Advanced Optical Communications

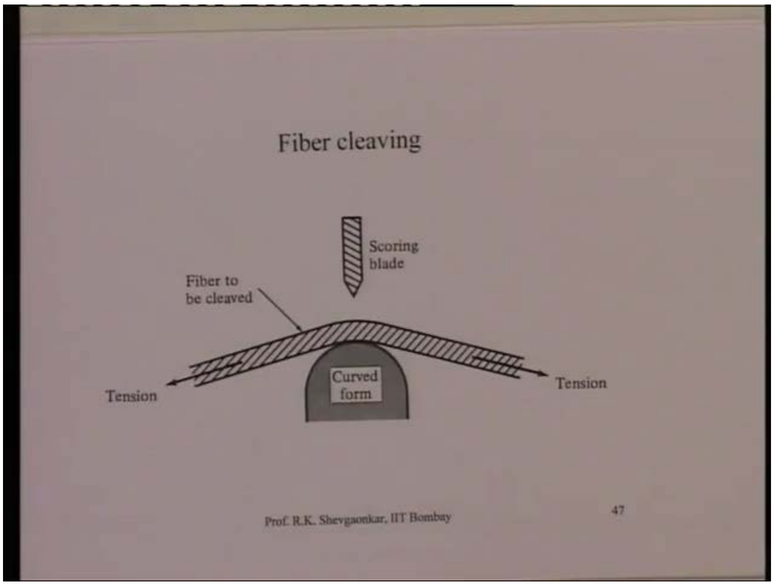
Prof. R.K. Shevgaonkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture No. # 11

Practical issues in Implementation of Fiber Link

In the last lectures we discuss about the characteristics of optical fiber, and then you also studied the signal distortion on optical fiber. In this lecture, now we study the practical aspects of optical fiber that is how do we handle optical fiber, and what kind of measurements are to be carried out on optical fiber before the fiber is accepted and commissioned into a system.

(Refer Slide Time: 01:04)

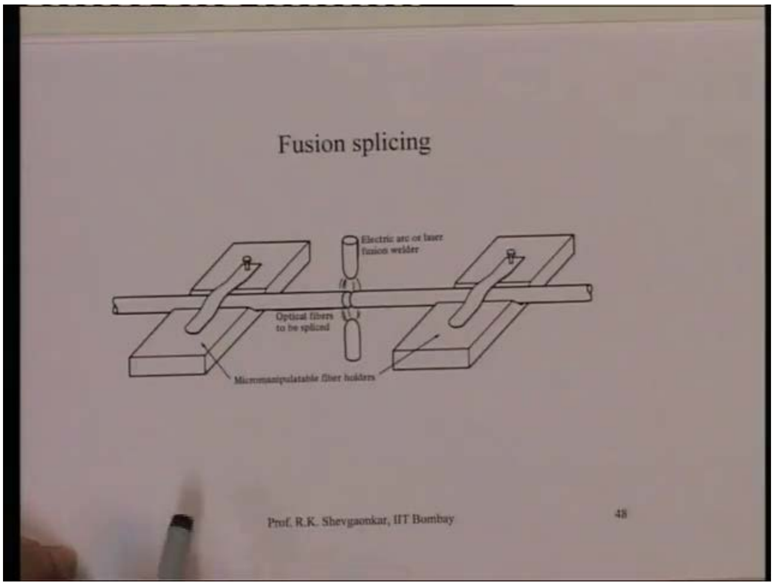


So, just on simpler note even a cutting of optical fiber is rather tricky issue. As you all know that optical fiber has to be connectorized; that means, at the end of the fiber a connecter has to be kept, but before that, the fiber has to be cut, so that it can be inserted into the connecter appropriately. And what you will notice is as the surface of the tip of the optical fiber is not flat, then there is a scattering of light from that, so light does not come in a systematic form of beam from the tip of the fiber, and because of that you have a loss when you try to connector this fiber or if you want to join this to fibers which are cut.

So, normally what we do is we essentially take the optical fiber, make a small gentle cut with a blade, and then pull the fiber very gently, so that the crack which we have got with the blade slowly develops along the crystal surfaces, and you have a reasonably flat cut at the tip of the optical fiber. After this also the fiber tip has to be taken and it has to be what is called polished. So there are certain polishing cards on which the tip of the optical fiber has to be very gently rubbed, so that the surface becomes reasonably flat.

So this process is what is called the cleaving of the optical fiber. Once the fiber is cleaved, then invariably you have to join the fiber, and that process is what is called just splicing process. There is various type of splicing which could take place. One could be very temporary splicing that means I have two fibers which I just temporarily want to connect and frequently you should be able to disconnect also. So, this can be added done by using connectors. So you can connect the two fibers or disconnect them or you can insert two fibers in the form of some kind of a rubber tube and then the fiber come inside the rubber tube and just get aligned and touch each other the light can be guided form 1 fiber to another fiber. So there is a possibility that without actually making a permanent joint one can couple light from one fiber to another fiber. Of course, this did not have any permanent joint for this fiber there is a large loss in this kind of joint. So normally if you want have a good efficient launching of the fiber and if the joint need not be of the temporary nature then we normally go for what is call the fusion splicing.

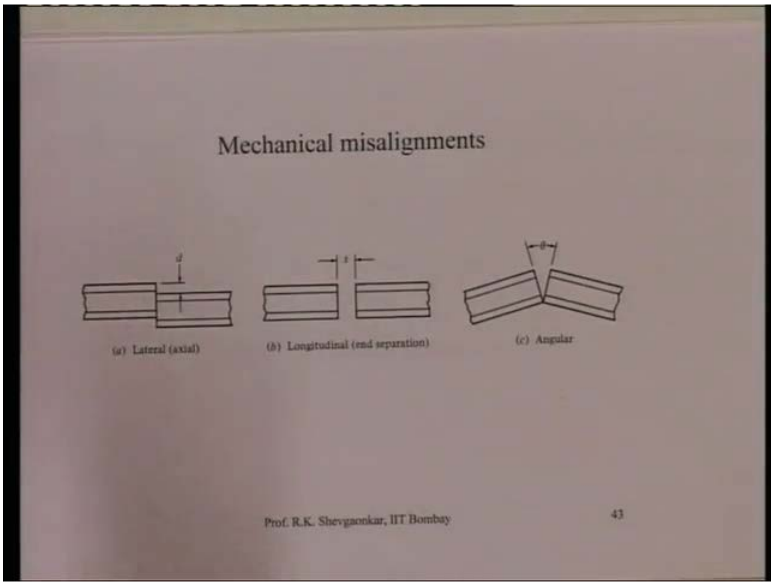
(Refer Slide Time: 04:07)



So, idea here is we take this two fibers which come whose tips are cleaved, then you have got reasonably flat tips, you bring them to close to each other and then this process of joining by fusion is identical to the soldering process in electrical circuits. So in electrical circuit also if you want to joint two wires you bring them together and essentially you put a solder and then you make permanent joint at the tip of the wire beside the same thing do here that the two fibers are aligned perfectly and then an arc is passed at the joint. So that momentarily the glass melts and at that point of time if we give a small push to the fiber essentially the two semi molten glass tips of the fiber fuse into each other and you get a permanent joint.

So typically whenever we want to have the joints and in the joint is of permanent nature then fusion splicing is the one which is preferred. You can also at the joints which could be u e cured kind of joint where the fiber ends are dipped into some kind of a liquid and if the liquid is exposed to the x-rays liquid solidifies. So you get a temporary kind of joint the tip of the fiber, but fusion splicing is the one which is predominantly used whenever we have the network late of for long distance communication. Now, when we are doing this kind of a joining of the two fibers there are possibility of mechanical misalignment between the two fibers.

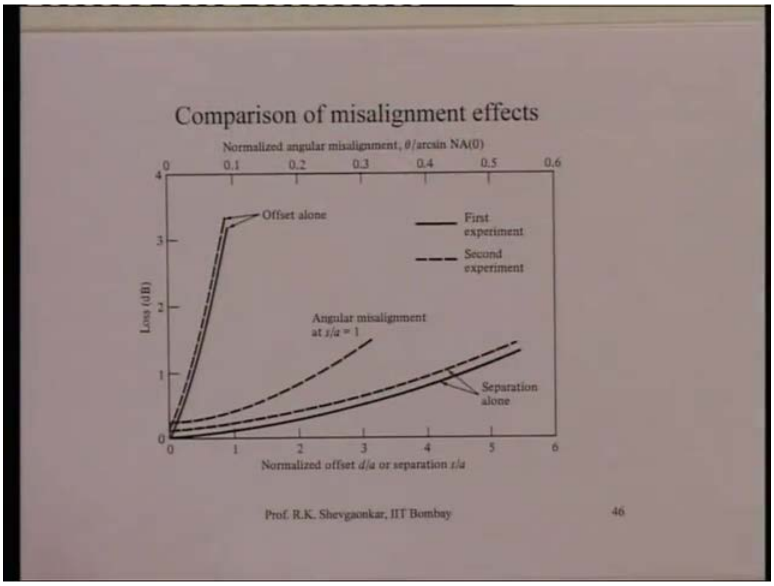
(Refer Slide Time: 05:58)



So, either the fiber could be laterally misaligned that mean the two tips of the fiber may not be axis may not align the x-ray will be slightly displaced, one possibility. Other possibility is that there may remain small air gap between the two tips of the fiber and this is more common in that temporary joint which we got with the tubular pipe the rubber pipe. Third possibility is that there will be a small angular misalignment between the 2 fibers.

And each of this essentially gives you a joint loss, in this case you can easily see the core are not over lapping the entire energy which is coming from this core is not guided into the second core. So you get a loss here. Here you are having a small air gap, so the numerical aperture cone which comes out of this completely does not overlap with this fiber. So, the part of the energy essentially leaks out from here and we get a loss. In this case again the same thing that numerical aperture cone goes like this where as this cone can receive energy from this cone. So you can get a loss if there is a angular misalignment between the two fibers. So in a practical system whenever we try to make a joint we can get loss due to any of these three things.

(Refer Slide Time: 07:23)



And here is the comparison of misalignment effects. So, we have got here the loss in terms of dB as a function of normalized offset or the separation between the two tips of the fiber. Now, here it is normalized with respect to the core radius. So you can see here that if the two fibers are latterly misaligned by the core radius, there is the substantial loss of power and if the two cores are not over lapping at all; that means, there is a misalignment by 2a then no power essentially will get inside the second fiber. So, this is the loss which increases very rapidly as the misalignment parameter.

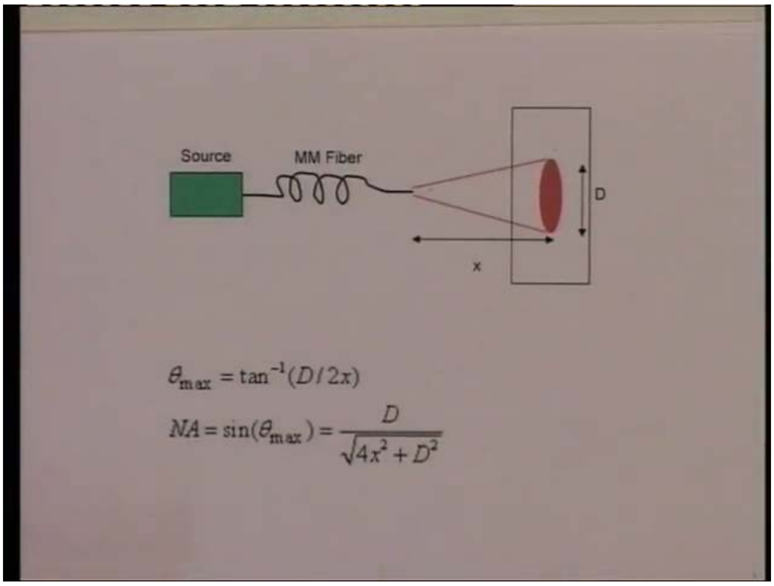
So that is what this is shows you the loss in dB as if function of them misalignment. So by the time you weight a misalignment of one; that means, a misplacement of 1 radius the loss will be of the order about 3 to 4 dB. The angular misalignment loss is a rather milder loss which even if you are having a substantial misalignment in terms of theta which is given here and this theta is in terms of the numerical aperture normalized to that. Third one when you are having a separation you get loss, but this is the mildest possible loss.

So even if you have a separation of the order of about 3 to 4 radia of core, the loss could be still of the order of about 1 D b, but in any good system normally these losses are minimized. So whenever we do a splicing of the fiber, the fiber is aligned perfectly in all respects as for the separation loss as for the angular misalignment loss or the air gap loss. So a typical splice loss could be of the order of about 0.5 d B to 0.1 D b.

So technology today has matured in splicing the optical fibers and as a result you get a very good a performance at the joint with a loss as low as something like 0.05 d B and the splicing machines have also become now automated. So one does not have to very too much, simply 2 fibers are inserted inside the splicing machine. The splicing machine automatically does this alignments and it does the alignment essentially by launching light from one fiber to another and it adjusts the parameter if the six degrees of freedom. So that the light coupled is maximum and at that instant of time essentially the arc is passed and the fusion splicing takes place. So, this technology is now a pretty matured technology

The next thing which we want to do on optical fiber is the measurement of parameters of optical fiber and we have seen the optical fiber has certain characteristic parameters. Its first parameter is the numerical aperture, next parameter is either is v number or mode field diameter, but the most important parameter for optical fiber is its loss. And this loss as we know has two components. One is because of the intrinsic characteristics of the fiber and second one is because of the environment in which the optical fiber is laid. So, you have to make the measurement of the loss basically in both the situations.

(Refer Slide Time: 11:17)



So, let us first say that I want to measure the numerical aperture of the optical fiber. This could be a very simple experiment. We know that numerical aperture is nothing but the sign of the angle at which the light ray can be launched inside the optical fiber. Now whatever cone is launched inside the optical fiber the same cone also emerges from the tip of the optical fiber. So, what we do, we have a source here. We launched the light inside the optical fiber and from the tip of the optical fiber, light come out. This comes in this form of this cone. We can project this cone on some screen at a distance x from the tip of fiber and we will get a spot of light of diameter D.

Now, this angle which we have here, this angle is double of the numerical aperture cone. So, essentially what we want is the half of this angel thus what gives you the sign inverse of the numerical aperture. So, if this diameter of this is D and if this distance is x the D upon 2 x tan inverse that is the maximum angle at which the light rays could be launched inside the optical fiber.

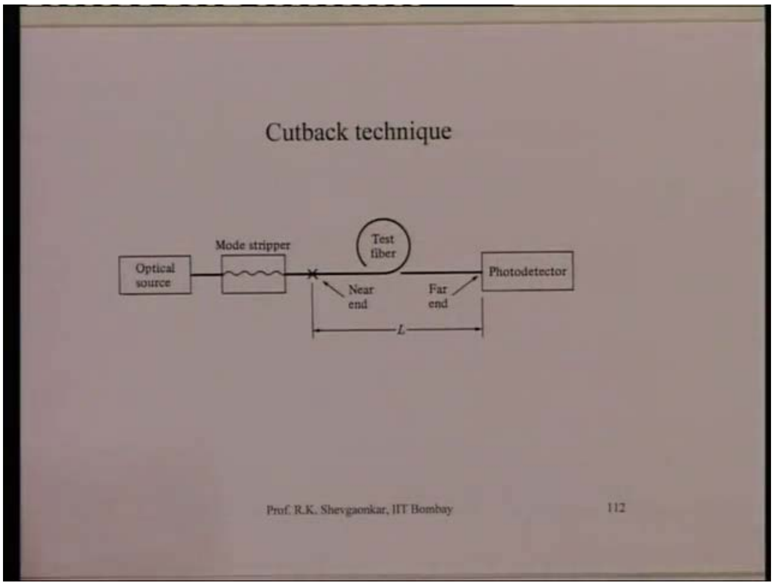
So, sign of this quantity theta max that essentially gives you the numerical aperture. So, numerical aperture is equal to sign of theta max and theta max is tan inverse of D upon 2 x. So, you can substituting into this we can get the numerical aperture which is D upon square root 4 x square plus D square. So, by measuring the diameter of the spot which is created by the emerging light from a distance x from the tip of the fiber, one can calculate the numerical aperture of the optical fiber. So, this is the simple experiment which when one can conduct on the optical fiber. And since we are doing the measurement here by measuring the spot size essentially one can use the light source which could be visible light source.

So, typically a red light source a helium neon laser can be used and the numerical aperture of the optical fiber can be measured. So, this is one of the first parameters which one can get. One can also get from this experiment what is called the mode field diameter if you had a single mode optical fiber.

So, instead of just measuring the spot size if you have an optical sensors, which could measure the intensity distribution. We can move the probe on the screen and essentially find out the variation of light intensity as a function of radial distance in this spot. So, we can create essentially the distribution with the single mode optical fiber creates which is very close to gaussian distribution and from there we can get the parameter what is call the mode field diameter. Now since the mode field diameter is a function of wave length essentially one can carry out the measurement at certain wave length and then appropriately scale the mode field diameter the other wave length approximately. The third thing which is dimension important parameter is the loss.

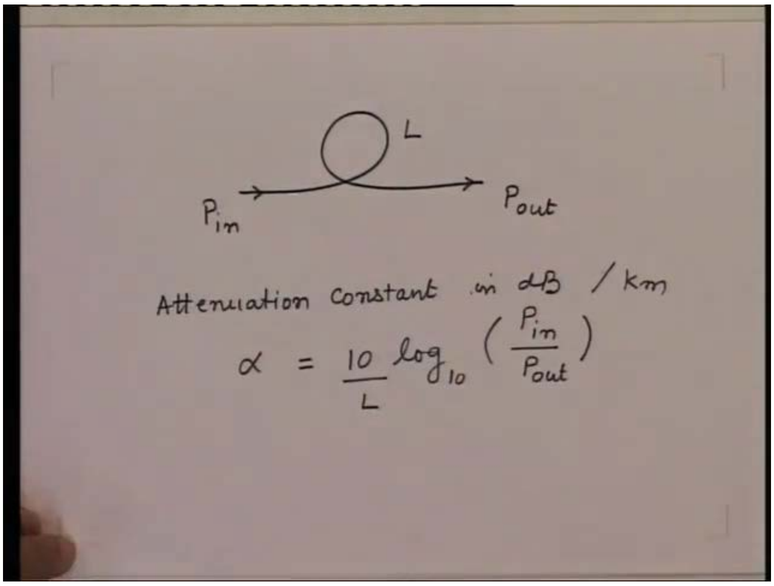
Now, since the loss is because of two parts, one is intrinsically in the optical fiber, then other one into the system normally before the fiber is commissioned, the loss in the optical fiber can be calculated and there are two techniques for calculating the loss in the optical fiber. One is a destructive technique and this technique can be employed only before the fiber is commissioned into the system. The other technique is non destructive and this technique can be use even after the fiber is commissioned into the system and also during the running of the fiber during the operation of the fiber this equipment can keep monitoring the status of the optical fiber.

(Refer Slide Time: 16:04)



So, first method which is destructive and which can be employed before they commissioning of the optical fiber due to what is called the cutback technique. Now idea here is a simple first you have a optical source here, you put the light inside the optical fiber, you measure what is the output. From there you can find out what the corresponding loss would be. So, if I know the power which is put inside the optical fiber. If I know the power which is coming out of the optical fiber the ratio of these two powers will give me the attenuation. So, if I knew the fiber input.

(Refer Slide Time: 16:45)

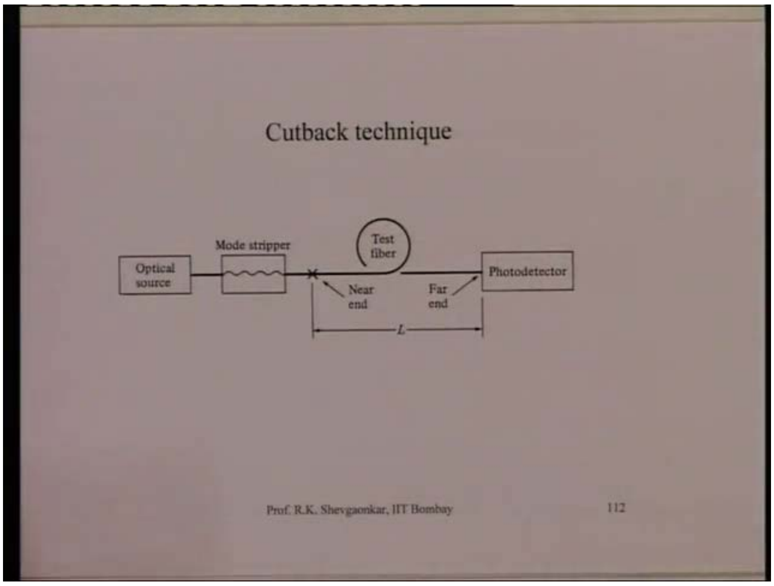


So, if I it is my fiber. I put a power here which is P in I get a power here which is P out. So, I can get the attenuation constant alpha which is nothing, but 10 log to the best n of P in by P out. So, principally this method is very simple. Essentially we measure the light which is going inside the optical fiber, the light which is coming out of the optical fiber and just by taking the ratio of that and log gives you the attenuation in d B for the optical fiber for that length. If you want have the attenuation constant in d B per kilometer you can essentially divide by the length of the fiber. So, this is L in kilometer y can divide by L. So, you get loss of the fiber in d B per kilometer. Though principally this technique is very simple in practice there are certain difficulties. And the difficulties that normally when the light is launched inside the optical fiber at the launching point there are substantially losses, because of scattering of light.

So, though this quantity can be very reliably measured, the light which gets inside the optical fiber is not very reliable parameter. Where even if I knew the source of light and how much power is coming from the source, how much light actually get inside the optical fiber is still a very uncertain parameter because of the coupling losses. So, as a result all though in principle this thing looks a very simple process you cannot really use this technique in this form because this quantities is very unreliable.

So, normally what we do is we give this method what is call the cutback technique.

(Refer Slide Time: 19:08)



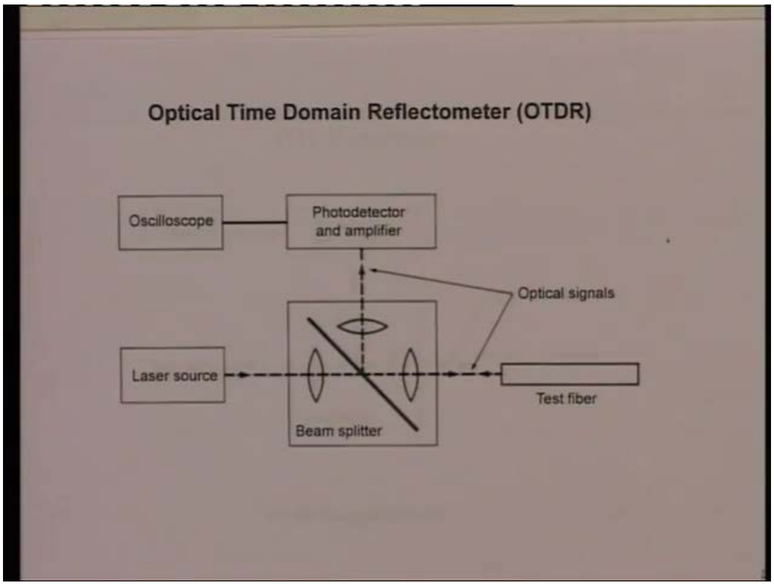
So, you take a very long length of optical fiber L launch the light inside this. And there is a device which is called here the mode stripper, where when the light is launch inside the optical fiber at the launching point, you have a large number of modes, which are generated. Which very quickly die down and finally, the mode which are well confined to the optical fiber which propagate. So, you have certain distance here which guaranties that. Now you measure the light output after the light is passed through this fiber.

That is the quantity which is P out. Then what you do you simply cut the fiber over a distance of about 10 meter or something like that and you measure again the light which is coming out of this point which is what is called the near end of the optical fiber. So, if the this length is typically of the order of about a kilometer or something like that loss of the fiber over distance of few tends of meter is negligibly small.

So, then we can say that whatever light comes out from this point; the near end of the fiber after the fiber is cut that is same as the P in for this fiber. So, we do the measurement of light coming out only. In first case with the full length of the fiber present you get that which we call as P out then you cut the fiber here near the near end of the fiber and that P out is essentially P in. Then getting the ratio of these two you can use this this formula and you can get the attenuation constant of the optical fiber.

So, before the supplier gives you the optical fiber, this method can be employed because as it is very clear you have cut the fiber. So, this method cannot be employed after the fiber is commissioned into the system. Otherwise this method is a reasonably accurate method if you can afford to cut the fiber and that can happen only before the insulation of the optical fiber. The very powerful technique which can be employed to estimate the loss of optical fiber before and after commissioning of the optical fiber what is called the optical time domain reflectometer.

(Refer Slide Time: 21:47)



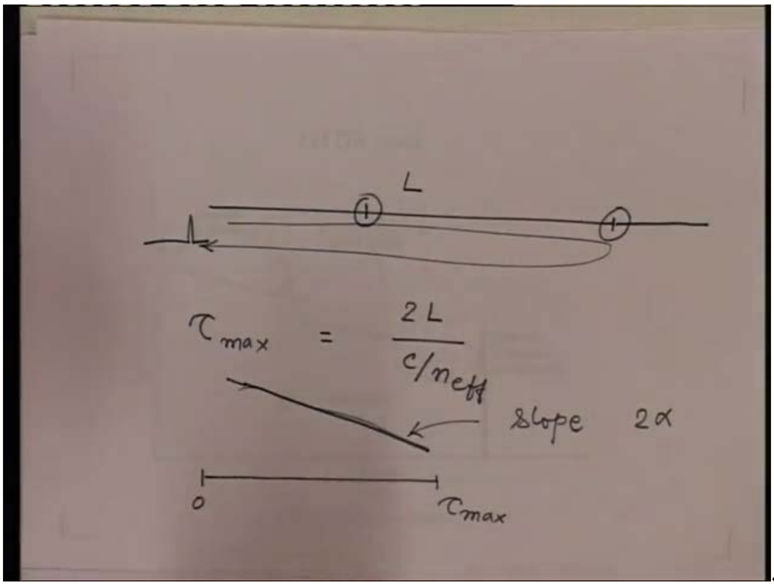
So, what we have here? We have the device what is called the optical time domain reflectometer, which is nothing but an optical radar. So, you recall in radar what we do, we essentially send a very narrow pulse of radio wave. So, pulse goes, it get reflected or scattered from the object. The eco of the pulse gives receive back, and then from the eco essentially we get two parameters. One is the delay of the eco; that means, the return time of the signal, and second one is the amplitude of the eco which tells us from what size object the signal has reflected. So, from these to parameter then we estimate the size of the object and the distance of the object. Precisely same thing essentially we do in this device what is call the optical time domain reflectometer or in short called OTDR.

So, this OTDR has basically components like this. It has a laser source, which launches the light, then you are having a beam splitter. So, the light passes through this. This goes inside the fiber which is to be tested. The other end of the fiber is not needed now. So, light which goes inside the optical fiber because of the scattering or reflections at various points the light get reflected. It comes back. The return like is diverted through this beams splitter in this direction; you detect that light and plot that on the oscilloscope as a function of time.

So, if you launch a very narrow pulse of light, what you will see is that we do not have only 1 eco which will be coming from here, the eco will come from different points. So, some energy may get reflected from here, some may get from here, some may get from here.

So, what we see is that the signal which is getting reflected from various points will arrive at different times. So, it will have a different location on the oscilloscope screen. So, for a very narrow input pulse given from here, you will get a signal which is much spreaded in time. Thus what will appear on the oscilloscope? So, the maximum time separation of spread which we will get would correspond to the maximum return time which you can get on the optical fiber.

(Refer Slide Time: 24:42)



So, note here if I had an optical fiber of length L a pulse is launched from this, the pulse will go all the way up to this point and comeback. So, it travels a distance of 2 L and if the velocity of the light inside the fiber is c divide by n where n refractive index all we can call an effective. If you are having a fiber which are refractive index n 1 and n 2 for cladding and core then the delay maximum which you get from here that will be equal to this 2 L divided by the velocity which is c by n effective.

So, for a very narrow pulse launched inside the optical fiber we get a reflection which has a time spread of t max. So, typically that is the spread over which the signal will come of 0 2 tau max.

Now, what can ask a question now that when the signal goes inside the optical fiber why do I get a reflection and you will recall that inside an optical fiber we had this microcenters which were we giving you the scattering loss. We can now rely on those losses and as we know the scatterings loss is because of the scattering of light which takes place in all directions. So, as the light goes inside the optical fiber a very tiny fraction of that light is get scattered in all directions. So, part of that light essentially will travel backwards inside the optical fiber. That is the light essentially we are try to capture. So, now, the pulse when it goes into this for a nice uniform fiber the scattering loss of scattering mechanism is identical at every location on the fiber; however, if you ask how much will be the scattered power ? You will see the scattered power will be proportional to the local power density at that point.

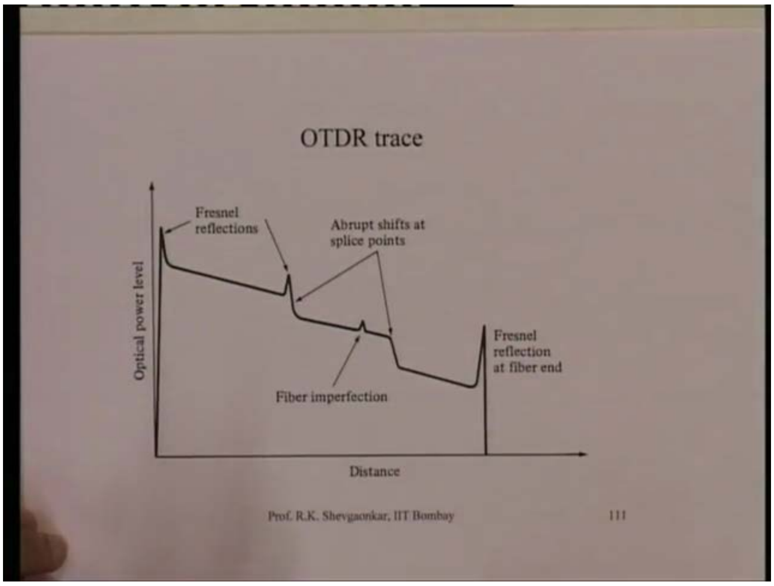
So, what that means, is that initially when the pulse is launched if the scattering takes place here, you will have a much larger amplitude of the scatter signal than if the scattering same kind of scattering takes place here. Because by the time signal reach here it could have attenuated because of the loss in theoptical fiber and then whatever scattered light you get from here is further attenuated as it travels. So, the reflected signal or scattered signal which you get from near end of the fiber is much stronger, compared to the far end of the fiber and in fact, the ratio of these two scattered light is proportional to the loss in the optical fiber. In fact proportional to twice the loss in the optical fiber because the pulse is going to get attenuated by attenuation constant, the scattered light is further going to attenuated by the same attenuation constant.

So, the refracted signal will be w attenuated and thus the reason you see that in this times spread you do not get the scattered amplitude which is constant. This scattered amplitude essentially monotonically decreases if you are having a nice uniform fiber because it is the near end you get a must stronger reflection on the further end essentially the reflection is very small. So, if we take this trace of the oscilloscope the typical trace would essentially look like that.

So, oscilloscope display or what you call OTDR are display essentially we would look like that. So, if you had fiber which is absolutely uniform fiber then we will get trace which will be a straight line if you plot this in terms of the logarithm in terms of d B your d B per kilometer will be constant and slope of this line essentially will be equal to 2 times alpha because the signal as the attenuated and the scattered light is further attenuated.

So, just by measuring the slope of this line the trace essentially one can calculate the attenuation constant of the optical fiber, but, now let us say that the fiber is not absolutely uniform here. Let us say fiber had a joint here and I had another fiber here. So, at this point this is the junction may be there is one more junction here or there is connector here and whenever we have junction like splice or a connector you have partial reflection of the light from that point not the really scattering this is the partial what is called final reflection we takes place from this joints. So, you will see suddenly at this from the signal which is getting reflected from this point certainly as the large amplitude because at this point certainly more amount of light is reflected, but, beyond this points is now the light amplitude is reduce because more light is reflected the signal level of the scattered level will draw compare to what it was here.

(Refer Slide Time: 30:44)



So, typically you would see that you get a trace on the OTDR which will look typically like this. So, firstly, at a very short distance you will see a very strong peak and this is the peak because there is a reflection of the laser beam from the tip of the fiber where the light is getting launched inside the optical fiber; that is this peak then inside the fiber you get scattered light which are the slope which is equal to 2 alpha. At this location you again have some joint or something. So, you have a final reflection and a dimension beyond that again its drops because now more light is lost in this process and like that the you have some small perfection.

So, it typical trace would essentially look like that and these points where you see this abrupt changes into a your trace these are the locations in the fiber where either there are connecters or there are splices, joints or there are some other imperfections inside the optical fiber and it at the fore end of the fiber since beyond that of the fiber is not there again you will see a strong reflection from the other end of the fiber which is this reflection. So, it typically the trace of the OTDR would look like that. So, OTDR actually can tell you lot of things at tells you the attenuation constant of the fiber which you can be measured by the slope if can also tell you that where the imperfections in the fiber are where are the connectors located inside the optical fiber and soon.

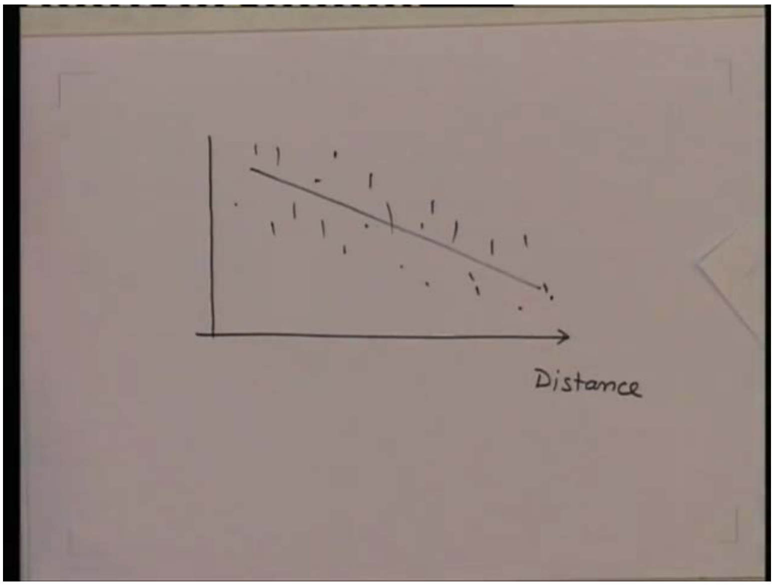
So, OTDR is a extremely powerful technique for measuring the losses on the optical fiber and not only losses it is also possible to a essentially monitor the status of the optical fiber. Now since this method requires access of the optical fiber only at the input, we do not have to have an access to the finite of the optical fiber this measurement can be carried out even after the fiber is commissioned and precisely what is done in practice periodically you connect an OTDR to the optical fiber, find the trace of the optical fiber and it gives you perfectly the locations where the connectors are located. But suppose you find suddenly an anomaly into your trace and say suddenly at this locations, suddenly there was a sharp P which normally when you install the fiber was not there. So, you can immediately come to know that there is somewhere tempering or something has taken place to the optical fiber. So, OTDR not only helps in carrying out the measurement of the attenuation constant of the optical fiber, but it also helps you in monitoring the status of the optical fiber during the operation of the optical communication.

And that is the reason this technique is an extremely powerful technique. Now certain issue one can ask here. Firstly, to get a trace ideally speaking one light pulse is good enough. So, if I just send one light pulse you will get this reflected signal which will look like that, I got a trace and there should give me all the information which I am looking for; however, note here that the light which were measuring is extremely weak light because it is coming because of there is relay scattering predominantly.

So, for typical light which you can launch inside the optical fiber, if I want to have a substantial reflected signal, we should have two things happen. First thing the power in this pulse should be very large, that is one. Second thing is pulse should be very narrow because otherwise we will not be able to identify the faulty locations, the separation will depend upon the width of the pulse. Larger this width of the pulse more will be the ambiguity in the distance of the two imperfections in the fiber. So, to get what is call the higher resolution of the faults on the optical fiber, you have to make this pulse width extremely narrow, but you want certain amount of powerful detection because otherwise your signal will not be detected properly.

So, as a result essentially you have to increase the peak power of this pulse because every power has be maintained at a certain level. So, ideally for OTDR we require reasonably high power very narrow pulses; that means, with very high peak power thus what we normally do in other radars also and these are the pulses which essentially go inside the fiber and get a reflected, but the dimension even be the high power the light which you can receive from 1 pulse that is very small and it gets completely submerged into the noise or statistical variation of the signal after detection. That is the reason just 1 pulse launching will not suffice in practice because with 1 pulse we will not be get a trace which is like that.

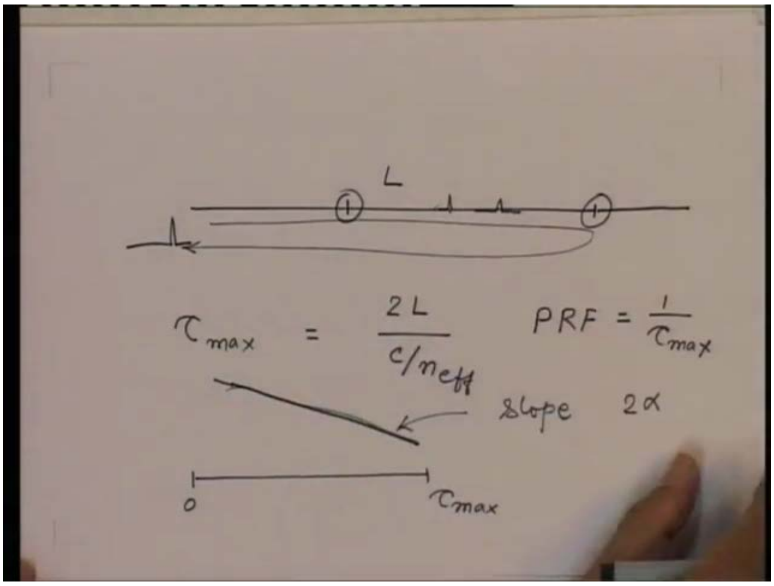
(Refer Slide Time: 36:53)



So, in fact if we just transmit one pulse and if you take the signal and plot it as a function of distance, the signal will not have a trace like this, but, signal actually will look something like that. Something like this because the signal is completely submerged into the noise.

So, what we have to do essentially we transmit multiple pulses and go on averaging the signal which come from various pulses and there is slowly the signal to noise will prove and then the trace of the OTDR will be merge. So, you will get a trace slowly getting merge from this because the signal to noise ratio will improve after the integration that is the reason, we have to transmit multiple pulses on the optical fiber for measurement of the loss. So, two issues now come in when we are launching now the multiple pulses inside the fiber, what should be the minimum separation between these 2 pulses or other word what should be the pulse repetition frequency. Secondly, how narrow should be the pulse width for a given resolution on the optical fiber.

(Refer Slide Time: 38:24)

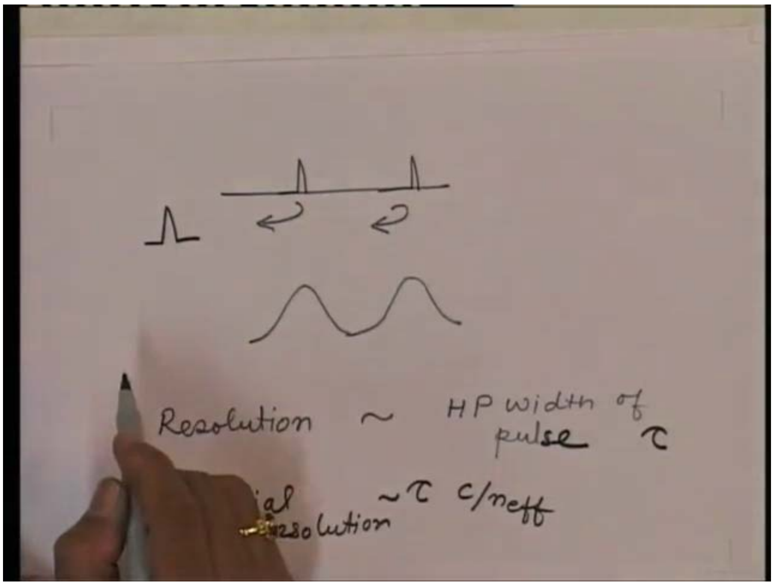


Firstly, you will note that for every pulse which is launched, that returns signal or eco will be spreaded over a time which is this time, which is tau max; that means, if we had another pulse transmitted within this time, we will not know whether the received signal is because of the previous pulse or the next pulse. In other words there has to be a minimum separation between the two pulses which should be tau max which essentially is given by this.

So, if you have the maximum distance given to you, then you can get the repetition frequency for the pulses which will be essentially 1 upon this tau max. So, you can get the pulse repetition frequency PRF that is equal to 1 upon tau max. Here L is a distance or the length of the fiber. So, depending upon over what distance one would like to carry out to the measurement on the fiber, one can decide the pulse repetition frequency. Typically one can use this technique for distance of about 50 to 60 kilometers. So, you get a pulse repetition frequency which would be extremely small which would be typically of the order of about few hundred cycles or few hundred pulses per second. The second pulse repetition frequency you can get. Second thing what we have now is the resolution and what the resolution essentially is the suppose we had two faults on the optical fiber something like this, the pulse energy will go here will get scattered, will travel back. Pulse energy will get scattered from here will get travel back and the energy which is going to come here at that instant of time if I see the pulse the pulse will have a width which will be a exactly same as the width of the launched pulse.

So, if we forget about first scattering loss for time being, suppose we had reflection coming from this point on this point essentially we will received two reflected signal, two reflected pulses of is original width one from this location, one from this location.

(Refer Slide Time: 41:09)



So, essentially what we will get for the two events or two faults on the fiber, we will get that two pulses which will be reflected one from here one from here. So, this is one pulse, this is another just separated in time. Now if the two faults are close to each other these pulses will overlap.

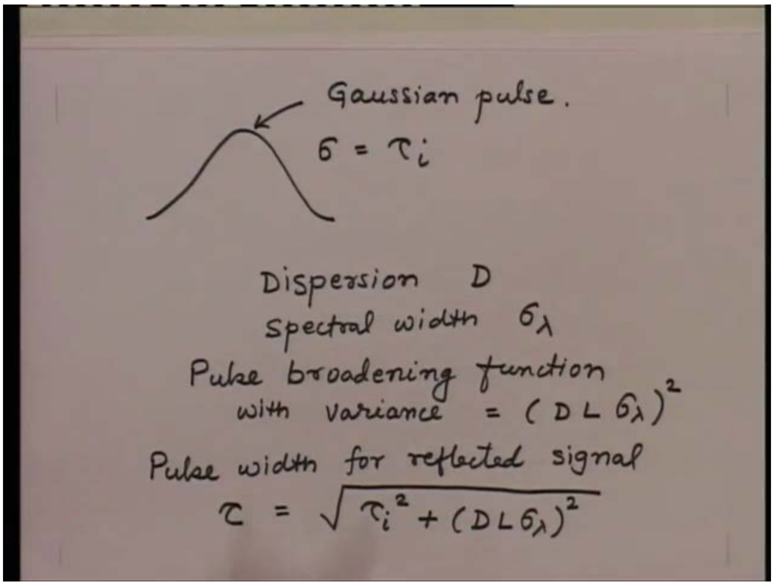
So, we can define a resolution is the minimum distance you should have between the two faults on the optical fiber which can be identified as two faults. If the two faults are located within distances smaller than that, then the two faults would appear as one fault. So, approximately we can say that the resolution is approximately equal to the half power width of the pulse in time.

So, this is the half power width of the pulse in time. So, you can get if the half power width is larger you will get a larger separation between these two. So, ideally we want the half power width of the pulse should be as narrow as possible; this width can be converted into the special distance. So, you can say that if this was pulse of width was tau, then the tau multiplied by a c upon n effective that gives you the spatial resolution. Note however, that the half power width of the pulse because of that dispersion present on the optical fiber is a function of distance on the optical fiber.

So, initially you launch certain pulse inside the optical fiber which has some value of tau, but as it propagates on the optical fiber because of dispersion this pulse broadens. So, if the pulse was reflected from a nearby location it would have a width which will be almost same as the width of the transmitted pulse whereas, if the pulse was reflected from a location which is very far away at the far end of the fiber, then the pulse would be broaden because it would travel at distance to L on the optical fiber and since the resolution is related to the half power width of the pulse which we receive, in other word we are saying is that the resolution will become a function of distance on the fiber.

So, the faults which are very close to the near end of the fiber you will get a smaller resolution. The fault which are toward the fore end of the optical fiber you will have the poor resolution. So, if we approximately say that the pulse which is launched inside the optical fiber is of Gaussian nature and tau essentially is the standard division of that pulse input pulse. And let us say the pulse broadening which takes place inside the fiber it is also more or less of Gaussian nature.

(Refer Slide Time: 45:06)



We can say that initially you had a Gaussian pulse with a sigma which is equal to tau i, this is the approximately a Gaussian pulse. Now, if I say that the broadening phenomena which is because of dispersion is also Gaussian and if the dispersion on the fiber is given by D, dispersion is D and the spectral width of the source is sigma lambda and length of the fiber is L then the broadening function would be Gaussian function with a standard deviation which will be nothing, but D into sigma lambda into L. So, we have a pulse broadening function with variance equal to D into L into sigma lambda square.

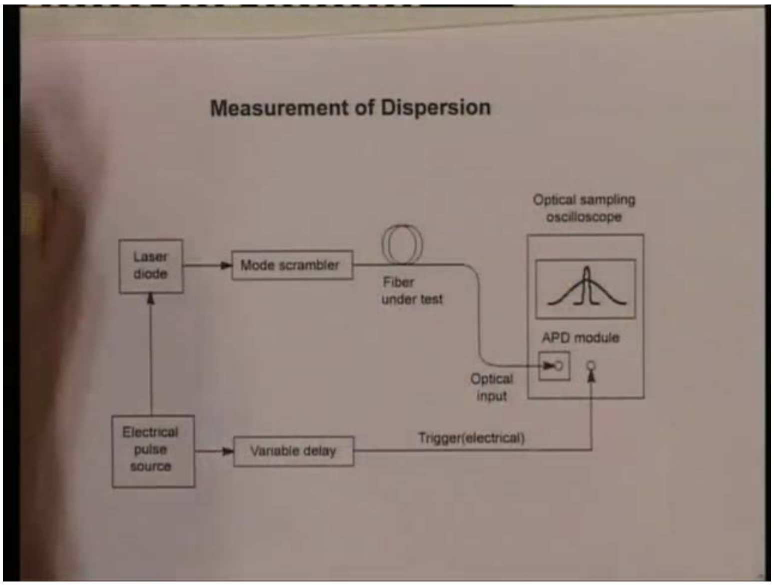
So, when a Gaussian pulse is launched inside the optical fiber it gets broaden because of this broadening function which is function of distance L. So, since the both of this function are Gaussian, the reflected pulse which will be received by the OTDR will be simply contribution of Gaussian pulses. So, output will again Gaussian with a variance which will be sum of the two variances. So, you can get now the pulse width for the reflected signal that will be equal to. So, that is just called tau that will be equal to square root of the variance of the input which is t i square plus the variance of the broadening function which is D into L into sigma lambda square. Thus what precisely now we have that the resolution which we are going to get, now would correspond to this pulse width. So, when the length is small. So, that this quantity is negligible compare to this width you will get a resolution which will be decided by the input pulse. But, if the distance is substantial so that this quantity becomes negligible compared to this one, then the resolution essentially will become proportional to this quantity L. So, if we consider OTDR and if you consider the long distances which are there the fiber depending upon the dispersion parameter and the spectral width which are using for the OTDR source we will get the resolution of the OTDR which will becomes function of the length of the fiber.

So, now we find something interesting for the OTDR measurement. One is OTDR measurement is the extremely powerful measurement because this measurement can be carried out even after the fiber is commissioned and in fact if you can have multichannel transmission one of the channel can be connected to OTDR may be on permanent basis. So, if anything goes wrong on the optical fiber immediately you can get alert. So, OTDR technique can be employed to find out the status of the optical fiber and continuous monitoring of the loss performance of the optical fiber. The OTDR signal, the resolution which you can get on the OTDR is decided by the pulse width which you can launch and typically nanosecond kind of pulse is launched inside the optical fiber, but, the resolution will be a function of distance on the optical fiber. So, the faults which are towards the near end of the optical fiber, they have a much finer resolution compared to the faults which are towards the far end of the optical fiber.

But typically today the OTDR are of extremely good quality and one can get a resolution typically of the order of about few meters on the optical fiber; that means, sitting in the office on the console, we can find out a fault location on the optical fiber with an accuracy, special accuracy of few meters over the length of the optical fiber which could be typically of the order of about fifty to hundred kilometer. Therefore, this is a very extremely important a tool.

So, OTDR or optical time domain reflectometer is one of the extremely important equipments which the, we will have to use in monitoring the status of the optical fiber. Lastly the parameter which we want to measure is the dispersion on the optical fiber.

(Refer Slide Time: 51:14)



So, here the setup is as follows. Essentially we have a laser diode, you just have the pulse of the signal which we launch inside this and then you get the signal output and then you measures simply the pulse broadening inside this. So, idea here is simple. By launching a very narrow pulse, you find out what the output pulse would be and as we saw in the previous case, the output pulse would (( )) of the input pulse and the dispersion broadening function. So, if we have an estimate of the output pulse and if we assume that the broadening function and the input pulse both are Gaussian in nature, then one can essentially point out the variance due to the dispersion broadening function.

So, by using a set of which is similar to the previous one, one can also get an estimate of the dispersion on the optical fiber. Many time what we do is, we just let the signal pass back and forth in a short length of optical fiber to emulate a very long distance on an optical fiber, so that you can get a large pulse broadening, because of dispersion and you can get the estimate of the dispersion from that.

So, in this lecture, essentially we have summarized some of the measurement techniques, which are employed in practice for the optical fiber. So, first we saw the numerical aperture measurement, then we went to the loss measurement; and in this type, we saw two techniques the cut back method and the OTDR method, and then by using similar setups we could get the measurement of the dispersion also. So, this essentially concludes our discussion on the optical fibers.