Signal Processing for mmWave Communication for 5G and Beyond

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Module - 03
Wireless Channel parameters (Time varying nature)
Lecture - 13
Time varying Model

Welcome to Signal Processing for millimeter Wave Communication for 5G and beyond. Today, we will be covering the week 3 part that is the Parameterization of the Channel. We have already explained a lot regarding various parameters, but now we will be talking about the time varying nature of the channel and that is how the module 3 would be.

And, in the last class we have just briefed about the time varying nature of channel, now, we will be talking about it is modeling issues what are the different ways to model channel.

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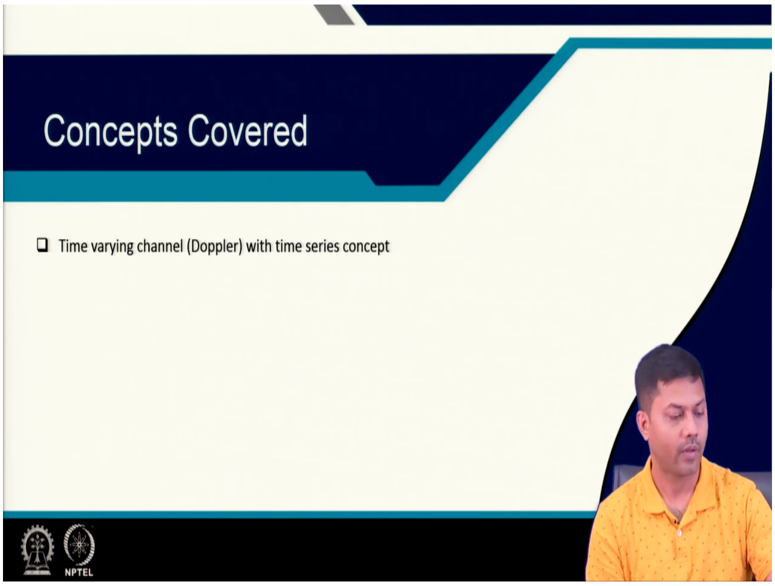

So, the concept that will be covered today is only one concept and it is actually very big theory that is coming into picture, but we will be trying to make it as precise as possible. So, that is the time series part because time series is a I would say it is a mathematical tool by which you can model the time varying nature of the channel.

So, today we will be going through that concept and in subsequent class also we will be going depth into it, ok.

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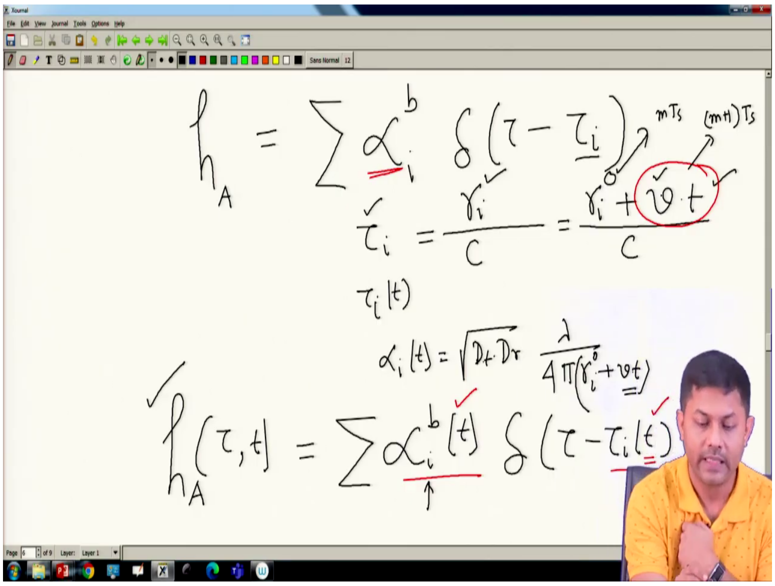

So, in the last class, if we see this is where we were right we said that the channel at the analog or the r f level will be varying over time. Why it will be varying over time because the gain is varying over time and the delay is varying over time and why? We have explained it.

Now, let us see the modeling part what how we can do the modeling issues, but now the problem here is that as we just talked in the last class. This tau and t you cannot mix them together for modeling, ok. You have to keep it slightly separate that mean you first process in the tau domain, do your frequency analysis whatever things that you need to do in the tau domain then you bring it back to the t domain and that is how the philosophy is from for the channel modeling.

So, you cannot mix both tau and t together, you cannot I mean of course, it is a multivariable system like a tau and t, but the processing philosophy is not together, its like a one hot kind of first. You model in the tau then you go to the t. So, in a in a sense when you say I am trying to find out the coherence bandwidth or everything like that. So, it is as if like I am talking of a fixed time; that means, at a particular t equal to t 1 I would say at say t is equal to t 1 so and so is happening.

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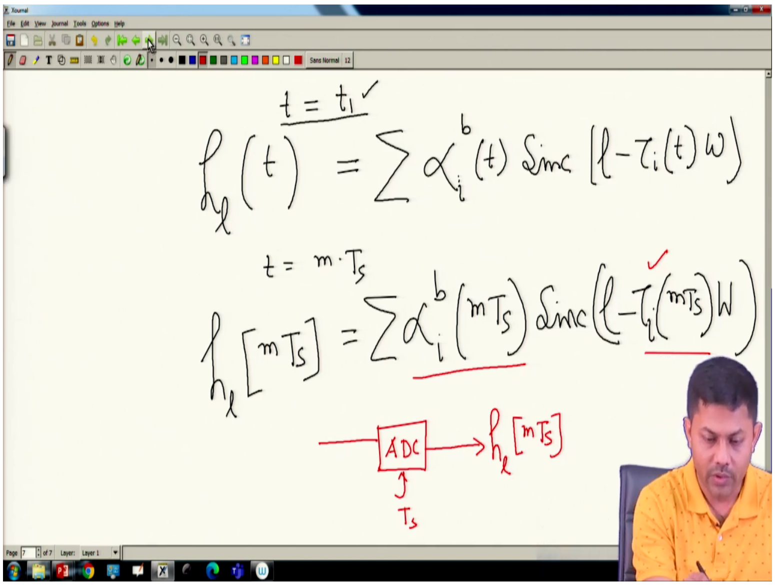

So, that mean I am fixing the t and then I am proceeding for the tau domain analysis ok and that is precisely what the philosophy. So, that means, my channel h even if I go into the you know digital domain so, that was h l that we have already seen it, but that is now a time varying, ok.

Now, it was earlier t was the case right because t is the initial analog or the continuous domain, but when I digitize it of course, t has to be sampled, but if I draw the equation here alpha i b this was the time domain case sinc this will be the case because it is the time varying nature. But, now as I said t is equal to t 1, ok. So, that is whole digital times digital taps that we have already defined it they all become time varying, ok.

So, now, t equal to t 1 is a time that I am observing. Now, I am observing in ADC in a sampled manner, right. So, that means, I will be observing t at predominantly m into T s sequence, right. So, t is not a continuous when after ADC. So, that mean when I am in a digital domain my channel would be something like that this will be sinc tau I of w this is what is going to happen.

So, all my alpha is like as if like I am sampling the alpha at different different time spacing. I am sampling the tau at different different time. Why alpha is I have to sample at different time? Because they are time varying I am observing after the ADC at different m T s.

So, if you have an ADC here this is what your digital view of the system right you have the ADC and the sampling time is T s. So, this is where my observation is. This is how I am observing that because it is a time varying thing ok; that means, lth tap itself is a time varying. Got my point? So, you have you may have L number of tap capital L number of tap and every capital L number of tap itself is a time varying thing we will explain that how exactly comes into picture here ok.

So, now this is a interesting modeling aspect here. So, basically the way we should model is that you separate t domain and the separate the tau domain. So, these are the basic philosophy of the modeling, ok. Now, what happens to the FIR filter? Suddenly, you see that this FIR filter is a time varying FIR filter you stop to model, right.

Because if you have an FIR filter and if the coefficients are itself a time varying you cannot deal with such kind of things, right. You cannot deal with it because you receive a data you receive the second data by the times coefficients all changed; you receive the third data coefficient changed. Its not possible to you know deal with such kind of things ok.

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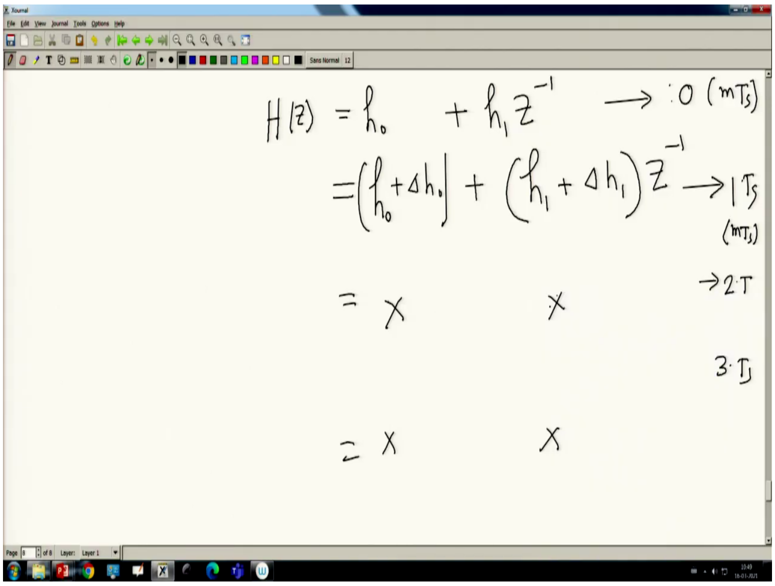

So, now that is the concern I tell you. Now, let us say I have model the channel as a simple you know simple two tap channel. Let us say simple two tap channel. So, this is my channel h 0 plus h 1. This is my this is my simple first order channel. I have defined it ok. The channel that is existing, I have just having two taps into it.

Now, I say this taps are time varying, what does it mean? This h 0 and h 1 are no longer valid after some time, it is varying over time, right. So, what does it mean? It means this h 0 would become some change will be there. So, either it can be dash you can say h 0 dash or I can say h 0 plus some extra part comes into picture h 0 plus some delta h 0 will be there because it has changed, right.

This is may be at time say at time say at time 0 because I am sampling at different values. So, this is at time 0 and this is at time 1; 1 meaning sample value of 1. So, this is my m T s.

This is at time m T s where m equal to 0 in the first case and this is m equal to 1 in the first second case and so and so forth it just moves around it just moves around. So, every time I may have a here I may have a 2 T s, here this is the 1 T s, then you have a 3 T s. Every time you have some channel changes again some channel changes, again some channels and so on so forth.

Can I deal with such kind of FIR filter? Because every time the coefficient itself is changing I cannot deal with it right because it is varying. It is varying over time, right. So, you give the first data h b data you deal with h 0 h 1. You get the second data by the time the coefficients have already changed. So, you cannot deal with it ok.

Now, what is the way around? What is the remedy for taking of taking out of this kind of mess I would say, ok we will see. So, that mean I need to do a right modeling for it and that model guide us what I need to do what I need not to do ok because it is a time varying nature. Now, I make two conclusion here or rather I will make one critical conclusion. Conclusion is the following.

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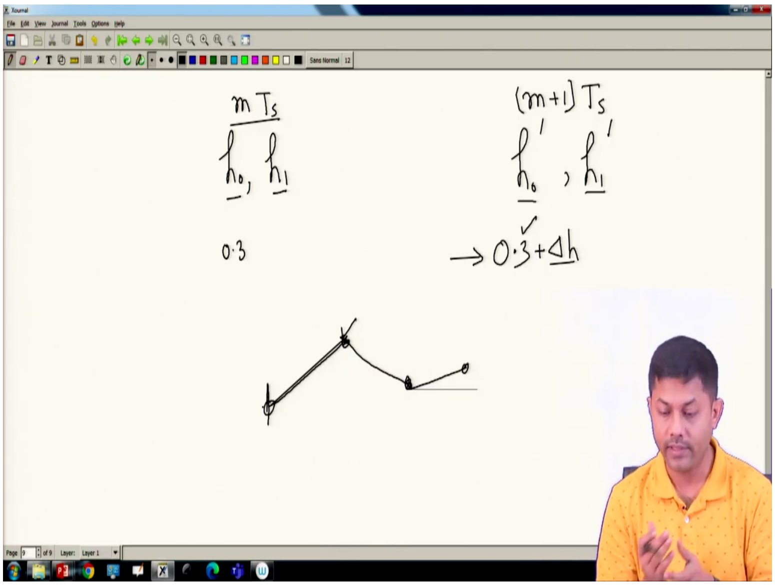

I would say I am observing the tap at m T s time and observing the tap at the next ADC sample m plus 1 T s ok. And, say I have two digital taps that I have seen in my channel how they appear because of those alpha and tau they make it different. So, because of that those differences will become.

Here I may see this h 0 dash h 1 dash question is that is the h 0 and h 0 dash are completely uncorrelated random variable? Is h 1 and h 1 dash are completely uncorrelated random variables or there is a correlation between them? In a simple word given h 0 and h 1 can I guess something about h 0 dash and h 1 dash, is it too off?

Say for example, if h 0 is say 0.3, can I say this will be purely a random number? I have no relationship with what it was earlier it will be like that or will it be 0.3 whatever was earlier there plus some extra randomness that comes into picture ok instead of delta I would say delta of h; some small random value is added along with whatever was earlier.

Is the change like this or is the change completely uncorrelated or independent different? That means, if h 0 is something I cannot even guess h 0 dash what is the h 0 dash ok. So, it is something like a Brownian motion. So, is it like a you have one position, the next position is completely off you do not know where the next position would be or is it or you can guess something ok or is it some sort of a random walk where you know you had originally a value the it will just gets a small delta.

From there I gets another delta, from here I get another delta that mean this value really depends on what where it starts from was it like that or it is kind of a completely random Brownian motion. So, we will see that. So, that comes from that definite that concept comes from how the channels have been structured.

So, look at how the channels equations have been here. So, how I see the tau I changes tau i changes with r i 0 plus v into t that mean if r i 0 refers to some value at say m T s and this value that extra m plus 1 T s is how much it has progressed right m plus something like that m plus 1 T s; that mean, within T s time probably it has moved v into T s time.

So, the distance from m T s to m plus 1 T s the extra distance that it covers it is I mean its not a completely random kind of things. So, it has some correlation with respect to what it was earlier then there is an extra random because if the v itself is a random number the extra delta that comes into picture is what it was earlier and then some extra kind of things come into picture. So, it is a correlated data, but there is a randomness because v can be random.

You may not know what is the velocity of your system right in a real system I mean when you talk about mobile do you really track how my velocity would be. You may be walking in different speed, you may be driving with different speed, the environment can also be moving in a different speed randomly, right.

So, the velocity or that v itself is a random number and hence that you know Doppler spread or Doppler velocity everything becomes a random number, but there is a catch here.

The catch here is that even if it is a random number that the movement of that particular element will not be completely independent in nature. If you already have some sort of a positions of the system after T s time the position of the complete system will not be completely random from whatever earlier there will be a slight change over there.

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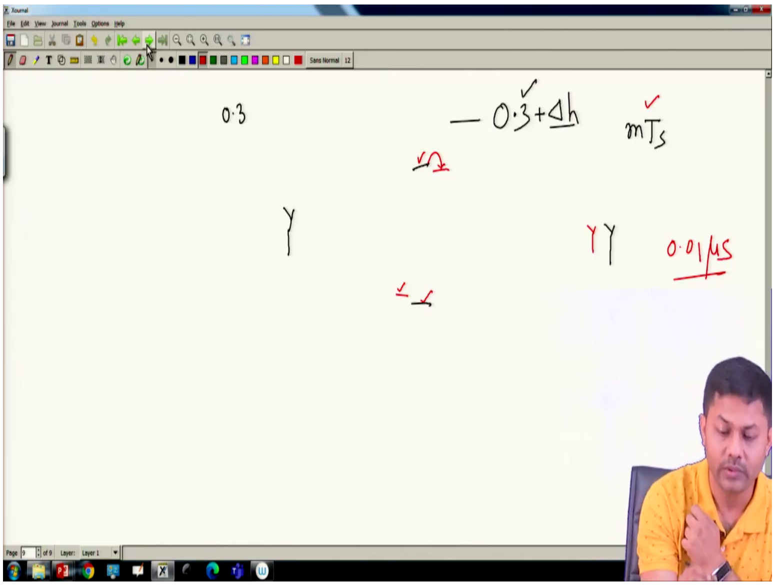

So, in a sense I can say if I look at the you know the environment say I have a T s here, I have a reflector, I have a reflector here, this is a snap shot say for example, at m T s. See if there is a velocity the only thing can happen is that either this may move somewhere here or this may move somewhere here or this may move somewhere here. That is the only thing happen if the m T s that gap is small. If the gap is large ok so that means, that there are concept on the T s as well.

See if this T s is a small enough a small number then I can say after that small T s time say if the sampling time of the ADC is say 100 mega Hertz which means 0.01 micro second. So, 0.01 micro second how much you expect? 0.01 micro second how much you expect the whole environment to be different. It would not be so much different even if something is moving. So, slight difference right.

So, that means, this red snapshot which is coming at m plus 1 T s and the black snapshot that is your m T s they have some correlation if this reflector was somewhere here after T s it will be slight change. If this was there at m T s after m plus 1 T s there may be random movement, but it is not like a very off ok. So, this drives us to a concept called it is a correlated change of the channel.

So, from time to time the changes are actually correlated changes and that drives us a very interesting modeling concept of the time varying channel that is called a time series concept ok. So, this should be made very clear that the changes of the taps from time to time are not completely uncorrelated, it is a correlated changes, but it is random in nature. Why it is random in nature? Because v is random v is random number, your velocity of the system is random. You do not know who is moving at what speed, right.

If that is the case everybody is moving, but the movement the movement does not make the whole thing extremely uncorrelated, it is a correlated movement ok because when where you are standing after say 1 micro second you cannot say that suppose I am standing at a you know at a position in Kolkata.

After 1 micro second I cannot say that I will be in New Delhi. It cannot be that much random, right. I may say after 1 micro second my movement may be just 1 millimeter extra that may happen, right.

So, that means, I can always guess I can always guess what the it is a guess. So, that is still a random motion ok. So, this drives us a very interesting philosophy of channel varying modeling, ok.

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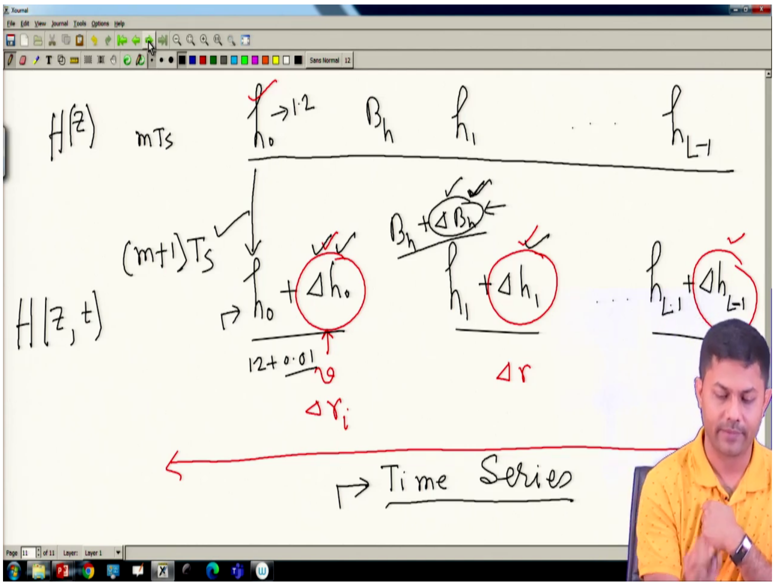

Now, this is one part; that means, that channels h 0 channel h 1 whatever channel h L minus 1 I mean digital domain perfectly, ok. Let us not go back to the analog or RN because the same effect is happening, right. So, this is at time m T s. So, they may change they may change whatever was h 0 plus some extra delta this h 1 whatever was h 1 plus some extra delta plus some extra delta at m plus 1 and m plus 2 m plus 3 and so on.

So, those changes are happened. So, which means these things I can model it as a random variable, if this is known to you if h 0 h 1 minus 1 are known to you that mean at m T s you know what exactly the channel taps are at m plus 1 T s. The only difference would be whatever value was there plus some extra random value. Why this random value coming into picture? Because the velocity is random.

So, the delta r i whatever we have shown earlier the delta r i the delta r i itself is a random number, but it is a delta r i ok because of the delta r i this delta h i will be appearing. There will be some delta r i j and all because everybody is contributing because of them they will also subsequently appear. So, this can be modeled as a random number, this one ok.

Second thing is that what happens to the bandwidth that is also interesting point. So, this part will model it will definitely model how the modeling philosophy would be. The question would be what happens to the bandwidth because now you can see the bandwidth is also time varying because if you take this tap these taps there will be a say H Z.

I would see H Z here at this point this is not H Z anymore this has changed because coefficient has changed the new coefficients have appeared. So, obviously, I can say my H Z whatever my channel transfer function that is also dependent on time meaning it is a m T s if it is in a digital. So, that is a time varying nature it is showing it, right.

Now, how do I measure that time varying that mean the bandwidth whatever the bandwidth I have explained it say B of h bandwidth of your channel. Here it will no longer B of h it will be some delta will be there, some delta because the channel coefficient have changed. If the coefficient have changed obviously, the bandwidth you cannot guarantee right. So, the question would be can I measure can I somehow guess that part also ok.

So, there are many things that now appears into our hand – one is that can I guess what the changes are or can I model those changes number 1 point; number 2 point is that if the bandwidth itself is a time varying can I guess this changed bandwidth how it can be modeled into my system where I can change my bandwidth I can model my bandwidth things very well, ok. So, let us see what it can be done, ok.

Now, before I get into the you know this measurements this delta measurement I want to give you a physical notion of that what exactly happens to that bandwidth ok that is interesting philosophy, ok.

Now, this determination of this delta B h that extra bandwidth how much it can be shifted determination of delta h 0 its a random number of course, how much they can be changed by that modeling is all it is done by a interesting mathematical tool called time series and in our all subsequent classes I will be talking about this time series.

And, it this is a mathematical tool which defines this time varying nature which also very well you know determine how much the bandwidth change happens in a statistical sense. Of course, because this time series is a just statistical property of the sequence it is basically coming from the random process, but before getting into that I would like to have a some sort of a physical notion of my bandwidth change.

Now, this notion is very clear the channel tap changes physically whatever was value. So, that mean if h 0 was let us take an example if the 0 is say something 1.2, here it will be some 1.2 plus some small changes probably say 0.01 change and all something like that.

Now, is it 0.01 change? It depends on the velocity of course, right because if the higher velocity is there this random change will be higher, if the velocity is very small the changes will also be very small naturally. If you walk you just you are doing making a walking on your with your cell phone you are talking to someone and you are just walking.

It is changing. It is a time varying channel because you are you know you are making your movement versus the case you are travelling in a train and you are talking that is also time varying your train is moving at a speed of say 120, 100 kilo meter per hour and it is a very high speed train. It is moving.

So, in all cases time is changing, but how much you can guess that when you walk the variation of my channel will be smaller because my velocity is also small. If the velocity is small the delta r i that you know that extra distance that I am covering because of the; because of the Doppler that will also be small and so and so forth.

So, how much this changes intuitively I can say that depends on your velocity, ok. If the velocity is higher the changes will also be high; if the velocity is low changes will also low; if you do not move anything velocity is 0, so that means, there is no changes. So, h 0, h 0 here it will also be h 1, h 1, here it will also be h L minus 1, h L minus 1. So, everything remains constant, there is no change ok.

Now, this whole modeling can be done by time series, but before I get into time series I would like to have a physical notion of the bandwidth change – what exactly happens, when there is a Doppler or time varying nature, how the bandwidth changes not by a measurement, but some sort of a physical notion that I would like to have it, ok. Let us again go back to our equation h ok.

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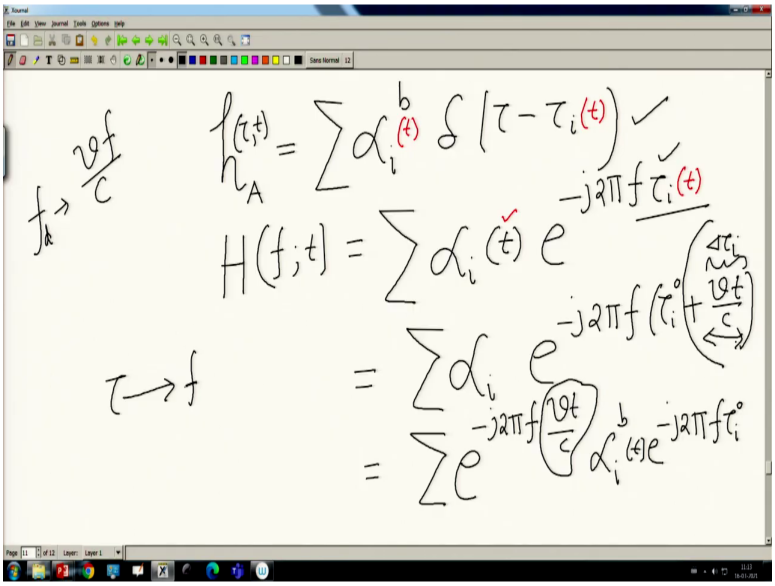

What was our h? Our h analog let us take it analog not an issue because it will be similarly reflected in the digital. Alpha i b this was our delta minus tau i, now this will be time varying. I put a different color here to ensure that it is a time varying part ok. So, that just to ensure that is a time varying put a different color. So, that ok. This is the case, ok.

Now, what happens to the bandwidth of it? Ok. Now, what was the bandwidth? So, let us take the transfer function, let us take the Fourier transformation. Let us assume that I am taking the Fourier transformation with respect to the tau domain. So, this would be tau this would be t. So, I am taking the Fourier transformation. So, with respect to the tau domain; t I am not changing it ok.

So, the tau becomes so, this tau becomes f it is a Fourier transformation on tau. So, the tau becomes f, but I am not changing anything on t. So, t becomes t, clear? So, what it would be?

This will be the case this will be the case e to the power minus j 2 pi f and tau i this was the case right because if you take the Fourier transformation exactly that will happen.

Now, this tau i becomes time varying. This will also be time varying, ok. What happens because of that? Replace the tau i. So, let us say I replace the tau I, ok. Now, this tau i initial value plus v into t by c right at extra tau extra delay that. So, this part extra delay part that is coming into picture.

Now, you just do some mathematical operation here. What will I get here? This part you take it out take it off right. v 2 c into alpha i b it is of course, time varying e to the power minus j 2 pi f tau i 0 that initial value of every tau i that is what it means. Now, what is this part? This part is nothing, but your it has if you remember this has something to do with your Doppler frequency how the Doppler frequency was defined.

Doppler frequency was defined by something like v f by c that was the Doppler frequency that we have to find it. Take this fellow off, right.

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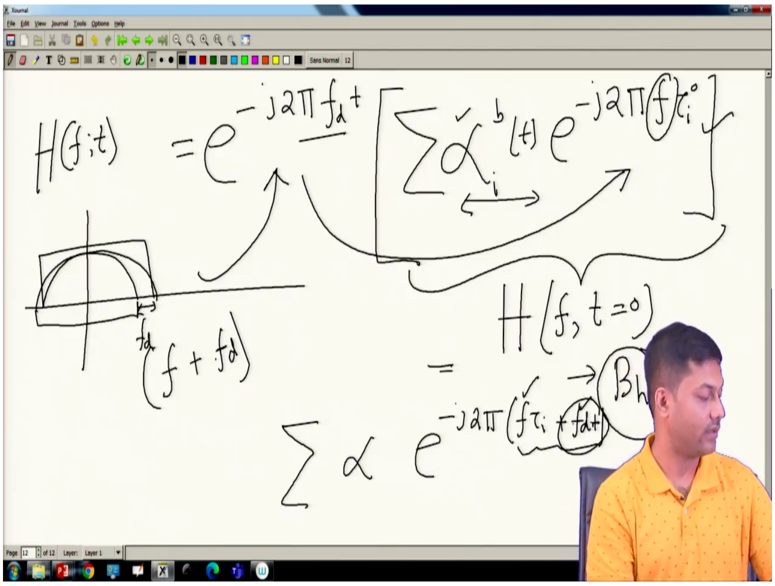

So, go to that what it would be. So, that means, my H of f it will be minus some j 2 pi f d f d t plus the original one. This one let us assume that my time of observation is not so high. So, which means that this would not be changing so much. So, that mean as if like it will be changing of course, if I do not consider the t to be very long; say, it is fraction of time I am considering.

So, the alpha would not change because if there is a movement this reflector will be slightly moved because of which the alpha may not change so much. It is only the phase of that this one will change so much ok. Then what happens this was my original f at say t equal to time 0 when I start it how much bandwidth it was showing? B of h bandwidth it was showing.

Now, look at this what it is creating. It is just creating some sort of a phase difference I mean what is the difference in that case I mean how do you model that case. So, which means that this B h whatever original was there does the B h changes? That is the question I am trying to answer it here ok.

Now, you see that it may change. Why it is changing? Because this was earlier was there f, now if you see it here so, it is changing for f plus f d this much is changing right. This was earlier was B h, now if I put this fellow inside what will happen it is as if like this alpha was whatever was remaining e to the power minus j 2 pi f of tau i plus some sort of a f dt something coming into picture it is as if like that. Can I conclude it?

So, what can I say here? So, what is the bandwidth change that happens for such kind of system? It is as if like if it had bandwidth B h earlier, there is a slight shift in my bandwidth because f is now become f plus f d some you know some added component comes into picture. Now, this is in frequency domain. The same thing I can view more from the time domain as well, that I will explain it in the next class.

So, what does it mean? It means that if I had a bandwidth earlier because of this f d this will be slightly shifted that is the only thing happen. So, that mean the bandwidth was whatever was there it is as if like there is a shift. So, if you look at here basically an extra f comes into picture.

The extra bandwidth is now appearing here. Now, is it a extra bandwidth that appear or it is some sort of a shift? Actually you see it is actually some sort of a shift because it is e to the power minus j 2 pi, so, the f becomes f d.

It is some sort of an f d here that is coming into picture. So, in an effect when you see have a Doppler this was the original bandwidth, after Doppler the bandwidth just get slightly shifted left or right depending on whether it is a positive f d or a negative f d.

We will see more on that because I have just done from the frequency domain transformation I can go into the time domain and see how what it exactly means what it exactly means from the time domain point of view that makes the you know bandwidth shift happens.

This is the frequency domain view ok. So, with this I stop the class today and next class we will be talking more on the Doppler shift that can happen in my bandwidth case, ok.

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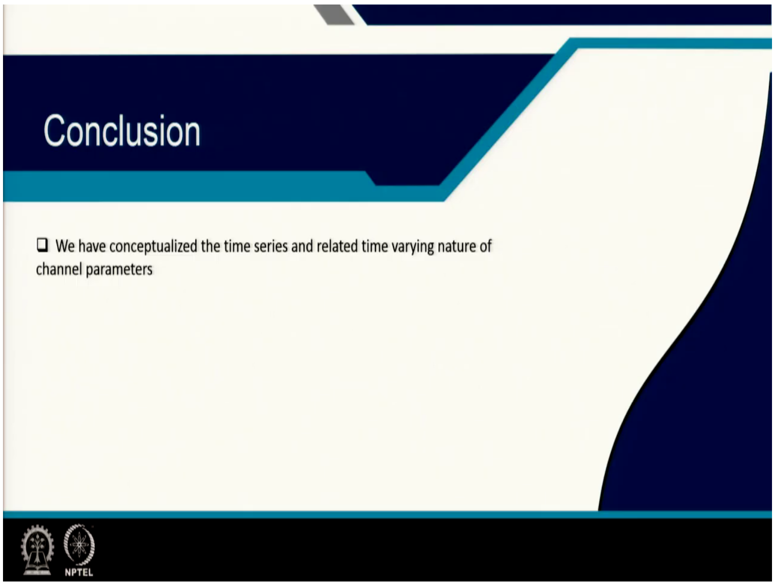

So, in conclusion we have just conceptualized the conceptualized we have not yet gone details into it time series and related time varying nature of the channel parameter. We will continue it in next subsequent classes.

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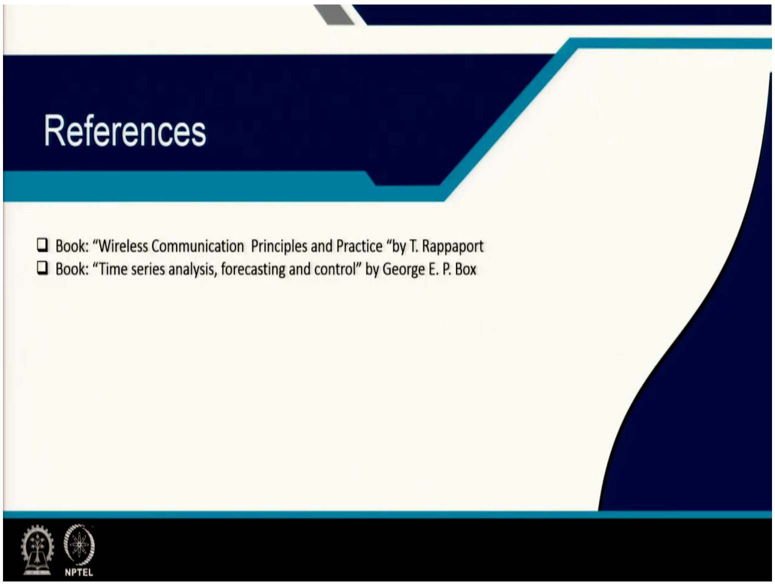

And. these are the two references by Rappaport and this is the classic time series. We have just started it.

Thank you.