Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – IX
Module-III
Power spectral density(contd.)

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Hello and welcome to the moke on optical communications. In this module we will first complete what we have started in the previous module that is discuss the power spectral density of polar and unipolar formats, both NRZ as well as RZ and then consider the performance of on-off keying digital communication system, you know the digital optical communication system under the influence of fiber loss and other noise processes okay.

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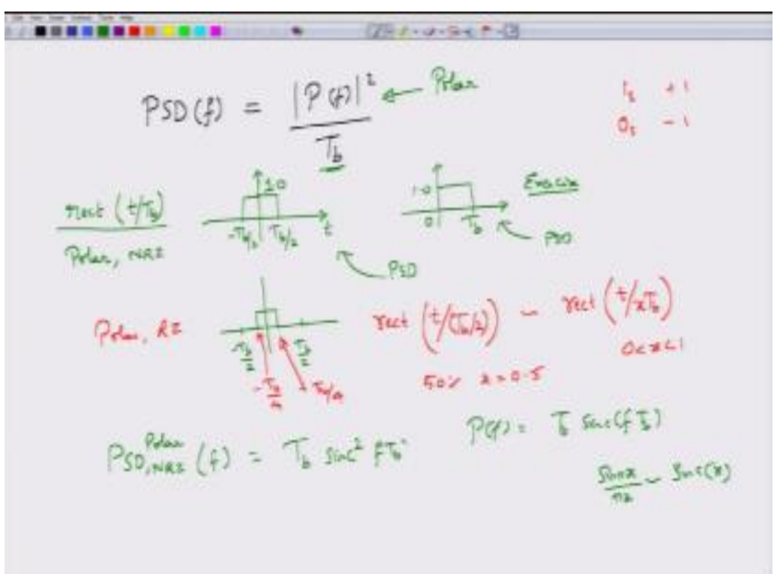

So let us begin by recalling the power spectral density which we have denoted here as PSD which was a function of the frequency F and we had derived this formula for the case of polar format right, for the polar format we have derived this formula which said that you take the basic pulse shape P(t) take the Fourier transform of that, take the magnitude square divided by the bit duration T_b okay.

If we assume of course, now the power spectral density of course, depends on the kind of pulse shape that we use. The simplest one is called as the rectangular pulse shape okay. The rectangular pulse shape which is in our notation denoted as rect (t/t) or T_b let us say is actually a pulse of duration T_b okay, and it is centered here at $T_b/2$-$T_b/2$ okay and an amplitude of 1.

So this is your rectangular function which has a duration of T_b. If you are not happy with this pulse starting at $–T_b/2$ you could always make the pulse start at T=0 and then have this pulse at T_b okay. Mathematically there is a delay of $T_b/2$ here compared to this wave form and that will translate into a phase factor, but since you are taking the magnitude square that phase will anyway go out okay.

So I will leave this as an exercise to show that the PSD that you obtain for this pulse would be the same as the PSD that you would obtain for this pulse okay. The shape of the pulse, you know with the amplitude is being the same, the shape of the pulse here has to be the primary concern not its location okay. So this is what we are going to consider for a rectangular pulse right. So we are to remind our self, we are looking at polar form and then we are looking at a NRZ format right, because this is pulse which is occupying the entire bit duration.

How would we represent a polar RZ duration? So let us say this is still $–T_b/2$ and $T_b/2$, but if I consider a rectangular pulse which is only half duration here okay, I am considering a pulse whose duration is only half of the bit period then this end will be at $–T_b/4$ and this would be $+T_b/4$ and this rectangular function can be written as rectangular function with a width which is only half okay.

So this would be the rectangular function. So in fact you can have a general way of representing this and then say a rectangular function divided by XxT_b where X will be a number that would be between 0 to 1, of course, you cannot really have it as 0, then it becomes an impulse and that is not what we are looking at okay. For a 50% duty cycle X=0.5 okay, so this corresponds to polar RZ format, remember in the polar format, one symbol is represented by +1 and symbol 0 is represented by -1 okay.

So let us evaluate the PSD for both these case, well let us first start with the polar NRZ format to call that one, let us call this as NRZ and also write this as polar format okay. This is some notation that I am inventing here, because I have to indicate both the cases of NRZ, the format RZ and the format okay. It is not a standard notation, it is just something that will distinguish the PSD for NRZ polar format versus RZ polar format.

So this one as a function of the frequency F taking the Fourier transform of the basic pulse shape. Now since the basic pulse shape here for the NRZ format is rectangular pulse occupying the entire duration. The Fourier transform of this right, so P(f) will be given by T_b sinc fT_b where sinc function as we will very shortly see is defined as sinЛx/Лx okay. So this is what we call as sinc of x.

So if you substitute this expression P(f) then the magnitude of $P(f)^2$ here will give you $T_b^2$and $sinc^2$, there is a T_b in the denominator here which cancels with one of the T_b in the numerator. So what you get as the power spectral density is T_b $sinc^2$ (FT_b) okay.

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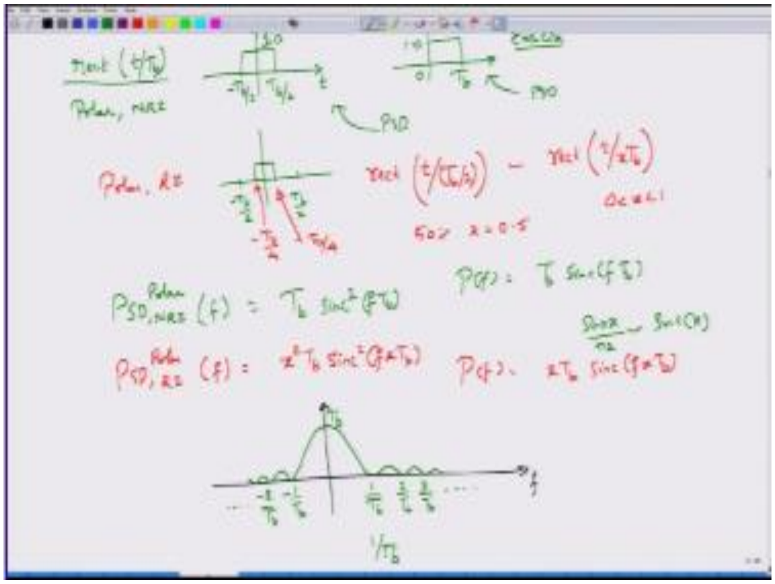

Let us also look at what you would get for the PSD of a polar format but RZ okay. So you get polar format of the RZ here, since the rectangular function has a duration of $T_b/2$ or in general has a duration of XxT_b the corresponding Fourier transform here will be XT_b sinc FXT_b okay. And then when you square it, so obviously this will be T_b^2 but there is a T_b in the denominator for the power spectral density.

So this will become X^2T_b okay and then you have sinc^2 FXT_b let us sketch these as a function of the frequency F okay, you can also normalize this frequency by dividing it by T_b so you can do that one, otherwise you can just leave it as a function of F. So for the PSD polar format, you see that this is a sinc^2 FT_b function, and that function goes something like this okay.

So that function goes like this and there are of course, an infinite number of side lobes, but these side lobe amplitudes keep on dropping out. So what would be the value of this sinc^2 at F=0, that would be equal to T_b whatever the amplitude of the sinc^2 function at F=0 will be T_b here and the first 0 occurs at $1/T_b$, the second 0 occurs at $2/T_b$, third one occurs at $3/T_b$ and so on, on the positive frequency side.

Similarly on the negative frequency side it would be $-1/T_b$-$2/T_b$ and so on okay. There are this infinite number of side lobes which as we can see are carrying less and less energy or less and less power as you go higher and higher in terms of the frequency. So if you were to arbitrarily define the bandwidth of this $sinc^2$ function as the frequency difference wherein the first the $sinc^2$ goes to the first 0 that is to say that is this main loop and if you define the band width of this pulse as a main loop pulse band width then the base band width.

Because it only unitizes the positive frequencies will be given by $1/T_b$ however when this pulse goes to the pass bender it gets modulated on to carrier then this fellow this is instead of 0 you will have fs that is the signal frequency of the modulation frequency around that the main loop width is 2 times or $2/T_b$ okay so that is the band width of NRZ format let us look at the RZ format band width.

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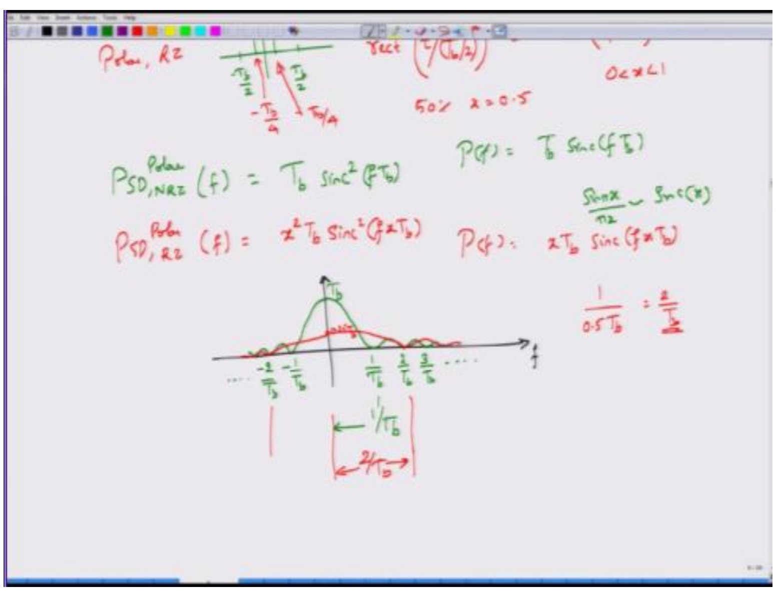

And for this case we will assume that x= 0.5 okay so with x =0.5 the amplitude of this function becomes 0.5^2 which is about 0.25 times T_b right so the amplitude at f= 0 will be $0.25T_b$ which is fine but where does the first 0 occur the first 0 occurs at $1/xT_b$ right so 1/x is 0.5 so 1/0.5 T_b which is nothing $2/T_b$ and then the next 0 occurs at $4/T_b$ and so on so the main loop actually extents you know up to this point and then goes to 0 here and then goes to 0 here so it goes to 0 here and then goes 0 here okay.

Did not come out very nice sinc function because the amplitude as been scaled down and the low width as been increased okay but if you are looking at the main loop width that main loop with will be so from the positive frequency side the main loop width is $2/T_b$ okay where as for the case of RZ it was just $1/T_b$ okay so for the RZ it is $1/T_b$ for NRZ so it is $2/T_b$ so with a RZ you see that there is a larger band width requirement compare to the NRZ format.

So which means that why are we even wondering about whether use NRZ or RZ if our goal is to reduce the band width then NRZ is preferred over RZ however with NRZ it turns out that the pulse is on all the time so whenever there is a one there is a one you know there is a pulse only when there is a 0 there is no pulse if you get a long string of 1's what happens is that the DC value you know the time average DC value over say last N block of pulses starts to become non zero okay non zero and it will start to deviate from half.

So this process when it starts to happening this is called as you know then this leads a problem in the sense that you are synchronization circuits do not really work very well okay so in order to avoid that one utilizes not an NRZ format but with as RZ format which more or less tries to keep the average value around 0 okay for a polar format the average will be around 0 for a unipolar format NRZ even worst because the average is as such something like half and then you start having non zero the average starts to derivate from 0.

Okay this phenomenon is called as baseline wander okay the base line that you are going to use for the threshold starts to wander and this happens when you get a sequence of long once with RZ there is a transition going on so it can you can just pin down where the 0's are so it helps in synchronization is a short answer for that and we can NRZ or the RZ depending on whether that synchronization problem is severe or not severe in optics we sometimes use NRZ format or we use NRZ format we do not really use RZ format because of additional problems NRZ format is slightly proven to nonlinear effects than RX format we will come to that one when we discuss fiber based fiber base non linearity's and how they would affect the performance of the system.

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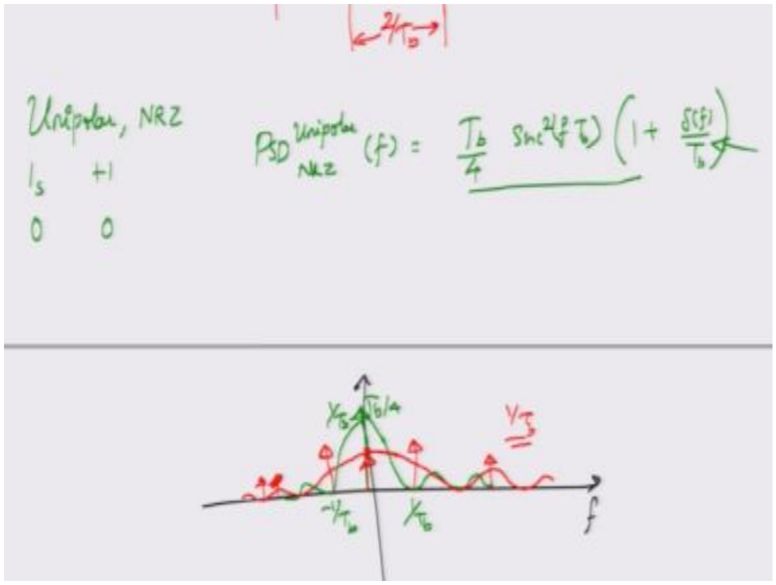

Okay let us look at one more format which is the unipolar format in the unipolar NRZ I am not going to derive the power spectral density in this particular case remember for the unipolar format symbol 1 is a pulse or a +1 amplitude and symbol 0 is 0 you are not sending anything over here and the polarity of this pulse is always single that is why it is a unipolar format the powers spectral density of the unipolar format and NRZ turns out to be T_b /4 sinc^2 fT_b okay.

And 1+ δ f/T_b do not be through off by this δ f term this δ f is just a δ function which is present at f=0 this part which you have seen is exactly similar to the RZ format except that the amplitude has reduced to T_b /4 right rather than having an amplitude of T_b the amplitude as reduced to T_b/ 4 + there is a δ function at the origin so if you where to sketch that you would see the sketch to go something like this so this f and you are looking at the PSD's so you have an amplitude of T_b/4 so let us put that one which goes to 0 at 1/T_b.

And then similarly a symmetric one at -1/T_b and so on in addition to this there is a δ function the amplitude of the δ function is given by 1/T_b okay so this is a δ function that exits for the unipolar NRZ format for the unipolar RZ format with a point you know 50% due to cycle you do get this behavior in addition to this okay the amplitude of course is smaller because that is factor of x sitting there for the RZ so the amplitude may be you know something that is smaller here the width of course is large right so you have a width of say $2T_b$ okay.

So you have width of $2T_b$ and interestingly you also get a sequence of impulse function so you get one impulse here you get one impulse here or rather you get yeah you get one impulse here and then you get one more impulse here, here and so on so you get one impulse every $1/T_b$ and then you get a something at 3/Tb not here so not exactly over here so you get an impulse at this is $1/T_b$ this is $2/T_b$ this is $3/T_b$ so this is where you get one more impulse okay here so you get this additional impulses but those impulse can actually be now used for carrier synchronization, so in case you are looking at why this format is interesting is because you have a impulses series of impulses which you can pick of or carrier synchronization.

So we will stop with this pulse formatting and look at the next topic which is going to be about performance of on-off keying systems which is subjected to only fiber loss.

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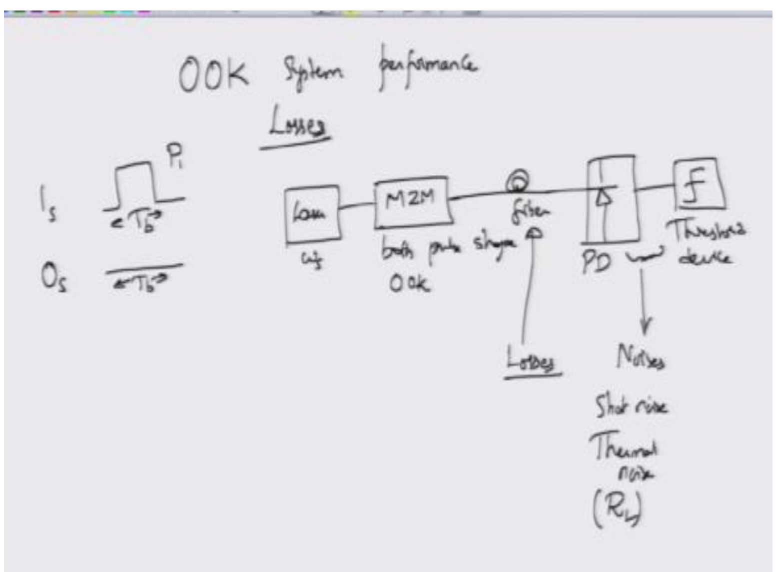

And noise processes that typically occur in a photo detector circuit okay, so on-off keying system performance is what we are interested in the next module we are going to look at the performance in terms of or next or the next module we are going to look at the system performance because of dispersion for now the focus is to look at losses, how would losses impact the performance of on-off keying systems, okay.

Let us first review what on-off keying system is, whenever you want to transmit a symbol one you can do so by transmitting an optical pulse, okay. The optical pulse has a certain peak power P1s let us say the duration is of course Tb right when you want to send a symbol 0 you do not transmit anything over the duration Tb you do not transmit anything if in for a general case if you want you can also transmit a slightly different power, okay.

So you can transmit a power which is say P0, P0 > 0 but normally you do not transmit anything for a symbol 0, okay. The transmitter side system consists of laser which is producing your continuous waveform so you have a laser here which is having a carrier frequency of ω_f this can be pulse shaped using one of the pulse shaping components that we discussed you know such as a Mag center modulator.

And then you have a amplitude modulator that you can use okay in order to turn ON and turn OFF the pulse shaping circuit okay, in fact if you are not really concerned about the exact pulse shape then you can eliminate all this components and simply use a Mag centre modulator in order to generate both pulse shape because your naturally getting a pulse shape as well as and the you bias the Mag centre modular.

With the data at such that the Mag centre modulator appears to give you 0 so you can do both pulse shaping as well as ON – OFF keying modulation in the same device, okay. So you can do the same device and then transmit it over the fiber, okay. So in addition to this channel there might be additional channels that are propagating but that is not of interest to us, okay. There might be additional channels there might be something else.

You know coming off from the optical fiber network we are not really concerned about that what we are concerned about is, if you imagine that two parties are there with transmitter and receiver in a single span that is there are no repeaters in-between you just have an optical fiber connected between transmitter and the receiver, so at the receiver what you will have is a photo detector okay.

The photo detector circuit is very simple you just have to have a photo detector followed by either a load resistor in order to convert the current into voltage or you can have a trans impedance amplifier which will convert this current into voltage but in a very nice manner in the sense that it would not load the circuit okay, so you have a photo detector followed by a threshold device, okay.

The objective of the threshold device is to simply look at the photo current that is received if the photo current is above a certain threshold then it will declare that as a bit one and if it is below threshold it will declare as a bit 0, right that is what you would expect, when you transmit a symbol 1 you expect a optical power to be greater than 0 and it must be greater than a certain value, right.

So you can define that as a bit one if the power of if the photo current is less than the threshold so this is the threshold so if the threshold is less than the threshold then you simply declare it as the bit 0 okay, what can go wrong here, in this circuit what can go wrong there are two things that are going wrong here, fiber does not preserve the same optical power for example at the output of the Mag centre modulator if the optical power is P1.

It would not be exactly the same power that you get when you receive it because of the fiber losses, so there will be losses that are induced by the fiber which reduces the optical power, okay. If the optical power reduces very much because the length of the fiber is very long okay if you are the long length fiber and the optical power is very small then there is nothing to detect and then you would not really be able to distinguish 1 and a 0, okay.

You do not want to get into such a situation but you want an sufficient length of the fiber and a minimum optical power so you want to operate at the largest optical link while maintaining the minimum optical power that is possible, okay. There is a trade of here if you go slightly beyond this way then the power that you are going to obtain will be very small on the other hand if you come here this might be just the critical value of the optical power that is received.

Which can be still utilized for detecting and differentiating between bit 1 and bit 0 okay, so that is where we are looking at so that is one of the things that can go wrong, the second thing that can go wrong is, in this circuit the photo detector and the optical receiver circuit you find noises right, what kind of noises do you find, well we have already seen the short noise which is what would operate in a circuit such as a trans impedance amplifier.

And when the optical power is sufficiently large so if you have a optical power sufficiently large, large enough such that the short noise can dominate over the thermal noise and that is where you would like to behave okay I mean you would like to operate the system, so short noises dominating the thermal noises when the optical bit correspond to symbol1 is a typical condition, however when the bit is 0 you are not transmitting any optical power.

So the short noise has nothing to you know there is no input so unless there is a main photo current shortness does not enter into picture so there is no short noise when you transmit 0 symbol the noise in a trans impedance amplifier is a kind of very difficult to evaluate at this for this course level so we will assume that the thermal noise is coming mainly from the resistor that you are going to put the load resistor R_L is the one that is giving you thermal noise.

So these are at this point the only things that are going wrong in our model and we want to evaluate what happens to the signal, okay,. So let us try doing that by first looking at what we are going to received.

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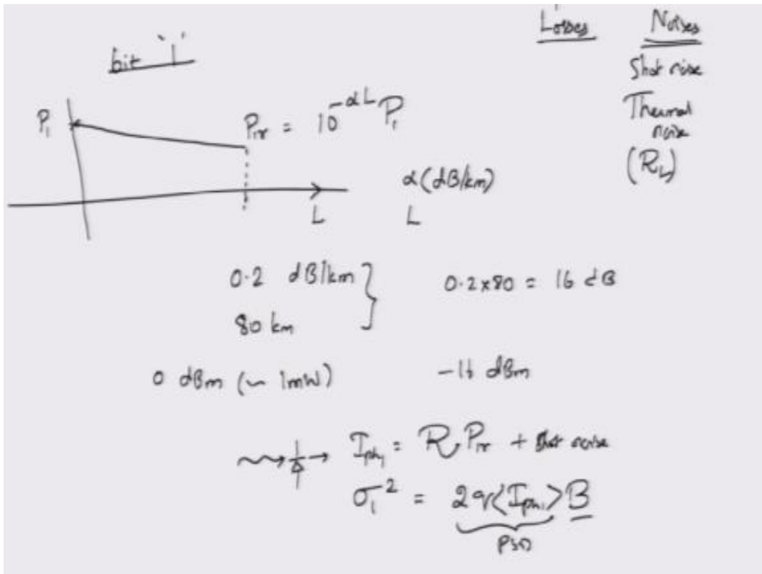

And how we are going to operate this threshold device let us also look at a little bit more on the losses as well as the noises okay, what would the losses do, suppose you transmit our P1 when you are transmitting a bit 1 or the symbol 1 when you are transmitting that bit, you start with a power P_1, however as a function of the length of the optical fiber this power P_1 starts to drop, so at some length L here you say that okay I am going to stop at this point, okay because if I let it go further than the optical power would be reduced below what my detectors can receive or detect, right.

There is something called as detectivity and sensitivity that we talked about, there is goes this concept of noise equivalent power, right. So your signal better be at least couple of noise equivalent powers high so that you are able to distinguish that optical power from the background noise, okay. So you want to operate your detectors with a minimum detectable level but you cannot really operated below the minimum detectable level, okay so you do that one.

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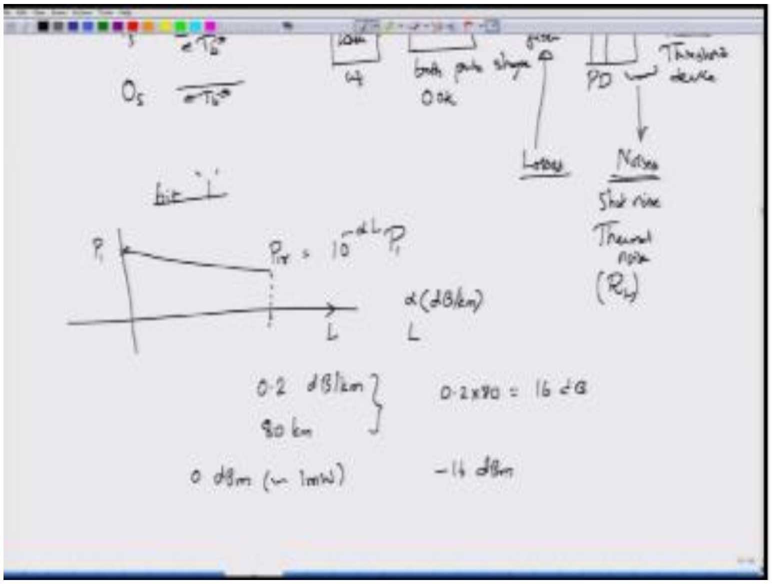

So at this point the received optical power we can write this as P_1r will be given by $10^{-\alpha L}P_1$ where this $10^{-\alpha L}$ I have used because this, α is measured in dp/km, okay and L of course is the fiber length. So if for example, the losses are 0.2 dp/km then if I go a length of 80km then the total losses that I am going to look at will be 0.2x80 which is 16 dp, okay and if I start my optical power at 0 dpm which is already pretty high 0 dpm corresponds to 1 mW actually, so this power which I am receiving will be -16 dpm, okay.

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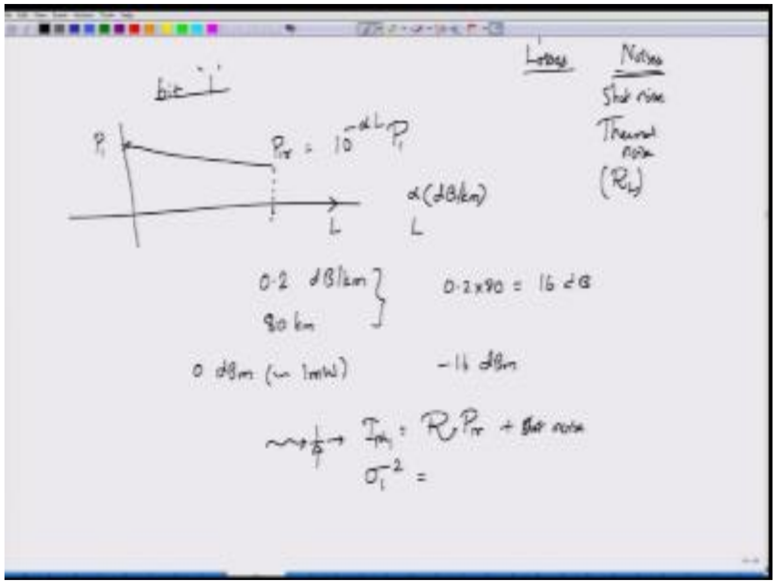

So this is what I am actually receiving, so anyway the point here is that you get this P_1r. Now this optical power that comes in must go to a photo detector , now what would be the output of the photo detector it is a photo current, the photo current that you are going to get with a bit 1 will be the responsivity of the photo diode times whatever the optical power that we have received, which is R.P_1r our life would have been so simple if this is what we received, unfortunately what we receive is not just this mean photo current or the average photo current but also the short noise, right.

And what about the short noise well, we know the short noise variance so let us call this as σ_1^2 indicating that this is short noise when bit 1 is transmitted, this short noise depends on the mean photo current level, the larger the mean photo current or the larger the optical power you get a larger short noise variance.

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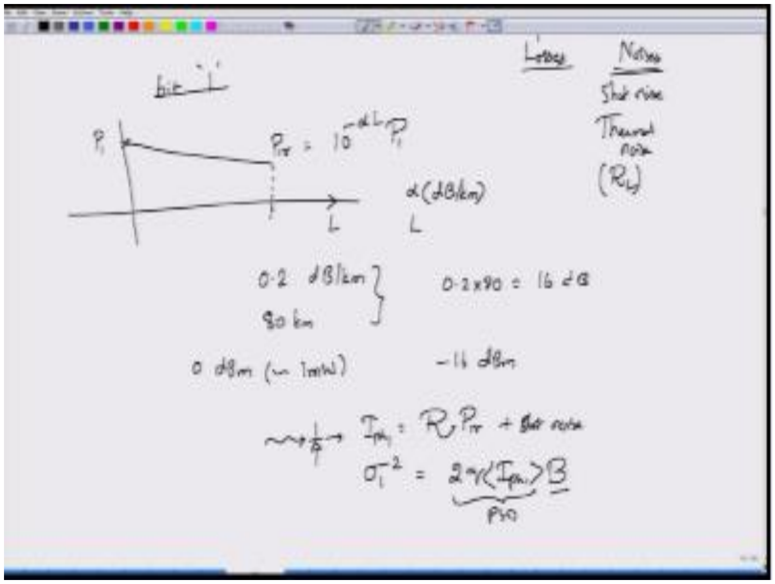

So σ_1^2 is given by 2q the mean value of the photo current which I am denoting by this brackets times so if you have an optical band width, sorry if you have an electrical band width of B then the total noise in that band width will be multiplied to the spectral density, so this is the power spectral density that you are looking at and then this is the band width that you are looking at, okay so you assume that optical band widths are the filter that you are going to put are pretty large in band width, okay.

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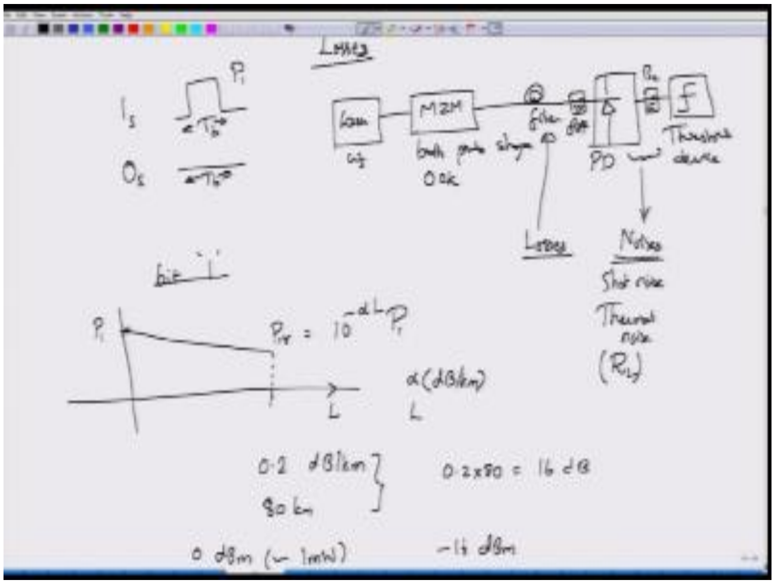

So normally before you even put this through the photo detector you put a optical band pass filter, okay this optical band pass filter band width should be sufficiently larger compared to the electrical band width and we have assumed that condition. After the photo detector amplifier you normally put a electrical band width Be or in fact that is a kind of integrated along with the photo detectors circuit itself in order to see what is the overall band width.

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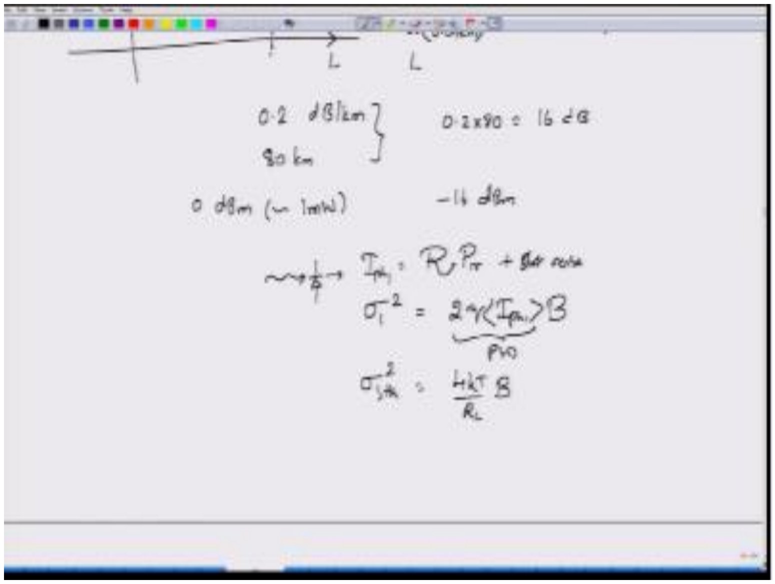

And I am not distinguishing between optical and electrical because I am assuming that optical band width is very large so I am only concern with the electrical band width and I have just written that one as B here, okay. So this is the short noise, there will be thermal noise as well, okay so when you have σ_1 there will be thermal noise assuming that this is a low across a low register what would be the thermal noise component it is $4kt/R_L$ B, right this is the current noise variance that we are looking at.

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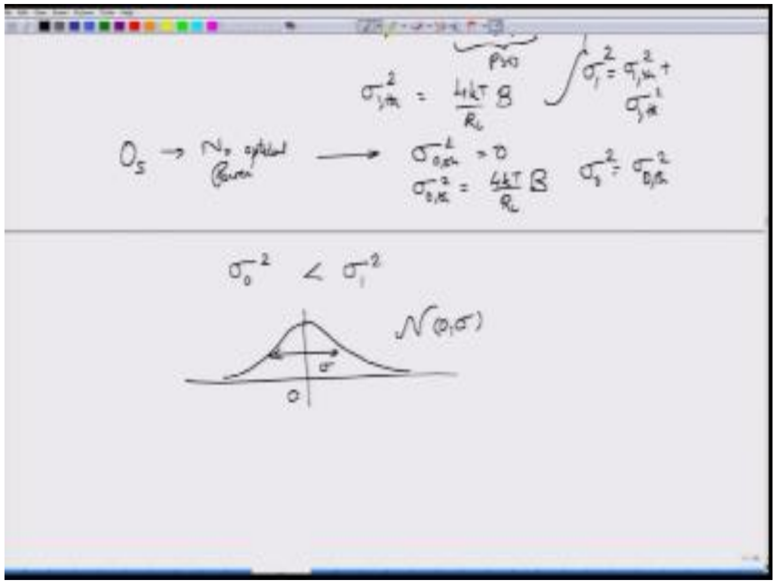

So the spectral density is completely independent of what the received optical power is. The case with symbol 0 is very simple with 0s you are not transmitting any optical power, so no optical power here so therefore there is no nothing that is being received so you do not get σ_0^2 right, σ_0 short noise, so let us write this as σ_1 shirt noise and σ_0^2 short noise is equal to 0 because there is no optical power and we have assume that all the back ground light is all gone, okay.

So what you get is only the thermal noise and thermal noise is independent of what you are actually seeing in terms of the optical power, and anyway in this case there is no optical power so this is the thermal noise. Clearly, the total noise variance, right which we can call as σ_1^2 will be the sum of short noise variance and the thermal noise variance, because these two processes are happening independently of each other we can combine the total variance.

We can obtain a total variance by adding these two together, okay and σ_0^2 here is simply σ_0 thermal noise square and one of the most important things that happen with an optical communication system a digital optical communication system is that σ_0^2 is less than σ_1^2, okay. If you assume these two are Gaussian random processes a typical Gaussian random variable the probability density of that is in the form of a Gaussian having a mean 0 and a variance of σ, okay.

We normally indicate that by writing this as N(0, σ) to indicate that the variance here is σ and the mean is 0, and in an electrical communication system this variance would be the same whether you transmit bit 1 or bit 0, because short noise is not there unless we are of course using devices which have short noise we will assume that we are not doing that.

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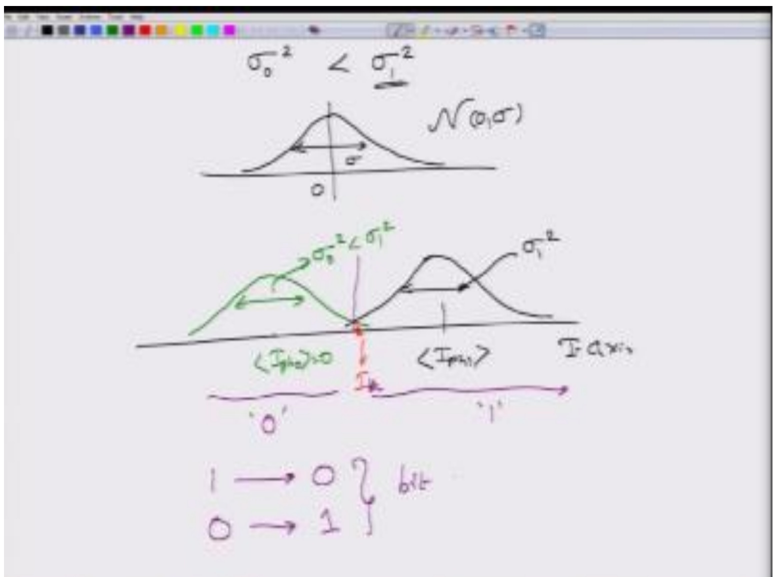

Because of the short noise that is present σ_1^2 depends on what is the optical power that is being received. In other words what is the photo current that determines the variance of the short noise which in turn determines the variance of bit 1, so when you transmit bit 1. You are transmitting anything on bit 0, okay you are transmitting only optical power on bit 1 which causes this is the current axis, okay so this is the I axis or the current axis. The mean photo current that you are going to obtain when you transmit bit 1 is non zero value here and it is given here and there is a certain variance of the noise process.

This variance of the noise process is because of both σ thermal noise square and short noise as well, so this is σ_1^2 that is the variance of this is concern with σ_1^2 what about 0 well for 0 the mean photo current is 0 because this is nothing that we are receiving but there is a variants of the noise process here okay which is dependent on the thermal noise hello one σ_1^2 which is less than σ_1^2 okay it might not look very obvious but the noise variant here is much more wide or the black one much more wider compare to the green one okay green one represents the current mean this is mean photo current.

So mean photo current iph of 0 = 0 to what is this threshold business that we are talking about when you suppose it we received this current okay please note that this is the increasing current axis when you receive this current here you can then go back and then look at what is the probability of this current value okay this is the received current this received current IR there is a certain probability of this to come from bit one and there is a certain probability that it must have been just a noise coming from IPH 0 that is to say coming from bit 0 transmission okay.

If you want to distinguish which one it is which and to minimize the errors in that decision you normally chose a certain threshold point the way to the threshold point here would be to chose the current as the point where these two probability density curves meet okay any current value that falls in this region will be attribute to bit 1 any current alls ion this region will be attributed to bit o wand when you send a one you might mistaken only classified as a 0.

If the value falls below this threshold which we can call it as I threshold if it is falls below I threshold then you might mistakenly consider this as a 0 if you transmit a 0 and because of the thermal noise the value of the current pushes above the threshold then you might mistakenly assign a one top 0 when you do that we say that your committing bit errors okay.

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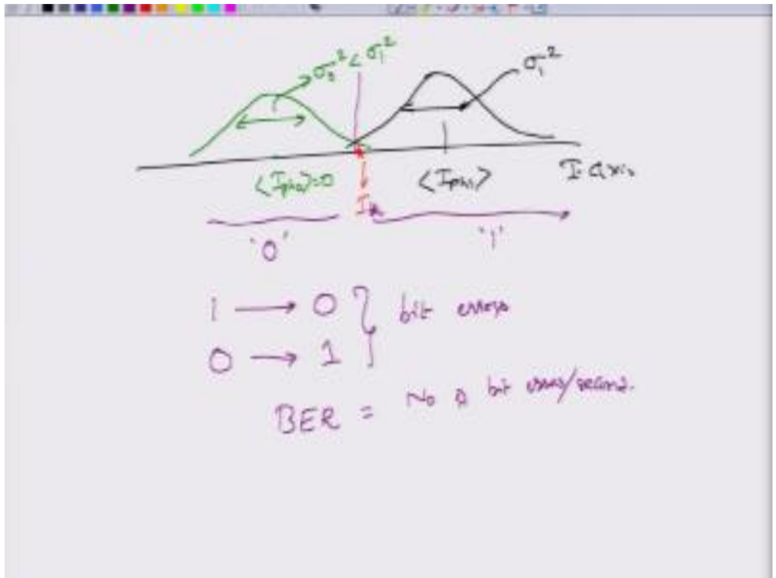

And we quantify this by saying how many bit errors are you making per second okay. So this is a number of bits that are there in error per second okay so number of bit errors per second okay so this is what the BER is and we quantify the system by this BER measure.

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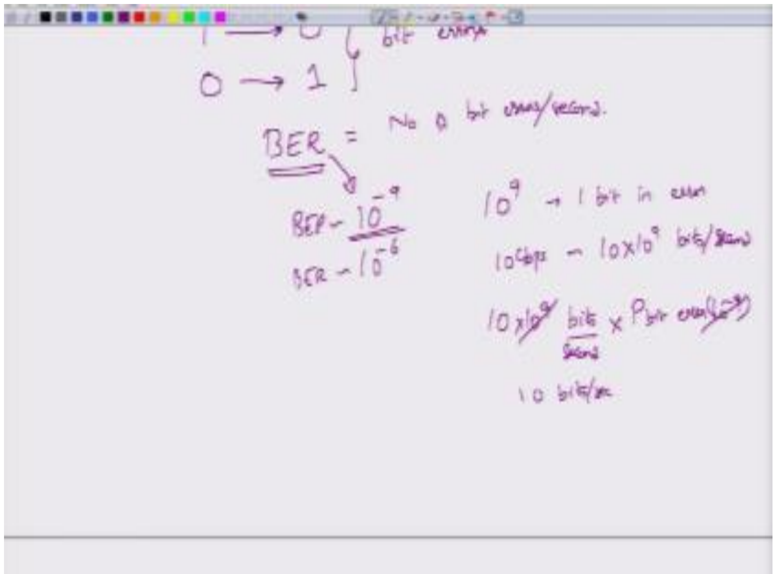

And you want this BER to be very small okay of course very would means 0 but unfortunately that is not the condition typical value of BER in the optical communication system at say up to 10 GBPS was around 10^{-9} okay these systems did not have any coding or anything so this was around 10^{-9} 10^{-6} was kind of acceptable but 10^{-9} was preferred what is meaning of 10^{-9} it means that you transmit 10^{-9} bits but one bit will be in error if the bit rate is 10 GBPS which means that you are transmitting 10 x 10^{9} bits per second and my probability of bit error is 10^{-9} then how many bits are there in error per second well 10 x 10^{9} bits per second and probability of bit error is 10^{-9} okay so when you multiply this cancels out with this.

So you are going to get 10 bits per second so that is the bit error rate this is bit error probability okay but the kalock will use is that you use the same value for bit error rate you do not really talk about bit error probability because kind of normalize it with the transmission rate or the data rate

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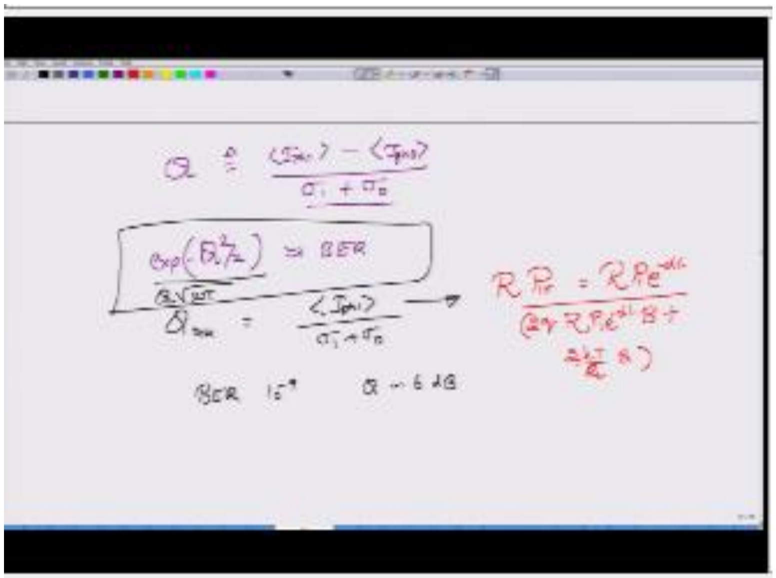

So this is BER in optical communication systems you also find another performance measure which is called as the q factor okay q factor is defend as iph1 which is the mean photo current that you are going to receive and transmit bit one to the mean photo current that you obtain when you transmit bit 0 / σ1-σ0 okay so σ1 correspond of course to the variant of the noise process when you have transmitted bit 1 whereas σ σ0 is the variants that you obtain after you have transmitted bit 0 okay.

So you can defined the q factor the relationship between q and BER is roughly that q2 exponential of –q2 / 2 is approximately the BER of the system this is σ1 + σ0 okay so this is not σ1- σ0 this σ1 + σ0 remember in electrical communications system σ1 – σ0 okay therefore they normally talk of either the signal power to the noise variants noise variants is usually defined as N0 or N)/2 depending one sided or two sided power spectral density.

So there is no specific difference between the noise process for σ1 that is for bit 1 and bit 0 here you have to distinguish between the two and clearly the q factor for the on off keying system will have only the mean photo current for bit one because mean photo current for bit 0 is 0 / σ1 + σ0 okay so this is what the on off keying q factor would look like and the relationship between the BER and this fellow if roughly that exponential of $-q^2/2$ /√2π x q, q x√2π is bit error rate okay.

So you can convert from the q factor to be here if someone gives you the q factor you can convert that in to corresponding value of BER and for a BER of 10^{-9} which was quite common in 10 GBPS optical communication systems the corresponding Q value is about 6dB, okay and if q>6dB well the BER is actually less than that , okay, so that's the point and you if q is small the BER of course become large, okay.

So this is all about the performance of the system and as you can clearly see the performance is determined more or less by the loss, why is determined by the loss? Well what is the photo current that you have received, the photo current that you received is R_t $P_{1r,}$ itself is given by P_1 $_{10}{}^{-\alpha l/10}$ when you express α in terms of $d_{B\pi}$/km, you might want to write down $10^{-\alpha/10}$ if you want to express this one in the natural units, of nipper per meter, then this would be $e^{-\alpha l}$, okay.

So let's say whatever that is, this is the received optical power multiplied br r will give you the mean photo current, divide this one by the total noise variance, right so you have $2qRP_{1e}{}^{-\alpha l}$ B+2Kt/R_l× B, so can probably put B as a common factor, and then take it out and then you evaluate this one, so this is what is going to be the Q factor, okay.

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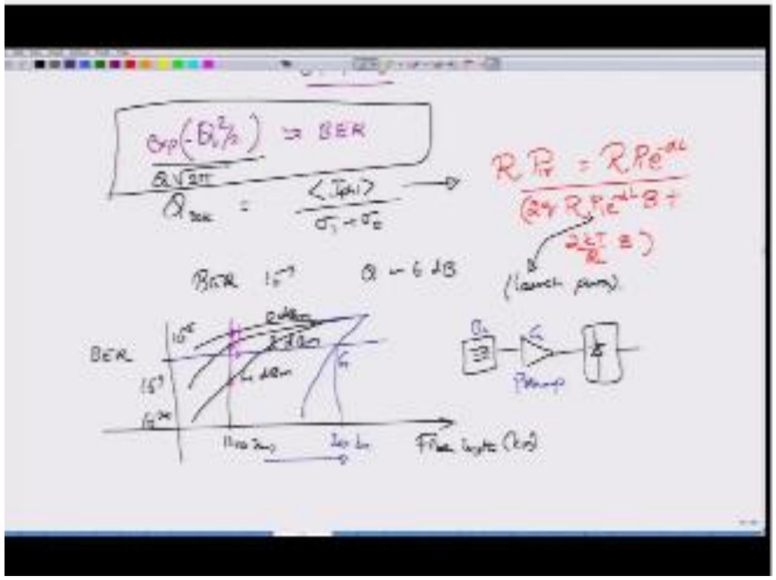

So if you plot the BER, as a function of the fiber length okay, so as the function of fiber length for different launch powers, launch powers mean different values of Pn right, this is the power that I am launching , so this is called as launch power, and in this case the launch power is , the power that is carried by the bit 1, okay, so if you look at fiber length in kilo meter versus BER, for let say about 10 to the power, for 0 d_{Bm}, the BER more or less is about 10^{-5} , this is not, this actually depends on the system, I am just giving some values which kind of making sense for a typical 10 GBPS systems, okay so with a 10 GBPS system, with an electrical bandwidth of 7.5GHz, and Rl of 1 k Ohm with the responsibility assume to be 1 amp/watt this is what the BER.

Is of course fiber losses 0.2dB/ km, now this is not even meeting or specifications right? So this is not even meeting or specifications and this is not something that you would like to use for, if you want to use this system then what you would like to do? Would be to increase the launch power, so if you increase the launch power then the BER starts to go down, okay.

With this 0dBm launch power the BER is not even going below 10^{-5} but if you use the say 2 d_{Bm} launch power, then you might be going below to 10^{-9} okay, so this is already sufficient, in case you increase your launch power further, then the BER goes down to 10^{-20} or 10^{-25} this would happen for at the 4 d_{Bm} system, and all this values so if you look at this particular line which I have drawn this is for 140 km, you know according to the calculations for the system values that we did.

So you that this values actually increasing as you reduce the optical power, on the other hand if you increase the optical power the BER of the system starts to decrease, now this is all for a system without any amplification in the middle, okay suppose I put an optical amplifier , followed by a band pass filter or rather I should put a band pass filter first and then follow it up by an amplifier, so if I do this kind of a receiver before I give it to the photo detector and hence for the further processing.

These curves will undergo a drastic change, the curves will actually for higher lens they will add kind of converge but at lower lens of the fiber they would actually exhibit a behaviour that goes like this, this of course depends on what is the gain of the amplifier that you are looking at and what is the bandwidth of the optical filter that you have, but the general idea is that with this amplifier at the input of the receiver side this is called as the pre amplifier.

With the pre amplifier you are able to meet les say this is the target 10^{-6} you are able to meet the 10^{-6} target write at a very large length, so let's say this is around 200 km, so the use of an optical pre amplifier is to extend the range over which you can communicate, so from 140 km, you can go all the way up to 200 km, okay this is all about the performance measure of the ON, OFF keying systems which is disturbed only by the loss, in the next module we are going to look at the performance measure when there is chromatic dispersion , right so before we go there, there are some work sheets that I will send out, so please solve some of the exercises, you have to reproduce these scraps for the parameters that we send in, thank you very much.

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