Signal Processing for mmWave Communication for 5G and Beyond

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Module - 07
Details of Beamforming in mmWave and MIMO
Lecture - 39
SISO Beamforming

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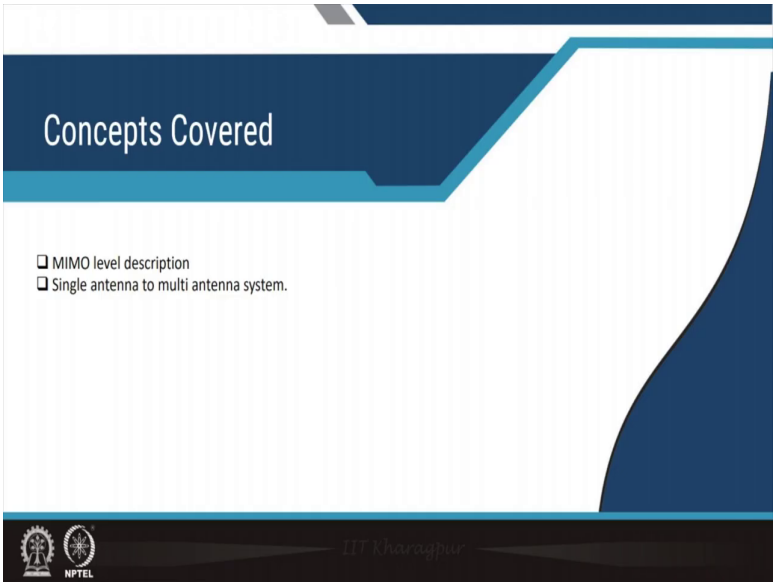

Welcome back to the Signal Processing for millimeter Wave. So, today we will be now moving. So, today we will be covering the like things that will be covering are the following to a MIMO level. So, far we have talked about single antenna input single antenna output system now we will be graduating to the multi antenna system.

So, now, let us see in the multi antenna system how things go on, how exactly the steering is done and other things what are the other aspect that will be coming. Now along with the MIMO; obviously, the natural extension will also be MIMO OFDM right and then OFDM and all things will naturally be appearing it.

So, let us graduate to MIMO things and let us see how from a beam form beam forming point of view in millimeter wave how exactly the MIMO configuration is done. So, we know single antenna single output system. So, when I again repeat the misconcepts in that many people have when you have a single antenna system single antenna is not SISO system, SISO meaning single input single output what does it mean, it is a single data stream single output data stream nothing to do with antenna right, you can have multiple antenna just like your beam I think that part is much more clearer.

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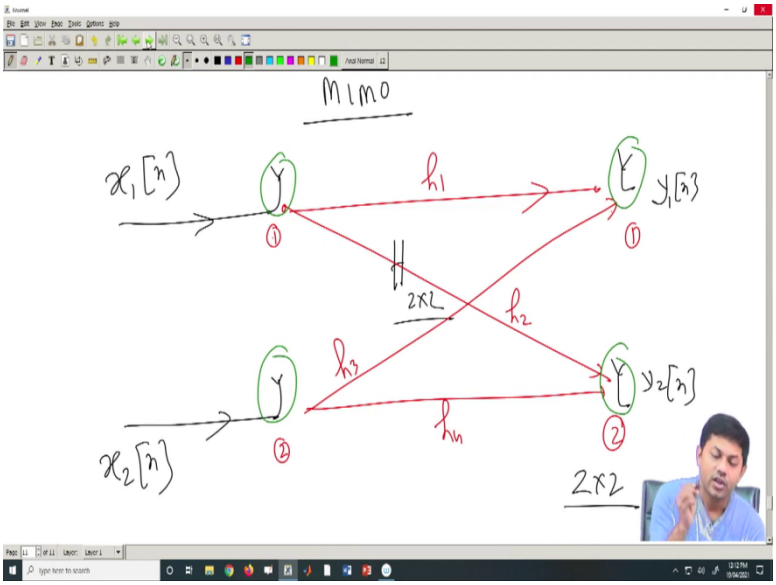

So, now when I say MIMO beam forming context in the context of beam forming MIMO meaning again the same thing multiple data from the input side at the same time multiple data at the output side for observation ok. So, let us think out think of it from the transmitter point of view let us say what happens when I go for a normal MIMO forget about beam forming so right. So, you have one data stream; one data stream here or say let us say I am just taking 2 cross 2 system or a two input system ok.

So, this is my x 1 data. So, it is this is from a digital side I am creating one set of data and from digital side I am creating another set of data. So, this is your and if I have a receiver suppose this goes to one antenna, this goes to one antenna, if I have a receiver let us say I have two receiver. So, it is a 2 cross 2 system simple I mean we have already explained it in the context of 6 gigahertz sub 6 gigahertz channel model.

So, here your channel is a 2 cross 2 straight forward ok now you may say that ok hey beam forming also we are doing the similar thing right yeah that, but that was from a multi antenna system not multi data stream system.

So, as because here I am pumping the same data with one antenna so, similarly we may think that ok number of data number of antenna remains the same. So, that is something that you need to come out of that notion. So, when I say so, this is the MIMO part ok. So, what is the data model of a MIMO part?

So, if I say I am receiving y 1 n here I am receiving y 2 n here and what are the different you know branch street I can think of. So, these are the you know these are the channel part now here I am talking of the single tap system. So, which means that from one antenna to another antenna it is just it is having only one tap no multiple tap because moment there is a multiple tap you cannot handle just by a MIMO rather you have to bring in MIMO OFDM.

So, we will talk about the OFDM part in the context of beam forming after we finish the MIMO. So, there I will first talk about what exactly the OFDM thing, then we will talk about MIMO OFDM and what is MIMO OFDM beam forming. So, here we are talking of MIMO

beam forming ok. So, from the MIMO beam forming point of view I am completely assuming my tap is a single type channel, which means that from any point of any antenna to any antenna it is a point to point if I think of the number of taps will be just 1.

So, that mean from 1 here, 2 here, this is also 1 here, 2 here. So, from this one to this one it has only one tap let us call it h 1, here it may be h 2, here it may be h 3, here it may be h 4. So, this is just one tap you know that is coming into not multiple taps it is a fire filter, but having one tap ok. So, this that is the configuration I am talking of easy configuration ok.

Now, let us see from now I am introducing a beam forming now when it is a beam forming physically I will have multiple antenna right that is the; that is the point unless you have a multiple antenna the beam forming cannot happen. Now the question is that, does it mean that these two antenna I will utilize for beam forming a transmit side? Or these two antenna should I utilize them for beam forming other R x side?

The answer is no, because here if you look at you cannot even form a beam if this is what the configuration. Suppose this is a MIMO configuration, does it really form a beam suppose instead of 2 antenna at the transmitter side I have say 100 antennas at the transmitter side and I am feeding 100 datas, will it form a beam? No, it will never form a beam I mean to form a beam what is the criteria? It is not just multiple antenna more than that there has to be phase aspect coming right.

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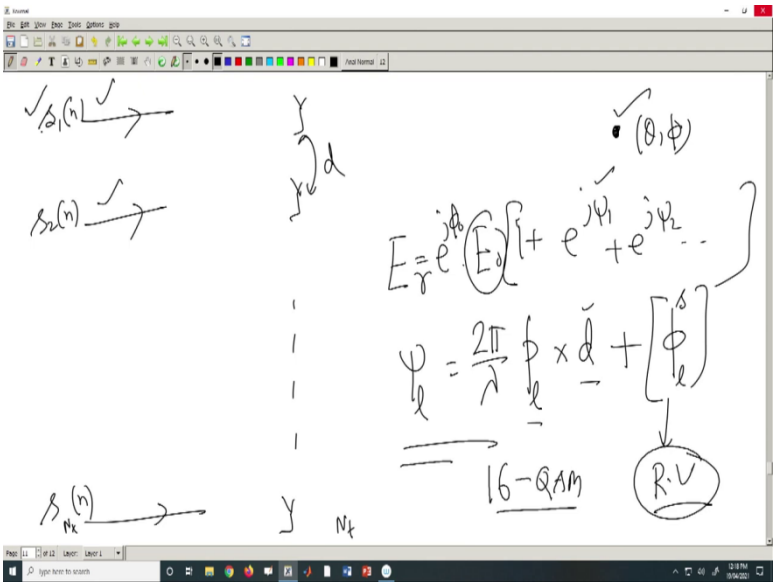

So, question here is that suppose I have a multiple antenna. So, there are N t antenna, but on each and every antenna I am feeding a different data. So, say I am feeding here s 1 n I am feeding here s 2 n and I am feeding here s N t n alright. So, that is the data I am feeding it ok. So, now, does it form a beam the question? And each and every antenna is isotropic antenna let us see that gives the answer why this is not same as your beam forming case ok.

So, what happens when this kind of thing? So, let us say a similar concept you have just bring in let us say I am standing at a position theta and phi let us say the distance between them is also d all things are maintained ok. Now, what will happen, the received E r earlier what we did E 0 1 plus E to the power j phi 1 and so on so forth you are doing it right now and this one e to the power j phi 2 and all things we are doing it.

Now, what was the phi 1 for us, if it is ULF it was 2 pi by lambda, do not think about ULF just generalize it, position of the antenna where it is. So, let us say it is not exactly a 1 or rather the lth 1 this was the vector multiplied by the d vector, d vector was the position vector of this area this point where I am observing right.

Now whatever comes it will be coming, but now will it be the case when I am feeding multiple data will it be the case? Do not be the case why because apart from the phase difference that each and every antenna is seeing because of their distance inter distance and another phase will also appear because I am feeding the data differently. So, far if you look at the SISO case I am feeding the same data steering part you keep it apart we know how to handle steering keep the steering part apart.

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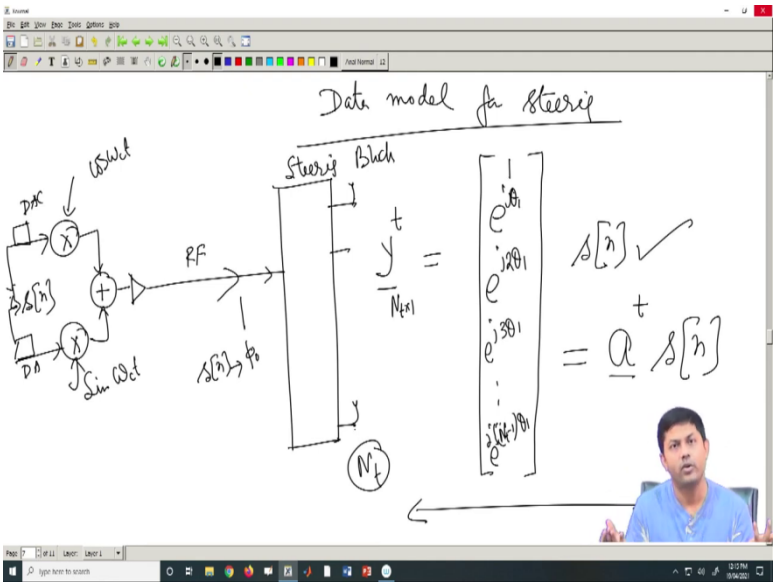

So, earlier if you look at it is the same data going everywhere right. So, from the data point of view every antenna is facing the equal amount of phase right. So, if this s n here is having a phase say whatever something say phi 0, that phi 0 will be seen by every antenna and hence at the receiver side that phi 0 has no impact. So, what does it mean, it means that when I do the E r here on the E 0 part there will be a common there will be some common E to the power j phi something will be coming into play right.

So, here if I just draw it there will be an x raised to the power j phi 0 because for every antenna it is the same data going, but now that is not the case, which means that every point I will see a different way. In fact, this will also not be one it may be something else. So, this phase plus another phase will be coming it is not phi l let us put it at lth data some put it different symbol phi l s ok.

And the worst part is that this is a random variable this is the worst part, did you see any random variable on E r, is a single input single output system? No, who is random here, nobody was random there E 0 was determined by a distance each and every phase differences among the antennas was also fixed.

Why because, the distance among the antennas are fixed. So, p l was fixed d is fixed. So, it is not a random variable. So, that is the reason E r is constant, constant in the sense that it is nature, it is phase nature or it is plotting nature is constant, but now along with phi l I am having R random variable here, why it is a random variable because s 1 is a random variable, is a random variable; obviously, why because that comes from a constellation.

So, from time to time it may be different say I am taking from 16 QAM this is my data 16 QAM is my constellation. So, what is the phase of s 1 to s N t I do not know I know this phase of 16 QAM, but at a particular time will there be any correlation between phase of s 1 and s 2 and s 3 and so on nothing it just randomly picks up right.

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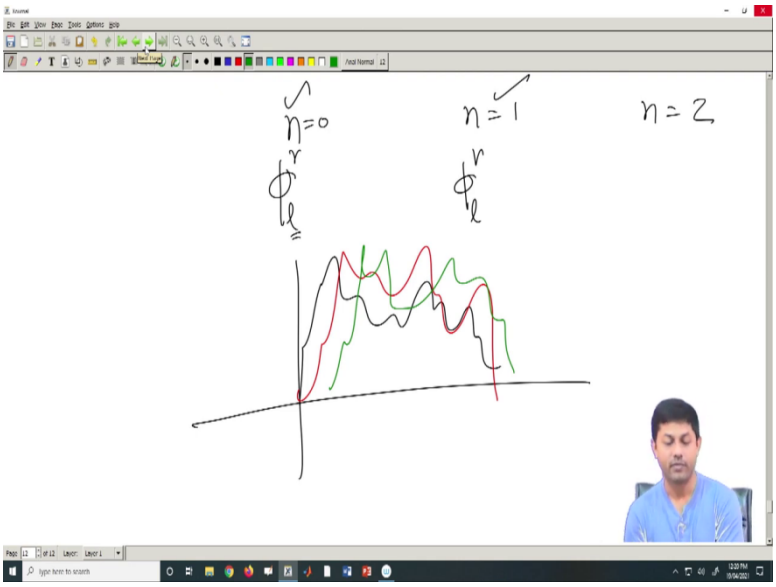

And the worst part is that what about the time? Say for example, at n equal to 0 at n equal to 1 at n equal to 2 so; that means, individual phase phi l r whatever I have drawn that itself is different for every antennas across the antennas that is same at a particular time go to the next time that mean I change my sampling time I go to the next sampling time, this phi r l is again different that mean time to time this random variable itself is different and across the antenna that is also different.

So, that mean it is random in time in random in space. So, it is a random variable. So, if it is a random variable what will be the spectrum here, can I see a nice beam there, I do not know how the phi l r would be there unless the phi l r is certain you know it is a constant it is you cannot form any beam.

So, you cannot even predict how the beam would be and even if you know this is what the phi l next time again the beam pattern will be change; that means, from time to time the patterns of the beam itself is first of all this itself will not create a beam because this is a random variable and you do not know how the random variables will be placed right it has if it is a 16 QAM 16 values will be placed there randomly.

So, the beam probably I am just making some you know drawing. So, beam probably is something like that beam will be, when I go to the n equal to 1 again some other beams can be created when I go to the n equal to 2 probably a different set of beams may be created, you have no prediction about the beams.

And that is the reason when I say MIMO general MIMO normal MIMO it simply means I am sending multiple data to different different antennas, moment it is though it is a multi antenna system they will never form a beam because to form a beam I need to precisely control the phase, now at every point I am seeing a different phase and that is random.

So, it will never form a beam ok. So, this is the first part of our understanding. So, MIMO is not same as multi antenna beam forming system they will never form a beam ok. Now let us understand in the context of MIMO how can I do a beam forming what is the beam forming concept in the context of MIMO.

So, let. So, I hope you understand the problem associated with the MIMO system as far as the beam is concerned. So, this is not a beam forming part. Now let us see how I can extend it to a beam forming part ok.

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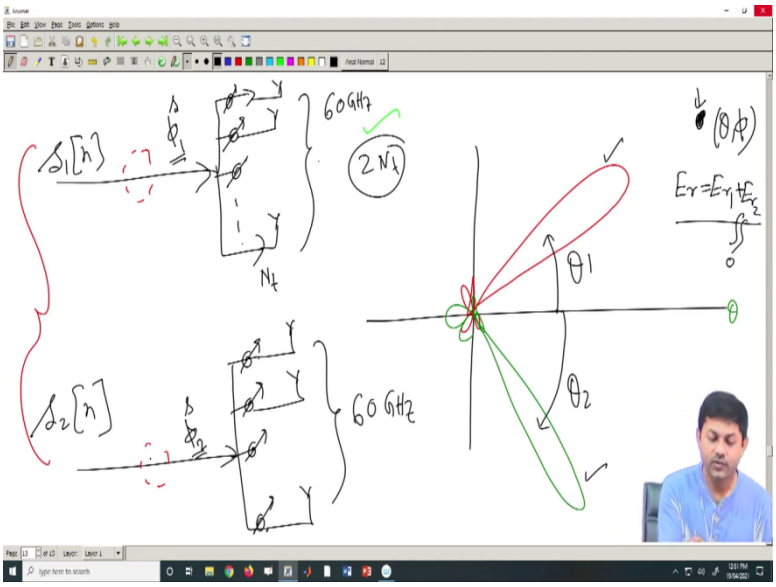

Now, let us take a very simple example and try to understand what if this is what we would have done let us take a very simple example of two data system. So, let us say I have s 1 n data I have s 2 n data two data, I have taken it ok now you can think this is some sort of a MIMO system with two input not two antenna ok two input say 2 cross something depends on how many R x I have.

Now let us say this one I individually send it across say anti phase shifter. So, I have a phase shifter here, just like you can think of that I have two SISO system parallelly going on ok, think this way though it is not the correct way of configuring, but let us assume to start with this is how assume this is how I am going it ok.

Similarly, here also I am just putting the way we have done a SISO beam forming let us say I am feeding this on a separate antenna first assume separate antenna though this is not the configuration but let us assume from our simplicity or understanding point of view ok.

So, what I have done? I have two system, two feed line, two data line rather and that data line. So, this has its own R F analog everything, this has its own R F and, but they are two you know two separate data line ok, but in the same IC chip or in the same mobile system, but there are two different data system ok. I can create an individual beam here I can steer it individually, I can also create a beam here, I can also create a individual steering there is no problem.

Now if I can ensure that this beam and the beam number 2 they do not interfere with each other with great I would say with the main lobe great lobe or main lobe that they do not talk to each other ok. So, which means that if this is a simple ULA configuration let us say with this is the beam let us not put in a single one let us put it on a similar line ok.

Let us see from the first side I get a beam of in this direction whatever and from the second side I get another beam like that main lobes I am not interested in the side lobe main lobe, now from here this is my theta polar diagram I have drawn. So, this is say one direction this is say another direction.

So, this is theta 1 and this is theta 2 positive or negative does not matter, but this is what I have done I can create that, will this system work, is this a feasible system, cost wise do not worry this is not the reality there will be some more optimization will do. So, number of antennas will not be the same the way I have drawn, but this is just from your basic understanding can I implement this will it create any problem.

Now, here if you notice it this is basically a 2 cross 2 system, it is not 2 cross 2 at least the two input system if I say this is a MIMO system this is the first instances of my multi data transmission in a beam forming manner.

So, I have individual point I create I just take one data and do a single input single output kind of beam forming separate them physically and we have to ensure [FL] both the phases of this two system are different in the sense that both the beams they do not know they do not overlap now this is a feasible system because there is no point in that. So, that mean this though it needs 2 N t antenna that is ok I am not worried about that part first, but at least this is a basic MIMO beam forming aspect.

So, which means that when I was drawing this fellow that multiple antenna I feed it to a multiple data I feed with equal number of antenna even if the number of antennas are more they do not form a beam because of this randomness in the phase, but now will it create a phase, will it create a beam forming now.

Yes, let this be a random phase here let there be a random phase here that is coming from my input side let it be, because a common phase here no matter if it is a random or not does not change my beam direction my beam will not be you know steering or beam will not create any vibration there because the steering part totally depends on the steering vector part.

And if there is a input phase let it be random it does not create any problem. So, which means that this configuration whatever I have done that may be the first basic step of my MIMO beam forming ok. So, I can create a two separate, but one key point here is that this theta 1 and this theta 2 should not overlap with each other.

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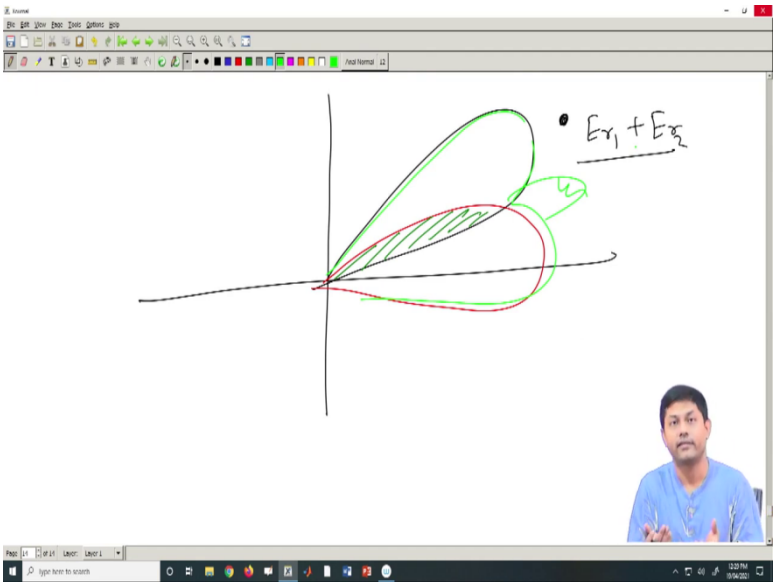

Which means what happens this kind of scenario appears, this may be problematic why because this is the reason where it has you know tremendously overlapped ok, because of the overlap the actual beam will be addition of both of them because any beam is an addition of both of them right. So, whether the beams are separated in space or not, suppose I am standing somewhere here I am standing somewhere here in a direction of theta and phi.

Logically I will receive this and that both because both are going at the same frequency at the same spectrum now for the green curve it will not reach here because; obvious reason, its main direction is different, but logically here when I say E r the received electric field will be E r 1 plus E r 2 from one system plus another system.

Now here it may be almost equal to 0 because that is in a different direction, but logically they will be equal right now. Similarly, when I am like a overlapped beam see if a receiver is sitting somewhere here I will be receiving E r 1 plus E r 2 both.

Now, because they overlap they will interfere. So, the effective beam when I add them up I do not know whether it will look like a this particular, whether does it look like these or because of this addition suddenly some extra power may come appear that side because they add up right and you do not know that they will add constructively or destructively you do not know that part.

So, something may happen here you can try it in MATLAB or any other software and try to see if they overlap what is the you know what is the E r 1 plus E r 2 you may see that they not they do not exactly create a very nice set they may distort it they may get distorted. So, it is advisable though when you have multiple such you know physical MIMO system you have to create two separate you know the separate beams like that.

Otherwise if they overlap you know they will destroy the beams each other then they may be creating interference part of it, but in this case the only problem here is that you need 2 antenna. So, this is not a physical this is not how exactly it will be done, but this is only for your understanding part ok, just for your understanding that I am creating a configuration like that ok. So, now, this is the first point of from MIMO.

So, in a conclusion for this particular configuration I need it is as if like each and every data stream is creating a separate beam for it. Now if I have you if I ask you a quiz question see if I have M number of suppose I have an antenna system I have not still talked about the receiver part what happens there well I am still in the transmitter side.

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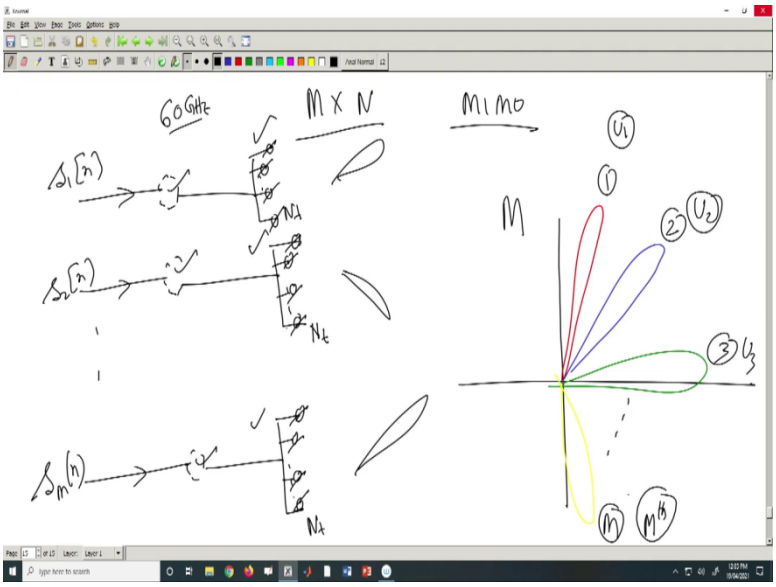

Let say I have M cross N MIMO system, but I am I want to do a millimeter wave beam forming. So, what is the first thing that I need to do first thing is that I will have this is my second. So, physically this will be the data and they have their own RF and ADC. So, when I say multiple RF does it mean that RF will be RF frequency will be same or different, no RF frequency is not different just the RF circuit can be placed differently because if you have a multiple RF then there is no point of separating the beams and alright.

Suppose here if you look at if the RF frequency itself is different for this two stream suppose this is working at 60 gigahertz and this is working at 70 gigahertz, do I really need to separate them physically from a beam point of view? No, because these two different frequencies right if that if they have if there are two different frequencies why need to why do I need to

separate them anyway they are orthogonal in frequency right ok. So, I am assuming that it is not 70 gigahertz it is still 60 gigahertz or it will be 70 gigahertz both the cases.

So, RF I am making the same, even if I have multiple data stream the R F will be same. So, I am not changing any R F frequency. So, here when I say I am having multiple R F, it is already multiple R F circuits, but the frequency of those components should be same see if it is at 60 gigahertz everybody will be 60 gigahertz ok then what I do I separate them out.

Here also I separate them out how many let us say N t everybody I put it equal here also N t. So, this is the first configuration. So, this part is perfect. So, that mean moment I say I am having MIMO system say M cross N. So, M side. So, it is like a M number of such branches I can create it and I have the potential to create a beam in M different direction because each an individual point can have their own phase shifter, can have their own phase shifter. So, these are my phase shifter say like a M number of SISO system kind of that ok and I can create.

So, the quiz question is that how many in how many directions I can create my beams? It should be the M if I have M cross N number of data I can create M number of direction of my beam. So, when I having when I am having a MIMO the potential benefit of this MIMO is that of course, there is a data part that is a different issue, but from a beam forming point of view is that I can physically create M number of beams in M different direction ok. What does it mean?

It means that if I see my beam individually I can steer it if I see my beam I can have a beam like this, I can have a beam like this, I can have a beam like that, I can have a beam like this and so and so forth ok, probably I put a different color. All different M numbers so, this is my first beam, this is my second beam, this is my third beam, this is my Mth beam.

So, I can potentially create M number of beams at different direction so; that means, I have one user here, I can serve him second user, I can serve him third user, I can serve him and you have Mth users you can serve him ok. So, using MIMO potentially I can create M number of beams as many as beam I get I can create that many number of data stream like I want.

So, with this basic configuration I end the MIMO beam forming part for this session in consecutive sessions we will be talking more about the MIMO beam forming what are the actual configuration that is taken, how the beams can be created so and so forth. And what are the R x side, what is the equivalent for the R x side, what are the data model that is that I am creating it ok. So, those are the things I can discuss it in the next subsequent classes. So, with this I end this class.

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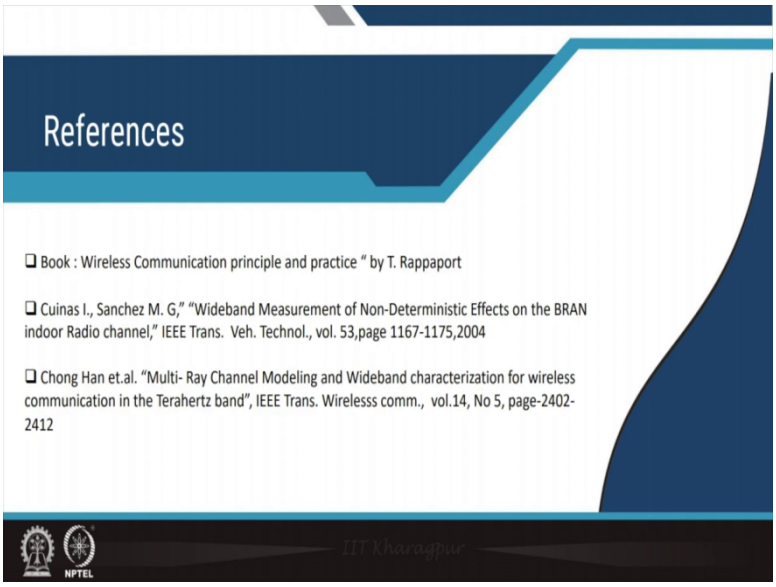

So, in conclusion we have kind of completed the yeah and the reference will be same as what we have seen.

Thank you.