**Signal Processing for mmWave Communication for 5G and Beyond**
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**Module - 08**
**Hybrid beamforming concept and Beamforming in MIMO**
**Lecture - 41**
**Structural implementation of MIMO Beamforming**

Welcome back, so now, today we will be talking more about the MIMO part; MIMO Beamforming part. In the last class we have just started it and we will continue it. We are graduating towards more and more complex systems.

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So, today we will be covering the like things that we will be covering are the following: So, whatever I have shown in the last class, it was more of a basic configuration. And, we will see how in practical sense, how things are actually done and what are the different difficulties, what are the different you know, what are the different level of complexities that is evolved here ok. So, let us go back to my earlier diagram again.

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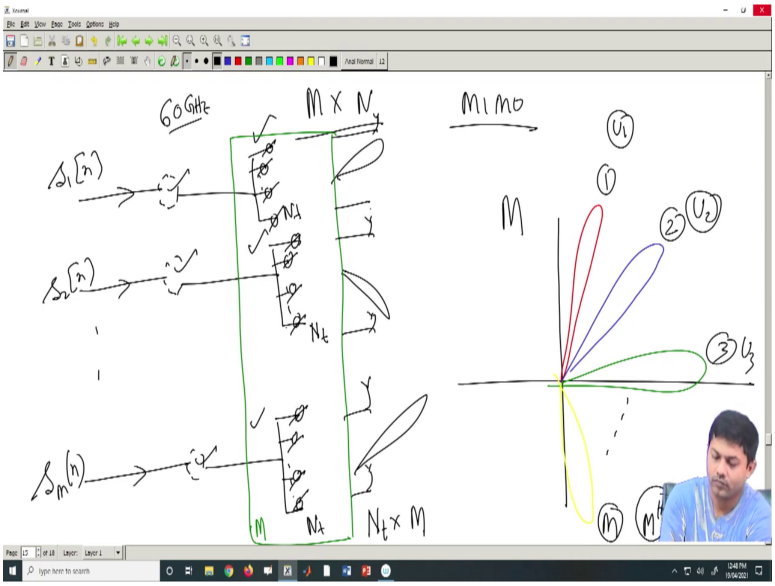


So, this is what we did it in the last class, the last diagram, where I can if I have M number of data stream I can potentially create M number of you know beams in different directions and I can serve users. Now, there are many questions than answers, happens for that. The first question is that, what if I have more than M number of users, what happens?

So, how do I serve them ok? Suppose, I have 10 antennas, but there are 200 users. Does it mean that, I can because I can clear only 10 beams right, so how do I serve the next or the rest of the 200 or next rest of the 190 users there. So, how do I do that? So, we will answer that, different type of questions that arise in this case, but this is more from the beam forming point of view what are the things can be done here.

Now, for this particular configuration, so what are the input side in this case. So, I can see that the input side I have M number of data ok. So, that mean if I think this is the same old box that I have created in the last class; last class. So, how do I model this from a DSP point of view? Suppose, I mean I am viewing it from the signal processing point of view, so how do I view it?

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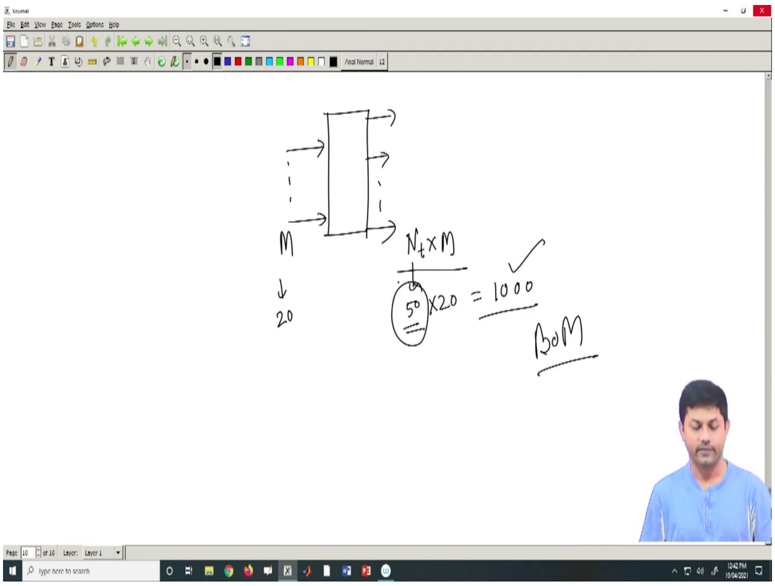


So, it is as if like, I have a box which has M number of inputs, and how many such outputs ok. So, that is how so and we will see what is there inside it. So, this is kind of a steering vector, but now this steering vector would be now this particular steering vector should be slightly complex to understand here ok.

So now, the question is the following; question is that, if you go by the this diagram this particular diagram. So, here you have M number of inputs, but how many number of outputs it has? Each an individual one is getting N t you know phase shifter output right and there are M such point, so I can say this has N t cross M outputs ok.

So, which means this would be N t cross M ok. Now, take an example; let say, M is say 20, say I am having large MIMO system 20 or 40 kind of thing and N t can be say 50. So, which means that this particular block, this whatever I have drawn here has an input output system of 20 input and 1000 output.

That is pretty gigantic, right. It is a very gigantic one, 20 input and 1000 output ok and inside it is not giving me very good benefit in the in terms of the beam width and all. The only advantage it is doing is that, it is creating different different beams, because everything is like a physically isolated and then there are space wise isolated.

So, I can create beams in different direction, but I still have to handle 1000 antenna which is not possible to have it right. This 1000 antenna in a small area is not so easy to get it, I mean you cannot fit suddenly 1000 antennas in a small area. So, even if you take a 60 gigahertz, you know 60 gigahertz r f placing 1000 antenna in a U l I you forget it, even if you have a UP I kind of configuration it is not so easy area it is not about a small area that you can think of.

So, naturally can I optimize the number of outputs keeping the same you know configuration same. Keeping the same configuration; that means, I still want to do M number of beams. I still want to do M number of physically space wise isolated beams. I do not want to compromise on the beam width, so can I keeping that in mind. Can I optimize the number of antennas?

Second point is that apart from you know apart from area and cost of course, cost is also an issue, because 1000 antenna the cost of Bills of Material will BOM; bill of material will also be very high for 1000 antennas right. Because, physically you have to place that and transfer bill of material will be very high and, using 1000 antenna if had it been a SISO case if it was a 1000 antenna.

So, can you believe the beam width it can give extremely high right, I mean extremely high in the sense that it is a very sharp beam it can get. Like probably, you can check it in the computer, probably it can be 1 degree or even less than that, that kind of a beam width it can create it, but I am still not getting the advantage of it. Because, effectively for each an individual stream probably I am still using only 50 antennas, so the potential of 1000 antennas is not being used by everybody, right.

So, a second configuration is thought of where number of antennas can be optimized and I really do not need 1000 antenna and that answer I can we can think of, where instead of 1000 antenna we still need 50 antennas, and I can exactly get similar thing what we have got it ok so, how that can be done here ok. So, let us take only the two case example, it will be easy for us to understand.

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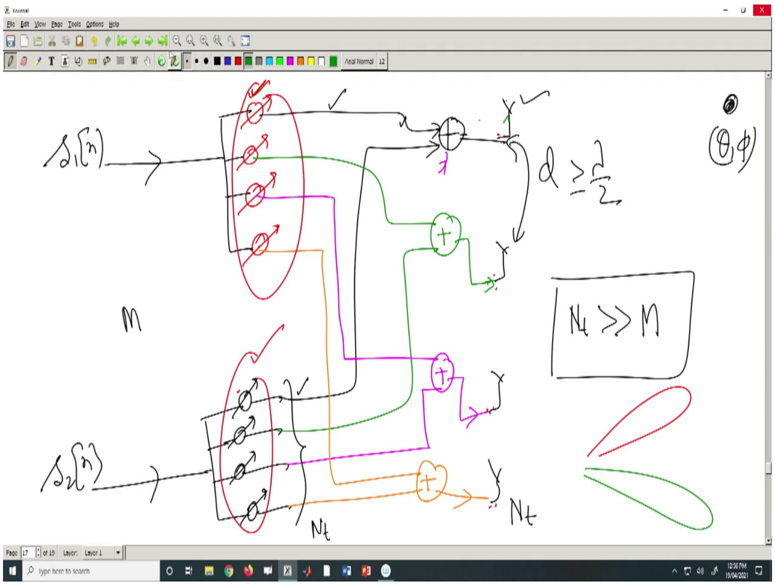

So, let us say I have only S 1 n and, let say I have just 4 antennas, 4 phase shifter. 4 it is the same phase shifter, but 4 antennas I am feeding, that is what I try to say. So, I can have a phase here, I can have a phase here, I can have a phase here, I can have a phase here, ok here also I can get a let me put a different color.

So, that it will be easy to distinguish it. So, these are the 4 phases I have created. But now instead of feeding, individual lines to individual antenna what I do is the following; I have split across 4 phase right, so I have 4 physical antennas. Having a distance d which is greater or equal to lambda by 2 similar thing; no change.

Now, instead of two sets of such 4 antennas, I am having only 4 antennas ok. Now, what I do? For each and every individual antenna before it get fed, what I do is that, I take the first line here and the first line here, I just add them up got it. What I do? I take the first line here and take the first line here and add them up and I feed it ok.

Take the second line here, take the second line here add them up feed to the second antenna ok. And then, take the third one take this third one feed the third antenna ok let me put a different color here. This is the fourth one; this is my configuration. So, instead of using antennas for each an individual you know data, I use only one set of antennas, but now I am having this configuration.

That mean; if I have say another set of antennas instead of S 1 S 2 S 3, what I would have done? Nothing, this adder will be one more line will be added. Three branches will be there, because three buckets. So, this bucket this is one bucket, this is second bracket and there is a third bucket fourth and so and so forth right.

So, here this adder will be, if it is a fast antenna, it will take fast data from each and every bucket. Got it? If it is a second antenna it takes the second of the first bracket, second of the second bucket, second of the third bucket and so and so forth. This is how I am doing it here ok. Let me just remove this part ok.

Now, this is a new configuration and this is more I mean this is much better than the other one right, because I am still having the same number of antennas, sorry I am having a reduced number of antennas, but I am having the same effect that we will see it here.

So, if I have four you know phase shifting point here, physically I will have you know that number of antenna. So, if I can generalize it, see if I have N t number of antenna here and this branch is also N t, so I really need only N t number of antennas ok. And one assumption here we will always put N t should be much more greater than your M. So, M is basically the number of you know number of physical channels, number of physical data that I am feeding it here.

So, this criteria has to be satisfied. So, your number of actual physical antenna will be much much more than the number of data. So, otherwise this scheme has an issue ok. So, this will work. So, this is the first assumption. Now, will this create the same effect as the earlier one? Will it get the same number of beams, will it also get the will it also do a beam steering as we have you know as we have envisioned. We will see that it does not really make any difference. Why?

Let us take the first antenna case or rather I will say, I am standing somewhere you know standing somewhere at a point theta and phi ok. So my job is to show you that it really does not matter it has not broken the system which was here. So, this is these are two equivalent system basically ok. So, instead of feeding them individually this system is also doing the same job ok. So, let us understand that.

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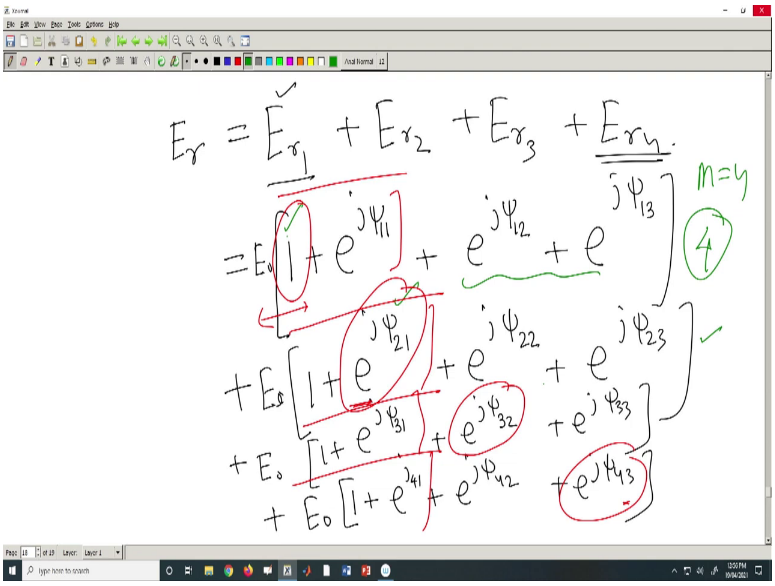

So at a point theta and phi, let us say, I am having E r ok. So, what does it mean if I get E r? So, let say this anything from first antenna is E r 1, second antenna E r 2, third antenna so and so forth. Similar one, E r 1 plus E r 2 this is the electric field correct. Now, what is E r 1? And, if you look at E r 1, E r 1 will have data from first one of the first bracket, first one of the second bracket, and so and so forth alright. Correct right?

This is how the actual benefit will be coming it here ok. So, what does it mean? So, if I take it so that mean, if I go to the first bracket. So, let us call it E 0, let us not divide the power part let us make the power remain same for all across all the antennas it easy to handle it ok.

So, the for the first so it has it is also taking data from first second third and fourth right every individual see, what does it take? 1, it will take then what does it mean? The first of the second one. So, let us call it 1 and 1 ok. Then it will take first from the third one. So, let us call it first from the third one, first from the fourth one.

This is E r 1 plus e to the power j it will take the second from the first one, I am just at least I am trying to do the first one so that it will be easy for you to this is how some similar configuration will be there and, if I takes little more pen and draw all of them. And similarly, the fourth one E r 4 so, what does it mean?

It is the fourth from the. So, let say that is the first one has no phase difference with respect to anything that it is all relative 1 2 3 4 ok. This is what it is (Refer time: 15:53). Now you group them, vertic because they are all added up, correct this all added up right ok. Now, you appropriately group them and see what happens ok. So, what I am trying to say is that, you take this one, this one, this one and this one.

You just group them. That mean I take the first one, so it is basically this one I take the first one of the first. So, it is as if like on the first antenna first one is going. Take the second from the first, so which means I take the first one then I, so let me just put a different color. Take this one, take this one, take the third one and take the fourth one; group them up.

Who what do they represent? What does that first one meaning? First one meaning, this is the first data from the first antenna alright. This is this one. What does this part represents? It is the second data from the second and to the second antenna, that mean it is the second data to the second antenna. What does the third component represent? It is the third data to the third antenna. What does the fourth one represent? It is the fourth data to the fourth antenna right. This is how the configuration can be thought of here right.

So, now if you can combine them together, what will I see? So, I will not see any differences right. So, it is the same as you just group them together, that is all, right. So, it is as if like this four data is going to four antenna, separately. This four data going to four antenna separately and so and so forth. If I have multiple antenna you can have multiple data's that you can create it there right. So, four data you can just create each and every data that you can create it here.

So, this is the beautiful part of my configuration. So, this particular configuration does not create any difference with respect to your previous one, because it is the same ok. Now, in this case, I may have drawn four cases, but actually it will be two, because each and every antenna will have only just two two here, only two two cases it will have it ok.

But I have drawn here ultimately for four cases it is drawn. So, even if you have in the particular case, the four one so it will be like a one data here, one data here, another data here, another data here, so it is like a 8 data that is coming right. So, just think from this particular configuration, so it is like 1 antenna 2.

So, there are fourth there are 8 data that will be coming. So, how do I configure it the first, this one second to the second antenna, third to the third antenna, fourth to the fourth antenna group them together. For the second for the second group again you group the first data with the first antenna, second data with the second antenna, third one to the third antenna, fourth to the fourth antenna.

So, you just group them together. You just mix them up. What does it mean? Does it really create any problem? No, because this is a different phase, this is also different phase. So, ultimately this will create beam in one direction, this one if it is a green this will create beam in the other direction. As long as that part is maintained, even if we add them together it makes no differences, it really makes no differences ok.

So, this is the point here I am trying to understand here. So, here I have drawn actually for the 4 cases, M equal to 4, but 4 data that I have created, but you can also create M equal to 2, in that case 2 part this part will not you know appear in that particular case only, you know 2 data's will be just coming into picture here. So, anyway so ultimately what I am trying to do here. So, what I am trying to do here is the following even if you have as long as you can maintain this phase differences.

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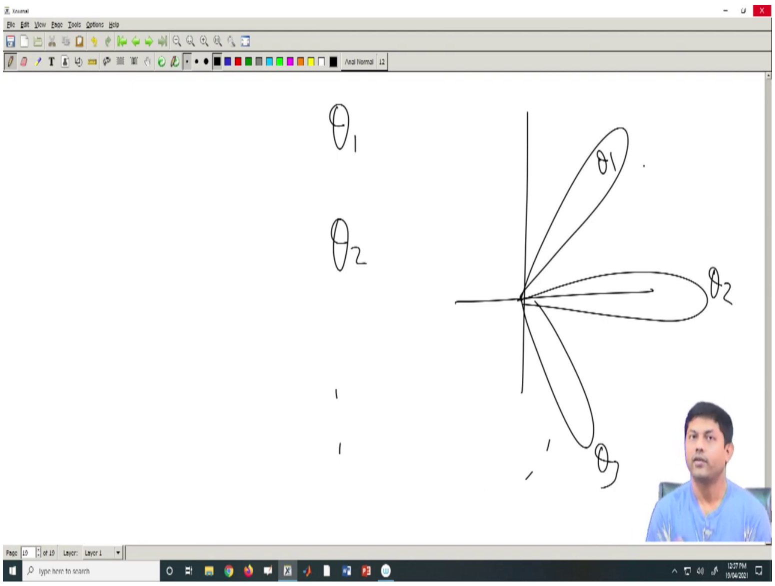

Theta 1, theta 2 and so and so forth all this phase; that means, this, this, this, this is a, theta 1, this is theta 2, this is theta 3 and so on and so forth. As long as you maintain that there is no problem, even if you add them together there is no problem, because they are orthogonal beams. So, as long as they maintain that orthogonal these angles are orthogonality. I do not have any problem. Now, that brings us to an interesting point. What will be my DSP data model?

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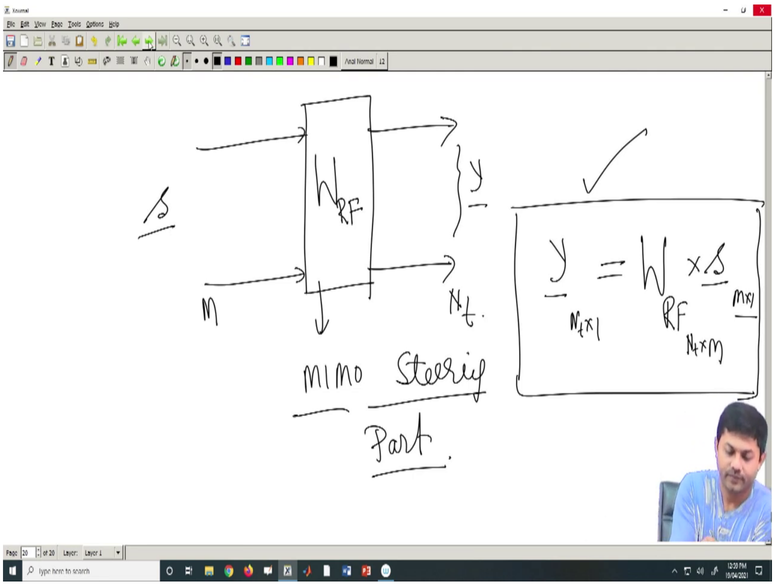


So, now, it is as if like that whole system, this whole system is no longer N t cross M now. What it would be? Now, it will be N M cross N t. So, if I go here, so now I have M number of inputs here, I have N t number of data here ok. So, I have M number of input, that is how I can view it. So, this is my steering part. This is my MIMO steering ok. This is my MIMO steering, nobody else ok.

So now, it is as if like I can think of it like some you know some mathematical model where at M number of inputs coming N t number of inputs going. So, if I represent this as some matrix operation, this is how we view it now that may be phase shifter that is ok, but that is some sort of a matrix operation.

And here, if I say I am sending of data vector S and I am receiving, I am giving an output Y vector. So, I can always think of Y vector, whose dimension is N t cross 1. That will be equal to W into RF, whose dimension would be N t cross M multiplied by S vector, whose dimension is M cross 1.

So, this is an important data part. This is an important data part ok. So, this is a phase shifting or rather a steering data model. So, that mean, if I send a data it is as if like I am passing it through a matrix W RF, whose dimension is N t cross M and I am creating a data out of it some complex number out of it. So, if I remove all my you know the connection parts, how exactly my connections and all are done.

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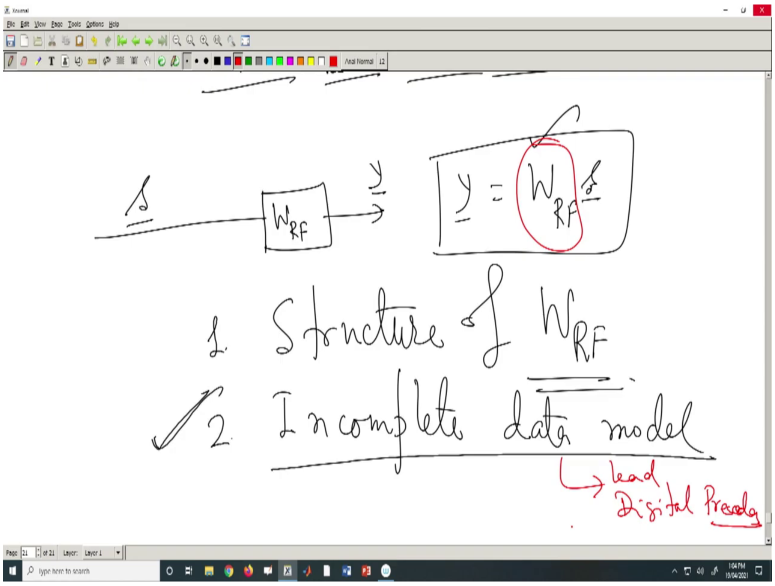

So, it is as if like from a MIMO point of view, I have a data vector S, which goes through W RF and goes through us data called Y vector that is all. So, on a Y vector will be W RF into S vector. So, that is my data model. So, this is my data model point of MIMO beam data model, but this is still impartial ok. This is one part.

Now, some of the discussion which leads to the second part of the, as I say this data model is still incomplete ok it has some more points that needs to be added up, ok. Now this W RF, what is the structure of this W RF that we need to understand? So the first point; structure of W RF, is it just like any complex number or it is something else you need to understand that ok.

second part is that, why I still say this is incomplete data model. So, I say that this data model is an incomplete one. What is this incompleteness, where exactly the issue that is coming into picture here ok. So, let us so out of these two let us first attack the 2nd problem. Structure will come to that.

And as you can understand or you can guess what is W RF, because W RF is also the steering. So, if you look at the structure, I have not changed. I have not change the structure here. So, you see this is the structure. So, which means the W RF is something to do with this individual steering models ok. If that is the case, then you can guess the W RF.

It is the same as same you know the same steering vectors, but it will be it will certain way of you know oriented, that is the only part, but the more o ring part is the following. More o ring part why am I saying, it is an incomplete data model, where is the incompleteness comes into picture that we need to understand.

So, probably we can answer that in the next class. Where the exactly the incomplete data model comes into picture and why and what are the structures part of the W RF part. So, in the next class we will start from 2, and that incompleteness leads to another structure we show that. So, that is called digital precoder. So, you can think this W RF as some sort of a precoder right.

I mean if you have thought of what is precoder? That mean, a data which is again multiplied by some sort of a matrix and then again it is going for a transmission, so it is a precoder ok. Instead of doing the coding at the transmit at the receiver side sorry sorry instead of doing the equalization at the receiver side I am doing something at the transmitter side itself so that I can gain some something. Gain maybe, S n r or maybe a data those kind that is what the precoder done.

But, here also you can think this is actually a precoder this W RF, this W RF it is a precoder ok some sort of a precoder. Now, what is this precoder doing? This precoder is doing a beam splitting, basically it is just doing a beam splitting. So, you have multiple beams and you are just splitting the beams at different different directions. So, that is it is purpose ok. So it is doing a precoder. So it is called an RF precoder or a phase shifting precoder.

But, when I say incomplete data model, so that incompleteness next class we will answer that. When it make it when you say it is now becoming a complete data model that it will lead to another you know precoder and that precoder is called a digital precoder. So, this will lead to so it will lead to digital precoder.

And we will see what exactly the digital precoder structure would be, how that can be from, what is the motivation for this particular digital precoder ok. So, with this I conclude this particular class and in the next class we will talk about the structure and the other data model part of the MIMO data MIMO beamforming.

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So, in conclusion we have kind of completed the yeah.

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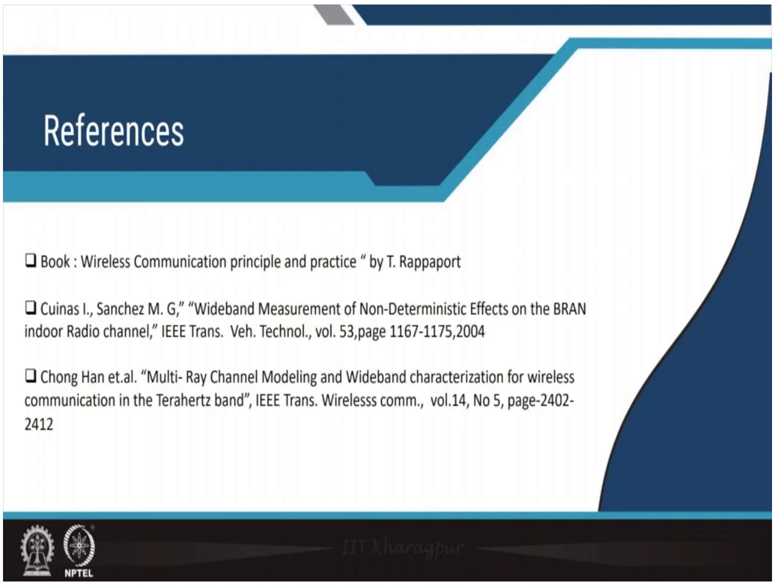


And the reference will be same as what we have.

Thank you.