Signal Processing for mmWave Communication for 5G and Beyond
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Module - 01
Wireless Channel - A ray tracing model – Part-I
Lecture - 05
General channel Model

Welcome to Signal Processing for Millimetre Wave Communication class for 5G and Beyond. So, last time we have discussed the RF model of my channel right. Now, today we will be mostly discussed what happens when you go to the analog part and subsequently what are the dependencies on the delay and gain part.

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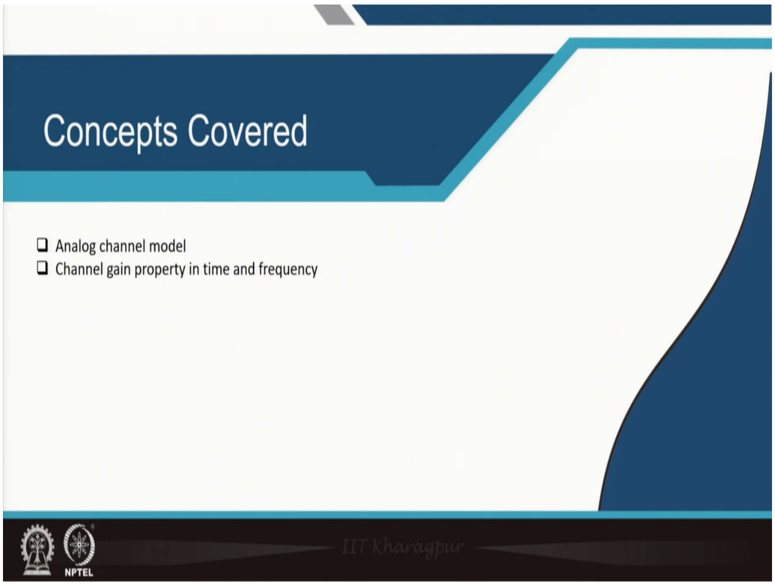

So, today we will be mostly covering the analog part which we did only touch upon last time, but more details this time. And more channel gain property that we just again touched upon last time, more details into time and frequency part ok.

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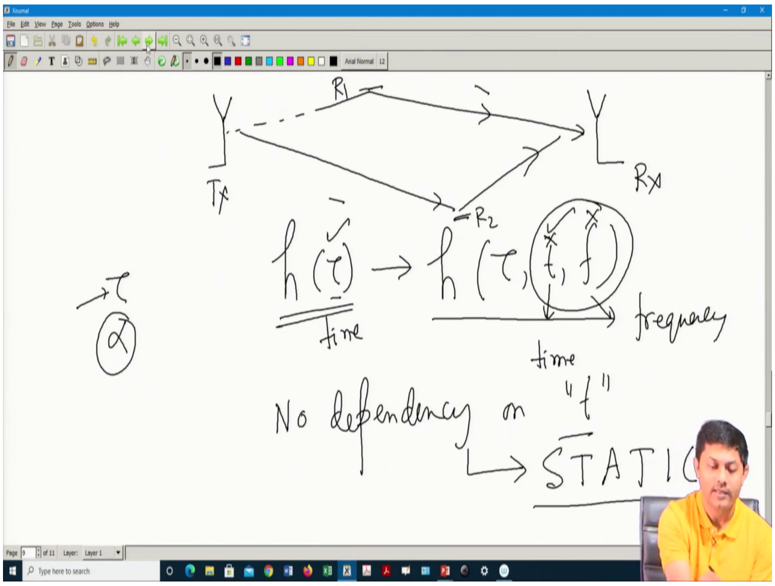

So, we again draw the diagram, where we have a single antenna to single antenna. And there may be multiple objects here. I am not again getting into whether it is a reflectors or scatterer multiple objects ok. And the ray can go here and ray can go here ok. So, this is the ray tracing model and multiple such objective which are doing the job. Now, last time we have modeled the channel when it is an RF model right. So, we saw that this tau h tau whatever you call it channel it is in fact it has a dependency on tau time and frequency.

Now, there is a slightly confusing things here. What is the tau here? It is time. What is the t here? This is also time, this is frequency. What does it mean? The channel depends on time and time; I mean it is slightly confusing right. We will explain it what exactly this time and that time.

So, if you notice in fact I clearly divided though their time clearly divided the whole thing into two different notations; one is a tau notation, another is a t notation ok. Both are time, but both are totally different notion of time ok. And this is pretty I mean this is very important for a channel model to understand what is the difference between tau time and the t time ok.

And frequency is fine, frequency is well understood component. And we can see it has nothing to do with tau and t, so that we understand. So, now, this whole channel in RF we saw that it is dependent on tau which is a delay t which is a propagation time, and f frequency.

Now, before I get into the t part and f part which will be slightly complicated way of understanding the channel let us understand that the dependency of channel does not have anything to do with the t and f. Let us assume for the time being ok, just to avoid our complacency because we have analog model description and subsequently the digital model description. So, let us not bring these two points for the time being ok.

So, let us assume that it has no dependency on time ok. What does it mean? The whole system is static. So, no dependency on time on this t notion, time notion – this time notion not the tau time notion. What is the implication on that? The implication is that the system is static right. System is completely static.

What does it mean? Transmitter is not moving, receiver is not moving, any of these reflectors or scatterer whatever. So let us call R 1 R 2 whatever whosoever is there, nobody is moving anywhere, everything is just static. Can I think of such scenario is impractical? Yes, of course.

Say, for example, you are speaking just standing you are just sitting on a chair and you are speaking to somebody else ok. And let us assume that the person with whom you are speaking he or she is also inside the house some other room. So, she is also sitting in a normal chair. So, nobody is moving. As no chair as none of the object inside the house is moving. So, I can think of this is more of a static environment, nobody is moving ok.

Can I think of a dynamic environment? Yes, everything else is a dynamic environment. For example, I am say travelling in a car, and I am speaking to somebody else. What does it mean? It means I am in a receiver or a transmitter both can be possible. I moving ok, as I moving somewhat some other cars which are passing by they are also moving.

So, I can think of this whole scenario is a dynamic scenario, so that is where the t dependency come into picture we just saw that, but again detailed description will be given subsequent classes. But currently I am assuming that my system is a static environment meaning I have not moving, the whole thing is not moving at all ok static environment.

So, what does it mean? It means it has no t dependency ok, that means, the tau i this delay and the alpha the gain, they are not dependent on time because everything is fixed. Now, I say that I do not want that f dependence also. Because I want to have a simple model for the time being, and then later on I will bring them back for millimeter wave and other thing.

Now, how do I get rid of the frequency dependency because that is nothing to do with static? Even if you have a static environment, your frequency dependency still can be there. Why, because what does the what does the f do and who impact the f, I mean who basically creates the f dependency understand that.

If you look at the last class, we have said the f dependency comes because this alpha has a frequency dependence that is why the frequency dependency coming. Tau does not have a frequency dependency. It is the alpha the gain right. So, can I avoid that? Naturally no, I cannot avoid that part, but I can do one thing for our modeling purpose, and this is what interesting part.

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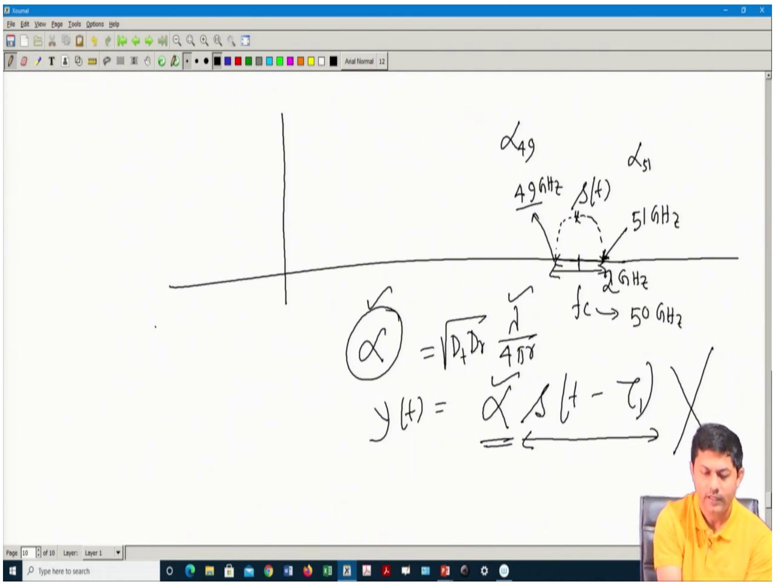

What I can assume that let us say I cannot get rid of the frequency dependency, but I can do one thing. Let us say this is what my actual spectrum, this is what my f c, my r f c whatever it is. Let us say let me not assume any value here something 6 giga Hertz, 100 giga Hertz whatever value you can assume around it the spectrum is sitting ok. Let us say the total occupancy is 1 giga Hertz.

Let us see this f c let us have a value let us say I am having 50 giga Hertz. And around 50 giga Hertz, I have total occupancy of 1 giga Hertz. What does it mean? So, this will be 500 mega Hertz, this will also be 500 mega Hertz, total 1 giga Hertz occupancy ok.

So, the point here, a component here, what is the frequency E is facing? It is facing 51 giga Hertz. The component here is facing a 49 giga Hertz. The component in between will be facing any value between 49 to 51 giga Hertz right, correct, right. Now, think of the alpha value, the gain value we are talking of.

What is the meaning of alphas dependency on f, what does it mean? It means that if I change my f or frequency my alpha will be different as simple as that and it is evident here. Now, obviously, the alpha if I have a total band of 1 giga Hertz, the component which is sitting at 49 giga Hertz it will be facing some alpha let us call it alpha related to 49 giga Hertz.

The one which is sitting at 51 giga Hertz will be facing some value of alpha because if I say that I do not have any other reflector it is just a you know simple distance. I can apply my free space equation worst case then I will have a gain we have just seen last class it will be something like a D t D r lambda by 4 pi r right.

This lambda will be different for both the cases. It is the same signal just that its band is very high, that means, within the same s t, this is the same s t, but it has a band of 1 giga Hertz that means my sampling rate at dac, I am making a 1 nanosecond sampling rate that is what it simply means.

So, it occupies sorry it occupies and my sampling rate is 500 mega Hertz. So, it occupies a total 1 giga Hertz occupancy at the RF level. So, which means that the one which is so the component so that means, within s t, I have all the components present from 49 giga Hertz to 51 giga Hertz.

And each and every component within s t will be facing different value of alpha. Then this whole data model collapse. When I say my y t is equal to alpha into s of t minus tau let us say I do not have reflectors you know so this itself is a collapsed collapsing concept. This does not hold true. Why does not hold true? It means that across all the frequency of s this alpha is constant that is what it means, then only this equation is valid, simple linear equation is valid.

What is the assumption here? Across all the components that is present within the s t everybody is facing alpha attenuation that is what it means. But when I look at the actual spectrum I see that hey it has a 49 to 51 giga Hertz total band, total band, so it sorry there is a small mistake here it is should be 2 giga Hertz total band is 2 giga Hertz not 1 giga Hertz.

So, total 51 to 49. So, I am saying that within that whole 2 giga Hertz band, this alpha itself is not constant because 49 is facing one alpha, in between somebody else is facing some other alpha, this fellow facing some other alpha. So, that means, this model completely collapses. I cannot write like that because alpha is not constant throughout my band ok.

But what is my intention in my modeling here because I want to make my model simpler. So, I want to make my model such that the h is independent of mine because that is my start point, then we will go to the millimeter wave and all the other models where we will see what happens when I make my frequency dependency prominent.

What happens to that model? We go step by step, but in this particular model I am assuming that my alpha is constant throughout what it simply means that this alpha is not dependent on any frequency within the band of operations, but that is not possible.

Then what I do? I make a small change in my band. Instead of taking total two giga Hertz band, I said no, I am not going to take 2 giga Hertz band, I make it smaller. Let us say I take a value let us say let us take smaller value.

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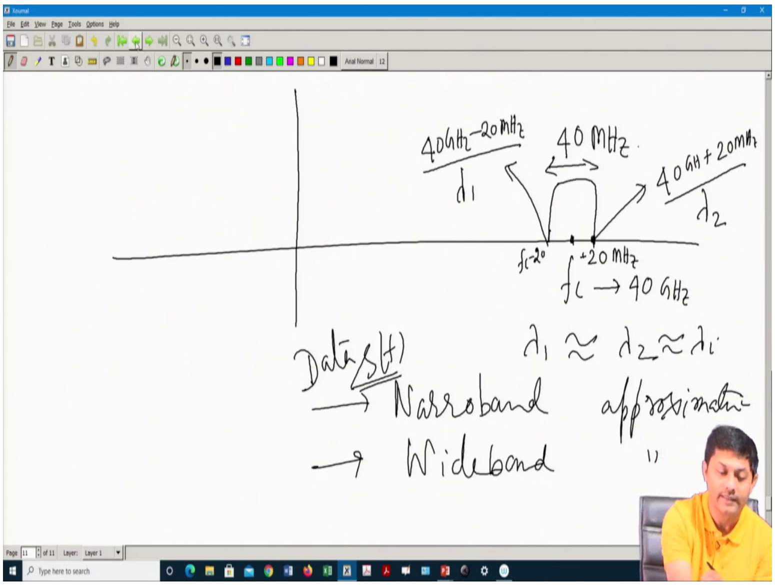

So, let us say same thing this is my f c. Let us I make a this spread is say 20 mega Hertz, this spread 20 mega Hertz f c plus 20 this will be f c minus 20 mega Hertz, not in giga Hertz. So, this f c let it be 40 giga Hertz. So, around 40 giga Hertz, I have a 20 giga Hertz plus 20 giga Hertz total for sorry, around 40 giga Hertz, I have a total 40 mega Hertz band, this is mega Hertz, not giga Hertz.

There is a very small narrowband. Now, think of the same scenario. Now, will my alpha, so this total band is how much? Total band is 40 mega Hertz. What was the earlier case? What was the total band? It was a 2 giga Hertz band. Sorry, it was not 1 giga Hertz, 2 giga Hertz band; it was a 2 giga Hertz band. In a second case, I am making it a 40 mega Hertz band very small narrow band, but let the r f be as high as earlier.

So, it was 50, let us let it be 40 that does not matter. Now, you think of alpha that is the core part of the whole discussion. This alpha is now not so much dependent on frequency within the band. What does it mean? It means that what is this point this point is 40 giga Hertz plus 20 mega Hertz point. This point is 40 giga Hertz minus 20 mega Hertz point right.

Will there be too much lambda difference? Will the lambda be too much different? Suppose, it has a lambda the wavelength let us call it lambda 2, let us call it lambda 1. Now, 40 giga Hertz minus 20 mega Hertz almost nothing, 40 giga Hertz plus 20 giga Hertz that is also nothing almost nothing, that means, this lambda 1 almost equal to this lambda 2.

Naturally, these are the two worst case points. In between also each and every lambda if I take it, any sample point you take it in between within this band, this lambda will be almost equal. What does it mean? This alpha will almost be equal alright.

So, that mean in a sense when I say my channel has no frequency dependency, essentially I am talking that the channel is a narrowband channel ok or not the channel is a narrowband the data that I am transmitting I am considering a narrowband data transmission ok, so that means, the band of operation I am talking of is a narrowband case.

So, now, that leads to two different concept of channel. One is called a narrowband approximation, and second is a wideband or broadband somebody call it wideband somebody call it broadband, wideband approximation whose it is the data transmission data s t. So, that mean if the s t has a very wide band, the channel characteristic will be very very different.

Whereas, if the data that s t has a narrow band say I mean narrowband can be anything less than 500 mega Hertz that is usually the narrowband, but usually 100, 200 mega Hertz I call it kind of a narrowband kind of things, but wideband meanings I am thinking of 500 mega Hertz, 1 giga Hertz, 2 giga Hertz, 10 giga Hertz kind of band bandwidth I am talking not the r f ok, r f is different, bandwidth is different.

So, when your data is having a narrow band case, my channel impact is that the impact of such cases is that it has no dependency on frequency. It has no dependency, the channel it has no dependency on frequency. So, when I say I am making an approximation not an assumption that the channel for the timing is not dependent on time and frequency, it simply means that I am assuming a static case, and I am assuming a narrowband case not a wideband case.

We will see what happens in a wide band because this is the very I mean it is a pillar concept for millimetre wave where the band will be really large ok. We have to consider. And we will see that what happens in that case how we exactly model it, but you will see we will discuss it that the fundamental of that definition will be totally dependent on this channel model.

So, if we understand the channel model which is independent of time, independent of frequency that itself will be the pillar for the next level of approximation ok. So, now, we understand that our channel is kind of a time independent and frequency independent.

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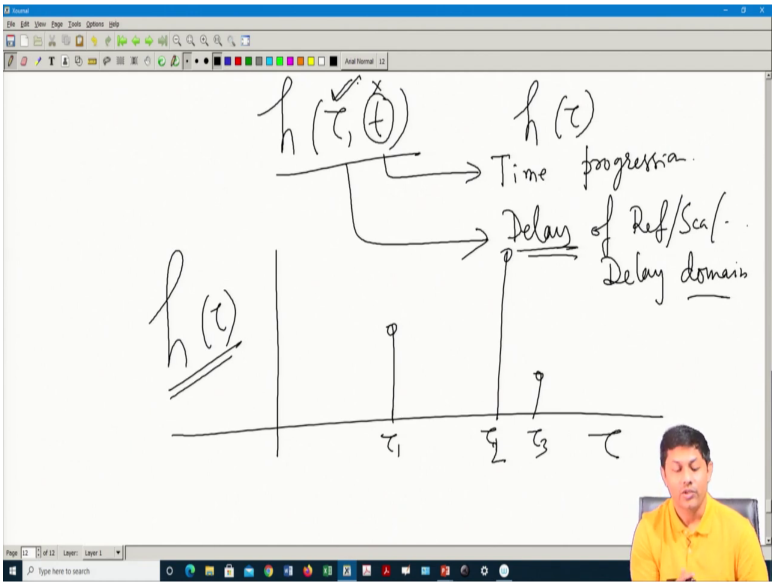

Let me answer the another question. What is the difference between the tau and the t part then? Frequency I am not bringing it because I am assuming it is a narrowband case. But let us understand the different though I am not assuming the time dependency, but as a side discussion let me let us make a difference between the tau and t because that comes up very often.

So, here what is t, what is tau? Now as you see predominantly the t may appear, may not appear. Suppose, my system is static, what does it mean? Channel is completely dependent on the tau part. Now, what is the tau? Tau, if you see it is actually the delay right, because if you look at the way I am drawing my channel, this is how I was drawing my channel right.

So, I was placing my impulse response somewhere here, somewhere here somewhere here. So, this will be tau 1, this will be tau 2, this will be tau 3. So, I am plotting over tau not over t.

Why, because this tau in a static case will not be dependent on the variation because they do not vary. T hey will remain constant, but this is a time notion because this is a delay.

So, that means this channel in a static system, it has a time dependency, but that time dependency is not a t notion. What is that notion? This is the tau notion ok, very fundamental to understand. So, that mean the channel in a static environment does not have a time variation, it depends on the delay time. And the delay time in a static domain does not depend on the time of progression.

So, that mean this tau is nothing but it refers to the delay of individual taps. So, delay of individual, individual reflectors or whatever, reflector, scatterer that that one. So, it is the delay popularly it is known as delay domain, so that mean this channel has a dependency on the delay domain part. So, this is one time notion ok then.

What is this t 1? t is your normal time of progression like you are sending a data you are observing it at different, different times, so that is your time, so that is a time progression ok. And this time as you notice it is a time progression, as you notice it may or may not appear into the channel depending on whether the channel is a static channel or is not a static channel.

If it is a dynamic channel, yes, t will appear. But if it is a static channel, if the system is static, channel does not have any t dependency. So, this t is a time progression, so that is the reason I have kept both the things separately. So, there is a tau domain and there is a t domain.

So, when I say t, it is a time of its a time progression like I am observing the data at different time right t 1 time t 2 time observing I am sampling that is the t. But when I say tau it is not that it is basically the delay among each and individual paths, so that is another time notion. And you can see that tau will always appear, tau will always appear.

Why it will appear? Because whenever you transmit it, there is a; there is a delay between the transmission and receiver because it is a there is a finite amount of distance. So, obviously, the tau will be appearing, but t may not appear all the time ok. So, that means, I can have a channel.

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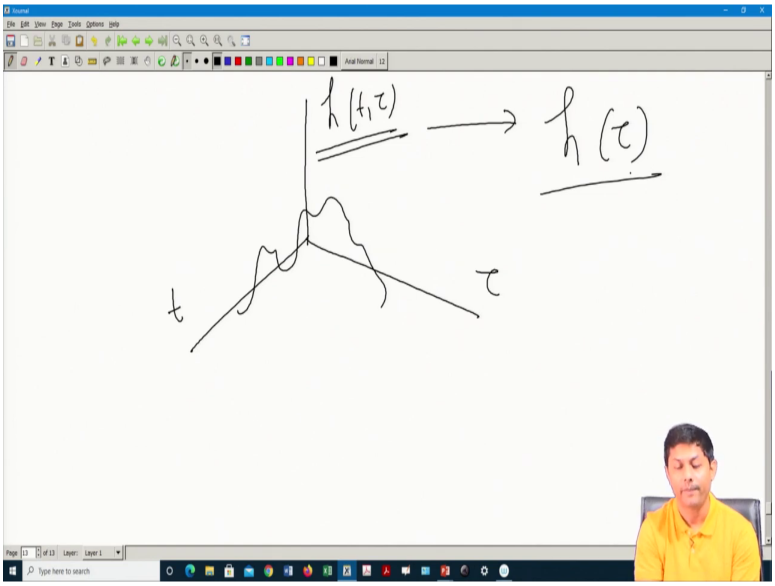

If I draw the channel in a three dimension case, so I may have a t domain here, I may have a tau domain here. And this is my h of t comma tau I may have some sort of a 3D curve in nature where something varies over t, something varies over tau that is what we will be seeing it. We will discuss this subsequent time. But my point here is that this two are two different time notion – one is a delay domain, another is a time of progression.

This two have to be completely different one ok. But in our case for our first initial discussion I am assuming my channel is completely delay domain dependent. It has nothing to do with time domain dependency, because it is a static environment ok.

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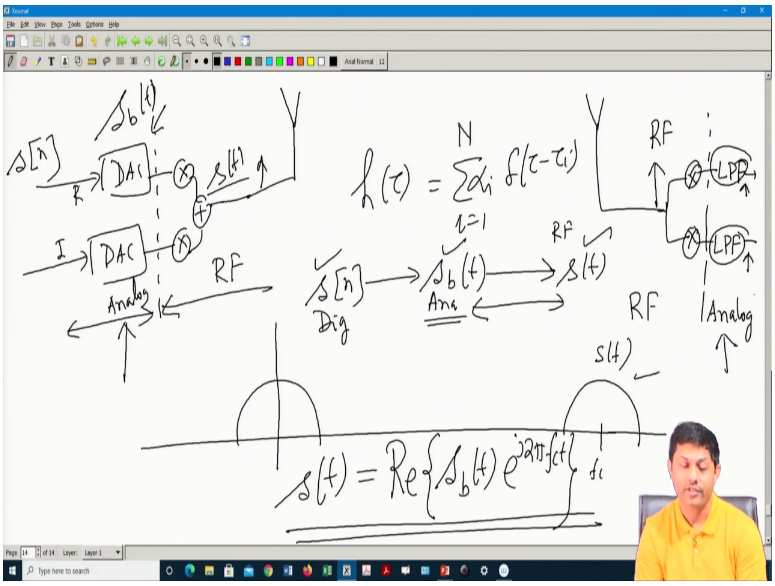

Next one is that. So, far what we have done is the channel is completely viewed from the RF point of view meaning I am standing here; this is what my stand point. I am standing there. I am looking at this. So, I am putting a you know I am putting a oscilloscope. I am observing the signal there. So, this is my view I am standing there ok. So, this is my s t. So, I am transmitting as if like I am transmitting here I am observing here.

Now, I am shift my observation point ok. It is as if like we are looking at an object through a glass. So, if you put a blue glass, you see that the object is a blue. If you put a red glass, you will see the object is red. Actually the object remains the object it is all depends on what you are looking through.

So, now, so far I was looking through the whole system from the RF domain that mean I am standing here. So, this is my RF domain, and that is how my channel was we have discussed it. This is how my channel alpha I tau minus tau y this is my channel, i is equal to 1 to N, N number of paths that it will have it ok.

Now, I shift my view. What does it mean? Now, I say I do a demodulation ok. I do a demodulation that mean it will go through this standard demodulator, there is an LPF here, there is an LPF here. And so this is where I am now standing. I am standing at here. Now, this analog right if you notice it because I have completely discarded the RF part. So, this is my analog domain. This is so for my RF ok.

So, what does it mean? That mean my view will also change here. So, there was a DAC here if you remember there was a DAC here if you remember, and this two were going through modulators right. And then we added up and create the signal. So, when I shift my observation to analog domain from here I have to shift my observation to analog domain, it is like I am here. So far this one is an RF domain. This one is basically my analog domain.

So, now, I am standing here, I am standing here ok. So, my view is now analog to analog, no more RF. So, what is the change that will happen here? Let us understand that ok. Now, if s t was the RF signal. What is the relationship between s t the RF signal and its analog equivalent? So, let us say this is my RF. And let us say the signal that I was going to transmit was say s b t. What is the s b t? It is the analog version or the baseband version I call it a baseband, baseband version of the RF.

So, what does it mean? It means the signal will have three versions. Here the signal was having digital version, s n that goes through the this is the real part, this is the imaginary part. That goes through two DAC and it gets converted to analog waveform. So, let us call that s b t ok.

So, you had s n which is the digital data. Then after DAC the same signal gets converted to analog. After modulation the same signal converted to s t that is the progression. So, this is RF, this is analog and this is digital. So, we have model this part channel part. Now, we are here.

And you see that s n to s b t, s b to s t, they are all related – same signal is just the different view of the signal. One is discrete, another is analog, another is a RF right. What is the spectrum, spectrum wise how would the s t look like? This is how the s t look like where you have the f c. How would the s b t look like? Same. How would the s n look like? Same only, because only thing is that it has been changed to analog to digital ok there is no change, but this is the s t part ok.

Now, what is the relationship between s t and s b t for a communication system? I may have said it, but I have not proved it because this is beyond the scope of this class. The relationship between RF signal and the analog signal in a communication is this. This is real part of your s b t e to the power j 2 pi f c t, this is what it is.

This is precisely what the relationship between RF and analog signal ok. If it is a communication signal, so that mean if I have an RF signal, I can always get a relationship between this analog version sorry baseband version and its RF version ok.

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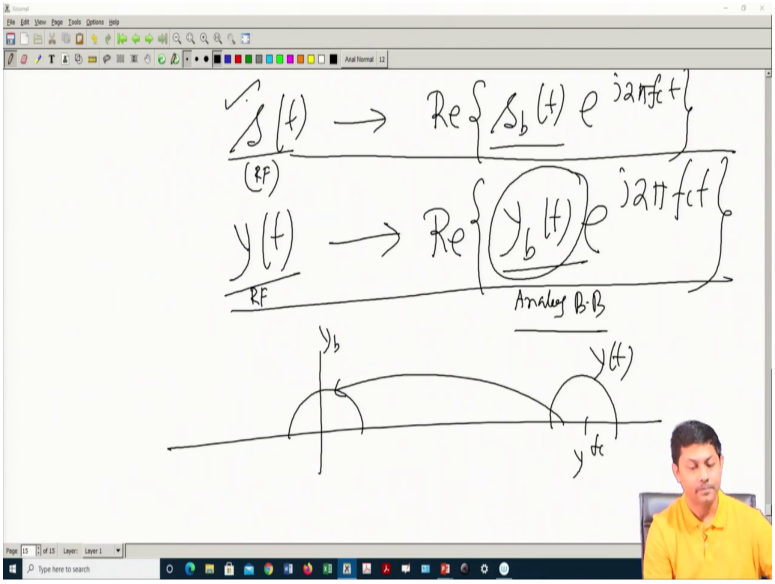

So, in a summary for today's class, so we have the s t which is predominantly RF, we always get a equivalent baseband relationship. Same question a I may ask what happens to the receive signal. If y t is the receive signal, I can also find because this is the relationship between a RF signal and its baseband analog equivalent.

If y t is my received signal at the receiver end I also can have its baseband equivalent, so that mean y t will have also some y b t. I am here to define it what is y b t, but it will just an analogy ok. So, this is important to understand.

So, this is the relationship between RF and its analog base band. I still have not defined what is y b t that will define subsequently. But it may exist, it will exist, not may, it will exist. It will exist that there is an analog baseband version equivalent to a RF version ok. So, if I plot if I observe this is my y ts spectrum, this is f c, I can think of it also has a base band equivalent.

So, this would be y b, it will have that because this definition says that there is a transmission signal which is s t and it has its equivalent baseband model and that is the relationship. So, if y t is the received RF signal that will also have an equivalent baseband relationship ok.

So, now, today we end this, this session. From next class, we will be talking about the definition of y b t, how I define y b t, and what is the relationship between y b t and s t, and the channel and that is what the analog model will start.

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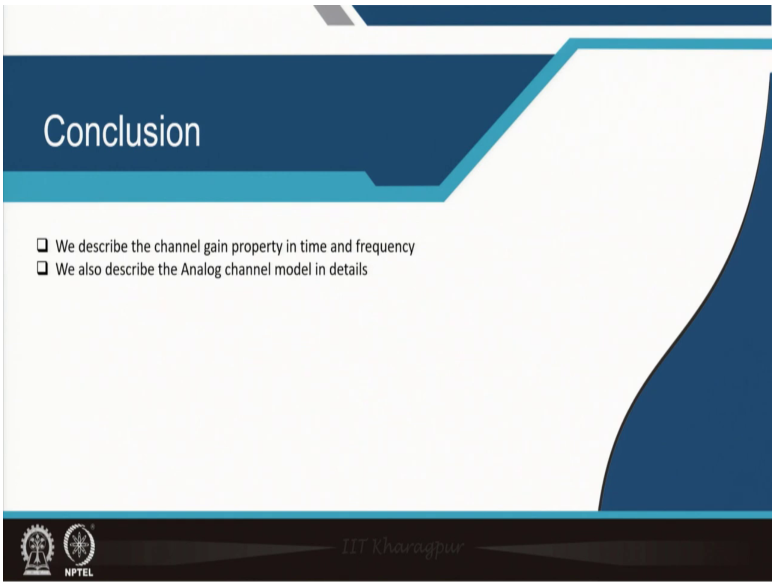

So, in summary cover it, but we have just started it the analogues system model because this is the baseband part that we have started, and subsequent classes more and more analog models will be now coming into picture.

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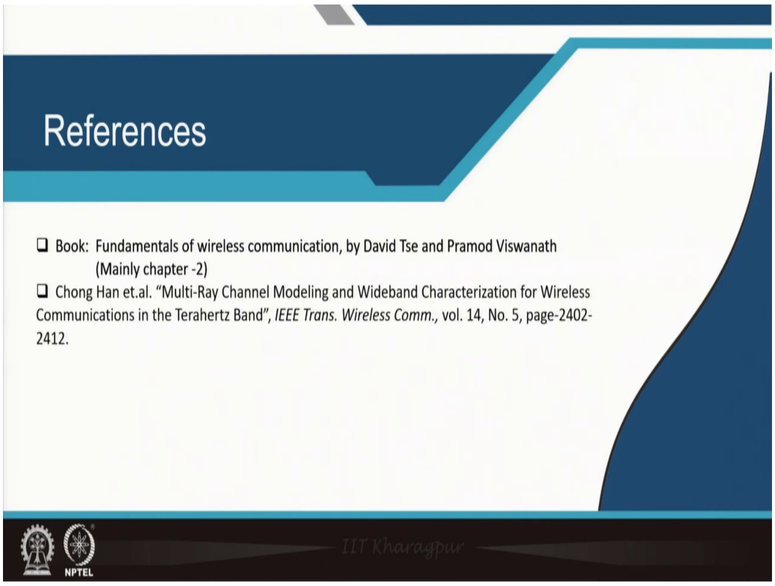

References are two, Fundamentals of wireless communication by David Tse and Pramod Viswanath and this particular paper. And this paper means mainly for the Tera Hertz communication paper, but take out the Tera Hertz part. The rest of the things it will very well describe the alpha property, that the gain property, how is the frequency dependency come into picture. So, we will talk more on that.

Thank you.