Fiber - Optic Communication Systems and Techniques
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Lecture - 55
Recovering Polarization

Hello and welcome, to NPTEL MOOC on in Fiber-Optic Communication Systems and Techniques. In this module we will look at the receiver operation; the signal processing operations that we perform in order to mitigate various you know impairments, that the signal as a propagate through the optical-fiber communication system will undergo. Now before doing that one let us actually look at a way to receive or recover the polarization of the transmitted signal.

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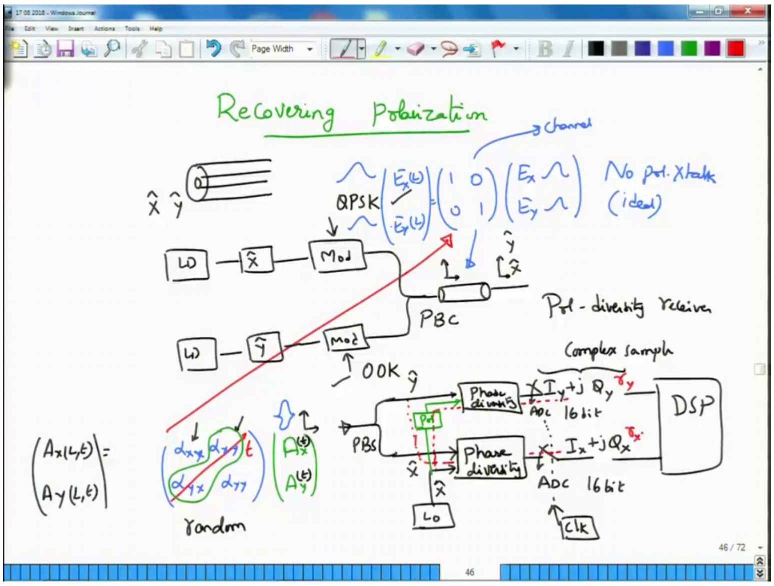

It is important to recover the polarization because in most optical-fiber communications today, we use both the x as well as the y polarizations in order to transmit information. So, usually what we have is y information source which produces or which produces x polarized light. And then you can modulate the data onto this one using an external modulator as in a usual sense and then combined this one with another laser output which is polarized along the y direction ok.

Again you can impose independent data on to each of those polarization components themselves, using whatever the preferred mechanism. And it is not even necessary that both should share the same modulation format. For example, the x polarized light could be QPSK modulated. Whereas the y polarized light could be a simple on off keying modulated ok.

Although in practice all these considerations depend upon what is the transmission reach, and the bandwidth, and the data rate that we want to achieve for a given application. It is important to note that with using two polarizations you can simultaneously transmit information at the two polarizations and there by doubling the usage of your bandwidth.

So, you combine these two using what is called as a polarization beam combiner and then launch into an optical-fiber. An ideal optical-fiber which does not have any problems associated with it, that is a fiber which has a uniform cross section no matter at what point you take the cross section the cross section remains the same. The fiber does not have any bends, or it does not have any micro bends that is small corrugations or small changes out there.

It does not have any major twists or anything like that. So, in a sense if you consider an ideal fiber then the two polarizations actually propagate independently of each other. And at the output they will be received as a two polarizations and there is no crosstalk between the two ok. We have already seen that when there is such crosstalk it least to what is called as polarization mode dispersion.

And there are actually as we saw there are more than one types of polarization mode dispersion. But in addition to polarization mode dispersion you will also have polarization dependent loss. What is this polarization dependent loss? That simply means that if the two polarizations stock to each other even if they do not have a dispersion, but if they just kind of mix with respect to each other; then the output power in one of the polarizations may be smaller while the other one may be larger ok.

And whether this is smaller or the other one is larger or whether the y polarization is larger smaller. And in fact, how much will be smaller and larger all these are statistical properties which makes polarization dependent loss something very similar to fading that you would encounter in wireless communication systems. And because, of this polarization dependent loss you are not sure how much to amplify the x polarization and how much to amplify the y polarization.

Because, these values actually change which forces you to either use same, which forces you to either track the polarizations for which you should at least be able to recover the polarizations, polarization of the signals, measure the intensity, and then use some sort of a feedback system; in order to track the polarization dependent loss; that your experience having as a function of time. Alternatively you simply assume a worst case scenario and put in an amplifier of sufficient power such that the output would be well beyond what you actually expect.

But such an approach would be wasteful of your optical amplifier I know system it increases the cost. And it may also lead to additional effects such as nonlinearities and additional amplified spontaneous emission noises. So, the sensible way although it is more complicated is to actually keep track of the polarization and then to adjust the optical amplifier gains according to the polarization dependent loss. So, the amplifiers gain will be adjusted in a dynamic manner depending on how much polarization dependent loss is happening at any given time ok.

But before we can deal with PMD and PDL and I would not discuss much beyond these simple ideas of PMD and PDL because we do not have enough time in this course. But the idea is that I should first be able to recover polarization only then I will be able to extract information separately which is coming in on the y polarization and information which comes from the x polarization. And for that we use what is called as a polarization diversity receiver ok. What is the polarization diversity receiver? In simple structure of that one would look something like this.

So, this is a signal that is coming in which has both polarizations x and y. And what we do is that we keep a polarization beam splitter; so we actually keep a polarization beam splitter and direct the y component in one of the directions, and the x component signal in the other arm ok. And, once they have been separately identified into x and y polarizations, what we then do is to actually keep a phase diversity receiver.

So, with a phase diversity receiver you will have your local oscillator going in as one of the inputs to the phase diversity receiver. And, let us say this oscillator is actually emitting an x polarized light and then you keep the same polarized light into the phase diversity receiver. Such that you mix the incoming or separated x polarization with the x polarised local oscillator. But the same time you also want y polarized output so you for that one what you do actually keep polarizer; which will change the polarization from x to y.

And you can do so by various things that we actually talked about or you know the birefringent crystals even if I have not talked about them. And you can convert one polarization to another polarization and then essentially put one more phase diversity receiver. Usually the signals are modulated with the same format so as to keep the rest of the processing kind of similar; if not when you will have to deal with the fact that one of them is a QPSK modulated and the other one is a on off keying modulated.

But if you keep both to be the same modulation then this output that you are going to get will be Ix plus jQx; where Ix stands for the in phase component of the x polarization. Sorry, this is y here so I have I y plus j Q y being the base band complex sample that I am going to get. Because what I would actually do would be to put a analog to digital converter here which would be running at the sample rate so, that I can actually generate the in phase component and the quadrature component at any given sampling time.

And then essentially obtain one complex sample for every symbol that I have been transmitting. So, once these are the samples these are actually discrete signals to digital signal, so please keep that in mind. Before the analog to digital converter they you have what is called as a analog signal because signals are vary in continuously in time or continuous time signals. Output of the ADC will be discrete complex sample and you do the same thing even at the other end.

So, you have an ADC running in the x branch as well. Usually these ADC's are synchronised to the same clock source ok so, that both are sampled almost at the same time and both characteristics of ADC's are also kept nearly identical. For example, if this is a 16 bit ADC you try to keep this one also a 16 bit ADC. So, that the two samples are not really different because of the processing that we have used. Of course, depending on the application you may want to change things, but in general for these high order modulation systems which are very high data rates you trying to keep them to be the same ok.

So, the output of the x polarized phase diversity branch would be I x plus j Q x, which is again a complex sample. You combined these two samples together and then process in a unit call DSP unit ok. We are going to study the DSP unit, but what things what are the things that can go wrong. One you may have you know thought that these two are orthogonally polarized x and y; the information is sitting here in the y polarization, the information is sitting in the x polarization without talking to each other but it would not really happened that way.

If this channel or the optical-fiber were an ideal fiber then sending something on Ex up pulse sending another pulse which represents information of course, on the y polarization. The output of this one would also be something like Ex at the output, which I will call as L Ey at the output of L with near identical shapes that you are transmitted ok. So, in that case the channel would essentially be the identity matrix or the fibre would essentially act like identity matrix. And no polarization crosstalk would occur ok; this is for the ideal case.

But unfortunately in a real world scenario there will always be some crosstalk which means; this value will be different ok. This value will be different will put alpha x x and y y just to be sure and this cross terms that we have put in right these are the cross terms that are going to tell you how much of the x component. We will call this as Ax and Ay instead of calling them as Ex and Ey because these are the time dependent (Refer Time: 10:41) that we are talking about. So, let us not write them in terms of electric field, but write them in terms of amplitudes or the complex on (Refer Time: 10:47) ok.

So these complex (Refer Time: 10:59) are of course, functions of time as well and the cross terms would essentially mean that the output that you are going to get at L. We will actually contain part of the signal from x and from x and part of the signal from y and the magnitude of these cross terms alpha x y and alpha y x which usually are equal to each other, but with a different phase normally are again statistical parameter.

So, this matrix that have written should not be interpreted as a deterministic matrix, but it is actually a random matrix that is matrix with parameters some of those parameters are essentially going to be random. And you need to actually remove this crosstalk from the two branches. So, essentially what we are saying is that some portion of x would leak into the y polarized output and then actually shows up here. Some portion of y would actually leak into the x polarized information and then show up at the output.

So, the idea would be to take this matrix which is actually a two cross two matrix is the way I have written and it is not a diagonal matrix and to actually make that matrix into a diagonal matrix ok. It is not so simple you need to actually work either in the time domain or in the frequency domain appropriately. And if you choose to work you will almost always have to treat these terms as functions of time and adjust them using some adaptive mechanisms ok.

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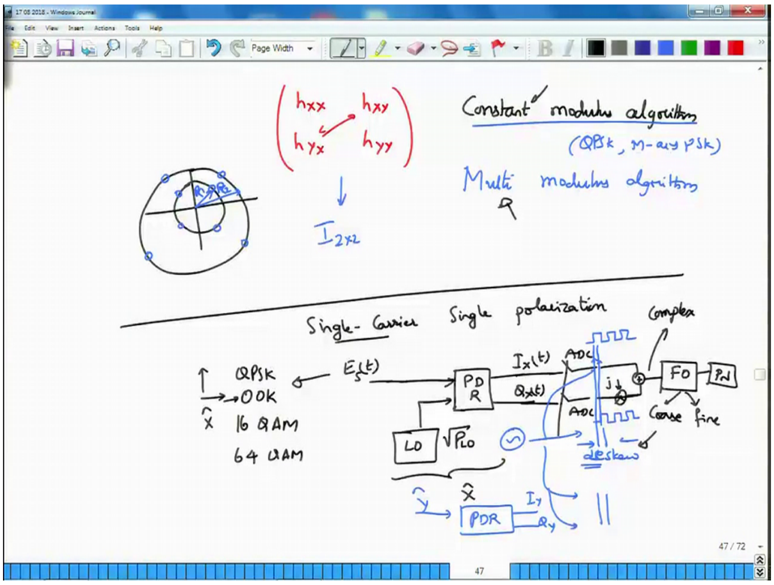

So, instead of alpha x is people also write h x x h x y h y x and h y y with the idea that h x x stands for the x polarized input and a pure x polarized output the impulse response of the fiber corresponding to that. Similarly for h y y will be the pure impulse response for the input that has been sent in which is y polarized and the output is also y polarized. And of course, these are your crosstalk terms that we talked about. And then you can actually adjust these outputs you can actually look at the samples that you have obtained at the two polarization.

So, we have actually written this as Ix plus j Q y and Ix plus jQ x. So, rather than writing that way we will put a shorthand notation for this we will call this as r y and r x. Now r y and r x correspond to the data that you have received or sampled on the y and x branches of the polarization ok. And they will have some component of x and some component of y and adaptively tuning would allow you to remove that polarization crosstalk. And one such a mechanism that we have I mean that we use is called as constant modulus algorithm ok.

This is motivated for those modulation systems in which the amplitudes actually occur or the amplitudes in ideal consolation are going to be constant. So, these are actually mostly used for QPSK or M-ary PSK types of modulation systems they can also be used in some sense for constant or rather only phase modulation systems. But to extend them to include say maybe a simple thing as an additional amplitude factor right.

So, now, you will have an additional amplitude factor let us say; so, this is an example of in system in which both amplitude is changing so one amplitude value is this fellow with a radius say R1 and other one is a radius R2 will put the capital R1 and capital R2 here. And R1 and R2 correspond to the amplitudes that may have and within one amplitude you can use a constant modulus algorithm. That is the amplitude is going to be constant in a single ring, but unfortunately when use more than one amplitudes you cannot use a constant modulus algorithm, but you have to modify it called as multi modulus algorithm ok.

So, this multi modulus algorithm can be used in order to make this matrix look like a identity matrix which is the two cross two identity matrix so, that is one you are actually going to do. So, from the big picture point of view polarization dependent class and polarization mode dispersion is some sense can be thought of as; matrices which couple the x and y polarizations. And all the operations that you are going to perform at the receiver most of the time has to be adaptive, but the goal of those operations at the receiver or to make this matrix go back to identity matrix ok.

So, by whatever the mechanism that you can use their basic idea would be to take a correlated matrix or take a matrix which has nonzero elements along the non diagonal element. A non diagonal elements and then you have to make those non diagonal elements go to zero as much of possible while making the matrix essentially look like an identity matrix. You may not exactly achieve the identity matrix, but you can get close to a an identity matrix, and how close and in what sense we are talking about close depends on the algorithms that you normally used ok.

So, this was about polarization recovery we are going to say a little more about this constant modulus algorithm and multi modulus algorithm later on. But for now let us assume that I am working with a single carrier single polarization that is I have both carrier which is a single carrier which is anyway what we have been considering. And then I also have a single polarization system by this I mean, that at the input I may have sent information only on one polarization or I may have sent on both. But I am only interested at the receiver side in the x polarized output so I am not interested in the y polarization.

So, I am interested in the x polarized input and let us see what kind of things can actually happen here. So, let us say this is the signal that we have received and then I need to have a local oscillator as well correct. So, let us say this is my local oscillator, this is the phase diversity receiver this is the shorthand notation I am using it is not really correct notation, but I am using this shorthand notation. And took this I am going to send him so let us say this is all x polarized. The output of the local oscillator will have some amplitude of square root P LO.

Whereas, the input that I have used here will have same polarization which we can either call as E s E s of t or we can call this as Es of t does not matter what we have used ok. And this could be as I told you could be a QPSK system, it could be a simple on off keying, all though not quite popular today. It could also be a 16 QAM system or a 64 QAM system so these are higher end higher order modulations. And any of these modulation a modulated signal should have travelled through the fiber and reached here. You have a polarization diversity receiver which produces right, the in phase component and the quadrature component which you are going to combine into a single unit called null to obtain the; let us put this as continuous time signal.

But then you are going to combine them into one complex sample by using a ADC here you have other ADC usually these ADC's have to be lined up. So, the clock of this ADC will be in this manner and in practice although we want the clocks to be lined up we may not actually have a lined up clock. So, this difference that you are actually seeing here is a minute difference called as deskewing of the clock or skew of the clock. And therefore, you need to de skew the clock de skew means they are not aligned with respect to each other.

So, you just have to make them align by going back to each other. So, the timing of these two should essentially be the same; so the skew in the clock has to be recovered. Moreover if I am actually going to use another phase diversity receiver for recovering the y polarization of course, in this case I would have Iy and Qy. And then I will have to deal with this dual problem actually of two more ADC's

So, I will you see that there are lot of ADC's and all these ADC's should essentially have the same clocking source which has to be distributed. So, there is a master clock which would distribute this clock source into different components of their. So, this is the complex sample that you are going to get after you have sample them through ADC's. And you need to overcome this skewy problem there are lot of algorithms to do that one.

One of the algorithm is called as Gram Scmidt Orthogonalization procedure, we are going to talk about little bit about that one in the few minutes now. So, after we have sample them so now, what we get is a complex sample. Let me just combine them here right away after multiplying the cube component with j of course, in reality I am not going to multiply anything with the complex number this is just for my intuition ok.

What I do obtain is a complex number; yes, but that will be represented as two real numbers in the processing unit ok. So, I anyway for my convenience and for our consideration consider this to be a complex simple ok. After you have done that one after you have done this de skewing and allowed the I n cube components to essentially come out. The next thing that you are going to do would be to estimate the frequency offset.

There are lot of methods for estimating the frequency offset most of them involve using some sort of an extra information called as a piolet and then you look for this piolet to do the frequency offset correction. There are two types of frequency offset correction; one is called as the course correction and the other one is called as the fine correction. Course correction is what you first do you do the fine correction later on because the next block that you are going to get after the carrier frequency offset is the phase noise block or the phase block.

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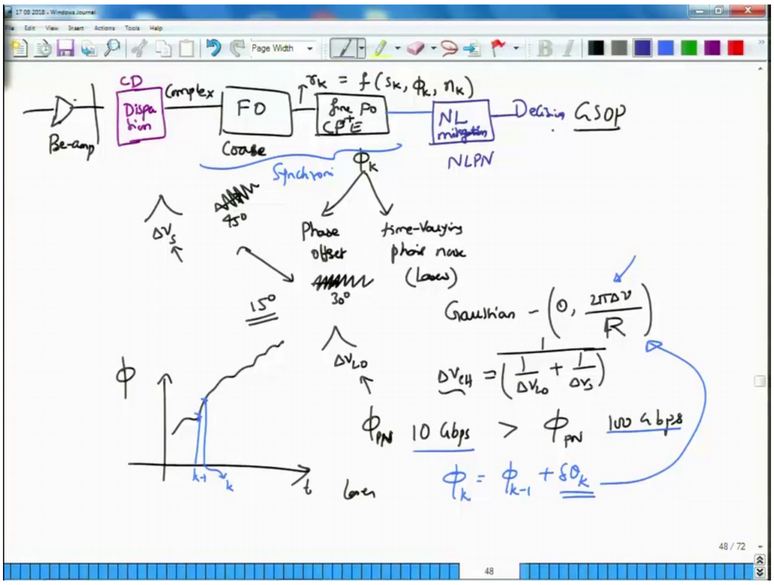

So, let we rewrite them here I am getting a complex sample from the ADC's. The first thing I am going to do is to put a frequency offset, I may do only course here and then leave the finer part to combine so fine frequency offset plus carrier phase estimation. Now carrier phase estimation or simply phase estimation is an extremely important block in the entire receiver system. So, if you can pinpoint the difference between DSP based coherent optical communication systems and the older systems is it is in this particular block.

Because as I have told you earlier also if you wanted have a proper coherent detection you need to have a local oscillator; whose phase is end frequency of course, has to match exactly with that of the transmitter or at least the difference between the two must be a constant ok. If it is not constant then it will rotate the consolation points and make here life very very hard. The conventional way of doing this you know you know matching of the two phases or keeping the track of phase is to use a device called as phase locked loop.

Unfortunately optical phase lock loops are very very hard to implement and that is the reason why coherent system were not really used for quite a long time ok. Because you could not make realisable optical phase lock loop which could track phases over long distance transmission and especially when data is also involved. And especially, even more especially when this data is actually varying at very high data rate ok.

In some few things in future years may be someone will actually develop nice rugged optical phase lock loops and then will go back to the analog methods. But for now we are dealing with digital methods, in which you are going to look at the sample that you gotten here. So, this is the sample that you have obtained and using these samples here going to estimate the phase ok. This sample will be a function of the actual symbol that has been transmitted that symbol itself could be a complex symbol indicating the higher order modulation that we have talked about.

It will also be a function of the phase and in this phase there are two distinct phase component that we want to talk about. One is a phase offset ok, this phase offset means that let us say the carrier phase is 45 degrees and constant it may not be I am just writing it in that way. Then the phase of the local oscillator may be is say 30 degrees. So, in this case the phase offset are what is sometimes called as nominal phase offset is about 15 degrees. But the phase is not going to be constant in this manner it is actually going to be varying around these 45 degrees.

And similarly the phase noise of the local oscillator will also be varying or the phase of the oscillator will also be varying. This variation is because as I have told you because of the finite line width of the local oscillator as well as the finite line width of the signal lasers ok. Because of this finite line width which is non-zero you are going to get these phases which will then impacts. So, you have to first look at the larger or the phase offset then correct the phase offset and after that deal with time varying phase noise ok. This phase noise comes mainly from lasers ok.

The lasers that you have used will introduce this phase noise and you have to actually overcome or compensate this particular phase noise by first estimating it and then compensate it. Of course, the received sample will also be corrupted by noise correct because I would have put before the receiver part I would have put a the front end preamplifier. The amplifier is going to actually amplified, but it will also introduce noise into the system. And that noise will actually show up at the sampled output ok. I am assuming that the de skewing has been done I and Q outputs are actually nicely orthoganalized using that gram Schmidt orthogonalization procedure that I talked about.

I will also talk about it in the next module because we do not really have time in this one. But then after performing the coarse frequency offset fine frequency offset then performing the large phase offset or estimating an compositing for large phase offset. Then you come to laser phase noise ok. Luckily for us laser phase noise is reasonably defined. I mean reasonably well defined as a Gaussian process with a variance which have a zero mean, but a variance which is given by 2 pi delta nu divided by R ok; where R happens to be the symbol rate of the transmitter system ok.

Delta nu happens to be the line width when you have delta nu Lo and delta nu s. Then you can define an effective line width which usually if the case of something like 1 by delta nu and o by 1 by delta nu s 1 over the entire thing ok. Or if the local of letter line width can be negligible then you can write down this delta effective mainly in terms of delta nu s. So, one of them is usually with dominant process dominant line width. And it is interesting to note that the variance of this phase noise which actually inversely proportional to R; which means phase noise for a10 GBPS system ok.

Phase noise which I have written it as PN for a 10 GBPS system, is actually going to be higher than the phase noise for a 100 GBPS system. This is surprising, but the route for this difference actually lies in the way the phase itself goes. If you look at the phase trajectory of a laser so, this is the phase and this is with respect to time the phase trajectory of a laser exhibits some dependents in this form. But then R corresponds to two instants in time are this is the phase noise which is actually the phase difference is what we are actually looking for.

So, you can infect model this phase noise as phi k equal phi k minus 1 plus delta theta k. Where delta theta k is Gaussian distributed with this particular variance. And k and k minus one are the two instants that we have looked at. So, k minus 1 and this instant is k. So, the smaller the separation the larger is the data rate and therefore, the phase will be more or less same as the previous phase. So, the smaller time separation larger symbol rate means the variance of the phase noise actually reduces ok.

So, that is the reason why phase noise for 10 GBPS there actually higher than phase noise for 100 GBPS. So, after you have estimated this phase noise which is time varying. So, clearly you need some sort of an adaptive system to track something that is time varying. Then so now you have perform the synchronisation as we would call it. Both frequency offset estimation and phase noise estimation would be performed. Now I am sorry, I forgot to mention one important topic before we go to the frequency offset. And that is dispersion compensation the fiber would have introduced lot of dispersion and then you have to compensate for the dispersion. After compensating for dispersion which we are going to talk about it in the next module, you do the coarse frequency offset correction, then fine frequency offset plus carrier phase offset plus the time varying phase noise.

All of them going to the same terminology called as carrier phase estimation. Then comes an extremely important topic called as Non-linearity Mitigation ok. Non-linearity Mitigation mainly deals with overcoming the non-linear effect of which non-linear phase noise which is a form of a phase noise is very important.

So, I will tell you more about NLPN in the next modules. After you have estimated and composite for all these impairment then, you make a decision about the actual transmitted symbol. And this decision could still be in error therefore, you characterize the entire system in terms of it is BER performance. We are going to see some of these algorithms in the next module.

Thank you, very much.