Antennas

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Module – 10
Lecture – 45
Horn Antennas-I

Hello, and welcome to today's lecture on Horn Antennas. But horn antennas are known as standard gain horn antenna, so that is one of the major applications of horn antenna. And another application where horn antennas are used extensively and they are used as your feed for large reflector antenna. So, these horn antennas are placed at a focal of the parabolic reflector, and that is how the excitation takes place.

But just to tell you about the standard gain horn antenna. So, I just want to tell something practical experience which we gained. So, I have been teaching a horn antenna since 1992 at IIT Bombay. But it was actually in around 2005 when I started my own company Wilcom Technologies Private Limited which was incubated through IIT Bombay, and we had supplied some antennas to the industry. And then they asked me have you calibrated the gain of the antenna? I said yes we have done that testing, we have done the simulation and these are the result. But they said no, have you compared with the standard gain horn antenna? And we said no we have not done that is there no till then we are not satisfied. So, then I went through the internet and I saw.

So, typically any standard gain horn antenna, the cost would be about at least 1 lakh rupee, and I did not want to spend that kind of a money and I felt that since I have been teaching horn antenna for more than a decade, why not I should design myself. And then even though I was teaching this course for so many years, when it came to the final fabrication then I realized lot of things are not available; and one of the major thing which I found, it was not available was how to properly feed the horn antenna; and then we started doing lot of work we did the design, and then we fabricated our self and so on.

Today let us start with the horn antenna, and we will tell you what is there in the text book and what needs to be modified, what are the things given in the text book and then we will also tell you something which is not given in the text book. So, let us start with the horn antennas. So, today we will start about horn antennas.

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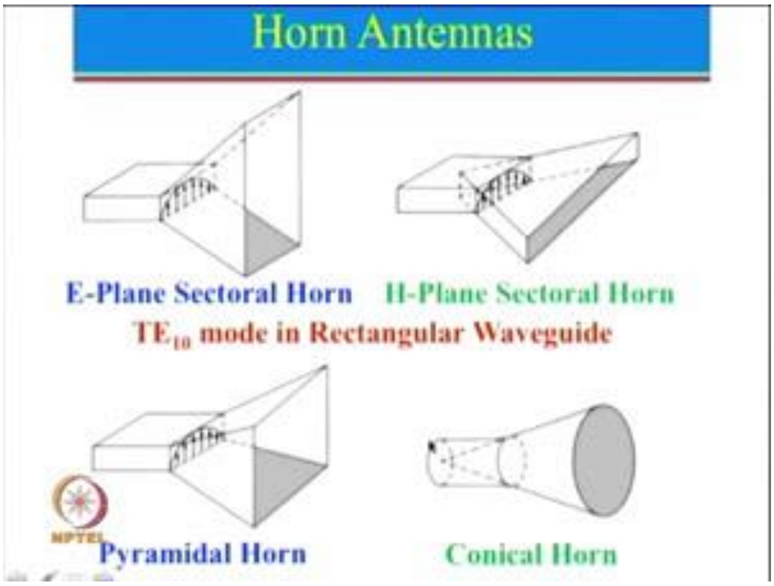

So, in the horn antennas these are the commonly used horn antenna. So, what are these here? There is actually a E-Plane Sectoral horn antenna, this is H-Plane Sectoral horn antenna and this is Pyramidal horn antenna.

So, what it is actually need to start with the let us say this is a rectangular wave guide, and in the rectangular wave guide we operate this rectangular wave guide in the fundamental T E 1 0 mode, and what T E 1 0 mode implies that there is a one half wavelength variation along this direction. So that means, along this direction there will be a lambda by 2 variations, and 0 variations along this particular direction here. So, one can actually see that since it is a metallic body. So, the voltage will be 0 here and voltage will be 0 here, and for lambda by two to happen. So, this voltage which is 0 here goes to the maxima and comes to back to 0 here.

So, this is the electric field variation or voltages variation along this particular axis, and you can see that these fields are uniform. So, there is no variation along this particular direction. So, this is the E-Plane. So, if we flair only in this particular direction it is known as E-Plane Sectoral horns. So, basically the width of the wave guide as been expanded in this particular direction and orthogonal to E-Plane will be H-Plane. So, if we expand this whole thing in H-Plane direction, this is known as H-Plane Sectoral horn antenna; and if the dimensions are expanded in both the direction that means, in E-Plane as well as in the H-Plane, this is what the configuration looks like and this configuration looks something similar to a pyramid, and hence it is known as pyramidal horn antenna and this is a conical horn antenna.

So, we are basically it is a circular wave guide. So, you can see this is a circular wave guide and then one end of the wave guide is expanded, and that becomes a cone. So, this is the reason why this is known as conical horn antenna, but today we will concentrate mainly on the Sectoral horn antenna, and then we will go to pyramidal and then much later we will go to conical horn antenna.

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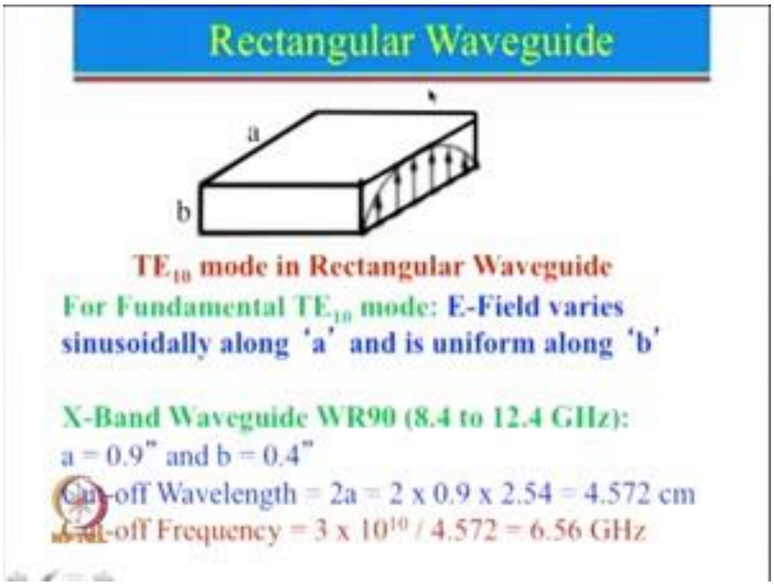

So, let us first start with the simple rectangular wave guide, because we need to understand how a rectangular wave guide works how. I am sure all of you might have taken electromagnetic wave course, where you would have studied rectangular wave guide, but just a quick brush up.

So, let us say a rectangular wave guide is defined by it is aboard wall and this is known as a narrow wall. So, this broad wall dimension is given by a, and this one here is height is b. So, for fundamental T E 1 0 mode as I mentioned. So, one corresponds to that E-Field varies from here to here, which is a one half wavelength. So that means, this is 0 fields here and this one goes to maxima and then goes to 0. So, that is half wavelength variation. So, one implies that and 0 means uniform field distribution, so that is what it is. So, now, for this particular case E-Field varies sinusoidally along a, and is uniform along b which is what it is, and h field will be perpendicular to this e field here.

Now, wave guides are defined are by its different band. So, this is X-band wave guide and there is a symbol for that and that is known as a WR90. There is a very specific significance of this number actually, what these numbers really imply that a dimension is equal to 0.90 inches. So, if instead of 90 suppose if this is a 230, then that will be 2.3 inches will be a; suppose if this is WR 20 300. So, if it is 2300 it will be implying that a will be equal to 23 inches and this wave guide is designated to operate in the frequency range of 8.4 to 12.4 giga hertz.

So, let us see what is the reason, why it works in this particular frequency region; so first of all now this is the dimension which governs the value of a. So, a is equal to 0.9 inches, and b is given as 0.4 inches. I just want to mention here that majority of the other wave guides, they actually have b approximately half of a. So, here this is 0.9 half would have been 0.45, but which is actually 0.4 over clear. Now for this wave guide we define cut off wavelength, and cut off wavelength is given by a very simple formula which is equal to 2 times a and 2 multiplied by a is 0.9 inches convert that into centimeter by multiplying by a factor of 2.54.

So, cut off wavelength is given by this number here, and then we can find out from here what is the cut-off frequency. So, cut off frequency is given by C divided by lambda, and here C is 3 into 10 to the power 10 centimeter per second, because this dimension is in centimeter. If it w as meter then it would have been 10 to the power 8 meter per second then we have to convert this into meter. So, any way if we simply this, this comes out to be 6.56 giga hertz. So, this is the cut off frequency of this wave guide.

So, in general I want to mention that wave guide is considered as a high pass filter so; that means, below this frequency it will be at a; and the propagation will only take place above this frequency. So, now comes the next question; if the cut off frequency is 6.56 giga hertz, then why this wave guide is defined from 8.4 to 12.4 and why not from 6.6 to 12.4 or other number. If a wave guide is known as high pass filter, then a high passed filter as a characteristic that any frequency higher than that it should pass.

So, why again this particular limit; in fact, if you look at this limit it looks like it is a band pass filter, where that is not a correct thing let me go step by step. So, rectangular wave guide as a cut off frequency which is equal to 6.56 giga hertz; whereas, if you actually see it is defined that X-Band wave guide was from 8.4 to 12.4. So why there is a discrepancy between this number and this number; now as I mentioned the rectangular wave guide is nothing, but a high pass filter. So, below this frequency there is a attenuation, so it does not really propagate; but however, just if you think about at 6.6 giga hertz, attenuation is still very high. In fact, I would like to show that if we take attenuation in the vertical axis, and then if we take frequency. So, suppose we have a attenuation in this vertical axis and frequency is going in this way and let us assume this is the cut off frequency.

So, attenuation is very high at cut off frequency, and this attenuation slowly starts decreasing and then it remains nearly flat. So, from here to here roughly about 1.3 times f c which is the cut off frequency, we have a relatively very small attenuation. So, that is why from the frequency region from f c up to about a roughly 1.3 times f c, it is still attenuation is still very high and hence it is not very useful thing. So, when you are designing a horn antenna, you must ensure that you are working in a proper region where attenuation in the wave guide itself is relatively small.

So, let us continue from here further. So, this is 6.56 and if you see this operative frequency is 8.4. If you take the ratio of this to this, that is actually equal to about 1.28 which is close to 1.3. Then comes the next part why there is a limit on the higher frequency. The limit to the higher frequency actually comes because as the frequency increases that fundamental mode 1 0 mode may actually become a 2 0 mode or the orthogonal mode may get excited. So, majority of the time horn antennas are operated in the fundamental T E 1 0 mode.

However, there are some special cases where we use different modes, and when we go to that topic later on I will tell you where there is a difference, but right now we will focus upon that horn antenna generally will work in the fundamental T E 1 0 mode and for this particular wave guide this is the operating frequency range and if you really see this is fairly large frequency range.

So, if we take entire frequency of around 10.4, you can see that the bandwidth is close to about 40 percent or so. And of course, one can choose different things also. So, instead of WR 90 suppose you take WR 230 or WR 340 then correspondingly this range will be different. So, we will have to use that particular wave guide where ever we want to use the antenna.

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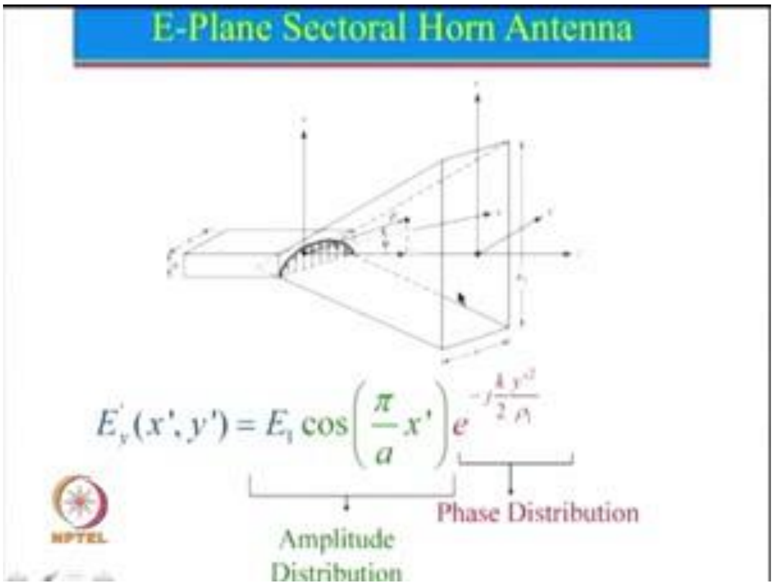

So, now let just look at the Sectoral horn antenna. So, this particular thing here shows E-Plane Sectoral horn antenna.

We know that this is a dimension, this is b dimension and this is the field variation along a and now this is the E-Plane and it is being flared in the E-Plane over here. So, since it is being flared up here this is why it is known as E-Plane Sectoral horn antenna. Now let just look at the axis also. So, this side here is x axis this one here is y axis, and this is z axis. Now when the wave is launched from here it is going to propagate in this particular direction, and if the wave propagation is in this direction then E and H field will be perpendicular to that. So, in this case E is in this direction, H is in this particular direction.

So now, one can see that E only as a component which is in the y direction. So, we have a E y over here, and this E y E 1 is just the constant and this is the cosine variation along this particular axis; and one can quickly check it. So, when x dash is equal to 0, x dash equal to 0 is at the origin. So, if x dash is 0 cos 0 will be 1, so that will have a maximum value. If we go to the h here, at the h x dash is equal to a by 2 half of this wave guide dimension. So, if this a by 2 that will become cos pi by 2 and cos pi by 2 is equal to 0. So, that is why it goes from maximal to 0.

So, that is the amplitude component; now this amplitude component which is at the wave guide that is being expanded to the aperture of the horn antenna. Now at this particular thing there will be a phase distribution also. So, phase distribution what is actually happening. So, from here the wave is getting launched from here. So, phase along the aperture will not be constant and that is the term here and this term can be better understood by the next slide.

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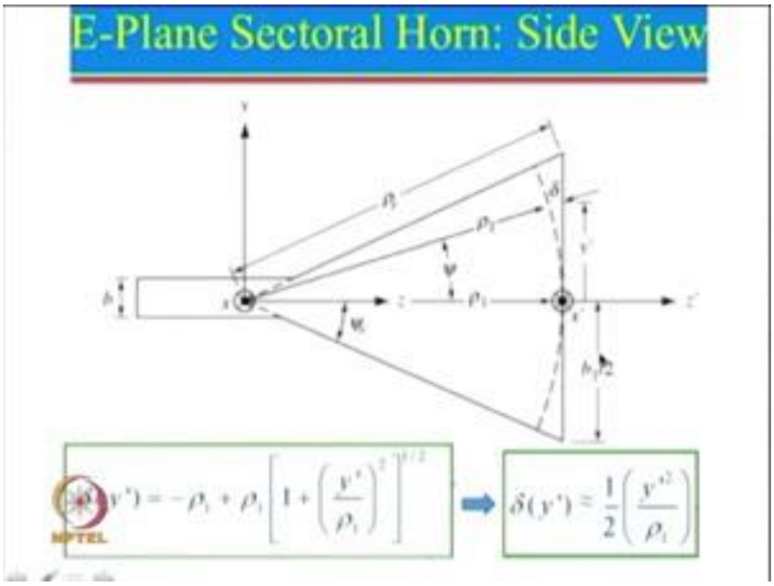

So, this is the side view of the Sectoral horn. So, from the side if we see we will see the dimension b, and then this is expanded in this particular plane here. The total dimension will be b 1 and this is b 1 by 2 and then you want to define the phase center of the horn antenna.

The phase center of the horn antenna actually not physically visible as such, one as to imagine and extend the dimension. So, this is what dimension b which has been flared to b 1, and if we extend this b 1 over here that will meet at this particular point which is the central point, and if we extend this here; so where ever this part is extended that become the phase center of the horn antenna. So, from here to this particular point, we are defining the dimension as rho 1 and this is Z axis as before.

So, now if you look from this point to this here, if this is rho 1 distance then we can see that if this was something like this here. So, all this dimension will be also equal to rho 1, but if we look at the aperture of the horn antenna, then what we see? The distance will be from here up to this point here, or add the edges the total distance from here to here will be rho time’s e. So, now, the phase error which will come into here, so this is the phase error. So, first let us find out what is this particular distance. So, this distance will be equivalent to total this distance minus rho 1.

Now, this distance here will be nothing, but rho 1 square plus y dash square, and square root of that. So, if you see here it is slightly written and different form, if we take rho 1 inside this will be rho 1 square and that will cancel this it will be rho 1 square plus y dash square, and that is what it is rho 1 square plus y dash square will be this total distance and from here we subtract minus rho 1. So, now, this is the distance delta from here to here and that distance now can be simplify this expression, if we expand this here now please notice I have use the term here approximately. Why approximately? Because higher order terms have been neglected; so if you just look at the first term here, so first term will be 1 plus half of this value.

So, this is a 1 plus half. So, you can see these two terms will get canceled, and that half will come here and half y dash square divided by rho 1, part of 1 rho 1 will get canceled. So, this is delta y now that is the distance. So, the phase error in terms of degree will be given by the term which is k. So, the k times this particular value here. So, that will be the phase distribution and one can actually see that. So, when y dash is close to 0 which is at the center point if you look at. So, there will be no phase that will be the reference phase, and as we go above here go to the extreme point here. So, y dash will become half of b, so that will give us the maximum phase error.

So, if this is considered as a reference phase, maximum phase error will come at the edges. So, one can actually see here, so phase error you can say starting from here as a reference, and this phase error will keep on increasing like this here. So, here sometimes student do ask a question what if we instead of taking a horn antenna like this why not we take horn antenna something like this here. So, then there will be no phase error. Yes at the periphery of the horn there will not be a phase error, but when we talk about we talk about the way which is coming here and then we talk about a plane wave here, and if you are talking about a plane wave over here that is what will be parallel to this here. So, phase error will come into picture.

So, by making a horn antenna of this shape, it is not going to make that phase error will become equal to 0; however, there are alternate techniques to balance out this phase error and that is actually many a times one actually uses a lens antenna over here. So, something like this here if we use the lens antenna. So, lens antenna will have a very small width at this particular point, and over here width will be larger. And if the wave which is propagating through the dielectric media, will actually experience more phase delay compared to n over here. So, that is how the phase compensation can be done. So, it is a very very common practice to employ one can actually just use one side of lens also like this here, or can use a lens like this also. So, both the things are possible and basically these are done to adjust for the phase error.

But otherwise if we do not have that option, then what we do we put a restriction that this phase error should be relatively small. So, let just see some examples and first we will start with the directivity curve.

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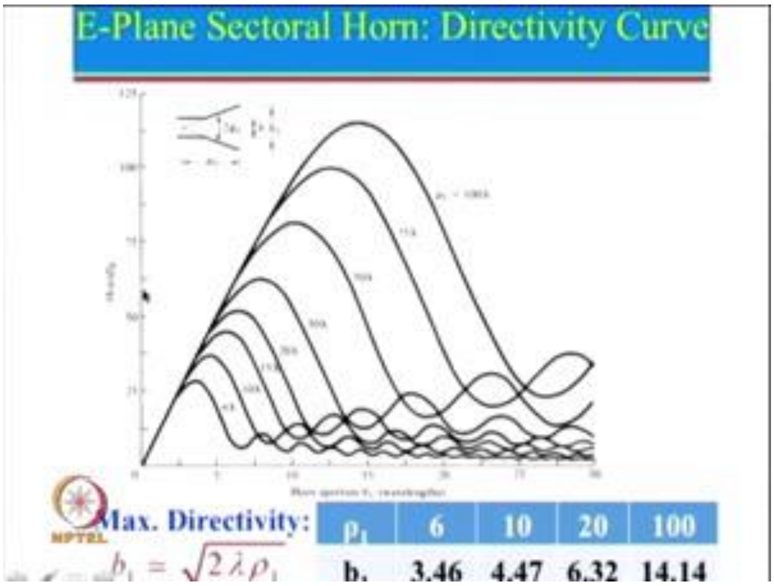

So, I just want you mention here these directivity curves have been reported in the literature. So, these things are there, so let us utilize the knowledge which has been given by so many researches in the past. So, what I want to show over is that this is the normalized directivity, because one of the dimensions of the wave guide is constant which is not being changed.

So, a is constant. So, that is what it is coming over here this is lambda. So, it is basically normalized with respect to that. What do we see over here? This is actually the horn aperture dimension which is b 1. So, basically b 1 is getting increased in this particular thing; that means, we are increasing the aperture dimension. Now what are these different curves here? These are the different curves for different value of rho 1. So, if rho 1 is 100 lambda that means, the horn antenna is very very large, and over here you can see rho 1 is about 6 lambda. So, it is relatively shorter, so that means the length of the horn antenna is relatively short.

So, suppose that we have fixed horn length which is 6 lambda, and then now for this fixed 6 lambda let us see what is happening. if we increase the value of the b 1 continuously. So, what happens? You can see that the directivity is increasing and then the directivity becomes maxima, and then its starts reducing. So, why it is reducing? The reason for that is let us say now we are increasing the aperture; so this distance is nothing, but equal to the rho 1 plus b 1 by 2 whole square. And the b 1 is relatively small phase error will be relatively small, but as we keep on for the fixed length of rho 1, as we keep on increasing this dimension. So, what will happen? Phase error will start increasing and now let just see the wave is propagating in z direction, and what we have seen E-Field is like this.

So, if E-Field is like this here, but now there is a phase error. So, because of the phase error it will not be aligned in this, it will be now aligned like this then it will get aligned like this, then it will if the phase error becomes 90 degree it is actually going in this direction. That means, contribution of this will be negligible or not there, but if you increase the phase for the now what is happening? This plane vector will be like this. So, this was starting was in this direction, and this is in the opposite direction. So, what will happen? even though you are increasing the aperture this field and this field here they will start canceling each other, and hence directivity will start decreasing.

So, there is an optimum value up to what level you can increase the value of b 1 till then you can get a directivity which is increasing, after the directivity will start decreasing. So, let us just look at this curve again. So, one can actually see that as we keep on increasing the value of b 1, we can see that the directivity is increasing and then it is starts decreasing. The same thing happens here suppose if I take this particular length you can see directivity is increasing up to this here, and then it starts decreasing if you take this one here directivity starts decreasing after this value.

So, from here we can actually just draw the line from here. So, if you think about this is 6 lambda, if you draw the line somewhere over here you can see this is the value of b 1.

So, I have written here rho 1 is 6, then b 1 is approximately this value. If rho 1 is 10 you can just again draw the line here and that is this value here and if you go to 100 one can actually draw the line here, you can actually say that will be somewhere here which is 40; and if you actually put this thing here this whole thing can be actually a drawn a line can be drawn through here, which will go through the maximum value and that equation is given by b 1 equal to square root 2 lambda rho 1.

Now, these are the values which are given and this is what it suggests that this is the value for which we get maximum directivity, which is over here. So, let us see now this corresponds to how much phase error.

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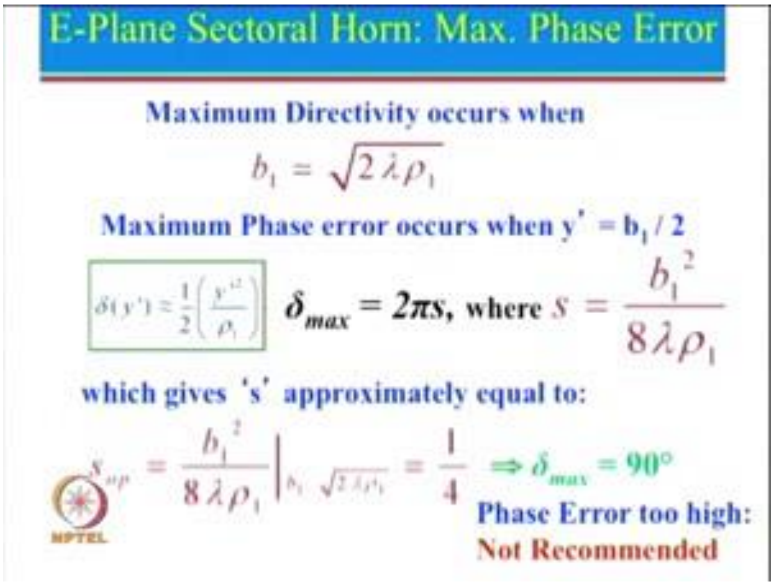

So, maximum directivity occurs when b 1 is equal to this particular expression here; and we also know that maxima phase error occurs when y dash is equal to b 1 by 2 that is at the end of the aperture. So, now, we can find the value of delta, delta expression was given over here and we know that the phase term will have a 2 pi times this here, and where S is given by this term here you can actually see y dash is equal to b 1 by 2. So, that will become b 1 square by 4, 2 is already there and this rho 1 and the lambda is coming because of that 2 pi by lambda which is the k term by phase, it is coming over here.

So, now if we substitute this value of b 1 over here, so S optimum according to this is substitute the value it comes out to be 1 by 4, and do we put s value equal to 1 by 4 over here this whole thing becomes delta max equals to 90 degree. So, this is what majority of the books tell you that I do not agree with this particular thing, phase error is just too high and I do not recommend that you should go to this particular phase error. In fact, let us go back and look if the directivity curve one more time. So, what we rarely see here is that this is the point where we get the maximum directivity, but this point also implies 90 degree phase difference.

But just think about it that instead of this phase error if I had taken up to this point only; then I would have got little lesser directivity, but this is linearly increasing and we know that directivity general expression or directivity is nothing, but we can say 4 pi area divided by lambda square; and area is nothing, but a dimension multiplied by b 1, here a is constant and we are increasing b 1. So, it should have been linearly increasing, but over here it is not increasing. So, if you just look at this particular point only, we said this is the maximum directivity point absolutely right. But however, if you look at a theoretically had this phase error not come into picture, and if we draw the line vertically up it would have actually gone somewhere here. So, we could have got the directivity this much here if there was a lesser phase error.

In fact, I never ever recommend that you design the antenna for about 90 degree phase error. In fact, our recommendation is design most of the time only for a phase error of about 45 degree.

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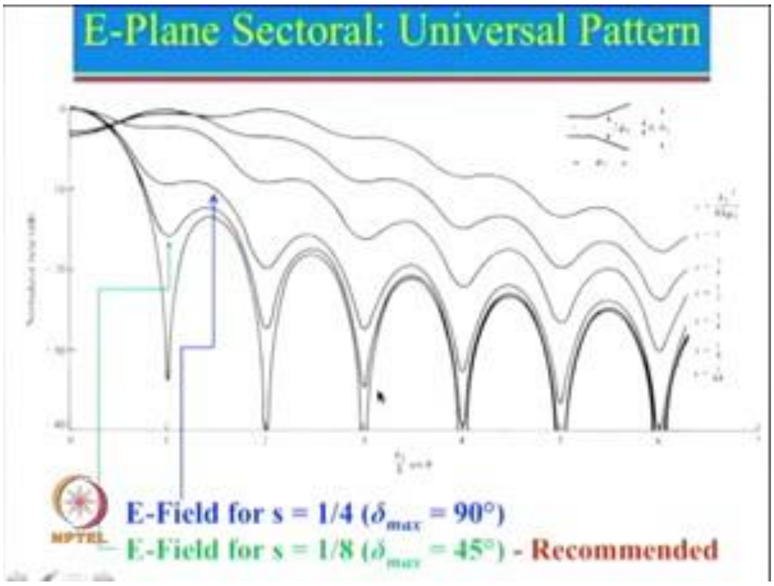

And I also want to show you now the E-Plane pattern here. So, this is the E-Plane Sectoral pattern this is known as the universal pattern, and this universal pattern if you look into that this is the E-Plane curve here, this is the field variation; and this one here basically corresponds to when the phase error is very very less, and if the phase error is very very less we can see that there are sharp nulls are there; where as if the phase error if you see now for 1 by 8, you can see that some nulls are coming they are not very sharp. But if you take phase error equal to 90 degree, you can see now this is the variation and if you see this value this is about close to minus 10 dB and you can see this is a much border region and this is radiating in the undesired direction and minus 10 d B is like 10 percent.

So, 10 percent of the power is getting radiated here here here and everywhere. So, resulting into the lower gain and hence lower efficiency, so in fact if one takes this kind of a number here delta max 90 degree then efficiency obtained is of the order of 50 to 60 percent; where as if we take number something like this here, then the efficiency can be 70 to 80 percent. So, we would rather like to design an antenna which is more efficient rather than going with this particular phase error.

In fact, I also want to mention this entire thing can be also explained in the form of the error theory also. So, I will mention about that in our next lecture how this E-Field pattern can be explained using a very simple error theory concept also. So, just to summarize we started talking about horn antenna, and we looked into various types of horn antenna they can be E-Plane Sectoral horn, H-Plane Sectoral horn, Pyramidal horn and conical horn antenna and much later will talk about variations of these horn antenna also.

So, we looked into another part that is the directivity of the horn antenna increases up to a point and after that it starts decreasing. The main reason is that the phase error starts increasing, and because of the phase error the field starts canceling each other and hence directivity decreases efficiency decreases.

So, we will continue from here in the next lecture, so till then bye have a good time.