Signal Processing for mmWave Communication for 5G and Beyond

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Module - 08
Hybrid beamforming concept and Beamforming in MIMO
Lecture - 43
MIMO Beamforming in Transmitter side

Ok. Welcome back, welcome back to the millimetre wave Communication for 5G and Beyond. So, in the last class we are talking about the different level of beamformings right at digital level at RF levels.

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So, today we will be covering the like things that will be covering are the following. See, if I can summarize. So, how my data would be looking at the transmitter side from the beamforming point of view is the following.

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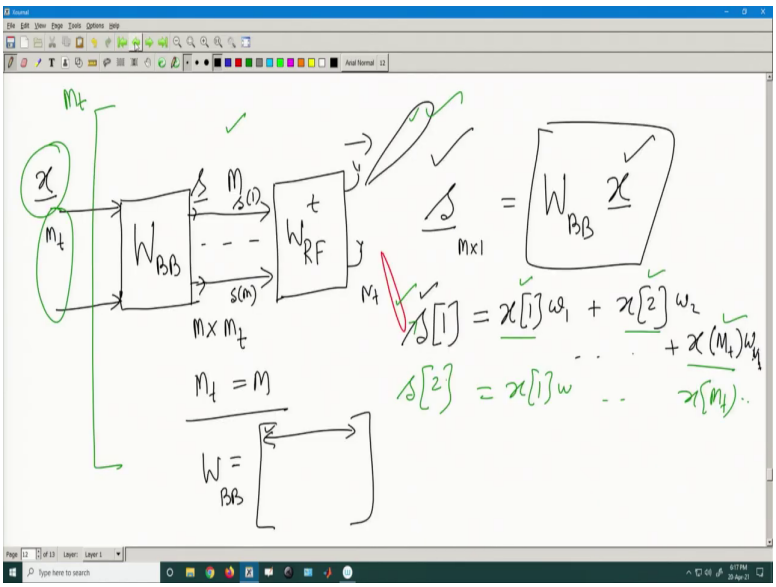

So, if you look at the earlier diagram, if I go back earlier diagram what I say? So, I just shift my focus from M cross N M cross N MIMO to M t cross N MIMO. So, now, actually my data is M t. So, the M t number of data's are actually being shifted that is my data. So, I will say that yes my M t data's are now part of every individual beams ok. So, if I now look at my data model. So, what is my transmit data model coming into picture.

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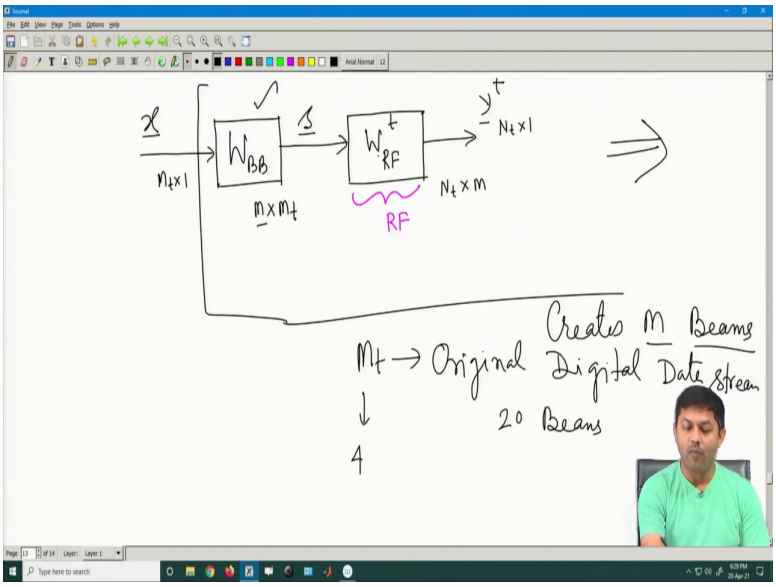

So, I would say this is my x vector whose dimension is M t cross 1. So, I have to write dimension very clearly. So, this is a vector going and then it goes through a matrix think of a matrix do not get into the terminology right away. So, let us call it W BB matrix whose dimension is M cross M t that generates a vector s vector, this was the original s vector we were discussing so, far, but before that now this W B comes into picture.

Now, this goes to W RF t ok and that is finally, my transmit data vector. So, this is a pure digital model digitally I am thinking it ok just the way we have model the retracing model the way we view it. So, my whole view is from here. So, I am viewing it probably just from here digital side that is my view ok it is a pure digital view of my data. So, this is the digital data model never think that there is an r x mixed up here.

Yes, internally the structure wise the implementation wise some part is RF some part is digital that is ok, but this is the digital view of my data. In internal implementation; obviously, this part is your RF part ok. Now this is the data model. So, here W RF would be what is the dimension here?

This would be M cross sorry this will be N t cross M this will be N t cross M right? That is the data and this data Y t its N t cross 1. So, you start with the M t cross data and it goes to M t data within it how many beams it will be created? It will create M number of beams right now this is an interesting point.

So, you have M t data. So, M t can be the actual mino size. So, when you say I am having a MIMO beam forming or a MIMO structure, this actually MIMO structure right if you understand because this is the number of data I want to transmit finally, that is my original information symbol stream this is my original information stream.

So, you have I have M t data stream that I would like to transmit it. So, now, for that I have created so, many internal structure of it and that goes through the beam forming. So, how many beams it will finally, create? Actually it will create M beams. So, it will create it creates M number of beams ok its interesting point.

So, you have M t data, this I call it original digital data stream. So, you have M t number of original digital data stream which will be going through M number of beams. So, it will be fed into in the when I go to the you know a r it will be on M beams. So, my M t can be 4 for example, but on 4 I can create say 20 beams.

So, accordingly you have to change your W BB right it is a it becomes 20 cross 4 20 cross 4 antennas accordingly I have to change that. So, if I want to get 100 beams suppose this 4 that I want to support at a time say 20 50 users ok. So, I have to create 50 beams on that. It does not mat it does not mean that to sub 50 users I have to create 50 digital stream.

So, that probably my original you know data stream can be still 4, I just want to split across say 100 users. So, I can create 100 beams on that ok and this W R F is mainly meant for the phase shift or the steering of those you know individual beams that is the beam forming ok. Now, there are certain names and terminology that you have to be aware of.

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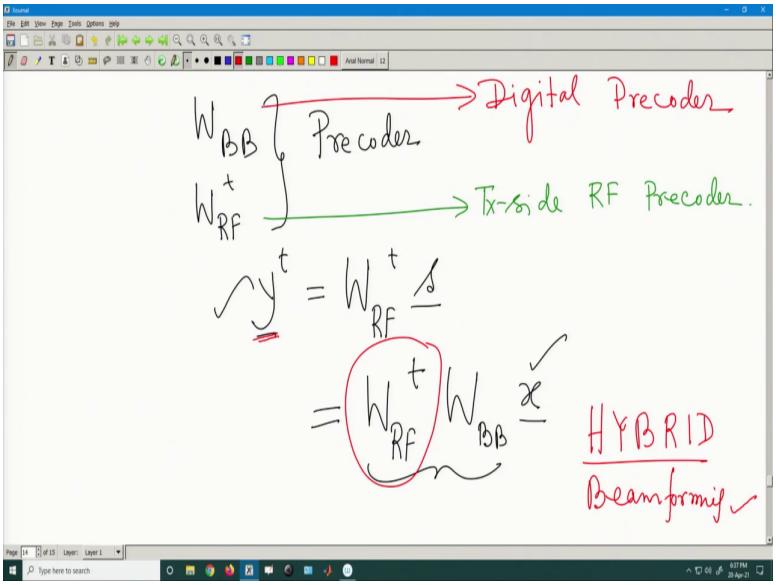

So, this whole thing this W BB and the W RF t both of them are called precoder. Why it is called a precoder? Precorder is its kind of some matrix manipulation of your data at the transmitter side. So, that is as simple as that that is your precoder right. I mean it is doing that job right fairly if you can understand.

So, this is where my transmitter transmitted data is going on this is what my input side is as if like I am having an input x and that data is kind of transmitted with using Y t. So, this W BB W RF combinedly they are nothing, but my precoder ok. Now there are still some more

interesting terminology now this it is called precoder obviously, but this one this W BB also known as digital precoder this is called digital precoder.

And this particular one is known as R F precorder transmit RF precoder transmit side RF precoder T x side RF precoder ok. So, these are the two terminology we should be aware of because if you look at the various resources papers and so on and so forth there will be left and right they will be using this term digital precoder and RF precoder.

But I put a term T x side because this is more on the T x side now you see an interesting point here. One part I call it digital another part I call it RF ok; obviously, you will understand the reason for it. So, the digital precoder whatever I have drawn here whatever I have drawn here this is purely in the digital domain ok it is not at all in analog domain neither it is in RF domain.

And this W RF is purely in the RF domain because if we have already discussed this structure W RF fairly enough right. So, this is purely in the RF domain and what is this W RF? It is nothing, but phase shifter nothing else ok. Does it have an amplitude variation? If you notice it is the e to the power j and so and so forth that is the digital equivalence of any phase shifter in the RF to the digital domain right.

So, it is a phase shifter, but you notice predominantly that I have not put any amplitude level variation at the W RF ok. Now, you understand the reason behind W RF you understand the reason behind W BB. So, W BB I have not given other reasons why W BB will be there one reason is that; obviously, I have x t I want to put in every users that is one simple reason, but that is not the only reason ok.

Now, this digital precoder was there for quite long time I mean it was in the literature for quite long time maybe 20 years, 30 years back it was there people do digital precoder transmit digital precoder. Now how do you design that? So, what was the purpose they kept it? Was there any purpose that those digital precoders were kept?

One reason is that this digital precoder sometimes boost up capacity, sometime they boost up SNR various cost function you can think of and they do some sort of a quality of service improvement for this digital precoder. But apart from that when I talk about the MIMO beam forming those aspects are still there.

So, you can still design your W BB as per whatever maximization you would be doing earlier, but inherently it is also doing another purpose that on the individual beams it is spreading the complete data that x M t that whole data will be spread across all the you know all the beams that is one of the important aspect of it.

So, which means that? This W BB is an integral part of your you know MIMO beam forming part, but this was an optional part for MIMO communication. If you look at any non MIMO communication where beam forming was not there this precoder is kind of an optional I mean you need not to have a precoder it is just an optional you can directly send the data to the feed to the antenna and so on and so forth you need not to have a precoder.

But this precoder you can if you have a precoder you can always boost up some of the quality of service parameter like SNR and capacity. So, here so, but that was an optional. So, you may want or may not want, but here in the MIMO beam forming you have to be there it has to be there why?

Because this is the one component where it mixes up the x d n ensure that every beam has that component. Does it mean that it also does not support other benefits that precoder was doing earlier? Yes, that is there that continues to be there. But knowingly or unknowingly this is also serving the second purpose.

So, like the data split across all the beams. So, from a MIMO beam forming point of view, this W BB is more of a mandatory component this is what I am trying to say. Because if you do not have W BB, you understand the reason I mean what would the impact of that so; that means, individual data will be going to individual beams, it is not spread across all the users its not spread across all the beams ok.

So, this is a mandatory component when you go for a MIMO beam forming. So, that is the point I am trying to make it here ok. So, now, what is the final data model that I am getting transmit data model I am getting? So, the final transmit data model that I am getting. So, these are the precoder part. So, final transmit data model that I am getting is that Y t bar what is it? It is nothing, but W RF t into s. So, this will be W RF t into s vector which is equal to W RF t multiplied by W BB x.

So, this is my final data model of the transmitter side. So, it is as if like I am transmitting a signal x, which goes through a precoder and this gives me my digital equivalent of my data its digital equipment I am repeating that its not RF equivalent because whole thing I am modeling from a digital point of view, but I am implementing in a different, different domain.

So, how I have implemented W R F? As a phase shifter. How I have implemented W BB? As a digital precoder. Now let us go to the structural part because we need to understand what exactly I mean by a digital precoder? Where exactly it is sitting in my actual trans digital system? You need to understand that. So, let us get into that part ok.

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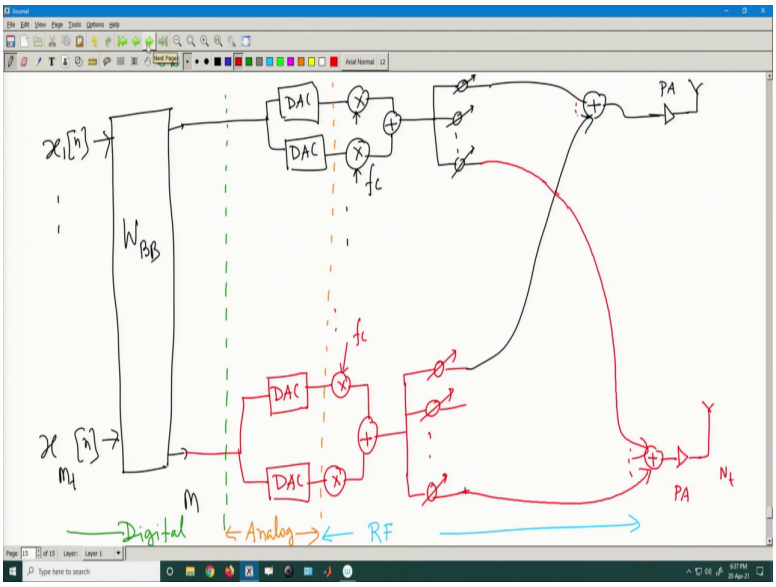

So, let us take I have x here ok and I have x M t n here ok. Now this data this data goes through matrix multiplication that is easy in a digital system I have n number of data and that creates M number of data here its pure digital ok. Then what happens? Then it goes to DAC.

I am writing the structure actual structure I am not writing for all of them because just the same for all of them then this will be going to multiplier RF multiplier then it will be added up, I am not drawing the filters part from there this will be kind of a phase shifter. Then what will happen?

Then there is a one more adder and there is a final antenna you may have a power amplifier here. So, this is the first data. If I have second structure that will be added up here, let me

draw the last one because its dot dot. So, this I draw it because you understand where exactly they sit in my trans receiver system ok.

So, this will be with f c I multiply; f c meaning cos omega c t and sine omega c t that is the part ok here also this would be f c multiplication f c meaning you understand right its a cos part and there is a sin part sine and cos which will be i and q component. Why I am drawing it? So, that you can understand in my whole scheme which part is digital who is sitting in the analog part ok.

Now, here the first will be going here ok now if I have another antenna here, the last antenna which is N t th antenna. So, I have a power amplifier here before that I have a R F adder ok its complete in the R F domain RF adder. So, the last part will be added up here and this last will be added up here right. So, probably I will for fairness of the diagram let me draw it different color code ok. This is what it is. So, there will be multiple such adder multiple such data line depending up on who else are there ok.

So this is the actual physical structure. So, now, you can demark it where is the R F, which part is analog, which part is digital. So, till here I would say let me put a straight line here. So, it will be easy to understand. So, this whole thing is your digital ok. Now, put a different color code this part is analog ok and from here its R F implementation wise ok.

So, this is the clear demarcation where exactly digital part, where exactly analog part, where exactly R F part ok. Now you can see the W RF is here in the RF domain and W BB is actually sitting in the digital domain. So, what does it mean? It means that I have some component I have some DSP component rather not I mean it is influencing my inside my signal modeling.

So, I have a signal model where the actual implementation wise this is digital and this part this part is more of a RF part ok. So, it is like a mix and match unlike your normal MIMO system where you have everything is digital and finally, it goes to the DAC and you know multiplier of RF signal and it goes through that.

But the a model of your signal sitting inside the R F was not there. So, this is the only place where a model where you have a component which is where you have a component which is modeled as a digital domain, but its implement is in happening in the RF domain ok. So, this is this mix and match exist only here and that is one of the reason why this particular scheme is called hybrid beam forming.

It is a very popular term hybrid beam forming ok. That mean each and everything is not purely digital a part of, but again the model wise you are in the digital domain. So, this is your model Y t bar. Its model the data model is in the digital domain, but when I implement it a part of it is in digital, a part of it is in RF domain and that is the reason I call it a hybrid beam forming ok and its very popular term.

So, you can see when I go for a millimeter wave communication says 40 gigahertz, 60 gigahertz or more than that people always talk about hybrid beam forming this is the reason ok. Now, this structure is the actual structure that is implemented here ok. Now, to summarize it here. So, what we have learnt it in this particular whole scenarios are the following. So, we have learnt.

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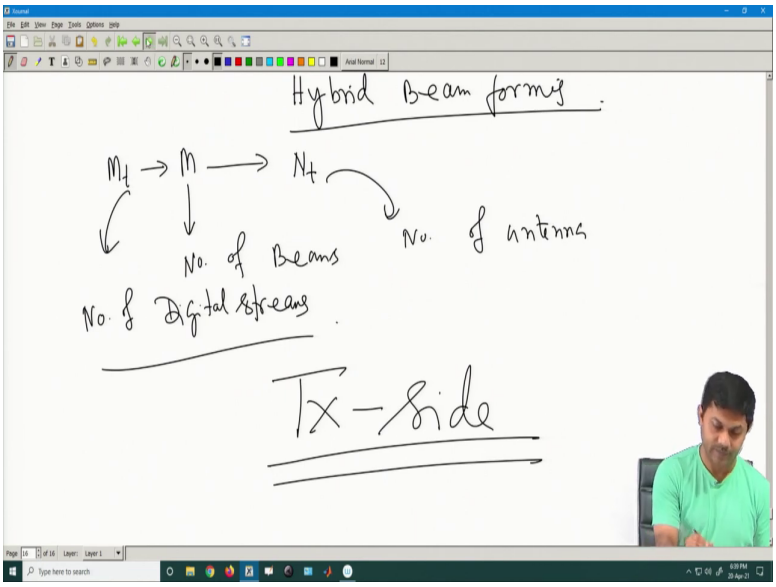

So, now, let me draw let me use this term hybrid beam forming directly hybrid beam forming. So, what we have learnt it here? So, we have learnt it M t digital symbols or M t digital stream data stream goes through a digital precoder, where it converts to M number of data stream and then it gets converted to N t number of you know antenna beams.

So, the number of beams so, this gives you the number of beams, this gives you the number of antenna and this gives you the number of digital stream ok. This is the complete T x side we have not gone into the R x side ok. Now, let us model what happens when I try to model it in the R x side? Because so far whatever I have done is the T x side, I have not gone into the R x side ok let us get into that understand. So, now, I will be introducing the R x side beam forming what happens? Suppose this is the signal I have sent it.

So, what is the signalization I have sent? M number of beams I have sent now I am receiving that what happens ok? Now as you notice as you notice here see if there are M beams which means there are M distinct receivers right because one receiver can receive one beam it is not supposed to receive multiple beams. Then I mean its physically wide apart right.

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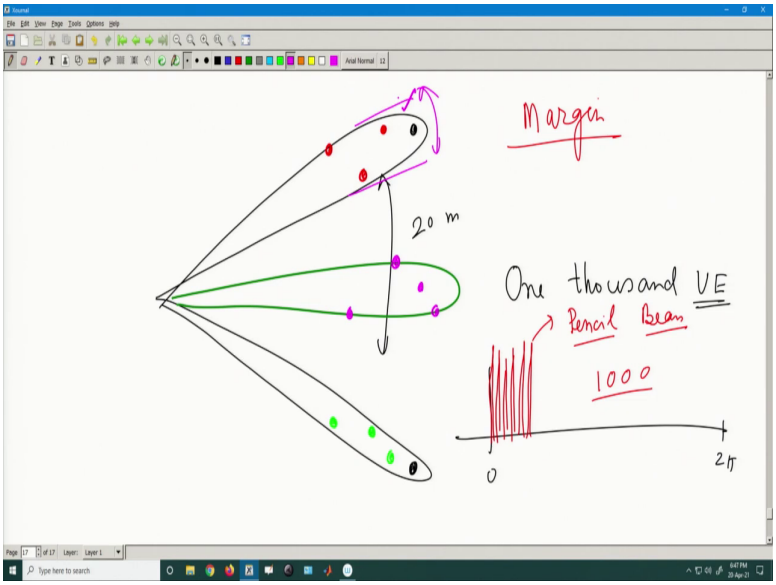

This one beam is going like this direction another beam is going like this direction ok probably the distance if this is long enough maybe 20 meter or maybe 10 meters. So, its not physically have it is not it is not possible to physically have a receiver which is 20 meter wide right.

So, it is assume that one beam will be one user is sitting in one beam. So, that is the; that is the logic here ok. I have one more interesting question that I would like to throw. Now this M

capital M has a limit right I mean you cannot have infinitely more very large limit you cannot have it.

So, for example, how many beams I would like to have it? Can I have 1000 beams? Can I create it? After all it is too much ok practically, but if you look at the 5G you know base station how many users that can be tagged with 5G? Its lakh 1 lakh users can be tagged, but at a time probably it may not serve so, many users.

So, let us assume take a conservative number let us say one base station in a 5G wants to serve one thousand users at a time one thousand users at a time at a time it wants to it and he wants to serve it using bean forming. Let us assume that is a very simple problem I want to like you I would like to have it. So, it has to create thousand beams ok. So, which means that on a 0 to 2 pi scale if I plot it thousand individual non overlapping beams it has to create it ok.

So, what does it mean? I have to have a very very surf pencil beam kind of. I call it a pencil beam this is also a new term in 5G and millimeter wave context pencil beam what does it mean. So, extremely narrow beam. Now to create such narrow beam how many antennas I need? I do not know, but probably maybe 100 150 I do not know it depends.

So, if you go into that level of you know dimensions. So, you need so, many such antennas that can create such kind of pencil beams. Secondly, there is no guarantee that each and every beams are specially distinct if the space then you know if the angular space is very small ok there will be always inaccuracies here and there.

So, that is also limitation ok because your instrument limitations your instrument inaccuracies your circuit inaccuracies are always there. So, the way you want the beam structure will never happen. Suppose you want a certain phase it will never create that certain phase. So, there will be phase distortion at your phase sector. So, these are all practical aspects of course, this part will be covered subsequently in latter part of this course that is called impairment.

So, using such kind of impairment you have to have lot of margins. So, this is a term called there is a term called margin. Margin meaning it is like a relief that you would like to have it.

So, if you give margin for such pencil beam, it is not possible to have 1000 beams at a time ok it is not virtually possible ok.

So, what is the way out? Does it mean that? I have to get less number of beams of course, if I cannot get a 1000 being; obviously, I have to get less number of beams second thing is that if I create sec less than less number of beams how do I serve the users there? Because the users will be 1000 almost right. So, what is the way out?

So, this is again an engineering problem an optimization problem where the particular you know the particular base station can group some of the users. Say for example, if it takes a certain direction it says ok in this particular direction maybe there are 1000 users, but are all the thousands users completely scattered or I can group them something can I group it as if like can I have some users here?

Can I have some users? Can I have some users like this I can group them. I have one more beam, but I can have some users here that mean I can group it. So, instead of 1000 beam probably I may require less number of beam instead of pencil beam I require slightly wider beam. So, that I can cover more and more users in this case. So, these are again different level of optimizations, it again depends on resources and it depends on the capability.

If the base station does not have very large capability to support such a pencil beam, it has to create a wider beam, then it has to group the users and try to maximally you know fit the users in a particular beam. So, based on that it you know it creates a beam, based on that it you know create the width of the beam.

So, which means that it has to have a mechanism to control the width of the beam that is what I am coming to the point because it is not possible to serve every individual user using one one beam is very difficult. So, I may have to group them together and if I want to group them together, I have to widen the beam. Now, if I create too much widen I mean that is again coming back to the same 4G problem where I had not creating any you know beam forming I am just radiating in isotropic manner power loss will be more.

So, the risk of widening the beam is; obviously, the loosing of more and more power. So, then it is like a its a tug of war kind of things, its a balance kind of thing how many users you can pack it within one beam versus how much power loss you can allow it ok. So, this again different engineering problem.

So, I just put forward the questions. So, the next class what I will be talking is how do I individually control this beam. Suppose can I have question is can I have say 4 beams with two 4 different you know 4 different beam width connection if that is the case what should be my architecture?

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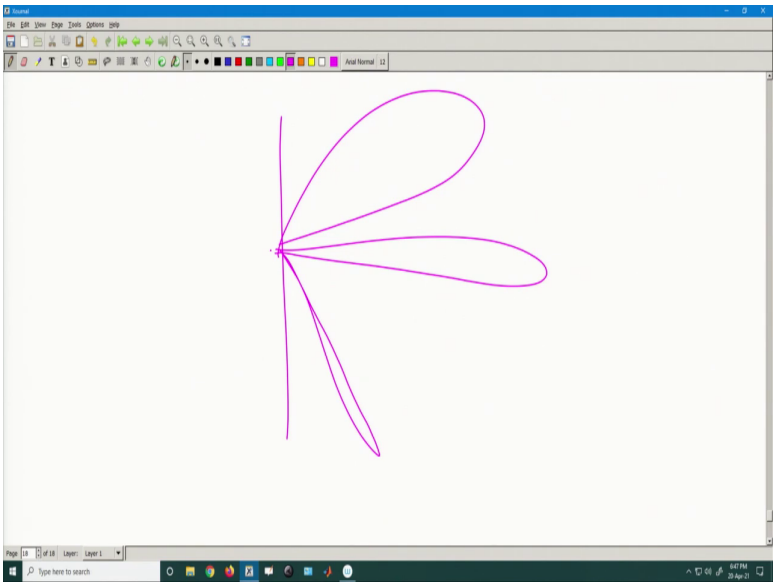

So, which means that can I have it something like that? Maybe this is wider this is a very narrow specially and this is like that. So, three different you know beam structure three

different beam width how do I do that using my same structure that I have created earlier ok. So, this is the motivation for my next class ok. So, with this I end the topics here.

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So, in conclusion we have kind of completed the yeah and the reference will be same as what we have.

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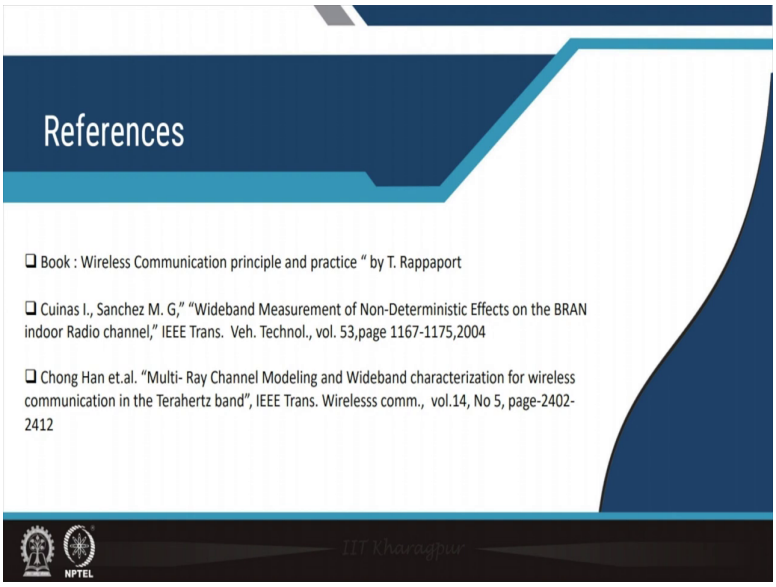

Thank you.