Signal Processing for mmWave Communication for 5G and Beyond

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Module - 07
Details of Beamforming in mmWave
Lecture - 36
Different geometry of antenna from electrical point of view

Welcome back. So, today we will be talking more on the beam patterns what are the different characteristic of the beams. So, so far what we have talked about is mainly the channel part how the modified channel would be in the context of Different geometry of the antenna, the beam forming part different geometry of the antenna either at the t x side or at the you know r x side. So, today we will be talking more on the beam part which we have not touched about.

Now, the only thing is that when you have a beam this is more from the antenna theory. But trust me that I will not get into the electromagnetic waves this is not something that is scoped in this class, because we are more thinking from the electrical signal point of view. So, from electrical signal point of view how exactly a beam look like for us. Of course, some of the concept may come from the electromagnetic theory, but more or less I will try to avoid it.

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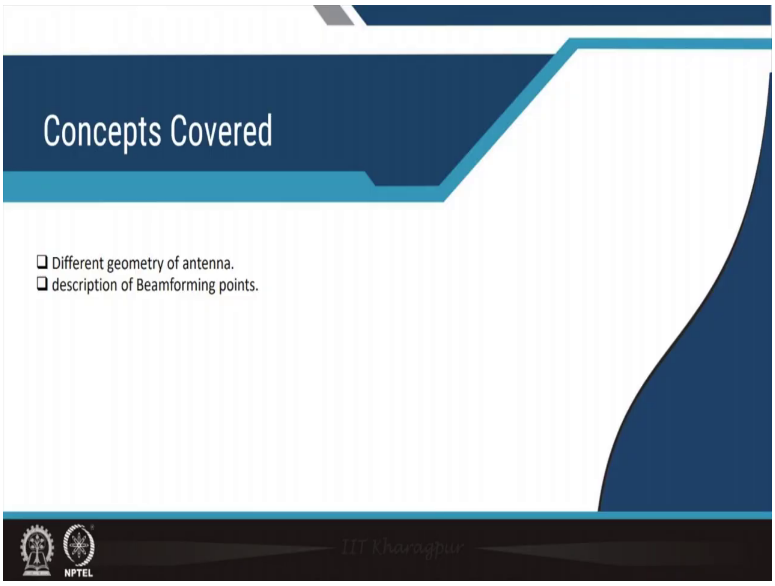

Things that will be covering are the following ok. So, in general some of the definition that I will be talking of from the beam point of view and then we will show whatever configuration that we have taken in the earlier case like ULA UPA or certain geometries like a rectangular shape and those kind of geometry whatever some lattice structure.

So, in that context how exactly the beam would look like those are the things which will be explained it, which we will start explaining today. So, let us see some of the beam property or ok.

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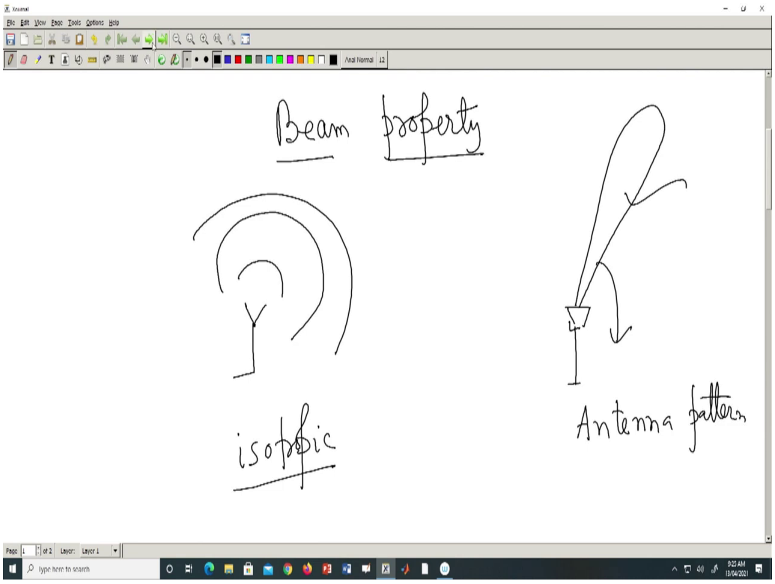

So, these are the beam property. So, when you say beam so it is mainly the electromagnetic wave propagation. So, definitely it is in the air not inside the antenna. So, this is an antenna so when I say beam it is basically this I am talking so these are my radiations.

If it is some sort of a directed antenna this is an isotropic antenna and we will be dealing everything in an isotropic manner and the reason has been given. Then what if I have a directed antenna? So, directed antenna can be horn antenna I am not drawing the exact geometry of the antenna. So, let us say this is one of my directed antenna and it creates a beam like that ok.

Now, this all what exactly they are what is this beam and what I am drawing here you need to understand ok. Now, in this context few electrical signal definition I would not say it is electrical signal, but it comes from that angle.

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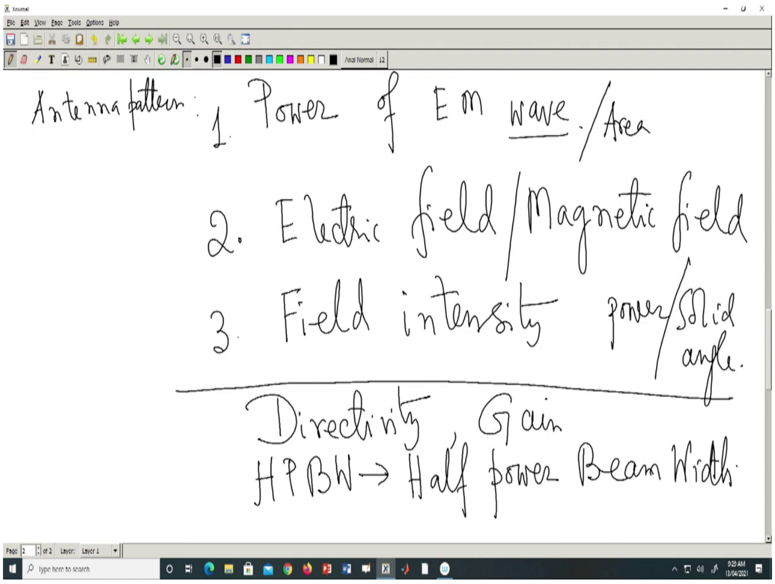

One is called the power of so this is a antenna pattern, what does the mean what does it mean the antenna pattern? Antenna pattern refers to so whatever I have drawn here these are actually called the antenna patterns, so these are all called antenna patterns.

Now, what exactly it means that antenna pattern what do they represent so we need to understand that. So, they represent many things ok, so what I meant by this antenna pattern it could be power basically nothing but the power of what power of the electromagnetic wave power of EM wave ok. It could be electric field, it can even be magnetic field because if it comes from the electromagnetic wave I have ok.

There is one more term is called field intensity. Now, when I say power of electromagnetic wave that is not a very good way of defining the antenna pattern it should be power of electromagnetic wave per area, so something like that per unit area I would say ok. Similarly, when it is a field intensity it will also be some power per unit solid angle. So, there are different way you can you know you can express this particular antenna pattern ok.

And depending on that various aspect will actually come out, but we will not get into this so deeply because this is more on the antenna pattern, but we define some of the aspect which are required for us.

Because we are also dealing with this beam right we are also creating the array of antenna trying to create the beam. So, it is necessary to know some of the basic property of these beams in what sense we are talking of in which language you are talking of those should not be disconnected.

So, that is the reason why we know some of the basic thing, but again I am repeating this is more of from the antenna theory which I am not getting into the aspect very details it is just overall as much as you need to know that ok. Now, apart from that some of the other parameters which you need to know from the beam point of view one such parameter is called directivity ok.

Sometime another parameter comes is called gain, is called antenna gain or antenna directivity. Then another important parameter that comes into picture which defines how good your beam would be is called HPBW it is also known as half power beam width. We just defined some of the parameters in a basic sense and try to understand or try to correlate how it is something to do with what we exactly discussed so far.

Because that is because this is when you say beam forming we need to know what are the properties of this beam. So, these are the different properties that we need to understand that, what is power per unit area what are the different electric field or magnetic; magnetic field may not be so much important for us because if we know the electric field in the oppose, in the orthogonal direction there is a equal amount of magnetic field.

So, it is good enough to know only electric field so even that is comes from the electromagnetic theory right. And third one is definitely the electric the field intensity which will be more on the power per solid angle, then some of the parameters directivity gain and HPBW half power beam width ok. So, let us define few of them and try to characterize it and try to see what are the aspect that is coming into picture here ok.

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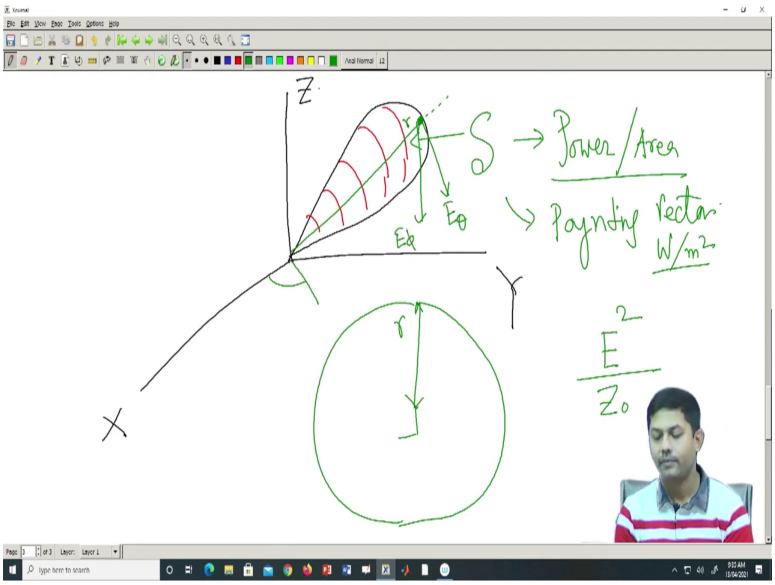

So, let us draw the diagram with our dimension. So, this is our Z dimension this is in X dimension this is in Y dimension right. Now, the beams or when I say beam what does it mean it is basically a power that is coming out of the it is basically electromagnetic power that is coming out of the you know that is coming out of the antenna.

So, if you draw one beam like that. So, let us say this is my beam which is going here, I mean you think this is more of a dumbbell kind of shape I am not able to draw in a two dimensional case but you think this is some sort of a dumbbell case. And so what does it mean?

So, at a direction you know at a direction r if you take any direction r. So, you can define the electric field of what does it represent, what this dumbbell represent? This dumbbell can be the power, this dumbbell can be the electric field or this dumbbell can be the power per unit area or a per unit solid angle.

So, what is meant by power per unit area? So, if you look at this if think of a balloon ok just think imagine a balloon right, the surface of the balloon I am talking off. So, this dumbbell you can think that it is kind of a surface of the balloon ok. So, I can define, so what does the balloon represents. So, it is a particular shape and the surface of that balloon represents the power the power shape of the radiation ok.

So, now; how I define that power? So, power can be a total power, now you see the total power never decreases right. Total power in a particular distance if you take a 360 degree you know area say for example, I have an antenna here and it radiates in whatever direction either isotropic manner or in a beamed manner or in a certain direction whatever it is, the total power if I just draw a circle suppose I consider a distance r and I consider a total power around r that remains same ok.

Because it is the same power which is going in all direction so if I consider all direction; obviously, the amount of power will always be same. So, then how do you define a power? So, it is not the power rather it is a power per unit area or a power per you know solid angle. So, you know the solid angle right solid angle is basically it is an angle occupied by a certain geometry kind of things.

So, now it is not the total power I am interested rather it is a power per area or a power solid angle that I am interested in. So, this one I would say it is a if I define a parameter let us say S ok which represents power per unit area. Now, this is this parameter is also known as pointing vector ok and if you open a antenna book there is classic definition there is a classic way of defining it.

So, in our case we may not need so much for this, but at least you should know you should at least brush up some of the basic concept of this antenna. Because we are also dealing with some of the basic parameters of it ok. So, this is the pointing vector. So, how do you define it? So, when you have this kind of you know pattern.

So, basically I am talking of this pattern is nothing but it is a power per unit. So, it is a diagram it is like it is a balloon which represents the power per unit area that is all it is representing ok. Now, how to define it even more in terms of the field? So, what is the unit of it? It should be watt per you know meter square, obviously this per unit area I am talking of the power.

So, now, now if you think if you think from the electric field and power relationship what is the power relationship between, what is the relationship between a power and electric field? So, electric field if there is an electric field called E, how did you find the power of it? So, its E square define divided by you know it is Z 0, Z 0 it could be the electric field which is incident upon a certain load.

So, that defines the power right. So, if in that sense I can have a pointing vector with respect to the electric field also because its electromagnetic wave right. So, at any point of time you have electric field you have a magnetic field that is all right. Now, if I think the electric field in terms of the polar coordinate that mean at any point.

So, this is a point I can think of in this point I have one electric field which I call it E theta one electric field which I call it in E phi it is not the direction of it is not the direction at which it is moving. So, probably I should not draw it in that direction it is not this direction but if I exist because phi is this direction. So, it is somewhere parallel to that field, but they are kind of orthogonal in space.

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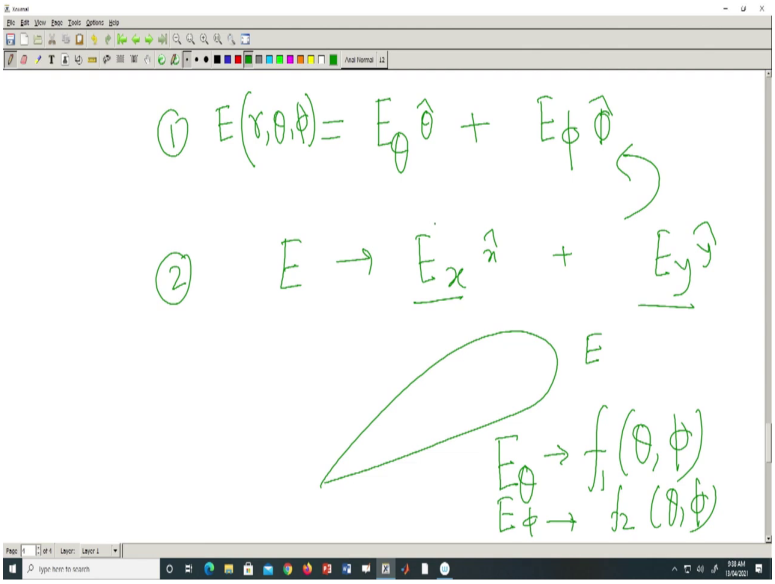

So, the electric field I can define it at any point at any point meaning it should be theta and phi. At any point the electric field of the balloon shape you know the power. So, that balloon shape can be a power that a balloon shape can also be an electric field, it all depends on how you define that.

So, let us say I am defining that balloon as an electric field also. So, then it should be E theta and then say let us theta cap is the unit vector in the direction of theta, then E phi in the direction. So, this is the actual definition in terms of vector. Now, this again comes from the electric antenna field; antenna field theory that at any point of time if there is an electromagnetic wave going on. So, if it is a radiation at any point of time at a distance r and the electric field has two component one is the theta direction another is a phi direction.

Similarly, it is simply like an electric field has a two component in terms of E x E y provided the electric field is moving in the direction of Z then in that direction definitely there is an electric component so there will be something like that. Similar, thing when I convert it to polar I have a polar form also so it is like that. So; that mean, every electric field is as if like a vector having a component in x direction and y direction naturally it will have a component in theta direction and phi direction.

If I express the whole thing in terms of the polar coordinates. So, either this expression or this expression any of the expression is valid from a electric field point of view. So, the balloon I was talking can also represents E. So, that mean if I say that this balloon is representing the electric field of my antenna and I can draw it.

So, in which direction the electric field components will be there? It will be mainly in the x and y direction and its movement will be happening in the Z direction or if I express it in the polar form it will have in theta direction and phi direction, but its movement will be in the r direction so there is nothing called E r ok.

So, but if you look from the antenna theory this e theta does not means that it is only a function of theta this will be some function of theta and phi both. So, let us call it f 1 and E phi will also be some function of theta and phi both. So, theta does not mean that it only contains theta e phi does not mean that it only contains phi, because it will have theta and phi because if you look from our earlier discussion, how do you convert a x y z coordinate to a polar coordinates?

It will have x and y both as theta and phi so similarly this is how it is. So, E theta meaning it will contain x y all this content and all these components it will be. So, anyway whatever direction you want. So, this is the main com we need not to know exact form and all these things, but at least from a definition point of view what it means what are the aspect, that we need to know it ok.

Now, we may not go into so much details of any really form the beams, but it is good to know what are the, because it is good to know which language you are speaking right. So, if somebody ask ok this is the electric field we should know in, which direction the fields are, what exactly the geometries are, what are the you know parameter that will be involved in this particular case. Now, we will be definitely another point for all our discussion so far we restrict our discussion to isotropic antenna.

So, which means if it is a some other antenna like parabola or a or any other antenna we are not you know you are not dealing with that kind. Everything for us is an point source or an isotropic point source isotropic and it is a point source. Meaning it is not some sort of a beamed kind of antenna it is just an isotropic antenna we are dealing with it and in that sense this is. Now, with multiple such isotropic antenna it will form a beam and we would like to define it how exactly it can be done.

So, this is what it is. So, finally, we need not to know what is e theta in phi to us it is like 1 E that is coming into picture ok. So, that matters for us so this is one way of defining it.

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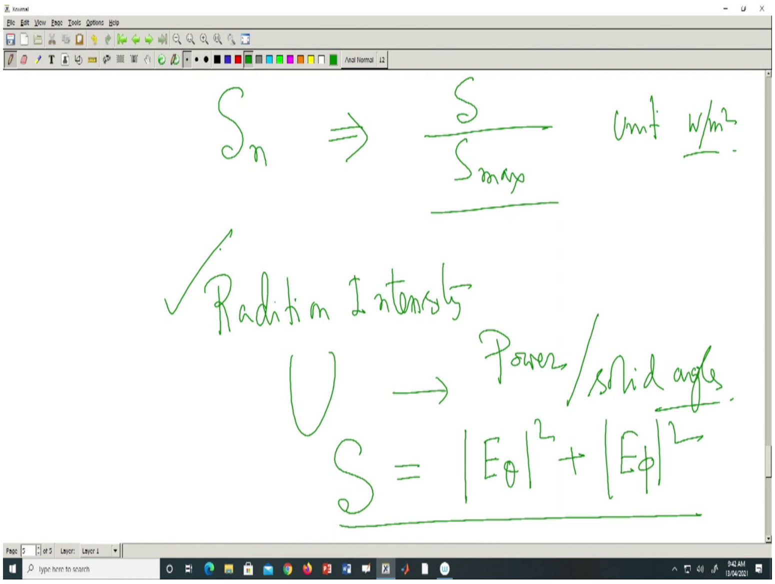

Second way of defining is basically so that is one more parameter called normalized pointing vector S n, it is nothing but whatever you know S you have and then you have some sort of a S max, just kind of a normalizations ok. And, then similarly radiation intensity or a field intensity.

Now, this units are this unit is this is a unit less naturally because I am it is not unit less it is just that maximum value will not go beyond. So, units will be watt per meter square. Now, radiation intensity it is expressed as U it is also a power it is a power, but it is per unit solid angle ok. So, what does it mean? It means that ok.

So, before I get into that. So, what is the S definition then? S is basically if it is a vector case, this is what is coming finally. See E theta mod square plus E phi square this is an important relationship ok so that is the power per unit area. Now, radiation intensity radiation intensity is more of the power per unit solid angle.

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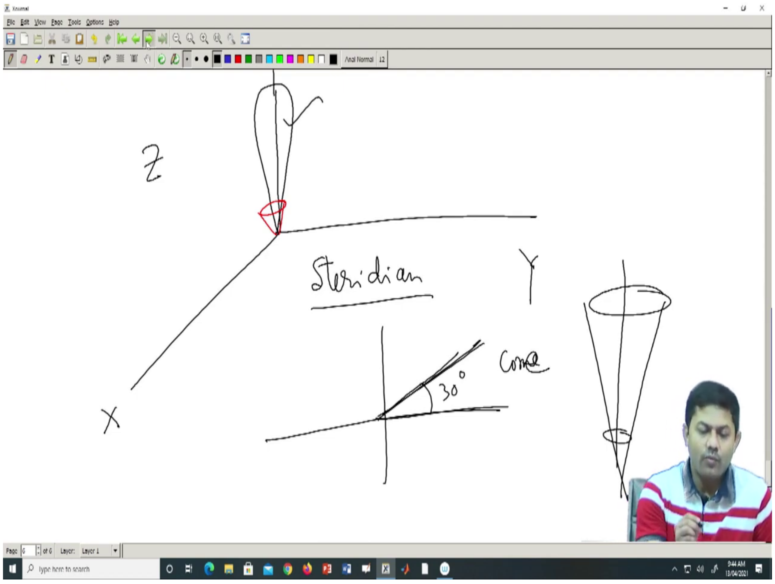

So, how do you how do you view it? It is something like this ok. So, let us say this is what my let me draw it in a other way around. Let us say the beam is exactly moving in Z direction it will be easy for us to visualize it. Let us say it is moving in Z direction, the beam is moving, but you can think it is a balloon which is who stop directed towards the Z direction

So, this is how the beam is right. So, now, what is solid angle solid angle is more of a cone you can think of, it is not just a two it is not a single dimension angle it is a cone kind of thing. So, it is basically you can think of you can think of this, now this whole thing you can think of this is like a cone right, it is like a cone with a cone within that cone it is going.

Now, that cone that is also some sort of a angle so this sort of cone angle is actually called a solid angle. So, its unit is a steridian; it is not radian it is a steridian. Radian meaning if it is in the two dimension X and Y you can have like for example, here. So, it is a you can say this is 30 degree ok degree or radian whatever way you can express it. So, you can that is in a normal angle, but when you say steridian so you can think this is actually a cone, it is a three dimension cone you can think of just like a you can imagine a cone right.

I cannot draw it is like a cone you can think of it like a cone ok now this angle how do you express such kind of angle. So, it is basically in the three dimension solid angle. So, now, this power when I express this power within one unit solid angle that is basically called a radiation intensity. So, ok just the definitions ok just definition. So, now, that means, that if I integrate the whole u over the complete you know solid angle I will get the total power as simple as that right ok.

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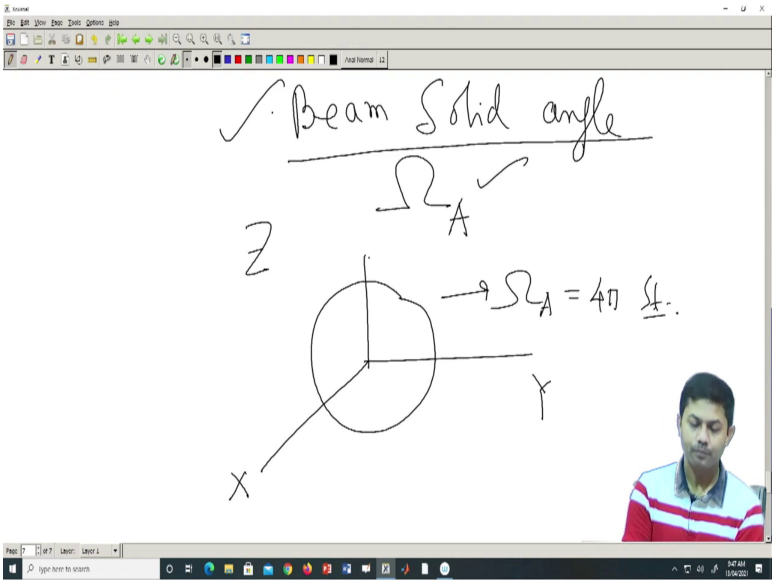

Now, there is one more aspect comes that is called beam solid angle it is a another parameter that we should know ok. So, what is beam solid angle? Beam solid angle represents, how much solid angle is occupying the actual power is something like that ok. And it is a very important parameter for a beams it is called beam solid angle. Say for example, I have a X Y Z, X Y and Z; let us say my antenna radiation is like a ball ok.

So, how do you, what do you say my sigma A? My sigma A will be completely occupying the whole 360 degree so, it is a 4 pi steridian, like because in all direction; that mean, the whole 4 pi steridian will occupy the complete power right. So, for such things sigma A will be 4 pi steridian St I can see because it is the complete sphere. So, how do you get that? So, basically this definition is important I mean it represents like what should be my power you know power radiation shape.

Because, we are interested in the shape not exactly the power yeah. So, this is one more point that I would like to say here the exact numerical value of the power is less important for us compared to the exact shape of the beams. Because, we are interested in the shape in which shape it is going? How the you know radiation pattern is looking like? That is more important power is in our control I can always pump more power from transmitter side and I can quit the power part.

So, more than power it is the shape that matters, I should see whether the shape is a narrow shape wider shape. So, how to define that? So, then these are the important aspect that we always look for ok. Now, this is one such parameter beam solid angle that actually defines what should be the it is an indication. So, it is it is just like one value ok. It is an indication that how much solid angle is actually occupying that particular power so that is kind of an indication. So, what is the definition of it?

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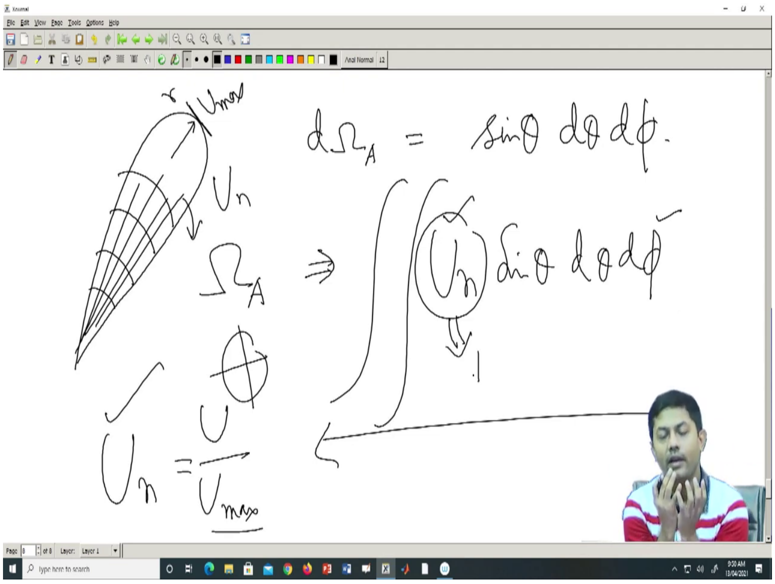

So, definition of it is that, what is the d of sigma A it is sin theta d theta d phi so that is the definition. So, if I integrate it over all theta and phi I will always get you know the complete area of that steridian part right ok. So, this is what the actual definition. So, that means, the way I should define my total sigma A is that I need to know what is my this definition either my radiation intensity or my pointing vector. So, here also there is a normalized definition of my radiation intensity.

So, radiation intensity also has a normalized just like your S n which has a normalized pointing vector this U E also has a normalized radiation intensity ok. So, just like that U also has a normalized radiation intensity; that is the U divided by U max at a particular distance r of course, I am talking of that part. So, this U n sin theta d theta d phi of course, there will be two will be there because d theta and d phi.

So, this represents what? This represents the angle how much solid angle is occupying that particular beam because this U is representing the beam intensity that is the balloon you can think of that is the equation of that balloon right. So, if you have this balloon; this balloon I am talking. So, this if it is representing a U so this lets say this is U. So, let us say at a distance r this is the U max you normalize it so, you get U n ok.

And, then if I integrate that U n because U n itself representing a three dimensional shape if I represent this U n over all the sphere complete sphere theta and phi that mean I am you know integrating over 0 to pi and 0 minus pi to pi 0 to pi. The complete theta and phi because theta varies from you know 0 to pi and phi varies from total 0 to 2 pi it complete it covers the complete polar coordinates. If I integrate it over this U n what does it represent? It represents the amount of solid angle.

This particular you know power is occupied ok. So, this is one of the important parameter which represents what is my beam solid angle. Now, you can think of what happens for an isotropic case? So, for isotropic case what is U n the U n is just 1 right because it is a U by U max if it is an isotropic case what happens? U max is everywhere right.

So, it is a 1 so for isotropic case this is just 1. So, this whole thing occupies the complete sphere; that means, the complete solid angle is occupying my power.

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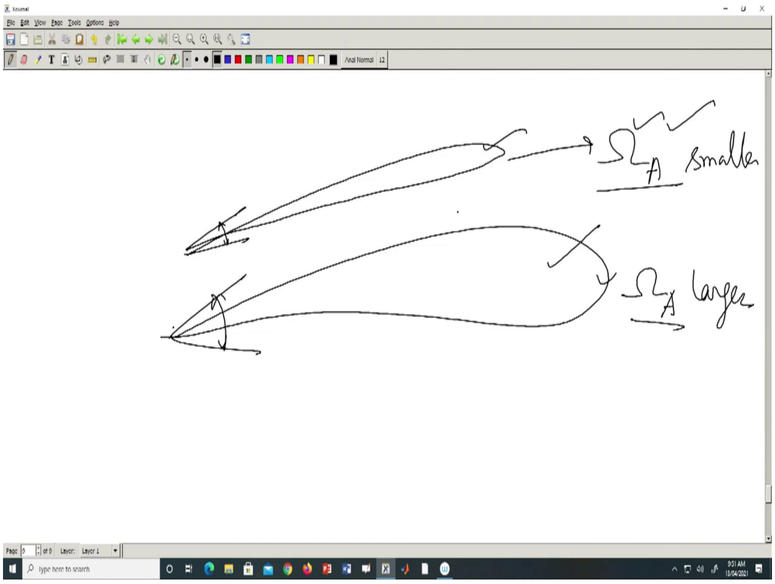

Now, if the beam becomes narrower and narrower, if the beams becomes you know narrowers compared to this fellow. This is a wider beam this is a narrower beam just visually I can think of this is my radiation intensity pattern is showing like that. So, which one will give me sigma I larger.

Now, this one will have a larger sigma I, this will be smaller sigma I because the cone that is occupying this power solid angle cone is much smaller than compared to this fellow this is this much cone is required whereas, for this fellow only smaller solid angle cone is required.

So, the sigma a will be much smaller compared to the larger one. So, smaller the value I can think, I can imagine this beam will be much more narrower and sharper this kind of thing. We will do some more maths later on to exactly you know motivate you what are the different type of problems that may appears here ok.

So, with this I conclude this session in the next class I will be talking more on the other parameter side and with some examples definitely.

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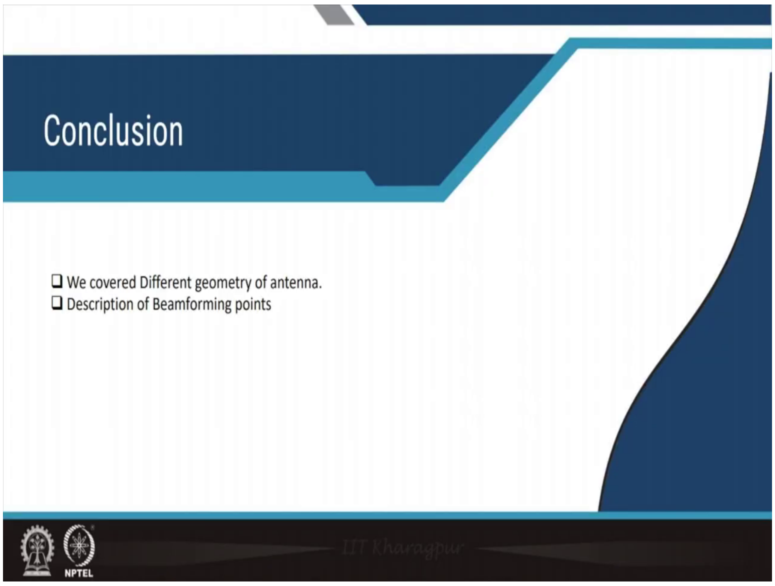

So, in conclusion we have kind of completed the concept. So, this is the reference.

Thank you.