Microwave Theory and Techniques
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Module - 10
Lecture - 46
Fundamentals of Antennas

Hello. In the last 45 lectures, we have talked about various microwave components and circuits. Today and in the next few lectures, we will talk about antenna fundamentals and several other antennas. So, let us start with the Fundamentals of the Antennas.

So, first of all we actually look at the radiation pattern of the antenna. So, antenna radiation pattern is defined in three-dimensional.

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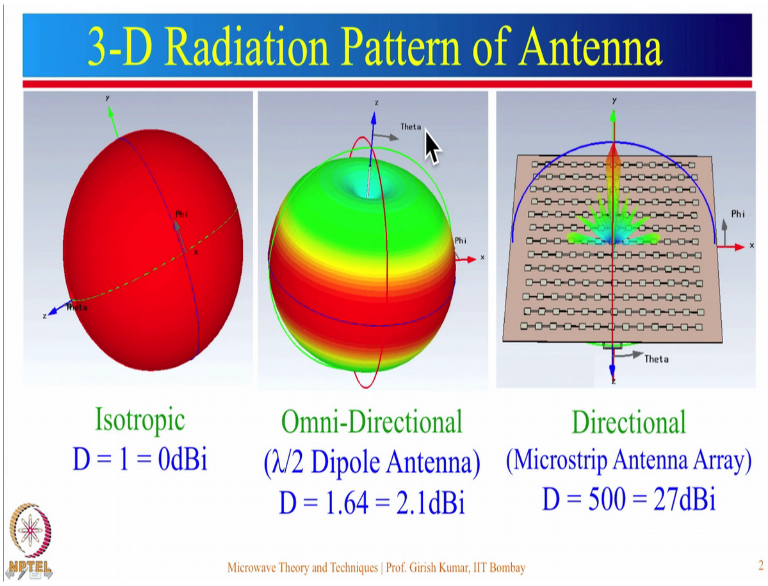

3-D radiation pattern of the different antennas are shown over here. So, this is the radiation pattern for isotropic antenna. Basically, an isotropic antenna will radiate equally in the sphere ok. So, it will radiate equally in all the directions. However, I want to tell you there is a no isotropic antenna in the real world. So, this is basically speaking a reference antenna for the other antennas. So, for this reference antenna we say directivity is equal to 1, which corresponds to 0 dBi. This is the radiation pattern of omni-directional antenna. Majority of the time we say lambda by 2-Dipole antenna or any small dipole antenna will have a omni-directional radiation pattern. In fact, there are many other antennas which also have omni-directional radiation pattern, for example, loop antenna, monopole antenna, slot antenna.

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So, to understand in a very simple manner, so just think about this particular pen. So, if I see this pen from this side or from this side or from this side, we will see the full length of the pen, but as we move from here and we move to the top of this particular thing here, and if you look from here, we basically see a tip of the pen. In fact you can understand the radiation pattern of dipole antenna in this simpler manner.

So, what is the radiation pattern of the dipole antenna? Well, it is 0 in this direction, and it is maximum in this direction, and then it is going back to 0 here. So, here color red implies maximum radiation. And as we move along color green here implies lower radiation, and minimum radiation is present in this particular direction. So, this is what is omni-directional about. So, it is omni in this particular direction; and it is directional in this particular direction that is how the name omni-directional antenna comes into picture.

You can also understand this in another simpler manner. Let us say if we have a current carrying conductor then how will be the magnetic field; magnetic field will be uniform in this particular direction. So that is what we have we have a current carrying dipole antenna and we have a uniform field in this particular direction.

The third type of the antenna which is known as directional antenna. Here I have given an example of a microstrip antenna array. You can see that there are several elements of microstrip antennas are there in this direction as well as in this particular direction. So, this is a planar microstrip antenna array. The reason why I am showing you this, this particular antenna has a directivity of 500 which is about 27 dBi. How do we get this? You take 10 log 500 which is 27 dBi. Compare this directivity with the directivity of omni-directional dipole antenna which is only 1.64 corresponding to 2.1 dBi. So, you can see that by using arrays of the elements, we can increase the gain significantly.

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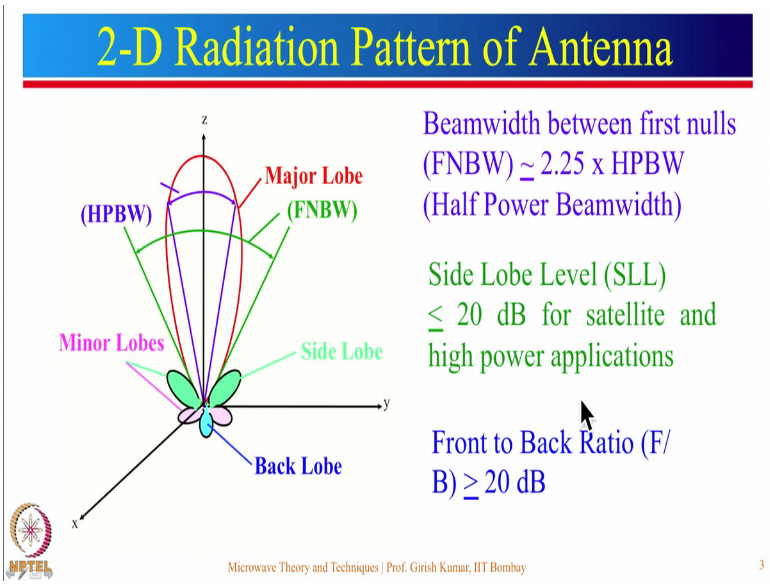

So, let us look at 2-D cut of the antenna. So, here is a typical directional antenna. So, let us define various terms over here. So, this is a major lobe and these are all the minor lobes are there. Minor lobes are classified again in two parts; and that is side lobes and then back lobe. So, back lobe is in the back side of the main beam, and side lobes are along the side of the main beam. So, we define certain quantities over here. So, one of the quantity which we define is half power beam width. So, half power beamwidth is defined where beam maxima reduces to half of its value. So, this angle here is half power beamwidth. And then if you see this pattern goes through the null, and then there is a side lobe. So, beamwidth between the first null is defined as FNBW.

Now, generally speaking beamwidth between first null which is FNBW is approximately equal to 2.25 multiplied by half power beamwidth. However, if you read different books, they actually say this is approximately two times, but I have checked for different antennas I have found this number gives better result for FNBW. Then these side lobes generally should be less than 20 dB for satellite and high power application. I just want to mention here, these are actually negative value. So, do not get confused actually speaking side lobe levels are minus 20 dB below the main beam ok, but generally speaking we still write as side lobe level less than 20 dB.

So, what 20 dB less implies it implies 1 by 100. So, just think about a high power application if we are transmitting let us say 1 kilowatt of power 1 by 100th of that will be 10 watt power going in the undesired direction. For some of the defense application power transmitted maybe 1 megawatt pulse power. So, in that particular case, 1 by 100th will be 10 kilowatt of pulse power going in this particular direction and that may create lot of harm to the people or to the equipment in that particular region.

Hence, for high power we definitely want side lobe level should be much less than minus 20 dB. Similarly, for satellite application also we would like side lobe levels to be low, because if we are looking at this particular satellite, and if the side lobe is high, then it may pick up the signal from the other satellite also. Generally speaking we want front to back ratio also known as F by B to be greater than 20 dB. So, this is the front this is the back. So, the ratio of the two should be generally greater than 20 dB.

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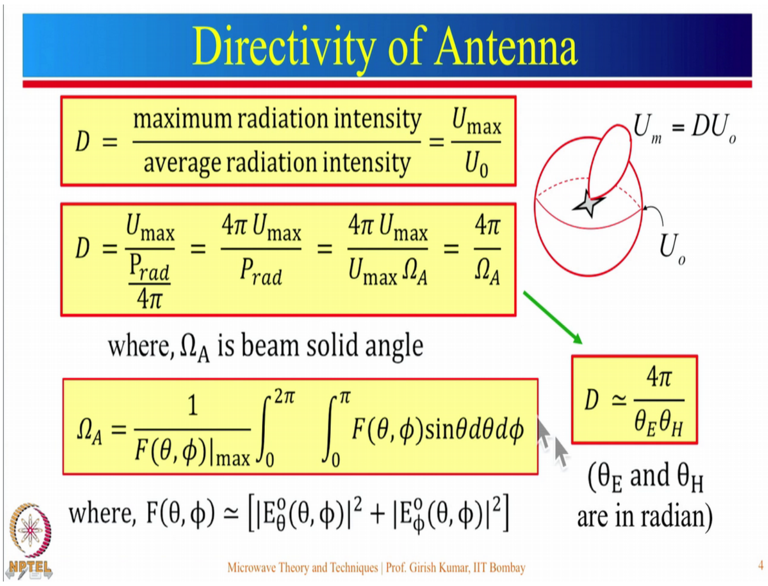

Now, how do we define directivity of the antenna? Well, directivity of the antenna is defined as maximum radiation intensity divided by average radiation intensity. So, just think about this is the spherical pattern for which we have mentioned directivity is equal to 1, and this is the lets say pattern for a given antenna. So, directivity is defined as maximum value in this particular direction divided by the average value which is U 0, so that is how we define U max divided by U 0. So, now, U 0 can be represented in terms of p radiated divided by 4 pi. Why this expression because if we assume that power is radiated equally in all the direction. So, we know that the area of the sphere is equal to 4 pi r square.

So, if we take r as 1, then we can say average radiation intensity will be p radiated divided by 4 pi. So, this directivity expression is simplified to 4 pi divided by this is known as capital omega A. So, capital omega A is beam solid angle. And this particular thing can be approximated as product of theta E theta H. What is theta E, theta E is the half power beamwidth in the E-plane; and theta h is half power beamwidth in the H-plane. Generally speaking this e and H-planes are perpendicular to each other.

So, suppose if we talk about this is E-plane, then this will be H-plane now of course there is a longer expression for this particular term over here. So, this particular expression is used when we calculate E theta and E phi we will show you in the next lecture how to calculate these E theta and E phi for a given antenna. But, right now we will use this particular expression over here. So, you can see that this is relatively simpler expression. So, let us see now how this particular expression can be used further.

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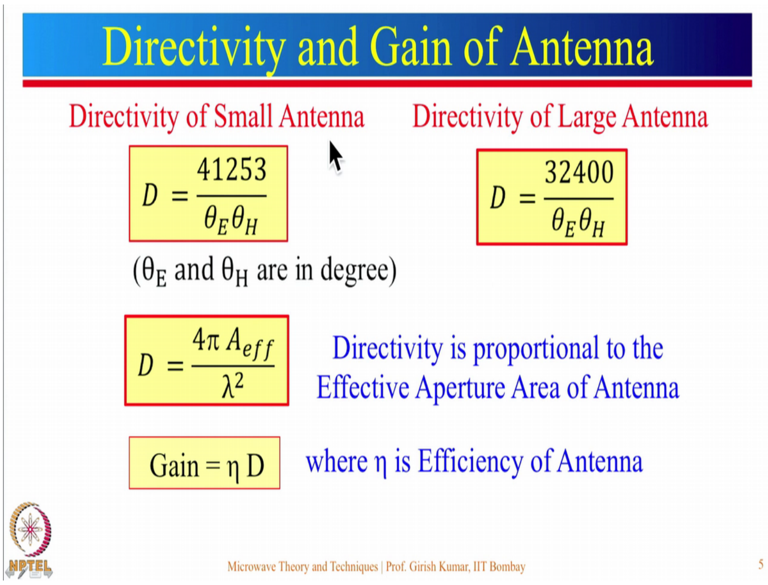

So, directivity of small antenna is given by this particular thing over here. Now, you might wonder earlier we had theta E and theta H in radian here theta E and theta H are in degree. So, what do we do we simply convert pi radian equal to 180 degree. So, of you just do the conversion, you will get this particular number. Now, this particular expression is good generally for small antenna; but for larger antenna directivity is given by this particular expression here. You can see that this number is slightly smaller than this particular number here. The reason for that is for large antenna, there will be many side lobes. So, lot of power will be going to the side lobes and hence directivity decreases. Hence, we use this particular expression for directivity.

Directivity is also defined in terms of 4 pi A divided by lambda square, where this is effective area of the antenna. So, larger the antenna, larger will be the directivity. You can also see that it also depends upon lambda; lambda is given by c by f. So that means, higher the frequency smaller will be lambda, so that means, for smaller value of lambda directivity will increase.

So, remember it is not the physical dimension which is important. It is actually the normalized value which is important. For example, if we have a rectangular aperture, then area effective will be something like L multiplied W. So, now, you can think about L by lambda and W by lambda; or if we have a circular aperture then area will be pi r square. So, again we can write as r by lambda and r by lambda. We also define another quantity which is gain gain is given by efficiency multiplied by directivity. So, we will see some of these things as we move forward.

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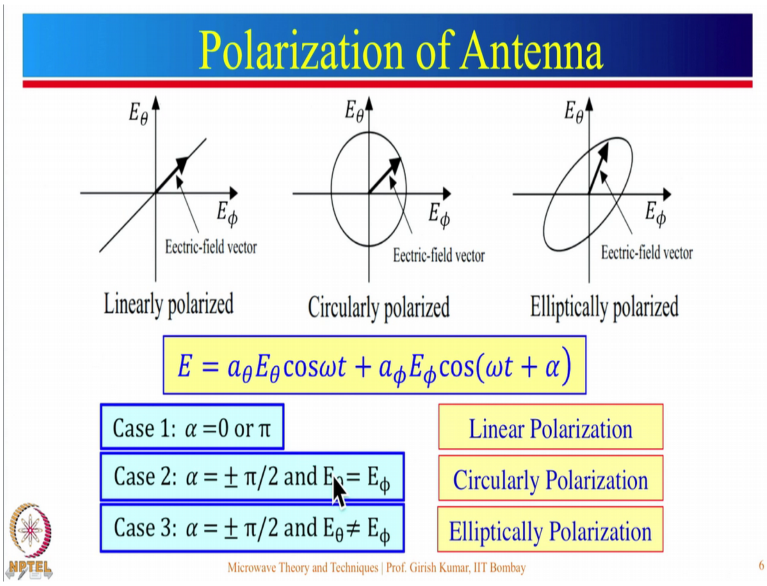

The next thing which we are going to define is polarization of antenna. So, there are three different types of polarization, linear polarization, circular polarization, elliptical polarization. So, how do we get these polarizations? So, one has to see a total electric field may have E theta component and E phi component. So, this is E theta component, this is E phi component. And between the two components, there may be a phase change which is given by alpha.

Now, we will take three special cases. If alpha is equal to 0 or pi, then what will happen this expression will become cos omega t, so that means, this one here and this one they are kind of varying or you can say these are in the same phase. So, you can see there this is E theta, this is E phi. So, as E theta increases, E phi increases. So, hence there is a linear polarization. In case when alpha is plus minus pi by 2, and E theta is equal to E phi, then what will happen this is E theta and this term will be equal to this term over here and then we can say omega t. Now, is plus minus pi by 2. So, this expression will become sin omega t. So, this is cos omega t; this is sin omega t. And if you plot that we will get circular polarization; if E theta is not equal to E phi, in that particular case we will get elliptical polarization.

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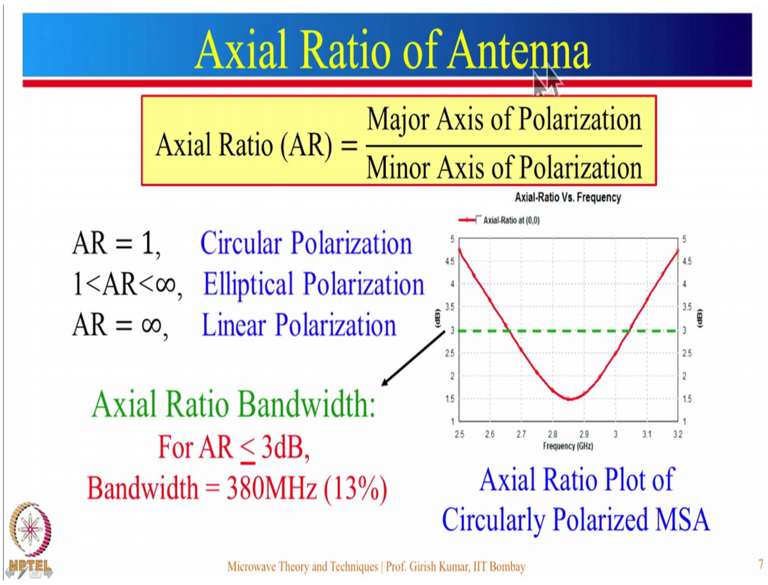

So, from here we define axial ratio of the antenna. So, axial ratio is defined as major axis divided by minor axis. So, if axial ratio is equal to 1, then it is circular polarization. If axial ratio is between 1 and infinity, then it is elliptical polarization. And if axial ratio is infinity that will be linear polarization; you can actually think about that for linear polarization if this is the major axis; what is minor axis that is equal to 0. So, major axis can have any finite value, but minor axis is equal to 0, so that will give us axial ratio equal to infinity.

This is the typical axial ratio plot of circularly polarized microstrip antenna. When I talk about microstrip antenna, we will give you little bit more details, but over here you can say that this is axial ratio versus frequency. I have drawn a line at 3 dB. So, generally speaking axial ratio bandwidth is defined for axial ratio less than 3 dB. And in this particular case we can say that bandwidth is equal to 380 megahertz which is 13 percent. So, I just want to tell you perfect circular polarization is defined for AR equal to 1. However, up to AR less than 3 dB it is acceptable as circular polarization.

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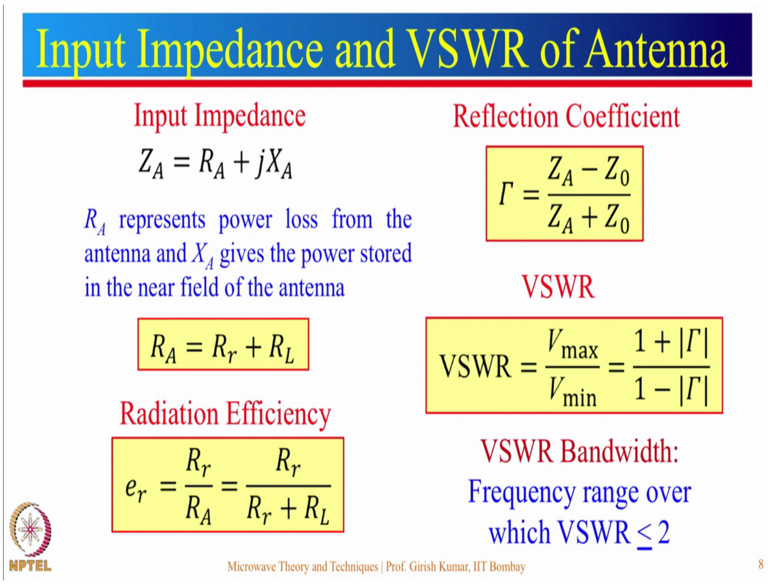

Let us now look quickly at input impedance and VSWR of antenna these things have been covered earlier also. So, let just go through it quickly. So, input impedance can be R A plus j X A where R A represents power loss from the antenna and X A gives power stored in the near field of antenna.

Now, R A can be divided into two terms; one is R r; second one is R L. R r is the useful resistance which represents radiated power from the antenna; R L represents losses in the antenna this can be conductor losses or dielectric losses. So, we define radiation efficiency as R r divided by R A which is nothing but equal to R r divided by R r plus R L. It is better that we design R L to be as small as possible or we can say other way that R r must be much greater than R l, so that we can get high efficiency.

Now, reflection coefficient is given by this particular expression, and VSWR is given by this expression. Now, majority of the time for antennas, we define VSWR bandwidth for VSWR less than or equal to 2. However, for some stringent application, this could be less than 1.4 or 1.5 ok. So, depending upon the application, we have to design the antenna accordingly.

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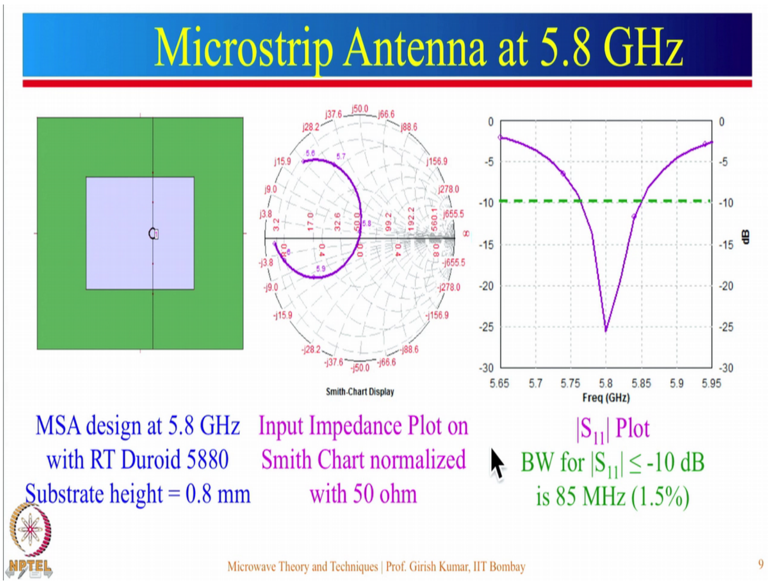

So, let us take an example of a microstrip antenna which we had designed at 5.8 gigahertz. So, when we talk about microstrip antenna later on I will talk about this antenna in more detail, but today I just want to tell you what are the VSWR bandwidth and radiation pattern for a given antenna. So, this antenna was designed at 5.8 gigahertz. So, just to tell you quickly, so what we have here this is a ground plane and this is on top the ground plane or rectangular patch.

So, just thing about a ground plane here and a patch on top of that we have already talked several microwave circuits, so it is very similar to that. And this one here is the feed point. So, we have used a co-axial feed to feed the antenna such a way that at the desired frequency input impedance should be around 50 ohm. So, this is the plot on the Smith chart as frequency changes impedance changes. This is the reflection coefficient plot. And you can see that as frequency changes reflection coefficient is varying. And in this particular case, we define bandwidth for S 11 less than or equal to minus 10 dB, it is approximately equivalent to VSWR less than 2.

So, bandwidth in this case is about 85 megahertz which is 1.5 percent, in fact, microstrip antennas are known to have smaller bandwidth. However, later on I will talk about several broadband techniques, where we can increase the bandwidth of the microstrip antenna.

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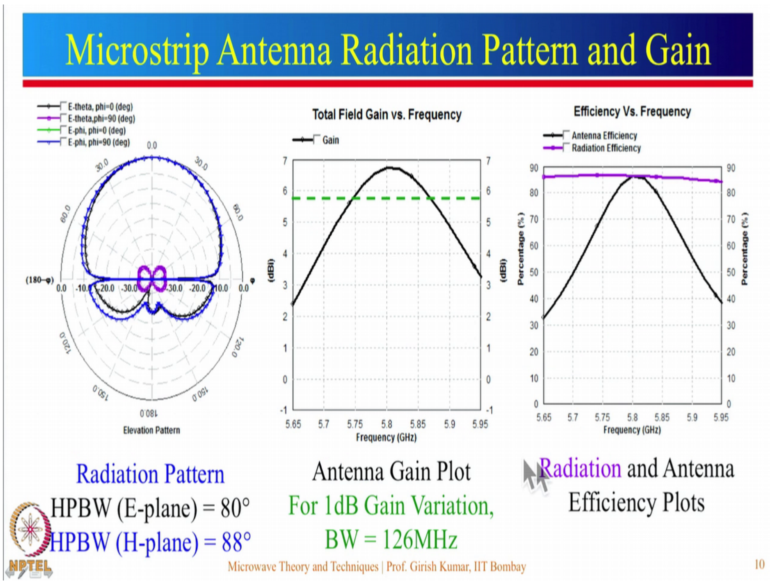

So, these are the radiation pattern gain and efficiency of this particular antenna. So, you can see that the radiation is in the broadside direction. And the back radiation is relatively small. And for this particular antenna, we can actually calculate half power beamwidth in the E-plane which is shown with the black color that is 80 degree, half power beamwidth in the H-plane is 88 degree. And this is the gain plot with respect to frequency and I have drawn a line which is about 1 dB below this; generally 1 dB gain variation is acceptable.

So, in this particular case we can say bandwidth is about 126 megahertz. Now, one can see here radiation efficiency shown by purple color so that is; what is the radiation efficiency. So, radiation efficiency you can see is very high that is about 85 percent or so. Now, this is the total antenna efficiency. Now, this antenna efficiency is changing, it is very similar to the change in the reflection coefficient.

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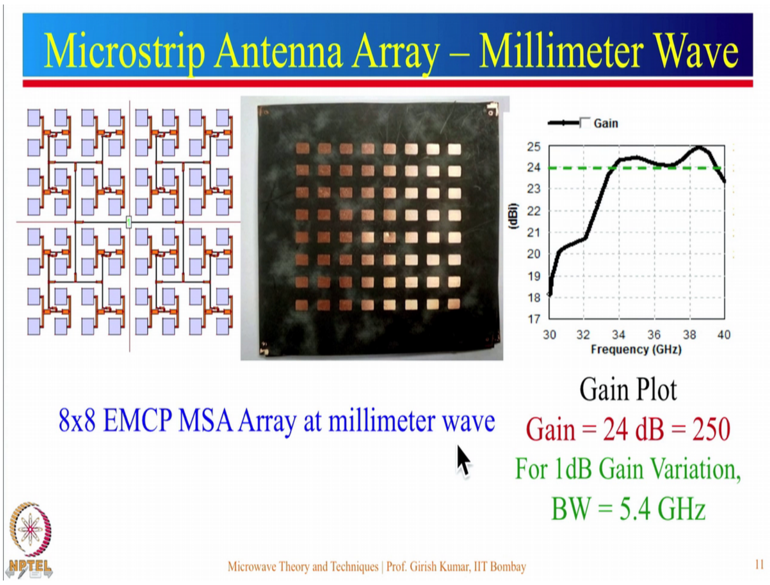

Now, let us see how we can increase the gain of the antenna. We can increase the gain of the antenna by using large number of elements. So, here is an example of 8 by 8 electromagnetically coupled microstrip antenna array. I just want to tell you what is electromagnetically coupled. So, basically here there is a one patch we put another patch on top of that. So, these two patches resonate at nearby frequency and this whole thing is done to increase the bandwidth of the antenna.

As I mentioned in the previous slide the bandwidth was very narrow, but by using electromagnetically coupled antennas we can get bandwidth of 15 percent or even 20 percent. So, for this 8 by 8 array I just want to show you. So, this is where the feed in network is there. So, recall we had discussed about power divider. So, you can think about this is nothing but a two-way power divider another two way power divider and then there is a connection here. So, if you look from here this becomes like a four way power divider and this is the central point. So, we can see that from this central point all these power divider networks are spreading and feeding all the 8 by 8 elements which comes out to be 64 element.

So, really speaking this is an example of 1 is to 64 power divider. So, this is the top layer of the fabricated antenna. And I have just shown here gain plot. You can see that the gain has increased significantly compared to the gain of a single element. Here the gain is around 24 dB; numeric value of that is 250. And again, for 1 dB gain variation if you look at the bandwidth that is huge bandwidth which is equivalent to 5.4 gigahertz, but at millimeter wave frequency I just want to mention that 5 G communication may take place in the millimeter wave pan. So, this kind of a array would be extremely useful for 5 G and IOT applications.

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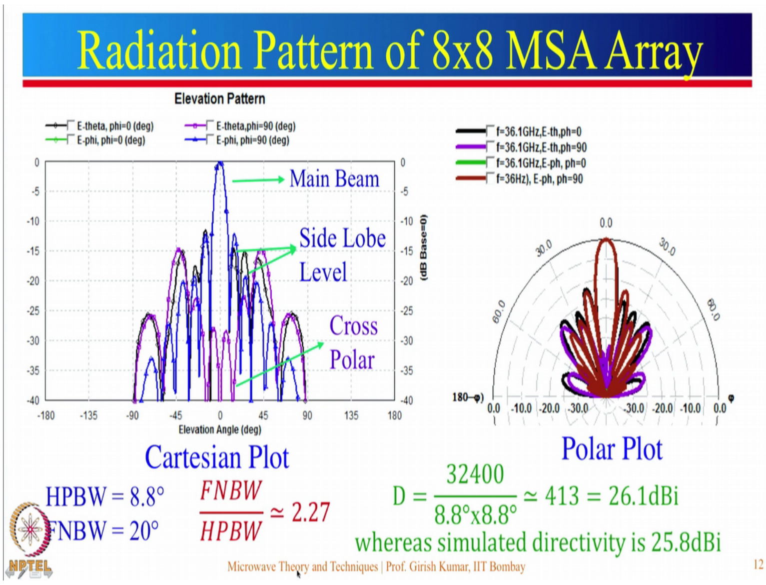

Here I have shown radiation pattern of 8 by 8 MSA array. So, this is the Cartesian plot this is polar plot. So, this is you can see here there is a main beam is in this direction, these are the side lobe levels. Let us see the Cartesian plot.

So, in Cartesian plot, we basically show the angle along the x-axis and this one here is the normalized value of the gain. So, we can see that here everything is normalized to 0 dB ok. So, from 0 dB you can see there is a variation over here. So, this is main lobe, these are the side lobes and this one here is the cross polar component. Generally speaking we would prefer cross polar component to be as small as possible. And you can see that along the main beam direction, cross polar level is very very small.

So, let us see what are the half power beamwidths in the two plane for this 8 by 8 array since this is a symmetrical 8 by 8 array half power beamwidth in E-plane and H-plane is equal to 8.8 degree. In this case first null beamwidth is equal to 20 degree. So, if we take the ratio of the two that comes out to be 2.27.

Now, we can use the directivity expression to find out the directivity. So, see this particular expression I have used 32,400 value which is valid for larger array. You can see that 8 by 8 array is relatively a larger array. So, half power beamwidth in e and H-plane is 8.8 degree. So, we substitute that value. And this comes out to be 26.1 dBi, whereas stimulated directivity is 25.8 dBi. So, you can see that this very simple calculation predicts the value of the directivity within a very small fraction of error.

Now, in the next lecture, I will talk about various antennas. We will start with dipole antenna I did mention what is a dipole antenna today. So, you can think about a dipole antenna like this. And we had also talked about the radiation pattern of the dipole antenna; it is omni in this particular direction; and it is varying like a figure of 8 in this particular direction. So, this is known as E-plane radiation pattern; this is known as H-plane radiation pattern. Monopole antenna is half of the dipole antenna. So, whatever things are applicable to dipole, they can be modified to monopole antenna.

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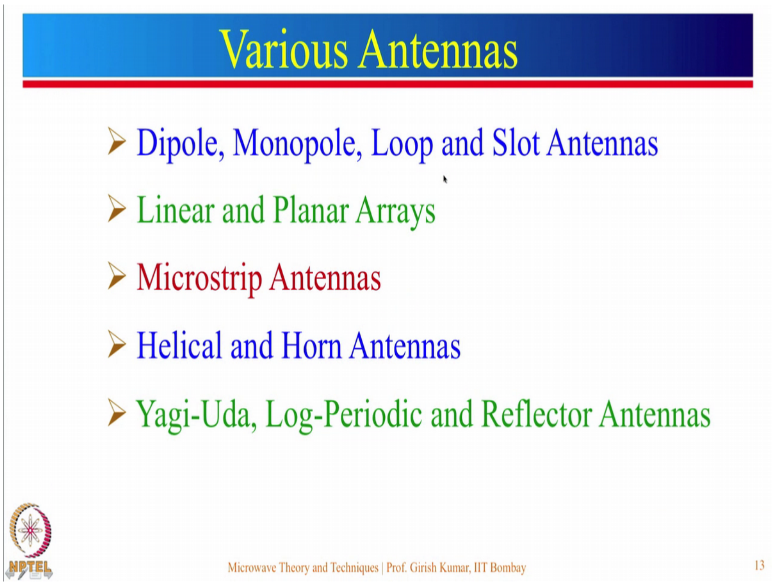

We will see that loop antenna. We will see that small loop antenna is equivalent to magnetic dipole antenna. So, whatever is applicable for dipole antenna, all you have to do it is make E-plane as H-plane and H-plane as E-plane. Slot antenna is complementary antenna of dipole antenna. So, again whatever is E-plane, it will become H-plane; and H-plane will become E-plane. Then we will talk about linear and planar arrays. So, basically linear array is antennas arranged in the linear fashion, planar arrays will be antennas arranged in the plane. So, there may be different elements. Now, planar array can be a rectangular array, it can be triangular array, it can be circular array. So, basically we use arrays to increase the gain of the antenna. I did show you an example of a microstrip antenna today. We will talk in detail about these microstrip antennas latter on.

Then we will talk about helical and horn antennas. So, helical antenna is nothing but you take a wire and the wrap it around and that makes that forms the shape of helix, so that is that is what is a helical antenna. A horn antenna can be a pyramidal horn antenna or conical horn antenna. So, typically there are different types of horn antennas that could be in rectangular shape or it can be in the shape of circular. So, generally speaking in the rectangular shape, we will talk about H-plane sectoral horn antenna, we will talk about E-plane sectoral horn antenna, and pyramidal horn antenna. In case of circular, we will talk about conical horn antenna

Then we will talk about three different types of antenna here Yagi-Uda antenna is known by the name of the inventors. So, Yagi-Uda antenna is generally used to increase the gain of a dipole antenna log periodic antennas are generally used to realize very broadband antenna we can even design antennas with the bandwidth the ratio of 1 is to 10 or even more; so that means, 1 log periodic antenna can cover a bandwidth of 3 to 30 gigahertz or 1 to 10 gigahertz or 300 megahertz to 3 gigahertz.

Then we will talk about reflector antennas. In reflector antennas we will first talk about corner reflector antenna. And then we will talk about parabolic reflector antenna. In fact, reflector antennas can give much larger gain then any of these antennas. In fact, reflector antennas can give gain of 40 db, 50 dB, 60 dB, and even up to 70 dB. Just think about 60 dB gain corresponds to 1 million ok. So, you can realize an antenna with the gain of 1 million by using reflector antennas.

So, these various antennas we will start discussing one by one starting from next lecture.

Thank you very much.