

Signal Processing for mmWave Communication for 5G and Beyond
Prof. Amit Kumar Dutta
G.S. Sanyal School of Telecommunication
Indian Institute of Technology, Kharagpur

Module - 05
MmWave parameters
Lecture - 25
3D Concept, AoA, AoD

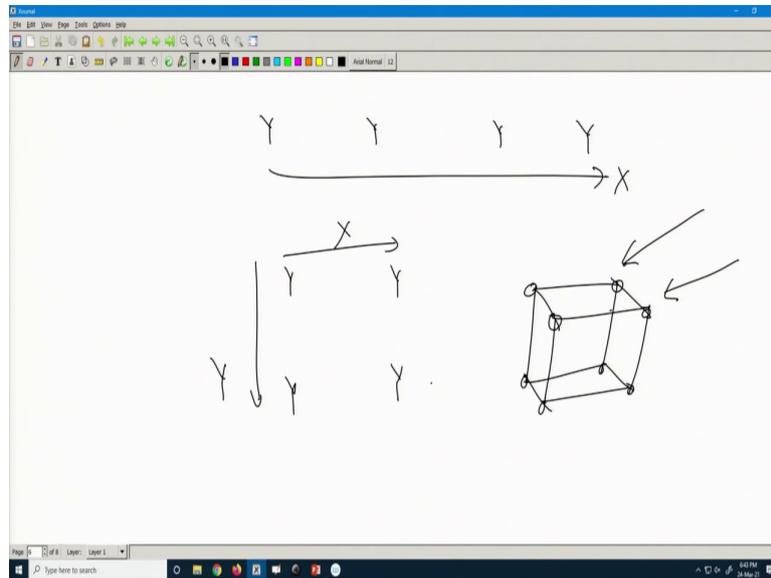
Welcome. Welcome to Signal Processing for millimetre Wave Communication for 5G and Beyond. So, today, we will be covering more on the 3D concepts of the channel and continue to have the AoA and AoD discussions.

(Refer Slide Time: 00:44)



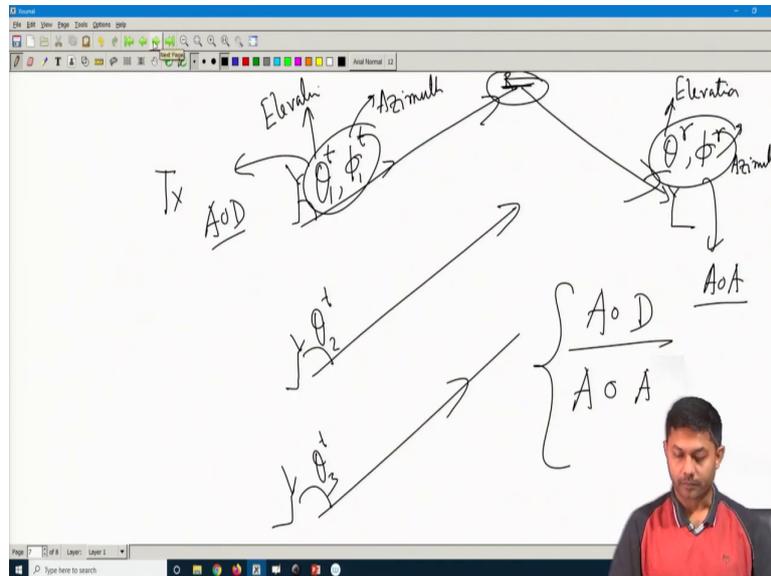
So, mainly these two important concept will be covered AoA and AoD, in the context of 3D, and then the 3D concepts of the channel will be covered.

(Refer Slide Time: 00:56)



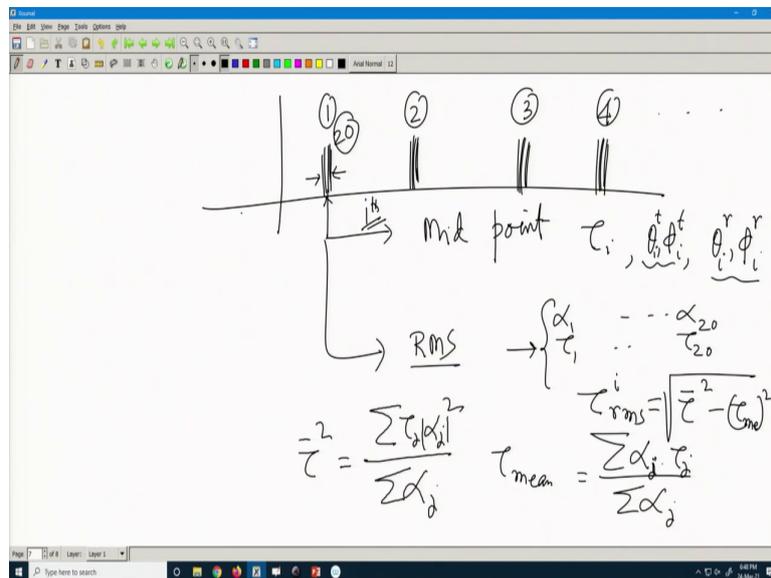
So, last class we left here, right. So, we discussed that there may be different configuration of the antennas, now that will come into picture here. So, let us understand why this considerations are important, and what are the consequences in my channel model because of that. Because this is not a very important concept when I was in the 6 gigahertz, sub-6 gigahertz and so on.

(Refer Slide Time: 01:22)



But, now this will be important. So, this we discussed it last time. And then, we somehow concluded that we have an AoD and AoA which will be common for you know common for cluster, right.

(Refer Slide Time: 01:44)



So, now, so, that means, if I have a cluster of the channels, you have a cluster of channels, I can have a common delay or common AoD and AoA. Now, I mean, question was what is the best way to get that, ok? The best way to get that is that you can have either the midpoint, midpoint and whatever delay AoD AoA it happens, you can just say rest of the bunch have the same thing.

This is one approach. So, that means, you can have midpoint; and say the tau. So, this is the 1st cluster, this is the 2nd cluster, this is the 3rd cluster, this is the 4th cluster and so on and so forth, ok. So, that means, it may have the, see if it is the ith cluster, I would say, I just take the midpoint whatever its value, I can take the midpoints theta phi t and I can take the mid points theta i t, this is i, this is i, this is i, angle.

This is one way of doing it. A second way of doing is that I can have the RMS. I can have the RMS within it, ok. So, this is all for a modeling purpose. You cannot estimate such things because the number of parameters are so huge, probably estimation may not be the right. When you do a modeling, so what is the best model that you can think of, ok.

So, I can also think of that whole cluster can have a tau AoA and AoD, which is RMS of all of them so, that means, for all of them say, within it there are say example, I am just giving an example. Say there are 20 such you know such tiny fellows are there. So, for all these 20 tiny fellows, 20 tiny fellows, you have their own individual tau 1 to tau 20, similarly all of them we have their individual alpha as well, ok. So, alpha 1 to alpha 20, correct.

And then what else they can have? See, they have that. So, can I have a tau rms corresponding to the i th cluster? Of course, I can have that and we have defined the RMS. How do I define the RMS? So, this was tau bar square minus tau say mean square that we have defined it. And what was that?

So, tau mean was summation of individual alpha i into you know let me j , put it j tau j divided by summation of all individual j . So, this is the mean, and the tau dash square was the similar one, alpha j tau j and alpha j square, mod square probably. So, this was the case, right.

So, now you can create an RMS value. Probably that gives you even a better way of modeling it. So, when I say I just want a single you know delay element, single AoA and AoD set, what I essentially say that I have their RMS value, every RMS component I have it. So, you can take say if whatever number of components that have just take the RMS of it.

(Refer Slide Time: 06:01)

The image shows a whiteboard with handwritten mathematical formulas. On the left, a vertical line is drawn, and a horizontal line is drawn below it. A vertical line is drawn from the horizontal line to a point labeled θ_i^t . To the right of this, the following formulas are written:

$$\theta_{i,rms}^t = \sqrt{\bar{\theta}^2 - (\bar{\theta}_{mean})^2}$$
$$\bar{\theta}_{mean} = \frac{\sum \theta_i \alpha_i}{\sum \alpha_i}$$
$$\bar{\theta}^2 = \frac{\sum \theta_i \alpha_i^2}{\sum \alpha_i}$$

Similarly, if it is tau it is the case. If it is say angle of arrival case, say I want to have all of them have a common theta for the ith case, what will I do? I can have an RMS theta i value. Similar way I can define; so, if I have theta RMS for the angle of departure, but this is the ith case, so ith case. So, I will put it in a different notations slightly a different notation. So, probably I will put ith case, but it is a RMS, ok.

So, I have the similar way of defining it. There would be some minus theta cap mean square. How do I define them? Again, with respect to the alpha i can define it. So, if I have a theta mean, similarly you bring in alpha there. So, theta i alpha is summation of alpha i. So, that is your mean definition. And theta bar square definition is very similar, theta i mod of alpha s square by summation of i.

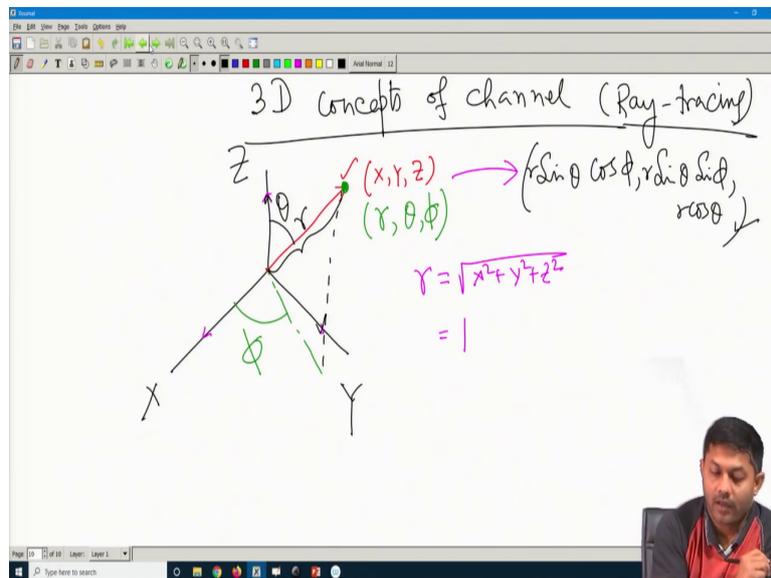
So, that could be one definition here, ok. So, this is a very classical definition. And I will put little mod here because I do not want to take complex numbers. So, this angle may not be complex angle here, ok. So, this could be RMS value. Similarly, you can have your ϕ_r , ϕ_θ , I mean θ_r , ϕ_r everything, everything has its own RMS.

But bottom line is that I do not want to have multiple such parameters for different cluster. So, this is the first criteria or rather I would say, this is the first criteria to model a millimetre wave in a more practical sense. And what are the different reasons? So, one reason is that as you can notice that the τ or the delay spread is not so high within the cluster, right this is the number 1. Number 2 point.

What about the magnitude? Are the magnitudes widely different? Ok. Well, that may or may not depends on how exactly the you know how exactly the scattering happens. So, it may be different, it may be same also. We will see that when you exactly model the beam forming case, we will see that what exactly the assumption for this particular α , ok.

So, next point. So, we have now defined these points, ok. Next go to the 3D concept because now as we know we have angle of arrival, angle of departure with an elevation and azimuth spacing. So, that mean now I no longer afford to have just a 2D model of my system. So, I have to go for a you know 3D model of my system, ok.

(Refer Slide Time: 09:06)



So, now I will be introducing the 3D concepts here. It is just the view. I will view it as a 3D. Now, will my retracing model invalid no, which is same retracing model, but now ray retracing will be happening in a 3D model. So, I would say 3D concept of channel, but background is still a ray tracing, that fundamental does not change, ok.

So, now I have this is my say this is my X, this is my Y, and this is my Z coordinate system. So, if I have a point somewhere here, ok. So, instead of saying X, Y, and Z, I can also express it in terms of the polar coordinates, right. Express the same thing in polar coordinate. How do I express it? Take the length, let us call it r, right. Take the angle with respect to the vertical, if you call it Z, fine.

Then, you take a projection onto the X, Y plane and then you; so this should be your phi, right. So, instead of X, Y, Z, I can say if it is in polar coordinate it is r, theta, and phi, this 3 points are required to you know to denote the same point in the X, Y, Z to polar coordinates.

So, this is important because this is the fundamental basis of my beam forming in millimetre wave, this is the part, ok, first thing. So, what is the relationship? So, relationship between X, Y, Z and r, theta, phi, I think; so, let us understand that part because that will also be very much valid when you go for the beam forming case, ok.

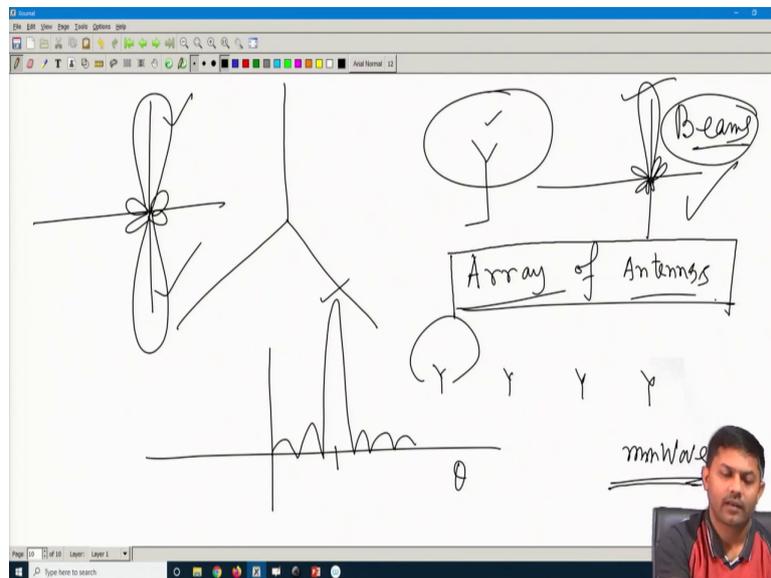
So, let us use a different. So, this is say X part, this is so Y part, this is somewhere Z part, right X, Y and Z. So, if I have X, Y and Z can I express the whole coordinate in terms of the r theta and phi? ok. Yes, we can do that. So, what is our r? r is X square plus Y square plus Z square. Let us assume for the timing, I do not want to get into the exact length. Let us make it 1, just for our normalization purpose. Let us say the point is 1, I am just considering a unit sphere, ok.

That means, X square plus Y square plus Z square is 1. If that is the case then, how do I convert X, Y, Z to r theta and phi coordinate? It will be sin theta into cos phi sin theta into sin phi and then you have cos theta, correct, that is why. Because Z is like this, so it is cos theta of r, r cos there is an r, here everywhere there is an r here.

So, that part is given. So, this is basically r cos theta is this angle, then you take a r sin theta from there cos phi and sin phi, that is it. So, cos phi will be your X part, sin phi will be your Y part, and the rest. So, this is your coordinate part. Now, this is important you know.

Why? Because when you go to the beam forming we will come to that point this concept are extremely important that how exactly in my polar coordinate, the channels, the antennas and the rays are actually moving in that. So, their X, Y, Z is not the right way to think about it, everything in terms of r, theta, and phi, these are the ways to think in a 3D model, ok.

(Refer Slide Time: 13:55)



Next, I now move to the point I continue to do the 3D modeling how exactly I do more is that, so, this is my coordinate system, ok. Now, the point here is that I start from the transmitter side, then I go to the reflector side, then I go to the receiver side. Now, when I go to the millimetre wave, the bigger trouble of millimetre wave is that if I use just one antenna, what is the trouble with one antenna.

The trouble with one antenna is that it is if I assume it is an isotropic antenna it can deliver the power, right. Why it cannot deliver the power? Because the path loss will be very high because it is isotropic, right, every direction all things are radiating.

So, I have to use some sort of a beamed kind of question and that is the reason why I am you know why I am studying all these 3 dimension because it is basically enforcing me to think the transmission direction and my reception direction is certain orientation, ok.

Because that concept is very prominent in millimetre wave. Why it is so prominent? Because if it is a 30 gigahertz or 60 gigahertz or 100 gigahertz, and if I just use isotropic antenna I cannot propagate the signal, maybe not more than say 100 metre or not even 100 metre probably, 10 metres or 20 metres. Most of the power will be lost, the path loss could be very high. So, I have to use some sort of a directivity.

So, what does it mean? I have to use the antennas power to be oriented or transmitted in a certain direction. If that is the case can I do it using one antenna? Yes, I can do it provided this particular antenna is a directive antenna. For example, dipole antenna or a horn antenna, they are all; they are all directed antenna, directive antenna, but I cannot afford to have such kind of antenna in my you know in my tiny communication system.

Probably you know if it is a base station, I may afford to have that, I may have a parabolic antenna, those kind of thing, but when it comes to say mobile station, say I have a small mobile say mobile phone, I cannot have a horn antenna, right because they it will consume more space. So, I have to use it a isotropic antenna. Now, using isotropic antenna can I create a directed beams? Obviously, that you can create it. So, this concept was array processing, array signal processing, array of antenna.

So, if I use an array of antenna, I actually can create, we will we will discuss that. We have a separate module for antenna arrays array processing, but I am just giving you a flavour why exactly this 3D point coming to picture. So, I can use in fact, multiple such antenna together and transmit the beam, ok.

Now, when I do that, so this is basically called array of antenna. So, when I do that, this spectrum if I look at the spectrum of my particular antenna it will not be like a this. I mean

individually they may be isotropic, but as a whole, as a whole this whole 4 will not create like a, it will not get like an isotropic beam, it will get a directed beam.

It is as if like if I plot the 4 antennas you know spectrum together I may see something like that, with respect to theta or phi whichever elevation or phi whichever angle you prefer you will see this kind of spectrum. So, that mean at a particular theta direction, I may be transmitting more and I may be transmitting less in other direction.

So, if I take some sort of a other kind of diagram, where I take the 360 views, I may see this could be views like that, something like that I can create it.

So, such kind of beams are required for my transmission in millimetre wave, because unless I have this kind of beam or something like that, 360 degree view beam patterns, if I cannot keep such kind of beam patterns most of the power will be lost. And that is one of the reason I need to know the angle of arrival angle departure, because I need to know which direction I am transmitting it. So, this these are actually called beams.

So, this whole thing was absolutely absent in my 6 gigahertz spec, in a 6 gigahertz transmission. Now, I could have done it, but I have not introduced that because their intention was to do go for a bulk, I mean bulk user bulk amount of power transmission. So, power loss was definitely an issue, but such thoughts were not there.

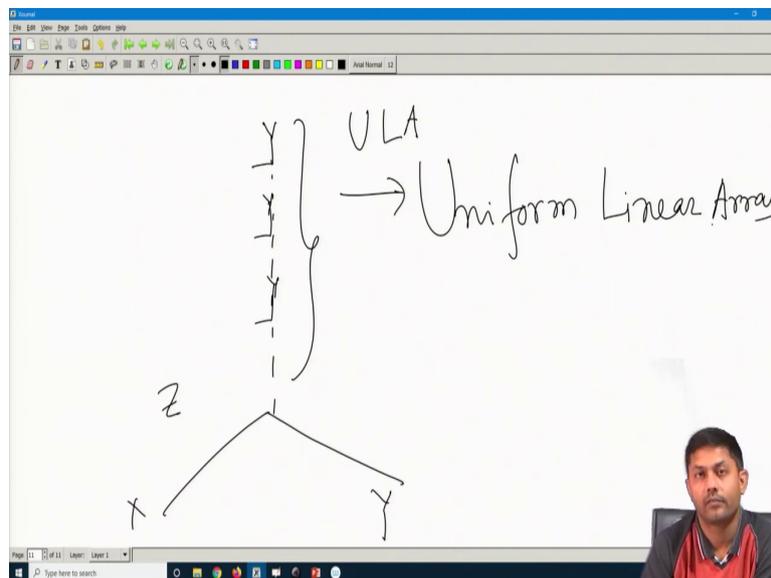
But moment I go for a millimetre rep as the path loss is so extremely high I really cannot afford to have a isotropic antenna, I have to go for a directivity of my antenna. The moment I go for a directivity of my antenna I have to bring in the concept of 3D. So, that is the reason why I introduced the 3D concept here.

Now, is it in the context of only antenna that mean, the way the so the point here is that when I want to create this kind of beam, naturally I am talking of array of antenna. Now, moment I say array of antenna if you have an antenna basics you may know, that the array of antenna works in a particular geometrical set. So, you are bringing in geometry there.

So, what does it mean? It may be sphere where antennas are present, it may be a square or a you know or some sort of a brick kind of structure or it can be just like a plane or can be just like a one normal line. So, there are many ways you can put your antennas and create such kind of beams. So, depending on space, depending on space of optimality, beams steering, and beams structure you can create those kind of things So, the concept is you are forced to bring in this 3D concept.

So, now, I am now talking that I need this kind of structure, this beam. I do not want a transmission which is like you know isotropic kind of thing. So, this is one of the plus point or rather I would say this is one of the forced, you are forced to use this kind of concept. The moment you have this naturally 3D comes into picture. Now, to get into that array of antenna there are different level of geometry is possible.

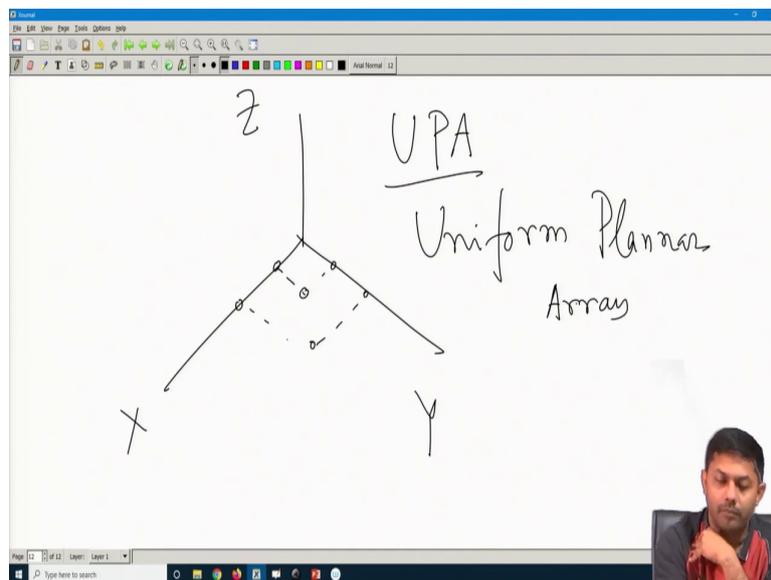
(Refer Slide Time: 20:42)



So, first geometry that is possible here in the context of millimetre wave is that you can place your antenna on the Z axis, just on the Z axis. So, you have X and Y axis, and this is your Z axis, you can place all your antenna on the Z axis.

So, you can have one antenna here, you can have one antenna here, you can have your antenna here, like that, you can place it, ok. Or, you can have everything on the X axis or you can have everything on the Y axis. So, what should be the beam pattern? So, such kind of concept or such kind of position of antenna is called ULA, Uniform Linear Array.

(Refer Slide Time: 21:36)



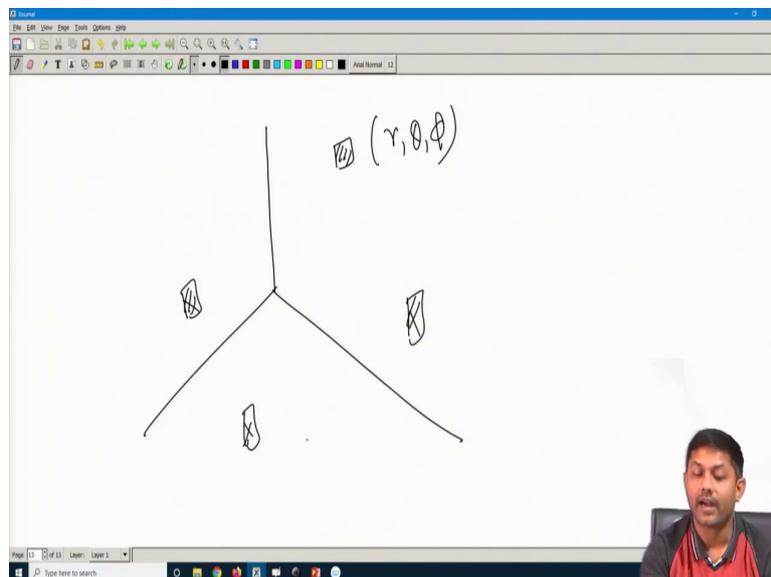
You can also have, have your antennas like this, so if you have a X, Z, you can have your antenna like this, some of them on X axis, some of them on Y axis, some of them even on a Z

axis, ok. Or maybe you can have it purely on X and Y axis, fine, something like that you can have it, like that. Say X, Y plane I can have it. So, this is called UPA, Uniform Planar Array.

Why all these things are required? Because I want to create beams, I want to create beams. So, this beams if you want to use a set of antennas, you are forced to bring the geometrical concept, you are forced, you cannot just randomly place some antennas and say, hey, this is what my transmission it will get a bit it will not work.

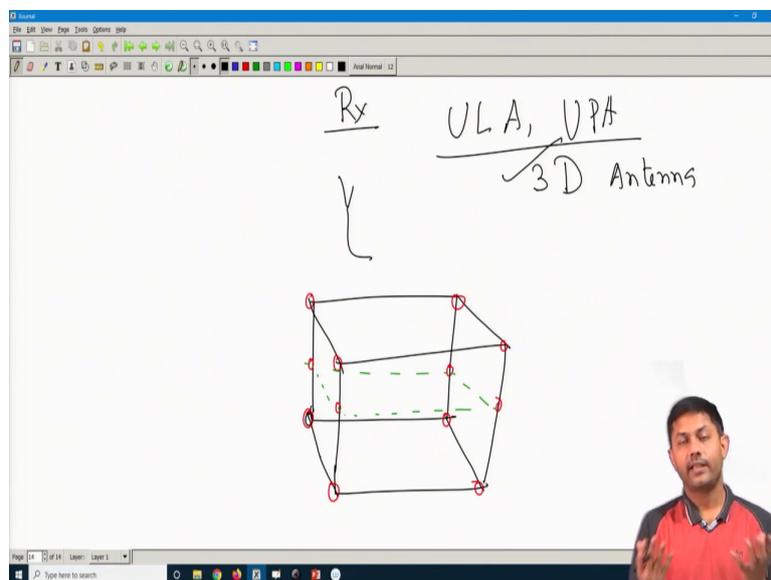
It has to have a geometry. Moment it has to have a geometry, you are in the polar coordinate. So, that mean, your transmission side itself is now in a geometry, ok. And these are the different type of geometry you can think of formal antenna, ok. What about your what about your ah reflectors and scatter? Of course, you do not have control, but they are also in a geometry.

(Refer Slide Time: 23:11)



So, which means that if I have 3D, probably you may have one reflectors here which has r , θ , ϕ positions. It has its own X, Y, Z coordinate. You can have a reflectors here, you can have a reflectors here, you can have a reflectors on the X, Y plane, anywhere, you can have it, reflector or scatter, ok. So, that can be on a certain geometry, right. So, that mean your T X is having a 3D geometry. When you go to the reflector or scatterer they also have a certain geometry, because they are placed in that geometry.

(Refer Slide Time: 23:54)



What about the R X site? Look at your R X. The R X are what? R X are just antenna. Does it also have a geometry? Does the geometry matter for it? Or, it is just like a one antenna whatever you have discussed just one antenna sitting somewhere? The question is that when you have a beam, so there are two concept we will explain you know subsequent classes, one is called transmit beam and there is something called a receive beam.

So, when you want to you know receive the signal in a much focused manner like I want to receive it in a the way it has come it is one antenna may not be enough. So, I can create that beam also in the receiver side, ok. So, this is called a received beam forming. So, again that enforces me to use antennas in a certain geometry. It is again not just haphazardly.

See in 6 gigahertz, we have already discussed about the MIMO concept, right, multiple input multiple output. But we never discussed the geometry of this antennas, like how exactly those antenna will be placed on the transmitter side, how exactly those antennas will be placed in the receiver side. We never even consider that. For us it is a point to point, antenna to antenna communication and we are done it. There is no 3D concept there.

But now because I am having a millimetre wave concept and because I am having a beams because it is not an uniform isotropic antenna radiation it is a beam radiation I am forced to introduce the geometry at every point. Now, it is the R X point. Now, when it is an R X, again the geometry has to be followed, right. I cannot just get away with placing antennas anywhere in my receiver.

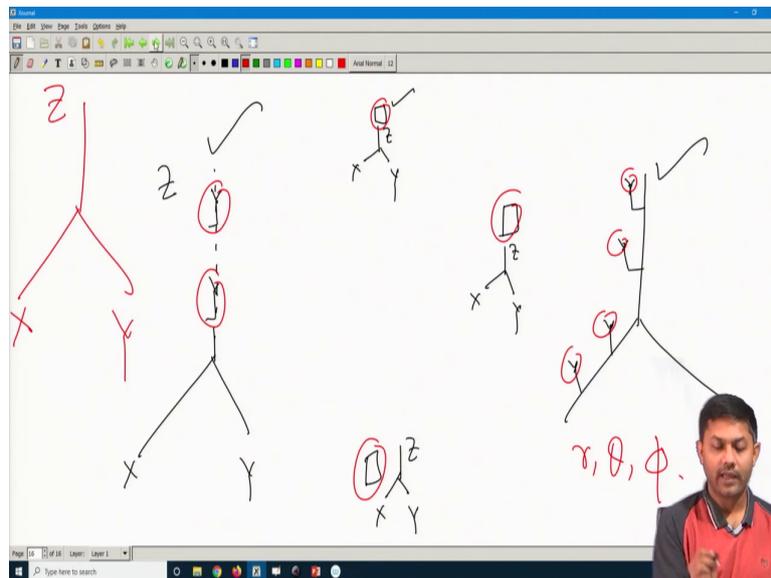
It has to be again certain geometry it has to follow. If I would like to have or if I want to exploit the beams at the received side as well same concept, same ULA, same UPA will also be there, uniform planar array, uniform linear array. That is also a 3D antenna position. So, for example, you can have like this.

And we will definitely explain that as well. You can place your antenna in a 3D manner. So, for example, I can have my antenna like this X, Y, Z coordinate. This is the planar part. I can have my antenna here. I can have my antenna here. So, it is like a 3 layers, right. So, it is a 3 layers I have, ok.

So, this is also now it is coming up in a beam forming concept. So, you have ULA, you have UPA which are mostly popular, you can also have a 3D antenna position. We will be explaining these things, all these things in a very details when the beam forming comes into

picture, ok. So, which means that whenever I have this kind of geometry I naturally have a 3D concept.

(Refer Slide Time: 27:17)

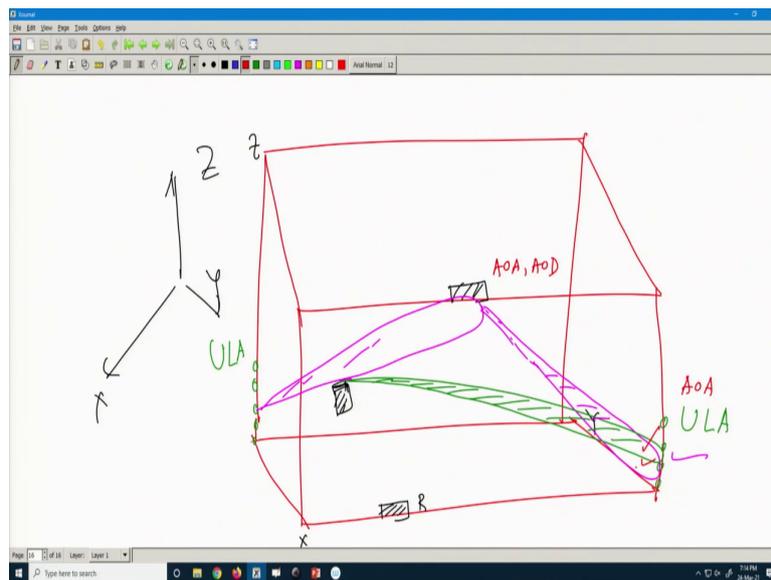


So, now if I look at my overall you know transmission and reception along with everything, what I see is that, I have a set of antennas which are oriented in an X, Y and Z plane. I have a set of receive antenna which are again they are oriented, there may be some antenna here, there may be some antenna in a certain geometry, and I can have reflectors and everybody will have their own set of geometry.

This is Z, X, Y; this is also Z, X, Y; this is also Z, X, Y. That means this will have angle of departure and angle of you know the way the transmission happen. This is angle of arrival and these ones will be where when the angle of in particular angle the recipient and particular angle they also gets reflecting, right. So, that is important.

So, that mean the whole thing is like as if like you are viewing it, whole thing in a geometry, and everybody is dominated by their theta, phi, and r position. So, every element, so this element, this element, these elements, all of them have their own individual r, theta, and phi position in the whole geometry. So, you can think of that way, ok.

(Refer Slide Time: 28:54)



So, in a another diagram I can think of is something like I can think of it is like a box say, I mean just in a room. So, this is like a, ok. So, it can be that my antennas are, transmitting antennas are placed like that in a ULA manner, my receive antennas are placed like that, here in this part of the corner in again a ULA manner, and I have a reflectors which is probably on this is a Z axis, this is X axis and this is a Y axis, right. So, this is X, this is a Y, and this is a Z axis.

So, I have one scatterer on the X, Y plane, I have another scatterer on the Z, Y plane, I have another scatterer on X, Y, Z plane itself. So, now, there it will be something like this. I have a I have transmitted a beam like that, or rather I put a different colour here. From here I have transmitted one beam like this. This is what my transmission is. From here I get this reflector is putting the beam like that, ok.

Now, let us say this is my second reflector because it is also getting a part of the power. So, from here part of it gets reflected here; or I put a different colour here, let us say green. So, this is my one beam coming from this reflector or scatterer. This is my second beam. So, this is my transmitter things, and this is my received thing, all are coming to this part. Now, you see this is exactly a 3D kind of system because each and every point has their own AoA and AoD, right.

He will face a certain angle of arrival, for this fellow and this green fellow, right. For green he will face one level of AoA, and for this pink he will face another level of AoA. And he will face different angle of departure here, he will also face a different angle of departure.

So, now this is what my channel view now. So, this is exactly what happens in the millimetre waves 3D concept. Now, everything is now a 3D. Now, you cannot get isolated from you know this 3D geometry, ok. We will talk more on the next class how exactly the parameter models in this concept coming to picture.

(Refer Slide Time: 32:17)

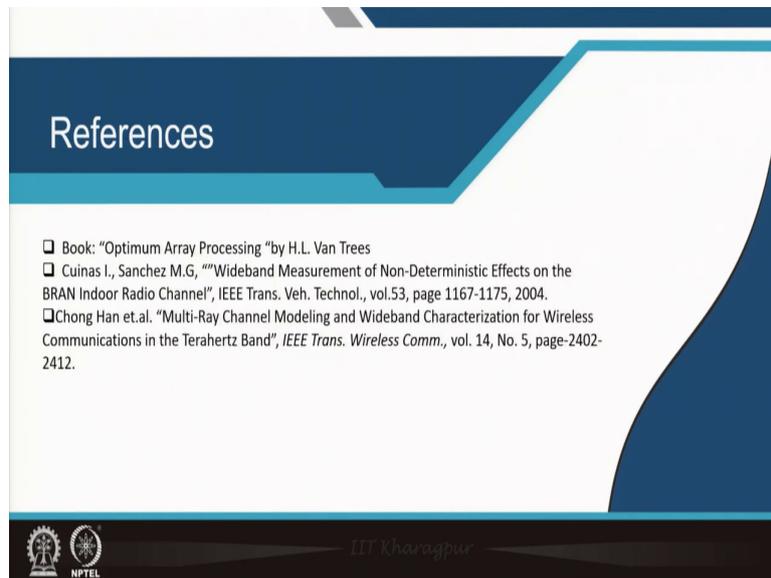
Conclusion

- We cover more on AoA, AoD
- Introduce 3D concepts of channel

IIT Kharagpur
NPTEL

What we covered now, we just say how on RMS or what are the choices of AoA and AoD could be, what is the best choice of AoA and AoD could be for a particular cluster. And, we also introduce the concept of 3D channel models. We will talk more on that. These are the various references.

(Refer Slide Time: 32:38)



References

- ❑ Book: "Optimum Array Processing" by H.L. Van Trees
- ❑ Cuinas I., Sanchez M.G., "Wideband Measurement of Non-Deterministic Effects on the BRAN Indoor Radio Channel", *IEEE Trans. Veh. Technol.*, vol.53, page 1167-1175, 2004.
- ❑ Chong Han et.al. "Multi-Ray Channel Modeling and Wideband Characterization for Wireless Communications in the Terahertz Band", *IEEE Trans. Wireless Comm.*, vol. 14, No. 5, page-2402-2412.

  IIT Kharagpur

With this, I conclude the talk today.