Optical Wireless Communications for Beyond 5G Networks and IoT
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Lecture - 41
Mat Lab Tutorial Part - 2

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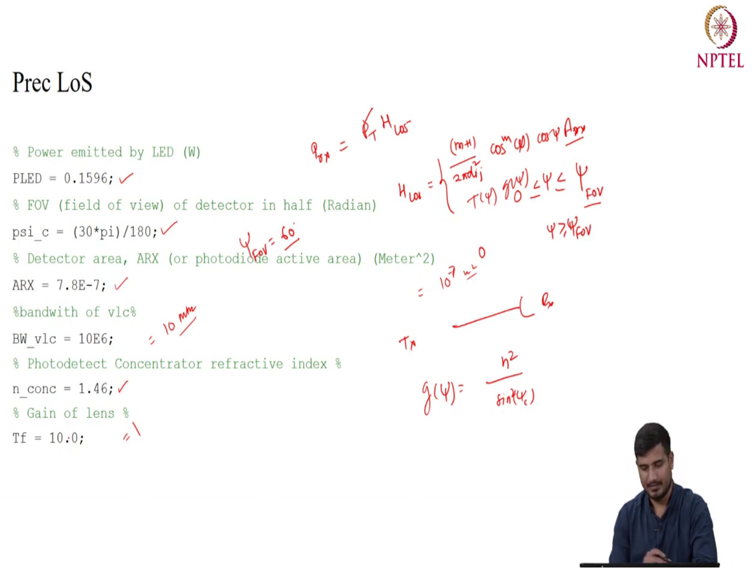

Now, come to the part of line of sight received power calculation. So, for that you require this LED power like I have shown you earlier. If we calculate received power, it is simply transmitted power multiplied with line of sight channel gain. So, first we have specified the value of LED or you can say this is the P T power. So, this is the example value I have taken in what is 0.15 watt, you can take 2 watt, 3 watt as per the your system model you can take different values.

So, this value we have is specified a line of sight channel gain we have calculated earlier based on the LED parameter and the receiver parameter. Similarly, come to the PD part as you know this line of sight channel equation is validated which is the value of m plus 1 upon 2 pi di j square cos m phi cos psi. So, this value is valid for the incidence angle value which lie within the field of view of the receiver.

After that if your psi angle is greater than the field of value the channel gain will be 0. So, we need to also specify the field of view of the PD. So, again I have specified this value in radian here you can also use the degree value here. So, that is 30 degree. So, generally the standard value of receiver field of view we take as 60 degree.

You can change this value there is no issue in that. So, this is how you give the value of you need to give the value of field of view of the receiver. Next, again when we calculate this received power there is also a term ARX like what is the PD surface area of the photo detector. So, you so, any anything that is in the equation you need to give as a input form.

So, this so, generally this value lies in 10 raised to power minus 7 centimeter square or you can convert into centimeter square you can take any practical value here and again the bandwidth of the system. So, here we have taken 10 megahertz system. So, we have specified the bandwidth value of 10 raised to the power 6.

And the again as they you need to this speed VLC system there if there is a transmitter there is a receiver. So, to receive this signal there is a concentrator which capture the signal. So, based on that this refractive index of that particular optical lenses that you are using that value we have been specified here. Because it is like in order to this equation it is multiplied with T psi and the g psi.

These are the optical concentrator and acceptance angle gain. So, in order to calculate this optical concentrator, you require the value of refractive index because it is it follow that particular equation n square divided by sin square psi c. So, this is the practical value 1.46 we have taken for the photo detector concentrator gain. And then this is the gain of lens. Generally, we take this value 1 you can also take any practical value like I have mentioned here 10.

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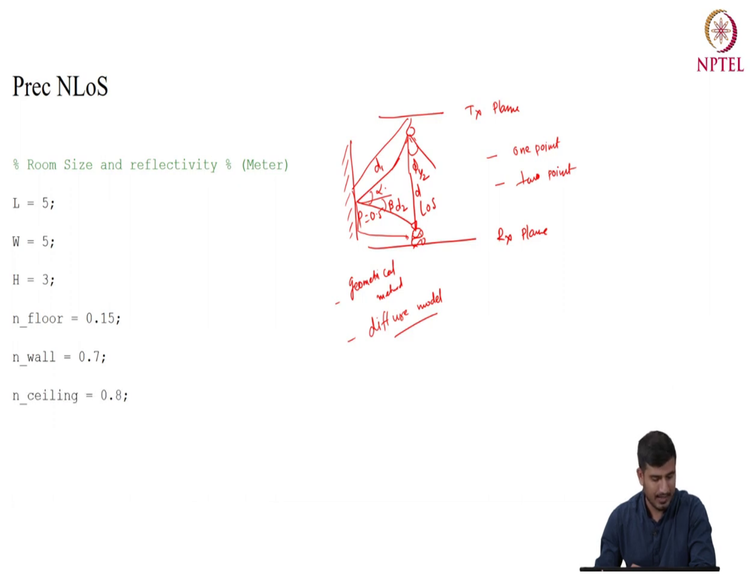

So, as you know this signal from like if this is the transmitter plane the LED is mounted here which is transmitting the power at the LED semi angle phi by 2. And suppose this is the receiver plane and there is a PD here which is receiving the signal.

And if it is the indoor room there will be a wall with some reflectivity suppose of 0.5. [FL] you will receive 2 signal; one will be the line of sight signal and another will be the non-line of sight signal, which is reflecting from the wall with angle suppose alpha and beta.

And suppose this distance is d LOS and this is d 1 and d 2. So, in order to model this non-line of sight channel gain you need to model this reflection. So, this reflection can be 1 point reflection in which the LED first getting reflected 1 point from the wall and received at the PD and it can be of 2 point reflection where light is reflecting from 2 point at the (Refer Time: 05:29) then again receiving at the receiver.

So, for that you can use this geometrical Lambertian geometrical method to model this non-line of sight reflection or you can use that infrared diffused model, where we consider the same reflectivity inside the room [FL] every analysis channel gain have the same value. [FL] so, in two ways you can model this non-line of sight reflection.

So, again you need to give the mathematical input as MATLAB require. So, again this is the room size that we have specified 5 cross 5 of 3 meter. This is the floor reflectivity; this is the reflection can get from the wall 0.7 and this is the reflection that we can get from the ceiling. So, these are the parameters values for the non-line of sight reflection.

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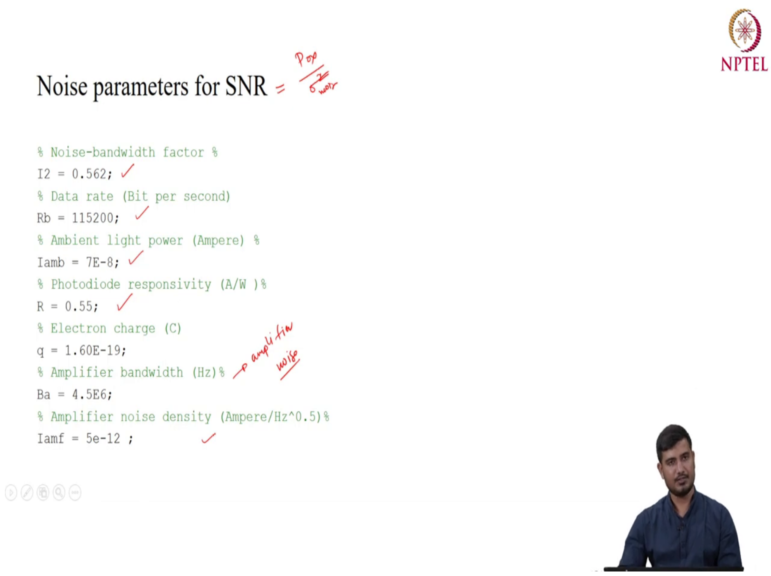

Now, in order to receive calculate this SNR you all with respect to the P receive received power you also required noise variance. So, for that you require this noise parameter as I have mentioned earlier there will be a short noise there will be a thermal noise. So, these are the different factor like this I2 is noise bandwidth factor data rate you are operating on ambient light power because ambient light behave as a noise to the receiver in case of visible light communication system.

Photo-director responsivity in what percentage your light will be converted into electrical signal. Then the electronic charge and the amplifier bandwidth in terms when we are going to include this amplifier noise. So, these all are the practical values you can follow any reference paper or as per your system requirement you can give them as a input to the system and again the amplifier noise in ampere per hertz ok.

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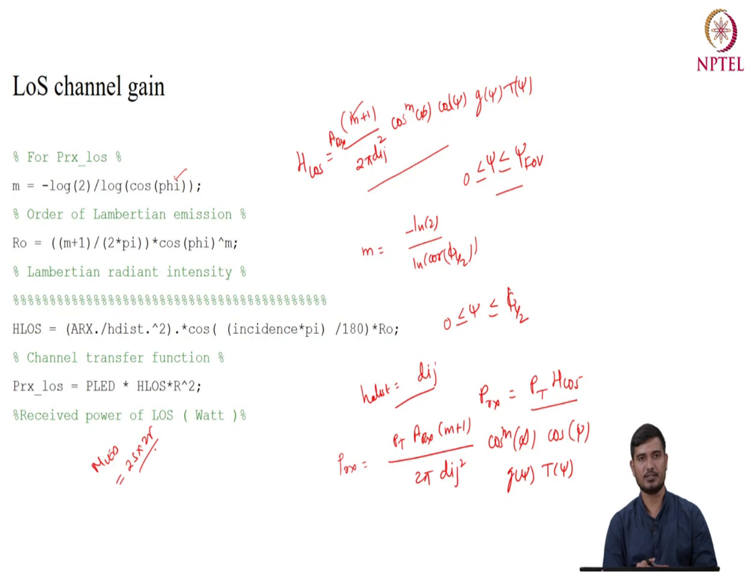

Now, we are going to simulate the line of sight channel gain. So, the first thing as you know line of sight channel gain equation is m plus 1 upon 2 pi dij square cos m phi cos psi PD gain optical PD gain concentrator gain and this psi should be in the range of 0 to field of view of the receiver.

So, the first thing you need to simulate is Lambertian parameter or Lambertian order. So, m is nothing but natural log of 2 divided by natural log of cos of semi angle. So, this is simply we have mentioned here and we have already mentioned the value of phi earlier. So, this phi again is limited within the LED semi angle value. So, this is how you can get the value of m, Lambertian order.

Next will be the now based on this Lambertian model you can calculate the radiation intensity which is nothing but m plus 1 2 pi cos phi m. So, we already know the value of m we have already given the input value of phi. So, now based on this radian intensity we can finally, able to calculate this line of sight channel gain with the receiver area of ARX.

Again, this h distance as I have shown you earlier this h distance is equal to your dij. So, this is how you are able to get simulate this particular line of sight equation. So, based on that if you have this line of sight channel gain value so, in VLC your received power is nothing but transmitted power multiply with line of sight channel gain.

And we have also already specified this transmitter or LED power earlier to the power R square. So, this is how so, if I write complete equation here [FL] it will be P T A R X m plus 1 upon 2 pi dij square cos m phi cos psi multiply with g psi and T psi. So, now you are able to so, this particular vector P received line of sight will give you the line of sight channel gain value.

And the order of this vector will depend on the number of LED as well as how you have divided your receiver floor how many number of grids like in our case we are going to divide into 25 cross 25 sub grids.

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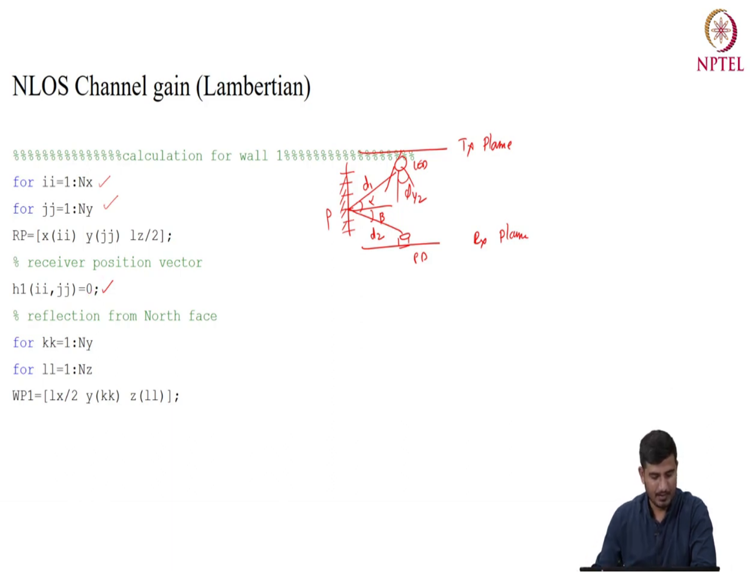

Now, we earlier we have calculated this line of sight channel gain. Now, we are going to calculate non-linear sight channel gain with the help of Lambertian model. So, Lambertian model as I have shown you earlier if this is the transmitter plane and this is the receiver plane.

And if this is the wall and you are you have this PD the LED is mounted here which is transmitting with the again semi angle value of phi by 2. So, the received signal will be from non-linear sight will be like this. It is taking the distance d 1 from LED to the reflection point of the wall and to receive the PD it is taking distance d 2 and this is the incidence angle to the wall alpha.

And if this is the angle of incidence or reflection which is making with respect to the PD is beta. So, now you are going to give these input values d 1, d 2, alpha and beta. So, how we can do it? So, again I have shown you earlier the like you have divided to cover the whole room you need to divide the room into number of grids and you will calculate the power at each grid.

So, you require the distance of LED to the each grid. Similarly, in order to get the reflection from the whole wall you need to divide this wall into the number of grids. And from each grid you will calculate these distances d 1 and d 2 and find out the value of alpha and beta. So, for the same you can run a loop which is ranging from Nx to Ny, Nx and Ny are the number of grids that you are dividing.

And this is the receiver position we have specify here which will vary in x and y coordinate and remain constant in z coordinate and based on that receiver position. So, first to store the value we have specify a vector h1 which will store the value of non-line of sight reflection gain from each grid.

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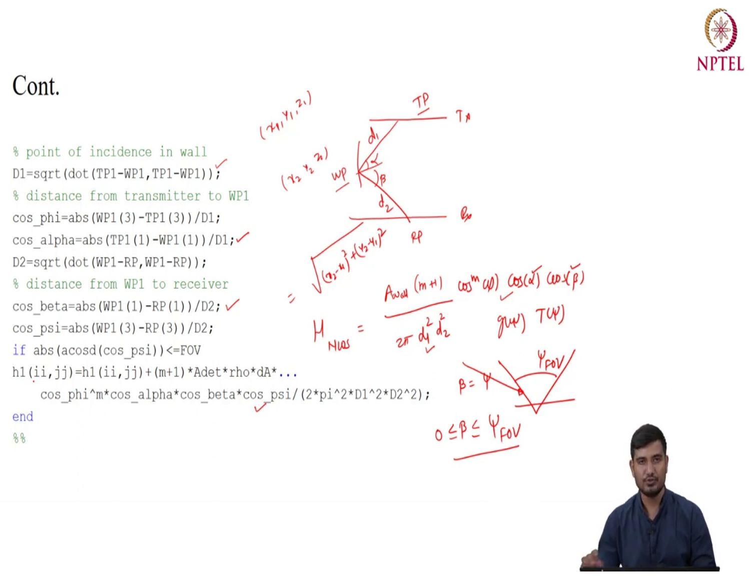

So, this is how you can calculate this distance D1. So, D1 will be nothing but a distance from transmitter to the receiver plane that light has taken. So, this is how we have (Refer Time: 13:50) So, for in order to calculate these distances d 1, d 2 and these angle alpha and beta what you required you required the transmitter position, you required the wall position vector or you can say the coordinate and you required the receiver position. So, receiver position we have already specified earlier.

So, based on this transmitter position vector and wall position vector you can calculate this respective distance. So, these are nothing but distance that we calculate with the help of Pythagoras [FL] like the if two coordinate like one point at x 1, y 1 and z 1 and another one at x 2, y 2 and z 2.

So, then the orthogonal or the minimum distance between them can be calculated as x 2 minus x 1 [FL] whole square plus y 2 minus y 1 [FL] whole square. So, the similar method we have approached here in order to calculate those distances d 1.

Now, based on those distances you are going to calculate these respective value alpha and beta. Because if I if you have gone through this non-line sight channel gain equation it is defined as area of the wall sorry, the area of the point from your. So, from where your light signal is getting reflected multiply with m plus 1 divided by 2 pi d 1 square d 2 square cos m phi cos alpha cos beta and g psi T psi.

So, now in order to simulate the non-line of sight channel gain with respect to the line of sight channel gain you required two distances d 1 and d 2 square and you required two angles alpha and beta and this beta is equalize the reflection angle psi. So, again this your beta should be lie within the field of view of the receiver in order to perfectly convert your optical signal into a electrical signal.

If any of your signal lies outer that field of view of the receiver if this is the field of view receiver. If any signal lie outside this it will not be able to convert into any electrical signal. So, this is how we have calculated distance d 1 d 2 and the respective angle alpha and beta.

And based on this like you can see here we are able to calculate this alpha we also able to calculate this angle beta and based on that. So, this is the simple channel gain equation I have written here which I have written here.

So, here will be the m plus 1. So, so, we have already specify this vector which are going to stored these non-line of sight channel gain value at these. So, what will happen the loop will run for the number of grids in each grid what will be the channel gain value will be stored in this particular vector h1. So, this is how we simulate non-line of sight channel gain if we are following this Lambertian order model. So, there are other model exist like diffuse channel model.

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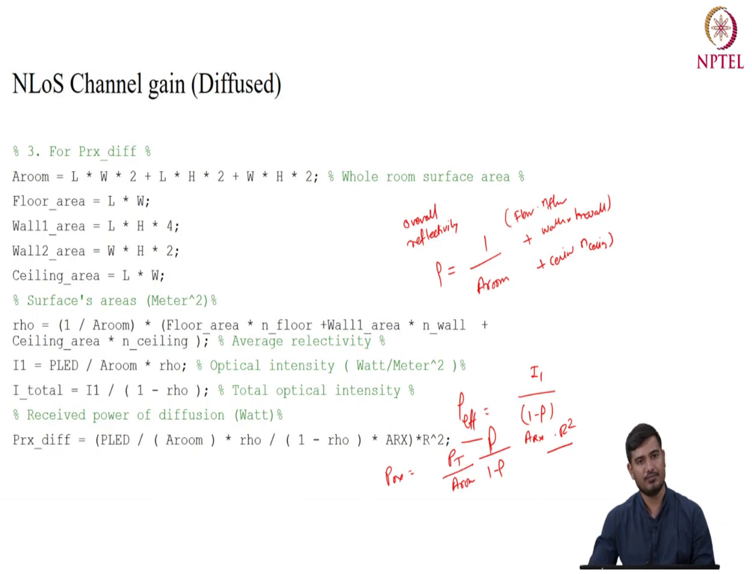

Non-line of sight channel gain as a diffuse. So, in this case we considered the non-line of sight gain with the equal reflectance from each wall. So, for that you required this. So, the room dimension of suppose has length L and has width W and height of H. So, based on that floor area, wall area and ceiling area you can calculate the overall channel gain.

So, if you can see here the diffuse channel gain you calculate first the overall reflectivity. So, which is nothing but rho equals to 1 divided by area of the room multiply with the floor area into n reflectance from the floor plus wall area reflectance of the n wall plus ceiling area and their respective reflection coefficient.

So, based on that your overall effective reflectivity will be nothing but I 1 which is the channel gain or you can say the illumination intensity divided by 1 minus rho. So, this is so, in diffuse we do not consider instant reflectivity we consider overall reflectivity. So, this model generally used in infrared communication we can also use it for a visible light communication as well.

So, so, as you shown if you have a mathematical expression available with you can use other different model also like two-point reflection model, one-point reflection model or this diffuse channel model respectively. So, again if you have this overall reflectivity available so, your received power will nothing would be the transmit power divided by the room area multiply with rho 1 minus rho. And again, you need to multiply with the area of the room and the respective distance is square.

So, this is how so, what is the benefit with the VLC channel modulation is it is not random in nature. It simply follow that particular mathematical equation or you can say it is it can be random if your if you introduce human blockages inside it then this distances will become the function of human blockages location. But if you have equation available with you can easily give them as a input and you can calculate the respective values.

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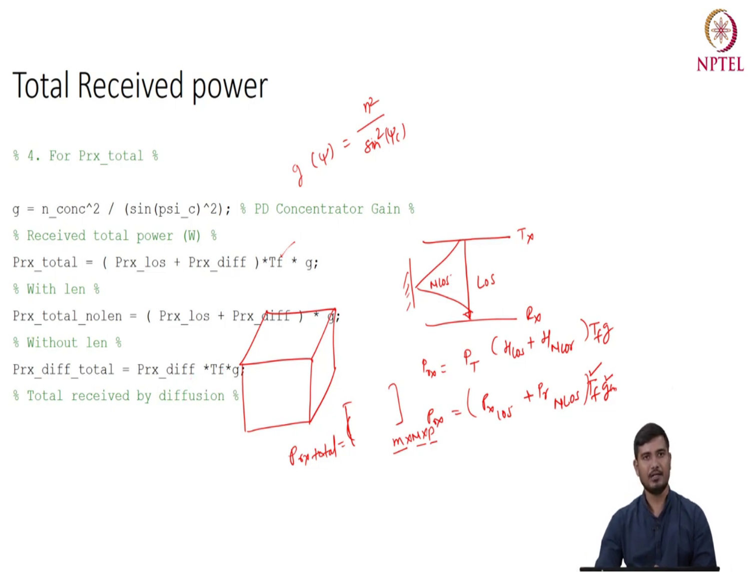

Now, so, based on that now you can calculate the received power so, again as I mentioned earlier this this will be the PD concentrator gain g psi which is defined as n square sin square field of view of the receiver. We have already defined the reflectivity of the medium and the field of view of the receiver. So, based on that now as I have shown you earlier the transmitter plane in VLC the receiver plane the total power will be sum of line of sight channel gain and the non-line of sight channel gain.

So, your total power P received will be transmitted power multiply with H LOS plus H NLOS multiply with respect to PD gains. And if you multiply PD inside it this will simply P received because of line of sight path plus p received with the with non-line of sight path multiply with T f and g and we have already defined the value of T f and the g psi.

So, this is how you can get the total received power and as you know we have considered a 3D room here. So, your output P received total will be of will be a 3-dimensional vector. So, you will get a matrix which will be of order of m cross n cross p. So, these value of m, n and p divide depends on the number of grids that you have considered inside the room.

So, again you can consider you can plot the received power value with lens where you can use this lens gain or you can plot it without lens also. So, just to compare the received power how it looks like with lens and without lens. Obviously, this without lens will be the worst one and with lens you can get the improved power or improved received power.

And this will be the with the diffusion with the with the diffusion because in the diffusion you are considering both line of sight and non-line of sight as a common factor or the common reflectivity. So, it will simply the P received diffuse multiply with the respective lens gain.

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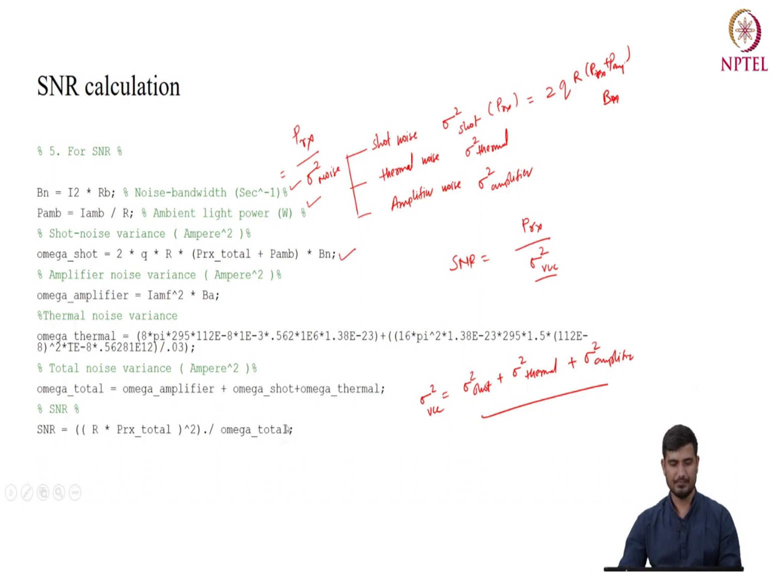

Now, in order to do the SNR calculation, we are already calculated received power. Now, we required the noise variance. Now, this noise variance has three parts, three types of noise there. Short noise as I have mentioned earlier. Thermal noise and the amplifier noise. Now, in order to simulate in MATLAB what you required? You required mathematical expression of short noise which is again in case of indoor VLC system it is a function of received power and then the thermal noise and the amplifier noise.

So, one we have already defined the all the noise parameter what we are going to do here we are going to simply write their respective equation and we have given the input of their parameters. So, we can get the value in vector form like we have define this noise bandwidth I2 into Rb where, Rb is the data rate.

And then the ambient light power which is the ratio of a ambient light intensity divided by the R radius of the room and then the short noise simply if you know it defined as 2q R responsivity into the P received plus P ambient multiply with noise bandwidth Bn.

So, we have simply written the equation of the short noise. So, you will get a vector omega short which will represent your short noise and then the amplifier noise which is nothing but I amplifier square into divided by the amplifier bandwidth. So, this is the amplifier bandwidth we have already defined it then the thermal noise variance.

So, this long expression you can see in any book. So, you can simply write that particular expression and define every variable that here you need to define it first and based on that you can get the total noise.

So, this sigma square VLC will be the sigma square short plus sigma square thermal plus sigma square amplifier. So, now you are you have calculated this total noise power as well. So, now you can easily calculate the SNR which is nothing but the P received divided by sigma square VLC. So, as I have shown as I have said your SNR will be the function of received power divided by the total noise.

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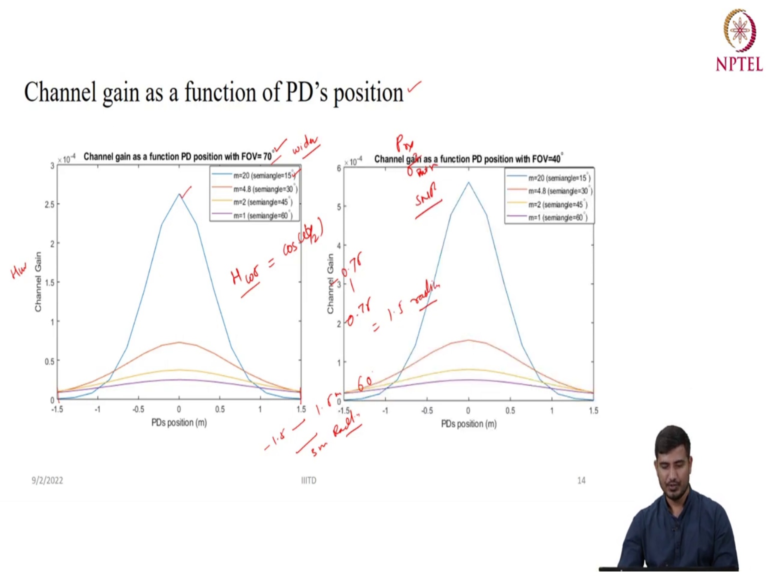

Now, as we have mathematically simulated all the parameters which required in VLC like received power noise variance and the SNR. Now, one by one we are going to plot it and we are going to see how by changing the different parameter these parameters varies. So, first we are going to study channel gain as a function of PD position. So, you can see here we have plotted this H LOS, H LOS you can refer in previous slides. So, you can see here these are the PD position from 0 to 1.5 to minus 1.5 and this is the channel gain H LOS.

So, you can see here by varying the LED semi angle value your channel gain varies and as you know it is a function of cos of LED semi angle. So, as cos function value maximized for the smaller value of angle and it minimizes for the larger angle of values. You can say for LED semi angle value of 15 degree the channel gain is maximum or you can say the it is of increased value. But and as you increase the value from 15 to 30 the channel gain value reduces.

So, this is the variation like your maximum channel gain value start decreasing if you start increasing the LED semi angle value. But with increase in LED semi angle value your channel gain value reduces, but the distance that it covers it increases. So, it means there is a trade-off wider LED semi angle value will cover the more distance you can see here it will able to cover you can say minus 1.5 to 1.5.

So, effectively you can see it can cover 3 meter radius with the angle of 60 degree. But you can, but if you see for 15 degree value it is only able to cover from minus 0.75 to plus 0.75 or you can say the effective value of 1.5 radius. So, you can see there is a trade-off wider LED semi angle value give you the lower channel gain with the larger coverage and smaller LED semi angle value give you the lower coverage with the maximize channel gain.

So, you can itself by changing the value of these LED semi angle you can plot this and again the receiver parameter like field of view we have considered as a 70 degree. So, it is a wider PD that we have considered here. Now, again you can see the variation by changing the field of view also. So, this is so, here if I remove this you can see here, we have plotted here is a again the channel gain, but for the smaller field of view.

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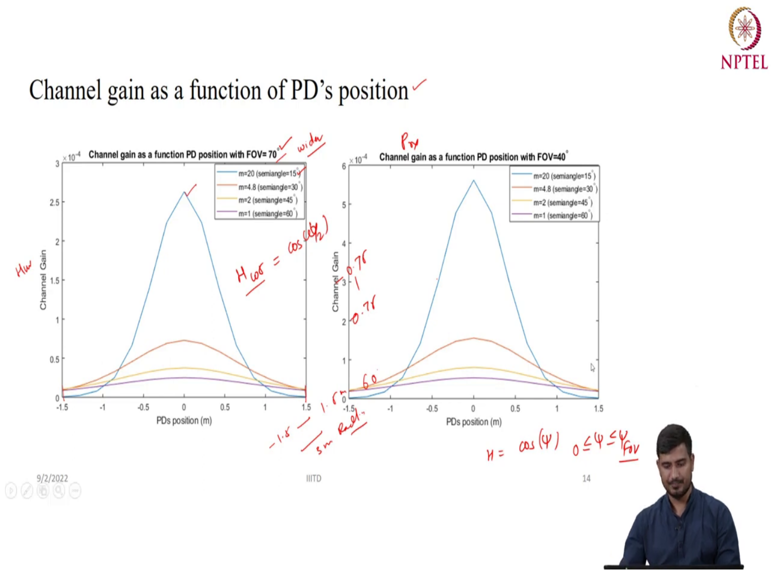

So, again you can refer to the equation your channel gain is also a function of incidence angle psi and again it is a function of cos where psi is limited between the field of view of the receiver. So, again smaller the field of view larger will be the gain, but the distances you cover will be less and the wider the channel gain you can cover more distances, but with the smaller channel gain.

So, this is how you can play with your LED semi angle and field of view of the receiver and you can analyze for different configuration and you can use for your as per application.

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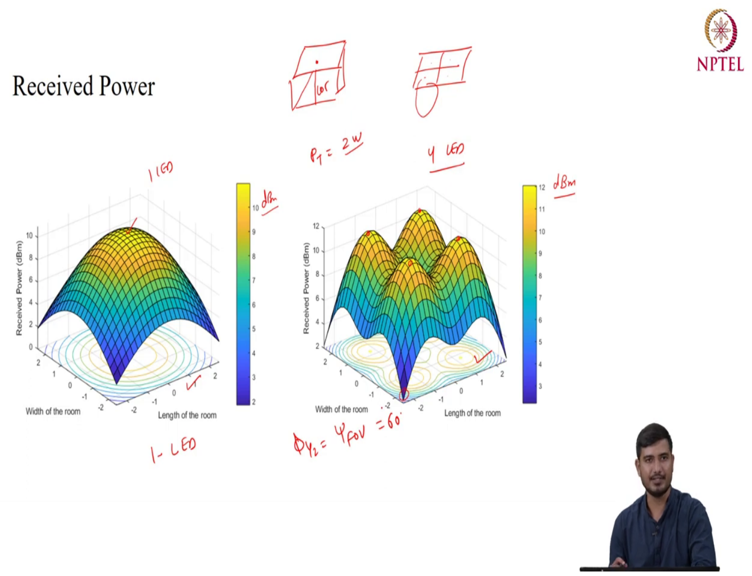

Now, now we are going to plot the 3D received power profile. So, this is with. So, this is the received power profile with one LED. It means in this case the LED is mounted on the center of the room.

So, you can see here the maximum power is at the exactly below the where, the LED is placed which is this which is 10 dbm the maximum power that we are getting and as we are going towards the edge of the room as the distance vector will be increasing like this will be the minimum distance which is which is exactly the line of sight. And as we go towards the edge of the room the distance increases so, the received power starts decreasing.

So, this is with the when your LED is mounted on exactly center of the room this is how your you can say the received power looks like and if we go for the suppose we want to plot this for 4 LED configuration where this like your LED is mounted in rectangular configuration as we have mentioned earlier. [FL] however, received power will look like it will be like this.

So, the received power will be maximum exactly where LEDs are deployed and again start decreasing as the distance increases. So, there will be a so, you can consider like it is symmetric in nature. So, it is simply the one LED configuration for this each sub coordinate and it is a overlap. So, and this and the area where they are overlapping it will be a improved performance.

So, again at the corner of the room the power is minimum and the LED where it installed it is will be the maximum. So, again for the simulation of this the total power we have considered of 2 watt, which is constant this is the 1 LED configuration and this is the 4 LED configuration and you can see you have improved in received power.

So, in this case the maximum power that we are able to receive is 10 dBm while here we are able to receive the power value of 12 dBm. So, again this is for the LED semi angle value and the field of view value of 60 degree both these profile. 1 LED and 4 LED you can plot it with different LED semi angle configuration you can see the variation.

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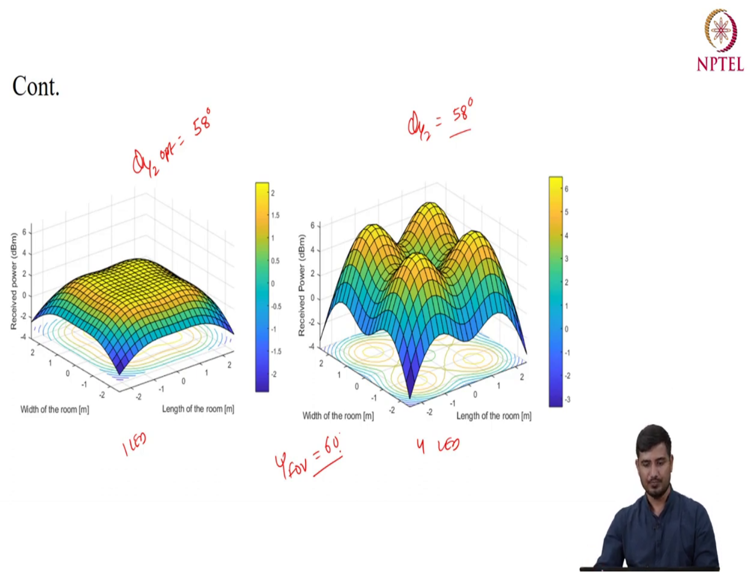

Like in our work we have tried to plot this with improved LED semi angle value or you can say the optimized Lambertian order. So, this is the 1 LED configuration with phi optimized as 58 degree and again this is with the 4 LED configuration with again phi LED optimized as 58 degree. So, this is the standard value that we have calculated you can also calculate this optimum led semi angle value as per your configuration and see the received power profile.

So, you can see this is the received power is more uniform in nature with respect to the other power profile that we have calculated and the again the field of view we have kept constant as 60 degree. So, you can see these variation which with yourself also by changing these value.

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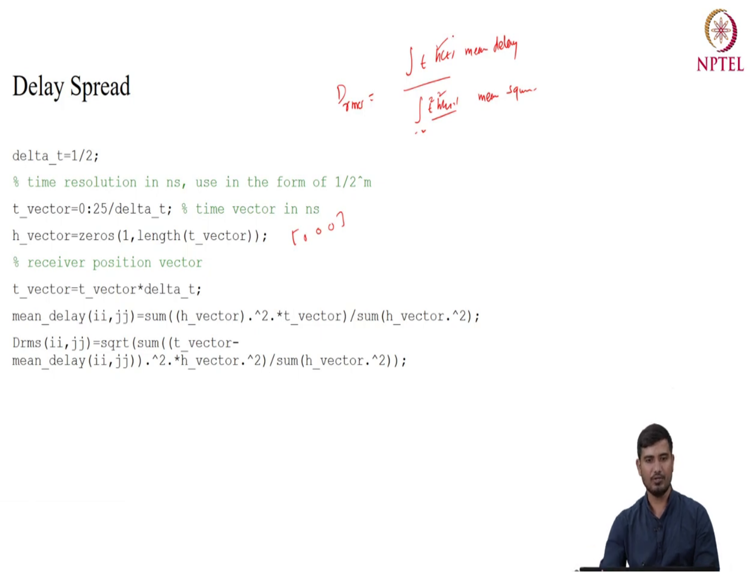

Now, as we have calculated this received power profile so, with the help of this received power profile you can also analyze the delay spread performance of the system. So, the delay spread actually the function of your received channel again only. So, as we generally know we define or characterize our delay spread with the RMS delay spread and which is nothing but t h t divided by the minus infinity to plus infinity h square t or you can say the average.

So, here in order to calculate the RMS delay spread you are going to require this channel gain which we have already calculated with the help of line of sight simulation model and the non line of sight simulation model. So, you can use those channel gain value here and plot this delay spread as well. So, for that first you need to define this time resolution in nanosecond because for what time instant that you are going to analyze your system and then based on that you can get the time vector in nanosecond.

So, here we have taken the time resolution value of 1 by 2 or you can see the 0.5 and based on that first you define this h vector which is. Firstly, it is a vector of 0 value and as you run the loop because for the delay spread analysis you need to consider all the channel gain values and so, that in each iteration that this vector value will be added here.

So, this is the t vector and this is the mean delay spread because you are going to divided this mean delay spread divided by the mean square delay spread and based on that you can get this RMS delay spread. So, this is nothing but a simple delay spread expression that we have written here this will be the mean delay spread mean delay and this is the mean square RMS delay spread. So, based on that now you have this delay spread again it will be a 3-dimensional vector because your channel gain is a 3-dimensional vector so, based on that you can also plot this delay spread.

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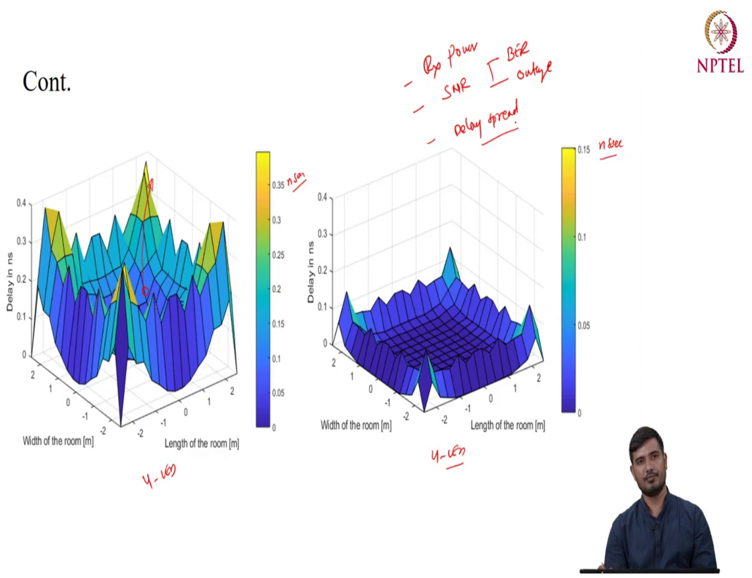

So, you can see here for different LED semi angle we have plotted this delay spread. So, the maximum value of delay spread that we are getting is 0.35 nanosecond and as we have optimizes LED semi angle we have reduces delay spread from 0.35 to 0.15 nanosecond. So, this is again for 4 LED configuration this is also for 4 LED configuration.

So, as we know the delay spread is a function of channel delay profile or the channel gain as the distance from the LED to the so, detector increases the delay spread will also increase. So, you can see at the center of the room unlike received power profile the delay spread is minimum and at the corner of the room unlike received power profile the delay spread is maximum while received power is minimum.

So, there is a trade off invisible light communication at the center of the room or exactly below the LED you will get the received power profile maximum, but the delay spread will be minimum because channel will take less time to travel to the PD and at the edge of the room the received power profile will be minimum and the delay spread will be maximum.

So, this is how we can characterize our indoor VLC system with the help of MATLAB where, we can calculate this received power and based on the received power you can calculate the signal to noise ratio, which will help you in plotting the bit error rate or the outage probabilities.

And based on that you can also study the delay spread analysis, which will help full in order to analyze your interference system or inter symbol interference. So, in this lecture we have studied how we can simulate this indoor VLC channel model with the help of MATLAB.

Thank you.