Fiber Optics

Dr. Vipul Rastogi
Department of Physics
Indian Institute of Technology, Roorkee

Lecture – 24
Splice Loss

When we use optical fiber in a system whether it is telecommunication system or a sensor system, we come across the instances where we need to join two fibers together. And when we make a joint between the two fibers then there are always some losses, these losses are known as a splice losses. In this lecture we will study about the splice losses.

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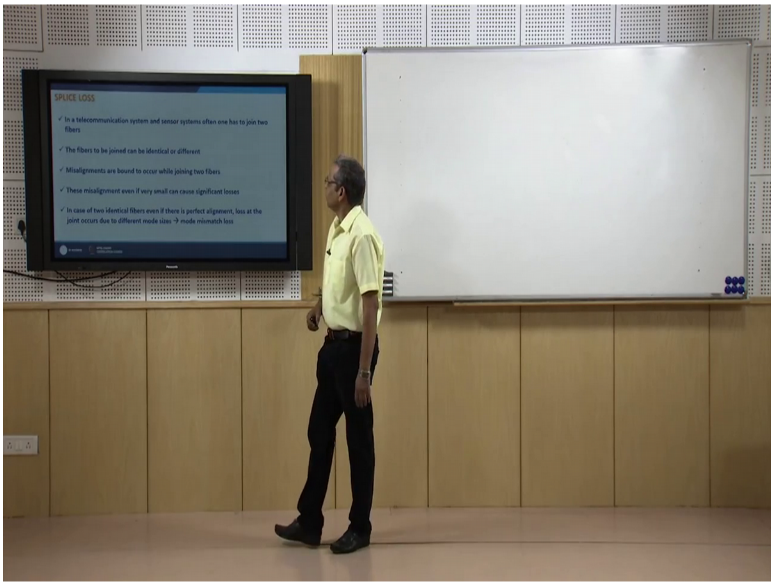

So, the fibers which we join can be identical or non identical for example, if I am joining two telecom fibers together then these fibers are identical, but when I am putting some telecom component which is also made of fiber itself then this fiber can be different from the telecom fiber its specs would be different from the telecom fiber, and the two fibers I am joining now would be non identical.

When I put two fibers together so how so ever precise alignment I do they are always some degree of misalignment. And these misalignments even if very small they can cause significant losses, and in case of two identical fibers even if there is perfect alignment, because of the difference in the fiber parameters there are always some losses. Basically the mode of one fiber would be different from the mode of the other fiber and because of this miss match between the modes of two fibers there would be a loss and that is known as ode miss match loss. So, what are the various types of misalignments let us first look into that, and then calculate the expressions for loss corresponding to these misalignments.

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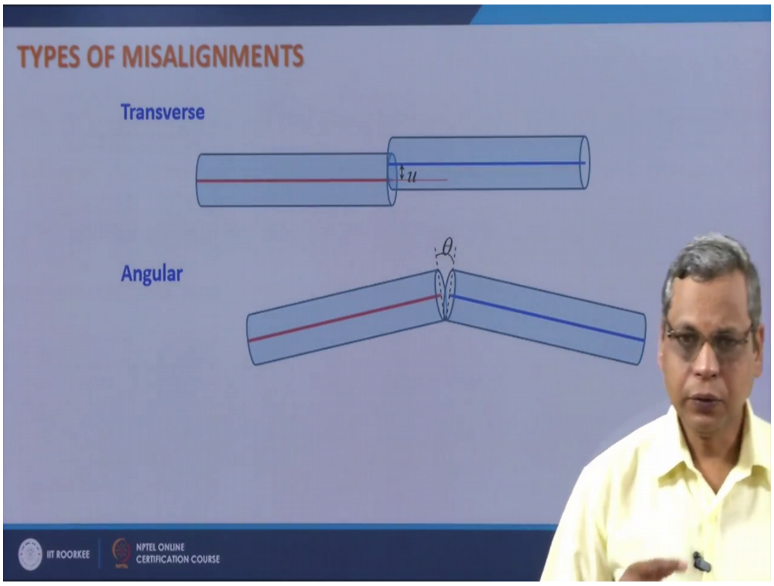

So, one type of misalignment is in the transverse direction, that a fiber is shifted one fiber is shifted with respect to another in transverse direction. Another is angular when you join two fibers there is some angle between them this is highly exaggerated, this misalignment is of the order of a degree or so.

This can be caused due to your finite precision of the stages at which you are putting the fiber or due to a not very sharp and in the transverse direction if this cleaving of the fiber is not perpendicular to the axis of the fiber. So, ideally what you should have, when you have two fibers and you want to join them then you first clean the fibers. So, this surface should be perfectly perpendicular to the fiber axis, but if it is something like this, then it will cause angular misalignment loss.

Third is that if there is a small gap between the two fibers, then there would be a loss. So, I have transverse angular and longitudinal misalignment losses. Let us work out the expression for loss in case of transverse misalignment and in this entire lecture I will use Gaussian spots and Gaussian spot sizes of the modes of the fiber and I will restrict myself to only single mode fibers.

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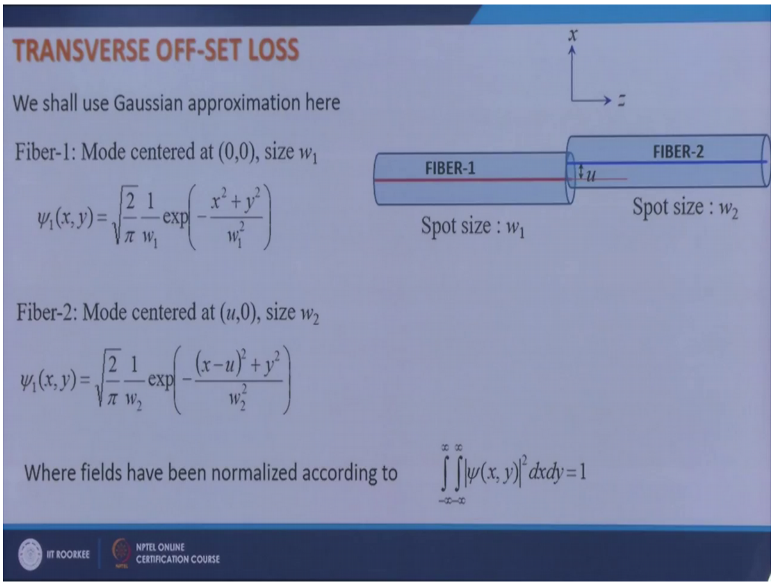

So, I have fiber 1 which has a spot size w 1 is Gaussian spot size, and I have fiber two which has a spot size w 2 this direction is z and this is x.

So, in whatever direction there is transverse offset I can choose my x axis along that, and accordingly I will use my y axis perpendicular to x and z. So, now, what I can do? I can write the Gaussian mode of this fiber and let us say the mode of this fiber is centered at 00 and has size w 1. So, the modal field would be given by psi 1 xy is equal to square root 2 over pi times 1 over w 1 exponential minus x square plus y square over w 1 square.

Now, this fiber is shifted with respect to this by an amount u in x direction. So, the mode of this would be centered at u 0 and it has a size w 2. So, the Gaussian mode corresponding to this would be given by this should be psi 2. psi 2 x y is equal to square root 2 over pi 1 over w 2 exponential minus x minus u square plus y square over w 2 square please make a correction this is psi 2. And in order to get these I have used the normalization condition that mode psi squared dx dy integrated over the entire range of xy is equal to 1.

Since I am using these two to calculate the losses, these are basically area normalized. Now how do I calculate loss well calculation of loss is very simple, I have a Gaussian of one fiber and Gaussian of another fiber then the overlap between these two fields will give me the loss or the fraction of power that is coupled from one fiber to another fiber.

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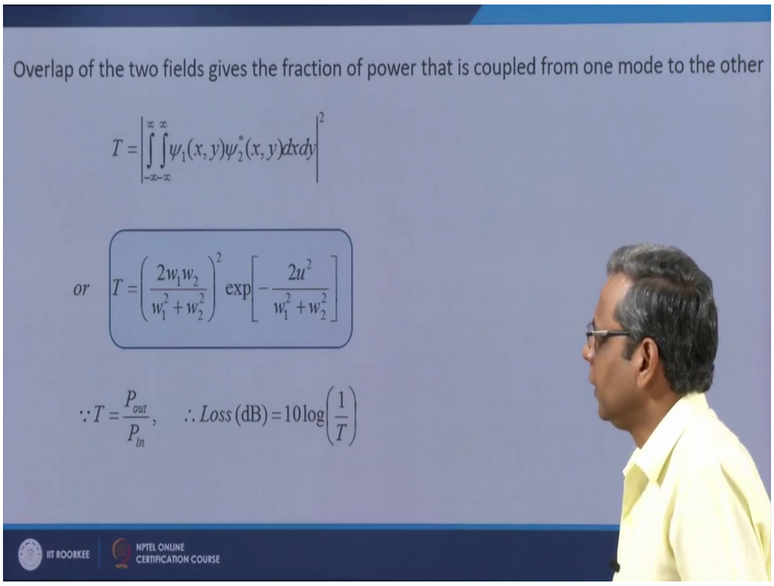

So, the fraction of power that is coupled from one fiber to another fiber would be given by T is equal to integral minus infinity to plus infinity over x and y, psi 1 psi 2 star dx dy mode square. So, this is the overlap integral and if I take it mode square then it will give me the fraction of power coupled from one fiber to another fiber, and this expression is true when these model fields are normalized according to the condition which I have stated in the previous slide.

So, now if I use the expressions for psi 1 and psi 2 which at I had written earlier and do some mathematics then I will get the expression for T as, T is equal to 2 w 1 w 2 over w 1 squared plus w 2 square whole square times exponential minus two u square over w 1 square plus w 2 square.

From here I can calculate the loss in dB I know this T is nothing, but P out over P in. So, loss in dB would be tan log one over T. I can see from here that if the two fibers are identical and there is no offset loss then this T should be equal to 1, and I can check that out if w 1 is equal to w 2 then this term becomes one and when u is equal to 0 this term becomes 1. So, from this expression of fractional power coupled from one fiber to another fiber, I can estimate the loss which is purely due to mode mismatch, and in order to get this loss which is known as mode mismatch loss which is purely due to mismatch in the modes of two fibers I should put u is equal to 0.

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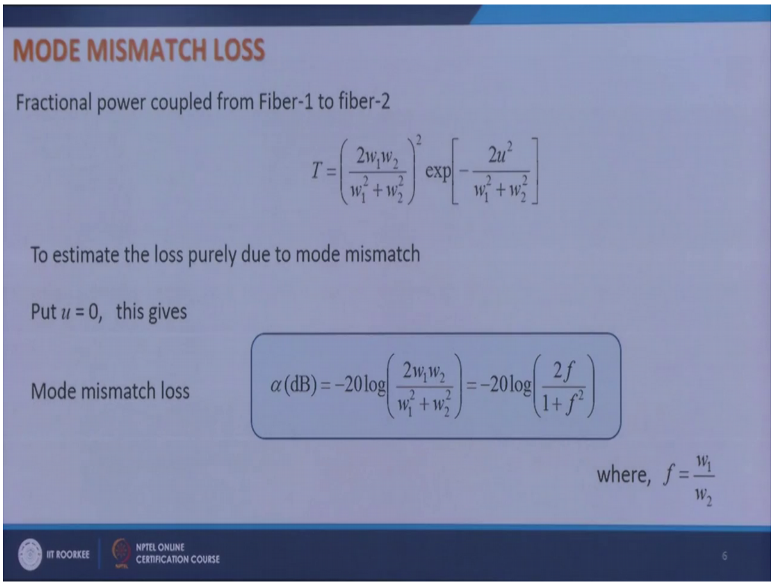

So, in order to remove any contribution from transverse misalignment. So, I put u is equal to 0, if I put u is equal to 0 here then alpha in dB would simply be minus 20 log 2 w 1 w 2 over w 1 square plus w 2 square. I can divide this numerator and denominator by w 2 square then I will have w 1 over w 2 here and w 1 over w 2 square here if I define this w 1 over w 2 by f then it can be written as minus 20 log 2 f over 1 plus f square.

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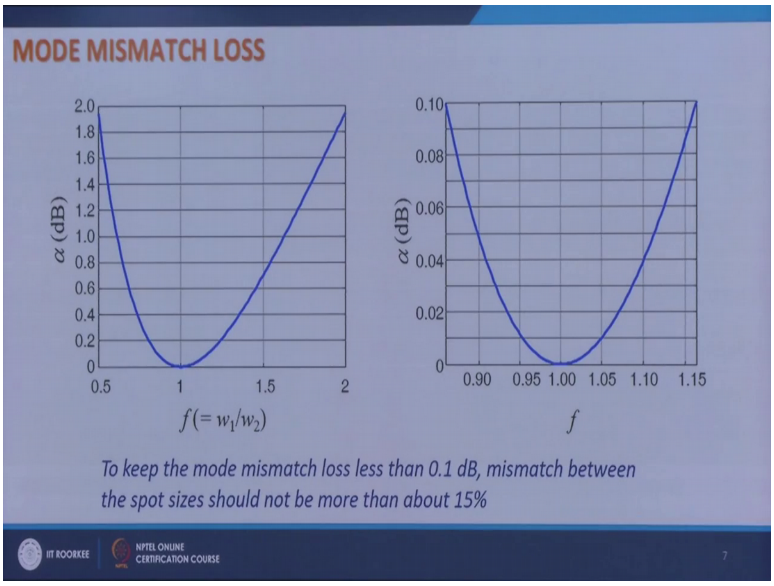

Now let me plot this mode mismatch loss as a function of w 1 over w 2, then I can see that if w 1 is equal to w 2 then there is no loss, loss is 0 db, but if w 1 over w 2 is smaller than one that is w 2 is larger or if it is greater than one that is w 1 is larger, in both the cases I will have mode mismatch loss. Let me zoom it to a level of 0.1 dB and when I do this then I find that that to keep the loss below 0.1 dB, to keep this mode mismatch loss below 0.1 dB the mismatch between the spots sizes should not be more than about 15 percent. So, if you have a mode mismatch up to 15 percent then your loss this mode mismatch loss would be less than 0.1dB and this kind of analysis is very handy and very useful when you estimate the loss or when you design your fiber components to be used in telecom systems. So, you always design the components in such a way that the fiber you are using for them should not have mode mismatch with the telecom fiber more than 15 percent.

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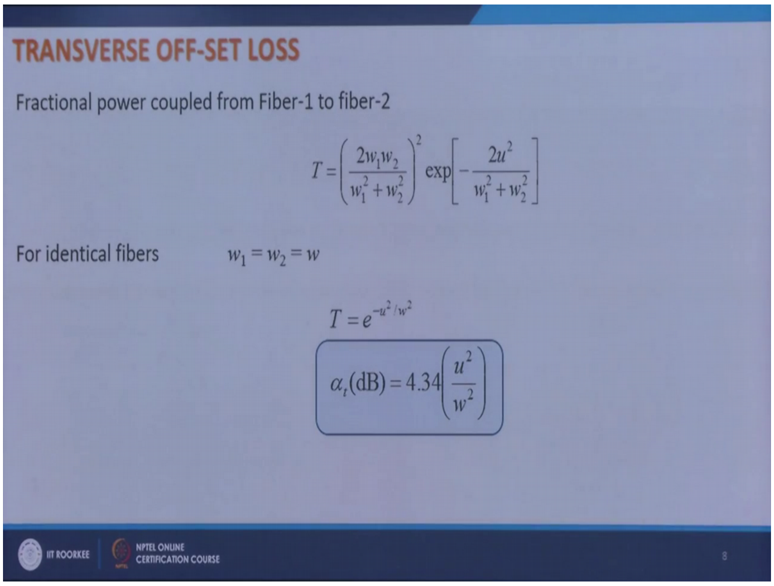

Now, let us calculate the transverse offset loss for two identical fibers. So, this is the fractional power and for two identical fibers w 1 is equal to w 2 and let us say it is wm then this t would become simply e to the power minus u square over w square because this will become 1, and from here I can immediately get the transverse offset loss in dB as alpha T is equal to 4.34 u square over w square.

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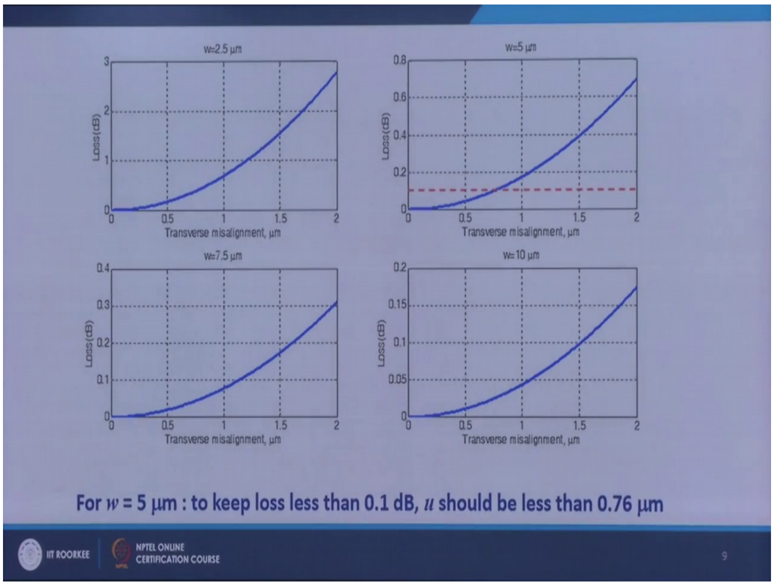

So, I can see from here that if w is small then your transverse offset loss is large, if w is large then the tolerance towards transverse offset loss is higher because the loss is smaller. So, to see this graphically I have plotted this transverse misalignment loss or transverse offset loss as a function of u that is transverse misalignment for different values of w. You see that this x axis has the same range in all the figures, while if you look at the y axis that is the loss axis you look at the numbers and these numbers decreased as I go for higher values of w. So, for higher values of w the transverse offset loss is smaller.

Now, let me look at 0.1 dB level for a telecom fiber, which has a spot size typically 5 micrometer. So, for w is equal to 5 micro meter, in this figure if I look at this line which corresponds to loss is equal to 0.1 dB, then I find that that to keep the loss less than 0.1 dB u or transverse misalignment should be less than 0.76 micro meter. So, this is the degree of precision with which I should align my fibers while making a splice while making a joint. Another misalignment is in angular direction and it causes angular offset loss.

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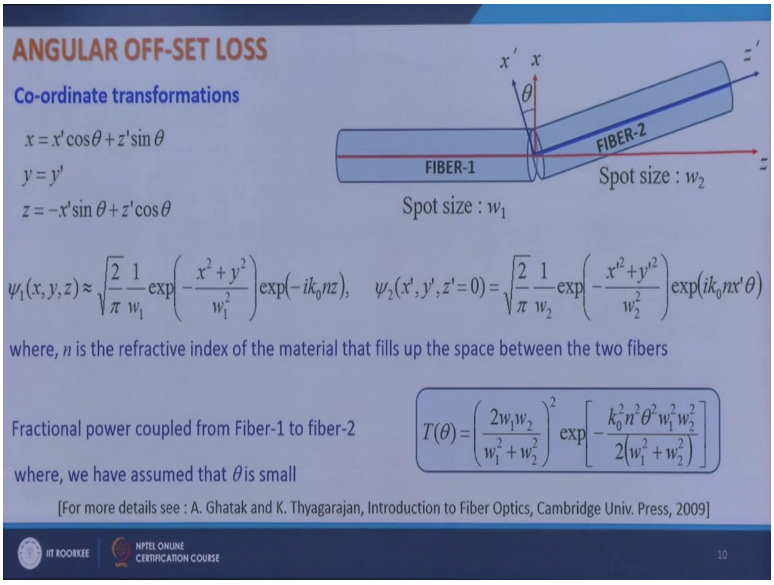

So, I have fiber one with spot size w 1, fiber 2 with spot size w 2, and this is tilted with respect to fiber 1 by an angle theta. So, again what I will do I will use Gaussians here, Gaussian mode of this fiber and Gaussian mode of this fiber and I will have to take the overlap of them now how I will take the overlap? Well I will represent the Gaussian of this in the rotated coordinate system. So, this coordinate system is now rotated by an angle theta. So, I have the this x prime and y as and z prime x prime and z prime which is rotated by an angle theta.

So, I should do coordinate transformations. So, the coordinate transformations are like this which relate x y z to x prime y prime z prime. Now I can write down the Gaussian mode of fiber one like this, and Gaussian mode of fiber two like this z prime is equal to 0 and this is a sum z. Where this n here and n here is the refractive index of the material which goes in the gap between the two fibers, and usually this material is nothing, but cladding material because when you join two fibers you align them and then fuse them together. When you fuse them together the cladding material gets melted and it goes in the gap. So, this n is nothing, but most of the time it is cladding material.

So, again I can find out the fractional power coupled from fiber 1 to fiber 2 by taking the overlap of these Gaussians and then it comes out to be T theta is equal to 2 w 1 w 2 over w 1 square plus w 2 square whole square, exponential minus k naught square n square theta square, w 1 square, w 2 square divided by 2 w 1 square plus w 2 square. In order to get this expression I have assumed that this the value of theta is a small so that sin theta is equal to theta and cos theta is equal to 1. If you want to look into more details about this then you can refer to the text book introduction to fiber optics by Ghatak and Thyagrajan.

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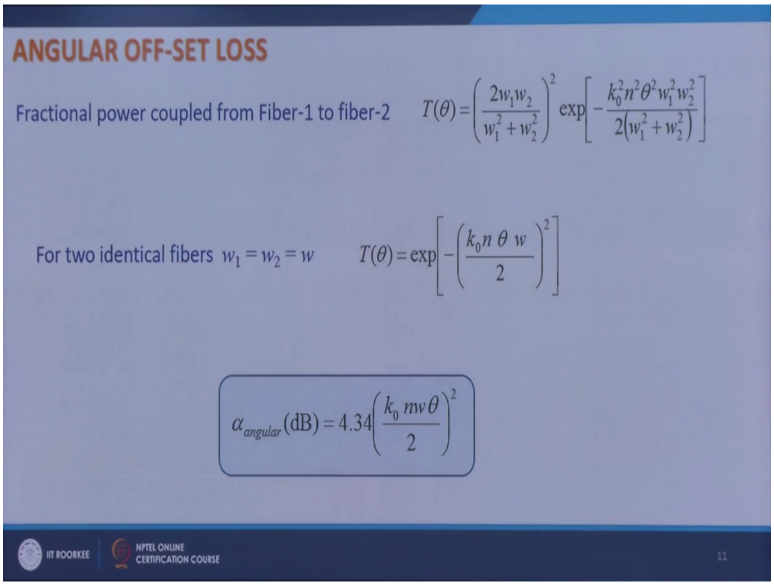

So, this is the fractional power coupled from one fiber to another fiber and from this now I can find out the angular offset loss for two identical fibers. So, where I have now w 1 is equal to w 2 is equal to w, and this gives me t theta is equal to exponential minus k naught n theta w by 2 whole square. So, the loss angular offset loss in dB would simply be now given by 4.34, times k naught and w theta by 1 whole square. So, this is the angular offset loss.

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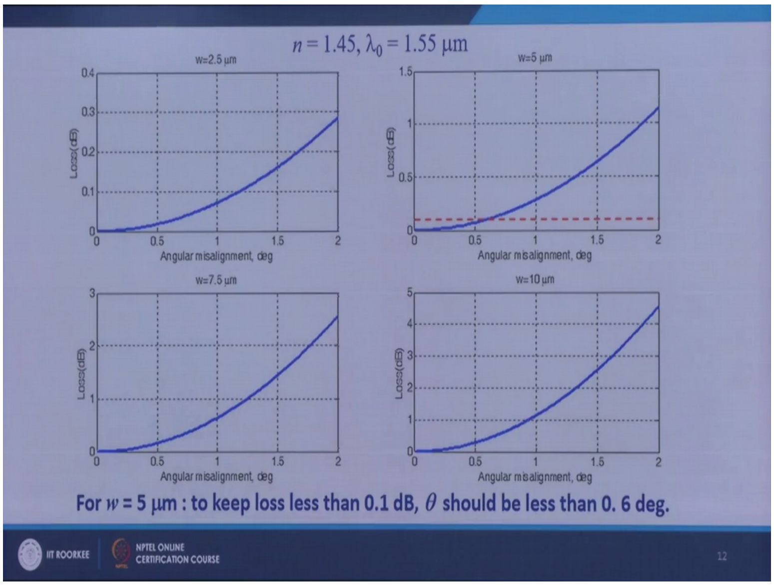

Here I can see that if w is large then angular offset loss is large. So, I have plotted it, I have plotted this for different values of w and I can see that when I increase the value of w the angular offset loss increases. And again I look at telecom fiber which has approximate value of w as 5 micro meter, and 0.1 dB loss level. So, I can see that if I want to keep the angular misalignment loss below 0.1 dB, then theta should be less than 0.6 degrees. So, with this precision I should align my fibers or with this precision I should cleave my fiber. So, that it is perfectly perpendicular it is perpendicular to the axis of the fiber.

The last one is longitudinal offset loss, which occurs when you join two fibers together and there is always some gap left between them and when you fuse them then cladding material goes in the gap. This also causes loss because the Gaussian mode when comes out of this fiber it diffracts.

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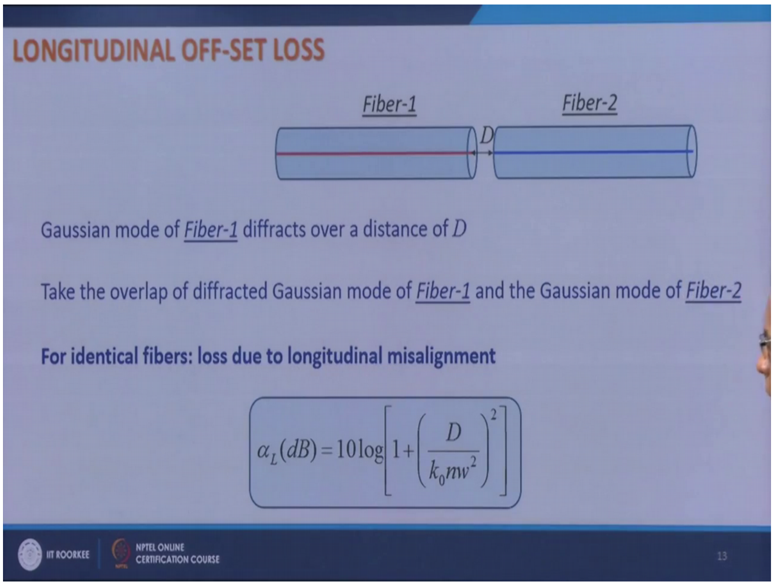

And when it reaches to this end of the fiber, then this diffracted Gaussian would be different from the Gaussian mode of the fiber tube. So, in order to estimate this loss what should I do? I should take the overlap between the Gaussian of this fiber and diffracted Gaussian of this fiber. So, when I do this then I can find out the longitudinal misalignment loss and it is given by alpha L in dB is equal to 10 log 1 plus D by K naught n w square whole square.

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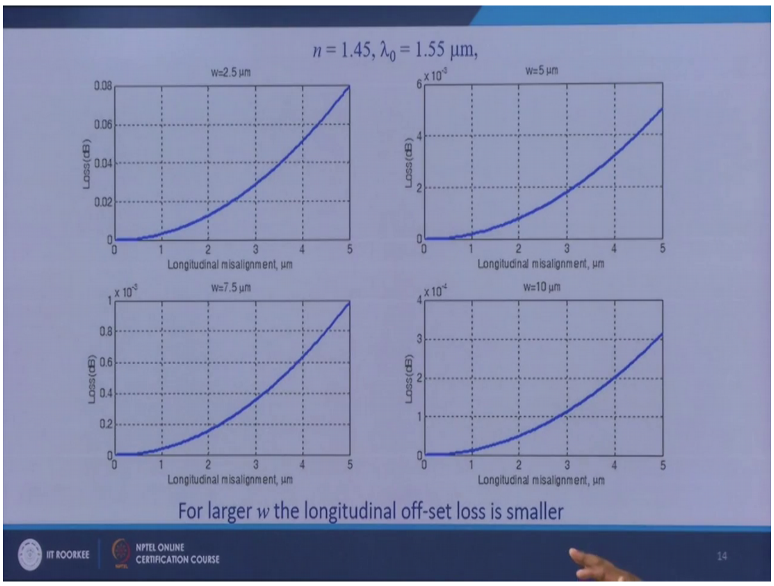

So, here I have plotted this for various values of w, and I can see that that this longitudinal misalignment loss decreases as I increase the value of w and it is understood that if I have small value of w then the diffraction would be large, and if diffraction would be large then the Gaussian diffracted Gaussian would be very much different from the Gaussian of fiber two; and it will cause more loss a. So, for larger value of w the longitudinal offset losses is smaller.

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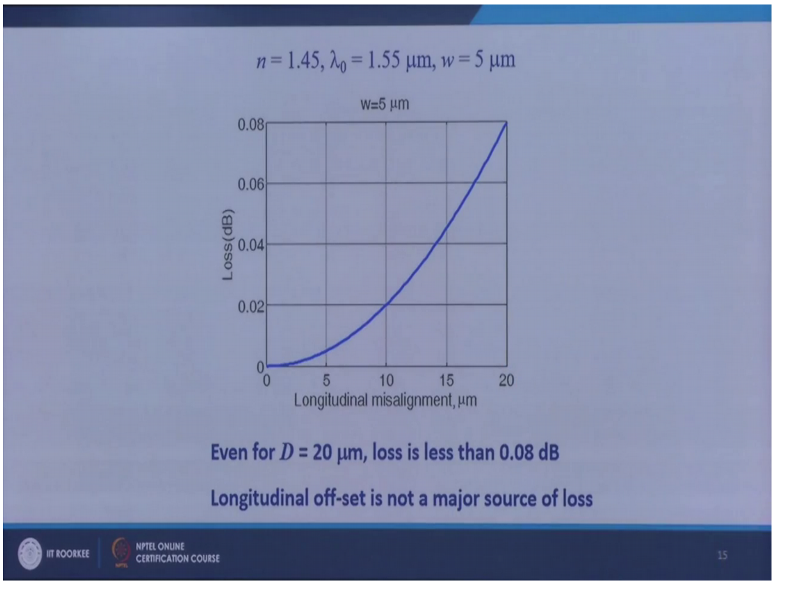

Again let me look into the values of loss which are close to 0.1 dB, and for that I had I have increased the range of longitudinal misalignment while plotting this loss curve for w is equal to 5 micro meter, and what I see that even for longitudinal misalignment as large as 20 micro meter, the longitudinal offset losses smaller than 0.1 dB. So, longitudinal offset loss is not a major concern for us it is not a major concern for us; however, the transverse and angular offset losses are quite large if the misalignment is large. Let us work out an example a numerical example.

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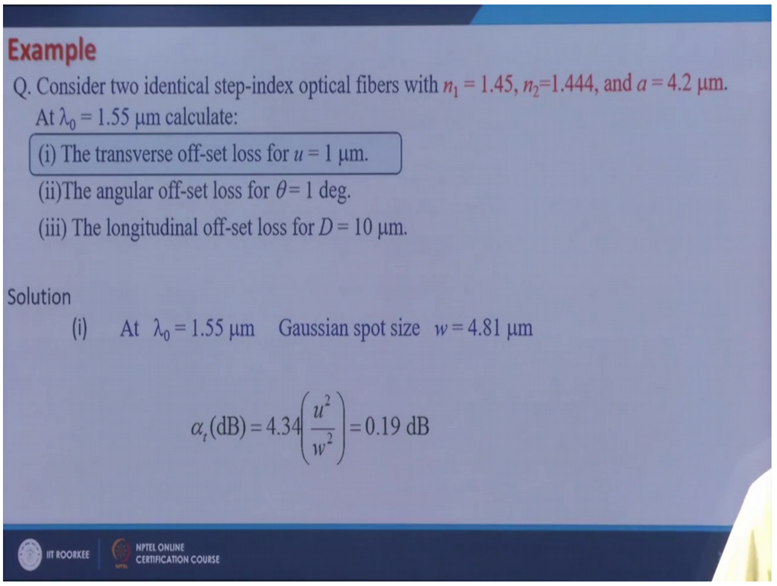

So, I consider two identical step index optical fibers with n 1 is equal to 1.45, n 2 is equal to 1.444 and core radius a is equal to 4.2 micrometer and I want to calculate a lambda naught is equal to 1.55 micro meter, all the three losses for various values of misalignments.

So, let us see how do they come out. So, the transverse offset loss for u is equal to 1 micro meter well. So, at lambda naught is equal to 1.55 micro meter, if I calculate the Gaussian spot size it comes out to be 4.81 micro meter. The easiest way to find this out is you first find out the value of V and then using the empirical relation you can find out the value of w for Gaussian spot size. So, it comes out to be 4.81 micro meter, now you can calculate transverse offset loss by the formula alpha is equal to 4.34 u square over w square, and it comes out to be 0.19 dB.

The next part is angular offset loss for theta is equal to 1 degree.

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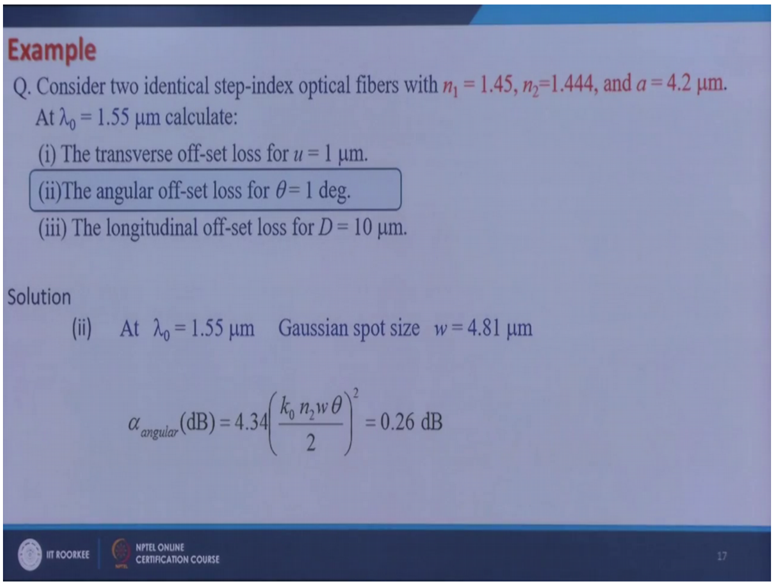

So, again you find out the Gaussian spot size w is equal to 4.81 micro meter comes out like this, and then you find out angular offset loss by the formula 4.34 k naught and 2 w theta by 2 you see that instead of n I have put n2 here because n 2 is the cladding material and this is the cladding material which goes inside the gap.

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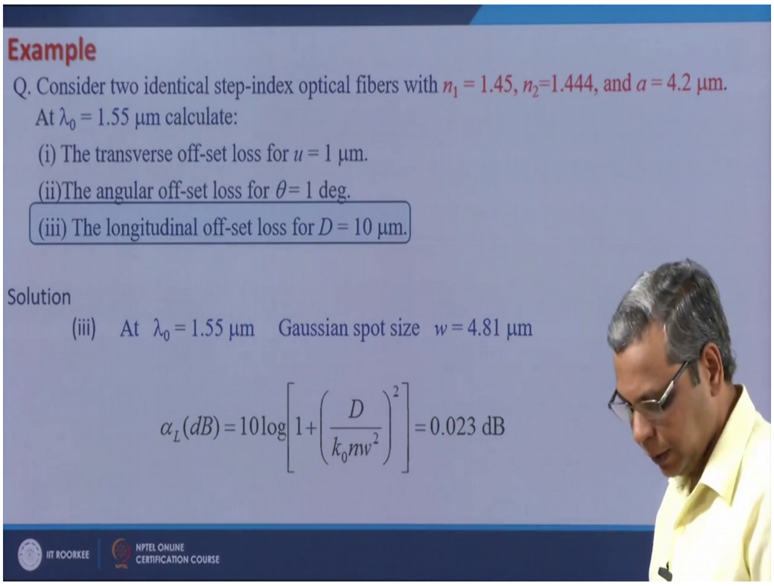

So, angular offset loss comes out to be 0.26 dB; third is longitudinal offset loss for D is equal to longitudinal misalignment d is equal to 10 micro meter. So, again the Gaussian spot size is 4.81 micro meter and if I calculate the longitudinal offset loss using this formula then it comes out to be 0.023 dB. So, again look at these figures that longitudinal offset loss is 0.023 dB the angular offset loss is 0.26 dB while the transverse offset losses 0.19 dB. So, I can see that that I need to when I join two fibers, I need to precisely align the two fibers in transverse and angular direction in order to have as low loss as possible.

So, this is all in this section in this lecture and what is left is another very important characteristic of a single mode optical fiber and that is wave guide dispersion. So, in the next lecture we would look into the wave guide dispersion and subsequently the total dispersion and this will give me what is the data carrying capacity of a single mode fiber.

Thank you.