Signal Processing for mmWave Communication for 5G and Beyond
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Module - 05
MmWave channel model
Lecture - 27
MmWave channel model with RX beamforming

Welcome. Welcome to Signal Processing for millimeter Wave Communication for 5G and Beyond. So, we will be continuing from the previous class. So, today's class will be mostly concentrated on the a millimeter wave channel modeling and with t x and R x beam forming part. So, this is more of a start.

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Some of the concept that will be covering today is the characterization of the multiple antenna part here. And we have done it in the 6G context, but this is more into it. And the important aspect will be the approximations involved ok. So, what are the approximation in the actual air to air channel model that will be that will be assumed in the millimeter wave channel model ok.

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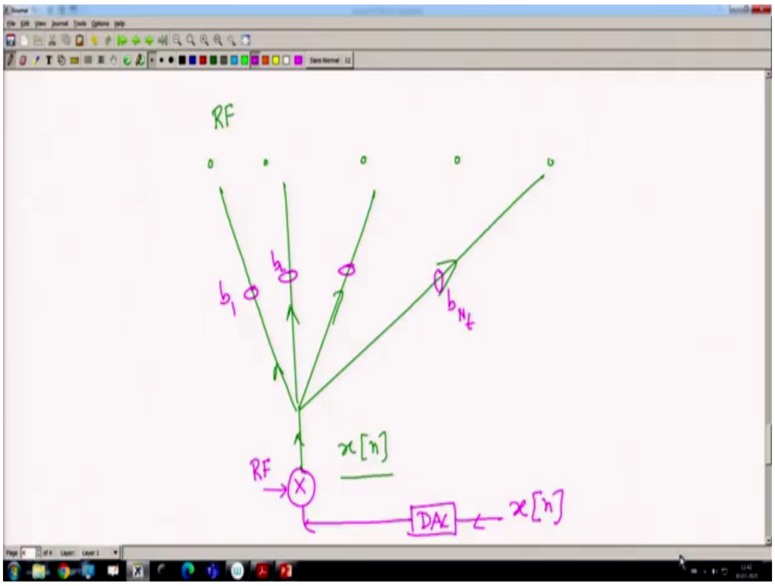

So, this is where we left it in the last class right. We saw that this is the actual architecture from the transmitter side where we have the x n, then you have a DAC, then it will have an RF. And from that from the RF, it just spread across multiple antennas for the beam forming purpose right. And then we saw that in between there will be some multiplying coefficients, and then we have to understand why they are exactly.

But details will be obviously, given in subsequent classes, but this is just like a online purpose of it. So, the issue here is that if I do not give that, suppose I directly feed them without any such b 1, b 2, like it is like a just a constant one right it directly it is fed. So, what will happen? What will happen is that this antennas may form a beam, but this beams may be in a certain direction fixed direction right. So, what does it mean?

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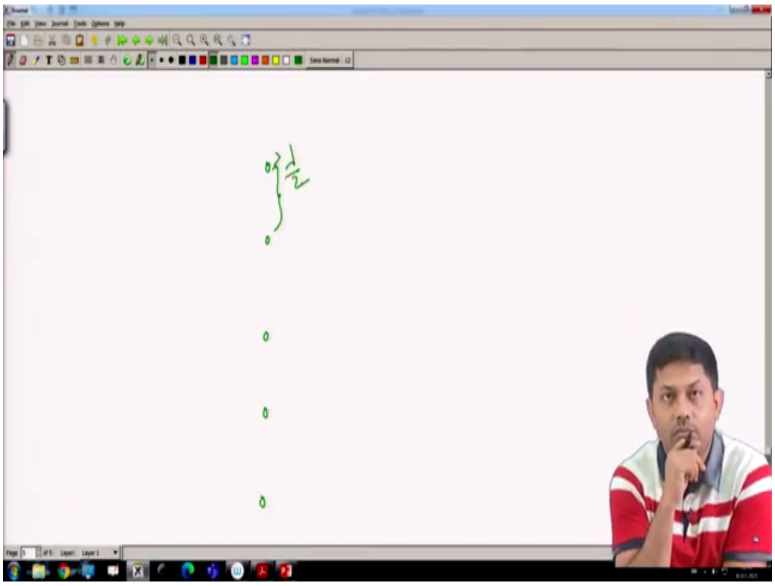

It means, I will have an antenna. These are all isotropic antennas. And I assume that the distance between them is at least greater than lambda by 2. So, this is my assumption ok. So, this distance is always greater or equal to lambda by 2. And you can imagine for a millimeter wave that is an advantage right. So, within a small geometry you can keep so many antennas.

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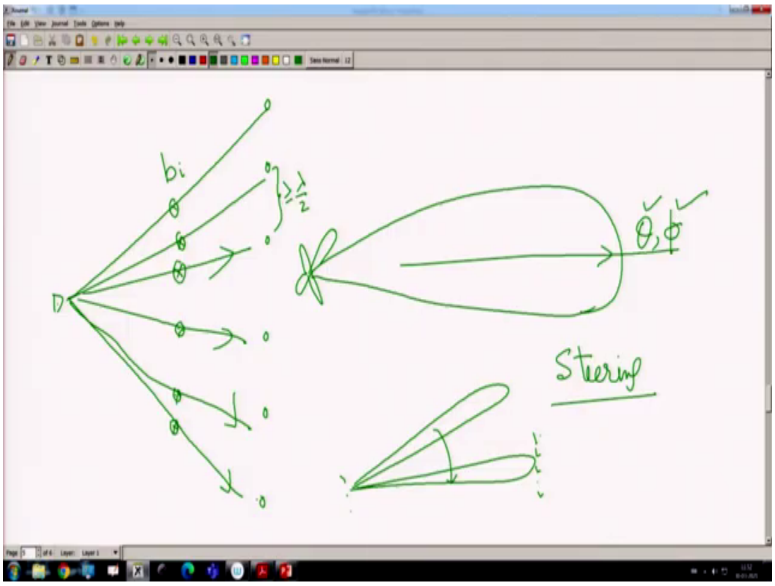

Now, let us say I have these antenna configurations and there may be one more. Let us assume that. So, if I feed them directly physically I am just connecting the RF data directly here. So, what is the consequence? Consequences that will form a beam, it may form a beam depending on how exactly the antennas are placed, and what is the phase difference and so on. We will explain that.

So, let us assume it forms a beam. But in which direction it forms a beam right? Because if you notice a beam or rather I would say how do you define a beam, it is like a it is a; it is a power intensity right. So, it is basically a physical physically how the power is getting transmitted, and what is the physical dimension it steps, what is the physical step it takes for the transmission. So, that is exactly the beams and all this thing coming.

When I say isotropic it is like you have an one antenna, and the power is radiated in all directions it is like a ball like a you know it is like a spherical ball. So, all direction the power is moving up. So, when it is a beam instead of a ball, you will have a some sort of a cone that is the only difference, so three dimension cone, so it will be going in a cone kind of things.

Now, in which direction it is going right? Now, any beam or any power pattern has to be defined in terms of theta and phi because it has an azimuth as well as it has an elevation angle that is how we define it right. Either you can define it in a x, y, z because three dimensionally I would view it, or I can define in r, theta, and phi – polar coordinates.

So, whatever it is. So, which means that in if I just see in a very simple two dimension pictorial view, I would say the beams can be somewhere like this. It created a beam. It created a beam like that ok. And there may be some side lobe here and there whatever based on how the antennas are configured ok.

So, it will the direction I am talking it will have you know certain elevation angle. It will also have certain azimuth angle. Clear? I am not drawing three-dimensional, three dimensionally you can imagine it, but I am not drawing in three dimension because it is difficult to visualize it.

Now, the pointer is that this may not be the theta and phi I want. Why? Because you do not know where your receiver is. Suppose, somebody tells you this is where your receiver is, that means, that particular receiver will also have some geometrical position xyz coordinate; in terms of polar, it will also have some sort of a theta, and phi kind of coordinate here.

Now, that may not be same as what this theta and phi are. So, what does it mean? It means that you may be transmitting in this direction from this set of antennas, but your receiver may be sitting somewhere here. So, you have to change your direction; you have change the direction of your beam. So, you have to change from this direction to this direction either it can be theta direction or phi direction depends which direction you need to change.

So, this concept like I have I am having by default one beam because of the antennas positions if I just feed them directly I will create that, but that may not be the right direction in terms of where the receiver is sitting. So, I have to transmit or rather I have to you know I have to move the beam in a certain direction of my intention. So, this is what is called the steering. This is called steering ok.

Now, this steering is not done by the antennas ok. So, this to do the steering that mean yes a beam is created, but now I want to steer it. Steer it means I want to change the direction of the beam. To do that, I need to put some sort of a, I need to put some sort of a multiplier here, the phase. Basically, what am I doing? I am changing the phase either elevation or azimuth whatever direction. So, I am doing I will do some sort of a phase change of my beam.

So, this is precisely what is done here that I am changing some of my phase ok that mean if I think of b coefficient multiplication, so this b coefficient or b i coefficient the ith part it is some sort of a phase change. That means, the effect of multiplying this b vector is nothing but a steering the beams in a certain direction the phase change I am doing it ok.

Now, there are two points here. If b is a, if b is some sort of a you know say complex number by multiplying by which I can steer the beams, can it be any complex number.

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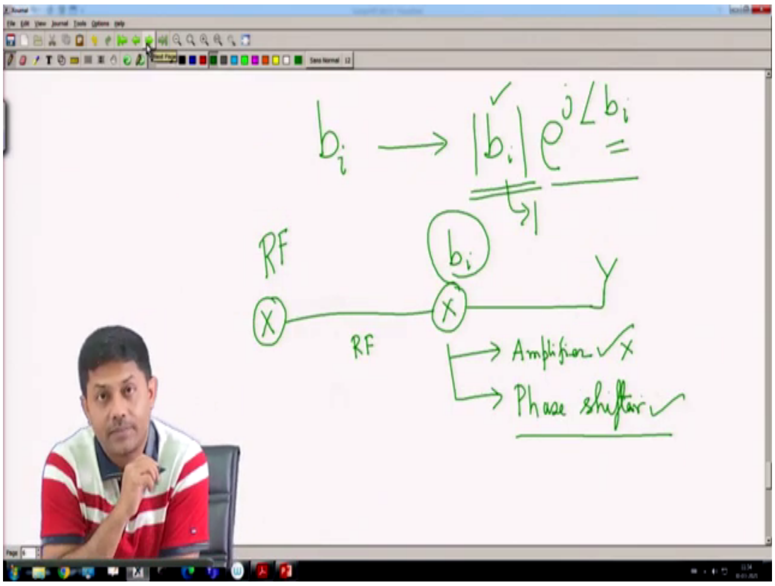

What I am trying to say is that can the b i can the b i take the general form of something like that. You know mod of b i into e to the power j angle of b i. Can it take this general form ok? Nothing stops it from having. Yes, because it is a complex number because I am multiplying with some complex number, and because of which it is you know doing a phase shift.

The point here is that if you have multiplication of b i with any such you know any such real number, what is the impact of it in an implementation? Say this is my RF modulator, output of my RF modulator. And this is further getting multiplied by a b i. So, this is my RF signal. Then it finally, goes to power amplifier ok. Power amplifier is just a booster.

I have not drawn power amplifier in my diagram in this diagrams or any of these diagrams because it is given. So, there may be a power amplifier, either just after the RF usually that is how it is given or it may be just before the antenna, but it can be just after the RF as well.

So, I have not drawn the power amplifier because it is like a equal power booster. So, I have not drawn. So, I have let me not draw it to confuse you more. Let me not draw that power amplifier is there somewhere. Let us purely concentrate on the physical aspect I am talking.

Now, this is fitting the antenna here ok. Now, what is this b i? This is a complex number. How can I implement it in an RF? So, you need to have an amplifier here then you need to have some sort of a phase changer as simple as that. Now, such things are very easy. So, you need to implement. So, to implement a simple b i, you need one amplifier right, you need an amplifier here and then you need a phase shifter right.

Now, phase shifter is very easy to do or phase shifter is easy to implement in a RF context. But what about this amplifier? This is an RF amplifier. So, what I what was our RF amplifier? RF power was a power amplifier whatever we have seen LNA, power amplifier, they are all amplifiers. So, which means that does it mean that b i will have individual power amplifier and then phase shifter?

So, if I have say from this RF, I have say hundred such antennas. So, what does it mean? It means that I may need 100 power amplifier that maybe too much right that maybe even too much to control it, because power amplifier itself comes with lot of area and cost. So, it is not a wise decision to have too many power amplifiers here. This may be very tough. So, power amplifier man may be just a common part.

So, what I can do is that I do not want to encouraged I am not encouraged to have a power amplifier rather I can just have a phase shift. So, which means that this itself puts the restriction that this b i, this part can be just one ok, I am only interested in the phase part.

So, this amplifier is not a very favorable component for us to implement. If somebody comes up and says that they want to implement an amplifier also, but if the cost permit if the area permits most will come to do it nothing stops, but usually that is not a very favorable thing because if I have hundred antennas it means I have to have 100 power amplifiers which is not a very good sign of you know design right. It is not easy job to do that.

So, we will be dealing mostly with the phase shifter, not the amplifier part. So, that means, all these b i s that we have talked about are mostly phase shifter ok if it is in RF. We will talk more about that. If this particular phase shifter is not implemented in RF or somewhere else that is the different issue. But as long as we put this you know we want to do up steering, I better put it in the RF domain, then amplification may not be a very good some solution here.

So, I will be just putting a phase. That means, the structure of b i what I should what I should say here the structure of b i is more of a phase shifter rather than an amplifier. So, this key part you must remember it ok. Now, let us get into the other part. What about the receiver part, the similar things can happen right.

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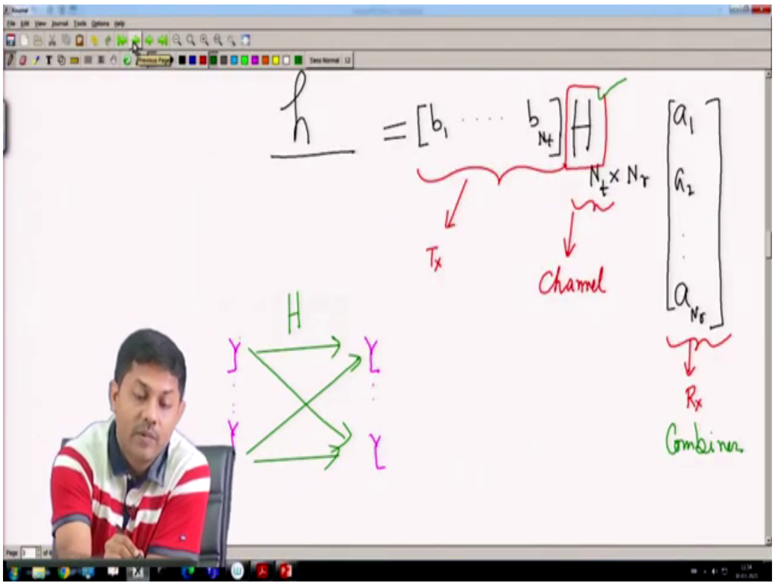

This a 1, a N r.

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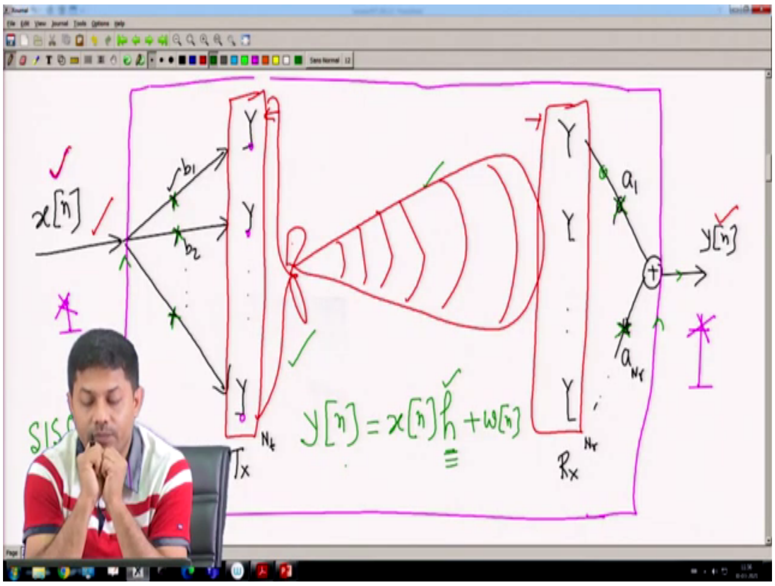

Well, it all depends on where you exactly combining it. Are you combining at the RF level? If the answer is yes, then again a 1 and a 1 to a N will have a just a shifting property, phase shifting property. If the answer is that they we want to do it after the RF or in the digital mode, then you can implement an analog you can implement any of the amplifiers.

What I am trying to say is that you put a digital multiplier here, I mean digital demodulator sorry RF demodulator here take it through the ADC, and then you try to combine it well and good. Then all this a 1 to a N r can be like a normal digital complex number multiplication.

Then you can have amplifier, you can have you know phase shift or everything. But if this thing is done at the RF level which is also done RF level, then a 1 and a N r will also take the same form as b 1. It is also like a phase shifter ok phase shifting way of combining it ok.

Now, let us go into the channel part this h part ok. So, now, in a very simple summary what we have learnt? We have seen b as a beam shifter or rather beam steering jump. This channel remains as a channel, we cannot help it. And the r s at the R x side this a 1 to a N r is more of a combiner.

Combiner meaning we have so many data coming and how optimally you can combine them so that I can get a single stream of data provided my data that I transmit is also a single stream. I am talking of a SISO, SISO case not in the MIMO case. So, this is what the scenario ok. Now, let us concentrate on the channel part. As we said that we have to do some sort of an approximation to make this whole scheme work. Now, we have to understand what are the approximation and why they are done ok.

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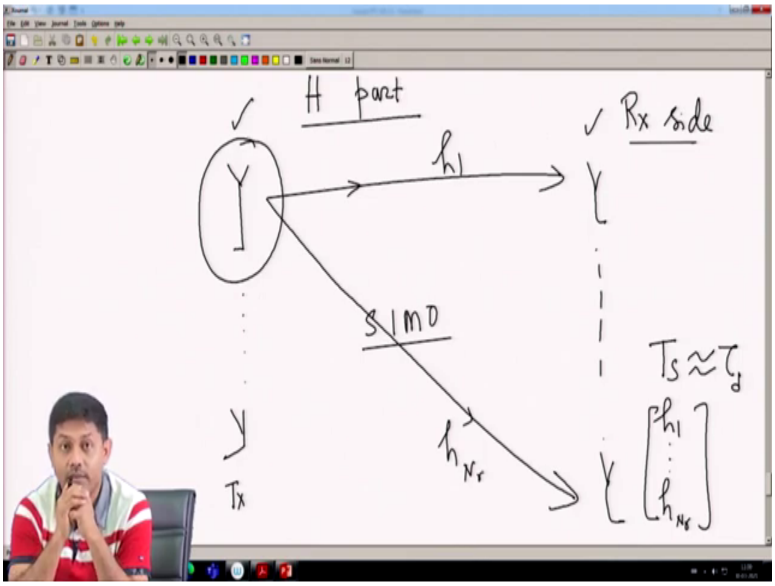

So, now, let us characterize the H part. Whatever we have learnt for retracing from antenna to antenna, will the hold true here? Of course, that is the fundamental, they all hold true whatever. But over and above to make the things simpler, we would like to have some sort of an approximation that is the key goal here, ok.

Now, as we said this H is nothing but a channel that you see it from multiple antenna to multiple antenna, from multiple antenna to multiple antenna. Now, for the benefit of our discussion let us assume that I am at the R x side because we have to build the whole model of H. So, I am on the R x side ok.

So, let us also assume a simple thing just for modeling purpose, and we will come back to this multiple antenna system that from the transmission transmitter side just one antenna is present not multiple antenna. Because if so it is as if like it is a SIMO system – Single Input Multiple Output system, I am assuming that first, and then we will go back to the multiple input side as well ok. So, this is our first goal is.

So, that I am assuming that there is only one T x here multiple R x, model that part of the channel and then come back to model the rest of the T x antennas along with that list of the T x antenna. So, that is our goal here. So, what are the, what is the consequence here? So, it is as if like I have one antenna and from there the data's are going ok.

So, if you think from your earlier you know earlier notion and also one more point here, here the here also I making small assumption here. The delay spread is comparable with your sampling frequency. So, what does it mean? It means that whatever your sampling time at the digital set the T s is comparable with your delay spread tau d. So, that it is as if like a frequency flat fading.

Let us understand the frequency flat fading first, then we will definitely go into frequency selective fading. So, that means, this whole antenna to antenna, this is more of a kind of a single tap channel. So, that means, from here to have single tap channel here to have also single type channel. This is what our key assumptions here ok.

And let us see how I can I mean is it a difficult things, is it totally different from what we have learnt it so far? I mean it is just like a SIMO channel right. So, it is as if like I can say this is channel is h 1, then channel is you know h N r, it is nothing but something like that right h 1 to h N r. What is the big deal? This is what we have learnt it right.

Yes, finally, it will be coming like that. But there are approximation to make our life simpler from millimeter wave. Because moment I want to go into millimeter wave those b and those a that steering vectors and those you know combiner it is it will be very difficult to design if such approximation whatever what I am going to explain it are not assumed or very tough to do. And these assumptions are real practical assumptions ok. Let us understand that ok.

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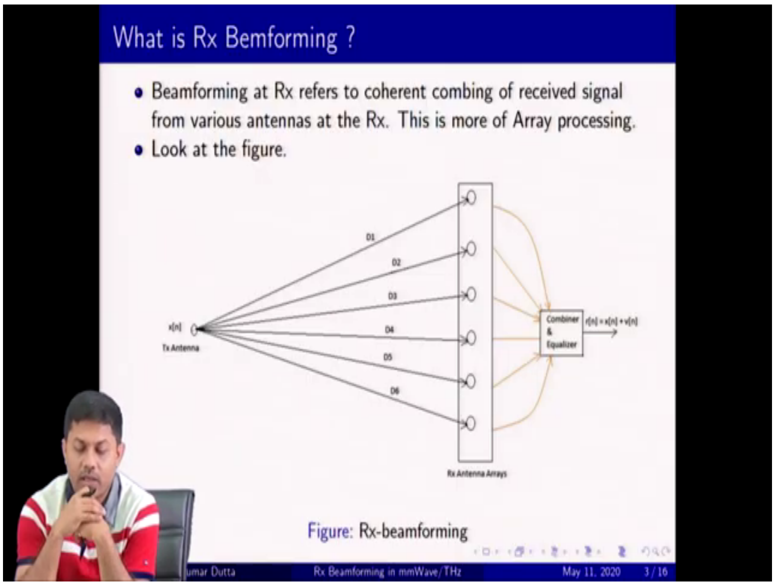

So, here I am just here I am showing you some of the slides that I made it for you for ease of understanding. So, let us assume this is what our scenarios. Let us assume that I have multiple antenna at the R x, and by transmitter side I have just only one. It is antenna; mind it, not the data stream. Data stream is symbol single. So, it is a SISO system ok.

At the Rx side, you can see there is a combiner here, combiner and then equalizer whatever. So, there is a combiner here ok. And let us say from this T x antenna, you have different distances through which the ray comes into the antenna here. So, let us assume that from this T x antenna single antenna, we have assumed it, it goes to in.

So, in this particular figure, I have assumed 6 antenna just for your ease of understanding and let us say that there 6 such distances that is the first thing that we always say that from this antenna there are 6 rays going. And I am in this case I am not assuming any reflector or scatterer, plane yellowish.

From there because as I said the approximation that you have to understand the philosophy of the approximation. So, the first easiest thing for any approximation is to do the approximation for the easiest scenario, then you go for complicated things. What is the easiest scenario?

Easiest scenario is that single antenna multiple reception. Then you assume it is a simple yellowish, no reflector, no scatterer, will come one by one ok. So, this is the simple scenario. So, no reflector or scatter is as if like you are in the you are in the space ok.

Then you introduce the reflector, scatterer, everything, and you will see that how exactly the a model changes here. So, this is my scenario ok. Got it? So, from this antenna transmit antenna, you have 6 such receive antenna, and the distances are D 1 to D 6 that is the basic assumption. And no reflector it is a pure line of sight communication ok.

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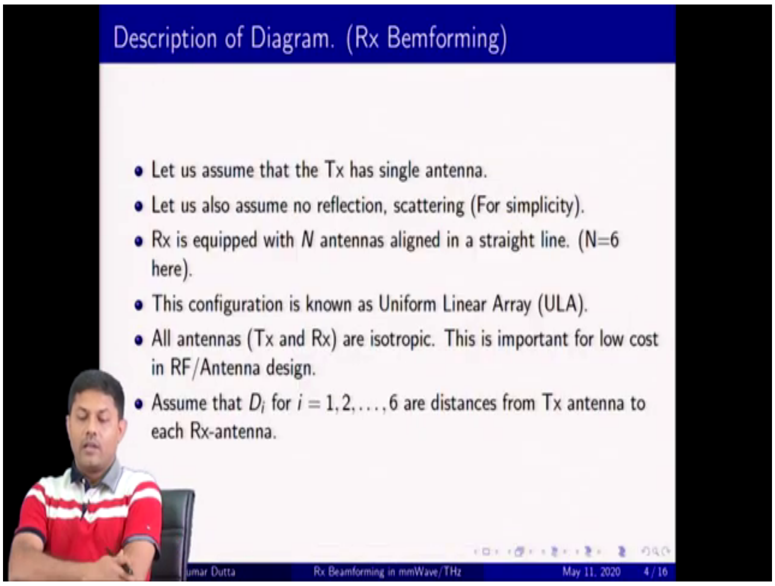

So, basic few assumptions that we have assumed here. I just reiterate what we have learnt it that Tx has single antenna, and no reflectors and scatterer for simplicity. Then we will bring it back, finally, that is what our millimeter wave part. And Rx has you have in this case 6 such antennas.

And this we have explained that this is mode of a uniform linear error that mean all the Rx antennas are placed in a line just line maybe in a z-axis or x-axis or y-axis just in a straight line ok. And all the antennas are isotropic antennas because that is what we start with. We do not deal with directed antenna. We do not deal with dipole antenna or those kind of antenna. We deal with a simple low cost isotropic antenna and that is the purpose ok, ok. And there are 6 distances D 1 to D 6.

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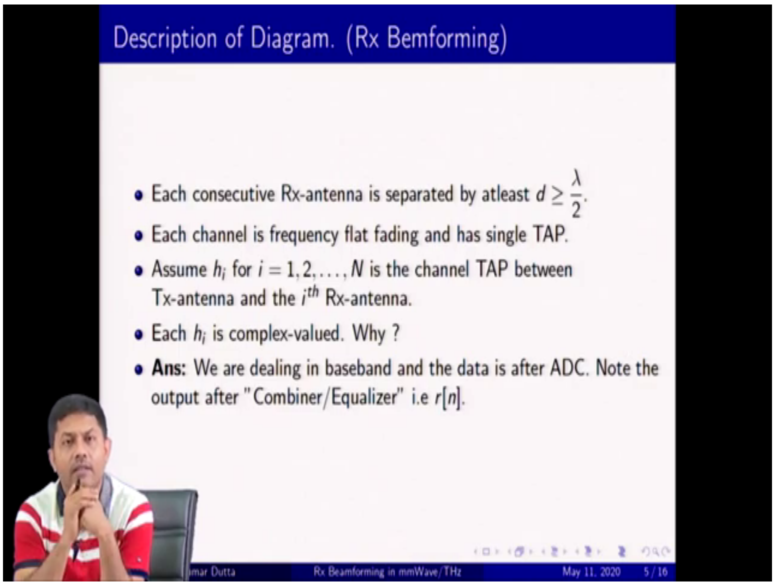

Let us see what happens. And this is some more assumptions. And each Rx antenna is that the distance is d, assumed to be d. So, that means, the distance here that this antenna the first antenna to the second antenna the distance is assumed to be small d not the capital D. Capital D is the distance from the transmitter to the receiver antenna structure.

But the distance among the antennas at the receiver side is d for the two consecutive. And the first antenna to second antenna it is d, second to third d and so on and so forth. Everything is a very equally spaced at d antennas ok. So, and that d is assumed to be lambda by 2.

Channel is again assumed to be a frequency flat fading because why again we assume that we want to take a simple case, then we will bring back the frequency selective one ok. So, that means, there will be only one antenna from the Tx to each and every antenna. Now, look at the fourth point here. Each h i is complex to valued.

Why h is complex value? Because if you look at our earlier discussion h will be complex it is as if like you are viewing the whole thing from a baseband right. So, h is a complex for us, because you do not deal I mean though this is an antenna to antenna which is in pure RF domain, but at the end of the day you will be looking at from the baseband point of view right. So, here I am assuming that h i is a complex number. So, this is the key part of the assumption.

So, though h i should be a real number because I am in a RF domain, but the point here is that as the whole thing will be done or rather then I will view it from the system prospective in digital domain, I will assume h i is a complex number for a simplicity ok. So, that is the more realistic assumption because I am making you know I am making you know I am making the things in from a digital perspective, ok.

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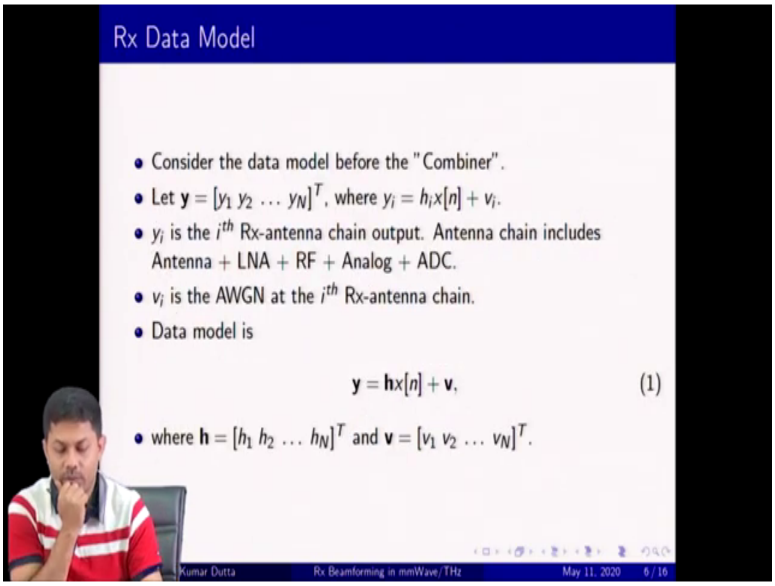

So, this is the data model. I am not getting into that part.

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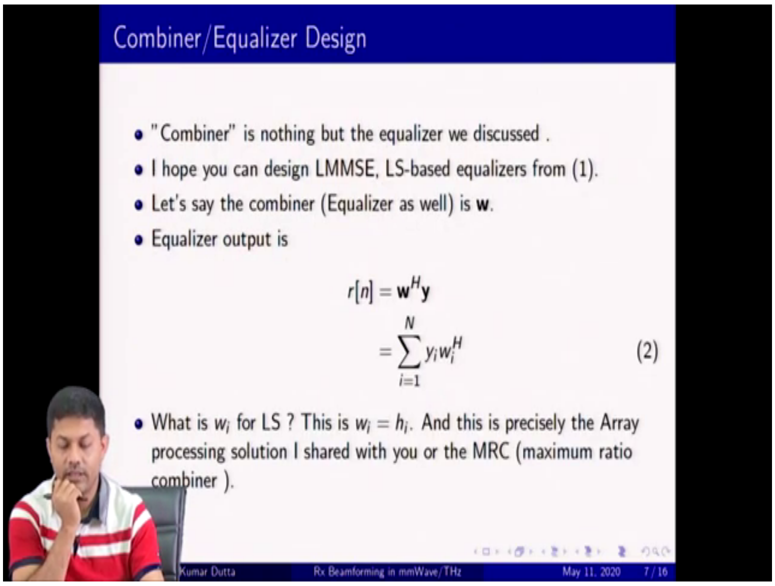

And finally, equalizer combiner and all ok.

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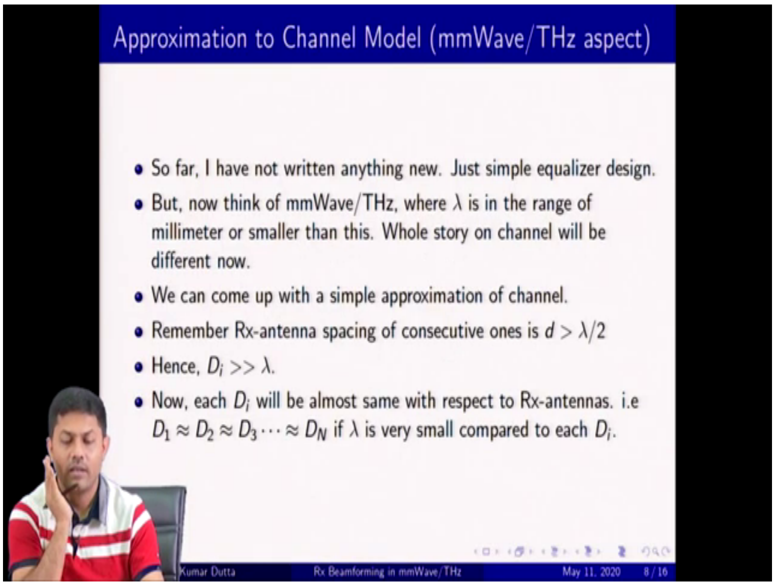

So, this is what our basic assumption ok. So, what are the things that are the assumptions, some of the assumptions I have already explained. Now, here the fifth assumption D i is made very greater than lambda. So, what does it mean? I am assuming that I am creating a far field scenario not a near field scenario ok. So, what does the far field meaning?

So, it means that Tx to Rx the distance between them is much, much larger than your normal at least two, three times of your lambda at least that is a very fair assumptions right. So, that part is a another critical assumptions that all these D i are really, really big it is compared to lambda it is really big.

Now, that brings a very important assumptions for the last one. Look at the last point. What does it say? It says that if D i, each and every D i is large enough compared to your lambda, and the antenna spacing between the every Rx antenna is just a small d which is in the order of lambda by 2. What is this capital D i? Are they really differentiable with respect to the R x? Actually, no. Why? Look at this way look at this way. What I am trying to say here is that this is a very critical assumption.

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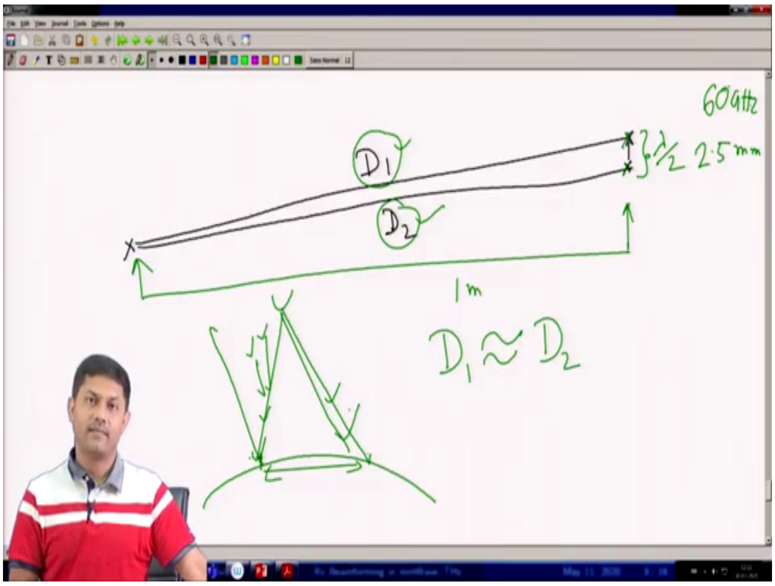

So, from here from this antenna, so there is an antenna here there is an antenna here, and the distance is D 1. From this antenna, there is one more antenna here ok. This distance is D 2. And I am assuming a far field and this distance at least lambda by 2. Now, think of a scenario say I am operating at 60 gigahertz. So, what is this lambda? Lambda is 5 millimeter; lambda by 2 is 2.5 millimeter. Imagine 2.5 millimeter the distance between this antenna and this antenna.

Let us assume I am slightly far field. So, let us assume the distance between them is say 1 meter, probably 1 meter can be thought of as a slightly far field kind of in this scenario. Will the D 1, if there is no reflector and scatter, will the D 1 and this D 2 will be different really?

It will be different logically, but as because the distance between the antenna itself is like a 2.5 say millimeter at 60 gigahertz. And if I stand 1 meter away from my transmitter, then this D 1 and this D 1 are of very insignificant different in their magnitude, that means, this D 1 can be approximated as this D 2.

The similar scenario happens when you are on earth, the distance between you suppose this is earth surface and this is the sun. Suppose, a person stands here another person stand here is the distance between the him and distance between him, distance between this person to sun and this person to sun will be different? Yes, logically, it is different because earth is a curved surface. You cannot say that there will be same.

But this distance is so large and this distance between the two person probably I am just standing in front of another person maybe few meters, even it is a kilometer this is millions of millions of kilometer. So, what is that you assume that this distance and distance are always same because it is so large.

Now, when they come to a particular point the tiny difference would really matter. So, it is as if like from the sun each and everybody is like an parallel they are receiving the data as if like that because everything is like parallel. And this is the key assumption in our case as well ok.

Now, with this I stop this class today. And from the next class, we will talk more about what are the other assumptions and approximations. So, this is the first assumption – critical assumptions that we make is the distances from the transmitting antenna to the receiving antenna for a far field is made equal. And that is a very critical assumptions ok, for my channel model approximation ok.

So, with this I conclude the class now. And we will continue for the next classes what are the other key assumptions that is coming into picture because these assumptions build the foundation for my approximated millimeter wave channel model ok. And as you can understand, I am not really deviating from what we have learnt from our 6 Gigahertz retracing model, but this is just a assumptions.

And we will apply our retracing model and we will see that because of this assumption our retracing model will give you much more simplified channel that is the job here ok.

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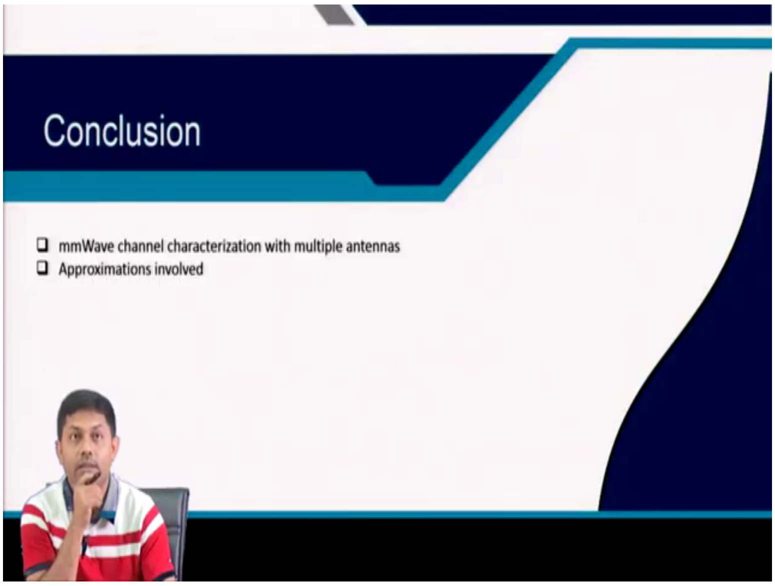

So, these are the conclusion that we have. We are in the process of characterizing the millimeter wave channels with multiple antenna and we have just started the approximations part. So, the first approximation that we have done today is the distance approximations ok. We will, continue that in other approximation in subsequent classes.

Thank you.