Fiber Optics

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

Lecture - 26
Waveguide Dispersion- II

In the last lecture we had seen that in a single mode fiber in addition to material dispersion, we have what is known as wave guide dispersion. And these material dispersion and wave guide dispersion they occur due to finite line width of the source, because of different wavelength components that are present in the light coming out of the source.

So, these 2 dispersions are also known as chromatic dispersions. Wave guide dispersion occurs because the mode propagation constant of LP 0 1 mode of a single mode fiber depends upon the wavelength. So, in the last lecture we had worked out the expression for the wave guide dispersion by first calculating the group velocity of the mode. In the process of working out the wave guide dispersion, we had assumed that n 1 and n 2 that is the refractive indices of the core and the cladding do not depend upon the wavelength.

So, we had not considered the wavelength dependence of the refractive index of the material of the fiber, in order to explicitly bring out the effect of wave guide dispersion. So, in this lecture we will see on what parameters of the fiber the wave guide dispersion depends on and how can we tailor the wave guide dispersion.

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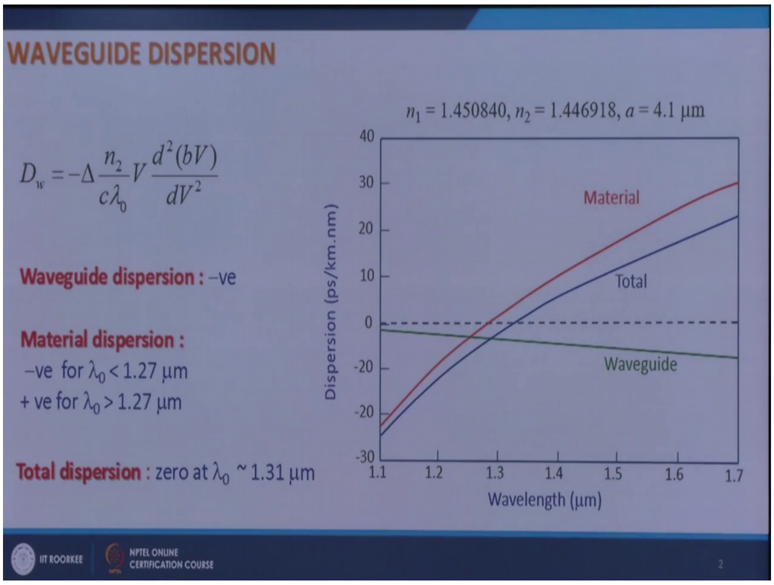

So, the expression that we worked out for wave guide dispersion coefficient is given by Dw is equal to minus delta n 2 c lambda naught times V d 2 bv over dV square. We know how b depends on V. So, if we work out this V times d 2 bV over dV square then we can find out wave guide dispersion. So, apart from this which depends on the value of V only, in this expression we also have the cladding refractive index and the value of delta that is the relative index difference between the core and the cladding. When we plot this dispersion coefficient as a function of wavelength, what we find that wave guide dispersion is always negative for silica glass fiber, for these particular values of different parameters corresponding to step index fiber and if I look at material dispersion for few silica glass it goes like this.

So, I see that it is negative for wavelength shorter than 1.27 micro meter, and it is positive for wavelengths longer than 1.27 micro meter. So, the total dispersion which is the summation of the material dispersion and wave guide dispersion is around 0 is 0 around the wavelength 1.31 micro meter, and below this wavelength the total dispersion is negative and above this wavelength the total dispersion is positive. What is the meaning of negative and positive dispersion let us understand that. Does it mean that negative dispersion compresses the pulses and positive dispersion, expands the pulses broaden the pulses no, move the dispersions will broaden the pulses? If the input pulses unchirped if the input pulses unchirped then both the dispersions negative dispersion and positive dispersion will broaden the pulses. Let us understand the meaning of negative and positive dispersion.

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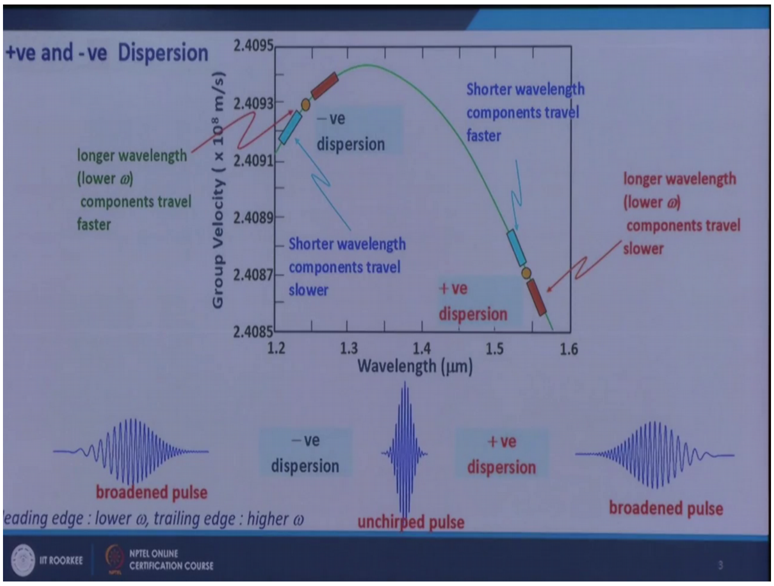

So, to understand this first of all I should understand why the broadening happens. The broadening happens because the spectral components have different velocities; the mode which is excited at different spectral components has different velocities. Now when these components have different velocities then I can have 2 possibilities, one possibility is the shorter wavelength components travel faster then longer wavelength component, and another possibility is longer wavelength components travel faster than shorter wavelength components ok.

So, what happens is that if I plot to understand this if I plot group velocity as a function of wavelength for a typical silica glass fiber; then it goes like this the step index fiber. Now let me pick up a point somewhere here which is less than 1.3 micrometer wavelength then I know at this wavelength I have just seen that at this wavelength the dispersion is negative. If I take my source at this wavelength, and then this is the center wavelength and then I see the components in the vicinity wavelength components in the vicinity of the center wavelength then I find that the shorter wavelength components have smaller velocity, while longer wavelength components has larger velocity. So, shorter wavelength components travel slower here and longer wavelength components (Refer Time: 06:29) travel faster.

So, if I launch a pulse at this center wavelength and this is unchirped pulse, then this the fiber at this wavelength gives you negative dispersion and pulse broadens because the shorter wavelength components travel slower than longer wavelength components. So, the pulses broaden, but what I also see in this broadened pulse that the frequency content in the leading and trailing edge is different; what you see that in the leading edge the frequency is lower while in the trailing edge the frequency is high. So, the pulse not only gets broadened, but also gets chirped and chirping is like this.

While if I take my laser source somewhere here, then I know at this wavelength the dispersion is positive and if I look at the group velocity of the shorter and longer wavelength components in the vicinity of this around the center wavelength, then here the shorter wavelength components travel faster and the longer wavelength components travel slower. So, now, if I launch a pulse around this center wavelength again the unchirped pulse, then it will experience positive dispersion and it will give you a broadened pulse like this which is chirped in the opposite direction ok.

So, here what I get the leading edge has higher frequency component, while the trailing edge has lower frequency components. So, because of this I have negative or positive dispersion, but both the dispersions will broaden the pulse if the input pulse is unchirped.

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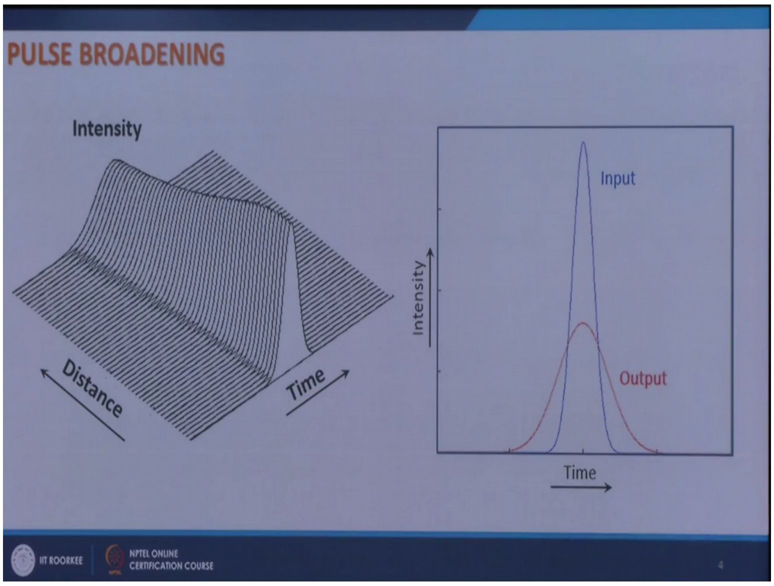

So, this is the intensity of the pulse. So, if I is I launch a pulse at 0 is equal to 0 at the input end of the fiber unchirped pulse, and I see how it evolves along the length of the fiber then I see that it will get broadened. If I capture this pulse at 0 is equal to 0 at the input end, and z is equal to l that is the output end then it would look like this. So, the pulse clearly gets broadened, but the total energy in the pulse will always remain the constant if I assume there is no attenuation. In the absence of attenuation the total energy in the pulse remains the constant. So, when the pulse broadened its amplitude goes down or its peak intensity goes down so, as to have the total energy conserved.

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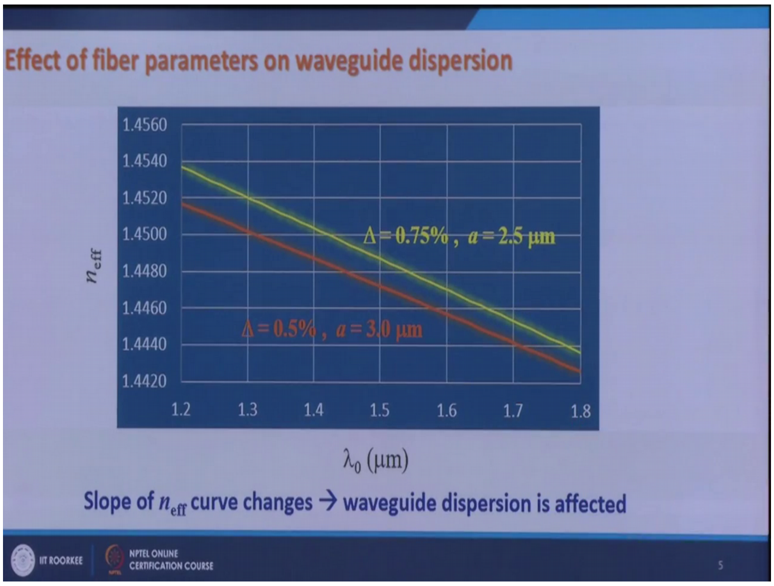

Now, this wave guide dispersion depends upon various wave guide parameters, because it is purely due to the wavelength dependence of propagation constant of the mode. Now if my fiber is such that beta depends upon lambda, and if I change the fiber parameter this dependence of beta on lambda can change or dependence of n effective on lambda gets changed then the dispersion will be different. In order to show this I have taken several examples.

So, one of the examples is that I take a fiber with delta is equal to 0.5 percent, and a is equal to 3 micro meter. And now if I calculate the effective index of the mode at different wavelengths and plotted, that effective index varies something like this. If I change the parameters of the fiber make delta from 0.5 percent to 0.75 percent, and bring down a from 3 to 2.5in order to keep V value almost at the same level to keep the fiber always single modded.

If I am increasing delta will have to bring down the value of a. So, now, again I if I plot n effective as a function of lambda naught then t goes like this. I see that the slope of this is different from the slope of this and hence d 2 bv over dV square for both these curves would be different and this will lead to change in wave guide dispersion. So, it will change the wave guide dispersion if you change the fiber parameters.

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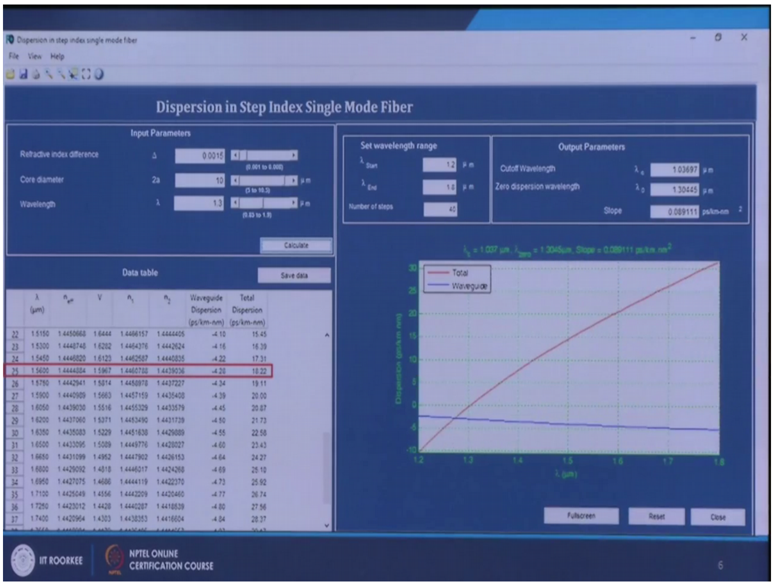

In order to demonstrate this I take numerous examples now this is from the software lite sim. So, where I can change the relative index difference delta I can change the core diameter, and then see what happens to dispersion. So, this is when delta is equal to 0.0015 that is 0.15 percent, and core diameter is 10 micro meter then I see that at around 15-16 nanometer wavelength my wave guide dispersion is minus 4.28 picoseconds per kilometer nanometer, and total dispersion is about 18.22 picoseconds per kilometer nanometer. Graphically if I look at it the wave guide dispersion is shown by this blue line and total dispersion is shown by this red line.

So, the zero dispersion wavelength for the total dispersion is around 1.3045. If I change the fiber parameter if I increase delta to 0.2 percent from 1.15 percent to 0.2 percent, and core diameter I change from 10 to 9 micro meter, then what I see that the wave guide dispersion increases to minus 5.17 and the total dispersion becomes 17.33, and the total dispersion wavelength changes to 1.31 micro meter. So, when I change delta and a change the wave guide dispersion, I further increase delta. So, it is now 0.3 percent and core radius is 8 then this is the wave guide dispersion this is the total dispersion, if I further change it then I increase the wave guide dispersion to about point about minus 8 picoseconds per kilometer nanometer if I further increase.

So, I see that if I increase the value of delta then my wave guide dispersion is changing quite a lot, if I am increasing delta then wave guide he magnitude of wave guide dispersion is increasing, and the total dispersion is decreasing. Here at delta is equal to 0.7 percent and core diameter 5 micro meter 0 dispersion wavelength could be moved to 1.426 micro meter which was earlier 1.3 micro meter or 1.3 micro meter. So, I can drastically change the wave guide dispersion if I change the fiber parameters.

What I also notice in all these curves are that for a given fiber, wave guide dispersion is larger the magnitude of wave guide dispersion is larger at longer wavelength as compared to at shorter wavelengths why it is so? It is understandable because at longer wavelength the field spreads more into the cladding at shorter wavelengths field is more and more confined into the core. So, at shorter wavelengths the mode does not see much effect of the cladding.

So, the dispersion is small because it does not see the composite structure. So, a strongly, but when you increase the wavelength then the field spreads into cladding also. So, the fraction of power that goes into cladding increases. So, the fiber modes is more and more the composite structure, and the wave guidance is effected more and more so with wavelength. So, that is why at longer wavelengths I see much stronger effect as compared to at shorter wavelengths.

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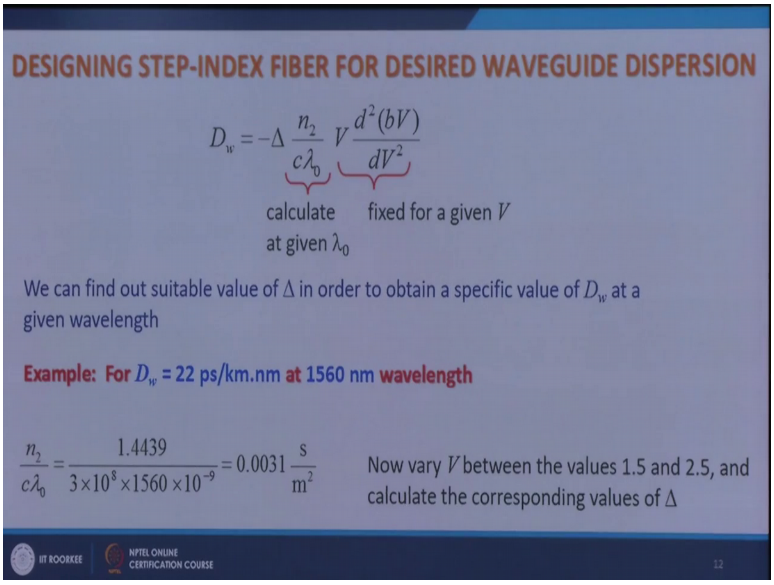

Now, can I tune my fiber parameters in order to get a desired value of wave guide dispersion is it possible. So, for that if I look at this expression of wave guide dispersion.

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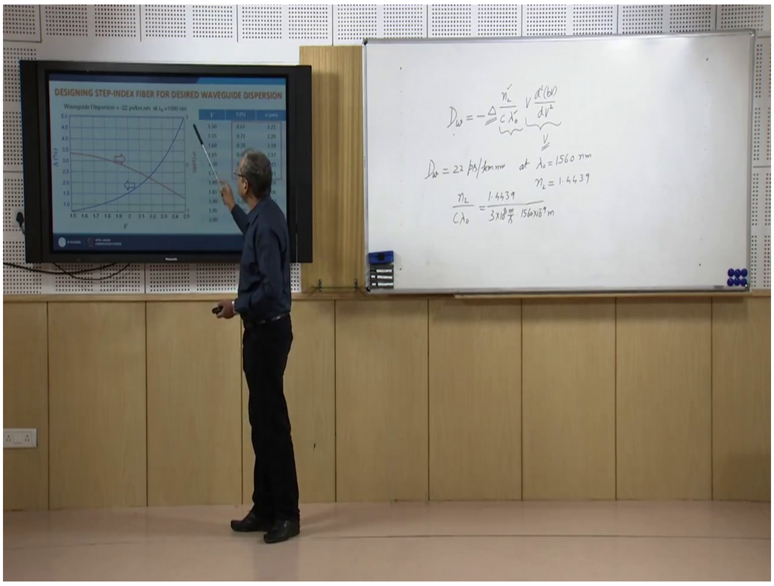

Then it goes as Dw is equal to minus delta n 2 divided by C lambda naught times V d 2 bV over dV square. Now for a given value of V this is fixed. If I want to obtain wave guide dispersion certain value of wave guide dispersion at a given value of lambda naught then and I always use silica glass fiber when I use silica glass fiber, then at a given wavelength this n 2 and lambda naught they are now fixed n 2 is fixed at a given lambda naught then what I can do.

Now, if I change delta for a given value of V, then I can obtain our desired value of Dw. So, if I fix Dw then I change the value of V and change the value of delta then an appropriate combination of V and delta can give me a desired value of Dw. So, I can understand it with the help of an example, if I want to target my Dw as 22 picoseconds per kilometer nanometer at lambda naught is equal to 1560 nano meter wavelength, then n 2 at this wavelength is around 1.4439. This is the refractive index of silica glass at 1516 nanometer wavelength.

So, this is now fixed n 2 divided by t lambda naught is fixed as soon as I fix this wavelength 1516 nanometer. So, it is 1.4439 divided by 3 into 10 to the power 8 meter per second times 1560 into10 to the power minus 9 meters this is the wavelength. So, if I work this out then this comes out to be 0.0031 second over meter square. So, this is fixed now I vary the value of V let us say from 1.5 to 2.5 and I get this V times d 2 bV over dV square for example, from marques formula which I have shown in the next in the previous lecture that it gives you much accurate value of V times d 2 vv over dV square for any given value of V lying between 1.5 and 2.5.

So, I get this from marques formula, and then vary delta and then calculate delta in order to obtain Dw is equal to 22 picoseconds per kilo meter nanometer.

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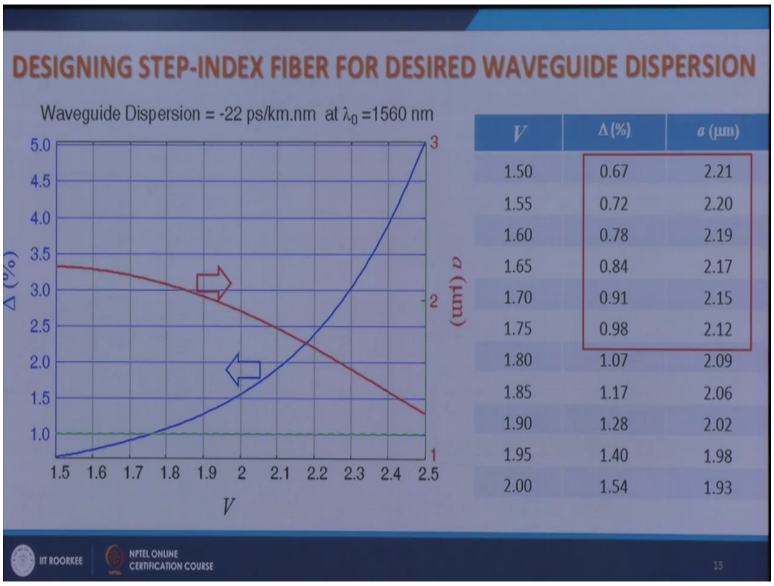

So, I do that and I plot it as a function of V. So, if I vary V. So, what values of delta will give me wave guide dispersion of minus 22 picoseconds per kilo meter nanometer at lambda naught is equal to 1560 nanometer. So, this is how it varies the delta varies with V like this in order to obtain this value. Correspondingly because I am changing delta for a given V then a has to change to keep the V constant, correspondingly the core radius varies like this. So, you are increasing the value of delta then correspondingly the core radius should decrease in order to keep this V constant. So, what I see that if I vary delta then to keep the delta less than 1 percent, I would like to keep delta less than 1 percent I would not like to have very large value of delta because if I increase delta then attenuation in the fiber increases ok.

So, if I typically keep the value of delta is smaller than 1 percent, hen these are the combinations of delta and a that will give me the wave guide d of minus 22 picoseconds per kilo meter nanometer. So, I see the value of a would be around 2 micro meter. So, in this way I can obtain any desired value of wave guide dispersion as I want to certain extent not any desired value.

Because if I want to have much larger value of wave guide dispersion then perhaps I will have to have very large value of delta and correspondingly very small value of a, which is not desirable because very high value of delta will give you very large attenuation and very low value of delta will very low value of a will make problems will create problems in coupling light from source laser source into the fiber. So, we will have to be practical.

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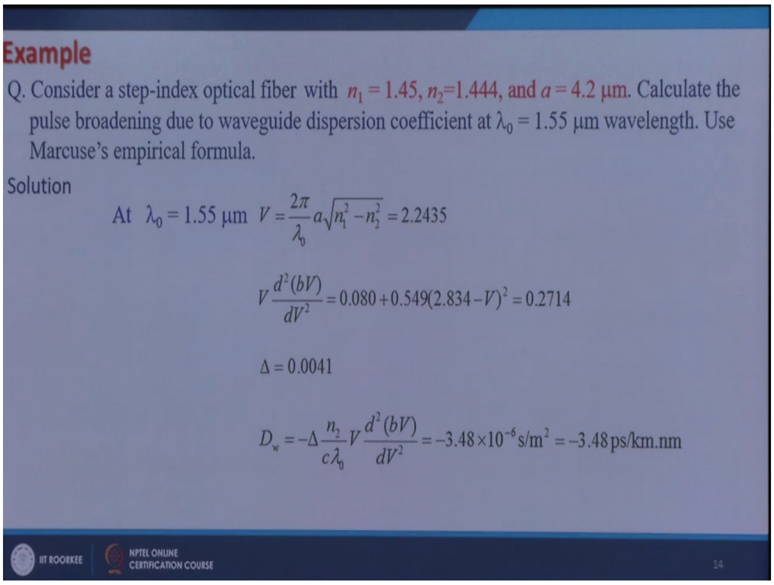

Let me work out an example, I consider a step index optical fiber with core refractive index 1.45 cladding refractive index 1.444 and core radius 4.2 micro meter and I want to calculate broadening due to wave guide dispersion at lambda naught is equal to 1.55 micro meter and I using Marques formula.

So, I want to calculate wave guide dispersion coefficient. So, solution is well what I need to do first? I need to find out this V times d 2 vv over dV square. So, I first need to find out what is the value of V at lambda naught is equal to 1.55 micro meter. So, V is given by this. So, if I calculate V then t comes out to be 2.2435 and marques formula for V times d 2 vv over dv square is this. So, if I put this value of V then the express the value of this comes out to be 0.2714 delta for this is I need delta also. So, delta if I work out for these values of n 1 and n 2 then it comes out to be 0.0041, now I have everything in place I need to just plug in these values into this formula and get the wave guide dispersion coefficient.

So, Dw it is given by minus delta n 2 over c lambda naught times V 2 d 2 bv over dv square comes out to be minus 3.48 into 10 to the power minus 6 seconds per meter square, and I can convert it into picoseconds per kilo meter nanometer and it comes out to be minus 3.48 picoseconds per kilometer nanometer.

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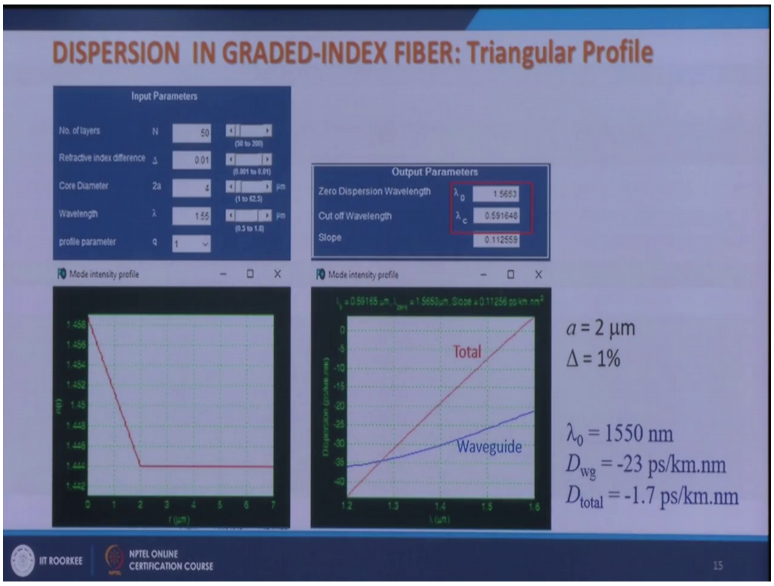

So, till now we had considered a step index optical fiber, and wave guide dispersion in step index optical fiber. We can also work out this wave guide dispersion in graded index optical fiber. So, in graded index optical the only thing is that you need to calculate the effective index as a function of wavelength. So, this we have done using the software lite sim where there is an option of calculating dispersion for graded index optical fiber. So, I just want to tell you how the profile refractive index profile of the fiber changes the wave guide dispersion. So, here I have power lap profile.

So, this is triangular profile which corresponds to q is equal to 1, I have taken delta is equal to 1 percent and core diameter 4, and this is how the wave guide dispersion total dispersion varied. So, at 1550 nanometer wavelength if I pick out the values of wave guide and total dispersion, and the wave guide dispersion in minus 23 picoseconds per kilo meter nanometer and total dispersion is about minus 2 picoseconds per kilo meter nanometer very small. And the 0 dispersion wavelength shifts to about 1565 nanometer. If instead of taking this triangular profile I take parabolic profile I am sorry it has to be parabolic profile it is not triangular profile.

So, it has to be parabolic profile. So, in a parabolic profile if I again take the value of delta as 1 percent and the core diameter I have now made 3. So, now, the total dispersion wave guide dispersion they vary like this, and at 1550 nanometer wavelength wave guide dispersion is minus 24 picoseconds per kilo meter nanometer and total dispersion is about minus 3 picoseconds per kilo meter nanometer.

So, by changing the profile you can change the wave guide and total dispersion. This is cubic profile which corresponds to q is equal to 3, delta here is 0.6 percent while the core radius is 2 micro meter, and lambda naught at lambda naught is equal to 1550 nanometer the wave guide dispersion is minus 21.68 picoseconds per kilometer picoseconds per kilometer nanometer and total dispersion is very close to 0, it is 0 picoseconds per kilo meter nanometer. So, 0 dispersion wavelength here I have got 1550 nanometer. So, so in this way I can even shift my 0 dispersion wavelength, I can tune my 0 dispersion wavelength added at a desired value if I change the fiber profile.

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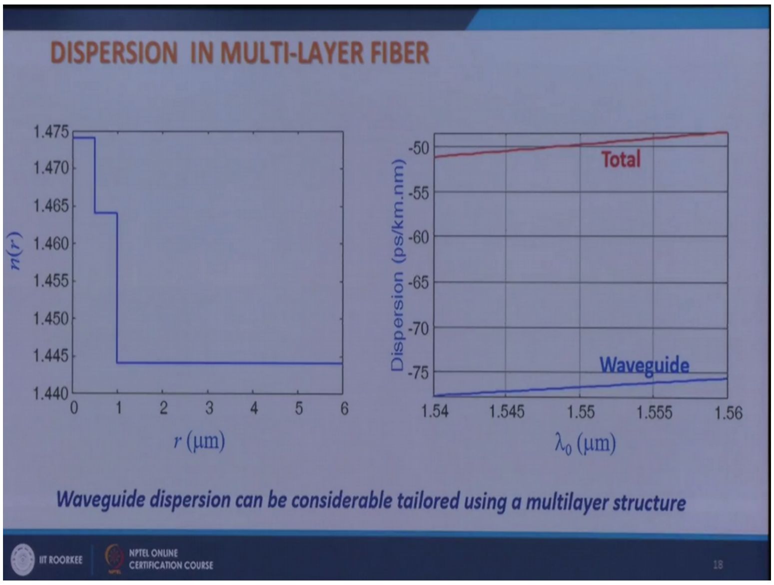

So, I have seen the step index fiber, I have seen graded index fibers, I can also have multi layer fibers where core is not made up of one layer, but I have 2 layers in the core one high index layer then surrounding it is small index layer, and then you have a cladding. So, I can have a multi layer and with the help of multi layer I just want to show you that you can drastically change the wave guide dispersion, just look at the values of wave guide dispersion here they are less than minus 75 picoseconds per kilo meter nanometer.

So, the magnitude is larger than 75 picoseconds per kilometer nanometers. So, you can enhance the wave guide dispersion quite a lot. So, with the help of multi layer structures you can considerably tweak with the wave guide dispersion.

So, in this lecture what we had seen that wave guide dispersion depends upon fiber parameters profile of the fiber. So, by changing the fiber parameters and refractive index profile of the fiber, we can tune wave guide dispersion to whatever value we want to certain extent.

Thank you.