Signal Processing for mmWave Communication for 5G and Beyond
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Module - 06
Beamforming and mmWave channel
Lecture - 31
mmWave Channel Model
(Continuing-Tx Side Multiple Antenna)

Welcome back welcome back to the mmWave Channel Models. So, today we will be covering the transmitter side multiple antenna effect.

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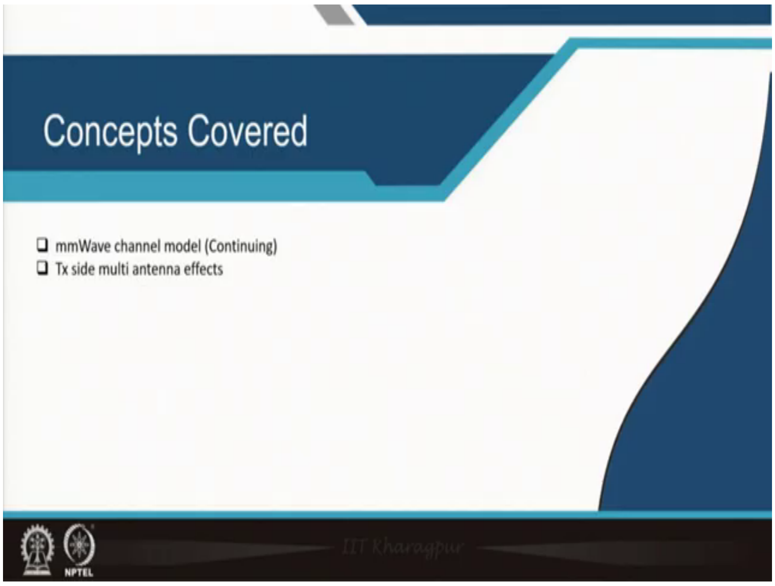

So, these are the things that we will be covering millimetre wave channel model of course continuing, but the new things that will be covered is the T x side multi antenna effect.

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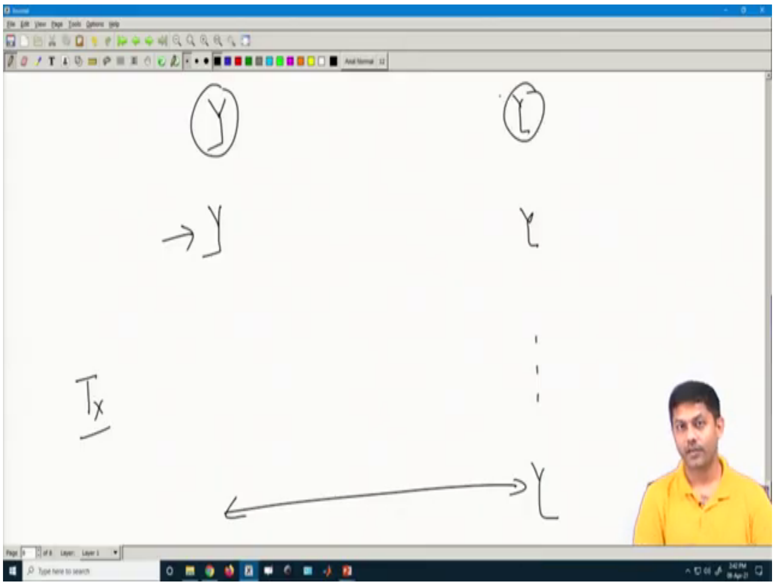

So, this is where we left right in the last class. But what happens when I introduce multiple antenna at the T x side ok. Now let us do one by one how exactly the whole thing changes here.

Let us say I have multiple antenna at the T x side, but at the receiver I have just one antenna. So, it will be easier for us to understand then ok. So, I am talking of a scenario then we will combine it together.

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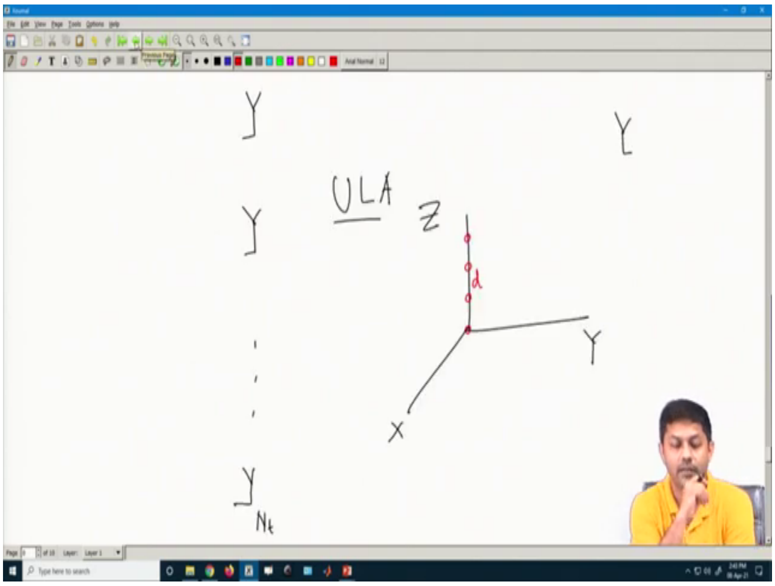

This is the first antenna this is the second antenna and I have N t number of antenna here, but at the receiver I am having only just one antenna it will be easier. So, in the first case one transmitting antenna multiple receiving antenna, in the second case we are starting with multiple transmitting antenna but one receiving antenna, then we will combine it together it will be easy for us to do.

So, now, let us see what happens? So, again the same sort of approximation we will do, but here we are saying that all these antennas are again in a line ULA. Physically they are all in uniform linear array. So that means, if you have this is x this is y this is z dimension.

So, physically the antennas would be present here like that it can cross even below also with the distance d. So, that is the antenna configuration I am talking of ok, but it is now in the transmitter side and receiver side just one antenna. So, let us see what happens to that ok. So, let us come back to here itself.

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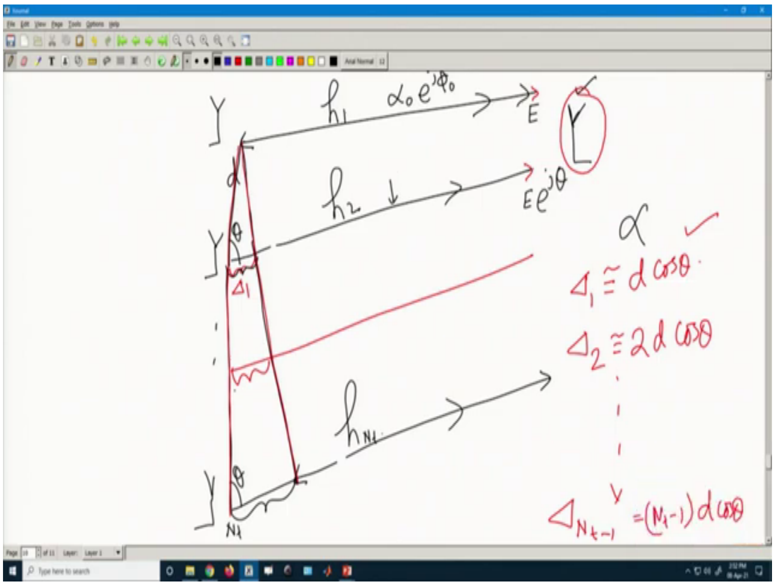

Let me redraw it again for your own benefit N t antenna equal distance d, one antenna here at this point right same set of assumptions. But now with respect to these antennas what sort of assumptions I can make?

It is like one ray is going like that alright will the second ray will be like this question unlikely. Why? Because if the distance between the transmitter and receiver is large enough where I have said that is a far field effect right, then probably this is not the configuration this is not the way the receiver will see the rays right. So, it will see like a parallel kind of thing.

So, here this would not be the case this will be more of a parallel branch it is like a parallel beam right. Why? Because this d and the distance between the antennas are incomparable are not at all in comparison. So, the distance between the d x and r x same for a millimetre wave can be 30 metre 20 metre, whereas d is in the range of millimetre it is very far I is like a far field effect right.

So, this antenna this receiver antenna will see the rays coming parallely though they are coming from different antennas, but they are spaced. So, closely it is as if like it is like a parallel set of rays ok then what will happen again the same set of effects will be existing there. So, which means that at this point if I say I have channel h 1 I mean just think from a previous 6 gigahertz channel h 2 now it will be N t ok. Now we will model this h 1 h 2 h N t correct.

So, now this h 1 h 2 h N t these are the different channel parts. Now in the earlier case they are just like a some complex number and we know how to do how to deal with it right, individually point to point each and individual h 1 is something like a summation of their own reflection. But now as they are very close by this this this radiation is going like a parallel radiation that is how the assumption here is.

Now, I can make the same approximation that each and every h 1 h 2 all this h N t will see the gain part of all these paths remain the same ok. So, the gain of each and every path is same is it different from my receiver thing. So, again let us assume the gain is alpha, because I am now forgetting my receiver side whatever I model that side I am purely in the transmitter side now same concept I bring it.

Now what is the phase difference here? So, now, instead of looking at the receiver side I will see the phase difference like this this phase difference right. So, due to this path there is a phase difference between this ray and this ray. So, that mean what if let us say I am receiving something say E just for my clarification E if I receive the amount of you know electric field E this one will be electric field E into e to the power j some phi will be there I mean I am trying to say it is an angle ok some angle will be present. Now be careful here which angle is it elevation angle or azimuth angle I have not said anything ok. So, the question is that how do I say it is an elevation it is a it is a azimuth angle.

Now currently my all configuration of antennas is in the z plane right it is not z plane z axis ok. So, in this particular case only elevation angle will come into picture, though I write it phi probably that may be confusing for you. So, make it theta I will show you how exactly 1 angle will comes here, but it can be 2 angles also. So, in that case how the phase will be I will explain it when I take the UPA Uniform Planar Array how exactly the phase will be right.

So, here it is just like a 1 phase coming ok. And that that phase is completely dependent on this path difference. So, similarly when I go to the last path, so these paths are all the same the d plus di, whatever you have drawn last time this is the same thing ok. Now I can say this is theta this is also some theta, so this this data will be there right. Again the same sort of approximation I will say that mean this path distance and this path distance are not, so different again the same sort of approximation.

So, what will happen you can what is this angle this angle this distance say which is delta 1, what was my delta 1 it will be d into in this particular case you can it will be cos theta. Say cos theta or sin theta depends whether you take the that angle or 90 minus theta angle. So, do not get into that conflict ok.

So, it can be cos theta or sin theta depends on which one you are taking ok. So, it can be cos theta also depends on which part of the angle I am considering. Now what is this theta in this particular case? This is nothing but AOD Angle Of Departure in this case.

So, I can say what is delta two the second antenna this delay would be 2 d cos theta, why 2 d? Because though it is dependent on this particular path, but I am saying this path and these paths are the same right almost the same in their values, so I am approximating. So, this is what I have seen in the r x side as well right similar thing I will do it here. So, this is how it is so you can generalize it delta N t minus 1 because this is the last one ok.

So, you can also see this will be N t minus 1 into cos sorry there is a d here d cos theta this is how the distance would be. So, naturally this particular antenna what will it receive see if I say what voltage will it receive. So this will say of course, summation of all of them right that is precisely it will be receiving it right.

So, the amount of power that this particular you know this particular antenna will be using the summation of all of them. So, what is the channel then? Then I can say my the channel. So, what is the channel is basically it is a vector right I mean how do you define the channel in the 6 gigahertz case in the multi antenna.

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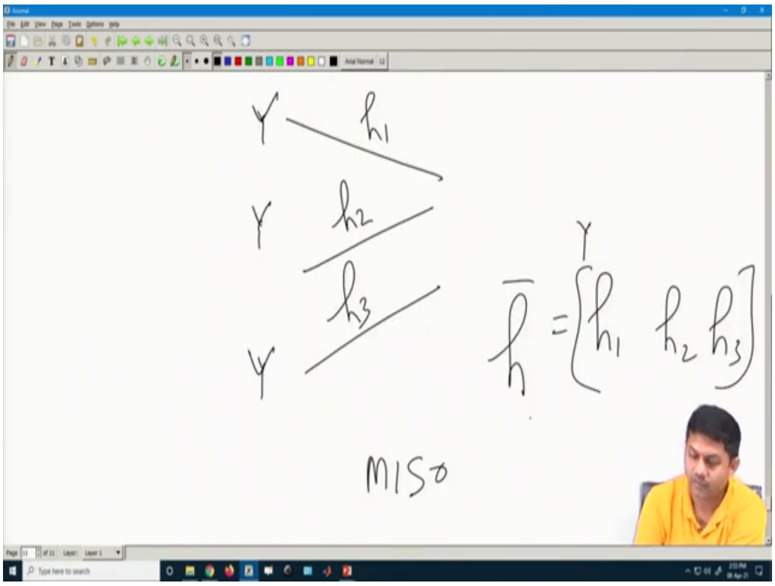

When you have multiple antenna and there is a 1 receive antenna it is a miso kind of configuration is like a MISO Multiple Input Single Outputs. Just like a MISO, but it is not a MISO it is just multiple input at the input side but 1 configuration here.

So,. So, what is the effective channel vector effective channel vector is again h bar is equal to h 1 h 2 in this particular case three I have drawn. So, this will be h 1 this will be h 2 this will be h 3 right. So, you just take the drawing from here and you can guess what should be the channel, because this will be whatever some gain into some phase will be there.

So, let us call it alpha 0 e to the power j phi 0 because it is a complex number I can always define it as a some gain and phase right. What happens to here is it alpha 1 no I am not talking alpha 1, because I am saying that as this distance between the antennas are very very small compared to my T x and r x. I would see each and every alpha is same ok that is an approximation and it is a valid approximation from the second antenna to the receiver I will see the same amount of amplitude degradation.

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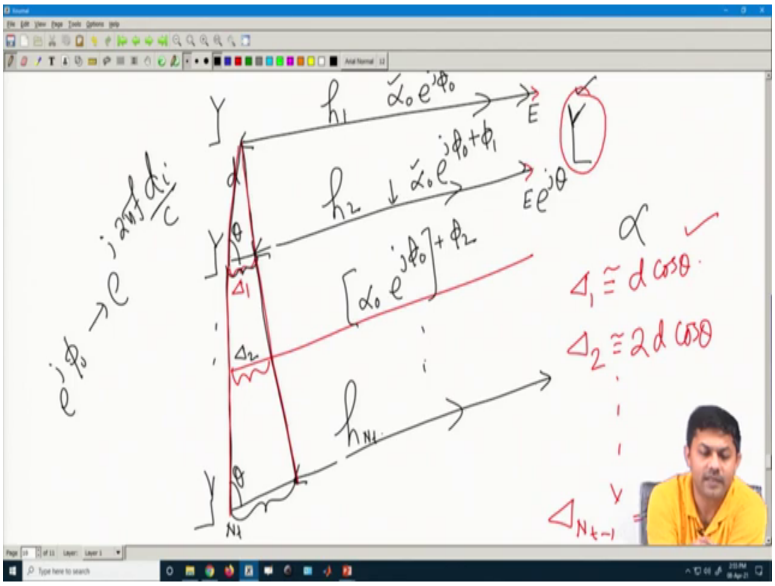

So, the alpha would remain same what about the phase there is naturally a phase because of this path and extra delta 1 path. The similar thing what we have done in the r x. So, there will be some extra phase that will be coming into picture extra phase that is coming into picture right.

What about the third part this is the channel alpha 0 e to the power j phi 0. What is this j phi 0, that is the delay due to the path it is a complex number. I would say that is basically kind of an analog things you can.

So, that is the delay we have done it in the 6 gigahertz sub 6 gigahertz that part right e to the power minus j 2 pi. So, this phi you can define it e to the power e to the power j 2 pi f into tau i right and tau i depends on distance divided by tau i depends on what distance divided by the C very similar thing.

So, that is you can you know what is phi 0 I mean you do not have to know, but some complex some complex number that will be coming the same thing. See when you go to the millimetre wave the channel concept whatever you have learnt in 6 gigahertz, they do not change at all it just that approximation makes the same concept what you have learned to take it to a different level that is all ok.

See in earlier we have defined different different alpha, now I am saying approximate it make the things simpler which is practical and that is how it is proceeding. In the third case alpha 0 to the power j phi 0 plus the phase due to this delta 2, what it will be? Let us call it phi 2 and so and so forth that is a similar thing.

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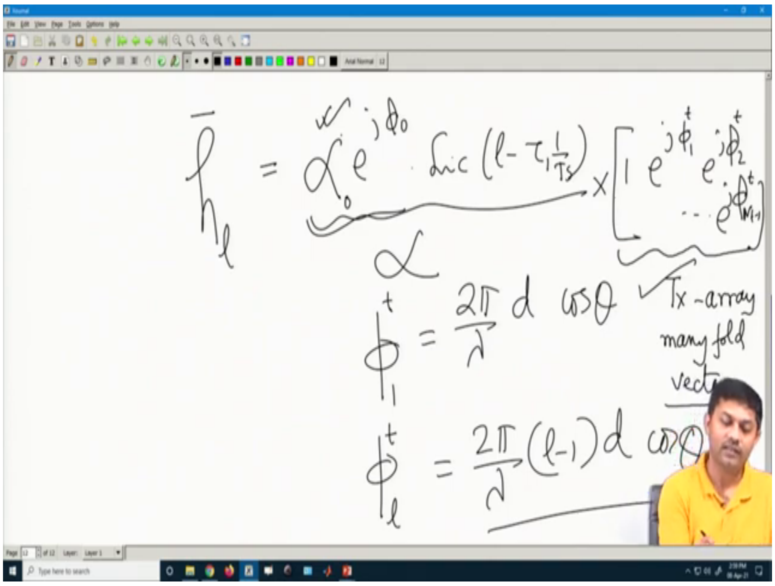

So, which means in the T x side also I can think of my channel if I think from the channel that mean the miso configuration also give me a channel similar to what I have done it for the receiver also. This will be a common alpha you can call it alpha 0 also no problem, I do not call it alpha 0. Now because alpha 0 e to the power j phi 0 this whole common term I engulf it plus multiplied by sink l minus you know.

Now, it will be one if I just consider only 1 because in this diagram I have not said any reflectors. So, tau 1 into 1 by T s this whole thing I call it alpha this is my ADC view, so then this will be alpha multiplied by again something e to the power j phi that extra phase part whatever this extra phase part this extra phase part will be now serially processed like that.

So, it will be 1 e to the power j some phase let us call it phi 1 similar things j call it phi 2 and so on so forth N t minus 1. Now, to differentiate this phi with the what I received in the Rx I introduce one more just some sort of a suffix here. So, that it is to differentiate that I am considering from the T x side, so phi t 1 phi t 2 phi 3. Now, what is this? Phi 1 t this is same 2 pi by lambda into how much it is d cos of theta. Now this theta is what is the angle of departure.

Now again the same concept come where is my angle of departure it should have 2 2 angle right, it is at the elevation angle it will have a azimuth angle. Why I am not seeing 2 angles here? I will explain that because the way I am taking the antennas are ULA antennas in the ULA antenna I will not see 2 I will see only 1 and what is the reason I will also explain it. But in this particular whatever I have drawn this will only come one angle ok the second angle will not come ok.

So, this will be my case now phi if I just generalize it l now this will be t. So, this will be 2 pi by lambda l minus 1 into d cos theta, so this is my delay part ok. Again the same many fold, now what should I call is also a some sort of a array many fold vector. Now I will call it T x array many fold vector got it so it is a T x array many fold vector.

Again this is only for single tap channel; that means, the sampling time is much larger than my delay spread ok and here also I have not assumed any extra reflectors or any extra scatterer. It just either it can be a yellowish or it can be just one reflector where you know just like one direction the things is moving ok.

Now what happens when I introduce the frequency selectiveness it just instead of h bar I will have h bar l, at different different l in my delay spread, I will see this matrix differently that is the thing. Will this vector array T x array many fold vector be different probably not, because the only difference that I will be having is this alpha part that part will be different because that will be like a sink tail right.

So, it may be a different sink tail I will get it, but definitely the phase part which the way the ray is moving that will not change ok. So, this is the T x side configuration now let us combine it, what happens when I combine them together ok.

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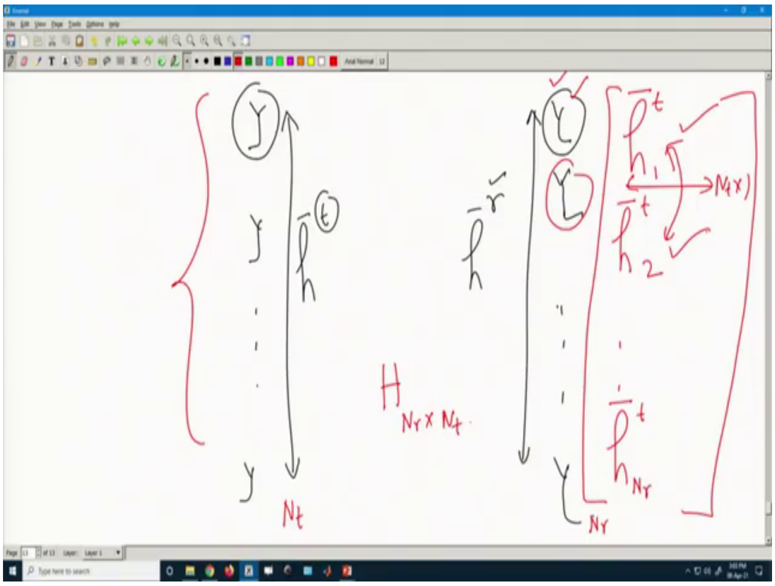

So that means my third configuration will be when I have multiple antennas in the T x side will have multiple antenna in the R x side ok. So, let us try to understand that, from this side I will get h vector corresponding to t from this side I will get h vector corresponding to r. That mean h bar t I will get it as if like I have only 1 receiver, h bar r I will get it as if like I have only 1 transmitter, now let us combine it ok.

So, which means that take this configuration and things separately that mean I have N t number of antenna first time I am viewing only 1 receiving antenna ok. So, what is my channel? My channel will be h bar into t that is the only channel I will see ok. You can think it opposite also complete opposite; that means, I have just N r number of receiver and only one transmitting antenna you can say that I have only 1 h bar vector I will see that is the channel right that is the channel it will be.

Now the same let us say I am fixing my transmitter side. Now, the same transmitter side now I go to the second antenna ok, what will I see I will get let me put a different notation. So, the for the first case that means, for the N t number of antenna I have N r number of antenna in the receiver, but I am only viewing the first one. So, I will get a channel vector transmitter side let us call it one with the first antenna first receiving antenna.

Then had it been second antenna similar thing I will get it had it been how many such vector I will get I will get N r number of such vectors I will get it right. What is the dimension of this vector N t cross 1 you just stack them together what will I see. So now, this is what my composite channel I will start seeing, but there is a catch there it is still not complete. What happens to these two this we have to get a relationship, but similar things can happen right.

So, it means that the way I am proceeding for the MIMO system meaning multi input and multi output channel model here is that, I have multiple input in the transmitter side, but I am receiving only one receiver first 1. Then I am taking the same set of multiple input, but I am going to the second antenna, same set of transmitter will be going to the third receiver antenna and each and every antenna receiving antenna with respect to each and every receiving antenna I will say different different channel.

Of course that is how this whole thing will be some sort of a matrix right, I mean this is natural I mean if you just forget about millimetre wave what is the channel between N t antenna and N r antenna it is a matrix. What is the dimension of this matrix it is the N r cross N t matrix that is all that is what I will see here also I will see the similar one there is no difference. So, this is some sort of a matrix will come I am trying to formulate how the row will be how the column will be as simple as that ok that is the only thing.

So, this is how my progress one. So now I will see one manyfold vector with there is the fast antenna I will see a second manyfold vector not manyfold vector second channel vector with respect to the second antenna. Now I try to find out what is the relationship between these two, that is the only thing I have to do here. So, what is the relationship between the two ok?

Now, what is the relationship? So, let us go to the what is the relationship between first antenna and second antenna it is only the phase which phase it is the received phase. That mean with respect to angle of arrival how much the phase difference I will see from first receiving antenna the second receiving antenna that is only difference correct right.

So, which means that from h 1 to h 2 t h 1 t 2 to h 2 t the only difference would be there will be an extra phase that will be coming into picture due to the angle of arrival this is what it is right..

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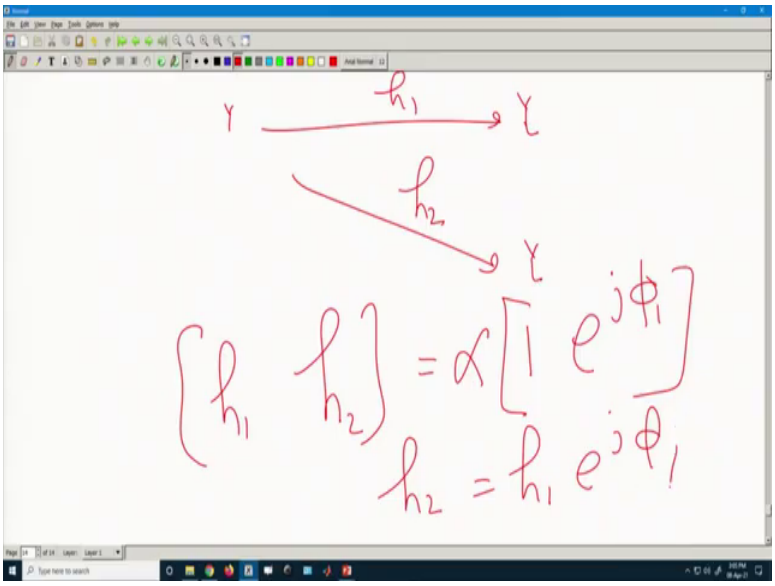

So, if you go to the first one, so let us say this is my first antenna this is my second antenna receiving antenna first antenna this is my second receiving antenna. So, this is my h 1 this is my h 2, what is the difference between h 2 and h 1? So, h 2 and h 1 if I plot it or if I just keep it there will be in one alpha let us say there is no reflectors I just make a life simpler 1 e to the power j phi 1 that is the difference right.

So, that mean I can say h 2 is nothing but h 1 into e to the power j phi 1 clear see just a phase addition. Similar thing you just do it here when I go to the when I am moving from one row to another row. So, what is the only difference, because it; because the I have changed the second I am change the receiving antenna because of the change receiving antenna there is a phase that will be coming into picture.

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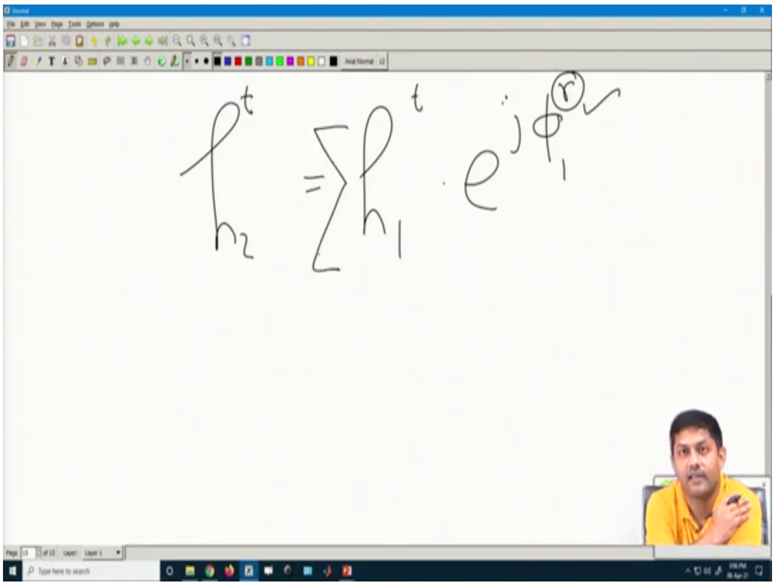

So, I can say my h 2 vector is h 1 vector into some phase how much the phase? That was that is the phase which is determined by the angle of arrival I think we have explained that R x channel phase right. So, that is the so I am putting r here just to differentiate between T x part and Rx part, so that is the only part will be coming ok.

If there are reflectors nothing you just add another point here if there are reflectors, but I am not currently adding any reflectors at this stage this is a simple different. So now, you combine them all together what will I get? I will get something like that.

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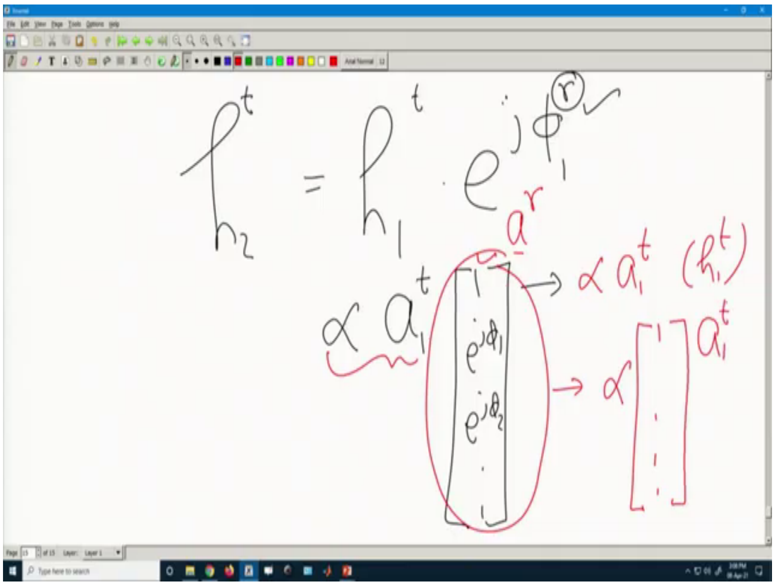

I will get one alpha I will get one alpha there is one manyfold vector which is coming from t side. Because I have different you know 1 e to the power j phi 1 e to the power j phi 2 and so on so forth this will be the coming to the next stage.

The first row is what first row is your see if I multiply alpha see if I multiply this one with the 1. So, this is my first h 1 t, then alpha a 2 with the second one alpha it will be the third one and. So and so forth I will get different different value of the things. So, now, this will be my a r not a r this is a manyfold vector coming from r right, that is the only difference that I will see here ok.

I may be dimension may be slightly opposite also. But it is something like that, but this will be the channel from the receiver side opposite if I think from the this side receiver side I will see actually opposite effect because I am think from the receiver side. So, I will see just this one blah blah this side and this is a 1 t side. So, ultimately my channel what I will be seeing is when I combine them together.

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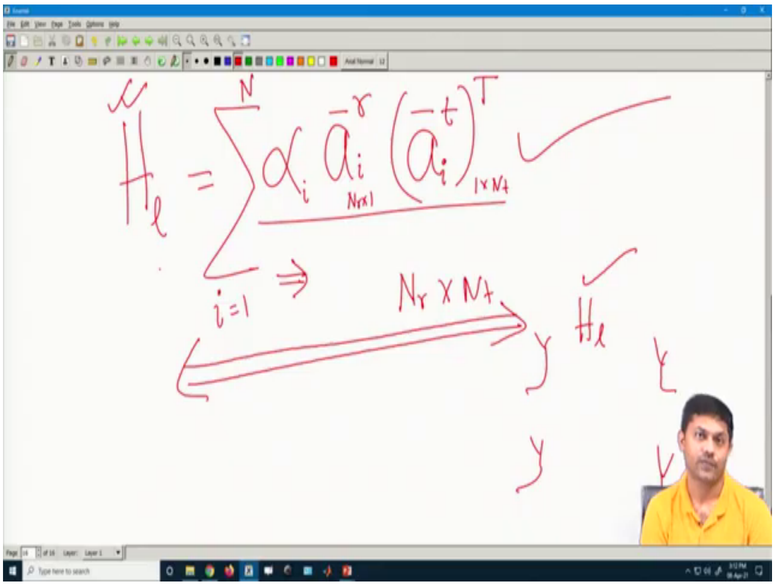

It is alpha ok there is a vector which is coming from t side there is an a vector which is coming from r side, this will be of course just for dimensionality matching this is what I will see as a matrix. So, this is N r cross 1 this is one cross N t. So, effectively your channel will be alpha whatever I am just trying to see the dimension it will be N r cross N t.

So, this is my channel at a particular sample point with respect to my tau. So, this is the channel no reflectors nothing everything is same if I add a reflectors what will happen? Just this part will be added up ok.

See if I add a reflectors my channel would be just another extra summation. Because now the effect of all the because this a t will be multiplied by multiple a r because there are multiple such reflector. See if I have a reflectors the only difference will be this will be I have to put a i here just to create a different index this i is equal to 1 to N and obviously, this i will be different. So, this is the nice channel model.

Now have I deviated from what I learned from 6 sub 6 gigahertz? No, everything is same just I made some approximation. Instead of thinking as a N r cross N t each an individual a complex number I make some approximation I try to get a relationship between each and every elements with respect to the antenna dimension with respect to the AOA with respect to the AOD that is the only difference I have done. And I have step by step explain. What are the approximation has led to this diagram this particular channel model ok.

Now what happens when I have frequency fast fading? This frequency selective fading meaning I have my sampling time is much larger than my delay spread sorry other way round my sampling time is smaller than my delay spread what will happen. In that case I will have h l here that is the only thing that mean at different tau sampling, when I sample at different points in my delay domain I will see different matrix that is all.

This is what we have also seen in the in the normal 6 gigahertz also. See if you have a multiple antenna we predominantly assume it is a frequency flat fading what if it is a frequency selective channel this h is no longer at h. That mean at different l at different sampling point I see different different h in delay domain of course and we have to use MIMO-OFDM to tackle such things. But ultimately that also becomes a single tap channels effectively.

So, single tap channel will come a multiple channel frequency flat fading selective will be coming later. But this is assuming that I am in a frequency flat fading channel and the one matrix I will see like that this is the classic channel model. Sometime people call it a geometric channel model whatever let them call whatever; name they want to tag it. But you should understand how exactly what are the chronological event that has happened in coming to this kind of channel concept ok.

So, with this I conclude this session in this way that you need to know the manyfold vector at the transmitter side receiver side you know, you need to know the angular parabola angle of departure and you need to know the gains which will make the complete things simpler for channel modeling ok.

Then I will explain what is the advantage of it, why did not I take just like a normal N r cross N t complex numbers rather than this model what extra gain it gives you in the next class I will definitely explain that.

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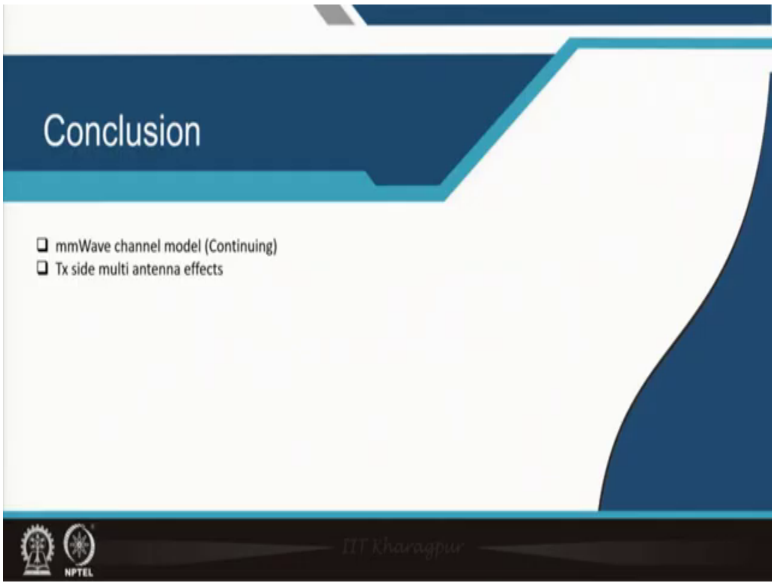

So, with this I must say so these are the concept that we have covered today millimetre wave channel model, just the basic model we have finished it and we introduce the multiple transmitter side and their effect.

Thank you.