Antennas
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Module - 01
Lecture - 04
Antenna Fundamentals-I

Hello everyone, and welcome to today's lecture on Antenna Fundamentals. So, today we will talk about the basic characteristics of the antennas.

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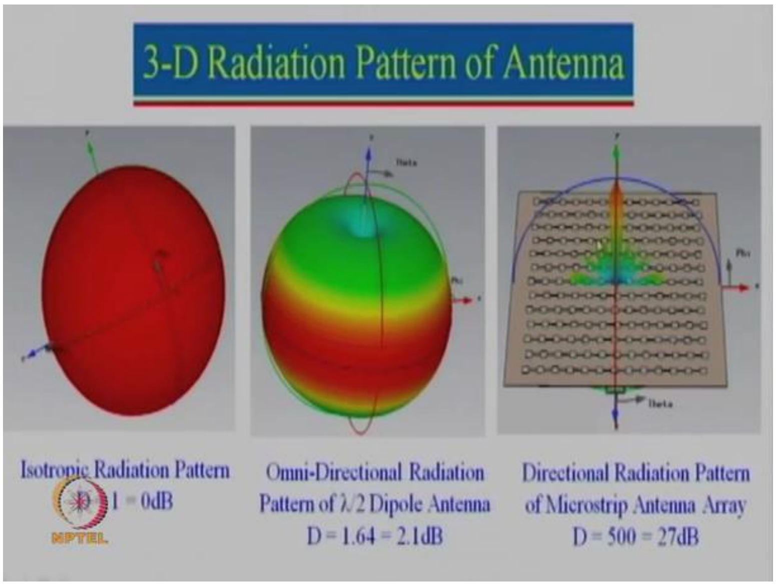

So, antennas are defined by its radiation pattern. So, in general antenna radiation pattern is actually taken as a 3-D radiation pattern that to make a life simple we do plot 2-D pattern also, but let us say isotropic antenna. Isotropic antenna is an antenna which radiates equally in all the directions whether it is this direction or in this here in the entire sphere it radiates equally in all the direction. So, we define for that directivity is equal to 1 and we take 10 log of one which is equal to 0 dB. I also want to tell there are no isotropic antennas as such, but of course, lot of research is going on to design an antenna which is known as quasi isotropic antenna.

Then there is a next time with thing which is a Omni-directional radiation pattern and what we have shown here is for a lambda by 2 dipole antenna. So, the dipole antenna is kept over here as one can see the red shows maximum radiation and then it is going towards lesser, lesser, lesser and least radiation. So, you can see that if the dipole is like this here maximum radiation is all along the dipole antenna and if the dipole if you see from here maximum radiation as we move up, up, up and if we see from the tip we only see the tip of the dipole or it is a very little radiation here and in 2-D pattern you can actually think of this whole thing as a 8 like this here and that 8 is getting rotated.

Then here is an example of a direction antenna I have actually shown the radiation pattern of a microstrip antenna array which we have designed at IIT, Bombay. So, you can see that there are number of elements are in this side and number of elements are there and we are feeding these things. In fact, we have used a series feed element over here and to feed with elements in this direction we have actually uses slotted wave guide antenna here. So, for this particular antenna we got a directivity of 500 and if you take 10 log 500 which is about 27 dB. What you can see here is the maximum radiation is in this direction and these are all the side loops associated with this particular antenna array.

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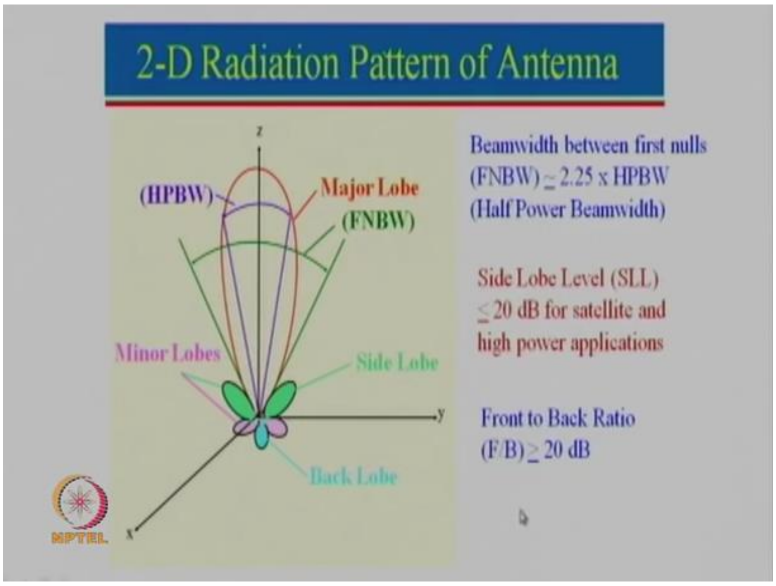

So, let say 2-D radiation pattern this pattern we have already seen in the last lecture. But here we just want to define few additional things now. So, just quickly recap this is the main beam that is known as a major lobe, all these are known as minor lobes. Half power beam width is defined as the angle over which maximum radiation reduces to the half power point. For E field it will be 1 then this will be 1 by square root 2 after the main beam there is a side lobe coming up, but in between there is null. So, we have a null here and null here. So, the angular distance between the two is defined by first null beam width. So, there is a simple relation between the half power beam width and first null beam width.

In fact, beam width between first null is actually approximately given by 2.25 times half power beam width. Well if you see in many books actually write this even further approximation which is two times half power beam width, but I have seen and checked with many antennas and we have found that this relation is actually better than using a relation of two times this one here. Then these side lobe levels now side lobe level we will see in time to come that if we feed arrays with uniform amplitude side lobe level is just about 13 dB or so. However, for satellite and high power application we want side lobe to be less than 20 dB. So, just imagine a high power transmitter which is transmitting let us say 1 kilo watt power in this direction. So, if it is 1 kilo watt and if the side lobe was just 10 dB, 10 dB will be one-tenth of the power. So, 1 kilo watt is in this direction; that means our 100 watt power will be transmitted in these directions, so which is not desirable. So, 20 dB would mean 1 by 100. So, if it is 1 kilo watt this is still 10 watt that also may or may not be desirable.

So, many a times high power application may even demand 30 dB or 40 dB. So, 30 dB would imply if this is 1 kilo watt 30 dB would mean all of these are less than 1 watt power. So, lot of these restrictions are coming day by day where people are going for high power and they would like a lower side lobe which poses lot of challenges for the antenna designers. So, front to back ratio generally preferred this 20 dB, but 15 dB may be acceptable in some cases, but many a time the requirement could be 30 dB, 40 dB front to back ratio.

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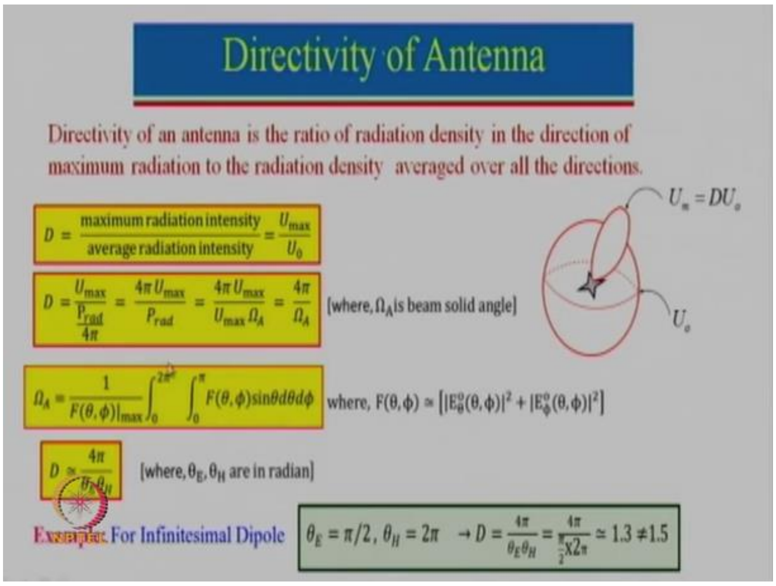

Then let us define directivity. So, we just looked into the directivity three examples. So, directivity is 1, directivity is 1.6, for directivity is 500. So, what is really directivity how do we define? So, the basic definition of directivity is that the directivity of the antenna is the ratio of radiation density in the direction of maximum radiation. Please note it is direction of maximum radiation.

So, for example, what is the radiation density in this? Divided by if it had radiated in the sphere, so that is how we define directivity and that is given by maximum radiation divided by average radiation intensity which is for let us say isotropic antenna and this one can be because the power radiated if it is isotropic we say that power radiated divided by 4 pi r square will be the power radiated in the spherical fashion 4 pi r square is the area of the sphere.

So, we are taking r is equal to 1. So, that is what it simplifies here this 4 pi goes up here and this is the simple term which is used to find the directivity, what is this term here? This is known as a beam solid angle and this beam solid angle can be obtained from the radiation pattern and one can see that one requires to do a double integration why double integration - because we have a theta and phi. So, all these parameters let us say d phi will change from 0 to 2 pi, theta will change from 0 to pi and that is how we need to integrate and what is F? F is nothing but it can have both E theta and E phi which may vary in theta or phi direction.

So, you can naturally think that oh my god it is so complicated well in this course we will try to make things simpler for you people we will try to use some of the approximate formula to calculate the directivity with some reasonable accuracy. Now this solid angle is approximated by this expression here if we think of this as a main beam. So, this is the solid angle there. So, what is done is you approximate in the two orthogonal plane, so half power beam width here and half power beam width perpendicular to that. So, this solid angle is approximated as theta E times theta H. Now this expression do not use blindly for all the cases we will just tell you when to use this expression and when to use modified version of this expression.

For example I have just taken an example of infinitesimal dipole. So, for infinitesimal dipole the half power beam width is given by pi by 2 and from where this pi by 2 comes? Because for infinitesimal dipole we will just show here, so what we have here - the maximum variation it is coming down to 0 here. So, from 1 let us say it is coming to 0 if we assume approximately this as a sin function then we know that at sin 45 it will be 1 by square root 2. So, 45 plus 45 and minus 45 will give us 90 degree which is equal to pi by 2 and it is an Omni-directional pattern, so in the h plane the beam width is 360 degree or 2 pi.

So, if I substitute these values in this expression over here we get a number which is 1.3 whereas, we know that for infinitesimal dipole antenna directivity is equal to 1.5. So, this number predicts relatively smaller, but yet it is reasonably close to this value here and you do not have to do any of these integrations also. We will tell you some simpler way to also use this expression for larger antennas also.

So, for small antenna we can use the same expression which is 4 pi theta E theta H where theta E theta H are in radiant. But now they are converted in degree.

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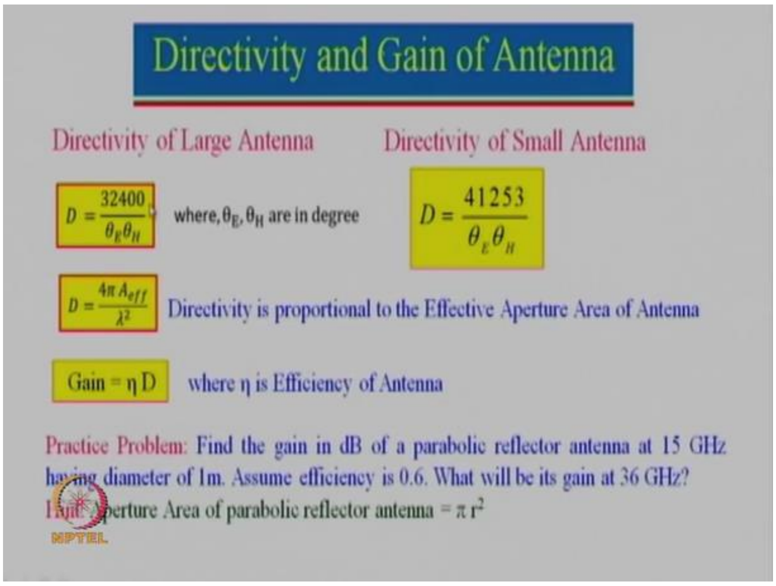

So, what you really do it is well you want to convert from radiant to this all you do it is from radiant conversion to degree is you multiply by 180 divided by pi. So, over here then we have theta E theta H are in degrees and that 4 pi after that 180 by pi accounted into becomes this particular number here. Now this is for small antenna, but for larger antenna this is not a very good number in fact, generally we use about same expression here we use about 32400 instead of 41000.

So, why we use this smaller number? The smaller number is used the reason for that is when we are talking about the solid angle we are assuming that there is a only one main lobe; however, in a given pattern there will be lot of side lobes are there. So, some power is getting radiated in these directions. So, effectively lesser power will be radiated in main beam.

So, to account for this here this is an approximate formula and if you use this formula invariably you will see that, you will get the directivity expression within plus minus 1 dB. Now directivity is also related to the aperture area as we saw in the last lecture if aperture is increased directivity will increase and again a forest frequency suppose let us say we take one frequency for that we have a certain aperture. So, for example, let us say if I take a diameter of one meter for let us say circular dish antenna. In fact, I have given an example here also we will come to that part also. So, from directivity gain is defined as efficiency multiplied by directivity. So, let us say we want to find the gain in dB of a parabolic reflector antenna at 15 gigahertz having diameter of 1 meter. So, if the diameter is 1 meter, what will be the aperture area of this thing? Well aperture area is given by pi r square; r is radius so in this case diameter is one meter. So, r will be 50 centimeter.

Now, that is A is now known what is lambda? Well lambda has to be calculated from the frequency. So, here F is 15 gigahertz lambda is equal to c by f where c is velocity of light. So, if you put that this particular number comes out to be lambda equal to 2 centimeter. So, that is what you need to put over here. So, lambda is 2 centimeter from there you can find the directivity; however, efficiency of this parabolic reflector is only 0.6, so gain will reduce correspondingly. I just want to mention here for a reflector antenna typically a maximum efficiency which can be obtained is about 0.8, a poorly designed reflector antenna or purely manufacture reflector antenna may give an efficiency of roughly 0.6.

Now, I have just given an additional part here the dish antenna diameter remains same what will be the gain at 36 gigahertz. So, 36 gigahertz the only thing which will changes lambda here. So, you can use that to find out what is the directivity and gain of a reflector antenna. Instead of reflector antenna I can give any other different problem also it can be an array let us say a square array or let us say or rectangular array. So, of course, if the rectangular array has a dimension of instead of diameter let us say the rectangular array has a dimension of 0.5 meter by 1 meter then all you need to do it is effective aperture will become l multiplied by w and you can do the calculation in the same fashion.

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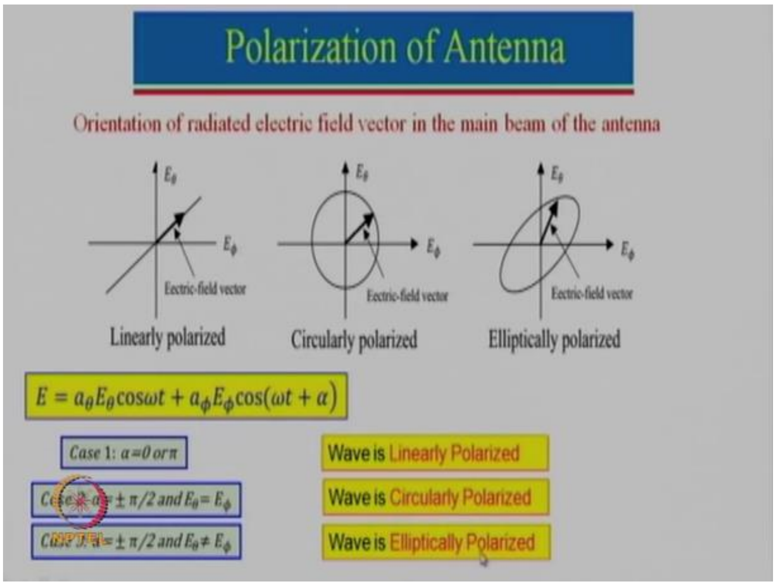

So, polarization of the antenna we saw in the very introductory lecture there are different types of polarization. So, here are more details of the polarization. So, we have three main types linearly polarized, circularly polarized, elliptically polarized. In fact, elliptical polarization is the most general form. So, just think about if the major axis is equal to minor axis then actually this will become circular polarization and if the minor axis goes towards 0 then this will reduce to the straight line. So, that becomes linearly polarized. So, let us say that for the polarization to be defined let us say any E component has theta component and phi component. So, E theta caused this and then there is a phase difference between them.

Now, I will first talk about circular polarization. So, if E theta is equal to E phi and if the phase difference between the 2 over here alpha is 90 degree. So, then we can say that the magnitude of this or the vector rotation will be nothing but it will be in the circular fashion and hence it is circularly polarized. So, here also it all depends upon whether it is rotating in this fashion or whether it is rotating in the other fashion. So, it is known as left hand circular polarization or right hand circular polarization. So, if this case is not too met then it can be linear or elliptical. So, in linear you can say that if alpha is 0 or pi it will be linearly polarized in for all other cases it will be elliptically polarized.

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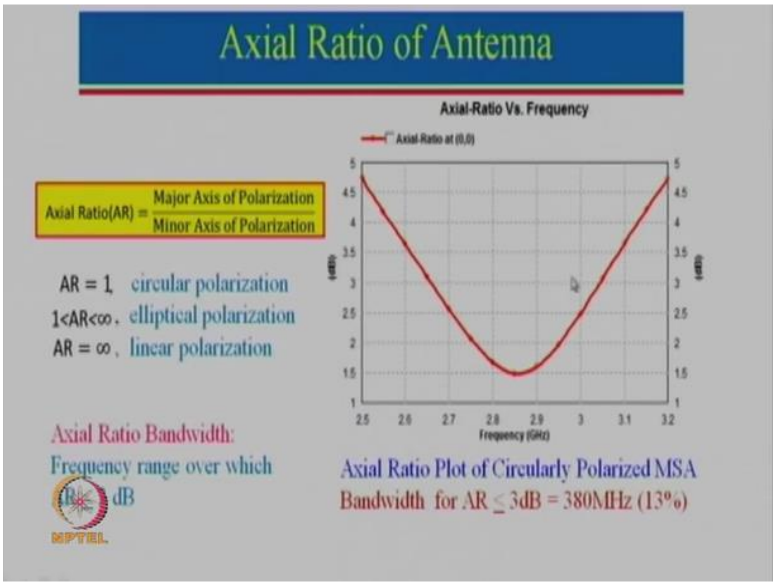

Now as I mentioned elliptical polarization is a general case. So, let us see how do we define axial ratio of antenna. So, generally speaking we want circular polarization for example, then for circular polarization axial ratio should be 1, what is actual ratio? It is nothing but ratio of major axis divided by minor axis. So, for circle major axis is equal to minus so axial ratio will be 1. For linear polarization minor axis will have a 0, so 1 divided by 0 will be infinity; anything in between will lead us to elliptical polarization, but yet we define circular polarization approximate circular polarization you can say that if the axial ratio this is the plot of axial ratio versus frequency.

So, you can see that this is axial ratio 1 2 3. So, if you draw a line over here. So, we can say that from this frequency up to this frequency axial ratio is less than 3 dB. So, generally speaking we define axial ratio bandwidth for circularly polarized antenna as frequency range over which axial ratio is less than 3 dB of course, in some application they may accept less than 6 dB also and in some application they even want axial ratio to be less than 1 dB or 2 dB also. So, it all depends upon application to application.

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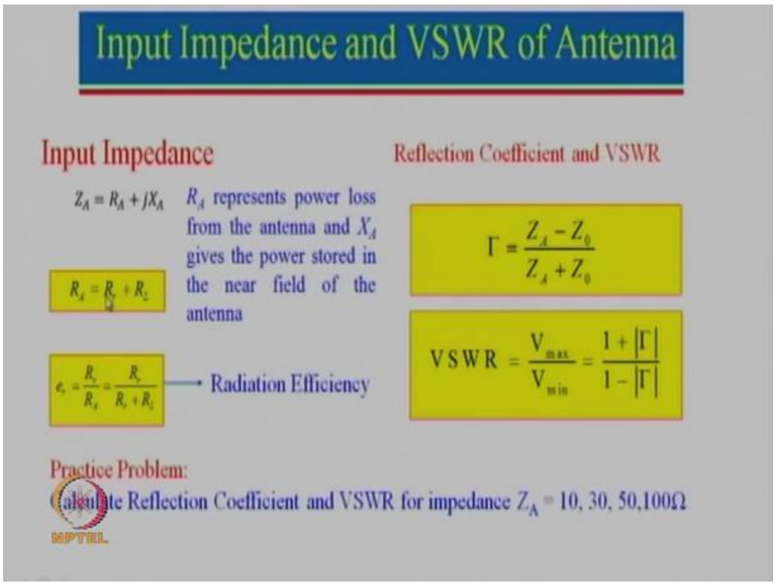

Now, let us look at the general input impedance and VSWR of the antenna. So, input impedance of an antenna can be a complex quantity which has a real component and imaginary component. The real component may actually consist of the radiation resistance plus the losses associated with the antenna. Now this radiation resistance is also kind of interesting thing in a sense it does not exist it is only a mathematical model. So, what is actually done? That power radiated from the antenna is considered as power loss from circuit point of view. So, power radiated from the antenna can be approximately written as let say i square R or v square by R. So, whatever is the power radiated divided by the current or voltage that will give us the value of radiation resistance, this is not really a real resistance which you think.

So, when we talk about a 50 ohm impedance of an antenna it is not that the resistor is 50 ohm; it is just a representation of radiated power in terms of either voltage or current. So, we define efficiency as the radiation resistance divided by the total resistance. So, what are the losses? So, losses in the antenna can be dielectric losses or conductor losses. So, that is what gives rise to the radiation efficiency then there is a next thing which is a reflection coefficient and VSWR. So, reflection coefficient as we saw is defined by this particular term here. So, if let us say Z 0 is 50 ohm I just want to tell you that majority of the countries in the world they have made a standard for microwave radiation and they actually use impedance as 50 ohm. So, we will try to keep this 50 ohm in this particular course here, but remember it can be different value, but if it is not specified assume 50 ohm.

So, now if antenna impedance is 50 ohm 50 minus 50 will be 0 we will get reflection coefficient as 0 and if reflection coefficient is 0 power reflected will be 0 and we define VSWR in terms of the reflection coefficient. So, this is just a practice problem for you people. So, calculate reflection coefficient for I have given an example of let us say only real impedance whereas, Z A can be complex in the next slide we will see what happens if these are complex, but just to quickly tell you over here let us say we want to do some quick calculation. So, if you put 100 ohm over here for this particular case. So, 100 minus 50 will be 50; 100 plus 50 will be 150. So, this will be 50 divided by 150 will be 1 by 3 and if gamma is equal to 1 by 3 we substitute the value that gives rise to VSWR equal to 2. So, please calculate for other cases.

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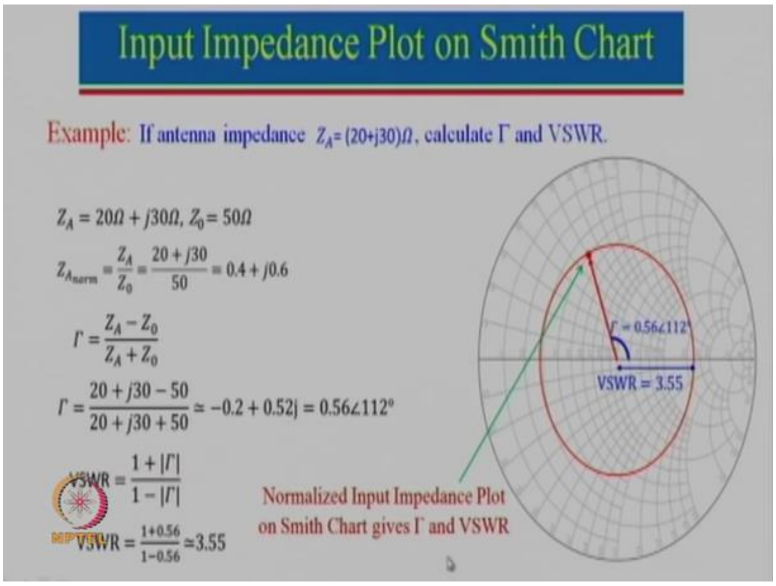

Now, let us see what happens if the antenna impedance is a complex number. So, here we have just taken an example of 20 plus j 30, now there are two ways to solve this problem where we want to find out the reflection coefficient and VSWR. So, one way is that we substitute in this particular expression gamma Z A minus Z 0. So, Z A is 20 plus j 30 we put here we do the calculation simplify it. So, this is the value which comes out to be reflection coefficient 0.56 angle this; and for VSWR - we only need the magnitude we do not need the phase. So, we put the value over here we get VSWR equal to 3.55. So, that is VSWR corresponding to the complex impedance.

Now, this is the one way to do it. The other way is to plot this input impedance on Smith Chart. So, this is a Smith Chart here just to quickly tell you what is this Smith Chart - the Smith Chart is a plot of input impedance or can be used for input admittance, but we will keep it now for input impedance. So, what this plot is you can see here there is a this central line here this is actually a real access line. So, impedance here is 0 and it goes to infinity and generally Smith Chart is used for normalized impedance. So, whatever is the characteristic impedance let us say in this case it is 50 ohm. So, we normalize the value with respect to 50 ohms. So, you can see that Z normalized is given by this here. So, what we need to do it is we need to locate this normalized value on the Smith Chart. So, what we have here this is a real axis. So, on the real axis if you see the Smith Chart it shows here 0 then 0.1, 0.2, 0.4 at the center it will show exactly 1 and then it will show 2, 5, 10, 20 and so on. So, on the real axis you locate the real value 0.4 which is this particular point over here.

Now, then you will see there are so many other circles are there. So, there are circles like this. So, these are known as constant resistance circle, what this really means is that suppose I have chosen this 0.4 along this entire this path here it will be 0.4 and if you just see here on this entire path the real impedance will remain fixed then we have all these curves over here like this. These are truncated circles and over here also these are truncated circle now this upper part is positive and the lower part is negative imaginary part. So, for impedance if you are plotting impedance all the positive values will correspond to the inductive impedance all the negative values will correspond to capacitive impedance.

So, over here now what we have that these are known as the constant reactance circle. So, for this entire this point curve here the reactance value will remain fixed, but as you move from here to here to here only the resistive value will change. So, our next part is to locate this impedance. So, 0.4 we located over here and then you move along the since it is plus we need to move up. So, we move up up up you stop at a point these are written here 0.1, 0.2 and, so you stop at this point. So, this is the point which is the normalized impedance plot, now all you do after that take this the central point draw this circle and wherever this circle cuts this point now that is actually known as a VSWR. So, at this point here just read whatever is the value that value will give us 3.55.

Now, there is a another thing now you can also calculate the reflection coefficient also there are two ways to do the calculation one is that actually below the Smith Chart normally there is another horizontal line shown over here and you can actually see if you just go down here this will show reflection coefficient as 0 and corresponding to this it will show reflection coefficient as 1 and this is scaled from 0 to 1. So, if you just draw this line here which is actually reflection coefficient 0 you draw just this line down here and you can read directly the value and that will be 0.56. So, this is the one way other way is you measure this dimension and you measure this dimension using a scale take the ratio and that will be 0.56 and you can measure the angle using a d which is there in the normally in the compass box, you measure that angle that will give. So, this is Smith Chart is nothing but graphical way of the representation of the Smith Chart and you can calculate using this calculation.

But I strongly encourage you people to practice Smith Chart and just take some any other random number and do some practice for example, let us say instead of 20 plus j 30 you can take as let us say 10 minus j 100. So, 10 normalized will be 0.2 that will be somewhere here and this is if minus j 100 will be normalized will be minus 2. So, 0.2 you go over here somewhere j 2. So, that will be the point and then you can draw a circle and note down what is the VSWR correspondingly you can do the calculation to verify your results.

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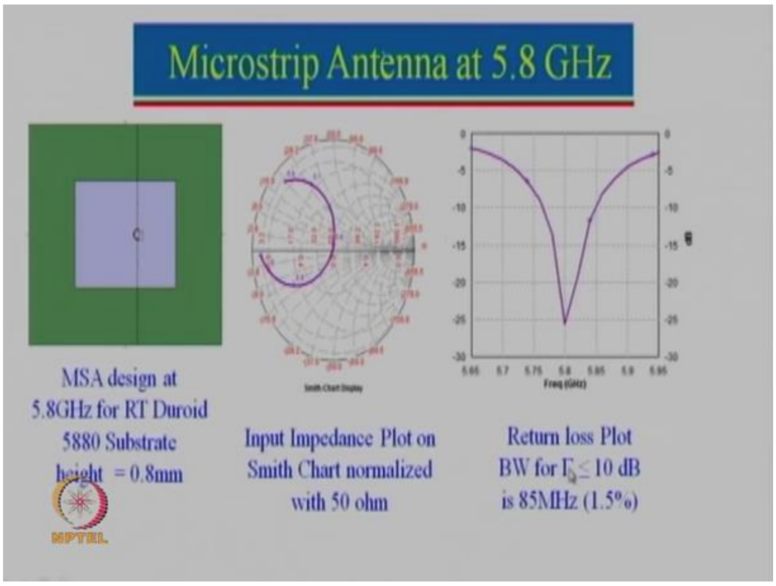

So, here is just an example I did mention to you about microstrip antenna, just to show you. So, we had designed a microstrip at 5.8 gigahertz and we chose the feed point carefully so that we can get the impedance match. So, here is the Smith Chart for this particular antenna if you see that this Smith Chart is passing through the central point where impedance is exactly equal to 50 ohms. So, there is an impedance match this is the reflection coefficient plot, which is a gamma plot here. So, just as an example I can say that impedance plot which is normalized with respect to 50 ohm and you can see there is a good matching and over here return loss plot is there. Now generally what we do we define bandwidth generally either for gamma less than 10 dB or VSWR less than 2 just to tell you VSWR less than 2 corresponds to gamma equal to 9.5 dB.

So, this bandwidth here is about 85 mega hertz you can see from here to here and this is at 5.8. So, you can take the ratio and that will give us a bandwidth you can see this bandwidth is relatively small. So, we will see the techniques later on how to increase the bandwidth of the antenna.

So, just to summarize we looked into certain characteristics of the antennas. So, we looked into 3-D pattern, then we looked into 2-D pattern, we looked into half power beam width personnel beam width side lobe levels and so on. We also looked at how to calculate the directivity of the antenna, what is solid angle, what are theta E, theta H which are two orthogonal component and how ban directivity has to be modified for larger array and then we saw how to calculate the reflection coefficient and VSWR. We quickly look into what is Smith Chart, how to plot impedance on the Smith Chart and how to calculate reflection coefficient and VSWR.

And I strongly encourage that please practice using Smith Chart and take some different examples to do that and then we just showed you one example of microstrip antenna how impedance matching can be done of course, detailed of microstrip antenna will be covered much later in this particular course, but we just saw that how impedance can be achieved and how we can find out the bandwidth of the antenna from reflection coefficient plot or it can be obtained from VSWR plot.

So, thank you very much and in the next lecture we will see some more antenna characteristic, we will see how to find out that Friis transmission equation, the derivation and we will take some more practical examples.

Thank you, bye.