Optical Wireless Communications for Beyond 5G Networks and IoT
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Lecture - 42
Simulation exercise on VLC Advance Modulation Schemes

Hello everyone. I am Dilnashin Anwar, Pursuing PhD from triple IT, Delhi. Today, I am going to give you an overview of how to Simulate visible light communication advanced modulation schemes such as colour shift keying and optical OFDM in MATLAB.

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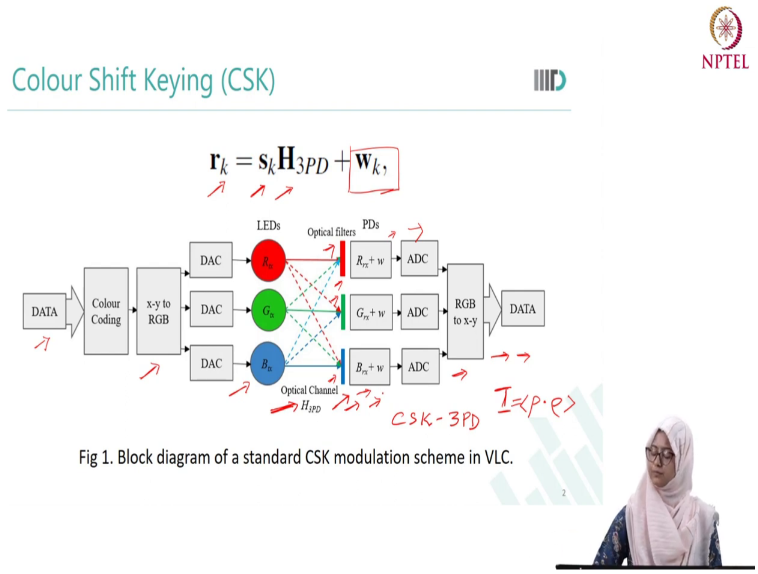

You must be knowing from previous lecture videos on colour shift keying that power envelop of the transmitted signal is fixed. Therefore, colour shift keying reduces the potential for human health complications related to fluctuations in light intensity. Further, CSK maps bits into symbols. Therefore, it gives double the data rate then on off keying. This is the block diagram of a standard CSK modulation scheme in visible light communication.

So, at first, we get the data in the bits and this block diagram is actually has been taken from the physical layer 3 of the IEEE 802.15.7 standard. So, at first the data in bits are being converted to symbols, and then from that symbols they are being colour coded. In the next few slides, I will be explaining how to do this colour coding.

And, then these colour coded data is being converted to RGB optical power intensities which is then converted to analogue because we have the digital data and then it is being fed to the different red, green and blue LEDs. The mixture of red, green and blue light generated from RGB LED source gets corrupted by the optical channel and you already have idea about the optical channel. After that it is being received at the receiver and as a receiver there are three PDs.

So, often this conventional and you can say standard CSK is named as CSK 3 PD. So, we have 3 PD at the receiver and it receives the mixed optical signal. Each PD have red, green and blue light filters. You can see here in front of all the PDs. So, the mixture of light is being filtered, the red filter filters the red light and it is being received at this PD.

So, from previous simulation exercise on ON – OFF keying VLC, you must be having an idea of received signal. So, this is the received signal and then this is the transmitted symbols. It is being corrupted by the VLC channel and then noise in being added to this received signal and this noise is the additive void Gaussian noise. And, we already know that PD, there are two types of noise in PD, short noise and thermal noise and both the process is being jointly approximated as additive void Gaussian noise.

After that the data is being converted from analogue to digital and then the same thing which we did at the transmitter side that is from x-y colour coordinates to RGB optical power intensity. We are converting it from RGB optical power intensity to x-y chromaticity coordinates. After that we have received the symbol and then we will get the bits. So, the basic idea of the any modulation scheme is very much required to simulate it in any of the platform.

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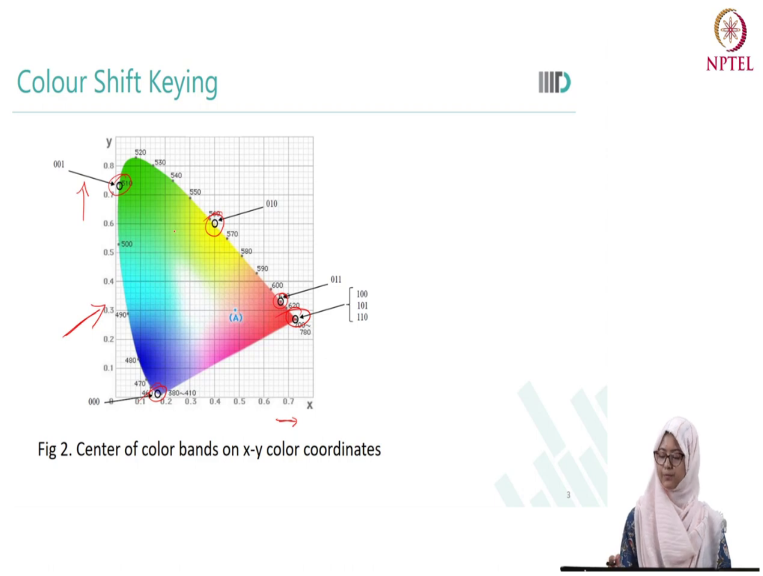

So, as stated after colour coding the mapping from x-y colour coordinates to RGB intensity is there. So, what is the those x-y colour coordinates? From figure 2 you can see the center of colour bands on x-y colour coordinates. So, you can see that there are few bands, which has been considered to design the constellation of colour shift keying.

This is the CIE-1931 chromaticity colour diagram and you can see there is x coordinate, y coordinate and the symbols are being coded in terms of x-y chromaticity coordinates. Here you can see blue, here it is red, and green. There other bands also which has been considered for designing the constellation of standard or you can say conventional colour shift keying.

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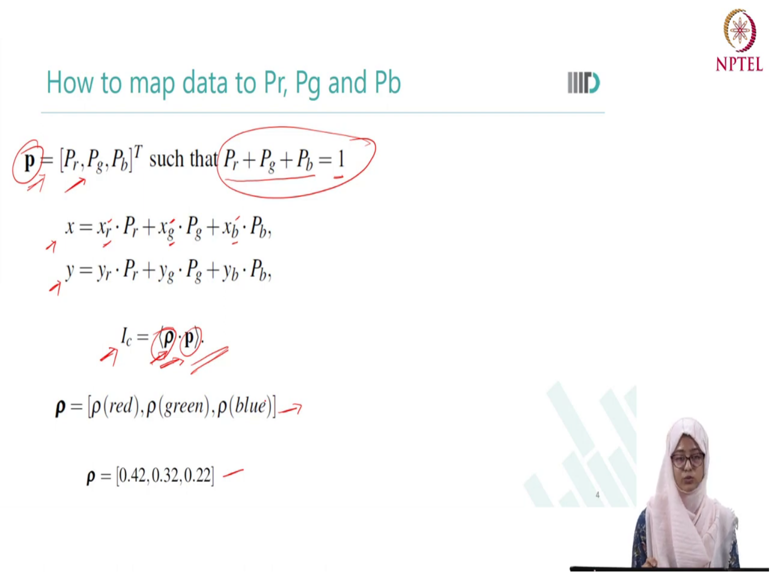

So, the first and foremost question comes how to map data to the optical power intensity? We are going to name it P r, P g and P b which corresponds to the optical power intensity of red, green and blue LEDs. So, it is somewhat easy to convert from bits to data, but how to do these colour codings and before converting those x-y chromaticity coordinates we need to do the colour coding as well.

For that we have literature available and we can take the mapping from there. So, we have colour band combinations available. I will be talking about that in next slide. So, we have P r, P g, P b that is actually being written in the form of a vector such that that this P r plus P g plus P b is equal to 1. So, again, keeping in mind which I have just said that CSK has a constraint of keeping total optical power constant so, that is why this terms will come.

So, in the previous slide we have just discussed about the x-y chromaticity coordinate and this x r, x g and x b are the x central chromaticity coordinate for red colour or you can say red wavelength of light then green and then blue. At the receiver side, if I go to the previous slide, however, at the PD side when the PD receives it, it has a responsibility particular to a wavelength of light and the PD gives the data in form of power into responsibility. So, that is why at the receiver side generally current is being considered.

So, we have a relation between the central chromaticity coordinates of red, green and blue band and the optical power intensities that are P r, P g and P b. This I have just discussed. Now, this rho is the responsibility of the PD to particular wavelength of light. So, in case of CSK, we have three LEDs; we have red, green and blue and PD will have different response to different wavelength of light. That is why this rho will also be in the form of a vector.

And, the dot product of this vector, the rho responsibility and the P which is the optical power intensity. This is what we are going to finally, obtain to modulate or you can say to simulate CSK in MATLAB to get this current, ok. So, this is the rho we are getting and this vector value has been obtained from the response curve of a practical PD, PD-36A2 from Thorlabs. So, you can refer to that. So, for our simulation, we will be considering these values ok.

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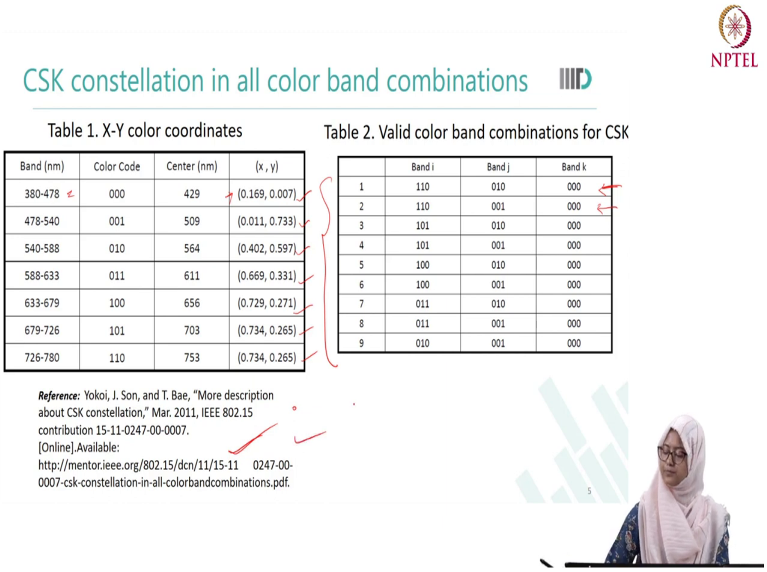

The authors as shown in the reference have considered X-Y colour coordinates based on different colour bands which were shown in figure 2 as discussed previously and based on that, they have taken valid colour band combinations.

So, these are the valid colour band combinations and these are the bands considered which we just saw in the chromaticity diagram which were being circled. So, we can see the x-y chromaticity colour coordinates in table 1. So, different band have different coordinates and then the combination of these bands have been considered to design the constellations for CSK.

The authors have contributed this work to the project titled IEEE P802.15 working group for wireless personal area networks and you can refer this as well. Here they have shown all the colour band combinations and the constellation points. I am going to show few of them here.

So, this is the colour band combination type 1; that is why it is being called as in short CBC 1. In the chromaticity diagram, we can see where the central chromaticity coordinates of all the bands fall. So, we can see here for that it is this, for that it is this and for 010 band j it is this.

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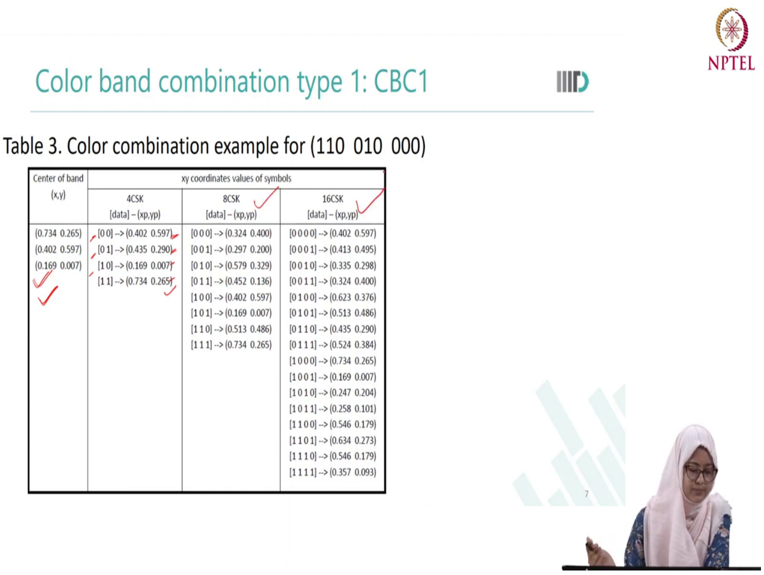

So, if you just go to the previous to previous slide, we are considering this CBC 1 and then we will be considering this CBC 2. For simulation we will be considering this CBC 2. So, you can match it from here as well, ok. So, from that we have got this colour combination example for 110, 010 and 000 colour band.

Here you can see the center of band is being provided by those authors and that is that has this work has already been standardized and has been accepted for designing the designing the CSK constellation symbols. So, you can see for different data or you can say for different symbol 0001, 1011, we have got the chromaticity coordinates and we are interested we have we are interested in these values and we are interested in these values as well. Because again reminding we need to find the values of P r, P g and P b. Here we can see it has been designed for 8 CSK and 16 CSK as well.

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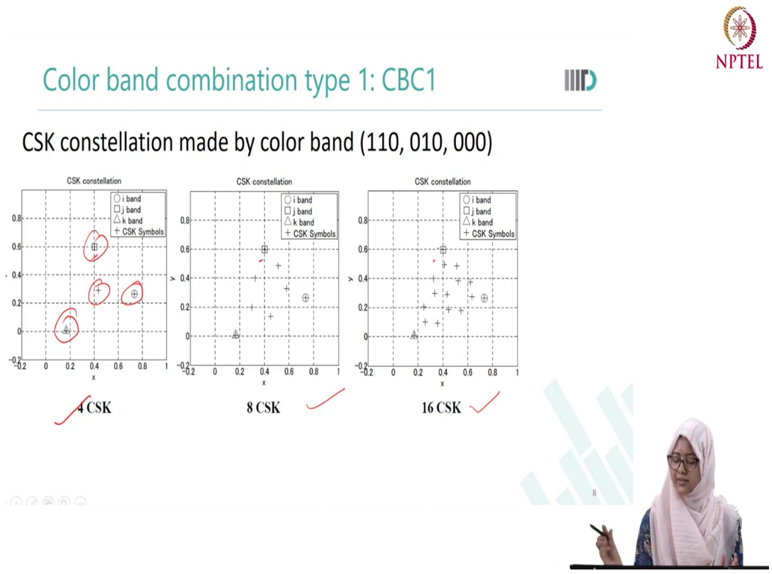

So, you can see from that what all CSK constellation points one is getting from CBC 1. So, from CBC 1 you can see just to give an overview that for 4 CSK we are getting these four constellation points. So, these plus mark is for the CSK symbol and then for 8 CSK also and for 16 CSK also.

So, it has been observed that these CSK symbols at least three of them take the values or you can say the chromaticity coordinate values of the bands, which is being considered to design the CSK constellation symbols. It can be observed here also in 8 CSK also in 16 CSK.

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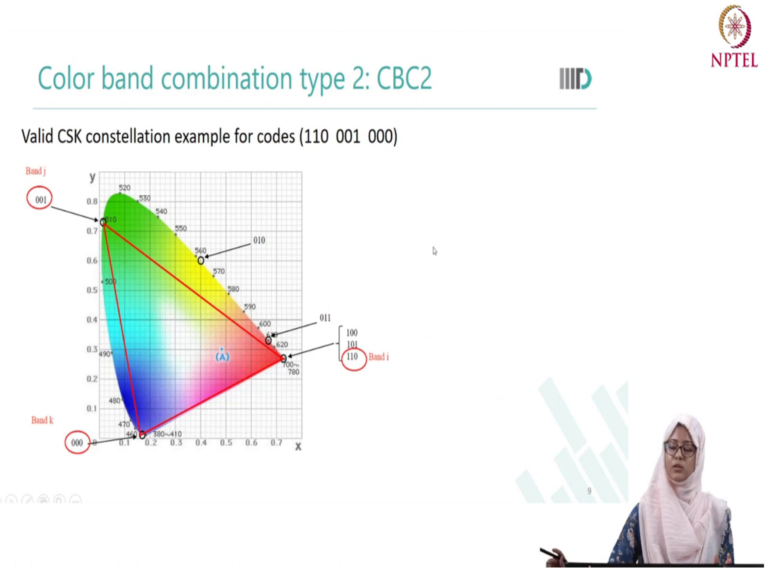

Now, coming to the CBC 2 type, just to give an overview we are going ahead with the CBC 2 for the simulation. Here we have band i, this is the band k and then band j. So, these three bands have been considered to design the constellation using CBC 2.

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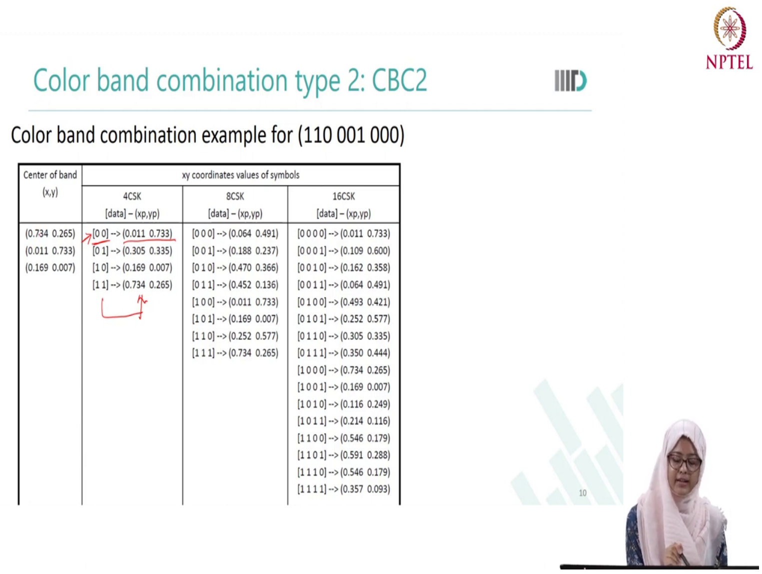

From this also we are getting the mapping from data to x-y colour coordinates. So, this is how we are going to map if we are going to consider 00 data for 4CSK based on CBC2 type constellation. Then for 00, the x-y colour coordinates will be considered this and the central chromaticity coordinates for red, green and blue should be considered this.

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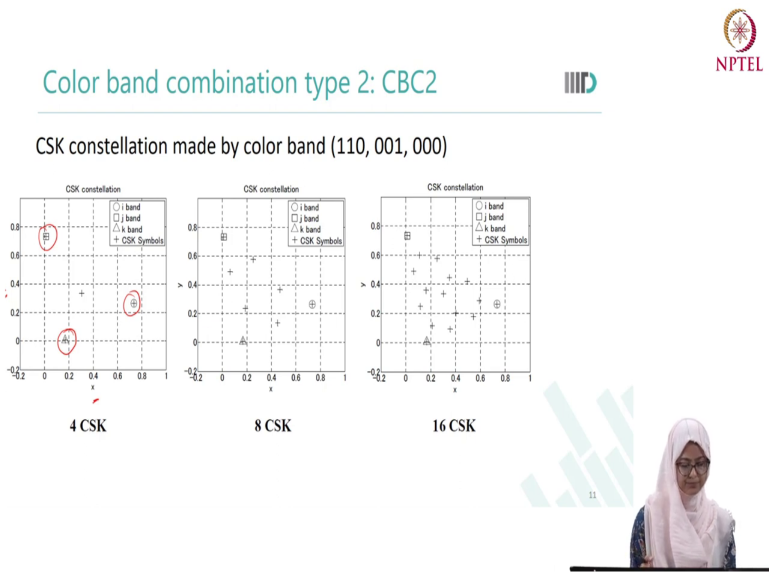

Again we can see the constellation points. However, you can observe the difference from CBC1 and CBC2. So, the constellation points we are getting a bit different from what we generated from CBC1. But these are based on the x-y colour chromaticity coordinates and we need to convert it into P r, P g, P b, in order to simulate and find various simulation exercises.

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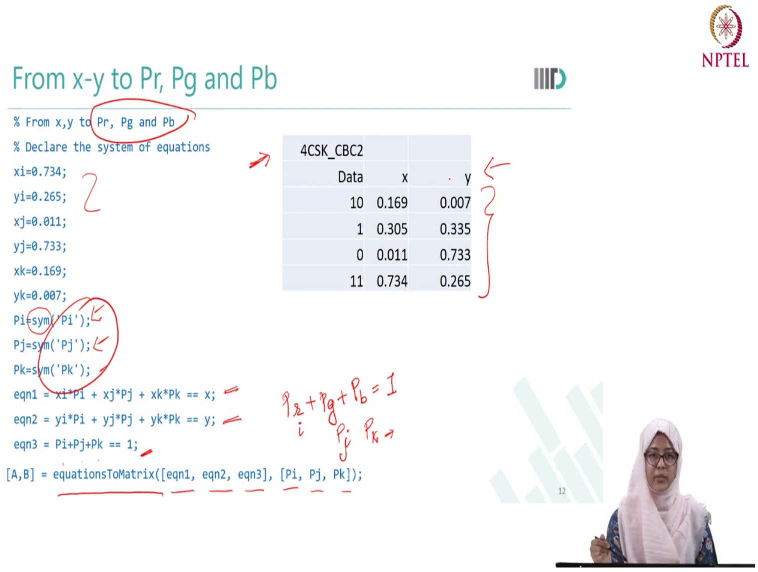

So, now it is clear that from bits to symbol one can do, after that from symbol to colour code that is from symbols 00 to x-y chromaticity coordinates can be done as discussed. Now, we have got those values x-y values from that we need to find the values of P r, P g, P b. So, here we can see that you can take let say we have considered CBC 2.

So, in CBC 2 we have these all values. So, from CBC 2 referring to that CSK constellation standard work, we have considered these values and then we have we need to consider this Pi, Pj and Pk as unknown variables. And, with the help of same function in MATLAB we are making these Pi, Pj and Pk as unknown variables. And based on the equations as discussed earlier we had two equations for x and y.

Another one is the power constraint for CSK. So, for that already discussed Pi plus Pj or Pk or you can say Pr plus Pj, Pr plus Pg plus Pb should be equal to 1. So, here instead of r just for the coding we are doing it Pr, Pj and Pk and also this naming matches with the CBC paper work.

So, here we have three equations and we have three unknowns, these three unknowns or you can say these three unknowns. Then we can find it using MATLAB using Lin-Sol you can find it. But before that you need to convert that equations to matrix form in a solvable form. So, we are having all these equations and then all the unknowns.

Just to remind you that for the simulation you need to save the values of this CBC 2 in an excel sheet. So, you just save this values let say data and its corresponding x-y colour chromaticity coordinates in an excel sheet you can name it as you wish we have named it 4 CSK CBC 2.

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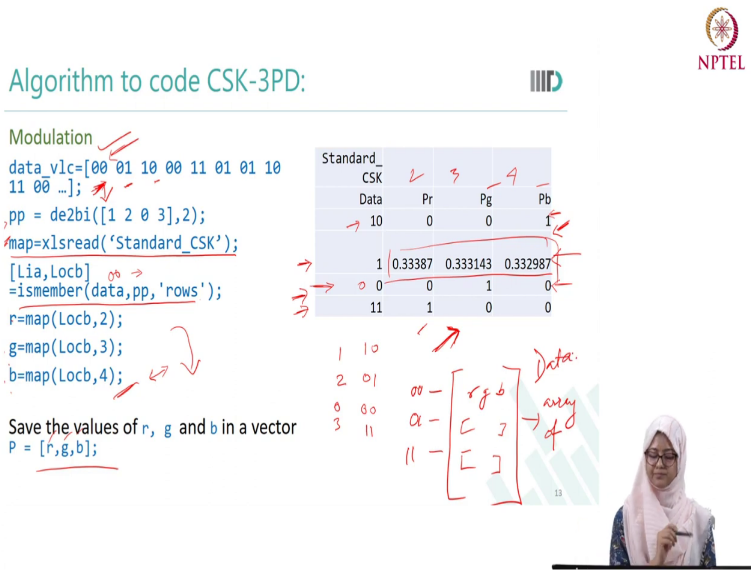

Now, before that the whole explanation was actually the constellation. How to get the constellation points of CSK because it was an available easily and this CSK is an advanced modulation technique of visible light communication. Therefore, one needs to develop these or you can say design these constellation points.

Now, coming to the modulation part, in every modulation part at first pertaining to signals and systems we need to generate data. So, we have generated data and that data bits are being converted to symbols. So, you can see here it is being converted to symbols. So, you can use reshape function in MATLAB to shape your data as according to the need ok.

So, here this is the part where in an excel sheet or whatever you wish you can even store in a MATLAB command, but it is always better to save it and call it later on because maybe if you just want and wish to have different types of CSK modulation schemes and work on different CSK, which I will be discussing in the advanced work.

So, the Pr Pg Pb from CBC 2 what we have got we have got this and from the constellation points also we were like seeing that ok for one symbol it was focusing on one chromaticity coordinate. It was lying on the same x-y chromaticity coordinate of you can say either blue or green and then red and then there was one in between. So, from that we have got the Pr, P g, P b values and then from that we are saving it.

Now, what we actually want? We want to take each symbol at a time and then modulate it. So, let say we are considering 00 we have considered and we want to see for 00 what a value will be there in the standard CSK or what value will be there for Pr, Pg and Pb. So, we have already saved these values in standard CSK excel sheet.

We are reading it in math and then one vector we are defining, but this Pb is actually defining the decimal to binary conversion and as per this data. So, this 1, 2, 0, 3 is nothing it is an representation of 10, 01, 00 and 11.

So, why do we need that? So, that we can locate the row of Pr, Pg, Pb or you can say we can locate the row of the symbol which is being sent by the transmitter at that point of time. So, from this we can find that whatever data 00 we are sending and to what row it is going to match and from that we see that ok it is going to match at the third row. And, for Pr, Pg and Pb we know it belongs to second row, third row and fourth row in the math, ok.

So, from that we have finally, got our r, g, b optical power intensities of RGB. So, here we are actually assuming that the DAC and the electrical to optical power conversion has been done and it does not impact much. So, we are directly considering these to be the optical power intensities. However, for many of the work you may consider it as electrical power as well, but as of now for simplicity we have considered it to be optical power intensity.

So, you need to save the values of r, g, b in a vector form because for r, g, b we have different responsivity. So, the data will be modulated in a vector form. So, let say for 00 the data whatever you got r, g, b then 01 you got something else in a vector form for 11 let say you got something else and that is how you are going to build your array of data, ok.

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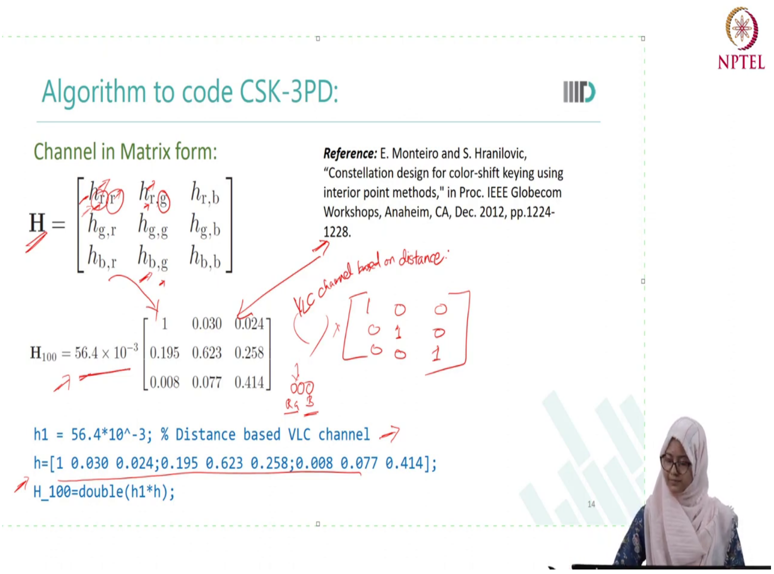

Yeah, one interesting part for CSK-3PD is that the channel gain is not just in a single form, it has to be in a matrix form. The CSK channel gain matrix termed as H you can name it anything, but it is a combination of 3 IMDD channels intensity modulation direct detection channels. Each element of H depicts the gain between the i-th LED and the j-th PD. So, this H represents the optical channel gain from r-th LED to the r-th PD. So, or you can say the red LED and the PD which is receiving the red light.

Similarly, here this is a channel gain corresponding to red LED and the PD which is receiving the green light. Here you can see the blue LED and the PD which is receiving the green light. So, in our simulation we have considered from literature one value of H. So, this these are the values of H in a better form you can see it. So, this is a constant term and this actually represents this.

So, what happens that the constant term this 56.4 into 10 to the power 3 is due to the distance based channel gain. For that you can refer to previous simulation exercise on indoor VLC regarding VLC channel. So, you can check the channel part over there. The estimated independent channel gain matrices in this reference actually. So, we have taken it from here.

Having utilized to simulate CSK 3 PD VLC system in our work, however, what we see that in CSK 3 PD, the 3 PDs are spatially close to each other. So, generally the interference from other light sources let say for blue, red and green may act as interference is being considered. However, at times it is being ignored as well and one can go ahead with a very simple channel gain matrix ignoring the interference and you can go ahead with this as well depending on your scenario and situation. And, this will have the VLC channel based on distance, ok.

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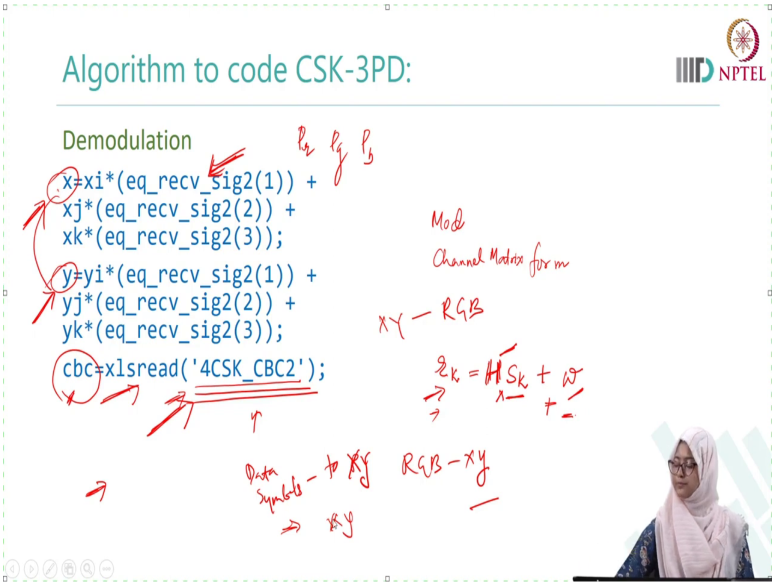

Now, coming to the demodulation part. So, I hope it is clear that from we have done the modulation and then have done the channel actually have seen the channel matrix form. So, at the receiver side we will have received signal, but again it will be in a form of vector or you can say in a matrix form that is why all will be in bold. So, that is why this SK and then H will be in matrix form and the noise will also be in the matrix form.

So, in demodulation we have received we have sent P r, P g, P b and this P r, P g, P b are actually being multiplied with the channel gain matrix and then the noise is added and we get the receiver. So, at the receiver side we need to multiply it with the specific xi, xj and xk, so that we can get the specific x and y which we did at the transmitter side, for transmitter xy to RGB and at the receiver RGB to xy. And, then here we have saved the CBC to data that is data symbols to xy.

So, we have got at the demodulation part we need to do these we will get xy and then from that we will be getting xls. You can read this xls read to read data from here. So, here what we need to do? We need to check that what values matches the cbc and the xy. So, the minimum difference between the value present in the 4CSK CBC2 and the xy will give us the actual xy which was sent or which was transmitted.

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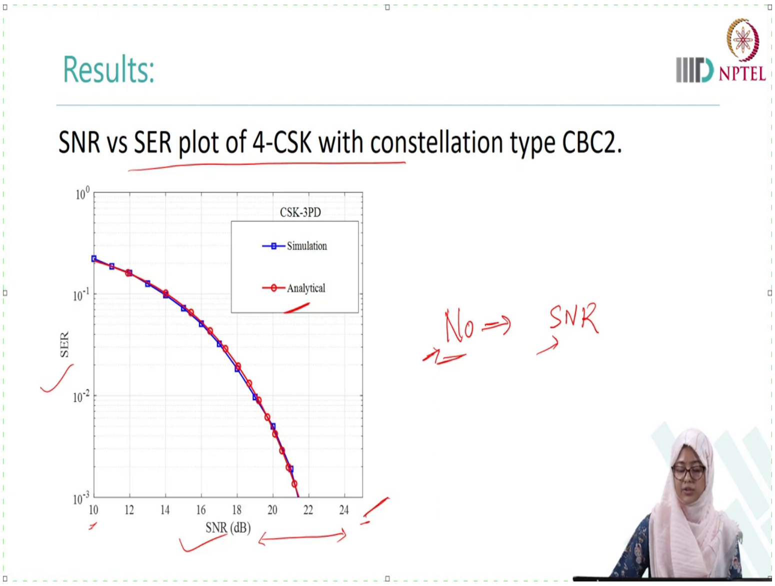

So, this is the result we have got. We have shown you the result. So, SER versus SNR of CSK 3PD that is the standard one and there is one thing for analytical that in analytical case always try to have N naught specific to the SNR you consider; do not just fix a N naught you can consider many literature for the analytical work. However, you need to find the values of N naught at each SNR.

So, let say here SNR is ranging from 10 to 25 dB you need to find the values of all those in order to get the analytical simulation.

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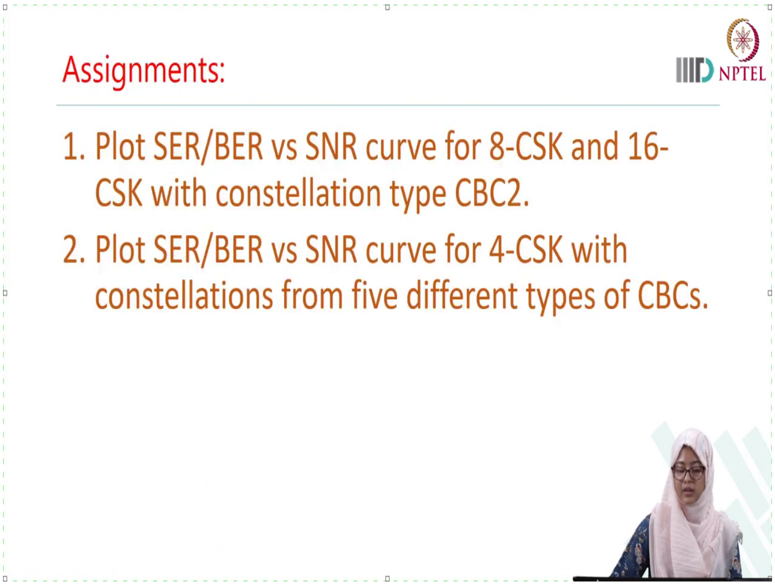

So, the assignment for this work is you can go ahead with plotting SER or BER versus SNR curve for 8-CSK or 16-CSK with constellation type CBC2 or you can go ahead with the SCR versus SNR curve for 4-CSK with constellations from five different types of CBCs for this you need to refer to that paper.

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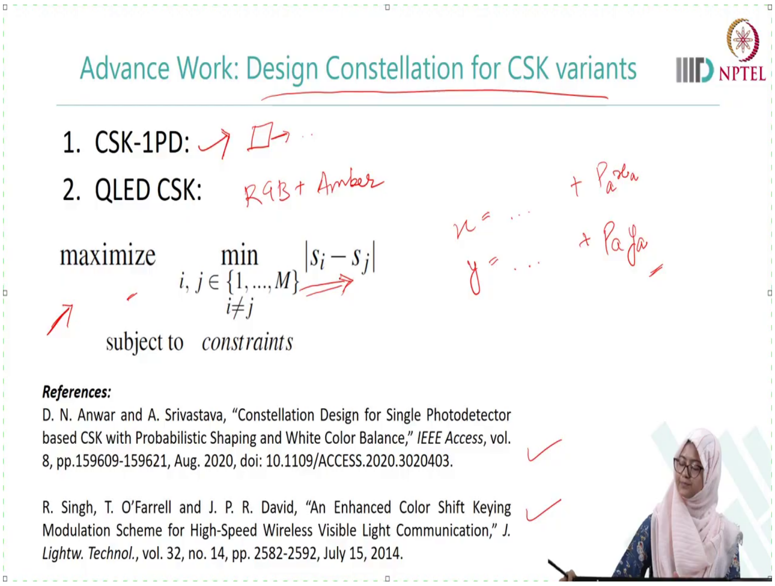

The advanced work is CSK-1PD and quadrature LED CSK. So, you can the advanced work is that if you want to design constellation four different variants of CSK apart from the conventional CSK. So, you can refer to these works. So, here again you have to take into consideration the constant power constraint of CSK and in QLED CSK case the x-y chromaticity coordinate equation will have an added let say amber.

So, apart from RGB in QLED CSK it will be amber light as well. So, here the equation will change to this and the basic just to give a bit of overview, the basic is to maximize the minimum Euclidean distance between two symbols. So, this is like the optimization of the CSK constellation symbols. So, yeah for CSK I hope the students can now simulate CSK, they now know how to design constellations for CSK and the difference from the basic VLC modulation scheme that is OOK.

Thank you.