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 - 01
Communication System
Lecture - 03
Fundamental of Ray - Tracing model

Welcome again. This is the module 1, 3rd lecture. So, today we will be covering the Fundamental of Ray Tracing Model that is the basics of any channel model. Now, there are many other channel models available, ray tracing is a very very basic and very fundamental and it is very easy also to understand. So, we will be covering the that particular channel model.

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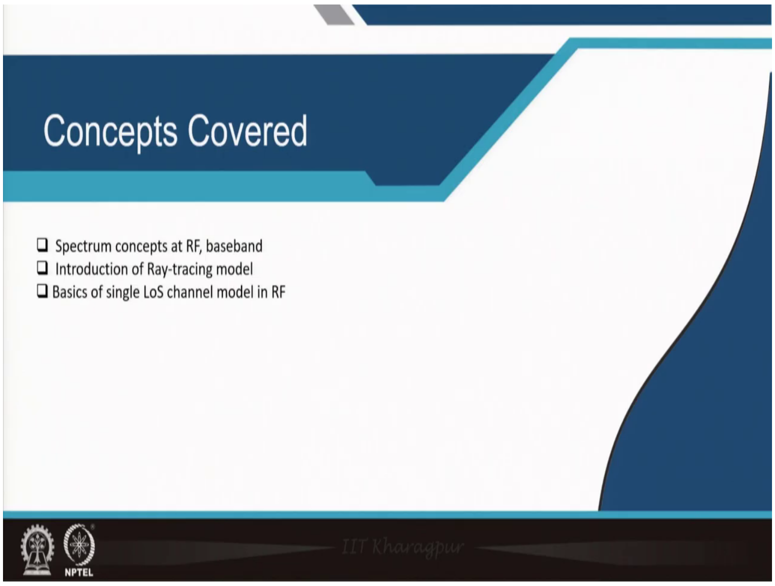

So, these are the various concept which will be covered in this class. Spectrum concept at RF and baseband predominantly at sub-6 gigahertz not the millimeter wave yet.

And today, we will be introducing the ray tracing model and basics of single LoS channel model in the RF. So, we continued from channel part what we have discussed about the analog and digital systems in the last two one or two classes. Now, we will be actually modeling the AIR part. This is what we have discussed.

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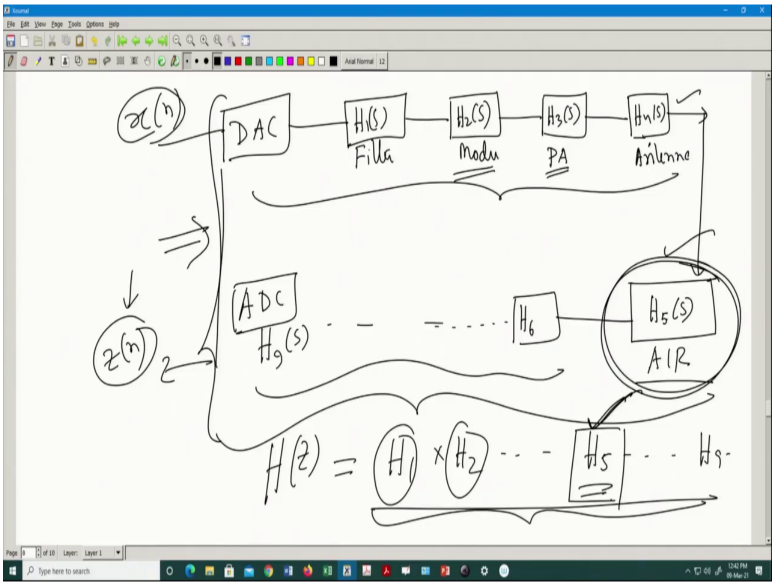

So, if you look at what we have discussed you can see. This is what we have finally, concluded in the last session that, you will be observing or you will be transmitting x n and you will be observing the z n, and this whole thing will go through the complete chain of filters.

I can think of that one. So, you have a multiple such filters may be 5, may be 10, does not matter, depends on the components. And each and every components you can modularize a filter and that whole thing combinedly will be acting as a channel ok.

And one of the component is AIR and this is our this is where our interest is. But when you say channel, it does not mean that other components are also useless, no, because depending on the frequencies each and every components will have a different different behavior.

For example, this modulator, this part, ok or the demodulator at the receiver they will have a completely different characteristic when you change different RF band. This power amplifier, have a different characteristic when you change your frequency band. Antenna; so, each and every component each and every component except probably DAC and ADC, each and every component will show a different behavior when I change my RF.

So, it is not that will be only doing the modeling at the AIR each and every components actually gets involved there. Now, in this particular course probably we will not get into the details of modeling part of you know modulator, power amplifier, and so on because we assume that they are kind of linear and they are kind of harmless to our modeling aspect.

But when you talk about the impairment at the end of the complete sessions, we will definitely bring back all these components and try to model the impairment parts and then we will show how things go in a very different way. But for the timing what we will assume that, that all these components are kind of a gain, just a gain, they just like a kind of a gain not creating really of phase distortion.

So, this is where our interest is, this whole part this H 5 or the AIR part this is where our interest is. Now, let us get into the AIR modeling. Before I get into the modeling part from the AIR side, I must tell you some of the story related to the RF bands. Why we choose different bands? Why we choose millimetre wave? Why we choose 6 gigahertz? Why we want to go beyond it?

So, this is a motivation. So, you need to know the motivation unless it will not be clear why suddenly I jump my RF, ok. Now, when I am in 4G because it is the era of 4G and just 5G has just started to enter into the system of our India, upper country. But the problem of the 4G is that it is mainly 6 gigahertz, 7 gigahertz RF, they are all my spectrums are.

So, what does it mean? If you go to any commercial vendor for your you know SIM card, so what they offer? They will give you a SIM card and there will be a base station connected with that SIM card wherever you are, but the RF part of that base station or your mobile station what will be connected with we will not have any frequencies which is like a 70 gigahertz or 100 gigahertz not like that. It will be very small, like 6 gigahertz 5 gigahertz or 4 gigahertz not more than that. So, these are called sub-6 gigahertz.

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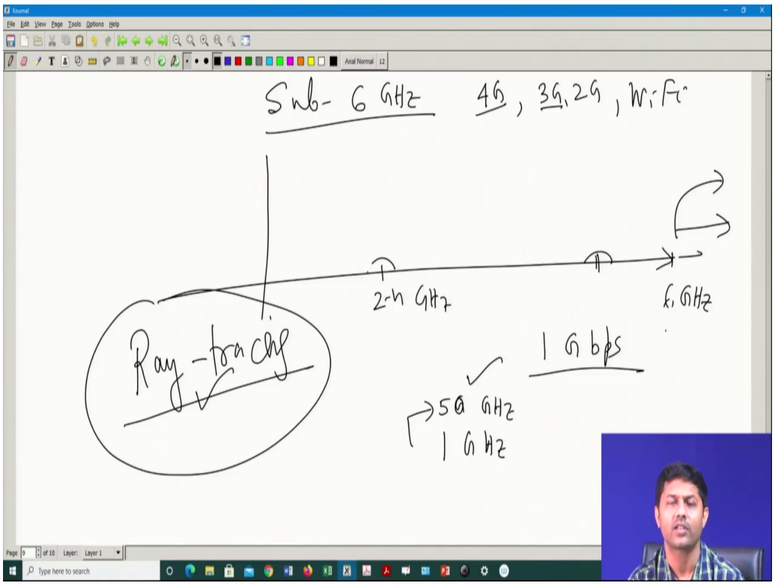

So, 4G is predominantly a sub-6 gigahertz RF. So, what does it mean? It means that if you draw the RF, so this is my 6 gigahertz predominantly. So, there will be slightly more or less like that, but predominantly it is up to 6 gigahertz most of my 4G is available.

But 4G bandwidth how much it is? It is 20 megahertz bandwidth as per the 4G specification. So, let us say I am operating at 4G, but you do not have to just operate 4G, right, I mean everything's, everything else will also be there. Along with 4G, there will be 3G, there will be 2G, there will be Wi-Fi also because that also you have to allocate band.

So, there are certain like a 2.4 gigahertz here and there is something around 5 point I think 5.2 or some gigahertz there also. So, that is some band is allocated for them also plus you have 3G. So, that means, this 6 gigahertz is very crowded, right. It is a very crowded.

Now, you do not have anything left for supporting 5G. Everything else is just packed up. Whatever is left out, small thing is still left out that can be given to 5G. But 5G is a data you know data hungry system, right. So, you can have at max 1 Gbps or even more kind of data rate.

Now, if you want to support that kind of data rate the small bandwidth is not good enough, right. And most of the spectrum which is available in 6G are like all occupied and mostly it is occupied every part of India. So, what is the way out for 5G? 5G something is available, but to support a very large data rate probably you have to go beyond 6G and so on so forth.

So, that is where the, so that means, you have to shift this RF and that is precisely what is done, you have to shift RF, right. If you shift RF it comes with thousand other problems. And that is precisely the modeling part of my channel this part involves here.

So, when you say when I am increasing my RF, what are the issues that you will be incurring in mainly in the AIR part of this channel that will be talking about. And this is very much

RFD. Of course, most of the components are RF dependent, but this part is of our main interest is.

So, here we are talking about why to increase our RF while we have predominantly a 6 gigahertz or at least say 7, 8, 9, 10 gigahertz also available. The issue here is that though they may be available, but it is not so much available compared to what I need ok, because your data rate might be very high. You may support 1 Gbps data rate, is such a very high data rate. And 100 megahertz or 20 megahertz bandwidth is not good enough. This is one part of the story.

Second thing is that, second part of the story is that most of the components that is available today are tuned for 6G or those kind of things. Now, even if you increase the RF suddenly increase the RF and say ok, I am going for say 50 gigahertz RF, there I can say I am taking 1 gigahertz spectrum. Does it solve my problem? No, it does not solve your problem. It actually comes with lot of other problem.

So, increasing the RF is also not a solution suddenly just because you have available spectrum there. Because when you increase the RF, what is the other problem? Other problem is what about the modulation, this part, this filter. What about the power amplifier filter, will they be same? No, it cannot be same. Why? Because this modulator, this power amplifier, this antenna was tuned for 6 gigahertz.

When you switch the RF to say 50 gigahertz, they may not work. So, you have to redesign all these components. And when you redesign all these component it is not a simple task because it requires characteristics, it requires lot of effort to make such components workable at a higher RF.

So, when I increase my RF these are the troubles that will come into picture. So, probably that is not something that I am going to touch it because our main focus is in the AIR part. So, these are some of the motivations that I need to really go into RF and I need to really concentrate, I need to go more on the RF side, I need to concentrate on the design aspect of the RF.

Now, before I get into the you know larger RF and its subsequent channel model, let us understand the channel model from the 6 gigahertz point of view. I will spend some lectures on the 6 gigahertz channel model. Because the reason is that even if you increase your RF and try to model your channel the fundamental base or the mathematics or the pillars are actually the 6 gigahertz model.

So, if you understand the 6 gigahertz channel model very well, understanding a higher RF channel is probably an addition to it because, if you increase the RF it comes with some other extra problems. But when you are in a lower RF channel model, if you want to understand, if you understand that part then it is like a simpler to understand the rest of the thing.

So, that is the reason I would like to start the channel model which is very at a lower RF. But to be very frank, to be very frank in this whole lecture I will not mention any of this 6 gigahertz or its a 10 gigahertz or 100 gigahertz, where I am; the way I will be talking of the channel model is called a ray tracing channel model, this, this model I am talking of, ray tracing model.

And this is a very very generic, well accepted way of modeling any channel. Now, this concept this ray tracing model if you if we understand it can be equally applicable when you increase your RF. So, it really does not matter which RF you are working. If you really understand what exactly this ray tracing model is good enough.

Now, today we will be starting the ray tracing model. But before that we need to understand what exactly happens when you have one antenna to another antenna transmission system. What are the physical phenomena, what are the you know physics involved inside it that needs to be understood very clearly. But now moment you talk about the RF immediately you know people will start thinking electromagnetic waves and all these things.

But my friend, I mean I am not talking of electromagnetic waves here. Because why? Because we are signal pursuing person. And I am not really getting into the same electromagnetic part. So, for us everything is an electrical signal modeling. Because why? Because we started digital. It has gone into analog, it has gone into RF transmission through AIR and so on so forth.

Finally, we are receiving a digital baseband. So, I am not interested how internally electromagnetic wave works. So, for me everything is you know everything is a electrical signal modeling and that precise the reason why ray tracing model is very very powerful tool, I would say. It is a powerful tool to model most of the type of you know RF channel that we talk about.

So, before, again, before I get into the ray tracing model there are some more things which motivates us to go for a higher RF. So, one reason for us to go into higher RF is definitely to avoid the congestion at the lower RF because up to 6 gigahertz or say 10 gigahertz most of the things are you know auctioned the spectrum is already occupied. So, I have to go beyond it. Now, there is one more point. The reason another reason is that, most of today, you know most of the area or reasons are clustered reasons.

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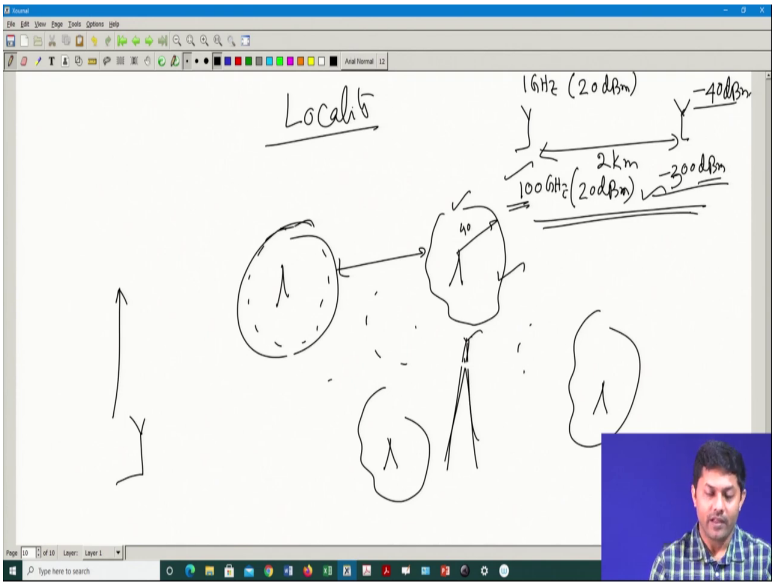

What is mean by cluster? Say for example, I have a locality, let us take a locality, ok in an Indian scenario or any world scenario also that does not matter. So, everything is like a cluster. So, people will be living in some areas, then there will be some you know gaps may be some small forest patch or some you know small region.

Again there are some locality, again there are some locality, again there are some locality this is how a city, village is built up, right. Now, when you have this kind of cluster thing then it will be good if you have some sort of a base station we just subs, this one locally, this one locally, this one locally, this one locally, instead having one base station who wants to serve everything together.

That may not be a very good, you know that may not be a very good option to go for it. So, this is another motivation why I should go for higher RF which actually achieves it using higher RF. Of course, this is not a very strong fact of the RF higher RF, but this is one of the very you know interesting advantage if you increase your RF.

Because what happens, when you increase your RF what is the first problem that you get? The first problem that you get is that when you transmit from one antenna and you increase your RF your loss of the signal will be very high, right. We will come to that we will when you come to the model part.

So, which means that if I have an antenna here, if I have an antenna here, so let us say distance is say 2 kilometer. I send a signal which is say 1 gigahertz RF, I send the another signal which is say 100 gigahertz RF, and both the cases I am sending say same power let us say I am sending 20 dBm power, here also I am sending 20 dBm power.

What will happen at the receiver? Which one will give you a very less receive signal? Second case naturally because its RF is very high, frequency is very high. What will happen? The loss transmission loss for this case will be extremely high. So, probably I am just do not quote me in a sense that this is the right number, I am just giving a tentative number.

So, let us say for this the first case let us say assume may not be right, but some tentative number I am giving. So, let us say this is minus 40 dBm if it is 100 gigahertz I do not know, but probably minus 200 dBm or something like that. This is almost everything is lost. So, 2 kilometer it cannot even travel. Maybe I am wrong we are probably 300, minus 300 dBm, right. What I mean to say is that for such distance covering when I increase my RF it will not work out.

So, this is the problem that every I mean all of us know when we started the electromagnetic wave propagation that when you increase the frequency; obviously, the path loss will be very high and we will model each and every component from that angle.

So, which means that even if I increase my RF, suddenly my loss on the signal will be very high. So, which means that if I have a small small locality, probably this will be a best fit if I increase my RF, because if it is a small locality. Suppose you have a locality in the sensor suppose you have you know flats, say you have some 20 floor flats, complete flat.

So, that, I can just have one antenna which will serve that 20 floor flats. I am talking of that kind of small locality ok. Or you have a small cluster where you have some 30-40 houses are there, within a sphere of say for example, 50 meter or say 100 meter, not even 100 meter in 50 meter sphere, I have 30 40 houses. I want to serve that locally.

I do not have to go for a higher RF. Why I do not have to go for a higher RF? Because if I go for a higher RF and this is the only locality existing there, what I have to do is that either I have to transmit a small power or I have I can go for a higher RF and just have a small you know base station here. Just have a small base station here which will be something like a 40 or 60 gigahertz kind of thing which will served like 30-40 meter radius kind of.

So, when I localize the system and this is one of the concept in 5G. In the concept, in the 5G context unlike your 2G or 3G where you know you have a one big base station tower and it was serving a huge area together, but when I go for 5G for the benefit of the networks, what I do? I will do a kind of segmenting when I do a clustering.

So, which means that instead of serving the whole area together which may be inefficient in a sense, I will be making small small base station will be serving a directed kind of areas because it will be easy for us to serve those areas from a power point of view. I do not have to transmit the whole thing.

Because for example, if you look at this kind of sparsed area, what will happen? I may have to put a big base station here, send a huge power, that mean anything which is sitting here all power will be lost because nobody is using that, most of the people will be using in the locality. So, that huge power will be lost unnecessarily in this whole you know this, this, this, this area.

But whereas, if I use a small base station and which is targeting only a small area, the power will be much more optimized and when I do that, so that means, when I have an advantage or an intention to transmit the or to serve a small locality, then it is why not you go to the higher RF because those are RFs are in your available spectrum, right.

We have just discussed that, because that is the whole reason I want to shift more and more because I want to increase my data rate, I want to come out of my congested region, then I am facing the problem of you know this transmission power loss.

Then I am saying that, why do not we create a small area why do not target a small area there I will just put a higher RF because it will give me a higher bandwidth advantage, but I only serve the small area.

So, these are the kind of motivation why I should go for higher RF and so on so forth, ok. Now, irrespective of the fact whether you have a higher RF or a lower RF what are the physical phenomenons that is going to happen in the AIR and this is what we are interested in.

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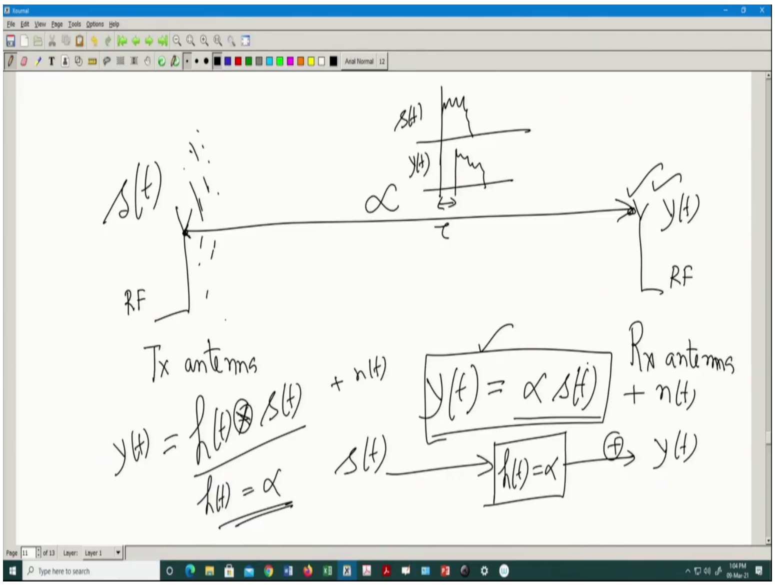

So, let us understand that. So, let us say I have a transmitting antenna. So, let us call it Tx antenna. I have an Rx antenna here, Rx antenna here. And let us for the time being let us assume that this antenna is transmitting an signal which is kind of isotropic, but you do not have to make that assumption, I am not so paranoid about isotropic assumption.

I am saying that you transmit a signal and we are getting it here. What are the physical phenomena that will appear between these two antenna that we need to understand.

And everything from a electrical signal point of view, not electromagnetic signal point of view, so we are electrically as analyzing it. So, I am sending an RF signal here because I am in RF domain. I am talking of antenna to antenna modeling. Then what will happen? So, when the signal gets transmitted, signal is coming out from this antenna, so, what can happen?

See, if we are in a space meaning above the ground very high altitude kind of things. So, what will happen? I would say that signal somehow it will reach this component directly, right. So, which means that from a electrical point of view. So, what I should say that let me just rub this part.

So, electrical point of view what I can think of is that this one whatever I am transmitting it I can get some sort of a direct path here. So, that mean I am transmitting s t, this is what we have seen it last time that I am that my electrical signal, internally it may be RF, that is fine, but that is the signal I am transmitting it. I was receiving y t here, right with a gain factor of alpha, voltage gain alpha, correct.

So, I when I transmit it if I am in a space or above the ground much higher the ground, I may say that the one electrical ray can just appear, one electromagnetic ray can appear here which will cause an electrical signal there. So, that is my view here. So, which means that this is my view that I can think of, alpha s t plus noise, noise will be there always because this there will be some thermal noise, that is the case.

Can we, say like that? So, that means, I am sending an s t signal, again I am saying everything is a filter for me. Why? It is linear or non-linear does not matter, everything is a filter for me. So, I will receive y t here plus noise that is, that part is there, I am not considering the noise part here right now.

So, this part can you tell me what it should be such that output signal will be like that. So, can I say my filter characteristic h of t can I say it is nothing but alpha constant? That is how it is, right. So, what is y t? y t has to be because it is a filter kind of thing.

Some sort of a convolution, let me, can I say y t is nothing but convolution of that plus noise, let me not bring the noise all the time, noise is implicit. So, hence forth I will just only talk about that because noise is implicit. So, can I think of like that? So, this is just like convolution, right. Now, if this is the result what should be my filter? H t is nothing but a constant alpha.

So, I can think of its a channel with just a constant gain filter, that is all I can think of this is a constant grain filter, right, fine. This is one part of the story. Now, this works, this is this I can say I am just now proceeding how I should model my channel because that is what my interest is, right, this part of the story.

But the story is slightly incomplete. Why is it incomplete? Because what I have not modeled in this particular case is the delay because you say that from this point to this point there will be propagation delay, I have not modeled that propagation delay and I should model it, correct.

So, which means that if I send s t, s t whatever my analog waveforms is this is my s t, but when I receive it at the y t there will be slight delay. So, this delay has to be modeled somehow. Let us call it tau, this is my y t, ok, so which means that I need to slightly modify this.

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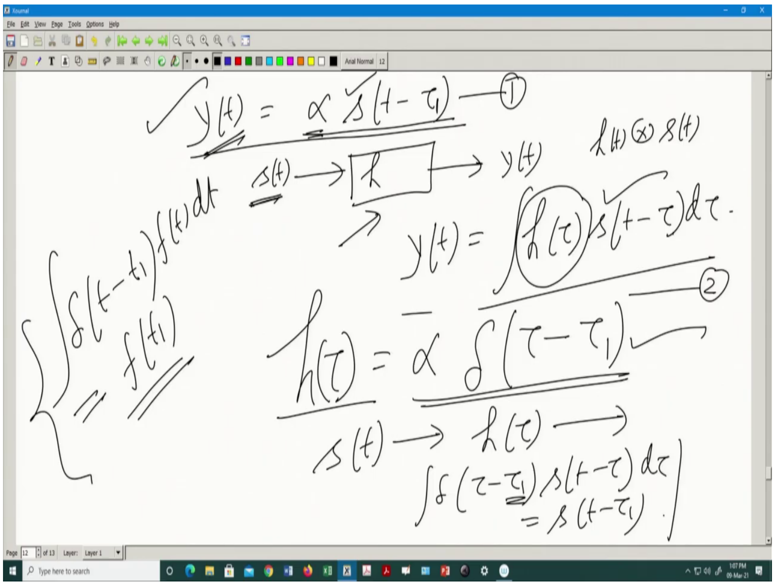

Then, what should be my receive signal? y t is equal to alpha s of t minus tau, alpha is the attenuation factor. So, this is a simple channel model. Noise is there, implicit, I am not again repeatedly saying, I am not putting the noise here, this is just a input output relationship, the second thing.

Now, again let us consider it. I am giving you s t it goes through a channel h and I am finally, getting y t. What should be my h now? You need to know that. Now, what was y t? Can I think of like that? This was a convolution, right. I am just done a convolution, h tau s of t minus tau d tau, this just a convolution.

So, it means that h t convolution of s t and I will get y t (Refer Time: 27:24) is the convolution equation is, this is the convolution equation. Now, let us say this is my equation number 2 and this is my equation number 1. This is the originally this how it should be, but this is what I am receiving it.

Then, what should be my h t? How an h t I can say what should be my h t or tau whatever such that when I put this into this equation I get equation number 1. If you think carefully it is nothing but h of tau, can I say it is alpha probably I should use a different let us call it tau 1 for my simplicity, tau 1, this how it is this how it is, right.

Because if this is my system and if I give s t here and if it goes through that h tau, convolve it, this is the signal, I will get this, alpha s of t minus tau 1 is precisely what I will get it, ok. So, here is a small mistake here. It should be tau, this have to s t minus tau and this is how it should be because this creates the delay s t.

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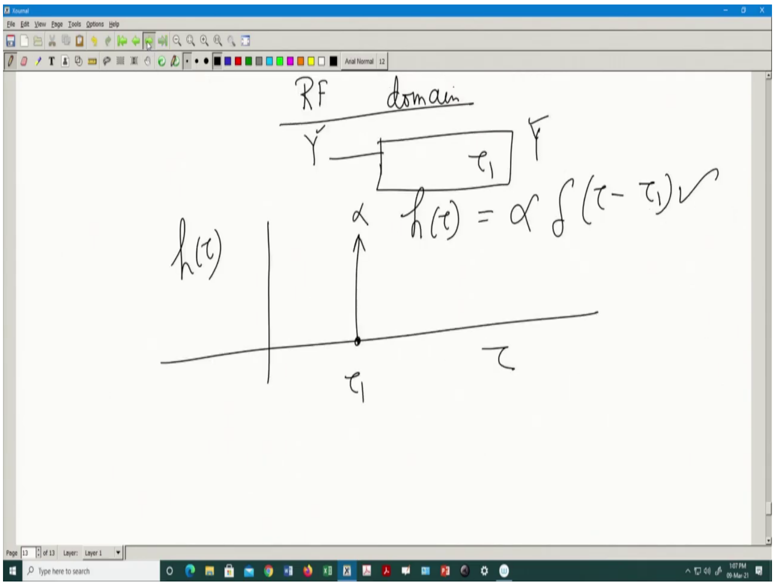

So, which means I can say that when I am in a RF domain I am completely looking at the RF domain point of view. I am in RF domain. I am basically modeling antenna to antenna. So, I am in RF, RF domain. Why? Because I am in antenna to antenna. If it is just a direct path, that means, this antenna transmit, this is receiving after say tau 1 delay, how do I model the filter which is present here?

I can say this filter is nothing but h tau is equal to some alpha tau minus tau 1, tau 1 is the propagation time delay between these two antenna that is what will happen. This is this has to be understood properly. So, what does it mean? It means that this channel is nothing but a single impulse response, right.

So, what does it mean? If I plot with respect to tau, I just get at tau 1 I get one impulse alpha and this is precisely my channel is, just a Dirac function. But what is the view of this channel? This is in RF domain, I am in RF domain. So, what is the difference between this model and the last model?

This model does not consider a delay part which is wrong, but it is not wrong because we have to create the baseline, what you are trying to do here, right. From there, I say I have a delay in my system because I have to model; that means, the channel is such that; because delay is what? Delay is not part of my s t, delay is part of my channel; delay, amplitude distortion everything is part of my channel.

If that is the case what does it mean? So that means, that my channel should be modeling the delay part as well; that means, if I give an s t in a black box and I am getting a data like that what should be this black box behavior such that if I do a convolution with s t I receive this particular y t, that is my goal, right.

Given this s t, given this s t, given this y t, given this you know equations what should be my h then, because you just create a analogy. This is original part. Whatever h t is there, it is just like a convolution, h tau s of t minus tau, but after all this I am receiving the I am getting like a equation 1.

Now, you compare between 1 and 2. 2 is what is the normal fundamental equation, 1 is what you get it, right both are same, because this is y t, it is also (Refer Time: 31:33). Now, compare between 1 and 2. If you compare it then what should be my h 2 such that the 1 comes?

The h 2 would be something, but that Dirac function because if you integrate with this kind of Dirac function will get delta s of t minus delta 1, this precisely what we will get it, right, correct, right. This is precisely what we will be getting, right no. Why? Because Dirac function t minus t 1, f of t integrate dt what it would be? It is f of t 1, correct, right.

This is the standard equation. Just keeping that in mind compare it; t minus tau 1 there, t minus tau 1 there, so what should be the? It will be just replaced by whatever here. It is nothing but your tau 1 here. So, replace you that means, you take integration d of tau minus tau 1 s of t minus tau d tau, it will be s of t minus tau 1 because same analogy here. Whatever I have drawn, I have created the same analogy here.

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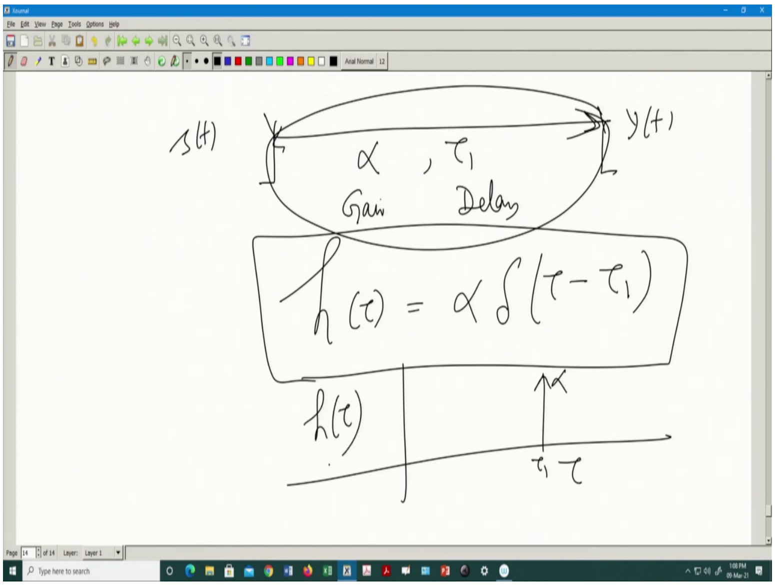

So, that means, in a summary we have just created the first fundamental channel model that if I have an antenna here, if I have a simple antenna here, there is nothing else in the system, just directly the data received here with a delay of tau 1 with a gain of alpha. I call it a gain, gain does not mean that it will be always positive sorry more than 1, it can be less than 1 also. See it is like attenuation.

So, I will call it a gain, I call it a delay. So, the channel here, so channel the filter characteristic as I said, so that means, from here to here if I have an s t, if I have a observation y t, the filter I am talking of here, h of tau is alpha d of minus t 1. This is my channel. We are faster. How does it look? It looks if I plot it with respect to delta, it will look like some Dirac function at point delta 1 with a gain of alpha. So, this is my channel. This is what my channel is.

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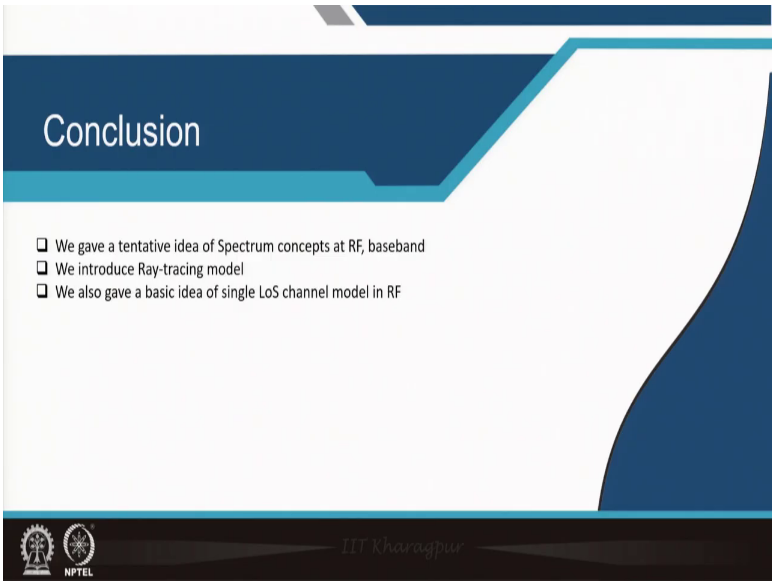

Well, we have covered so far the spectrum issues at the RF and baseband. We have also introduced the ray tracing model and gave a basic idea of LoS channel model at the RF.

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So, reference remain the same compared to my earlier classes. So, with this we end the session for this particular channel model. Next session we will be talking of multiple path. This is just a single path; that means, from direct antenna to direct antenna I have just one path.

Then, we will start getting into the more complex model, time dependency, frequency dependency, which is particularly involved in the milimeter wave context. We will talk about it. This is a very fundamental concept of the first channel model. I hope this makes the point clear.

Thank you.