Signal Processing for mmWave Communication for 5G and Beyond
Prof. Amit Kumar Dutta
G.S. Sanyal School of Telecommunication
Indian Institute of Technology, Kharagpur

Module - 05
MmWave channel model
Lecture - 26
MmWave channel model with RX beamforming

Welcome, welcome to Signal Processing for Millimeter Wave Communication for 5G and Beyond. So, today we will be continuing the module 5, which is the millimeter wave channel model and then in this particular lecture, we will be talking more about the channel models from the antenna point of view. And, we will also introduce what is called a beam forming ok.

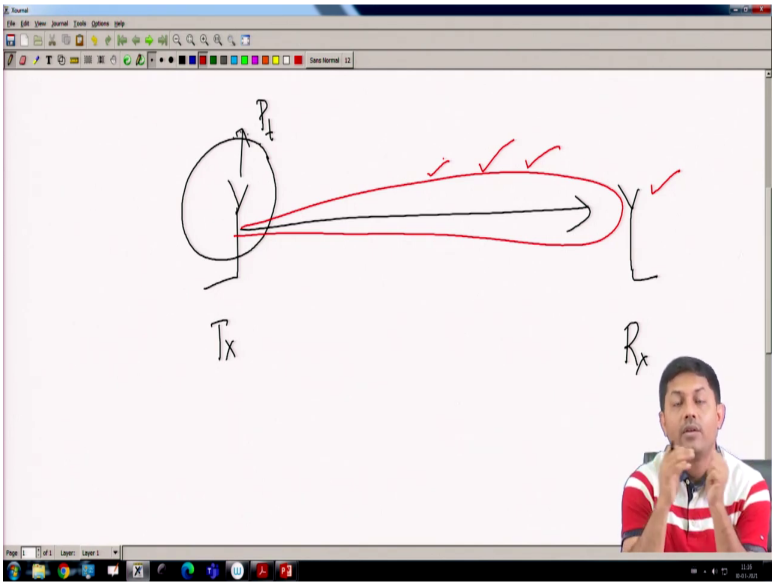
(Refer Slide Time: 00:54)

So, mainly within this short time we may be just introduce what exactly the channel model from the multiple antenna point of view ok. So, what we discussed last time is the following? So, we discussed that in a millimeter wave, because the key issue in the millimeter wave is the path loss ok.

At the same time it may also have other environmental issues as well as it can have various phenomena related problem, which will degrade the signal quality greatly. And, that was kind of absent I would say those phenomenon's were absent it is not absent, but the effect of those phenomenon's were not. So, significant compared to the millimeter wave in the 6 gigahertz domain or sub 6 gigahertz domain. And, we have discussed in details why they should be like that in the higher frequency in the higher RF frequencies.

Now, to mitigate that problem we cannot mitigate the environmental absorptions right because that is a part of environment. We cannot mitigate a reflectors activity or a scattered activity, because that is a physical you know physical phenomena and you cannot stop that. The only thing that we can stop it is that, how to improve the you know received signal quality? And, thereby increasing the reach of the signal at the receiver that is the only thing we can do ok.

(Refer Slide Time: 02:38)



So, what does it mean? Does it mean that you have to pump in more power at the transmitter level to increase the reach, suppose if you have an antenna here? Say I have just one antenna here and this is what my you know receive antenna here. So, this is my T x antenna and this is my R x antenna.

Now, because it is a millimeter wave the path loss will be so, high for whatever reason either due to the you know the plane path loss like, which is dominated by the Friis equation or it can be due to absorption or other phenomenon dependent things, what about the reasoning?.

This reach is not more than 100, 200 you know meters, if it is just 30 or 40 gigahertz. After that it will die down the signal itself will be dying down and R x antenna will not be able to you know recognize it. So, so, what is the mitigation plan? Because, we have to from an engineering point of view we have to do a mitigation.

So, does it mean, that I have to increase more and more power here does it mean that. So, that mean if I increase you know P t the transmitted power; obviously, it will increase the reach of the signal at the R x. But, that is not a very good solution why? Because you are increasing P t meaning it has two problem.

You are consuming more power which may not be good for the environment or anything and there are lot of other regulatory bodies, which will have a cap on that. Second thing is that it is a cost also right, because whenever you increase your P t, the cost of transmission will naturally increase it ok.

So, because of that increasing P t may not be a solution. So, what we discussed that or can we send the signal, in the direction of the receiver. That means, instead of sending the signal in an isotropic manner, can I send it in a directed manner, which means that if I know this is geometrically, this is where my receiver is present why do not I just send the power towards that.

See this could be one solution and that is a very elegant solution. Now to do that you have you know two approaches; one approach is that you change your antenna itself. So, that mean either you can take some sort of a directed antenna, like a dipole antenna, or a horn antenna, or there are many I mean there is a laundry list of antennas where you know they are all delicate like a directed antennas. Or there is one more method and this is what we will be discussing subsequently in those classes.

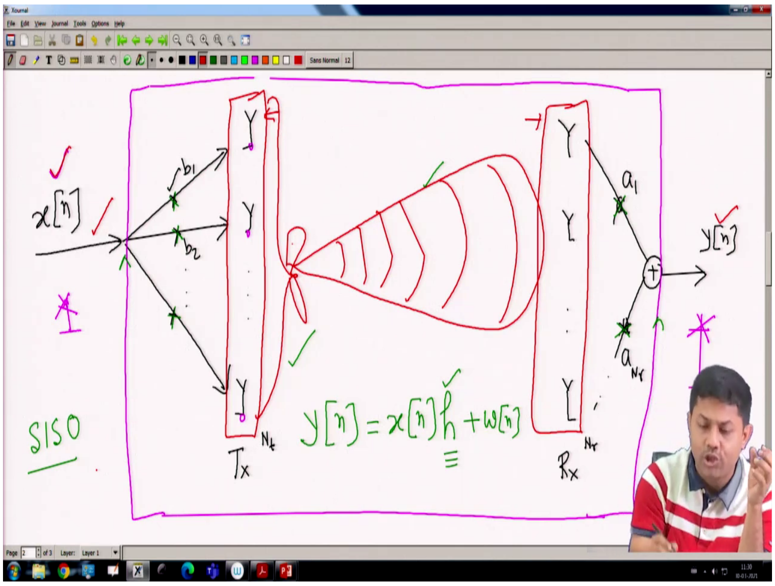
So, the question is that if I do not want to take the directed antennas. Can I create the similar sort of you know the spectral or the similar sort of power, using a low cost isotropic antenna. Because, if it is a directed antenna like a dipole or a horn antenna, the first thing is that they may not be physically miniaturized right.

They may be large in shape and also they cannot be put in a very small handset kind of you cannot put a horn antenna in a small handset, you cannot put a you know elliptic antenna in a small handset kind of things. Probably base station can afford that, but not just not definitely in a small handset right.

So, I need to have a small physically small dimensioned antenna, which is nothing, but a you know isotropic antenna. And, can I create the similar beam using that. If the answer is yes I would definitely prefer that. And, that is what we will drive the millimeter wave communications in the subsequent classes and so on.

So, we will not be using our directed antenna, because we may be thinking that I am in a best state I may be having a small handset. So, our beams which are inevitable to have will be created using the isotropic antenna. Now, let us talk about that. So, if that is the you know that is a must have feature in a millimeter wave communication, how would my you know communication scenario would look like.

(Refer Slide Time: 06:46)



So, which means that its not one antenna that is driving my scenarios, I may have a multiple such antennas I think we have explained that part. And, I can have the antennas in a line like uniform linear array or I have explained that, I can spread the antenna in a certain you know plane, that is called UPA uniform planar array or it can be in a certain geometry in a 3D steps array we will explain all of them.

So, fundamentally what will happen is that this is my data streams. Let us say I want to transmit a single data stream, but physically it may have to go through, physically it may have to go through a multiple antennas ok, this is from the transmitter side. And, there will be something here also that we will explain it later ok, that will be explained.

So, that is something called a steering, but from a simple beam forming point of view as we have just discussed that I need a beam. So, this is what my transmission scenario. Similarly, at the R x side also, I would like to have or I like to have I would like to catch the radiation in such a way that my you know my reception is much better. Either I can create again if again a big flat antennas or I can create again a beam forming in that case.

So, I can have beam forming or the beam kind of radiation, either from the transmitter side as well as from the receiver side. So, both way now it will be coming. So, now, once this comes into picture I may combine them with some more things will be here just like your antenna also. I am not explaining right away. And, then I can combine and I can get a receive signal.

So, this is the key difference between sub 6 gigahertz sub millimeter ever not the millimeter [laughter] I would say sub 6 gigahertz transmission and the millimeter wave transmission or even a terahertz transmission. This is the key difference, that I need a set of antennas here, I need a set of antennas here to create the beam to boost up my power ok.

So, does it mean that I am forced to have mimo communication? Actually, this is not a mimo communication. Mimo meaning multiple input multiple output, but that is from a input side that in the data point of view I am not sending extra data here. So, look had it been isotropic antenna or had it been a sub 6 gigahertz what would have done, what would have been done? Instead of multiple antenna here just put a single antenna ok.

So, what does it mean? If I have just a single antenna, because I have a single data stream I can just put a single antenna there. At the same time at the receiver also I can put a single antenna there. So, this is just like a SISO communication, single input, single output communication. So; that means, if I view my data from a pure you know baseband point of view. Let me put a different color it will be easier for you to understand.

So, if I view the whole system from a baseband point of view. Suppose, I am standing in a baseband I am sending like a baseband, I am receiving like a baseband that is what my view of my system right. So, I am standing here and I am receiving it here. So, how do you see, is as if like I send a digital signal and I am receiving a digital signal as simple as that.

If that is the case what does it mean? This whole black box, whatever I have drawn this black box is no longer like a mimo communication, it is no longer like that. If you look at it very carefully, it is just like a one black box having one input I mean one output. So, this is not a mimo communication.

This is a multi antenna communication, because there are multiple antennas are involved, but it is not a multiple input meaning this input they are not involved in this case. Now, that will also come into picture, there is a mimo beam forming and mimo millimeter wave communication that will come definitely it will be discussed in this course. But to start with you have to understand the basic difference between the mimo communication and the multi antenna communication here.

So, this is not a mimo communication. This is just that it is only for creating beams pattern. So, it is only to boost up my snr. I would say that because if I create a beam what will happen? It is boosting up my snr I am creating I am putting more and more I am ensuring that more and more power gets received at the receiver rather than, they are getting spoiled if had it if it was just like a isotropic antenna.

So, these antennas are all isotropic antennas, we will explain that. So, these are all isotropic antennas, but the way I will put them and that is what the content for subsequent classes the way I will put them that they will create.

So, if I look at the as a whole. So, if I see the as a whole how exactly the transmission is happening I will see, it is something like one beam is going like that as if like that, it is like a one you know beam is going like that ok. So, this is my power this is how the transmission this is what my power is going like this.

So, there may be some small here and there small leakage here and there, this is how the exact thing should be going on. So, this beam; that means, the directed power creation. So, that is the job of these antennas, in a sense that it boost up the snr. So, it is not that multiple data input it is transmitting, it is the single data input and single data input you are receiving.

So, as a whole if I look at from the you know digital side. So, I would see that the data model does not change. So, it is still like a y n is equal to some x n some power constant plus some noise, this is how I will see that. Now, what exactly is h scalar quantity as you see standing from here to here?

So, now, we will characterize this h. Now from a digital side it is as if like one just scalar, but if you go little deeper inside, it that mean if I stand slightly deep inside it suppose I am standing somewhere here, its no longer like a 1 quantity like a matrix channel will come.

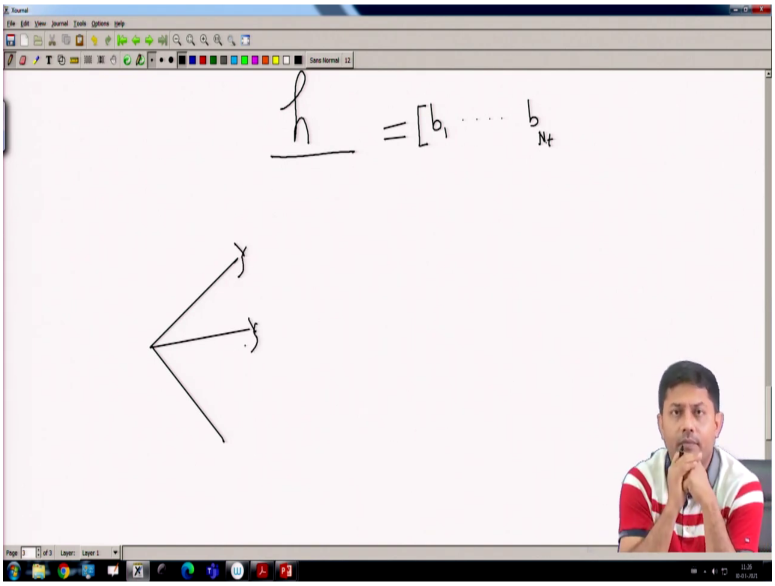
So, we will now characterize this. So, this our job is actually to characterize this h in the millimeter wave context, how exact? So, this is the fundamental architecture of the millimeter wave communication from a single input and single output point of view.

So, I would still see that this is nothing, but a SISO communication. It is a single input and you are receiving a single output communication. Internally there will be multiple antenna coming into picture only for creating this particular power pattern, that is the only job of this antennas ok. So, let us so, now, what are the points that we are trying to summarize here.

The point that we are trying to summarize here is that you have multiple antennas ok. So, there are three aspects that is coming into picture. So, I have put some sort of a cross here you noticed it here, I put some sort of a cross here we will explain it what does this exactly cross means. I have also put some sort of a cross here, I have not explained what exactly they are? Ok.

So, this crosses meaning there will be something there; that means, some you know mathematically there will be some complex term you can think of it will have some phase it will have some amplitude whatever ok. We will see that, what exactly it contains. Similarly, at the receiver also it will also have something like that. So, now, so, how can I if somebody gives you this diagram and say can you characterize this h can I do that definitely.

(Refer Slide Time: 15:01)



So, let us go to that part. So, in a very simple you know summary can I just model this h, this is my job. And, this h will contain what this is this h will contain three part; one part is this, one part is this model and another part is this model, if you have 3 components right.

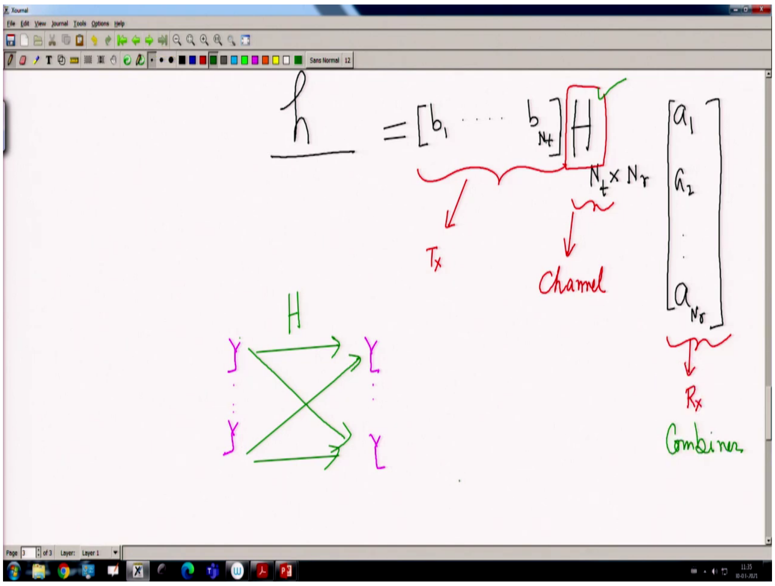
See, mathematically can I express because this h for a single antenna, for a single data to single data receiver this h is just like a scalar this is what I have drawn this is my data model, this is exactly my data model ok. So, let me clean up little bit, this is my data model. So, finally, I have to bring the h to a scalar, but I see lot of you know antennas and other multiple system constituents. So, how do I mathematically model it? So, can I do something like that?

So, can I say this h, what are three components that gets involved it will have some sort of a input multiplier, this is what is coming right. So, let us call this is b 1, this is b 2 multiplier, we do not know we will we gradually characterize it definitely. What are this b 1, b 2 and so and so forth.

And, let us say I have n T number of antenna here and I have N r number of antenna here ok. So, how do I characterize this h it is a scalar mind it, because I am dealing with a SISO case, but in between there are a lot of multiple antenna coming into picture.

So, can I create a model like this b it will have n t number of b 2, because at max what happens if b t if you do not care about b 1, b 2 it will be just like a normal line right, it is just like a normal line. It is just connected to each and every antenna right. What does it mean? It is like a 1, this multiplication is just one right, that is a that is one of the typical or trivial mode.

(Refer Slide Time: 17:20)



So, this is multiplied by that there is an h will explain it what exactly it is there is a matrix, which is a N t cross N r matrix. And, finally, this will be multiplied by let us say this is some sort of a a 1 to a N r. So, this will be a 1, a 2 dot dot a N r, can I think of it like that, this is what my h right the effective h, I would say the effective channel ok. So, now, it will have three component; one component is this, another component is this, and another component is this these are three things.

So, this is in the transmitter side. This is in the channel the traditional channel that we have already explained it so, far in our classes. So, that is I would say the channel, the traditional channel explanation whatever you have done the retracing model whatever. This is at the R x side got it.

Now you can see that, these three things combinedly make the h and that is a scalar, it is naturally a scalar right. See, if it is a this is N t cross one data this one this particular vector. This matrix is N t cross N r and this is like a N r cross one vector. So, now, what is this h? This h is nothing, but the traditional channel whatever we have explained so far in the 6 gigahertz, sub 6 gigahertz model.

So, the traditional channel was already explained right with the requesting and so on. So, that was not kind of a fire model whatever we have explained, that channel I am talking between what between this antenna, to this antenna. This whole matrix I am talking about; that means, there are it is like as if like you have N t cross you know N r mimo system, it is not a mimo system I should not say the word mimo, but as if like it was a mimo.

If you do not consider anything previously, if you do not consider anything what is being fed to the antenna and what is coming out of the antenna at the receiver. If, you just look at if your view is like a antenna to antenna it is as if like a mimo in that particular sense, but of course, this is not mimo as you said.

So, I can think of this is like a multiple antenna input, multiple antenna output. Say, N t cross antenna N t T x antenna and there are N r you know receiver antenna. If, that is the case I can think of so, there will be a channel, there is an air between that and so, that will contain all your you know all your DAC to you know adc model whatever you have explained it earlier.

So, that is everything is you know there ok. Everything is there. So, that complete model we have explained. So, this h whatever is whatever is appearing here as a channel. So, this h is nothing, but the antenna to antenna.

Now, what is the purpose of the antenna that we understand? That it will be creating some sort of a beam and we will see that, how exactly the beams will be formed. So, this is coming from the concept of array signal processing and so and so forth. Or you can also think of this is a kind of a multiple antenna, if I just put it on how to create a beam?.

So, those kind of circuit probably I can say that this is more of a antenna concept, but; obviously, you do not have to really know the electromagnetic theory here. To understand the beams, but if you really want to know it you can you are welcome to go ahead and understand that. But, this is more of from electrical engineering point of view.

So, if I have a multiple antenna, either in a linear fashion or in a plane or in some other geometry, I can create those beam structure. So, but whatever from electrical engineering point of view, I would say that there exists a channel in between; there exists a channel in between alright. There exist a channel and let us call that as an H and this is what this H is that will be some H right, some gain some array.

So, all your you know reflector, scatterer all this concept are between this antenna and this antenna, whatever you have learned that part is there. So, now, what we are doing is that? We are now creating an augmentation of our learning. So, what is the augmentation of our learning?.

We had understood the actual channel part right, from our earlier classes whatever understanding is that same understanding. So, between antenna to antenna that channel is fit. Over and above 2 extra part is coming, because why? Because of the beams part ok, because of the beams those two extra parts are now coming into picture. That how exactly I would you know, I would try to characterize that will come later, but those two aspect will come.

Because, the first one is coming at the T x this one, this b part, then this channel is basically your h and the last one is basically your my kind of a combiner. So, I would say this is I will call it some sort of a combiner, optimal combiner. How exactly you combine them? Because, ultimately you have to make a single data stream here and you have received so many data here.

Because, this is a SISO system, it is not a mimo system. So, I cannot decode individually. So, this is kind of SISO, what is the best way to combine them. Is it like you put some weight is there and combine them or can I do something that is again; that is again a we will a cover it, what should be the right way to design that particular combiner.

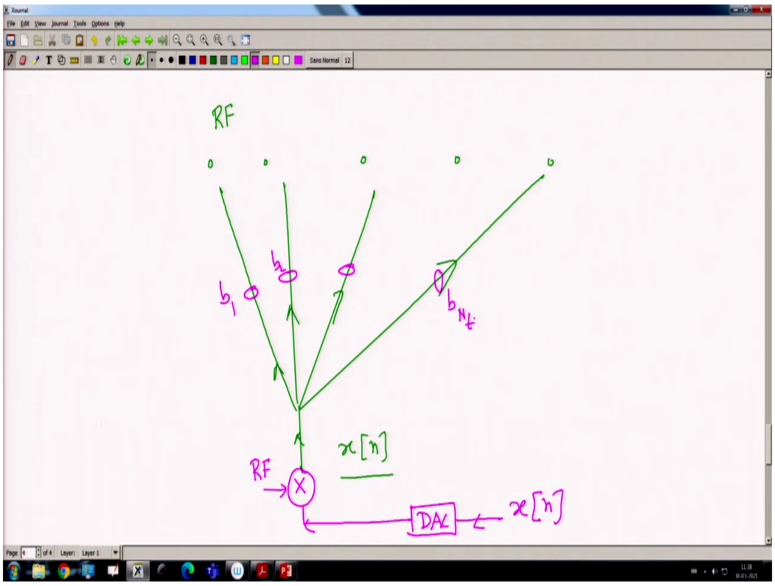
So, I would say this is receiver side, I have to optimally combine it and in the transmitter side, what exactly the role of b 1 to this b N t we will also explain it ok. But, you understand that this part is required at the transmitter side some sort of a you know phase or multiple amplitude changers and a receiver also I need something to combine the received data optimally so, that I can create one stream here. So, that is the job.

So, effectively this whole three thing creates a my h, this h. Now, we will go step by step ok. So, just as a brief, just as brief, at the receiver why do I need the a 1 to a N r, that is basically to combine them optimally. Because, I have to combine all the data stream from antenna and create a single stream. Was it the case in mimo? No, it was not a case in mimo. Where is in mimo the purpose was different, mimo was there were multiple data stream and I would like to have them in a multiple data.

So, that I can create a detection at the first level, but here that purpose is different here data stream is just one, I just received multiple times. So, I need to optimally combine them to convert to a single data point. Because, ultimately it is a single input single output system ok. What the purpose of the b 1, b 2?

The purpose of this b 1, b 2 is basically called a steering vector. What is the steering vector? Steering you know what is a steering right in a bus or in a car right. So, what does the steering do? Steering basically changes the direction right. Depending on how you exactly move it changes the direction. So, this b 1, b 2 also changes the direction of what changes the direction of the beams ok. The reason is that, if you have like a antenna, different different antennas.

(Refer Slide Time: 25:35)



Suppose, I am feeding them this is what say my x n. Now, these are antenna meaning in between there will be DAC adc, DAC and the RF signal is all, because this is RF. This part of my RF so, I am writing like a digital do not think that at the antenna this digital will be placed of course, the assumption here is that, you will have a DAC here. So, there is a DAC sitting here of course, followed by RF. So, to be very frank I would say the actual hardware architecture will be looking like this.

So, there will be a I would say there is a modulator here. So, I will put a different geometry, there is a RF modulator here. So, this is my RF. And, this will be fed from DAC and this is exactly my x n ok, this is the actual architecture. Because at the antenna it is assume that you are giving RF signal right, there is this is the actual part and it is good to know. Because, this will be now we will be playing with all this DAC, RF and how exactly?

So, where this gentleman's are sitting this b 1 and b 2. They are sitting in the post RF. So, I will be making them here you sit. So, this is my b 1, this is my b 2 and so and so forth. So, they are sitting ok.

So, this is the basic architecture from the transmitter side and similarly so, what is the purpose of it we will see that in the next class. What is the exactly the purpose of this b 1, b 2 and this b N t. So, that it will be much clearer from your point of view, that how exactly in a millimeter wave, what are the different components sitting and where they are actually sitting ok.

So, this is the actual physical chain that is sitting there ok. So, today we will stop it here for this class and then we will go to the next class. And, start doing more digging on each and every components and how exactly they are done? So in, the next class I will be start directly from the channel part first.

So, what are the channel you know we have already explained the channel part, but is there something else, that is coming into that h ok. We will explain that. There are some sort of an approximation to make the whole millimeter wave communication work, without those approximation things will break down.

So, it is important to know those approximation in the channel part ok. So, in the next class we will be explaining more on that and then definitely this b 1, b 2 ok.

(Refer Slide Time: 29:04)

So, these are the concept that we covered today just the millimeter wave channel module well, millimeter wave channel model with multiple antennas, we just started with that and the basic architecture of it ok.

Thank you.