Advanced Optical Communications

Prof. R. K. Shevgaonkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture No. # 25

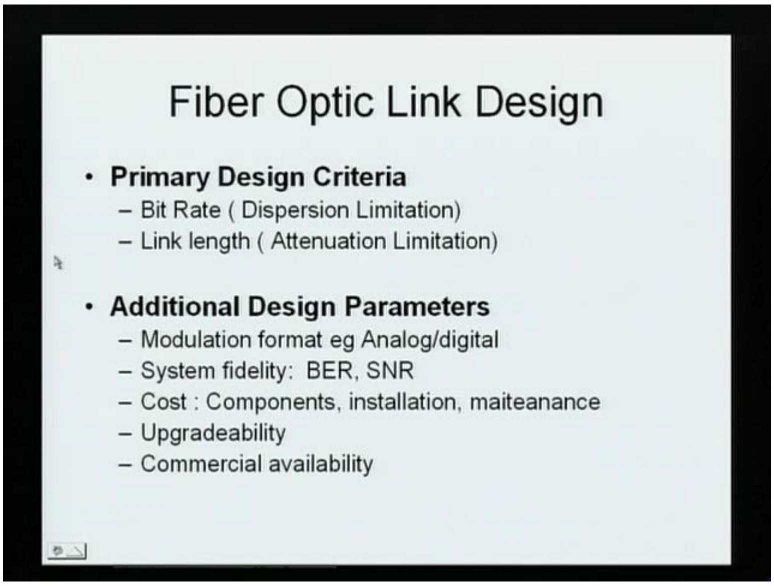
Fiber Optics Link Design

Up till now, we discussed the various components, which are required for a optical communication link. In the beginning, we discussed the medium, which is the optical fiber. We saw that on fiber when the signal is transmitted, there is the distortion and also attenuation; and distortion is characterized by dispersion parameter. Then we saw on the transmitter side, we have a device, what is called the optical source, which could be an LED or which could be a laser diode, and then these devices have certain characteristics, they have a spectral width, they have a finite bandwidth; they have some efficiency factors; and then on the other side of the optical communication link, we have an optical detector and amplifiers and all together we call that is the receiver; and we saw its characteristics, the contribution of noise. How do we calculate the bit error rate, which is the performance parameter for the digital data.

So, up till now essentially we have covered most of the primary components, which are required for designing an optical communication link. So, in fact after learning in depth, these different modules of the optical communication system, the topic what is called the optical fiber link design is rather straight forward topic. Essentially, what we are saying now is that with the knowledge which we have gained regarding different modules, how do we assemble together? And essentially find out what should be separation between the repeaters, when we design a long distance communication link.

So, idea now here is that we have certain performance parameters for optical communication link, which could be either BER, if it is the digital communication link or it could be signal to noise ratio. If it is an analog communication link, and then we ask how far can I go? So that these parameters do not go below the acceptable limit and at that location, when the parameter start deteriorating below the acceptable limit, essentially we have to regenerate our data, and that is what is done by module what is called repeater. So, the link designed essentially is finding out the location of the repeaters in a long distance optical communication link. So, in this lecture, essentially we are going to discuss, what is called the optical link design.

(Refer Slide Time: 03:50)



So, we have here the criteria for designing an optical link and we can design the optical communication link based on certain criteria. So, we can device these criteria into two categories. One we call as the primary design criteria, which is one is ofcourse the bit rate. There is essentially the information which I can sent on a given link and seen the information is going in the form of bits or pulses; higher the bit rate means more information transfer. But as we have seen that when the bits are transmitted on the optical fiber because of dispersion, the bits essentially broaden is spreading of the pulses. And then for a given distance, there has to be a minimum separation between the pulses.

So, that they do not overlap with each other. So, one of the primary criteria for design is what is the data rate we want to send on the required optical link. So, user essentially specifies this is the bit rate I would like to transmit on this optical link. The second thing over what distance this data is to be sent which we call as the link length and this is now essentially related to the loss or the attenuation of the signal on the optical fiber. In addition to this, then we can have some more parameters for designing the link. One is what is the modulation format, we are going to use. If you are having the television kind of transmission, we can say the signal in the form of analog just to save the bandwidth.

If you are sending data, then the signal has to be sent in the digital format. Also within the digital format also, we can use different formats like you can use the amplitude shift keying or we can use the frequency shift keying or the phase shift keying, if your laser is very narrow band laser. And we can have the analog modulation which could be amplitude or we can have some kind of a sub carrier modulation and then we can modulate this on the optical carrier. So, this is modulation format would be one of the additional parameters for designing the optical link. There has been mentioned earlier, we have the parameter what is called system fidelity which is measured essentially in terms of bit error rate for digital system and the signal to noise ratio for the analog system.

In addition to that for a analog system, we also require the knowledge of what is called the inter modulation products. So, it is not only that the signal should remain above the noise; but the signal should not get distorted. Because if the signal get distorted, essentially it generates certain frequencies and these frequencies may lie in the neighboring bands and can create interference. So, when we talk about analog communication link, we also have to talk about what is called the inter modulation products or how linear our system is. So, that the inter modulation products are as low as possible.

Then we have the considerations like cost and the communication link has essentially three cost components. One is the cost of the various modules which are going to be used in the optical communication link; so the cost of transmitter, the cost of the fiber and the cost of the receiver. Then we have a cost what is called the installation cost and in this case, the installation essentially means laying the fiber of the cable, which requires substantial trench work civil work. So, we have a substantial cost incurred in laying the optical fiber cables and there ofcourse we have electronic installation which is on the transmitter and receiver side.

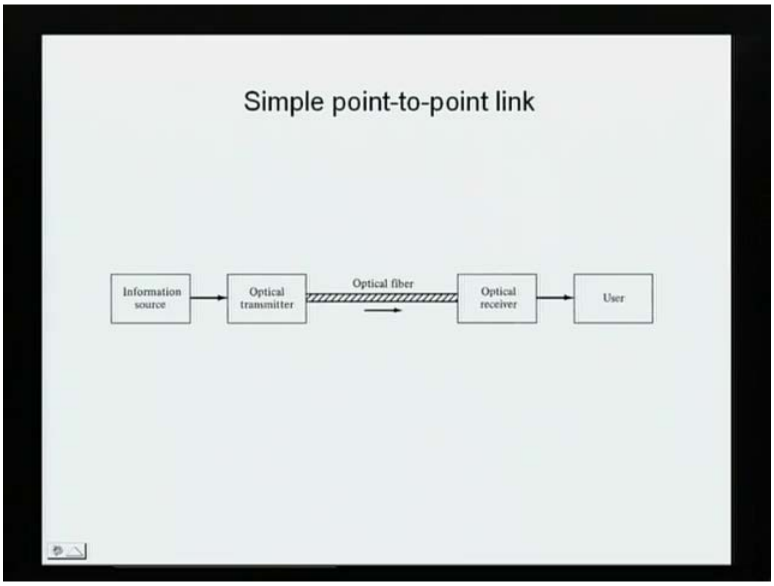
But infact for optical communication link, the installation cost for transmitter and receiver, they are negligibly small compared to the installation of the optical cable. Infact, whenever the optical cable is laid, the cable does not come with single fiber. Normally, the optical cable has multi cores. So, they have multiple fibers. For one communication link, you require only one fiber. But since the installation cost is substantial, when the fiber is laid normally a multi core fiber is laid; keeping in view that some later date, there will be more need for the bandwidth and then the multiple fibers can be useful in meeting that requirement.

So, installation cost is one of the major components of the optical communication link. The third thing which is important is the maintenance of this link; because the system is going to be laid over a distance of hundreds of kilometers and this is going to go into various environments. So, one requires a good maintenance of this cable. So, that the communication performance does not deteriorar, as the time progresses. Also when we talk about the maintenance of an optical communication link, typically we expect that atleast optical fiber which is the passive component of the link should last for 20 to 25 years and that is the reason, we incurs substantial cost into this.

Because the time scale which we are talking about is quite large. Then since the technology is not very static and if you look at the advancements which have taken place in the technology, there are rapid changes even over a span of about few years. So, if we design an optical communication link by the end of its life which is 20 years let us say, most of the technology is going to be oscillate. Because electronics it changing very rapidly. So, what that means is that then we should design the systems electronic systems, which are going to be connected to the optical fiber should be easily upgradable; that means with minimal change in the systems which are connected on either side of the optical fiber.

Your system should be able to accommodate the new technologies. It should be able to accommodate the new requirements on the communication link. So, they should be good upgradability possible in the fiber optic system and lastly, but not least that the component which you are talking about for the link, they must be commercial available at low cost; because there are always certain restriction on the component availability. So, when we design optical communication link, the commercial availability over a sustained period; because we have to maintain this link would be one of the important aspects of the design of a communication link.

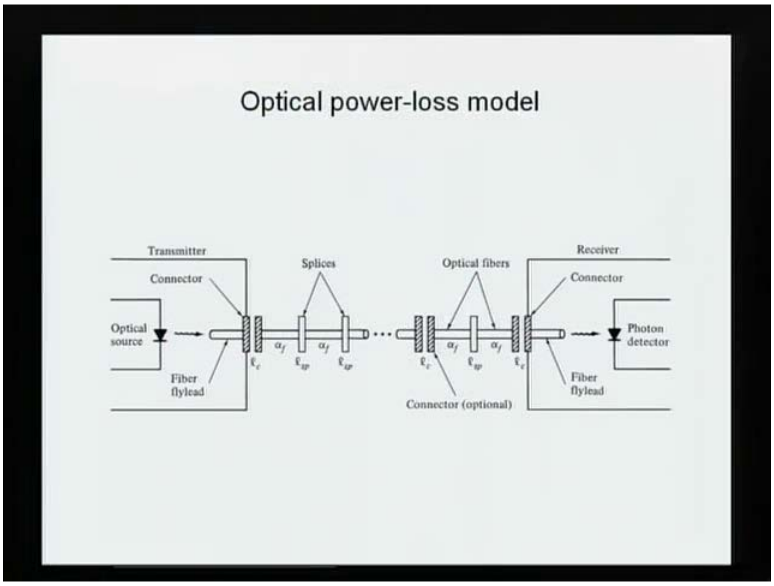
(Refer Slide Time: 12:57)



Once we get this parameter fixed, then let us consider the simplest possible link which we call as point to point link; that mean essentially we have one location, where the information is generated and there is another location, where the information is to be delivered. So, we have a source of information and we have a destination for that information and this information has to be carried in the form of light from one location to another location. So, then we have a simplest possible configuration which is information source. We supply the electronic information to an optical transmitter, which essentially consists of a driver and an optical source like LED or laser diode.

Then the optical signal is connected to optical fiber; signal travels. On the other side, the signal is detected by photo detector given to electronic circuit, amplifiers, decision makers and so on. And then you can generate our information back on the receiver side. So, when we are talking about the point to point link design, essentially we are saying that we have to choose these modules; you have to choose these modules; you have to choose the appropriate optical fiber and then for given values of these parameters for transmitter and receiver and the fiber. Find over what distance this information can be sent reliably; that essentially is the process for optical link design.

(Refer Slide Time: 15:02)



So, let us see if I now go to these modules which we have for the optical link point to point link, then on one side we have a transmitter which is optical source. Optical energy from the source is coupled to the optical fiber through a connector. Then the optical signal travels on the optical fiber. Now, seen this length could be of the order of about tens of kilometers. The optical fiber does not come in one stretch for that length. So, normally you have standard spools of optical fiber. So, if you do lay a long optical fiber, essentially you have to create joints of this optical fiber what we call splices. So, these are the sections of optical fiber which are joint here in the form of splices and then you go and doing it.

There may be certain test points where you have to put connectors; so that, fiber can be connected or disconnected for measurement purposes and like this, you reach to the other end where again through the connector, the optical fiber is connected to the receiver which is photo detector and you convert the light into the electronic form. Now, each of these components which you are seeing here like a connector or fiber section or is splice. Each of this essentially contributes to the loss of the optical signal. So, each one essentially has the best parameter for the loss or average parameter for the loss. And when we signal travels on this essentially at every location, additional loss takes place at this splice and at the connector.

(Refer Slide Time: 17:10)

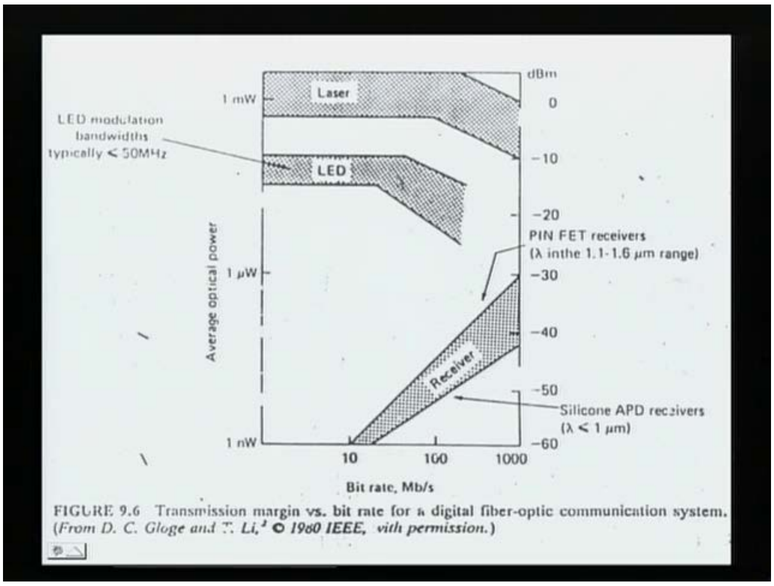


FIGURE 9.6 Transmission margin vs. bit rate for a digital fiber-optic communication system. (From D. C. Gloge and T. Li,[3] © 1980 IEEE, with permission.)

So, now the first step which we have now is to choose the sources in a transmitter side. So, here essentially we are saying the optical power which you can get for different sources like a LED's or lasers. And as you seen earlier for LED, you can get a power which would be 100 microwatt or few hundred microwatt. But you will not be able to get power more than this because of the efficiency constraints on a LED; whereas, if you go to the laser diode, then we can get power of the order of about few milliwatts. Also what we know from our early analysis that this is the power with a laser has.

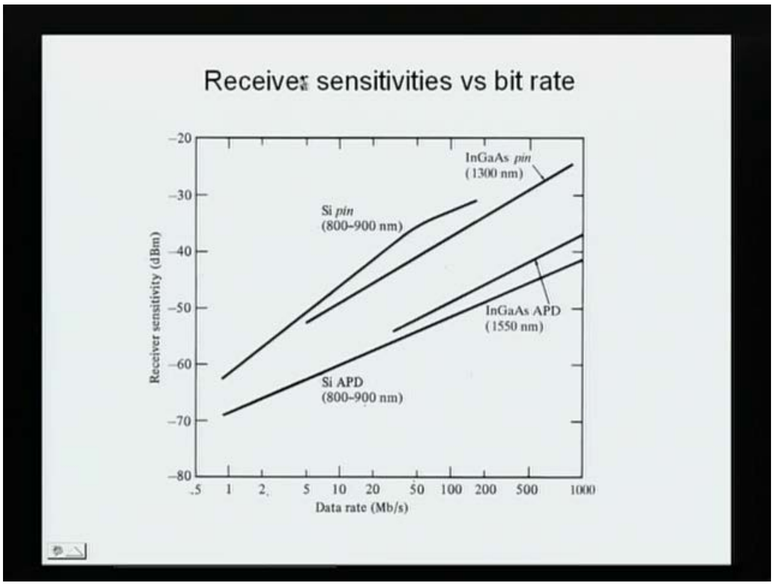
But if you modulate this optical source, then the fluctuating component of light reduces as the frequency of modulation increases; that means even if the laser is supplied the power, as soon as the data rate becomes higher and higher. The effective power supplied by the laser becomes smaller and smaller and same is to for LED, where essentially all these are junctions p n junctions which are essentially the low frequency filters. But typically if you are using the laser diode, then the transmitter has 1 milliwatt of power. And normally, the power in optical link design is measured in terms of what is called dBm; that means we say 1 milliwatt is taken as reference power.

So, every power is measured with respect to the 1 milliwatt of power. So, if we convert this power in terms of dB ratio, then 1 milliwatt power essentially is 0 dBm and every factor of 10 increase in power, you have a 10 dB increase. So, that means 10 milliwatt of power will be 10 dBm; 100 milliwatt of power will be 20 dBm and so on. Typically, when we talk about the optical receiver transmitters, we typically have the powers which range between minus 3 dBm to about plus 3 dBm; that means about half of a milliwatt to about t 2 milliwatts; that is the typical power which we will see from the transmitter, if you are using a device like laser.

So, as the data rate increases, the important thing to note is that the power supplied by the source reduces. The same plot also is giving now the minimum detectable power required for a given bit error rate as a function of the data rate or the bit rate. So, as you are seen in the presence of noise as the data rate increases, we have to essentially pump more and more power into the system. And we have seen that for the loop thermal noise dominated case, it goes as the square root of the bandwidth. So, as the data rate increases, essentially the minimum required power increases and that is what is shown here.

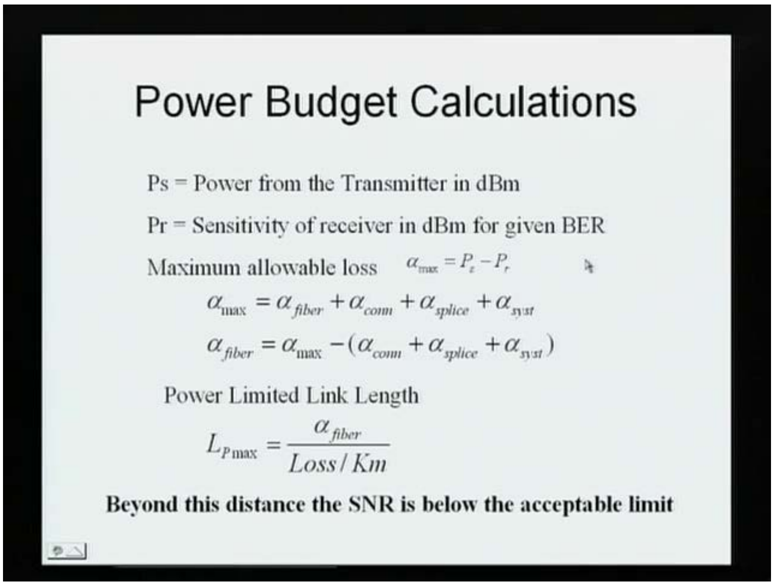
That if we use the simple PIN diode or the APD avalanche photo detector, then that is a kind of power range which would need. Say, if we go to about 1000 megabits per second, you will require a power of something like minus 40 dBm; whereas if you go to 1 gigabits per second which is 1000 megabits per second, you would require power about minus 30 dBm. So, typical power level which the receiver must get to get a BER of typically 10 to the power minus 9, the received power must lie in the range of minus 30 to minus 40 dBm.

(Refer Slide Time: 22:16)



The same thing essentially showed here that there receiver sensitivity versus the bit rate. So, here again we are showing the minimum power required for detection and that is the data rate which is shown here and these are the responses for the different detectors. So, for the silicon that is the wavelength range; indium gallium arsenide which is at worser 1300 nanometer; that will be the typical requirement of the power and indium gallium arsenide APD 1550 nanometer; that is the power requirement and so on. So, now I can choose the appropriate photo detector depending upon the band of optical window. It could be either 1310 or 1550 and then I can from the data rate which the user is specified for that communication link, I can now find out what is the minimum power required on my detector.

(Refer Slide Time: 23:28)



So, essentially we have now decided the optical source with certain optical power, which it is capable of delivery for that data rate and we also have now the minimum power which we must receive at the detector; so that, the signal to noise ratio is adequate to give the required bit error rate. So, essentially now we have got these two quantities. But you call P s, which is power from the transmitter in dBm and P r, which is the sensitivity of the receiver in dBm for a given BER for a given data rate. So, now you are asking a question if these two parameters transmitter and receivers are fixed, what is the maximum length of fiber including all splices and connectors over which we can send the signal satisfactory and this calculation is what is called the power budget calculation.

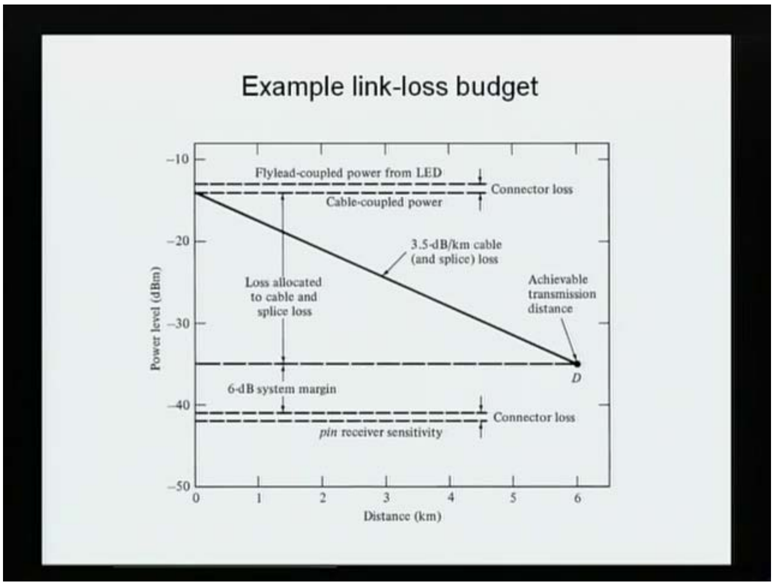
So, essentially we are accounting for the power losses at various levels in the communication link and those loses must be less than the difference between the transmitted power and the received receiver sensitivity. So, if you have the transmitted power P s and the received power is P r, then the difference between these two is essentially the maximum allowable loss in terms of dB. So, here every quantity in terms of dBm; so P s is in dBm; P r is in dBm. So, different of these two gives you in dB; that means the loss in terms of dB is P s minus P r. Now, where is the power lost on the optical fiber? The loss power is lost in various components. It has lost in the fiber first of all. Then some power is lost into the connector; then some power is lost into the splices.

And then normally what we do is we provide some system margin that as the time goes, the system performance deteriorate; because your detector gets eject. So, its response goes down; its sensitivity changes. Also because of the aging of the laser, the power supplied by the laser keeps changing. It reduces as a function of time. So, as the time progresses, the laser power reduces; so, this quantity p s reduces. At a same time, p r requirement increases. We got the sensitivity of the receiver degrades and this must be accounted for while designing the optical link. So, normally there is some margin left with you what is called the system margin. So, from here now essentially you want to find out what is the loss in the fibers which is possible.

So, alpha max is known from this P s minus P r and all this connector losses are known. Ofcourse, this splice loss also is proportional to the length in some sense; because if you use the fiber spools of standard length and as the length increases, the numbers of splices are also going to increase. So, typical loss which will get for the splice would be of the order of about 0.05 dB; whereas, connector may give a loss 0.1 dB something like this. And a system design, the specification generally is that one must keep the system margin which is 6 dB. So, once we know now these quantities, we know the maximum allowable loss; we know the loss in the connector; we know the loss in splices; you know the system margin, then we can find out what is the maximum loss permitted in the link.

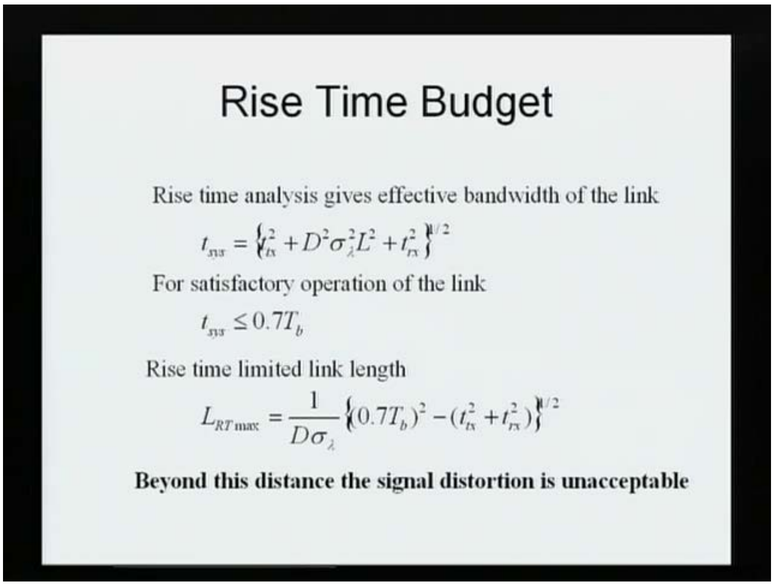
And once I know the quantity alpha fiber, if I divide this quantity by the attenuation constant of the fiber which is loss per kilometer, we get the maximum possible length over which the system will behave satisfactorily. So, this link length or this length we call as the power budget limited link length. What that means is that if we send the signal beyond this distance, then the signal to noise ratio will go below the acceptable limit and therefore, your BER will be less than the specified value. So, the one calculation which one does while designing the optical link is what is called the power budget calculation is essentially balancing the of the powers at various locations on the optical fiber. And that is one limit which you get for the optical link length, beyond which the signal to noise ratio is below the acceptable value.

(Refer Slide Time: 29:35)



The same thing has been shown essentially graphically here. So, we have a power level which you are transmitting. Then this is the minimum detectable level which has to be made to give for a given BER. We are providing about 6 dB system margin. So, that means this is the power difference which is available for loss inside the optical fiber. So, if there are no other splices and connector, essentially the power will decrease linearly and where this line essentially intersects this line; that is the length of the fiber in kilometers. So, the one calculation which one does in the optical link design is the power budget limited length which tells us that beyond that length, the signal to noise ratio goes below the acceptable limit.

(Refer Slide Time: 30:44)



The second calculation which does which essentially tells you what kind of data rate can be sent is what is called the rise time budget. Now, as we know that the system bandwidth and the rise time of the system are inversely related, larger the bandwidth of the system shorter will be the rise time. So, if we transmit a pulse which has the sharp edge, we will see that the sharp transition of the optical pulse if you have a substantially large bandwidth. So, essentially bandwidth calculation here we are doing in time domain in terms of what is called rise time and the rise time has different components. You have a rise time associated with the laser; I mean how fast the laser can be switched on and off.

You can have a rise time for the detector; again how quickly the detector responds to the fluctuations in the light intensity and then you have the equivalent sort of a blurring of the optical pulse because of dispersion on the optical fiber. So, we define what is called a system rise time and assuming that these quantities are independent and each one is going to give you a blurring. We can define the root mean square value of the rise time and that is what we call as a system rise time, which is t system. So, this is equal to the square root of the sum of the squares of the transmitter rise time, the rise time associated with the dispersion and the rise time associated with the receiver.

So, D is the dispersion parameter of the optical fiber; sigma lambda is the spectral width of the source or the laser or the LED which is used for the transmitter and L is the length of the optical link. Now, the standard is that for a satisfactory reception of the bits, the system rise time should be less than 70 percent of the bit duration. So, if we take the data which is let us say simple n or z data; where over 1 level of the bit, the optical intensity remains high for the entire bit duration and for 0, the optical intensity is 0; then the bit duration which we have is let us say is given by T b. So, the system rise time should be less than 70 percent of the bit duration; whereas, if we consider what are called the return to 0 data, where the 0 is indicated by no light.

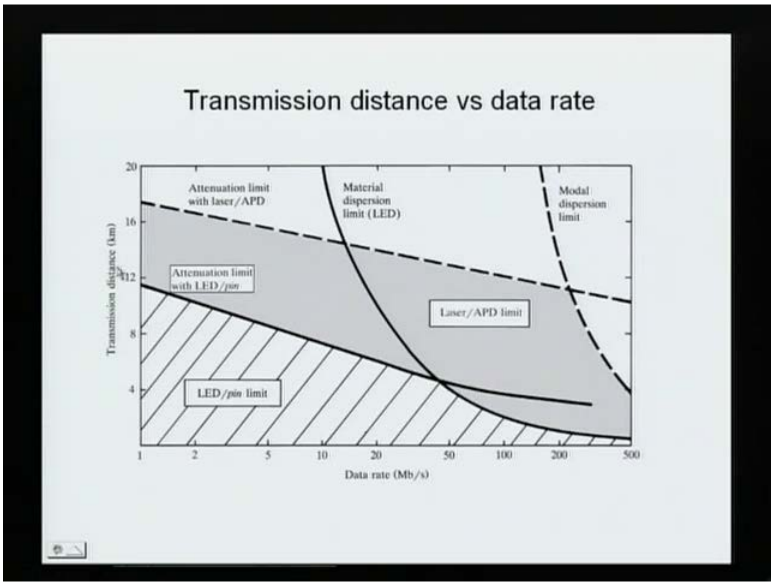
But 1 is essentially indicated by a pulse of duration of half the bit duration. Then essentially the effective pulse width will be half of T b bit duration and then the system rise time has to be essentially 0.35 of the bit duration. So, depending upon what kind of format we are using for the bit transmission, the t system will change; requirement will change. So, for a non-return to 0, the t system has to be 0.7 of T b. If it is return to 0 data, then t system will be less than 0.35 of T b. Once I get that, then I can substitute for t system in to this and invert this to find out what should be the maximum value of L to get that t system smaller than this quantity. So, if we do that, we get L rise time maximum length that essentially is given by 1 upon D dispersion parameter spectral width of the source and this quantity here.

Now in this also generally the transmitter rise time is much much smaller compared to the receiver rise time. The receivers essentially have a bandwidth which is much narrower compared to the transmitter, especially if you are using the DFB lasers and that kind of thing. So, normally this is the quantity which is very small compared to the receiver rise time. Nevertheless once you have these quantities now with us, then we can calculate what the maximum possible length over which the system rise time will remain less than 0.7 of the bit duration. Or what are we saying in other words is that what the maximum distance over which the signal distortion remains below the acceptable limit.

Or in other words, we are saying beyond this distance RT max, the signal distortion will become unacceptable and this length we call as the rise time budget limited link length. So, now we are having two lengths. One is the power budget limited; other one is rise time budget limited. Over the power budget limited link lengths, the signal distortion is acceptable. It is not excessive. But the signal to noise ratio is unacceptable; whereas, when I go to this length which is L R T beyond this length, the signal distortion becomes unacceptable and see here signal to noise ratio may be (( )). So, in either case whether signal either signal to noise ratio is gone below the acceptable value or the distortion has become unbearable. We have to regenerate our data.

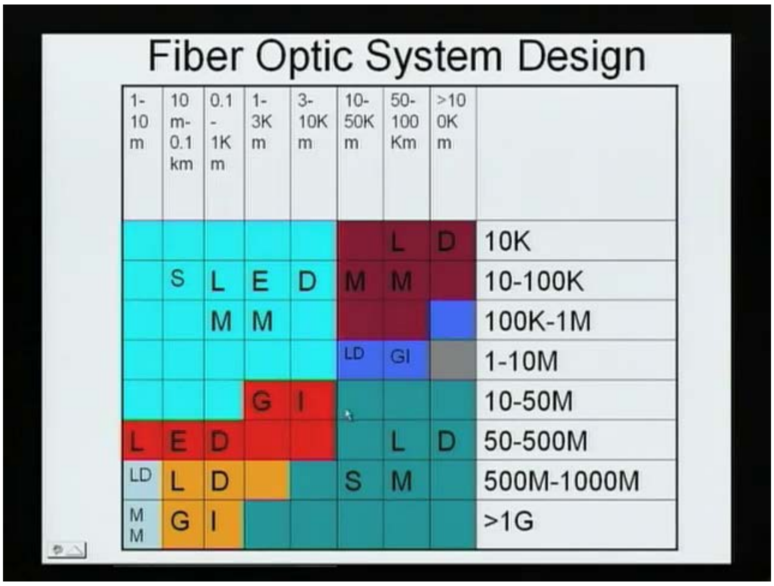
So, essentially smaller of the two; this value (Refer Slide Time: 23:28) L P maximum or this quantity L R T maximum whichever is smaller of these two; that is the location where we have to regenerate our data. And invariably, it so happens that the power budget limited length is much smaller compared to rice time budget length. So, invariably you have to regenerate the data at a distance where signal to noise ratio has gone below the acceptable limit, though the distortion in the data may be manageable. So, we are not regenerating the signal; because signal is become distorted enough. But we are simply saying the signal to noise ratio is not acceptable anymore and because of that, we have to regenerate the data. So, we have to essentially put the repeater at that location.

(Refer Slide Time: 39:25)



So, here essentially we are seeing now a plot of the data rate and it is the transmission distances in terms of kilometers and these are the different combination which we have. So, we can have material dispersion LED this could be the curve or you can have a modal dispersion which could be curvature. So, this plot essentially tells you that for different combinations of sources and the detectors, you can have the different transmission distances.

(Refer Slide Time: 40:08)



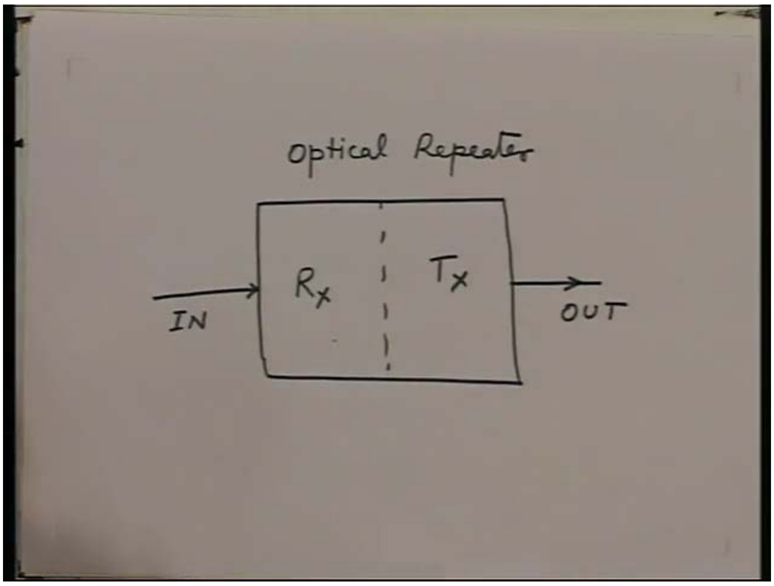
The same thing essentially has been summarized into this slide here. So, what we have done? These are now the distances starting from very short distances. So, this is 1 to 10 meters; this 10 to 100 meters; 0.1 kilometer to 1 kilometer; 1 to 3 kilometers; 3 to 10 kilometers; 10 to 50 kilometers; 50 to 100 kilometers and greater than about hundred kilometers and these are the different data rates which you have. Start with the very low data rates like 10 k or like what do you signal and can go as high as few gigahertz or few gigabits per second. So, these are the different combinations of the source and detectors which we get. So, here we are a having SLED, which is surface light emitting diode and multimode fiber.

Recall, multimode fiber has a large dispersion. So, this can essentially work for low data rates and also can work only very short distances. So, surface LED and multimode fiber combination is the good combination for something like local area networks, because these are the kind of thing which we are talking about are the low data rate, which are there on the ethernet kind of structures and where distance is also are small and local areas. So, this is the good combination. When the distance becomes large even for low data rates, we require large power and then you have to go to the source, which is LD laser diode though dispersion may not be very significant. So, we can use still multimode fiber.

But the source has to be laser diode, because the power requirement is large. Then we are having the other extreme, which is the large distances and the high data rates. And in this situation, essentially one has to take the source which is giving high power which is laser diode and then you require low dispersion also, because the signals are going to travel over very long distances which is this. So, we require a combination which is laser diode and the single mode optical fiber. So, essentially what this plot gives is the combination of source and the fiber for different distances and for different data rates. So, with this help of this now and with the help of the calculation for the transmitter parameter receiver parameters and the optical fiber, one can essentially find the location of the repeater.

Now, what does the repeater consist of? At the repeater, essentially what we are doing is we receive the light and since now, the signal to noise ratio has reached to non-acceptable level or deterioration is enough. Essentially, we have to electrically regenerate our data. So, essentially what we have to do at the repeater is we have to receive the signal. So, a repeater has a receiver which receives the optical signal converts to electronics; cleans it; regenerate the data electronically. Then it regenerated data is given to optical source transmitter, which converts the electrical signal into optical signal which is now given further to the next section.

(Refer Slide Time: 44:28)



So, essentially what we are saying is that a optical transmitter is placed with back to back with a receiver to make a repeater. So, we are having what is called the optical repeater and what essentially this is doing is it is having a receiver here and this having a transmitted here. The signal is received from here detector converted into electronics;

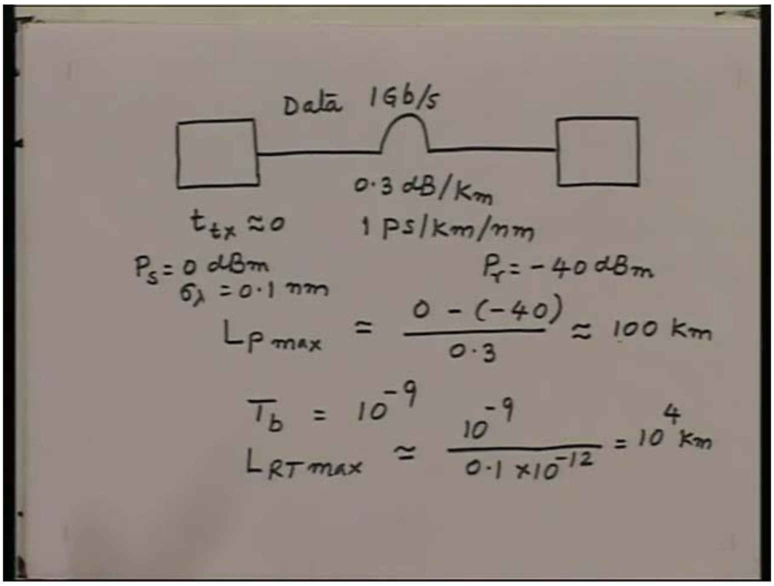
clean; supply to the transmitter and the signal is send again in the optical form from here. So, essentially an optical repeater is the back to back receiver transmitter combination. So, you have a substantial cause now in a repeater; because you require the entire electronics which you will require on the receiver side and you will have the transmitters, which are exactly at the starting point.

So, for a long length of the link when we talk about, essentially we are going to put transmitter and receiver periodically on a long optical communication link. So, installing a repeater actually is an expensive option; but since we do not have any alternative. If the even if signal to noise ratio goes down or signal is distorted any of these two cases, essentially we give the signal to the repeater and signal is regenerated and convert into light again. However if you ask this question that suppose you are not in optical domain; suppose we were in the electronics domain; suppose we are talking about let us say a radio communication link and suppose it some point in the link the signal to noise ratio goes below the acceptable limit.

But the signal distortion is manageable. Would we regenerate the signal at that location? And the answer is no; we will not do that. Since the signal distortion is still manageable, only signal to noise ratio is gone down. So, we will try to add an amplifier at that location and then beyond that point, again signal can travel. Whenever again if signal to noise ratio goes down; but if the distortion is acceptable. We can put another amplifier at that location and we can go on putting amplifiers in the radio communication link. Why then we have to put a repeater in an optical communication system? And the answer to this is that till about a decade back, there was no good optical amplifier available.

So, even in those situation where a simple amplifier would have surprised. We had to put a repeater; because there was no suitable optical amplifier. But if you are having a situation where signal to noise ratio becomes a problem, essentially we can use an amplifier optical amplifier and the entire process of conversion of the signal from optical to electrical back to optical that essentially can be avoided. So, we will discuss the optical amplifiers as we process. But just to give a feel how many… for example, amplifiers one could install in a typical link and how important the amplifier in mention is in the optical communication link.

(Refer Slide Time: 48:45)



Let us say I am using a transmitter of laser and let us say the rise time for the transmitter is negligibly small. So, let us say t t x is very close to 0. Most of the essentially rise time is coming let us say from the optical fiber and let us consider an optical fiber, which is single mode optical fiber. Let us say the transmitter is transmitting a power, which is let us say 0 dBm; that is 1 milliwatt 0 1 milliwatt and the minimum detectable power which I require here is let us say minus 40 dBm and a typical fiber has a loss let us say about point 3 dB per kilometer. So, if you calculate now the power budget length L P maximum, assuming that there are no splices and other thing just for simple calculation.

This would be approximately this 0 which is P s; this is P r; So, P s minus P r; so minus minus 40 divided by this thing, which is 0.3 dB per kilometer. So, we get about approximately about 100 kilometer as the link length and that is the typical situation which we see in the optical communication link. Because this is the typical power which we transmit; this is the power is required. So, that means the signal to noise ratio becomes unacceptable beyond a distance of about 100 kilometer. Let us say this fiber is a single mode optical fiber, where let us say dispersion is that say 1 picosecond per kilometer per nanometer.

And let us say I have a transmitter here which has a spectral width sigma lambda, which is 0.1 nanometer and let us say I am transmitting now the data rate of 1 gigabits per second. So, here data is 1 gigabits per second. So, that means the bit duration now is 10 to the power minus 9 1 nano second. So, my T b in this case is 10 to the power minus 9.

The dispersion is this per kilometer per nanometer. So, over per kilometer we have this multiplied by spectral width; 0.1 picosecond is the broadening of the pulse. Now, I have the L R T max which is approximately 10 to the power minus 9 divided by 0.1 picosecond. So, which is 10 to the power minus 12.

So, if you see this quantity is now something like 10 to the power 4 kilometers; that means if we consider a DFB kind of laser, where the spectral width 0.1 and a fiber which is having low dispersion 1 picosecond. Without distortion, the signal can go up to about 10000 kilometers. But signal to noise ratio becomes unacceptable beyond 100 kilometer. So, now we see there is a strong case in this situation for an optical amplifier, because that means every 100 kilometer, we could have put optical amplifier and we could have gone up to a distance of a about 10000 kilometer and that location, then would have put a repeater; because that is where now the signal would have distorted significantly.

So, normally in an typical optical communication system, most of the links are power budget limited and that is the reason, there is a strong need for an optical amplifier. So, that we can install this optical amplifier instead of repeaters, which is much more costlier than amplifier and go on putting this amplifier till we reach to a distance where distortion becomes unbearable and that location we can put repeater. So, having made now the case for the optical amplifier, then we will see in the following lectures, what are the different options, which are available for optical amplification, and which are the common optical amplifiers, which are used in long distance optical communication link.