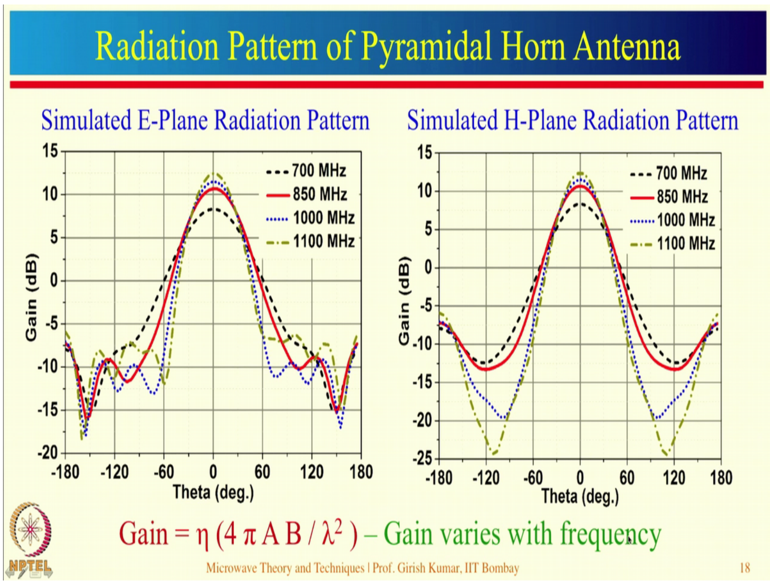

Now, let us see radiation pattern of pyramidal horn antenna in E-plane and H-plane. So, here we have shown the plot, it is not a normalized radiation pattern plot, it is actually normal gain plot versus angle. So, one can actually see the relative gain also. So, one can see at 700 mega hertz, gain is relatively small as frequency increases, one can see that gain is increasing. Why, because gain is given by efficiency multiplied by 4 pi area divided by lambda square. What is the area? A multiplied by B.

If you look at this particular gain expression, you see that A dimension is coming, B dimension is coming, but there is a nothing coming directly as far as the length of the horn antenna is concerned. However, we have seen efficiency of the horn antenna depends upon the length of the horn antenna. So, the length of the horn antenna comes indirectly in this particular gain expression. One can see lambda is in the denominator lambda is given by c divided by f. So, as frequency increases, gain increases. So, same thing you can notice over here, as frequency increases from 700 megahertz to 1100 megahertz, gain increases. So, this is the pattern for E-plane, this is the pattern for H-plane. So, you can see that there are little bit of side loops present in the E-plane pattern, whereas there are less side loops present in the H-plane pattern.

So, to conclude today's lecture. Today, we talked about two different modes of helical antenna, axial mode helical antenna and normal mode helical antenna. Axial mode helical antenna is generally designed for circularly polarized radiation pattern. Whereas, in normal mode helical antenna is generally designed as a replacement of monopole antenna and it radiates in a similar fashion as that of monopole antenna.

Then, we talked about horn antenna, we talked mainly about pyramidal horn antenna as E-plane sectoral horn antenna and H-plane sectoral horn antenna are special cases of pyramidal horn antenna. We had seen that efficiency can be improved by increasing the horn length and we saw that efficiency can be of the order of 70 to 80 percent.

So, thank you very much. In the next lecture, I will talk about some different types of antennas, till then bye.