Analysis and Design Principles of Microwave Antennas
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Lecture – 07
Idea of Efficiency, Beamwidth, Polarisation and Bandwidth

In the last class we have seen directivity and gain of an antenna. Now if we again recapitulate that both directivity function and gain function they characterize an antennas directional behaviour. That means, in various directions in space how much power it radiates, but there is a certain difference between them that that in the last lecture we did not bring out.

So, today we will start with that; that if we look at the numerator of both directivity function and gain function they are same that is at that specific angle what is the radiation intensity, but their denominators are different that in case of directivity the denominator is power radiated by isotropic antenna and in case of gain the it is power input to an isotropic antenna. So, to remember that basically one diagram becomes helpful.

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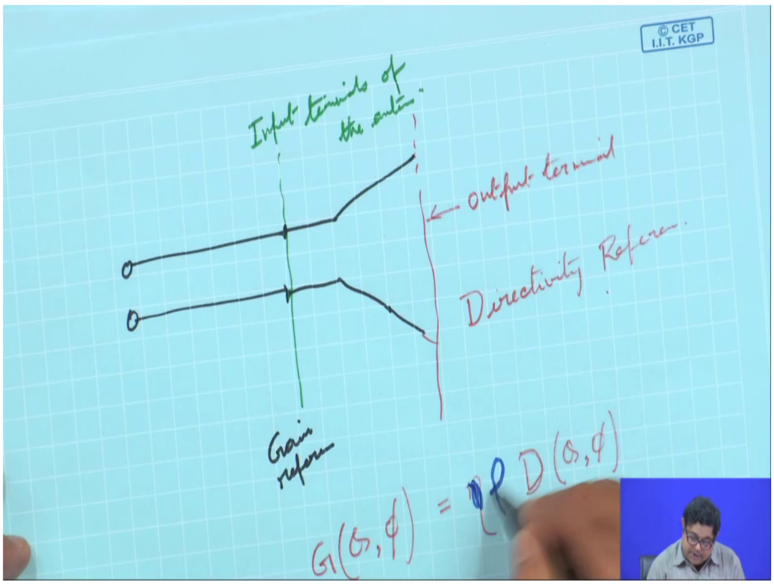

That is suppose I have a radiating antenna. So, we can say that this plane here we can call this as the something like output terminal of an antenna, because after this the web is being launched in free space. So, this is basically the directivities reference. That means, in the denominator of directivity function basically we say that power radiated by an isotropic radiator; that means, this radiation is taking place here. So, this plane is the directivities reference.

Whereas, this will let u see that this is a transmission line and this is the start of the antenna, this also we called input terminals of the antenna; input terminals of the antenna. So, this at these point this is the gain reference plane. So, gain is reference here that how much power is given to an isotropic antenna. So that means, what is happening, so, power is coming here then power is radiated from here so in between here what can happen one thing you see that while giving this power some power may gets reflected so, that is a mismatch. So, that is not present in the directivity thing. Similarly, some power maybe lost here that is also not present in the directivity thing.

So, that is why we actually relate this gain function theta phi that can be related to directivity function theta phi. If, obviously, they are proportional the proportionality constant is efficiency.

So, you see that gain actually takes care of all this efficiencies. Now there are several efficiencies that comes into play so one by one will see them.

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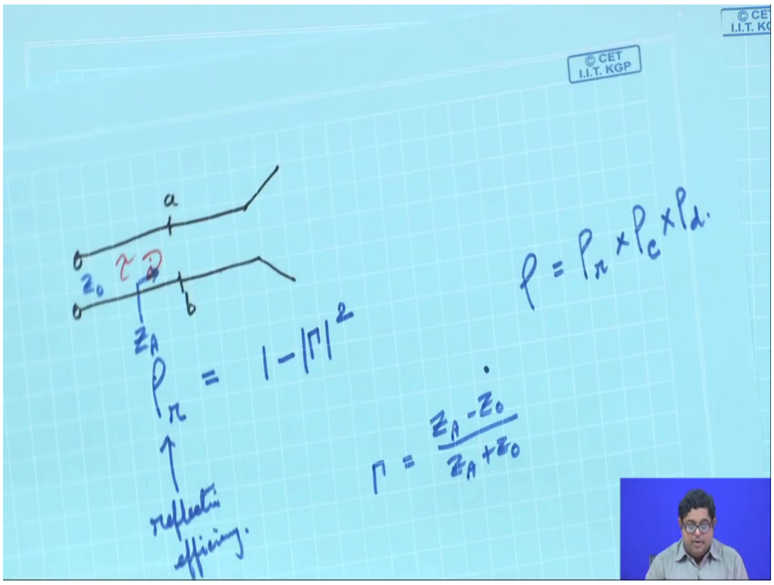

That the first efficiency that can come is as I said that there is a transmission line and then the antenna is getting started. So, this is the input terminal of the antenna generally we call this the input terminals.

So, here if there is an impedance mismatch, then there will be some reflection. So, this reflection due to mismatch due to that there will be an efficiency. So, this we generally call rho r the reflection efficiency and this in power terms generally if voltage reflection coefficient is gamma then 1 minus gamma square or 1 minus gamma into 1 minus gamma star whatever, so that is. So, here this that means we can say reflection efficiency. So, this is one part of the efficiency; that means if I now say that sorry this let us then use the symbol rho.

So, I can say that rho will be something like rho r into something that will come one by one.

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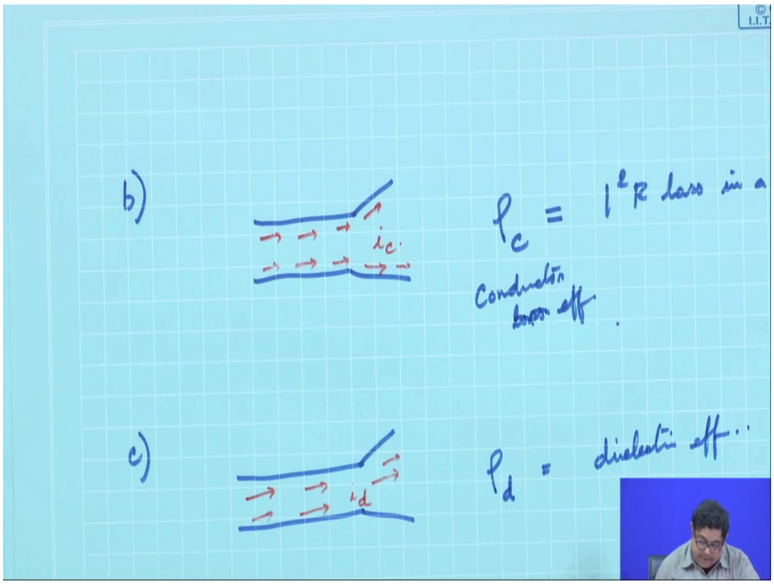

The second part will be that in the antenna; in antenna there are some metallic structures some conductors, so obviously, if electrons flow from there as a current then there will be some resistance, so that will there will be some loss.

So, that we can say that if this the antenna then there will be the conduction current flowing here on the metallic structure, so that will gives rise to the, we can say this is the conduction current i c. So, this will give rise to an efficiency which is conductor loss and later we will see how to calculate this conductor loss. So, this is basically we can say that conductor efficiency basically I square R loss in a conductor in a metal or in a conductor.

Similarly, there will be power dissipation in the dielectrics like even if nothing is there, there are dielectric or in many antennas there are various dielectric. So, there will be the displacement current through them and I can say again that there will be currents which are basically I can say the dielectric current i d.

So, there will be also in between dielectric currents i d. So, due to that there will be the loss; so dielectric efficiency etcetera.

So, now, I can complete this that rho will be rho r into rho c into rho d, but there will be another actually that we have not talk out, but later we will see that antenna has a polarisation. So, if the antenna is not; if there is a mismatch in the polarization of the way coming and polarization of the antenna then there is a polarization mismatch loss. So, that we will discuss later, but here I introduce that term that there will be another one that due to the polarization mismatch.

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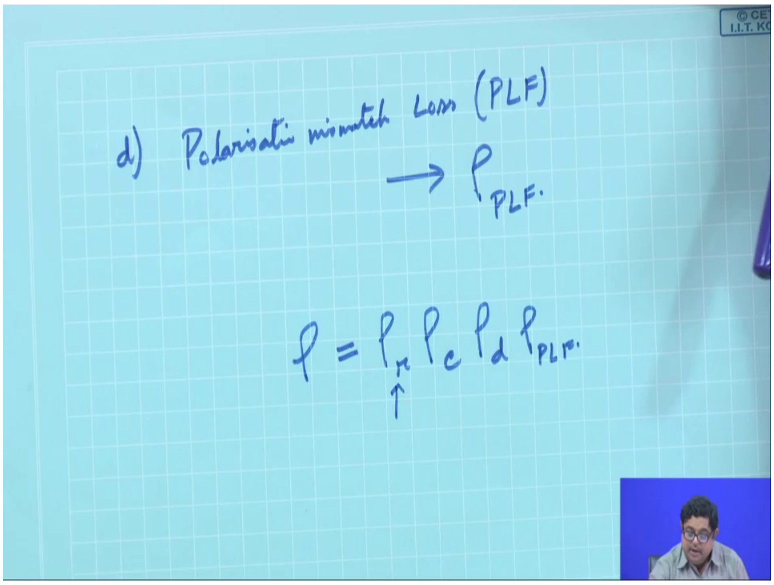

If polarisation is match then there will be maximum power can be extracted. So, polarization mismatch loss this is PLF. So, this gives rise to an efficiency which is called rho PLF. So finally, we can say that that rho is nothing but rho r rho c rho d rho PLF.

Here, I want to say that already we have discussed these. Now this gamma, this gamma is well known that if from these antennas int suppose the antenna is giving an impedance Z A and the characteristic impedance of this transmission line is Z naught then we know that the reflection coefficient gamma will be Z A minus Z naught by Z A plus Z naught. So, from there we can calculate voltage reflection coefficient and from there we can find what is the power loss.

So, these are things that was not said. So that means, gain it is a more useful quantity compared to directivity though both gives the directed nature both characters is the antennas directed nature, but the gain that also takes into account this efficiencies. So, ultimately at the end of the day I understand that how much power I have given and how much it was able to actually give.

Now, a related term is there sometimes transmitted people, because you know any antenna actually in the transmitting mode it is connected with a transmitter. So, the transmitter people sometimes use another term which is related to this gain that is called EIRP; effective isotropic radiated power - EIRP.

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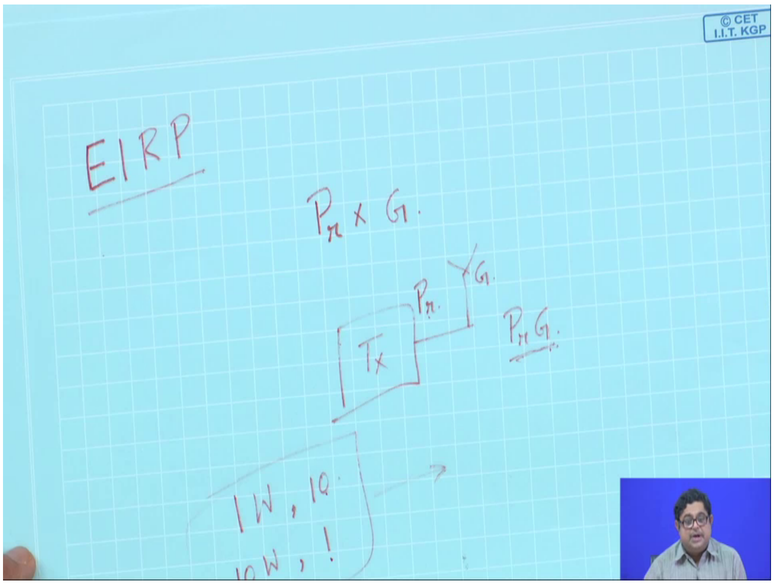

Now, what is the concept of EIRP? That it is a product of the input power given to an antenna and the gain of the antenna. Because at the end of the day it says that in a particular direction, suppose I have a transmitter and that transmitter has a antenna so that antenna has a gain. So, in a particular direction let us say at this direction this gain is G.

So, ultimately if this transmitter is giving me power P r then I am getting a power from here in this direction effectively as P r into G. As if that is why this isotropic term comes as if I have an isotropic antenna; so total power given is P r into G, for a actual antenna the power is given P r but it is getting multiplied by the gain, because it is a special gain.

So, in this direction power is being inject by that amount, but this term says EIRP. Now why transmitter people use it or you will see the space scientist they generally use this, because suppose I have an antenna with 1 watt power and gain of 10 and another transmitter system I have; where I have 10 watt power, but gain of the antenna is 1. Now both of them are actually giving effectively same thing, because one is having a higher power transmitter power, but the gain is less so, effectively this two are same, sothey actually make this two equal by incorporating these two things in the product.

Actually for link budget calculation this is sufficient, but if you are interested for a designer this is not a good parameter, because we want to have more gain to an antenna. So, same EIRP you use in both this cases same EIRP because obviously, one antenna is much better 10 times better in gain than the other. So obviously, that is a better design as per as antenna is concern. So, antenna people do not use this EIRP term much, but as a link budget calculation you should see this.

Also we have discussed the various this efficiencies, particularly in case of the current element that time we have seen that the current element is a very inefficient radiator, we have taken two three numerical examples to show that. Actually the reason is; one of the reason is this actually this gain function this is dependent on various parameters of the antenna. Now one of that is the size of the antenna: electrical size of the antenna. Now current element is a very small size antenna also we will see that planar antennas etcetera there also there is a term which we have not introduced now that is called effective area so that is also again electrical effective area. So, if any antenna is not having sufficient electrical area its efficiency will be poor.

Now next we go to another important parameter that is of antenna that is called Half Power Beamwidth.

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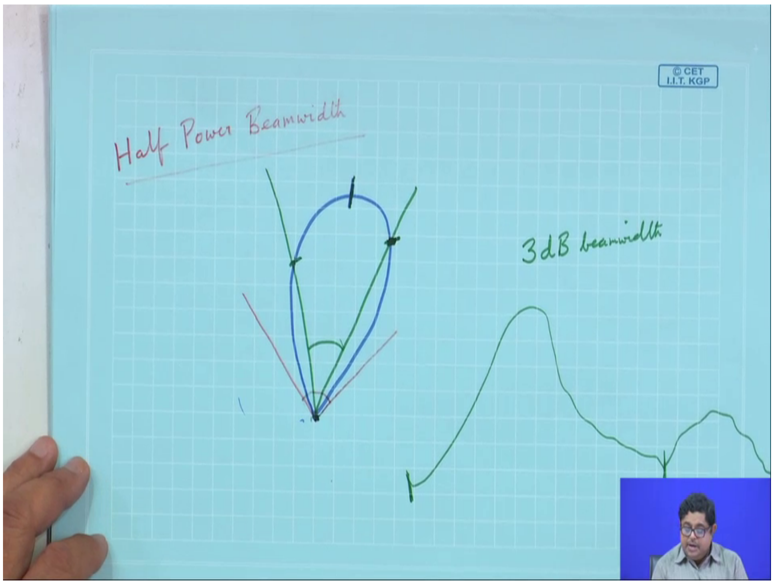

Now you see this also, because generally we have seen when the radiation pattern of an antenna that the there is a main beam generally associated with each antenna. So, most of the power is concentrated into the main beam. So, that is why how wide is that beam that is an useful criteria. So, if I have a very short beam, but I have sufficient power then that is good; that means, the antenna is very reactive. So, that is why people have come out with this that.

Suppose this is the main beam; obviously, there are side beams I am not drawing that. Now from here and let us say that in which plane I am seeing this pattern because we have seen pattern is a three dimensional pattern, but this pattern is in a plane where I have the maximum direction of radiation.

So, in a plane containing the direction of maximum of a beam the angle between two directions, so I draw two directions. How I draw this two direction? This is the maximum radiation direction. Now I locate usually we locate that power wise where from maximum I have half power, so this is one point where I have half power this is one point two where we have half power. So, these angle between them that is called half power beamwidth.

So, I can from the radiation pattern I can find the main beam, I locate the maximum and from maximum I locate the two points in the two sides usually the main beam is symmetric about the maximum mating; symmetric or at least it has two sides. So, there we locate at the angle between them that is called the half power beamwidth.

Also sometimes this is called 3dB beamwidth for obvious reasons, because half power in power if I have a half power that is 3dB. Now, actually we could have some other points also, like sometimes people say 10dB beamwidth; 10dB beamwidth means that whatever power we have instead of locating the half if I locate the one-tenth power of the maximum. So, if this point is one tenth of maximum, this point is one-tenth of maximum, then this angle will be called 10dB beamwidth. Sometimes we also say null to null beamwidth; null to null beamwidth means one null and another null. Suppose, generally if we have things like this, so, this is one null this is another null. So, this angles are null to null beamwidth. In the polar plot you see this direction is a null this direction is a null. So, this total angle is a null to null beamwidth.

So, usually like this. If nothing is specified when loosely only we say beamwidth that should by default means this half power beamwidth or 3dB beamwidth.

Now, there is related parameter that, I know that what is the main beams width, but how much efficient I am, because that how much energy I am wasting in the side bans and the how much efficiently putting into the main beam. So, that parameter is called Beam efficiency.

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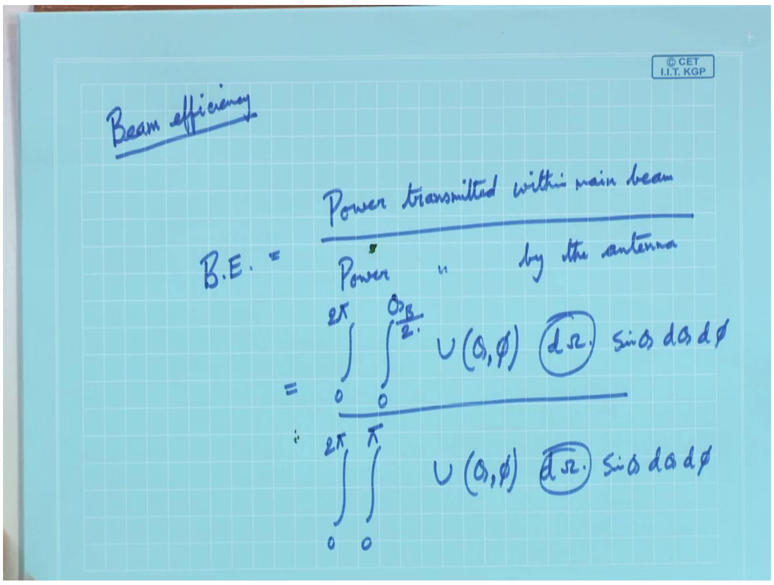

So, what is beam efficiency? You see whatever I said, the power transmitted within main beam divided by power transmitted by the antenna; that means, including a side, lobes etcetera everything.

So mathematically, how to tackle this? You see it is easy we know that if u theta phi is the radiation efficiency then if I multiply these by solid angle and if I take appropriate once then the same expression by taking the proper limits I can get it now. What you already we have seen that what is d omega; d omega is nothing but sin theta d theta d phi. So, I can put that sin theta d theta d phi.

Now what is mean beam? You see 0 to 2 pi I can do and here I can very easily do beamwidth by 2. You see if I do this since I am taking from 0 to 2 pi, I am actually in elevation plane if I have a beamwidth theta b then 0 to theta b this is the power in the main beam. And what is the power here? Here you take all the points; so, all possible angles 0 to pi. That will give you actually the beam efficiency.

So, basically we require in particularly when for radio astronomy or RADAR radiometry where you have you need to very efficiently use your power that time this beam efficiency should be of the order of 90 percent or more. Particularly radio astronomy people, because they are getting very feeble response from a radio star etcetera. Now if they cannot put it into the main beam then they many times would not be able to detect it. Similarly a RADAR, it will have to pinpoint its maximum power into the target direction it should not unnecessarily use it in the side lobes etcetera that will cause interference and also it will have problem in detection etcetera. So, that is why beam efficiency is one of the specification of the antennas

Now, next comes another specification it is for any electronic system, this is important.

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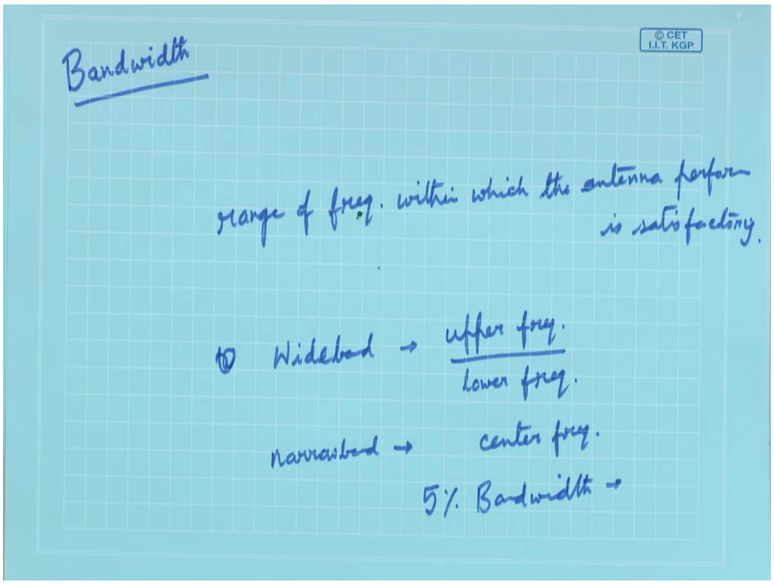

That is a related term do not get confused it is bandwidth. So, we have seen beamwidth now we will discuss about band bandwidth. Now, what is bandwidth definition? Bandwidth is range of frequencies within which the performance of the antenna with respect to some characteristic, like whatever we discussed that we have discussed various parameters. So, those some of those parameters confirms to a given standard or specified standard or specification.

So, I can say bandwidth is nothing but a range of frequency range of frequency within which the antenna performance is satisfactory. Now what do I mean by this? You see that suppose gain is an important parameter for antenna. So, I can say that gain of the antenna within this range of frequencies within which gain should be at least let us set 10dB. So, that will be called a 10dB frequency bandwidth. Now in for wide band antennas now what is this we require wide bandwidth because various actually a particular signal its band is getting increased. So, we want wide bandwidth. Now in that case always instead of this range sometimes we say that for I will say wide band things instead of range of frequencies we say the upper frequency by lower frequency range is a difference between upper minus lower, but if you divide upper by lower.

So, sometimes you will see that a wideband antenna people say bandwidth is 10 is to 1; that means upper frequency of operation satisfactory operation by lower frequency of satisfactory operation that is 10 is to 1.

Narrow band antennas: for them generally there is a centre frequency. So, within the range of frequency acceptable frequency there is a centre frequency and people specify that about that centre frequency in both sides how much you can go. So, people say 5 percent bandwidth. Now what is the meaning of 5 percent bandwidth 5 percent bandwidth means frequency difference of acceptable operation is 5 percent from the centre frequency of the bandwidth; 5 percent 10 percent etcetera.

Actually, the point is that antenna characteristic if you take frequency response of antennas for various characteristic like gain or suppose impedance etcetera etcetera. So, they are not vary equally in the also. Gain has a particular frequency response, impedance may have another frequency response etcetera etcetera the pattern may have another frequency response. So, that is why so we will have to say when we are saying bandwidth, now what bandwidth we are talking. That is why we will see that people talk of impedance bandwidth.

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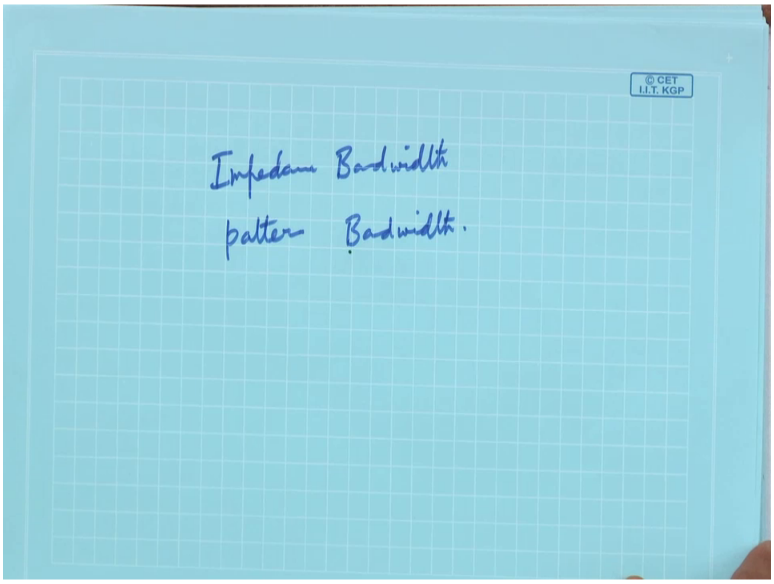

That means antennas impedance should be at least within let us say that how much more sometimes you know KSWR is a measure of impedance with respect to a standard particularly with a characteristic impedance of the transmission line. So, impedance bandwidth is a term. That is why we will see that many antennas people characterize ok; the 10dB impedance bandwidth; that means, our VSWR is or reflection coefficient 10dB. So, actually that is a characterization of impedance bandwidth.

Similarly, there can be pattern bandwidth etcetera, but all has the same thing that what is my acceptable frequency range, where the thing that is the antenna parameter that is specified that is acceptable to me or that is within a specification.

The next concept that will come is another important concept that is called Polarization, but I think for this time is up so we will need to see it in the next one.

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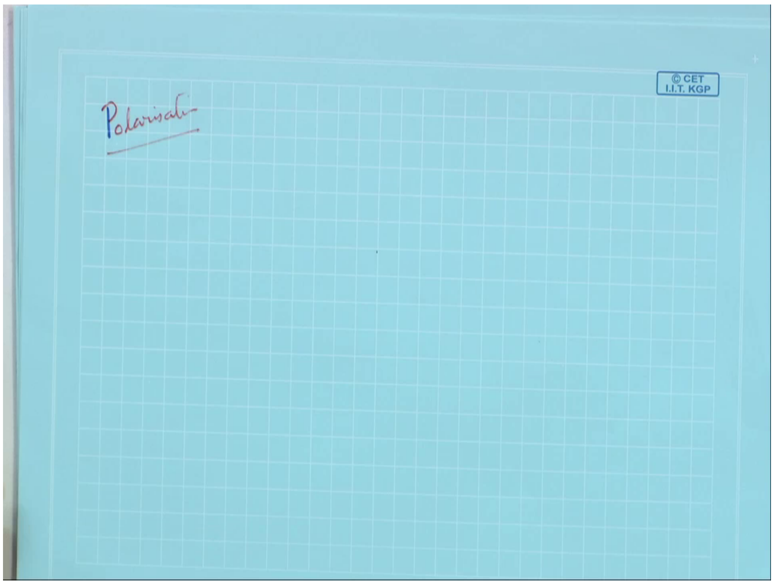

So, in this lecture what we have seen is that: what is actually the concept of efficiency in antennas, particularly what is the certain difference between gain function and directivity function of the antennas; so there we have seen various efficiencies.

And after that we have seen the concept of beamwidth and concept of bandwidth. So, this three antenna parameters we have seen in this lecture, some other more antenna parameters we will see in the next lecture.

Thank you.