Signal Processing for mmWave Communication for 5G and Beyond
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Module - 06
Beamforming and mmWave channel
Lecture - 32
Basics of Beamforming

Welcome, welcome to Signal Processing for millimetre Wave for 5 G and Beyond. So, today we will be covering or at least the starting the Basics of the Beamforming, because that is the code of the millimetre wave communication. And, some of the theories that that engulf the complete beamforming part that we will be discussing it here.

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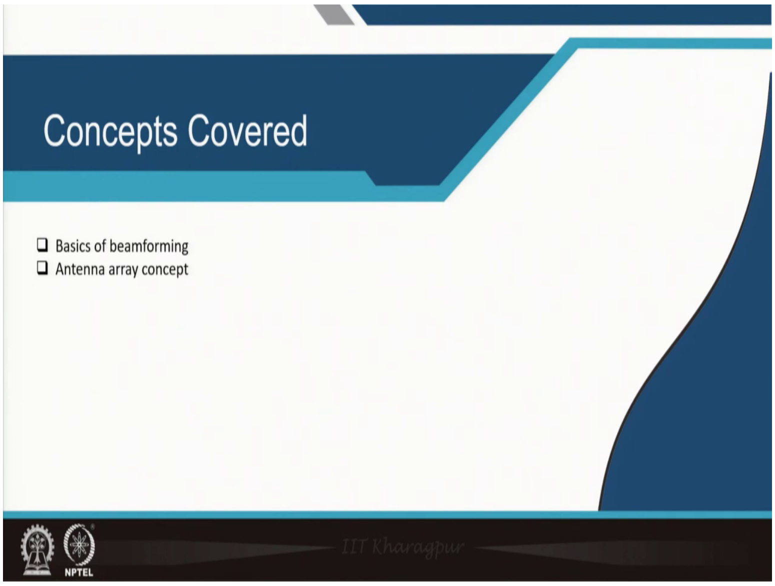

It is basically the basics of beamforming and some of the antenna array concept that will be coming up ok. So, so far we have what exactly we have modeled so far.

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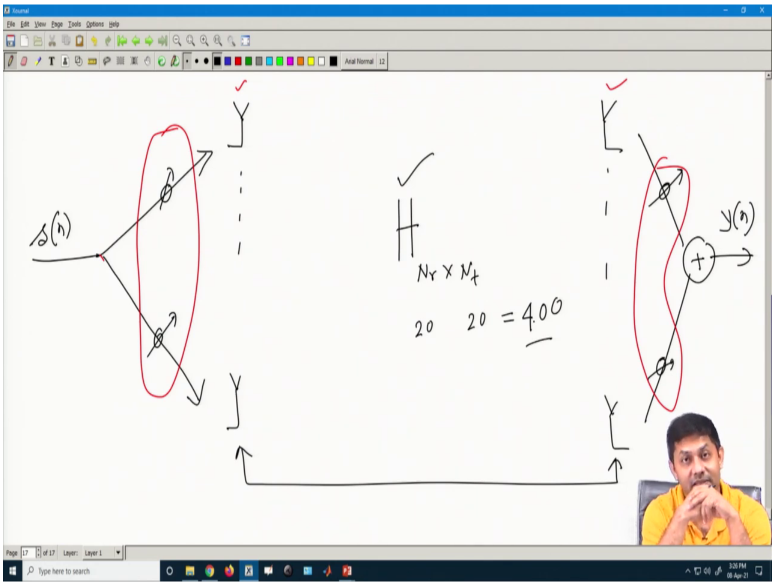

So, far we have model the so, these are my transmit antenna side, this is my receive antenna side right. And, we have said that there is a s n here, it will be fed like that and then it will be fed y n ok. But, then you have said this part will be creating a beam this is the antenna processing error, but this is how the concept comes into picture? And, we have said that there will be some phase coming into picture just to steer the beam and there will be some part here just to optimally combine them.

Now, so far we have concentrated our discussion between this to this ok. And, we have defined what exactly our channel is. What we have not discussed, how do I send it; that means, from here how do I send the signal to this point? Or, when I receive the signal how do I combine them optimally that is something that we have not discussed so far ok.

Now, let us understand few things why this approximation so, again I am coming from the last classes? Why we have done so much approximation in my channel model. What so, what is special about these approximations. That is one of the thing that we need to think about it right, does it lead to any conclusion that this whatever approximations you have done does it really making any sense to us.

The reason is that in millimetre wave we will explain it in subsequent classes, the number of such antennas might be very large. It can be 30, 40, 50 whatever sky is the limit, you can create, you can take as many as transmit antenna as many as receive antenna, but again this is not a mimo configuration.

This is just for beamforming concept. The point here is that, if you have such a large dimension this channel will also be such a large dimension. So, it will be N r cross N t. So, take an example let us say, N r is say 20 N t is say 20. Now, I am asking you to do a channel estimation in a normal case in a normal 6, sub 6 gigahertz context, if somebody gives you like that.

So, how many variables you have to estimate for such channel, you see it can be 400, because it is a 20 cross 20 matrix, each and every element you have to estimate it. It is a 400 elements, you have to estimate, but whenever I make those assumptions what are the things that you have to estimate, how many such variables you need to estimate?

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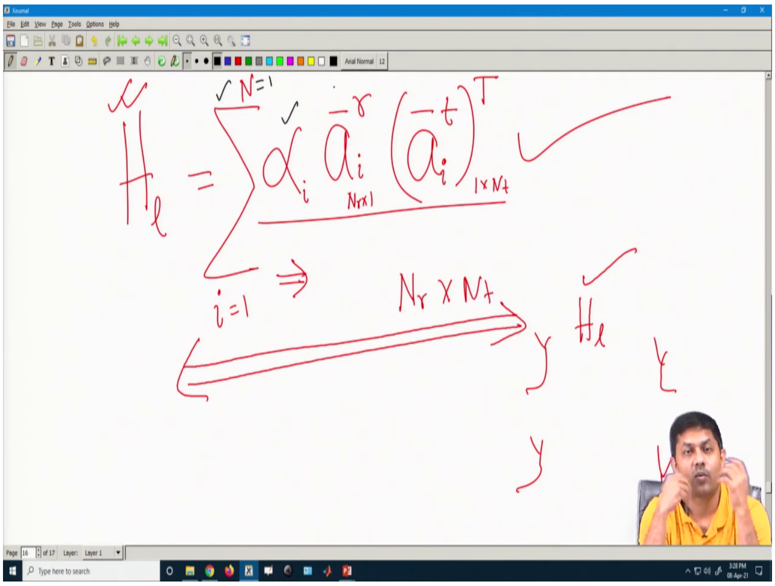

If, you remember the channel whatever we have drawn here, if you look at the channel. Let us not worry about this summation thought, because that will be coming, if there is a reflector. So, let just for our simplicity I am reducing that number to 1. So, let us assume N equal to one assume.

So, how many variables, I need to estimate it for that 20 cross 20, I have to estimate only 1 alpha, because this is alpha I have said that only one reflector is present. So, I have to estimate only 1 alpha ok, what about a is just a vector 1 vector, what is it is length 20 20 cross 1.

So, how many elements are there? Do I really estimate all 20 no, I do not have to estimate all 20, I will just estimate 1 variable right. So, what is a i? It is e to the power 1 e to the power j phi 1 e to the power j phi 2 and so on so forth each and every phi is again there is a formula right. So, it is 2 pi into I minus 1 d and so on so forth, and there is a angle of departure angle of arrival.

So, it is only a angle of arrival that matters there for t also angle of departure that matters there. So, how many variables? Angle of arrival sometime it can be 1 variable, if the antenna configuration is ula, sometime it can be 2 variable if it is a normal other configuration of antenna, like azimuth or elevation. So, let us take the worst case. So, you have a azimuth and elevation, for transmitter side also there is an azimuth and elevation. So, 2 and 2 4 plus alpha 5 that is all.

Just 5 variables I need to estimate instead of this 400 correct right. Because, the antenna dimension everything is known to me, the only thing that I have to estimate is the angle of departure, only thing I have to estimate is the angle of arrival, only thing that I have to estimate is the alpha, 1 alpha. If there are reflectors say the number of variables will multiplied by the number of reflector. So, look at the complexity reduction in my estimation starting from 400 variables to just 5 maximum ok.

So, that is the reason we definitely go for this kind of approximation and it works, there is no reason why it should not works ok. Specially in millimetre wave context, why? Because the dimension between 2 matrix, dimension between 2 antenna is very small. So, all these approximation whatever you have seen is equally valid ok. So, now, let us move on. So, that is one of the motivation.

And, that is the only motivation, why I should go for this approximations ok. Now, the next level is that, this s n I need to send in a directed manner right. So, which means that I need to send an antenna which is having a direction; that means, directivity should be very high, why I want to you know I want to save power.

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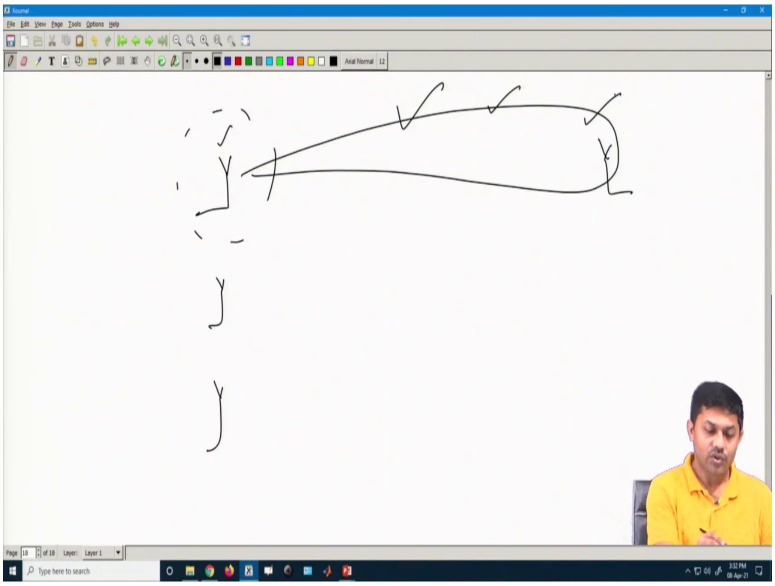

So; that means, from my transmit antenna. I want not an isotropic kind of a radiation; rather I want some sort of a directed radiation, because this is a millimeter wave. The power itself is very lossy power, because when it goes to the medium power will be lost most of the time ok. As you go as you go far and far the power will be lost very heavily and that that is easy to understand.

So, I need a direction question is that do I need directed antenna. So, which means that, can I use some sort of a directed antenna. For example, what if I use horn antenna, what if I use some sort of a parabolic antenna they are all directed antennas, and there are many directed antennas there.

But, the problem is that such antennas you cannot put it in a mobile phone right. Because, that is very small thin tiny devices, you cannot put a horn antenna inside it, you cannot put a parabolic antenna inside it. So, the physical dimension limiter to use such kind of directed antenna.

And, that is beside is the reason, we wanted to use multiple isotropic kind of small antennas and do some signal processing over that such that the beam will still look like that ok. And, that is the reason we have used this array, array of antenna. This array of antenna can also have a potential to use this kind of to create this kind of beam ok.

Now, this concept we call it an array processing ok. Now, let us see how exactly this kind of beams can be created using the arrays ok? So, that concept comes from antenna theory. Now, as we are doing signal processing here, I am really not getting into the electromagnetic part and all the other theories of the antennas.

So, here mostly I will be talking the stuff from electric field and electrical signal point of view, not really into you know all these electromagnetic theories. Because, that is not at this point of time, that is not something need not to be known, but of course, if somebody wants to know it they can create even much better model, but I mean need not to be know it.

So, now, we are concentrating on the fact, on how to create such kind of beam for us in a signal processing point of view, from a signal processing point of view, I would like to know that. Now, definitely the choice of directed antenna is not our is not in our code, it is only the arrays of isotropic antenna that is our choice.

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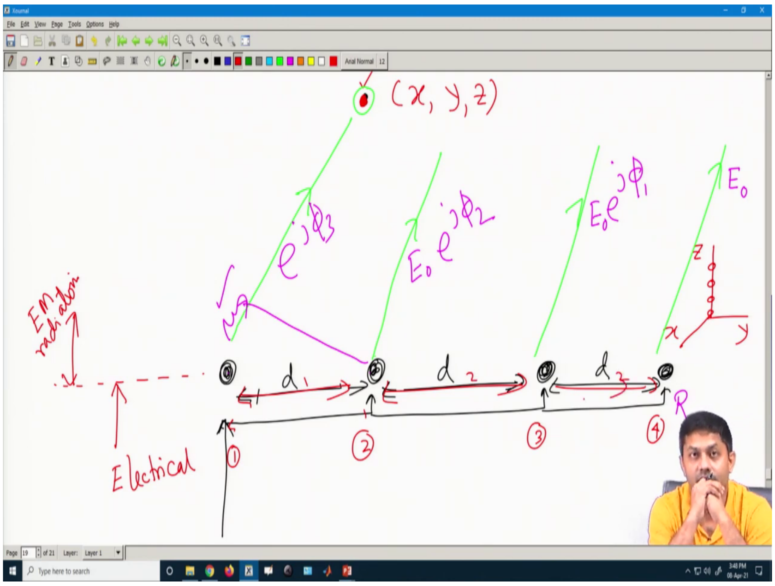

So, I will directly get into this kind of things. So, let us say physically I have these antennas, physically you know stripped on a particular breadboard in a circuit board I have just 4 antenna points. It is like a small metallic dot, you can see and that that acts as my antenna, isotropic antenna.

That mean, individually my radiation will be like this, like this kind of radiation individually. But obviously, when all 4 radiates, if you stand somewhere here you will receive all of their radiation and the effect will be something like a interference ok. Because, it is not an interference I would I would correct the statement, the effect will be more of a addition of all the spectrum ok.

Now, how that would look like is the question? Because, we want our spectrum like that, we want our power spectrum that is what I am saying, we want our radiation field radiation intensity like that ok, not the isotropic 1 ok. So, now, this particular one comes from my antenna concept ok.

So, how exactly I would do that? So, let us say physically I feed signal here and there is a the difference between them is d always ok. Now, for betterment of our class, let me remove this radiation part. Because, we assume that this is an isotropic radiation individual antenna will be creating an isotropic radiation ok. So, the distance is d here.

Now, physically I am feeding electrical signal, the way you are seeing it exactly the on this particular white screen whatever you are seeing, just imagine the that is a kind of a breadboard ok, that is a two dimension breadboard and this 4 antennas are stuck there. And, I am feeding the data here, then I am feeding the data here, then I am feeding physically like here, same data is just going like that ok.

This precisely what I am doing it here? So, what exactly I am doing. I am creating an intentionally a phase difference if you notice it from this 0.1 to 0.2 there is a phase difference. I am because I am delaying it right, 0.3 that is phase difference, 0.4 I am getting a phase difference, why the phase difference? Because, this distance the electrical signal is traveling through the distance so, it is creating a phase ok. So, I am intentionally creating that phase difference ok.

Now, what else? So, what am I doing then? This is radiating each and every antenna is radiating in isotropic manner. Now, let us say, let us say, there is a receiver antenna somewhere there. Now from the now from here, this part is your electrical domain and this part is your electromagnetic radiation, EM radiation right. So, from antenna it is an electromagnetic radiation. Now, let us see this particular receiver is sitting there, which is sitting at a physical location x, y, z.

Because, now I am thinking 3 dimension, because this is what I want right millimetre wave. Moment I create some sort of a concept of beams and all directivity angle of arrival coming into picture, I am subconsciously bringing the concept of geometry there. Obviously, and that is one of the aspect of millimetre wave.

If, you did if you do not want to consider all these things, then you go back to your you know that 20 cross, 20 channel and elements 400 variables, there is no concept of geometry that you can extract geometry definitely. But, you do not need because every point is known to you ok.

So, here I am (Refer Time: 14:59) the geometry, because I am dealing with the kind of variable, which r m, which are coming from geometry like angle of arrival, angle of departure, these are geometrical variables not just like a phase ok. So, let us say I am sitting or receiver is sitting at a coordinate x y z and this is the line. So, I will write a small line just to show you my direction.

So, this is x, this is y. And, let us say all these antennas whichever I have drawn here are sitting in the y direction. I mean you can put it in z direction also no big deal, you can even put it in other direction also, let us put it in a z direction for your simplicity, I do not mind it. So, this is in the z direction this all these antennas whatever I have drawn this in the z direction ok. So, what it is ok? Now, this x, y, z coming into picture there.

Now, instead of thinking from 3 d just for simplicity for a moment you think this whole diagram from a 2 d point of view ok. Just from a 2 d point of view you think of it. So, what will happen? It is as if like 1 radiation pattern is going here, because at the receiver I want to know, what is the electromagnetic radiation that is coming to me right? And, they are all added up.

Because, they are all these radiations are coming at the same frequency. So, definitely the effect will be like a addition of all of them now. After addition what will come that depends ok. So, let us try to understand that. From here, I am intentionally drawing a parallel line and you know the definite reason why I am drawing a parallel line.

Now, in this particular diagram it is not up to the scale, then you can say hey this something is sitting here, but it is all these antennas are going off. Actually, they would not be going off, because the distance, this distance and this distance, you know the dimensions, there this is in millimetre wave the other one is some several meter.

So, this is only for our understanding purpose. So, there is as if like this particular receiver is receiving them parallely. So, that is the one of the good assumptions that we have already made it right. Now, try to understand, what this particular receiver will see the phase difference between different antennas with respect to the electromagnetic waves ok. That is what the channel discussions we have done so far right.

So, how much it is or I will put it this way. You can think of it this way or you can yeah this is also fine so this distance. Similarly, each and every point we will see that phase differences because of this extra distances and this is extensively we have discussed when we talked about the channel model.

So, finally, when the you know the receiver signal comes to x, y, z point, how the what is the field, what is the electric field that it will receive? Ok. If, let us say this is my reference point, if he gives you say this electric field E 0, what he will give me phase delay. He will give me, he will give me, that is electric field he will generate see if I add them up.

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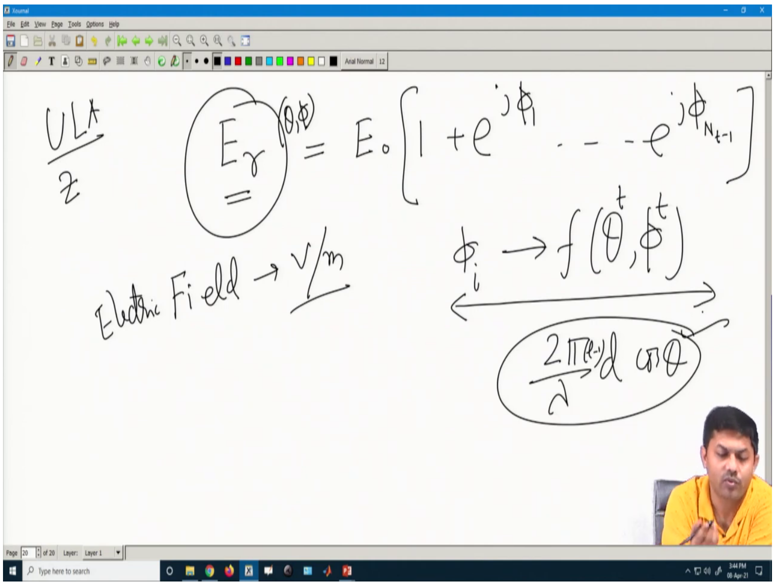

So, which means the received electric field at the receiver, how much it would be? It will be E 0 1 plus, if there are N number of antenna N t number of antenna this what we have seen it, but the only difference is now I am adding them up. So, when I add them up, this is my received electric field ok. Now, what is this phi? This phi is just a phase, but it can have either elevation, it can be azimuth or it can be both. See in a very general sense can I write it like that. This sum function of my theta and phi t, if it is transmitter side; obviously, theta t, phi t ok.

So, which means that this E r will be some function of theta t and phi t also, because individual phi i is also a function of theta t and phi t. Now, for a linear array we know what is that equation? For linear array it was 2 pi lambda d cos theta, phi was not there and there is a l minus 1 for linear array we know.

But, for UPO we will see that what kind of that, but my point here is that instead of getting into the exact equation, it will be some function of theta t and theta and phi. So, which means this will also becomes a theta and phi. So, what is this e? E is the electric field.

So, I can say, it is a, it is a field electric, field whose unit is volt per meter ok, that is the only thing I can get. Now, if my antennas are placed in z direction, how exactly my delays would be now we have drawn it is e to the power is like 2 pi d cos theta, can I generalize it now ok. So, what can what sort of generalization, before I go to the generalization.

So, that mean if it is a ULA antenna configuration placed in the Z direction, this is the received electric field whatever I have drawn here ok. Now, if I plot it with respect to what, because now phi will not come into picture, because only theta will come into picture. If, I plot it what will I get it, I get something depends on how the configuration is. So, I can plot either polar diagram or I can just plot it on a normal phase.

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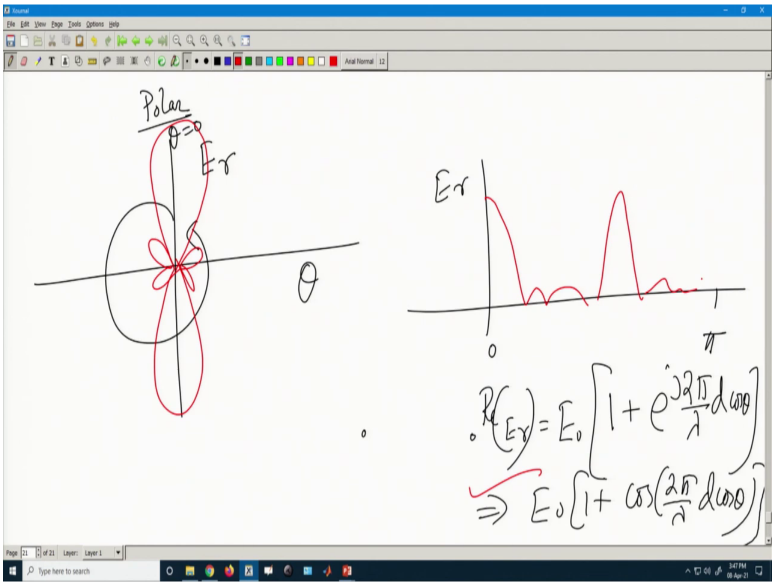

So, I can draw in a polar polar plot, what is the polar plot? This is with respect to theta. So, I call this theta equal to 0 ok. And, you move anticlockwise and you can plot this E r, the received electric field or you can also plot it between say 0 to pi, also you can plot it suppose this is from 0. So, let me just put it this way this is 0 to pi you can plot that E r also.

The question now comes, what should I see? Because that is our key intention, what is my intention? My intention is to generate a spectrum electric field like that beam. So, the question that happens is how will I guarantee that this is what it will be generated ok. So, this is the point that will coming into picture. Now for a ULA we know the equation, now take a simple case, take a simple case, but I have only two antenna.

So, what would be the E r in this case, E r will be E 0, E 0 is the initial electric field 1 plus e to the power j 2 pi by lambda into d cos theta, this is what is coming ok. This is what will be coming here, got it. Take the real part and you plot it, because we always take the real part not the imaginary part.

So, take the real part of it of your electric field. So, that is what I will be receiving not the imaginary part, this is what we have discussed it in the how you transmit? Because, what you transmit is always a real data, it is not complex data, this j is coming only from the there is a notion, but you will be receiving.

So, what will be coming. So, it will be some E 0 into 1 plus some cos of 2 pi lambda into d cos theta right something like that I will be receiving right plot that with respect to the theta. I will see some wonder I will see that this polar diagram will no longer be like this, this polar diagram whatever I have drawn.

It will be something like I will see some sort of a. I am drawing in a very general sense you have to plot plot it in the computer and see what it comes, this one you just plot, this part in a computer and see. So, you will see that there may be some peak here, there maybe some peak here, some more peak here and there like that.

So, this shows that I am really getting into some sort of a beam, because this is my electric field diagram. Now, electric field moment I create this kind of things I will say, my field is now no longer like a sphere, but it will be like a kind of a structure. Now, will the structure be always like whatever I have drawn in this red colour it depends.

It depends on what the distance among these antennas, it depends on what if I take some arbitrary number d 1 d 2 d 3 some arbitrary number will I get that beam pattern no, I do not think so. Because, this angle will be very odd in this case, this angle should be very odd. And, after this summation we do not know what it will be, I mean, I am just guessing something like this, some diagram something like this something like that.

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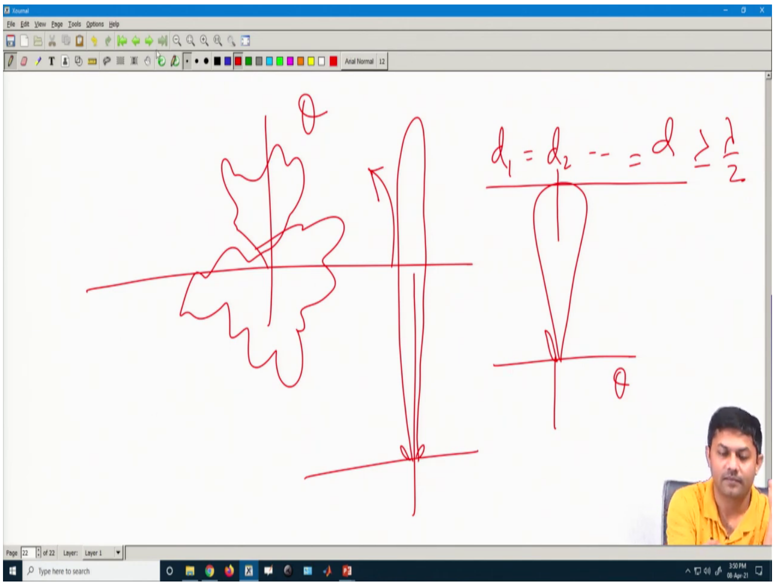

We do not know this is the polar plot with respect to theta something like that, I will get, I do not guarantee that that will be like a very good shape there is no such guarantee. So, if I take all of them equal d; that means, all the d 1, d 2s are equal to d. And, it is lambda by 2 greater than that, then I will create or I will get this kind of beam structure ok, it is a simple computer programming there will be some assignment on that as well.

And, I will see that if I increase the number of such antennas, the sharpness of this beam will increase. Now, we need to mathematically define it what is meant by sharpness, what is meant by all this, what is known by half power bandwidth; this is how to define a sharpness? Ok.

So, those concept exactly come from antenna, they are not signal processing part. So, the concept of directivity, concept of you know beam pattern, concept of beam area, concept of efficiency gain all things we will define it in subsequent classes, because now this is little bit from the antenna theory.

But, I am not getting into the electromagnetic part it is more on the parameter side. So, if all my arrays are equally spaced with a minimum distance lambda by 2. I will get this kind of this is my polar diagram with respect to theta, I will get this kind of beams pattern. Now, we will show that, if I increase the number of such N t this will be sharper and sharper with smaller and smaller side lobes.

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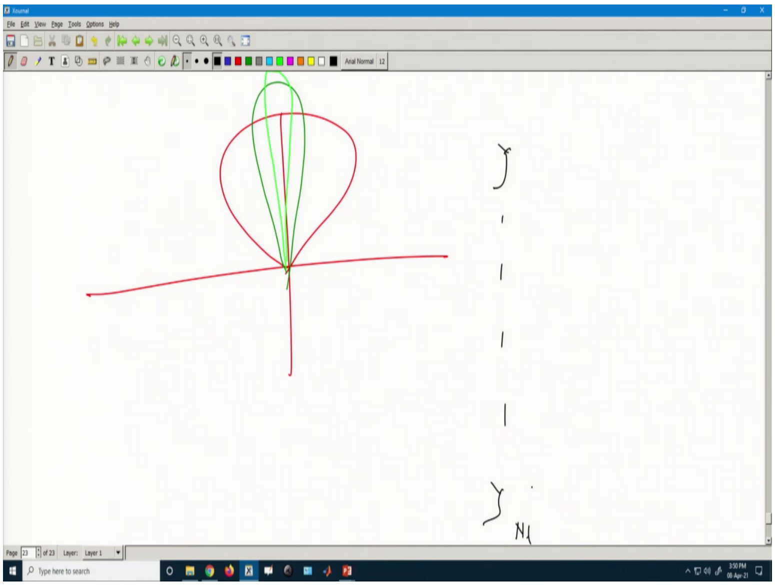

See if it is a 2 probably this will be larger, if it is 3 it will be slightly narrower, if it is and so and so forth this is how the beams will be created. And, that is the reason why at the transmitter side, I increase my I need to take more and more N t. So, that I create more and more beams there. Now, in the next class we will quantify it.

Like, how do you mathematically quantify such such kind of sharpness, what is the beam direction, what are the other beam parameter? Now, this is little bit from the antenna theories, but we have to learn it from our beam creation point of view ok.

So, with this I just introduced the basic concept of beams using the antenna array. And, this particular concept will be used only in the millimetre wave context. We are not getting into other type of antennas everything will be done from antenna arrays ok.

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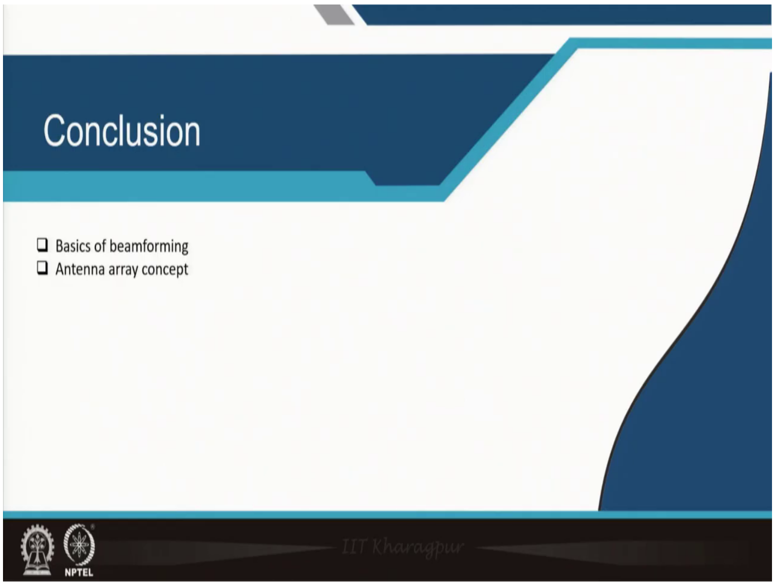

So, with this I covered some of the basic beamforming concept just using the antenna array. And, we just introduce the concept of antenna array for this particular class in the subsequent classes we will continue with the other parameters.

Thank you.