Signal Processing for mmWave Communication for 5G and Beyond

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Module - 04
mmWave channel model
Lecture - 23
Basics of mmWave spectrum

Welcome. Welcome to Signal Processing for millimeter Wave Communication for 5G and Beyond. So, today we will be starting the first lecture on the millimeter wave channel model. So, so far we have covered the sub-6 gigahertz model. Now, we are moving to the millimeter wave. And we learn that for the millimeter wave the fundamental part actually come from the sub-6 gigahertz.

So, this is the first basic introduction class for the millimeter wave spectrum, and then we will see what are the problems that millimeter wave spectrum will have, and what are the issues, and what are the extra parameters that come into picture that needs to be considered in this particular; in this particular model.

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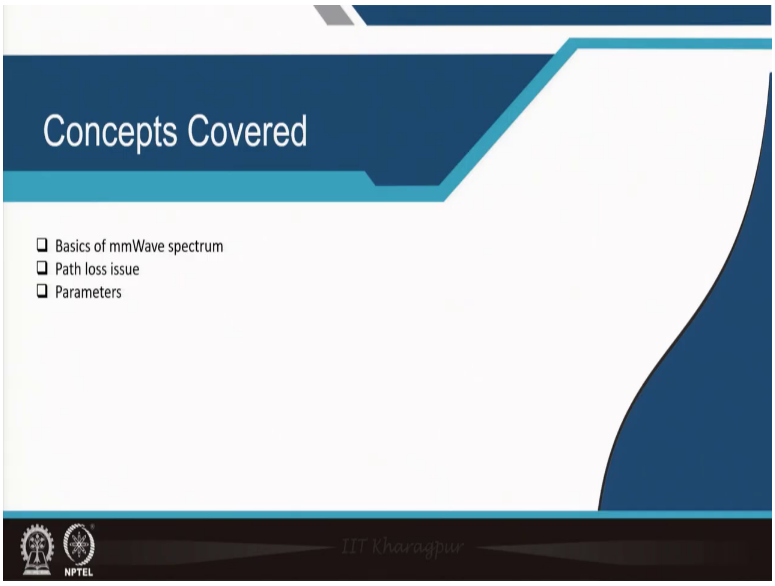

Now, the concept that will be covered today is the Basics of millimeter Wave Spectrums, and then what are the different path loss issues, and what are the different parameters that get introduced now, compared to my sub c sub-6 gigahertz, where it was not important, ok. So, far we have learnt a sub-6 gigahertz. And what are the parameters that we have learned? The parameters that we have learnt are coherence bandwidth, coherence time, Doppler, then Doppler spread, those kind of things. Then channel path, FIR model of the channels, many others, right.

What we have not put much effort to learn is that whether the concept encompasses the 3D models or not. For example, did you really consider or did you really care whether I am receiving from particular you know from a particular geometry of the physical locations.

Well, its not that we did not want to consider, if somebody wants to track the positions, they have to know that.

But in millimeter wave probably that becomes more fundamentals. When I do a signal processing such kind of concept like what exactly the geometry of the transmitter or you know receivers. So, they become more important. Or in a sense or the different you know the different reflectors scatterers, how they in a geometry, how they sit or how they move matters now, ok.

So, in the sense, I can think of this is more going towards the 3D model because now I will be considering something like elevation, azimuth, because these are the two parameters which are very much required, right in a polar coordinate system. So, now it will be more of a three-dimensional spacing rather than just two-dimensional spacing that we considered so far. But we will slowly move in to that.

Before we get into the exact 3D another parameter concept let us understand what are the issues that millimeter wave really face. I think we have discussed a part of it throughout our last few lectures. Now, we will go more details into it.

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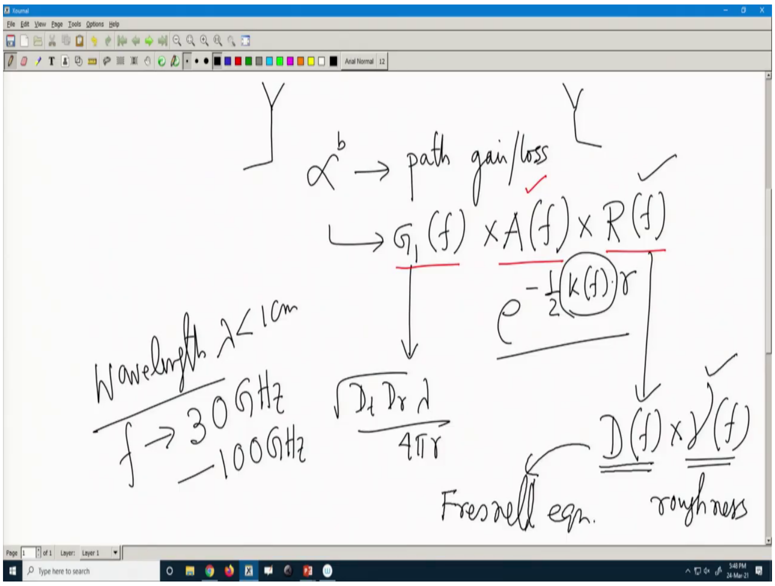

So, let us again consider only a single antenna case, single antenna case, right. So, the alpha or the path gain, path gain or path loss more of a same, right because when you say gain negative of it is a path loss. So, I may just refer it as a path gain. Sometime it may be you can refer it as a path loss also, it makes no difference. It is like gain, ok. So, if it was alpha b because we are considering only in the base baseband context, but alpha can go through the R f path. So, what are the issues that alpha b was?

So, the 3 components that alpha b is constituted of, one component was it was a fresh gain, right. So, let us call it G 1 gain which is part of the frequency of course, because the equation that we have learnt it was D t D r lambda by 4 pi r. So, that is the gain factor, right. Lambda meaning it is automatically a part of frequency. Multiplied by what is the other components, that influence the alpha absorption, so let us call it A f, ok, A f.

What is the other component? The third component was phenomena dependency, like for example, if it is a reflector, if it is a scatterer or if it is a diffractor, so the phenomena. So, let us call it R of f. So, these are the 3 components that usually affect the alpha. Now, the question is that the fundamental difference between the millimeter wave; so, why it is called a millimeter wave first of all let us understand that.

So, that means, the there is somewhere millimeter concept come into picture. And what is millimeter? It is basically the wavelength. Wavelength is in the term is in the order of millimeter it could be 2 millimeter, 3 millimeter or at least less than 1 centimeter. So, that is where the millimeter length comes, right. So, if that is what the case, so that mean the lambda has to be 1 centimeter.

So, what is the; what is the frequency I am talking of? The frequency I am talking of around 30 gigahertz. So, that means, 30 gigahertz on what I would call it a millimeter wave. Till what? Till I can say it is up to 100 gigahertz because beyond 100 gigahertz the sub terahertz and terahertz starts, they start. So, this is your total, I would say the spectrum 30 to 100 gigahertz, ok.

Now, here what are the issues that we encompass, ok, which we did not pay much attention to it. First of all that these 3 components, these 3 components were already there in the sub-6 gigahertz, they were there. Its not that they are I mean the its not that they were absent, but their effect was minimal especially the absorption because lambda is very high. If the lambda is large or then absorptions by different materials will not be so much because it depends on the frequency. The frequency is higher absorption by material for the R f frequency will be much higher.

Similarly, even for the R f also, I mean I think we have discussed this point that when the lambda becomes larger not every materials or rather not every not everything surrounding you surrounding the t x or r x would act as a reflectors or scatterer because it all depends on the order of the lambda.

So, that means, if the lambda becomes smaller and smaller naturally the number of scatterer also become larger and larger, because every tiny things which were not acting as a scatterer or a reflector, will now start acting as a reflector or scatterer, similarly for diffractor as well.

So, when I go into the millimeter wave such numbers will start increasing. So, it becomes a scatterer rich environment I would say. It suddenly become a reflector rich environment. In fact, I would say instead of reflector it is more scatterer that come into picture, and we will I think we already give a glimpse of it. Now, probably I can go into more details now.

So, now what is your G 1 f that is your (Refer Time: 08:23), the path loss part that remains same. I mean that has nothing to do with your whether you go for a millimeter wave or a sub-6 gigahertz or rather if you go for higher frequency, that equation always holds true.

Now, this A f that is the absorption coefficient that has some relationship e to the power minus half into k of f into r. So, that is the absorption coefficient. So, this k f is basically called the absorption coefficient. And that varies from material to material. And as you can see I put A f there. So, it means its a frequency dependent and moment my frequency or the R f operation becomes higher and higher this component becomes more and more prominent in my case.

But now there is one aspect that why millimeter wave suddenly comes into picture because as you know that this is not a very friendly you know R f, right because it gives you more loss, it gives you more you know absorptions. And we will also see that this R f part, this R f I am talking of the whatever I have written this R f the phenomena dependent which depends on reflectors, which depends on scatterer and diffractor that has basically two component, ok.

One is we call it D f multiplied by gamma f sometimes some paper wrote write it rho f. So, this is your this parameter is called roughness parameter, roughness parameter, ok. And there are certain formulas with that. And this one is a complicated function. There is no point in describing the functions.

It is there in the reference. It is a very big equations. It is no point in describing the equations what there. But what it says that this D f is basically are represents the phenomena characteristics. Say for example, if I have a reflection or if I have a scattering, what is the phenomena that is that it is reflecting. It is like you have a ray incident ray and then it is like a splashing the ray gets just splashed around everything.

So, this D f basically characterizes mathematically those kinds of equation. And they are also comes from Fresnell equation. There is a there are set of Fresnell equations which are mainly coming from the physics background and they actually define for a reflection, for a scattering, for a diffraction, what is the structure of waveform. And there is a very nice complicated equation. So, let me not get into that. And this gamma, this roughness parameter.

Now, let us get into the notion of all of them that what exactly they mean for us. So, now, when I go beyond 30 gigahertz R f one more advantage that I may get it. What is the first advantage? So, here actually if you look at the equations, all these 3 parameters they actually give you disadvantage, instead of any advantage, right because it is the path loss and path loss will be much higher, when I go for the higher R f.

Absorption will be much higher when I go for the higher R f. And this phenomena, will also be much higher when I go for the higher R f. Naturally, this roughness parameter will also be much more prominent if I go for the higher R f. So, what is the roughness parameter? Roughness parameter is mainly like a surface roughness kind of thing.

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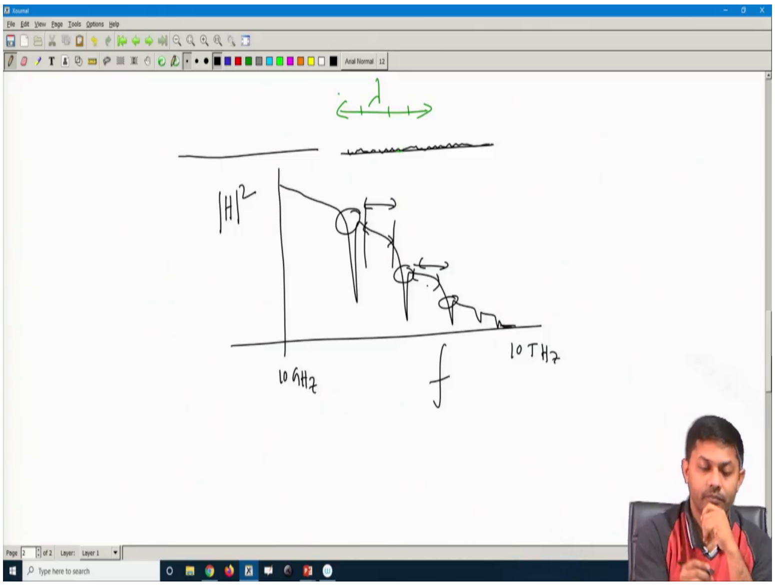

Say for example, if I have a surface of any material, you may see that well this is a very smooth surface, but if I make my lambda smaller and smaller or if you put this surface you know under the microscope you will see that actually it is not as smooth that as you think it may be rough. Now, whether that roughness can be viewed by the R f or not, depends on how close the lambda would be with respect to its order.

Say for example, the same thing which I view it as a smoother, if I put it under you know under a microscope, I may see that actually this is like this kind of thing. When you have this kind of rough parameter, the lambda or the wavelength if it is also in the order of such small tiny you know that roughness; that means, that will now start acting as a scattering.

So, moment you have such kind of rough parameter roughness increasing, roughness parameter increasing, the loss path loss and everything will also be increasing naturally because that is how the phenomena is. But this is very much frequency dependent. Why it is frequency dependent? Because the same roughness whatever I have drawn may not be seen as rough if my lambda is larger.

Say for example, my lambda is something like this large, say something like 4 centimeter, whatever the R f it corresponds to. If the lambda is like this, probably for such lambda this roughness whatever I have drawn may not be seen as rough, ok. So, that is why this parameter is a frequency dependent parameter. And these as a certain equations, while equation, I mean these are equations defined.

Now, the question is that if I have the R f higher and I have so much disadvantages then why should I go for it. Again, I explained it some time back that, the main advantages of going into higher R f is the availability of the spectrum because if it is less than 30 gigahertz most of the spectrums have already been auctioned. So, you do not have the much space left for say 5G service or in next say after you know after 10 years down, the line 6 G when it is comes, you may not have much spectrum left on that.

But your data rate will be much higher. So, if you have a very high data rate say 1 GBPS or 10 GBPS or 20 GBPS data rate. You cannot you know you cannot bound your data within just 100 megahertz or 200 megahertz bandwidth. Then, you require a very high constellation, and that also will not start, because higher constellation does not mean that you can get a very high data rate because you have to decode it also, right within the same power.

So, that becomes a big issues. So, better you increase your you know increase your spectrum and that automatically gives you higher capacity of the system and then it will always give you the higher data rate. So, naturally, I am looking for or people look for a spectrum where such kind of large bandwidth is available and that is why the concept of this millimeter wave becomes more prominent because the spectrum is available.

Now, it has its own disadvantages. Like, it has its higher path loss, absorptions and so on and so forth. So, this is the basic characteristic of the path loss kind of model.

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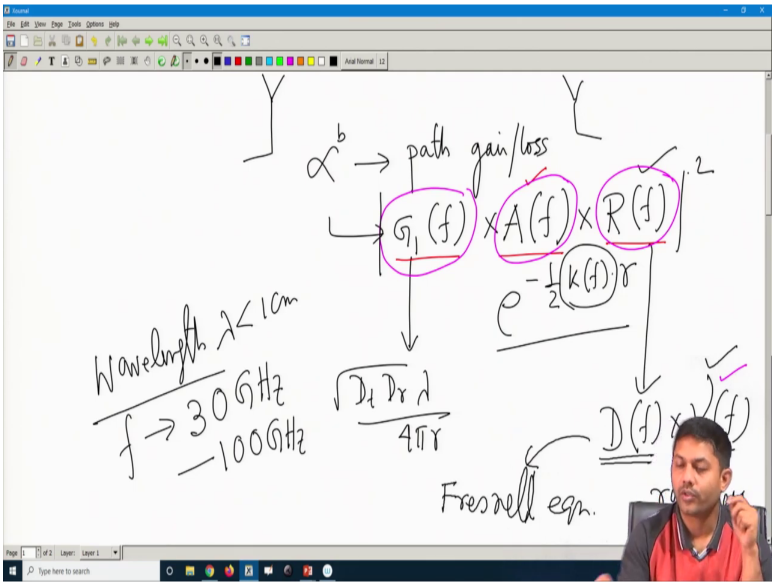

Now, if I draw the path loss say overall gain factor, so this gain factor this alpha, this alpha gain factor. If I you know just for a single tap or a single line if I just draw the mod square of this whole thing that is already diagram given. So, if I say my H channels you know mod square. If I plot it with respect to the alpha and naturally this should be swing this deeps and these deeps and these deeps and so on and so forth, right. It will not be going to 0, it is just going you know it just going down and down.

So, why this comes into picture? Why this comes into picture? Why this comes into? This is mainly because of these parameters, A f. So, this absorption coefficient suddenly becomes very high when at a particular frequency you have certain material which shows a very high rate of absorption. So, these are all your physics concept. And those frequencies are called resonance frequency of the material. So, for example, some material has a resonance frequency close to 60 gigahertz.

So, that when if R f goes through it, it just absorbs everything almost everything. So, it creates a deep down here in the absorption. So, you cannot use such kind of spectrum. So, you have to use this spectrum, you have to use this spectrum. So, that is something around 59 to 60 those around that. And there is also something around 80, 84 like that I am there are many. I mean if you look at the paper or the reference paper that is a very nice curve there and it goes up to 10 terahertz up to 10 terahertz. So, this is above 10 gigahertz to 10 terahertz, you can see the spectrum and you can see the absorption that.

But apart from that there will be natural absorption within this bound, within this band also, ok. So, these are the basic fundamental point of the gain parameter. What are the other issues that appears for a millimeter wave? The other issues that appear for a millimeter wave is the scattering, it is a rich scattering that will come into picture. Why? Because, now each and every tiny fellows will now act as a scatterer or reflector.

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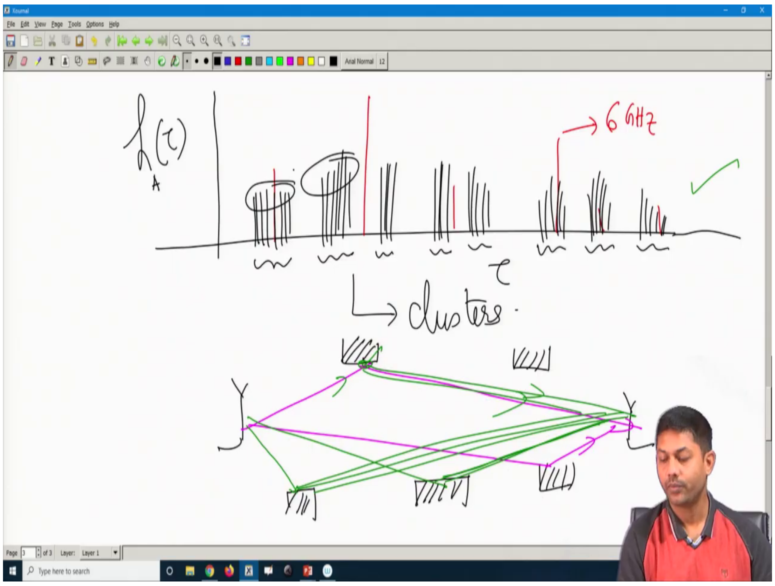

So, if I plot, suppose I plot, I plot the analog channel that h tau, let us say I do not have Doppler, let us say I am in a static say analog and this is with respect to tau, ok. It is Omni-directional antenna. What will I see? Had it been you know, had it been 6 gigahertz or 10 gigahertz, I would have just seen 1, 2, few of them, ok. So, this is say for 6 gigahertz.

But moment I go for a millimeter wave, as every tiny things also start acting as a scatterer, then I will may not definitely see only this small number of scatterer, right. I will see much dense scatterer. So, I may see something like that I will start seeing it, many more. We will start seeing. Naturally, because everything is now acting as a scatterer, more than reflection I would say it is scatterer that matter.

So, millimeter wave, I would say millimeter wave communication is in fact, a scatterer rich environment, with every tiny thing left as scatterer. But have you noticed one thing, how I have drawn? I have drawn some sort of a bunch. Look at that how I have drawn. See it is something like a bunch, bunch of data.

This is like within a bunch there are so many you know scattering. This is what is happening. So, this concept is called clusters. This concept is called clusters. So, this is a very interesting phenomena in millimeter wave. So, though you will have a lot of scattering paths coming into picture, but you will see in bunches. So, if one comes along with it there are several comes, then again after gap again several things will come. So, why these clusters come into picture? The reason is that as we said each and every tiny material surface will now act as a scatterer, ok.

So, suppose I had one antenna like this, I had one antenna like this, ok. Now, the physical environment they do not change, whether you change your 30 gigahertz or 100 gigahertz or 6 gigahertz, they remain same. So, for example, you are sitting in a room, right, whether the number of chairs, the furnitures, you as an individual or the people inside the room they do not change I mean at a particular time, right.

Even if you say 6 gigahertz transmission in that particular environment suddenly you make it say a 60 gigahertz transmission in that same environment. The environment do not change, it is just that each and every surface will act differently. So, let us say I have some block here, I had some more blocks here, ok. Let us say I have some more blocks here. So, these are some in the room or some other physical area where I am making it my transmission, and I am making my transmissions, right.

Had it been 6 gigahertz probably this was activated and this was activated. Why this other 3 things are not activated? One reason is that if ray false here, most likely it may act as reflector because lambda is large and when it is reflected it may not reach the receiver. So, if it is does not reach the receiver that will no longer be a reflectors, right. That is not to a reflectors or scatterer because ray is not reaching. Even if you have 100 chairs in an environment and only a particular time only 10 of that chairs say reflector ray which reach you, then I would say the environment has 10 reflectors, that is the thing.

But when you increase your R f, now, what is happening when you increase your R f? Now, the same fellow will also receive a data, it will also reflect, ok. Now, that may not act as a reflector purely. Why it will not act as a reflector? Because now a surface is not smooth, so now it will start as scatterer. So, when it is scatterer probably a bunch of ray can reach there. So, it is the scatterer now.

Similarly, here this is now acting as a scatterer. So, what will happen? When the ray incidents, when the ray is incident on it, its not one ray, but a bunch will be coming here. Now, this one which was not active earlier, it was active, but the ray does not reach ray was not reaching the antenna there. So, what will happen? So, probably this will now start acting as a scatterer.

So, now, how you now you see, you can just map it to the map it to the h tau here. What will happen? So, its like a one block as it is scattering, so we will say a huge bunch of rays entering into the receiver. Again, from another scatterer, again a bunch of rays entering into this. But when it was a sub-6 gigahertz or is when a smaller R f, what was the case? It probably it may be acting as a reflector, and maybe it is scatterer, probably the ray was not reaching because the amount of scattering was not so huge.

But now it is the lambda is very small, amount of scattering is a very very huge, very huge because the roughness increases, right, suddenly. Roughness meaning the apparent roughness with respect to the R f suddenly increases. So, this is the reason when you go for you know a millimeter wave instead of seeing a one one tap path I missed a bunch of tap paths and this is what is very important for us.

So, this will call it a clusters. And going forward when you start modeling the channel path instead of like a one ray, I will say its like a clusters, some block of clusters available within my R f part. And that is precisely, how I will be modeling the R f cases here. So, these are the first phenomena that appears into the R f. And this is a stark difference between a millimeter wave retransmission and the sub-6 gigahertz transmission, ok.

So, with this I make a basic conclusion. So, what we covered today? If you notice we just gave a very basics of how exactly absorptions and R f comes into picture here what are the path; pathless model does not change, that remains as it is. Its only the absorptions that makes some difference. But this part, this R f part, this part, this component part, it plays a very very important role in our case now.

Now, absorption is fine, because absorption if it is bad absorption you just do not consider the, you know do not consider that particular band you take some other absorption will be there. But may not be a very deep absorptions. This you can anyway increments, you cannot get rid of it. But this is a very new phenomena which was much more prominent in signal in millimeter wave. And we will see that how we will tackle it, does it change my complete thinking of my channel, ok.

Because if you notice, the issue now will be the issue now would be, can I have some sort of a different level of characteristic when I go for the channel? Because if the number of paths are so huge how do I model so much, so many numbers of paths. Does it have some common characteristic? Does it have something else? We will see that, ok. And that is basically a very important part of limited communication that is clustering, ok.

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With this, conclusion part. So, we have just covered the basics of the millimeter wave spectrum, and some of the path loss issues. Path loss issues in the sense that it includes the absorptions, the phenomena defendant things, and just one parameters we have introduced called cluster. We will subsequently we will see what are the other parameters that appears in the millimeter wave context.

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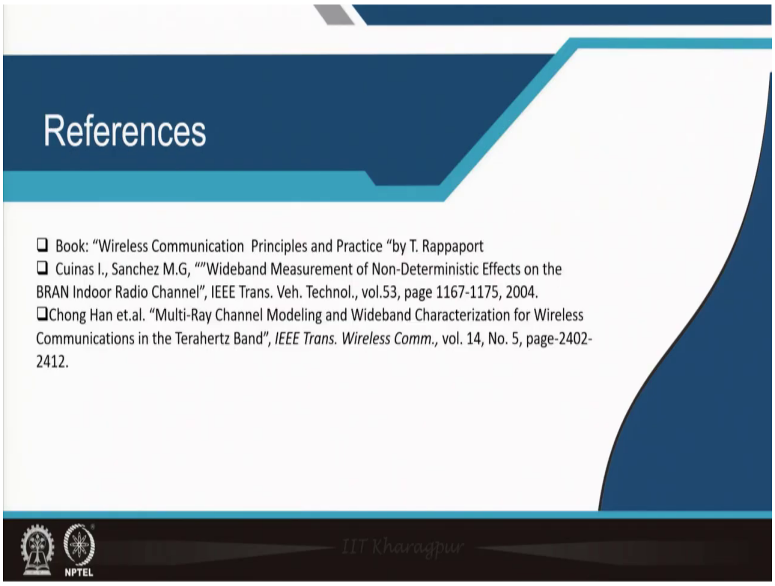

So, these are the references. You can see the third reference is same as what I referred in several papers, in the several lectures which is the terahertz model, but this will remain same. Though it is terahertz, but from a millimeter point of view the basic, you know the attenuation modeling is very same as this. And this is one of the paper, which describes the complete alpha characterizations.

Thank you.