Microwave Theory and Techniques
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Module - 11
Lecture - 51
Yagi - Uda, Log-Periodic and Reflector Antennas

Hello, and welcome to today's lecture on Yagi-Uda Log-Periodic and Reflector Antennas. We will first start with Yagi-Uda, then we will talk about log-periodic, and then reflector antennas.

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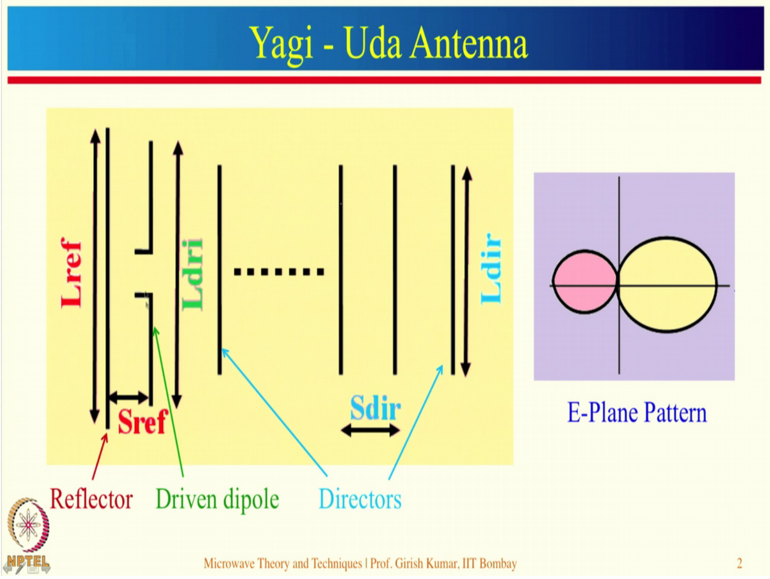

So, Yagi-Uda antenna consists of one driven dipole, which you can see over here. And then, we have a one reflector behind the dipole, and then after that we have multiple directors on the other side. So, what is the purpose of all of these thing. Now, we have covered that a dipole antenna has a radiation pattern which is omnidirectional radiation pattern. So, it will radiate equally in all the direction.

However, there are many applications, where we want the radiation to be only in one particular direction. So, if we put a reflector behind this particular dipole antenna, then what will happen, the radiation from that dipole will reflect back from the reflector, it will go in this particular direction. So, just by putting a reflector behind the dipole antenna; suppose if it is a lambda by 2 dipole antenna, gain will be approximately 2 dB.

And if you put a reflector behind this particular thing at an approximate distance of lambda by 4, then gain will be of the order of 5 dB, because it is double of the previous value.

Now, if you put a director; suppose we put just one director, you can see that now the total aperture will increase by 2 times. So, hence ideally the gain may increase by 3 dB, so that means, 2 dB plus 3 dB 5 dB plus 3 dB 8 dB. However, practically we do not get 8 dB, practically we may get around 7 dB. However, by putting multiple directors, we can increase the gain of the antenna. So, this particular radiation pattern is also known as end of fire array radiation pattern.

So, radiation is mainly in this particular direction. So, you can see that main beam is in this particular direction, part of that is going back here, because we are not providing infinite reflector. Reflector is also a simple wire. Hence, there is still a back radiation. So, we define another quantity, which is known as front to back ratio. So, compared to this value, how small this value is. Generally, we would prefer front to back ratio to be greater than 10 dB. So let us see; what are the typical dimensions for these Yagi-Uda antenna elements. So, I will start first with the feeder length.

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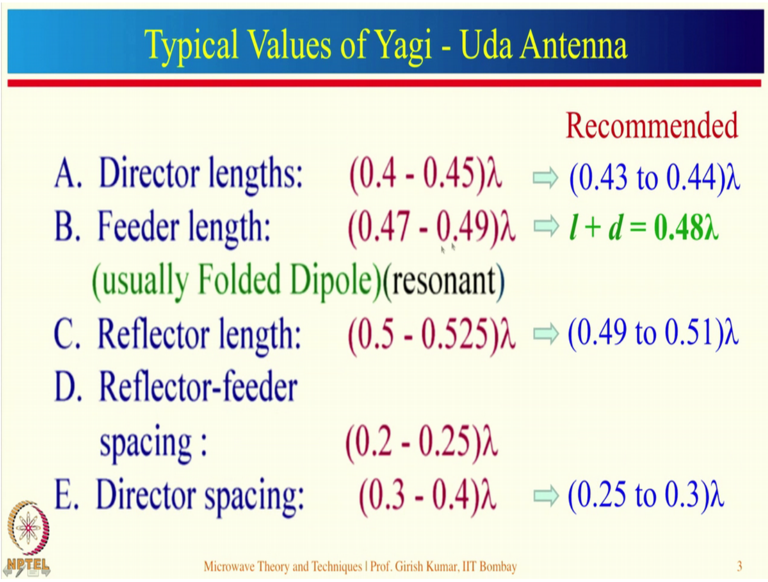

Now, what I have shown you here, these are the values given conventionally in the books. However, based on our experience, these are my recommended values. So, let us say feeder length, what is recommended in the book is typically 0.47 to 0.49 lambda.

However, I recommend that l plus d is equal to 0.48 lambda, where d is the diameter of the dipole antenna, and l is the length of the dipole. So, if we take let us say d equal to 0.01 lambda, l will be 0.47 lambda. If we take let us say d equal to 0.02 lambda, then l will be 0.46 lambda. Then after that, we will talk about reflector length. Reflector should be greater than the feeder length. So, here depending upon what is the value of d, we can choose the reflector length between 0.49 to 0.51, it should be greater than this particular length.

Then comes the director, so that length of the director, typically they have recommended to be 0.4 to 0.45. So, whereas what we have found, typically 0.43 to 0.44 lambda length of the director gives good gain. As far as the spacing between the reflector and the feed dipole is concerned, so that is generally 0.2 to 0.25, I agree with this particular thing. Director spacing, they have recommended as 0.3 to 0.4 lambda, whereas my experience is typically it should be 0.25 to 0.3 lambda.

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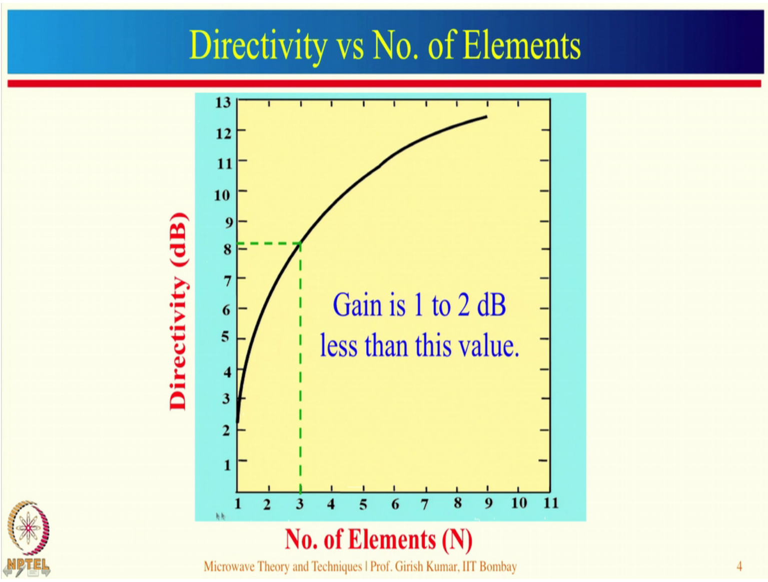

So, let us see what happens to the directivity as number of elements increase. You can see that starting from one element all the way to eleven elements. We can see that the directivity is increasing. So, you can see for a single element, directivity will be approximately 2 dB. If you take two elements that means, one dipole antenna and one reflector antenna, then the directivity will be of the order of 5 dB. If we take three elements, approximate directivity can be 8 dB, but as I mentioned gain is 1 to 2 dB less than this particular value. So, depending upon the requirement, you can take larger number of elements.

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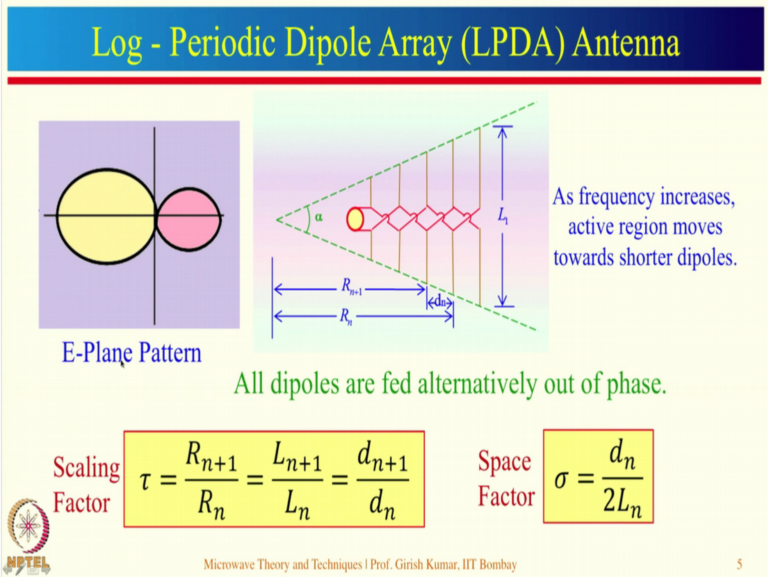

Now, let us talk about log-periodic dipole array antenna. Here, purpose is different than the Yagi-Uda antenna. In case of Yagi-Uda antenna, we try to increase the directivity of the antenna, whereas bandwidth is relatively limited. However, in case of log-periodic, more emphasis is given on the bandwidth. So, here all the dimensions of the dipole antenna vary logarithmically. So, let us see what the configuration is. So, here we have a one dipole, another dipole, another dipole and so on.

Feed is generally given at the smallest dipole dimensions. So, you can see that feed is connected over here, and then all the alternate elements are connected in the cross manner. So that means, let us say if we assume this is plus, so this plus will come here then plus goes here, whereas minus of this, goes up over here. So, you can see that this particular dipole element is fed with 180 degree out of phase ok. And then another element is fed out of phase, which is 180 degree. Again, this whole thing acts as a end fire antenna. So, the radiation pattern now is in this particular direction. So, you can see that main beam is in this particular direction, there is a back radiation, and again front to back ratio should be as large as possible.

Now, in case of log-periodic antenna, all the dipoles are fed. So, what happens as frequency increases? So, what will happen at the lowest frequency, this dipole will be resonant? As frequency increases, now this dipole will be resonant, then this dipole will be resonant, then this dipole will be a resonant. So that means, what is happening, as frequency is increasing, the active region of the dipole antenna is basically shifting towards the smaller dipole. Why smaller, because at higher frequency smaller dipole will act like a resonant length.

So, let us see now, how we define these lengths. So, typically scaling factor is defined, which is equal to tau is defined as R n plus 1 divided by R n L n plus 1 divided by L n d n plus 1 by d n. So let us see; where are these parameters here. So, you can say that this is L 1, then this is L 2, L 3 and so on. The distance here this is let us say R n, this will be R n plus 1. So, R n plus 1, you can see is smaller than R n; hence tau will be always smaller than 1. Similarly, L n plus 1 L n plus 1 is this dimension. L n will be this dimension. So, again L n plus 1 divided by L n will be small.

Now, you might feel, where is log coming into picture, log comes into picture if you take log on both the sides, so what will happen now, log of tau is equal to log of R n plus 1 minus log of R n. So, we can say that every progressive dimension is actually changing by a factor of log tau. Here all the dimensions vary in the same fashion.

Let us define another quantity, which is space factor. What is space factor, so space factor is equal to sigma is given by d n divided by 2 L n. Let us see now, where is d n, so you can actually see that d n is somewhere this particular distance here. So, if we take the centre of this particular point which is d n by 2 and that is divided by the length. So, basically this defines the space factor for a given array.

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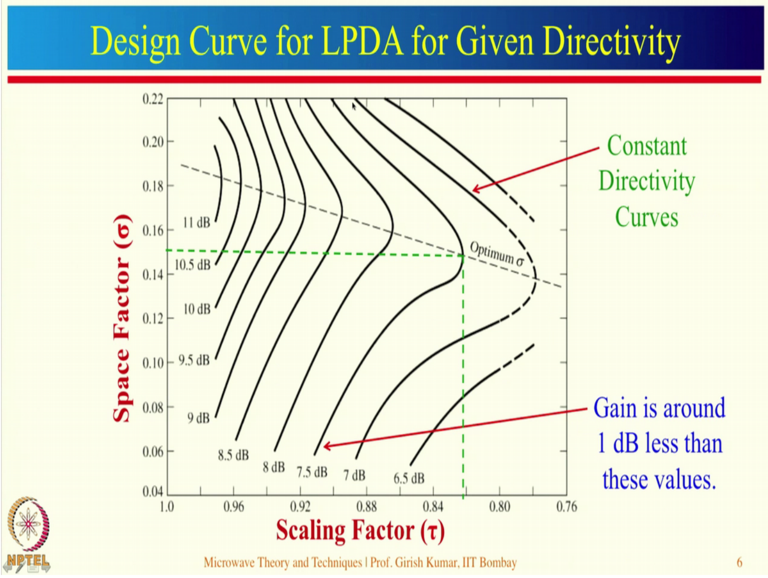

Here, we have design curve for log-periodic dipole antenna, for various values of directivity. So, let us see what we have here, so we have several constant directivity curves. So, if you take any point along this particular curve directivity will be constant. So, what we have here now, scaling factor is given along this axis space factor is given along this particular axis. And what is mentioned here that if you take the point along this dotted line that will give us the optimum value of the sigma and correspondingly tau value.

So, let us just take a case that we would like to design an antenna for the directivity of 7.5 dB. So, you can see that this is the directivity curve for 7.5 dB. If we take this optimum point along this dotted axis, so if you draw the line here, you can see that this comes out to be 0.8 is here, 0.84 is here, so roughly slightly greater than 0.82. Correspondingly, we draw the horizontal line. You can see it is between 0.14 and 0.16, so we can say it is approximately 0.15.

I just want to mention here. So, in the book, generally that write this as directivity curve or some books write this as constant gain curves. However, based on our experience, gain is in general 1 dB less than these value, so that means, if you want a gain of let us say 6.5 dB, you choose this particular curve here. Let us say if you want gain of 8 dB, then we should choose this particular curve over here. So, now let us take a design example.

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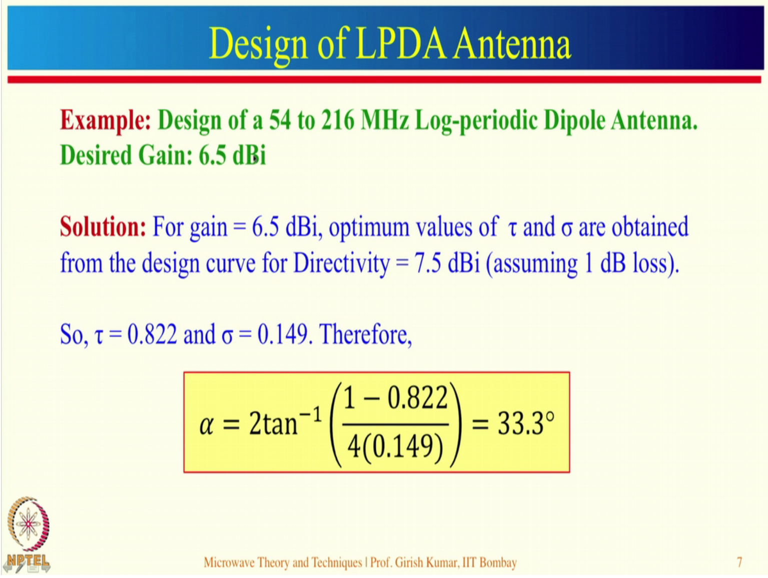

So, we are taking a design example of a log-periodic dipole antenna array from 54 megahertz to 216 megahertz. Let us say the desired gain is equal to 6.5 dBi. Now, as I mentioned for gain equal to 6.5 dBi, choose the optimum values of tau and sigma for directivity equal to 7.5 dBi, assuming 1 dB loss. So, we can read these values of tau and sigma from the previous curves, so tau is about 0.822, and sigma is 0.149. So, from here, we can also calculate the angle of the dipole antenna array.

So, if you see that all the dipole, let us just look at the previous slide, so this is the angle, this is the angle alpha. So, we can actually find out this angle alpha. So, how we can find the value of alpha; let us say if you draw the line like this, so this will be alpha by 2. So, tan alpha by 2 can be written as this length divided by this particular distance. So, let us say for this particular length R n, dipole length will be L n. So, half of that will be L n by 2. So, tan alpha by 2 will be L n by 2 divided by R n. So, now we can calculate the value of alpha which is given by this particular expression, and we can find the value of alpha over here.

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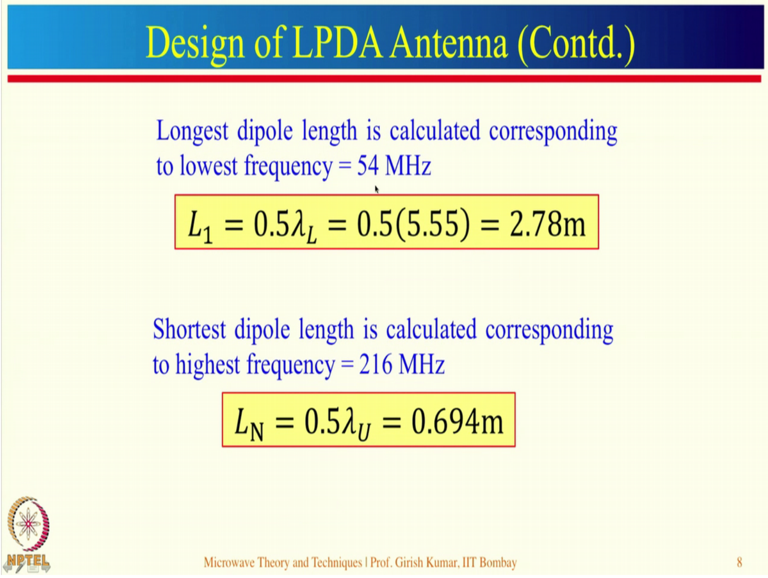

So, now let us proceed with the design of LPDA. So, first thing what we do, we find the length of the longest dipole corresponding to the lowest frequency. So, here you can see that the length of the longest dipole is approximately taken as 0.5 times lambda L. L corresponds to the lowest frequency; otherwise lambda is the largest ok. So, these symbols are mainly for the lower or upper frequencies. By 200, I had mentioned that we should choose l plus d equal to 0.48 lambda, then why I am taking L 1 as 0.5 lambda L.

You can take L 1 plus d equal to 0.48 lambda, but even this expression is valid. In the sense, we are designing a very broadband antenna. So, small deviation in the frequency will not make any difference. So, corresponding to 54 megahertz, lambda is 5.55 meter, so this length comes out to be 2.78 meter. Similarly, corresponding to 216 megahertz, we find the length L n, which comes out to be 0.694 meter. Now, we have to find the length of all the in between elements.

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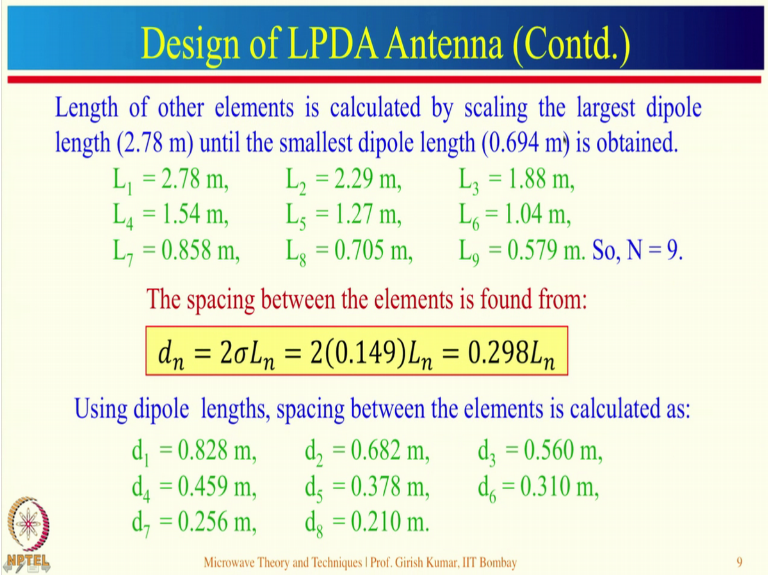

So, we start with the other elements calculation using that scaling factor ok. So, we start with 2.78 meter, so L 1 is this. So, what will be L 2, tau times L 1, so we obtain here. Then L 3 will be tau times L 2.

Keep doing this particular process, till we reach to a point where this length is smaller than this particular length over here. Please do not stop over here, take this particular element ok. So, now you can see, we need total 9 number of dipole antennas to design this particular log-periodic array. The spacing between the elements can be found using this particular expression d n equal to 2 sigma L n. And then, once we know this particular value here, you can find the different values of the using these values of length.

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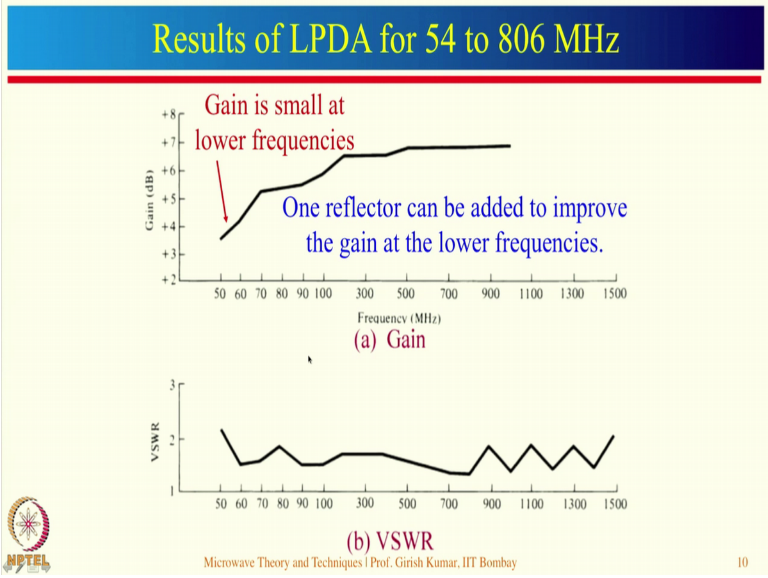

So, let us see the result of this particular design. So, you can see that this is gain versus frequency, this is VSWR versus frequency. So, one can see that VSWR is less than 2 over this entire band. Now, let us see gain. Gain as you can see here, gain is relatively small at the lower frequency, whereas gain is (Refer Time: 15:41) at the higher frequency. The reason for that is behind the longest dipole element, there is a nothing which is reflecting back.

So, what happens, the longest dipole will radiate like this, and nothing is there to reflect back, hence gain is small. So, in fact, I too recommend that you actually put one reflector behind the longest dipole. To that this whole gain curve will improve. In fact, if you put a reflector behind this curve instead of starting from here, it will almost start from here. And then, it will move like this here so that will give you relatively constant gain over the desired bandwidth.

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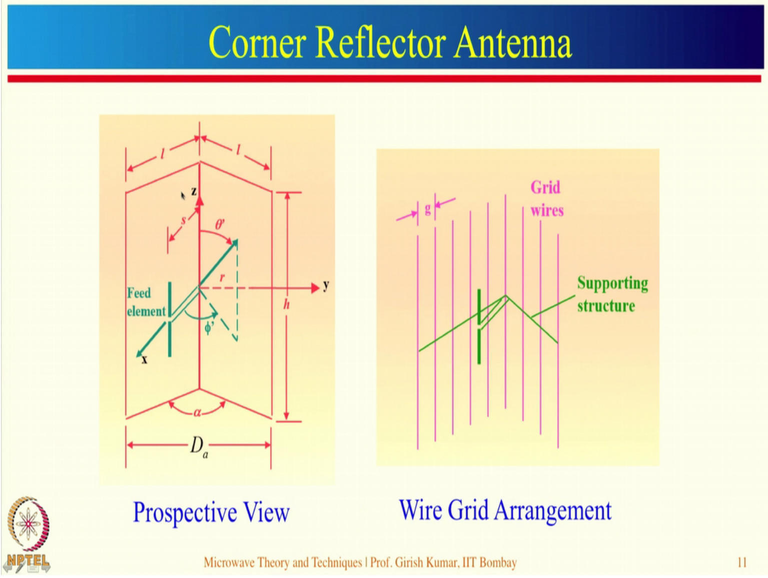

Now, let us go to the next configuration. So, we will start with corner reflector antenna. So, corner reflector antenna is defined by its angle alpha between the two metallic plates over here. Now, generally speaking these metallic plates are defined by the height and the length of each section. So, most of the derivations in the book, assume h to be infinity and l to be infinity. However practically that will never be the case. So, let me give you some practical tips over here.

Now, assuming that the feed dipole element has a length equal to lambda by 2, then height can be taken approximately as lambda, there is a no need of taking larger than lambda. As far as this length l is concerned, typically this length can be 1 lambda to 2 lambda depending upon this particular angle alpha. Now instead of using this particular configuration, one can use wire grid arrangement. Let me first tell you why we use this particular thing. Now, think about if this particular antenna is mounted on the rooftop, what will happen because of the wind, there will be lot of wind loading will be there. So, if the wind is coming from this direction, and let us say reflector antennas is placed like this, so there will be lot of pressure on the antenna.

However, instead of using this if we use this wire grid arrangement, then what will happen, there will be very small wind loading. Then the question comes what should be the spacing between these wire grid arrangement. So, I will just tell you, generally speaking this value of g should be less than lambda by 4. However, one can take this value as lambda by 10, and the absolute maximum for this particular value is lambda by 4. Never ever take the separation between the 2 as more than lambda by 4, and also there is not much need to take this length smaller than lambda by 10.

Now, comes the next part, you cannot have these wires suspended in the air, so you too need a supporting structure. So, here I have shown only one supporting structure here, but one can have multiple thing like this. So, basic advantage of this particular configuration is wind loading will be less, total weight of the antenna will be also less. However, this arrangement is good only for vertically polarized antenna. Please do not take this arrangement for horizontally polarized antenna.

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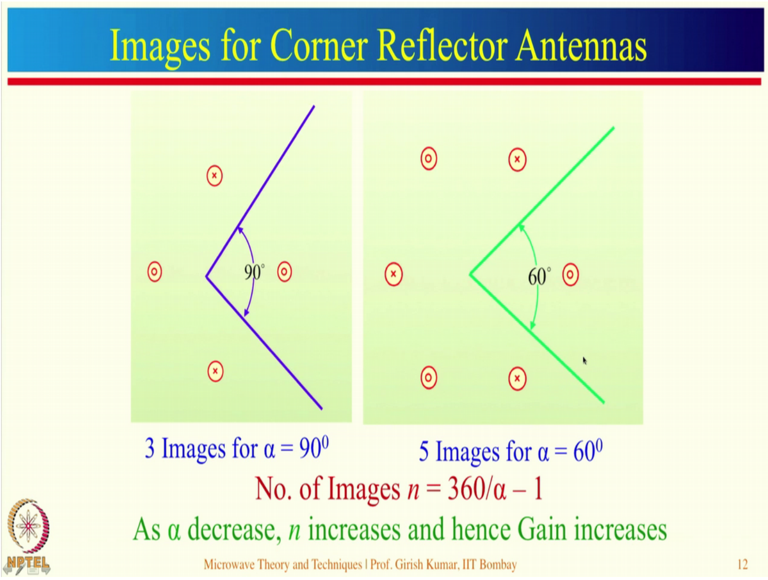

So, now let us see what happens if we have let us say different angle between the corner reflector antennas. So let us take a example of corner angle to be equal to 90 degree. So, this is the top view of the corner reflector antenna. So, from the top if we see, we will only see the line and the dipole antenna will only see the tip.

So, if we not take this particular thing as current going towards this particular direction, so we represent that as an arrow going over here, so we see the point. Now because of this metal plate, there will a reflection, so image will be form, image will be in the opposite direction. Just think about it, if you stand in front of a mirror, then what happens your right hand looks like a left hand in the mirror, and left hand looks like a right hand in the mirror. Exactly the same way, so this particular current which is going up here, it will be appearing going into the paper here, so that is shown as cross. Similarly, for this particular plate, there will be a cross over here.

Now, how do we construct this particular thing, this can be imagined in a slightly different way. So, just think about that this whole thing is extended like this, and this whole thing is extended like this over here. So, in that particular case, if this is extended like this here and this one is extended, you can actually imagine that image will be formed because of this particular thing, which will come over here. Similarly, image will be formed because of this here, which will come over here. So, there will be total three images for alpha equal to 90 degree.

Let us see what happens, if alpha is equal to 60 degree. So, again if we have a dot here, it will have a cross, it will have a cross here. Now, you again imagine this going all the way like this, this one going all the way like this over here, then because of these thing, there will be images, so we have dot, cross, dot, cross, dot, cross. So, now we will have total five images. So, this concept can be extended to any value of alpha, and then number of images n can be found using this particular expression here, which is 360 divided by alpha minus 1. So, here alpha is 90 degree; 360 by 90 is 4, 4 minus 1 3 (Refer Time: 21:49). Alpha is 60 degree; so 360 by 60 is 6 minus 1 equal to 5.

Now, one can actually imagine that. Since for smaller angle, we have more number of images that means, larger number of antenna array element, hence as alpha decreases, n increases, and hence gain increases. You can even think in a slightly different way also. Let us say if this particular dipole antenna had this been not there, it would have radiated in all the direction. But, now because of this particular reflector here, what will happen, all of these reflection will go in this particular direction, and a beam will be actually formed only in this particular area.

So, you can see that for this particular case, beam will be confined within alpha equal to 60 degree. Here, beam will be relatively broader, so we can generalize that as alpha decreases, that mean these metallic plates are coming closer. So, radiation will be confined only in this particular narrow region, so half power beam will decreases, which results in higher gain.

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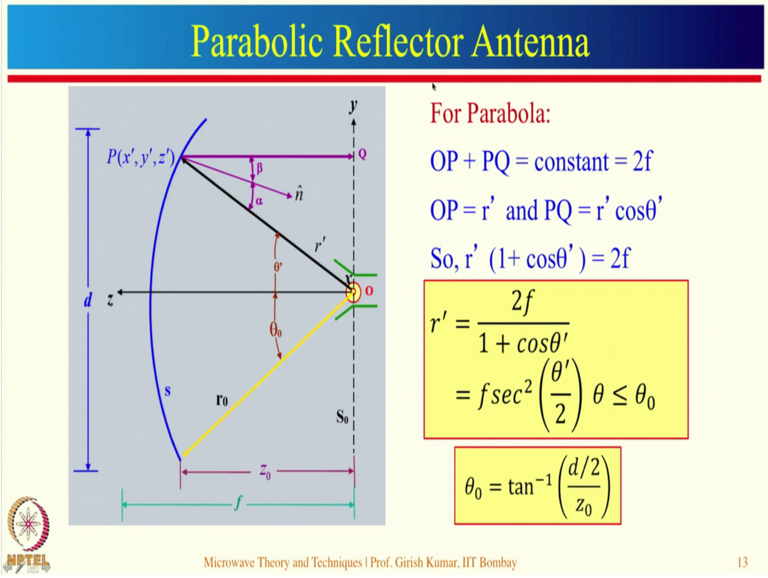

Now, we will talk about the next configuration, which is parabolic reflector antenna. So, basically a parabolic reflector antenna is something like a dish antenna, you might have seen at various places. So, generally you will see that a dish antenna has a some another feed antenna at the focal point of this particular dish antenna. Now, most of the time, it is actually nothing but a parabolic shape. So, just think about a parabolic shape here, and then you rotate this parabolic shape to make a complete circle. So, dish antenna will look like a circle here. If we look from this particular point, but otherwise it has a depth, and this particular thing varies in a parabolic fashion.

If you recall your high school, for parabola we know that OP plus PQ is constant, let us see where are these points. So, this is o, which is a focal point of this particular parabolic reflector. So, wave goes from here, and then reflects back, so this will be OP plus PQ. Similarly, we can say that this wave goes over here reflects back. So, what is this distance, this is f and then comes back here so that will be equal to 2f. So, we can write in general OP, P can be any point on this particular parabola and reflected over here, can be any point Q over here, so we can say OP plus PQ is equal to 2f.

Now, let us see what is OP. So, you can see, its origin has been defined over here. So, this distance is equal to r dash, which is equal to OP. And this distance PQ is nothing but r dash multiplied by angle cos theta dash. So, this is theta dash. So, this angle will be also equal to theta dash over here. So, this can be simplified in a so, OP is r dash, PQ is r dash cos theta dash, so we can take r dash outside, which is equal to 2f. So, from here, we can find the value of r dash as 2f divided by 1 plus cos theta dash. Cos theta dash can be written as 2 cos square theta dash by 2 minus 1. So, minus 1, minus 1, will cancel out; 2, 2, will cancel out; cos square theta dash by 2 can be written as sec square theta dash by 2.

So, this is the equation of the parabola, which is valid for theta less than or equal to theta 0. So, theta 0 is the angle, which is at the tip of the parabolic reflector antenna. We can also define theta 0 in terms of the diameter of the parabolic dish antenna. So, diameter is small d over here, diameter of the parabolic reflector antenna is taken as small d. So, how we can write tan theta 0, so tan theta 0 will be equal to this distance divided by this particular distance over here. So, we know that this particular distance is d by 2 which is over here, divided by this particular distance, which is z of 0.

So, now let us see how we can design a parabolic reflector antenna, how we can find the gain, and aperture efficiency of the reflector antenna.

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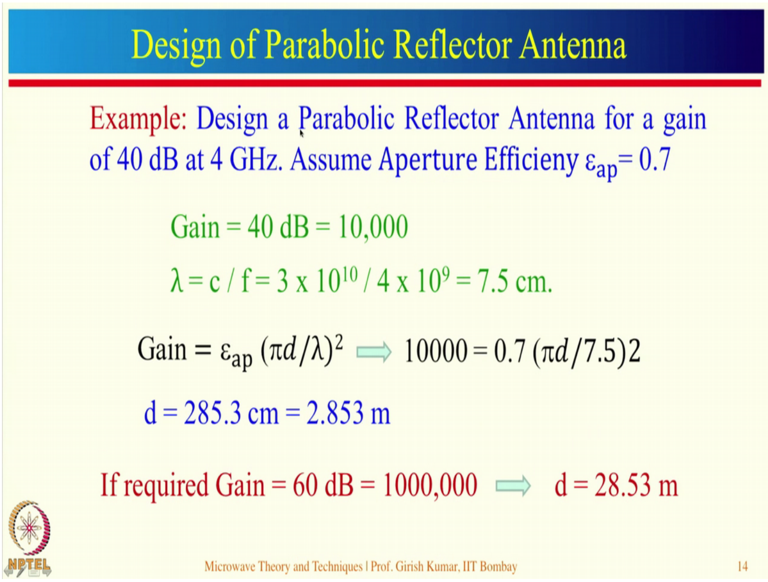

So, we will start with the design, and then I will tell you the different terms over here. So, we have to design a parabolic reflector antenna for a gain of 40 dB at 4 gigahertz. Assume aperture efficiency to be equal to 0.7. In fact, 0.7 is considered fairly good aperture efficiency. In fact a badly designed reflector antenna may even have aperture efficiency of 0.4 or 0.5 also.

So, let us see now, how we can find the diameter. The desired gain is 40 dB, which comes out to be 10,000, and lambda is equal to c divided by f. Here I have written c as 3 into 10 to the power 10 centimeter per second. You might be familiar more like 3 into 10 to the power 8 meter per second, but we have converted that to centimeter. So, this is 3 into 10 to the power 10 centimeter per second, frequency which is equal to 4 gigahertz is 4 into 10 to the power 9, lambda comes out to be 7.5 centimeter.

So, gain of the parabolic dish antenna is given by pi d by lambda square multiplied by epsilon ap, this expression I had given in the earlier lectures. So, basically this whole thing is equivalent to 4 pi a by lambda square, where a is nothing but pi d square by 4. So, if we now substitute the various values gain is 10,000, epsilon ap is 0.7 pi d, which we want to find out divided by 7.5 whole square. So, d comes out to be 285.3 centimeter which is 2.85 meter.

Now, just to take another example, suppose if the required gain is 60 dB, corresponding to this the numeric value will be 1 million. If we substitute this value in this particular expression, d will increase by 10 times, resulting into gain increase of 100 time. So, instead of 2.853, it will become now 28.53 meter. So, you can actually imagine, you need a very large dish antenna to realize gain of 60 dB. I want to now show you large reflector antennas, which are present in the world.

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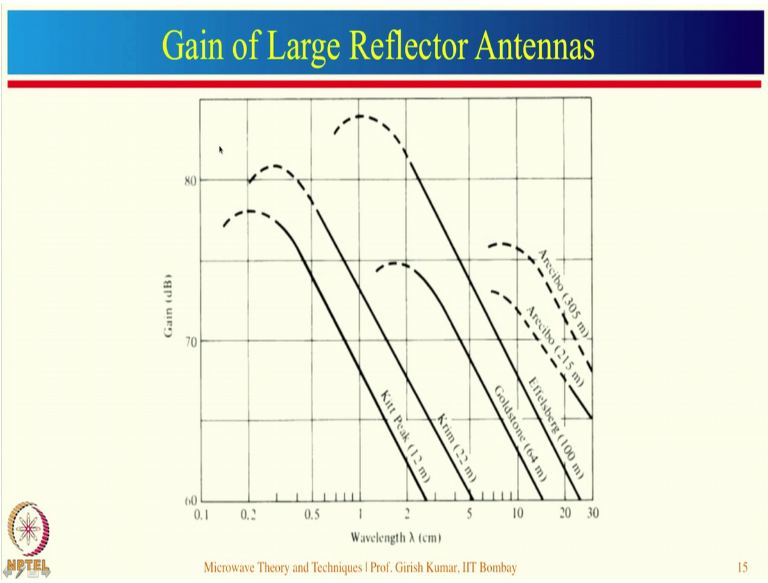

So, here are the examples of different reflector antenna. So, just to tell you what we have here, here is a wavelength in centimeter, this is the gain in dB. So, just to tell 10 centimeter will correspond to 3 gigahertz, 1 centimeter will correspond to 30 gigahertz. And these are the different reflector antennas, which are available in the world. So, just look at this particular antenna over here, it has a diameter of 305 meter, it is a huge antenna. This one here has a diameter of 215 meter, and you can see that their gain is very large. And these are the antennas, which are designed at higher frequency corresponding to lower wavelength.

So, you can see here very large antennas have been designed in the world to realize very large gain. You can think about this number here 60 dB corresponding to 1 million gain. And you see over here, this particular line corresponds to 70 dB gain; 70 dB gain implies 1 [FL] or 10 million. You can see that, you can really realize the very large gain by using these particular reflector antennas. In fact, to realize very high gain antenna, there is a only one choice, and that is to use reflector antennas.

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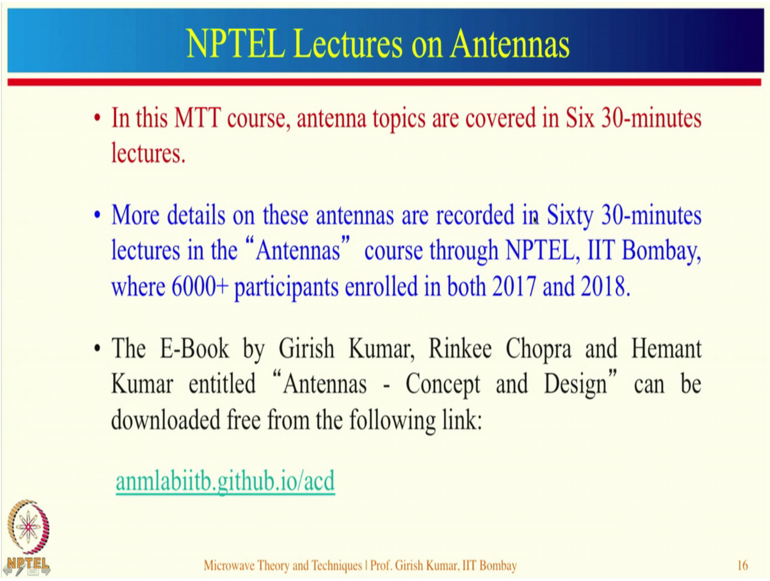

Now, to conclude this particular thing, I would like to mention that in this MTT course, I have covered antenna topics in roughly six 30-minutes lecture. I have recorded Sixt 30-minutes lectures in the Antenna course through NPTEL. So, you can actually think about six 30-minutes is about one-tenth of what I have recorded through antennas course NPTEL.

You can really think about, I have shown you a large trailer of a movie ok. So, for more detail information, please see these videos. You can also referred to the E-book, which is written by me and my two PhD students, the book name is Antennas-Concept and Design. You can download this thing free from this particular link over here. I just to tell you the code of this particular link also ANM stands for antenna microwave lab at IIT Bombay, and this ACD corresponds to antennas concept and design. So, enjoy reading this particular E-book and enjoy watching the larger version of the antennas through this NPTEL course.

Thank you very much. Bye.