Signal Processing for mmWave Communication for 5G and Beyond
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Module - 06
Beamforming and mmWave channel
Lecture - 30
mmWave channel model (continued)

Welcome. Welcome to the NPTEL class of Signal Processing for millimeter Wave communication for 6G and beyond. So, today we will be starting new model which will be the Beamforming part and we will also continue some of the left over channel models that we were discussing with different approximations. So, in this particular class we will be continuing the multi antenna channel model.

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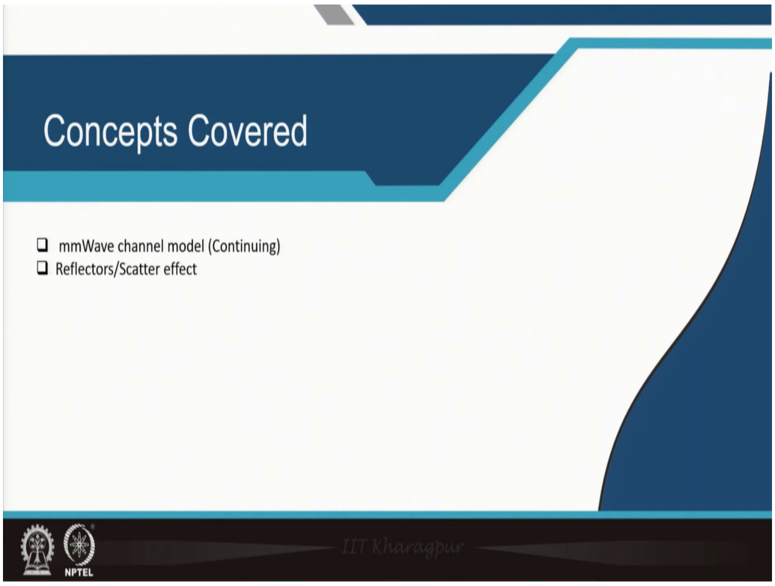

So, some of the things that we will be covering are millimeter wave channel model and the reflectors and the scatterer effects.

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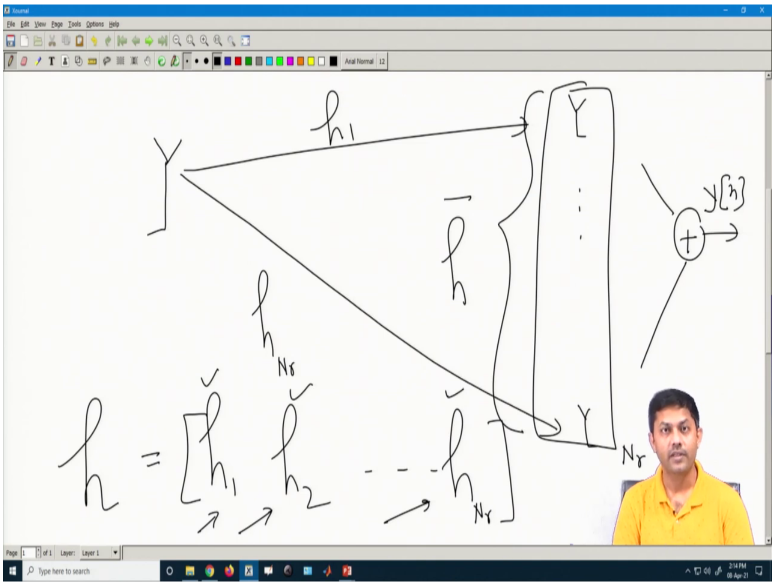

So, in the last class what we have discussed is that you have the transmitting antenna and in this transmitting antenna we are assuming that first I mean as a basic. Transmitting antenna was a omnidirectional or isotropic antenna and we were discussing what happens when they are received that multiple antennas right, that is the precise thing which we are discussing earlier.

Now, this was a simo, but it is not exactly a simo because we will be finally, converge them all together and get my Y n. So, this is still a single input single output system. So, you are discussing what the channel effect that we will see. So, in summary the channels that we have discussed was something like that this vector, channel vector. So, let us call it h vector.

So, had it been a normal case in the generalized case what was the thing? See this was h 1, this would be h 2, this would be h, let us say I have N r number of antenna. So, it will be N r number of antennas will be there and everything is a complex number right, the everything is a complex number. Who are they? So, this is my h 1 and this was my h of N r right. So, this was the normal case.

Now, when we go to the millimeter wave the only difference would be we can make some sort of an approximations right. I think we have discussed all the previous classes the approximations and using those approximation we can model this h all this individual of h with some sort of a correlation. We say that ok, the magnitude will be same only the phase will be different. So, those kind of approximation.

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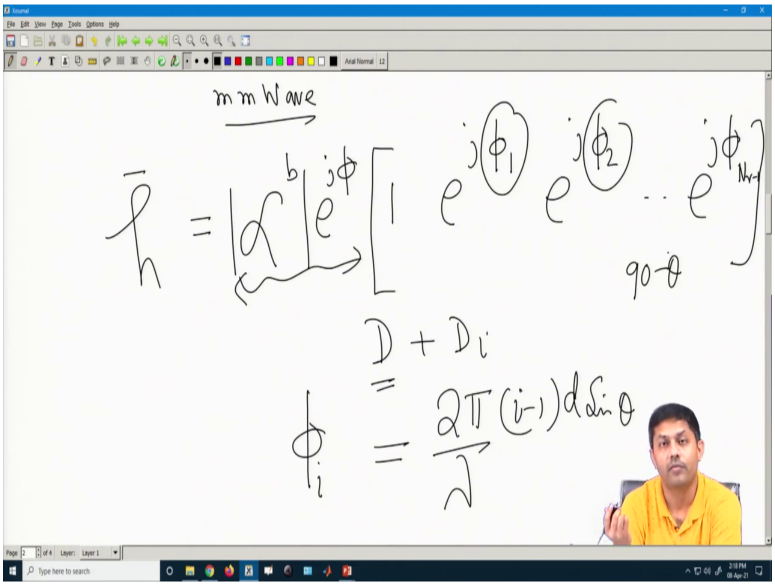

So, with that what is the effective channel wave. So, when I go to the millimeter wave the same channel will be something like alpha beta. So, this alpha beta was the it is only the magnitude path. So, I would say that is common for all the paths right because that is what we have discussed it.

And then there will be some sort of a common phase because the path whatever is there. There is a D and D plus i for ith path right. So, this D will introduce a common phase for all of them. So, this will be some I am just writing some common phase will be there ok and then it will be. So, I can call this whole thing as one complex number right. So, let us call it, so, I can think of it is a like a the complete complex number.

So, instead of writing like that I mean you can model it as a normal complex number also. So, then it will be e to the power then it will be e to the power j some phi 1 e to the power j phi 2 then e to the power j phi N r minus 1 you can adjust the indexing. So, this is what we have last time discussed it.

Now, the point here is that who are these phi, who are these phi? Now, if the antennas are placed in just like a line in a line uniform linear array then we solve this phi i or phi l if you can say that is ok, this will be 2 pi by lambda i minus 1 into the spacing between the antennas like this spacing. Next antenna this spacing if it is d. So, it will be d into sin or cos depends on which side you are thinking of the angle. So, if it is sin theta that is ok.

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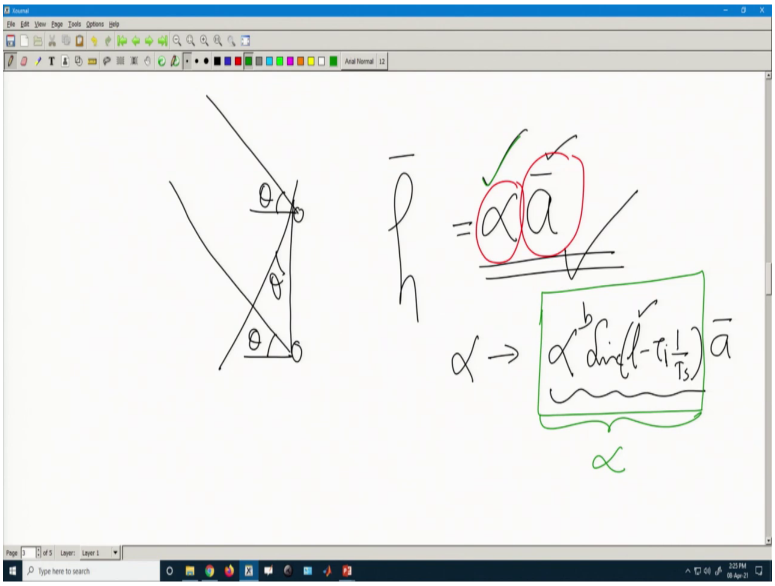

Sometime it can be cos theta depending on what angle you considers. For example, if this is the case suppose this is my antenna this is my second antenna ok. I can think this as a theta ok. So, this can be added as a theta. So, using that you can also think of something, right. So, it depends either I can think of this as a theta or this as a theta whatever depends on then it can be either sin theta or cos theta. So, that is not a problem.

So, here it can be sin theta or cos theta depending on whether sometimes in some paper you can see it is cos theta sometime you may see it is a sin theta depends like which angle you are taking. So, it is if you take a directly an angle of arrival then it could be cos theta in fact. If you say 90 degree minus theta that mean angle of arrival 90 minus angle of arrival then it will be sin theta. So, that is not an important thing. So, this is how we have seen it last time right.

So, now this particular complex vector there is a stuck difference between this the earlier one. Earlier one each and even individual points were a complex number and we did not think about the you know this common part to be out and all because it was not required for us it is more of a complex number. But, when I say millimeter wave that I will be more interested to look some of these approximation and there is definitely reason why we want to do this approximation.

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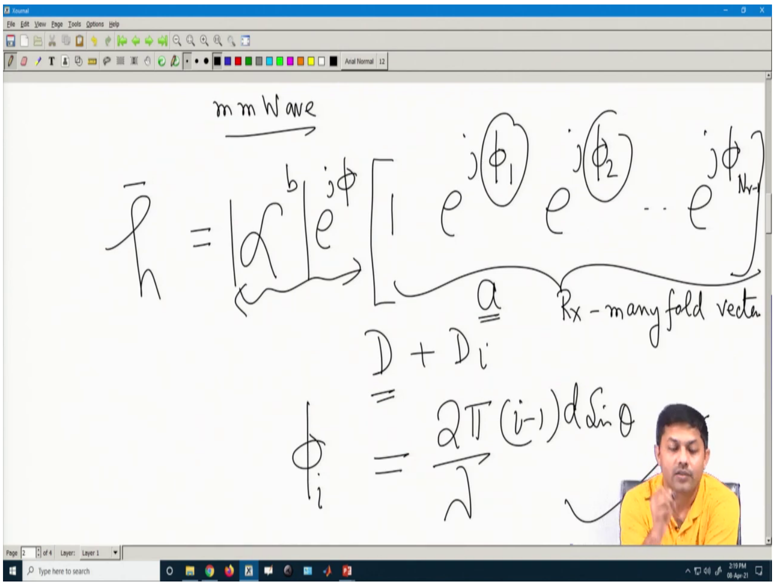

And so, this part is the I would say R x manifold vector ok. Let us say this vector I represent it as a a vector; vector a. So, can I say now my channel vector is nothing, but some common term? I am not so interested what is the value and phase some common term that is mod of alpha beta and e to the power j phase.

Let us call it alpha beta all together not discriminating the phase and magnitude. I am writing b continuously just to ensure that it is a base band, but even if you are confused with this notation of alpha you can just write in like alpha just to be safe ok, this is the vector if it is a row vector.

So, this is my channel now. And this what is a vector; a vector was my manifold vector array manifold vector. Now, this one is coming up with a one I would say there is no reflectors at all either one reflector or no reflector. I can say this is more of a line of sight kind of things.

Before I get into the other parts is this model reflecting my analog model or the RF channel model or the channel seen at the ADC that needs to be made very clear ok.

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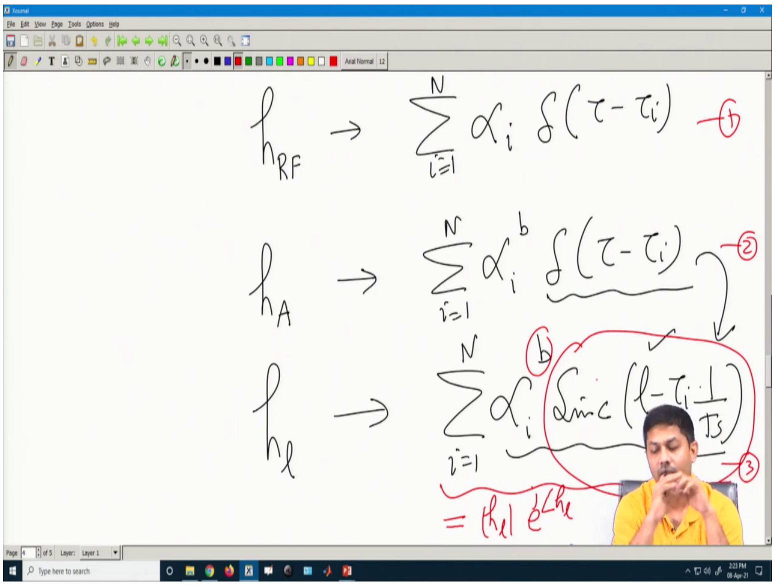

So, if you go back your earlier 6 sub 6 gigahertz channel model if you look at h of RF or h of analog and h of digital right. So, what is the only difference? The only difference is that the way you create your magnitude right. See if it was like that earlier it was like alpha I dirac tau minus tau i this was the case right. So, i is equal to 1 to if there are N number. If this is analog this should be the same alpha i b dirac.

I am repeating this so that you do not get a disconnect. What happens to the digital case? Digital case it was h l because that is the taps summation of i is equal to 1 i is equal to same thing, but the only difference would be this; this will be replaced by sinc that is the only difference. So, it will be sinc of l minus tau i into the sampling time. So, let us say my sampling time is 1 by T s. So, that was the stuck difference.

So, which means that when you go from analog to the digital the only difference would be in the magnitude this particular things will be multiplied sinc will be multiplied instead of a dirac function. And of course, this l will be coming because that tells you how many taps will be present we can unlike RF and analog.

So, now what happens to the earlier model whatever I have drawn, what happens to that? So, what does this alpha represented? Now, this part we are very clear that is the phase part. So, if you look at this earlier part or this part sorry this one, so, here what does it contributing to? It is nothing but a amplitude right, ultimately that is an amplitude. It is a simple, it is a real number it is not a complex number. So, the phase of the channel is coming from this part.

So, ultimately this whole thing I can think of some complex number with some magnitude and phase. So, I can say this is some mod of h l into e to the power angle of j of h l something like that. Whole thing I can just bundle up right, this is what it is right. Now, depending on the delay spread I may have multiple l. So, how does it translate to our millimeter wave channel?

Does it mean that when I am drawing this particular one, am I in RF model, am I in analog model or am I in digital model? I would say it is immaterial for us ok. The structure of the equation remains the same. If you look at this the structure of this equation number 1, equation number 2, equation number 3, all remain same. It is a summation of some alpha into something right.

It only depends on where what exactly those alphas are. So, when you go to the digital side extra part this sinc will be coming into picture, but I can whole thing bundle as a alpha right it is a modified alpha I can think of. So, here also when I get into here alpha this alpha is more of a generic term it is a gain.

Now, it depends on where you stand ok. So, if you stand in digital it will show you some gain. If in RF, if in analog it will be the gain, but this will remain that is the central point that would remain anyway unchanged. So, it does not really matter where whether you are in RF, analog or digital. This alpha will actually engulf that differentiation.

So, this is more of a generic model I can say think of it right. So, this if it is in digital say h this h vector whatever I am seeing in the millimeter wave context. Is this h vector if I want to see it from the ADC point of view there is no difference in the structure, so, alpha into a bar.

So, alpha into manifold vector, but this alpha will now be internally you know that is basically your it is a sinc. So, in case it is a alpha it can be internally it is a sinc of you know alpha b because I am still not considering any extra you know reflector. It is just one reflector or it can be just one LOS direct line of sight or if it even if it is not LOS it can be just from one reflector, so, multiple reflectors not coming.

So, if that is not the case there is no summation. So, it is alpha b sinc I would say l minus you know tau 1, now it will be one case 1 by sampling time into this a vector ok. Now, this whole thing I can call it my digital view of the channel ok. Now, depending on how the l is the channel will be different if it is frequency selective channel.

So, my point here is that you really do not have to worry how this amplitude comes into picture. If it is digital the sinc will be added, if it is not digital sinc will be removed that is all, but ultimately this is how the structure is ok. So, this makes the whole point much simpler. Now, I can call this whole thing as my new alpha that is all. So, that is what I have put alpha into a bar. So, it is a very general structure ok.

Now, what happens when I have multiple reflectors ok? So, this is just one reflectors. So, what is the only difference if there is a multiple reflectors? Just this summation will come into picture.

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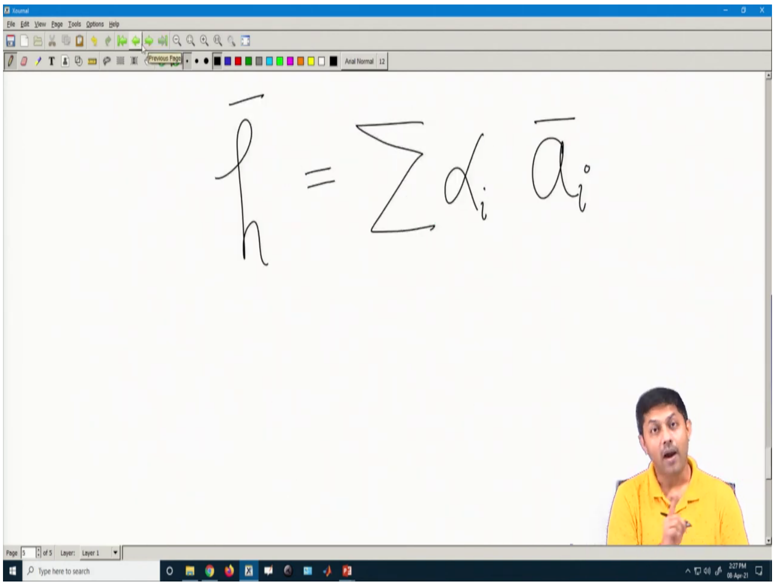

So, this new channel model if it is a multiple reflector my channel, my this channel vector will be what? Will be new multiple summation will be coming into picture. So, I can say alpha i, now when I say alpha i mind it alpha i means it can be analog, it can be RF, it can be even digital also. If it is digital internally sinc will be tagged down that is all ok.

So, this and then manifold vector a, now there are interesting points here. Will I have a single manifold vector that is something that we need to understand in this class ok. Is it a or is it a i, understand? Now, what I am trying to say is that now I am just extending my channel model.

So, this is my channel model this one. This is my typical channel model of my millimeter wave. I am done with it, but this is one filter this is one reflector.

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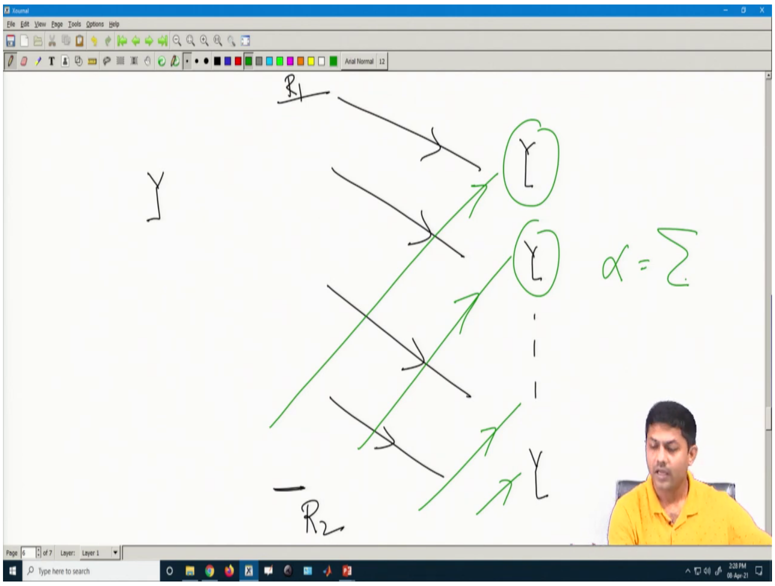

Now, I am saying what if I have multiple reflector? What does it mean? It means I have this antennas. I am just trying to extend it to multiple antenna case. Now, this is my still at the transmitter side I am still having one antenna ok, so, omnidirection isotropic. Now, there is a one reflector here which we have defined how things can be right. So, here it is like a parallelly rays are coming. This was the key assumption right. What if I have one more reflectors? Say let us say I have R 2 ok.

So, what will happen? From here also I can have parallel rays, that is the thing that is how I can think of it. So, it means at each and every antenna each and every antenna it is nothing, but two rays will be added up that is the simple way we have done it in the ray tracing model also right. Your what is your alpha?

Alpha is nothing but summation; here also the same thing will happen. It is the multiple of multiple summation will be coming. Now, the point here is that what happens to the manifold vectors. Because in the earlier case you notice it, it is very it is very much sensitive to in which direction the ray is falling.

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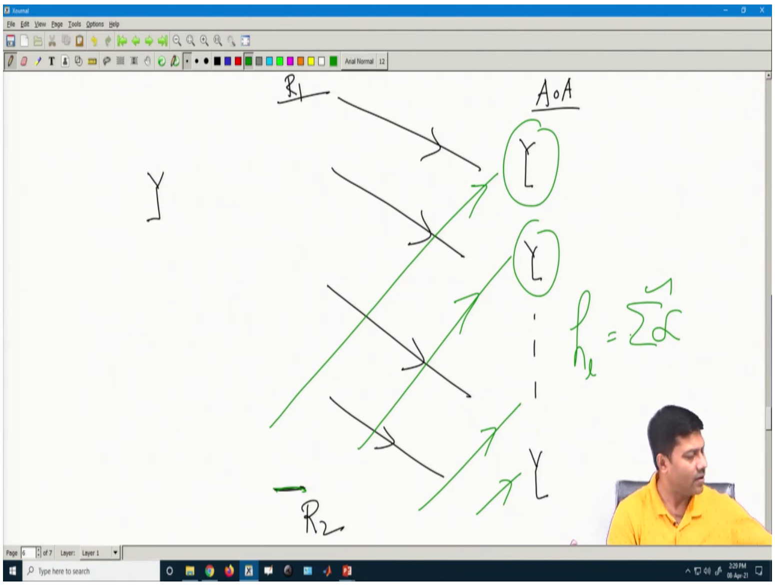

So that means, angle of arrival is coming into picture there. But, now when there is a second reflector how can I define my angle of arrival? Because this now there will be multiple angle of arrival. The rays are coming in all directions. If this is one reflector this there will be one angle of arrival. If this is a second reflectors, if there is a second reflectors this is a second reflector it also has another angle of arrival right. And if there is a third reflector that also has an angle of arrival.

With respect to the third reflector there is also another angle of arrival that is coming into picture. So, which means that if you think of that this is just a superposition of what I get. Just think of. This is electromagnetic wave and coming in all direction and one antenna is receiving this data independently. So, how can I model it? Just like in super positions right because they are in the same RF.

This is what is done in alpha also right. So, how the channel model was, what is the h l? h l was summation of alpha and all these things. What is this summation? It is a superposition, simple superposition ok. Same thing I will also do here which means my effective channel whichever I will see. There is no difference between this one and the ray tracing model.

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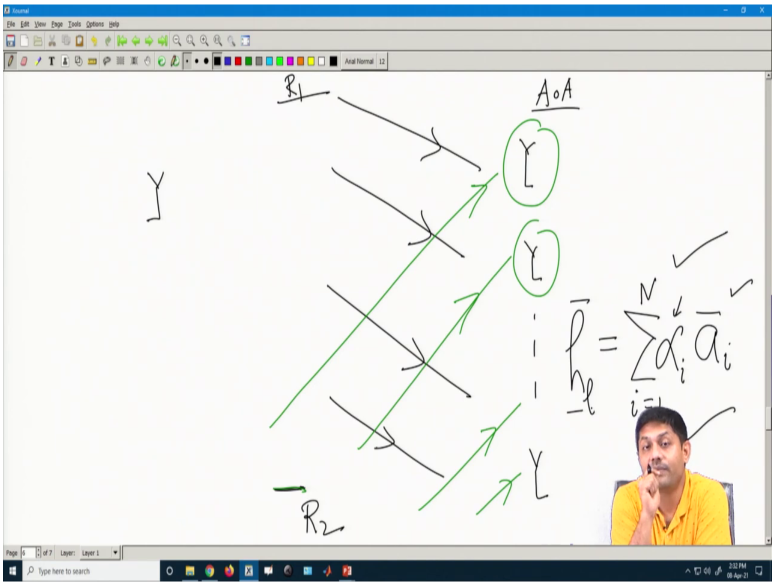

So, I would say my effective channel whichever I will see across these antennas will not be a super position of all rays coming from the different reflectors. So, I will have alpha that mean for the one reflector I have a one set of alpha which we have discussed it. And for one reflector I will have one set of manifold vector. Why?

Because, the angular parabola is different. Now, this summation is what my new channel. How is it different from ray tracing model if you do not do all these things? Same, there is no I do not see any difference here. Look at it. Is there any difference really at all? Is all are same? It just that how I split h 1, h 2, h 3, from real and so, from magnitude and phase.

So, I have just separated the phase part, but this is same as what we have done it from the previous one ray tracing model ok. So, that mean if there are multiple such reflectors the only difference would be the channel would be just super position of every individual point.

Now, if there is one I have one super position. If there is a second one I have just added up. This is my this all equation 1, 2, 3 tells me the same thing. The channel is nothing but the superposition of ray from each an individual reflectors right, reflector or scatterer. I do the same thing here as well. It is just the superposition of each and every ray whatever I am receiving here right.

So, this is precisely what I will get ok. Now, I still have not discussed what if my delay spread is large compared to my sampling time, how that would get model ok. We will come to that. So, this is clear. So, if I have multiple such reflectors each and every reflectors will be adding one manifold vectors; obviously, because its angle of arrival is different ok.

Now, what is the only difference from this one to the ADC model? You do not have to worry. Why? Because the alpha itself engulfs that part. The alpha will have sinc component ok. Because alpha has sinc component if you I can say this model is equally valid for ADC sampled also. So, this is the things I will see when I am in a ADC sample, but here catch is that I need to still say h l ok when I go to the ADC. Why?

Because if that is the stuck difference right that is the stuck difference between RF channel or analog channel and the digital channel. In the RF channel it depends on exactly number of reflectors, but when I go to the digital that is not the case. It depends on how many samples you pick up and in fact, it depends on the tail of the sinc.

So, if you continue to sample I will continue to see channel. So, that mean I can have infinite number of taps. So, that is why this index is very important for me. So, here also I will put the same thing here. So, I would say h vector for the first sampling instance l. If I change my in the delay domain if I make another sample I will get another h l.

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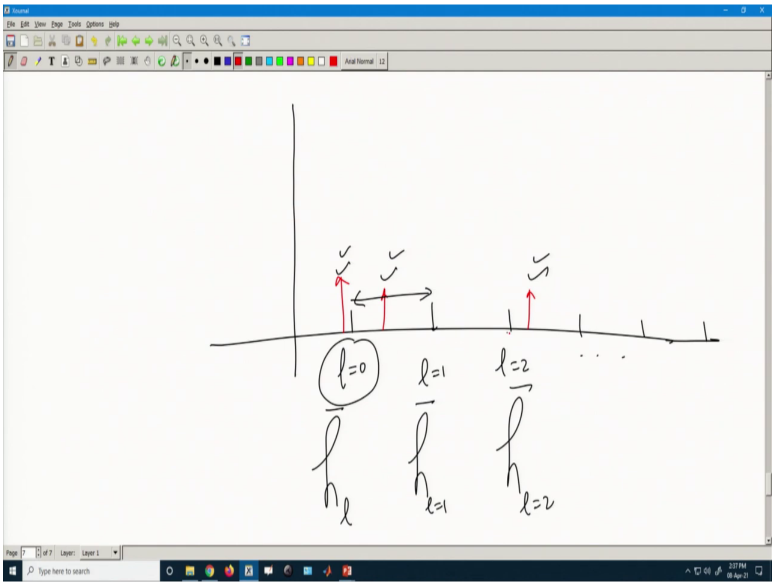

So, which means simply that if I plot my I cannot plot it because it is actually a vector I cannot plot it. Hypothetically you plot it like this is my l equal to 0, this is my l equal to 1, this is my l equal to 2 and so and so forth. In between the actual channel may be just here that is the three reflector say, but when I do a digital sampling I will see at every point I will see a channel.

So, I am talking of the first one which is the summation of all three. Second one which is summation of all three. Third one summation of all three contributed by their sinc weightage that is the only difference. So, which means that at l, I will get one vector because there are multiple antennas, at l equal to 1, I will get another set of vectors, at l equal to 2, I get another set of vector. Now, from now what is this scenario?

This scenario is basically frequency selective channel scenarios where the sampling time the sampling time this time is lesser than your delay spread because delay spread you can see this large delay spread. So, I will definitely get multiple such taps in this case, but I am so far talking of a scenario this particular scenario whatever I have drawn. Here the sampling time is much larger than your delay spread.

So, this is that particular scenario ok. So, that mean I may have a actual tap here, 1, 2, 3 taps original physical tap, but I may be sampling probably somewhere here and next sample put a different color, let me put different color and I probably sample somewhere here and the next sample somewhere here.

So, this is that scenario just one level of my taps that I will be seeing it ok. So, now next. So, this is the only difference when I go for multiple, but I am not getting into the multiple taps scenarios. In the sense that I am not getting into the frequency selective scenarios right away, but this is the concept. You will just extend it in the delay domain. I will get multiple such channel vectors I will get it.

Now, the question would be what happens to the manifold vector. So, it means that when I am in l equal to 0, l equal to 1, l equal to 2 will my manifold vector changes? Probably not, because the direction of arrival remains same, no matter whether you sample at different delay spread. So, what may change is only the gain part ok.

So, I will talk about that later when I will think of the I when I will talk about the wave dms with the beam forming. So, let us assume for our discussion that I am sampling or my sampling frequency is much lesser than your delay spread or sampling time is much higher than your delay spread. So, it is a kind of a frequency flat fading channel ok.

Now, so, this is the model that we have finally, arrived at. So, when I have just multiple reflector that is the only channel model that I will have it, but key part here is I will have different manifold vector. This is the very very key aspect ok for because every reflectors will be giving you different values of the data. Now, next I will only start it and probably I will continue it in the next class. What happens when I change the antennas from one to multiple antennas in the transmitter side?

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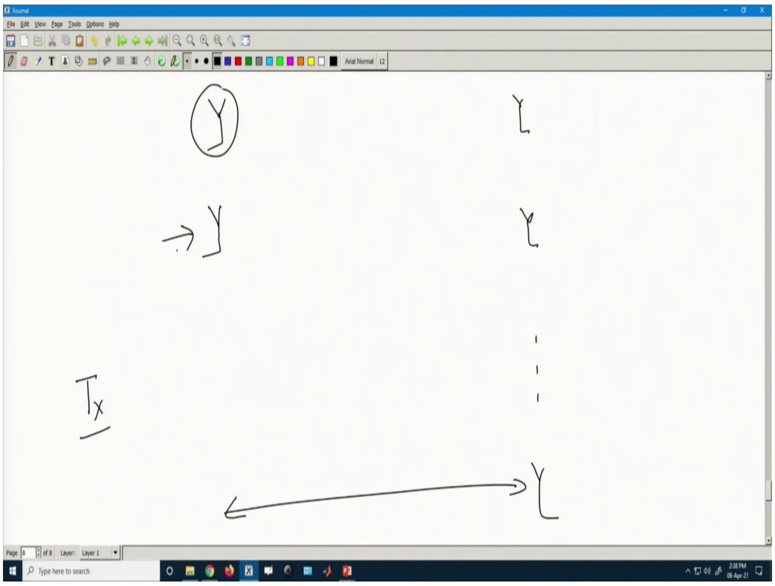

So, so far what is our configuration? One antenna and multiple antenna at the receiver. Now, what I will do? I change this configuration. If I have multiple such antenna in the T x side what is the extra difference that I will see here got it ok. So, this part I will cover it in the next class what happens when I increase the number of antenna in the transmitter side. So, this is basically the scenarios that I will be having right multiple antenna at the transmitter side, multiple antenna at the receiver side ok.

So, how exactly my channel model would be? Now, in a scenario in a in this particular scenario you can think that the channel from here to here will be some sort of a matrix right. Had it been only one transmitting vector, multiple receiving vector. It was a vector, but now moment I add extra transmitting antennas from the transmitter side now the effective channel will be a matrix.

This is what we have seen it from the earlier cases also, but now what will happen to the in the context of millimeter wave with all these approximation that I have talked about, how would I approximate that particular channel matrix, now we will see that in the next class ok.

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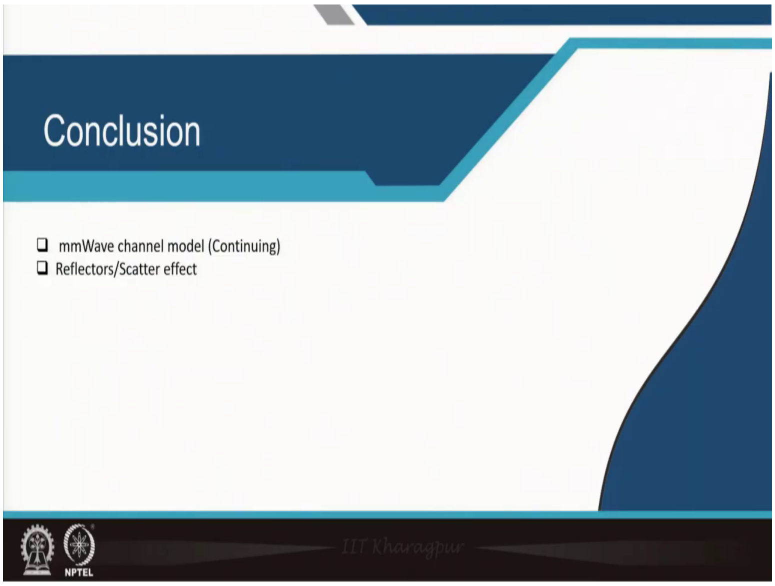

So, with this I this is what we have just concluded and the next class we will be talking about the T x side part, what happens to the T x side.

Thank you.