Industrial Instrumentation
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Lecture - 29
Optoelectronic Sensor-II

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Welcome to lesson 29 of industrial instrumentation in this particular lesson. We will consider will cover the optoelectronic sensor 2. Basically the contents we will like this that, we will first cover the basics of fibre optics. And then some basics of fibre optics, because we have already, discussed some basics in the industrial in the lesson 28. We will cover details the transmission applied in the optical fibre, then I will come to the fibre optic based sensors. Let us look at the lesson, so optoelectronic sensor 2 contents.

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Introduction to fibre optics traveling of light through the cable, then monomode cable multimode graded index cable and fibre optic sensors. These are the basic things; we should cover at the end of the lesson.

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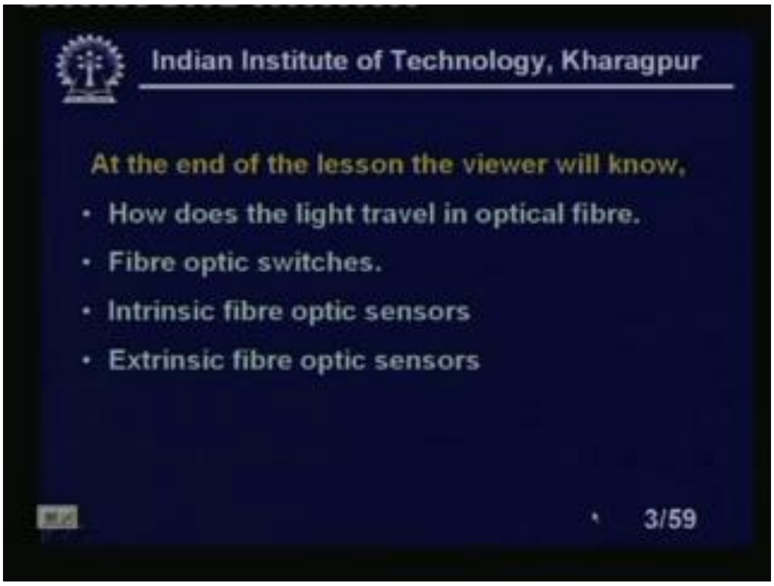

Now, please one thing you note that, in this particular lesson. Sometimes, I will tell the cable, but cable means basically I want to mention that it is basically, a fibre optical fibre nothing other than that right? So, at the end of the lesson, viewer will know, how does a light travel in a optical fibre, fibre optic switches, intrinsic fibre optic sensors, extrinsic fibre optic sensors, right?

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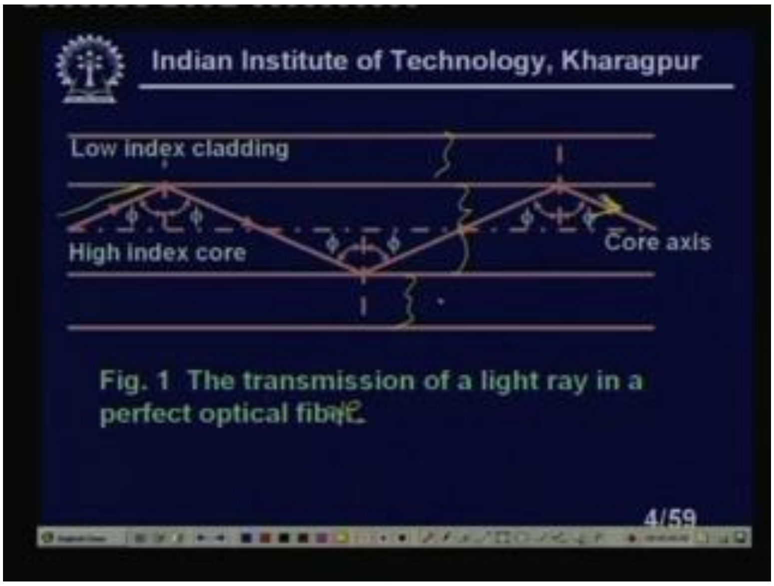

Now, you see, this is the, this the typical a fibre optics, you can look at lights are I mean, how the light travels in optic ((Refer Time: 02:15)) this basically, we have shown a step index fibre. So, in the step index fibre, you see here, please note that I am using the British English. So, it will be fibre like this, one or I can take the other pen. So, it is fibre and ((Refer Time: 02:34)) in the light travels, it always goes through a total internals reflections. You see here light is traveling and these incidence is such a way, that it will have a total internal reflections. So, that nothing no none of the lights, will be lost in the cladding and totally, it will be reflected. So, that refracting index of this one of the core this is the core this is actually, the core and this is a cladding right these are the cladding.

So, the refractive index of the core is higher than the that of higher than that of the cladding and incident lights we actually, arrange to and fall in such a way. So, that the light will get a total internal reflection, so it will follow zigzag fashion, please note it will be like this one, So, it is not like this, it will be like this light will follow, like this one. So, this phi should be greater than, the critical angle of incidence, because if it is not not more than critical angles. So, there will be no total internal reflection, so the, we have to arrange for the total internal reflection. So, that even this fibre is not steady, if it is bend like this one. So, light can travel through, this that is a idea of this I mean, optical fibre.

So, even though, we now, the light travels in only in a straight line using this total internal reflection. We can see, that the in the optical fibres, light can go through a bend path right. That is a tremendous, advantage and using that principles, we have used many though, if a bend like this. You will find that there is a loss of intensity and all those things if the light travels straight. So, loss of intensity will be, even though we are saying, that it is as a total internal reflection. And all those things, it will be some light will be dispersed. So, using that principle, we will find that, we may made several sensors right. We will come to that later on, now let us come to basic the principle, how the light travels in a optical fibre.

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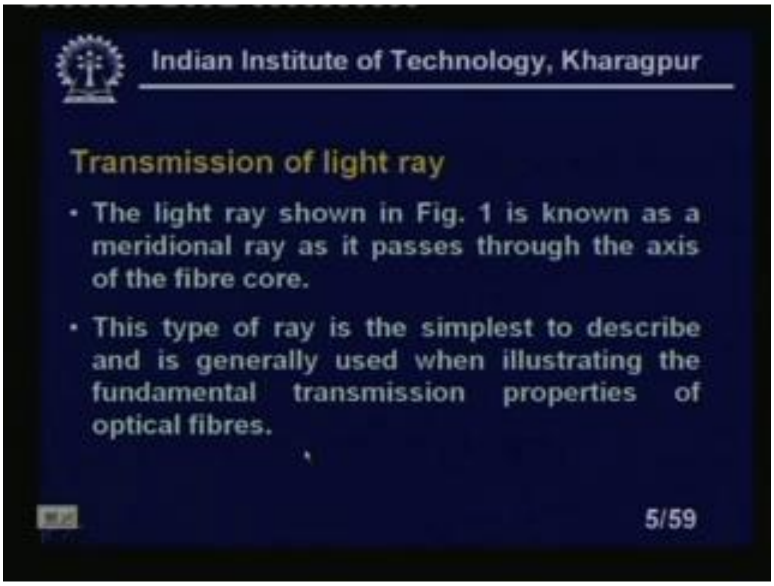

Transmission of light ray; the light ray shown in figure one this just the previews figure known, as a meridional ray as it passes through the axis of the fibre core. If cores, the fibre cores, we will call meridional ray this type of ray is the simplest to describe and is generally used when illustrating the fundamental transmission properties of the optical fibres. This always we use these fundamental transmission properties of the optical fibre.

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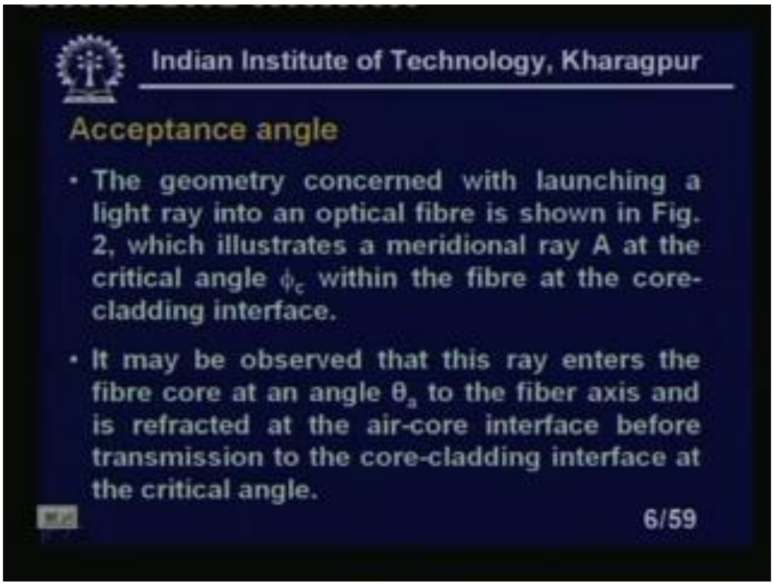

Acceptance angle look like this, you see the what is the acceptance angles? What is the numerical aperture? These are the basic definitions of the optical fibre. This we will discuss in this particular lessons at the beginning of this lesson. Now, the geometry connected, concerned with launching a light ray into an optical fibre is shown in figure 2. which is which illustrates a meridional ray A at the critical angle phi within the fibre at the core cladding interface right, see it is you see that here if you look at…

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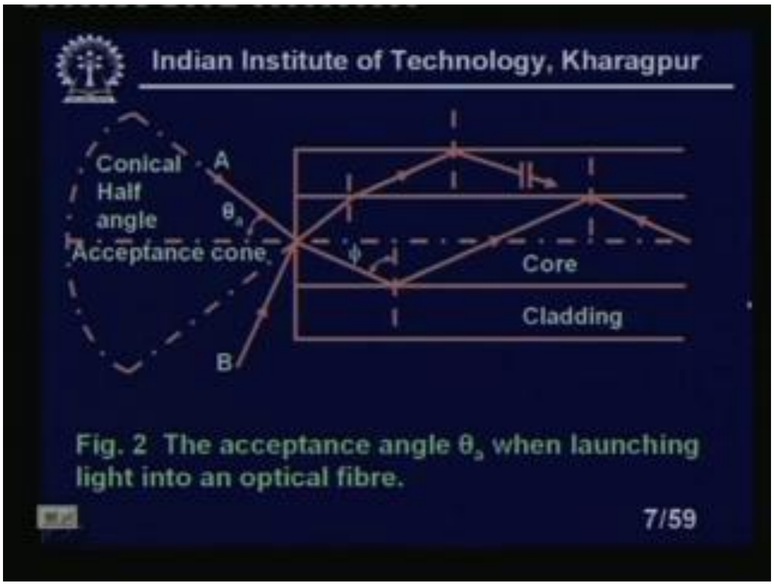

What is the, this the figure 2 you see, it is a is a conical half angle this is the phi theta a. So, theta is a I mean, because we must know, what is the, what is the maximum value of theta? A is allowed, because this face, if this is a face of the fibre. This face should be highly, polished if I fall the light in the normal directions that is, but that is not always possible. Specially, in the case of a if we use a light source as a lead light emitting diode there will be a different angle light can fall. So, I have to we must find, what is the maximum angle value of theta a. So, that, when the light enters the core, there is a total internal reflections right. So, that we must find it, light you see, travelling like this one and some light say, if travelling like this one having the total internal reflections. This light you see, this is the more than the acceptance angles.

So, this light, we will not get the total internal reflections. So, it will be reflected within the core and it is lost. So, this is the lost I mean, this will not be transmitted, through the core, this will be lost in the cladding itself. Whereas, if I can make within this theta angle of incidence is within theta a, we will find that we will get a total internal reflections, within the core of the fibre. So, we must find what is that? Let us go back again. Now, the geometry concerned, with launching a light into the, into an optical fibre is shown. In figure 2 which we have shown; which illustrates the meridional ray A, at the critical angle theta c within the fibre at the core cladding interface. It may be observed that the, this ray enters the fibre core at an angle theta a to the fibre axis and is refracted at the air core interface, before transmission to the core cladding interface at the critical angle right.

So, we have chosen theta a in such a way, so that it will be refracted in the air core, because when it is launch in the air. I mean, one launch from the transmitter, we are assuming, that it is for some distance. The light will travel in air then, it is coming to the core. So, when it is in the core it is refracted and it bends towards, the axis right, so that bent was the axis of the core. So, that the I mean and that bends will be in such a way that will be more than the. So, that when the light falls in the core cladding junction, so it will be more than the critical angle of the, this 2 this 2 medium. So, that we will get a total internal reflections let us look at.

So, this is the thing at which I talked about, you see this is a angle this is a ray and this is a maximum angle. I mean, if we go beyond that, I would not get any total (( )) this we have shown here. You see, it is more than theta a, So, light is falling another light is falling see. It is not, it is refracted there is no doubt, about this, because here the medium the refracting index here. This one of the core is higher than, that of the higher than that of the cladding. So, it will be, because if it is a normal, it will go away from the normal and I will get a total. I mean, I will get a bending like this one right, because there is a jacket ((Refer Time: 08:36)). So, the light will not go, so it will be cladding, it will be lost right that I told you earlier also.

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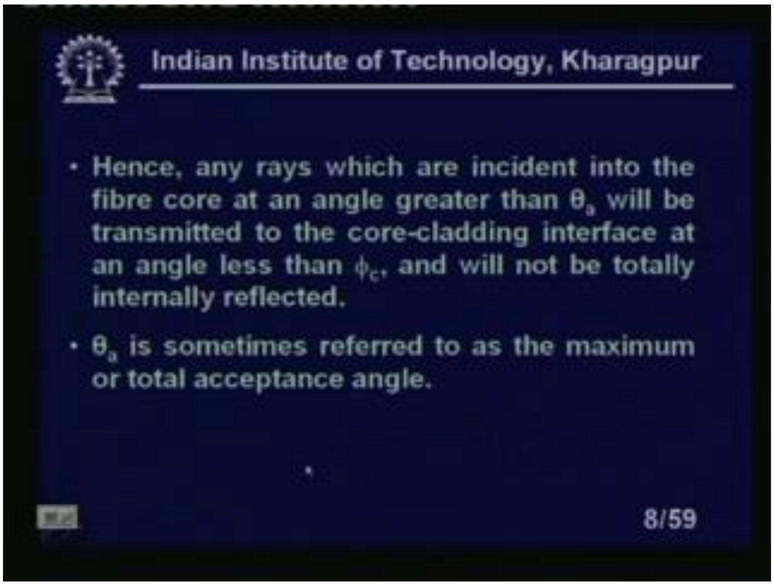

Now, hence any rays, which are incident into the fibre core at an angle greater than, theta a will be transmitted to the core cladding interface. At an angle less than phi c and will not be totally internally, reflected. See there is no totally internally, reflection as I told you and theta a is sometimes referred to as the maximum angle. Or total acceptance angle of the fibre optics, it is a total accept, you known it is a solid cone right. It is not a I mean, I mean, 2 dimension, it is a solid cone theta is basically, a solid cone.

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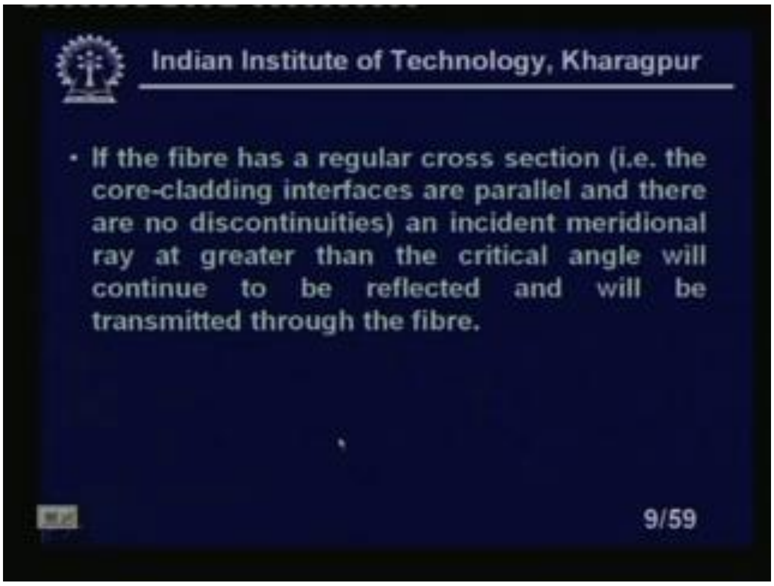

If the fibre has a regular cross section that is the core cladding interface are parallel. There are no discontinuities an incident, incident meridional ray at greater than, the critical angle will be continue to be reflected. And will be transmitted through the fibre that is a very good.

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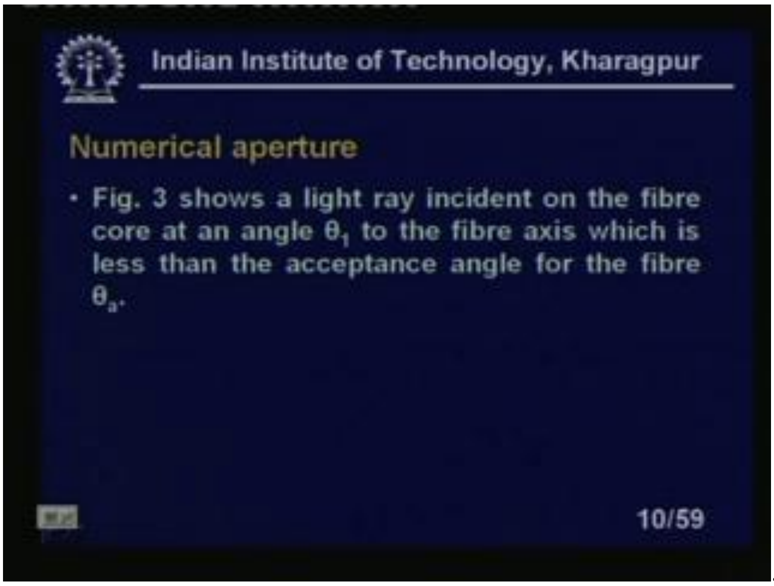

Now, what is the numerical aperture? The numerical aperture very I mean, it is a less specification of the fibres. So, must know, what is the numerical aperture? So, we will calculate here, the numerical aperture for a optical fibre. You see, figure 3 shows a light ray incident, on the fibre core, at an angle theta 1 to the fibre axis, which is less than, theta a acceptance angle for the fibre, because you see rays to be transmitted through total internal reflections. So, incident ray might be should be always less than, the acceptance angle, if it is more then, it will not be totally, internal reflectance right. So, it should be less than the acceptance angle for the fibre theta a. What is figure 3?

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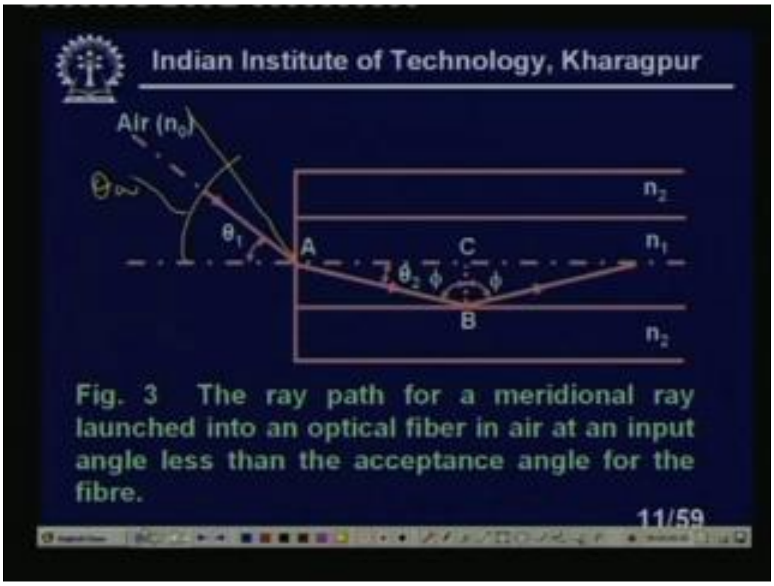

Let us look at this is our figure ((Refer Time: 10:19)), since theta 1 the acceptance angle is slightly higher. The acceptance angle will be like this one right; this is our theta a right. So, it is less than that, so I getting an I mean, bending I mean, because it is a higher refractive index. So, light will get, because this is the normal to the plane of the surface. So, it will be bend like this 1 this is theta 2 then it will go like this 1, clear let us go back again. The ray path for the meridional ray, so launched into the optical fibre in air at an input angle, less than the acceptance angle for the fibre.

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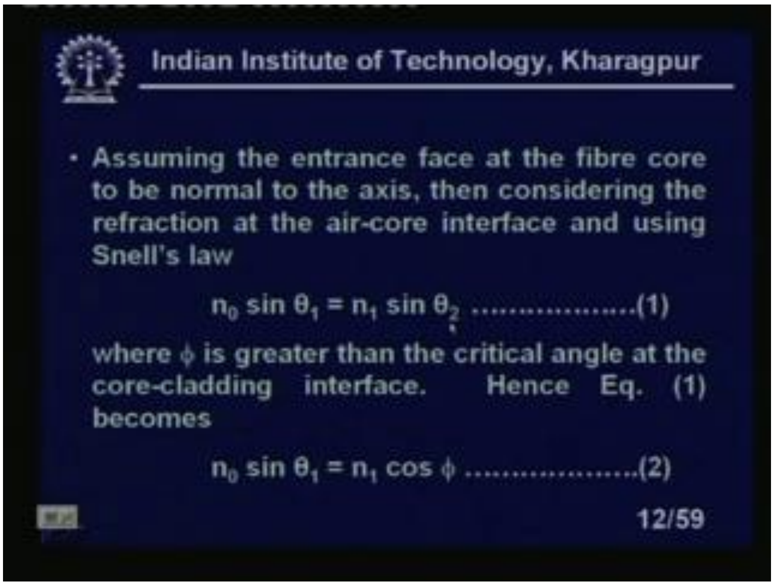

Assuming that the entrance face at the fibre core to be normal to the axis, then considering the refraction at the air core interface and using Snell's law. We are adding no into sin theta 1 equal to n 1 sin theta 2, right. So, this is n 1 this no this is the refractive index of air and this is the refractive index of the core. And this angle of incidence of theta 1 and this is the angle of refraction theta 2. So, that we can easily, write the Snell's law n 0 sin theta 1 equal to n 1 sin theta 2 this equation number 1 where you can see here, if the phi is greater than, the critical angle at the core cladding interface. If the phi is I mean, hence equation 1 becomes, if we write that the, you see if the sin theta 2 again you can go here.

Now, this is if you take this one, so this is you see this is a 90 degree. So; obviously, this is this is theta 2 so; obviously, phi will be basically, 90 degree minus theta 2. So, if it is there so; obviously, I can write that, where phi is greater than the critical angle at the core cladding interface. If it is phi is greater than the critical angle of the otherwise, there will be no total internal reflections. I can n 0 sin theta 1 n 1 it will be actually, sin of phi by 2 minus phi, because if you take that angle as a right angle triangle, what were here? This is right angle, triangle ABC is a right angle triangle. So; obviously, I can write what; obviously, that n 0 sin theta 1 equal to n 1 into cos phi, right.

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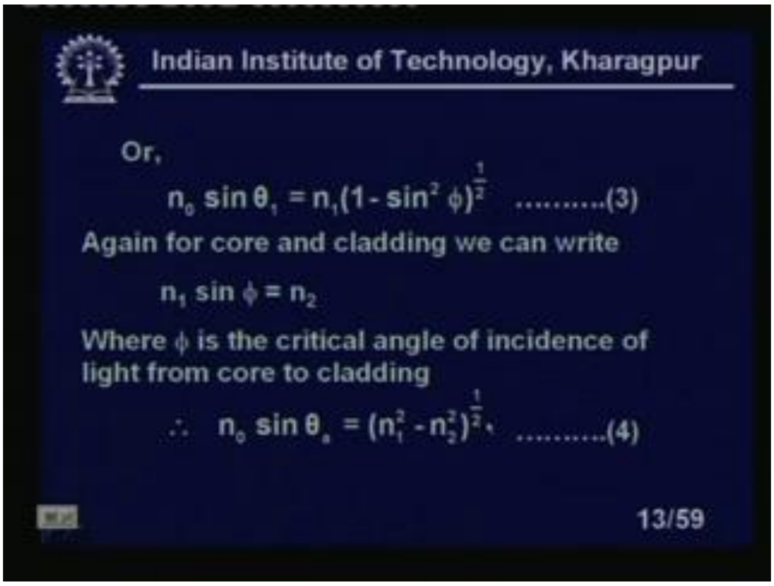

Or n 0 sin theta 1, so n 1 sin square phi to the power half, we can write this equation number 3. Again for the core cladding, we can write again, you see for the core cladding interface. n 1 sin phi equal to n 2 why see look at? You see, when light will be reflected here, because this is n 1 sin theta 2 n n 1 sin theta 2 equal to n 2 here. You see, when you it is reflected, so it will be phi. So; obviously, if I apply, the total internal reflection principles, I can immediately, write that expression. What is that again, for the core cladding, we can write n 1 sin phi into n 2 is not it, because that will be 90 degree so; obviously, it will be 90 degrees.

So, where phi is the critical angle of incidence of light from the core to cladding, because in that case, if it is critical angle. If phi is a critical angle, this will be sin n 2 into sin 90 degree. So, sin 90 degree is equal to 1 so; obviously, it will be n 1 sin phi equal to n 2. Where phi is the critical angle of incidence light from the core to cladding, so which I can, write sin theta a equal to n 1 square minus n 2 square. What is n 1 square? I put n one inside, so it will be n square n 1 square and we have here, we have we have n 1 n 1 square into sin square phi that is equal to n 2 square. So, in case it is 2 to the power half, so fine.

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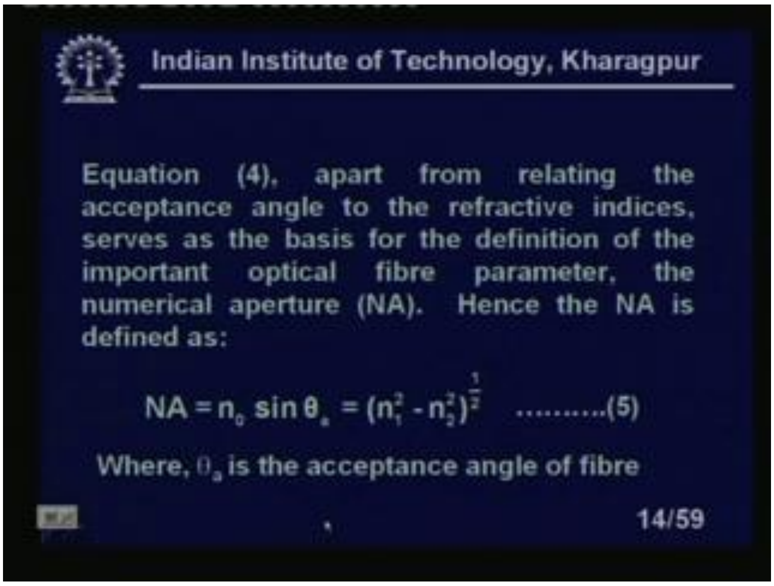

Equation 4 apart from relating the acceptance angle, you see this is actually, this n a theta a we got a calling the acceptance angle right. How to find the acceptance that is the reason. We made it sin theta n 2 equal to sin phi equal to 1 otherwise, we cannot do it. Equation 4 apart from the relating the acceptance angle to the refractive indices serves as the basis for the definition of the important optical fibre parameter, which is called the numerical aperture. Hence the numerical aperture or in a can be defined as na equal to n naught sin theta a. Theta is the acceptance angle equal to n 1 square minus n 2 squire to the power half equation number five, where theta a is the acceptance angle of the fibre I should actually, write the theta in the previous equation equation number 4.

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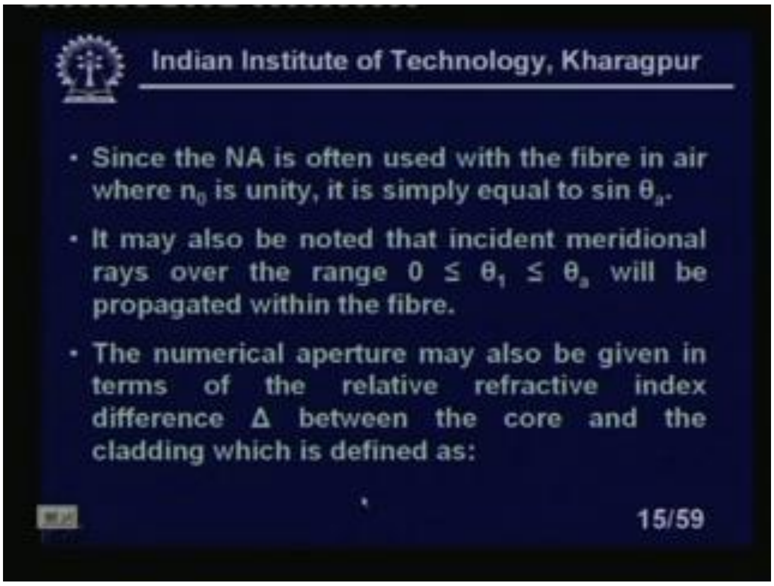

Since the NA is often used with the fibre in air. So, no is actually, unity with the refraction index of the air is taken as the unity, so it is simply, equal to sin theta a. So, it may also be noted, that the incidents, incident meridional rays over the range of theta theta 1 is the incident angle. So, it should be lied between 0 and theta, if it is 0, there is no question of total internal, if light will straight will flow will pass through the phi core. But if it is more than 0 degree, so obviously, more than 0; obviously, there will be total internal reflection, because it is less than theta a, we have chosen theta in such a way. So, that the, it will be any light within this range, if it falls it will go through a total internal reflections. So, the light will be propagated within the fibre, the numerical aperture may also be given in terms of the relative refractive index, index difference delta.

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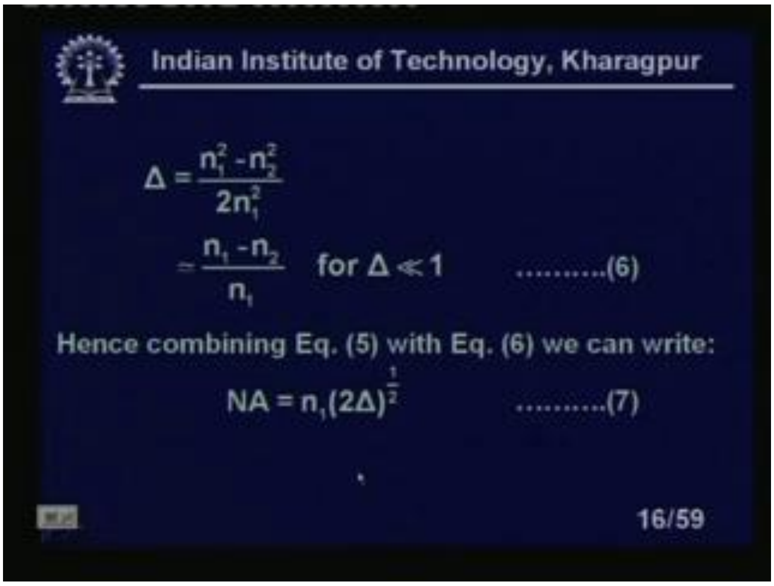

Between the core and the cladding which is defined as delta equal to n 1 square minus n 2 square by 2 n 1 square, so which we can write n 1 minus n 2 by n 1 for delta. If it is delta less, less 1 we can write like this one equation, number 6 hence combining equation 5 with equation 6. We can write that, numerical aperture is equal to n 1 2 delta to the power half, which is equation number 7.

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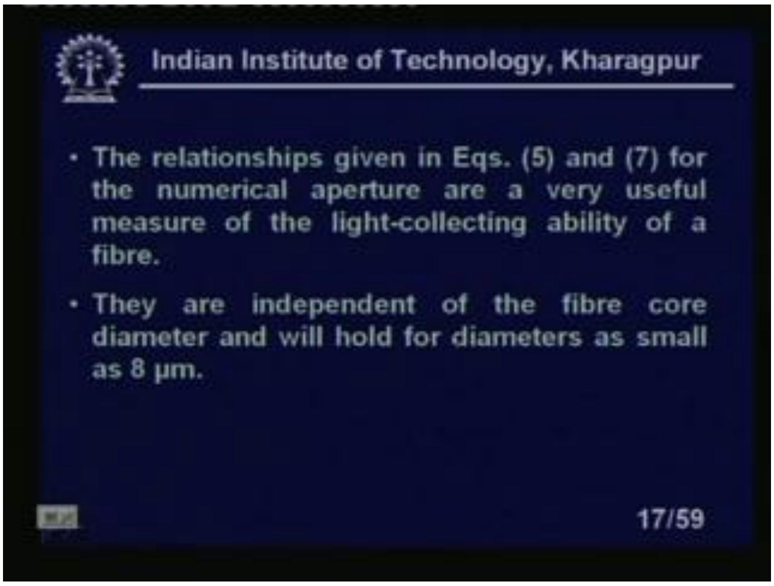

The relationships given in equation 5 and 7 for the numerical apertures are a very useful measure of the light collecting ability of a fibre, because we a must know accordingly.

We will make our transmitter, even though I mean, fibre optics sensor also, we need transmitters we need receivers though we talked about as, if we are only using for communication that is not actually true. You will find here also the light will travel to the fibre. They are independent of the fibre core diameter and will hold for diameters as small as 8. Even, if it is a diameter of the core is 8 micron the light will I mean this equations will follow.

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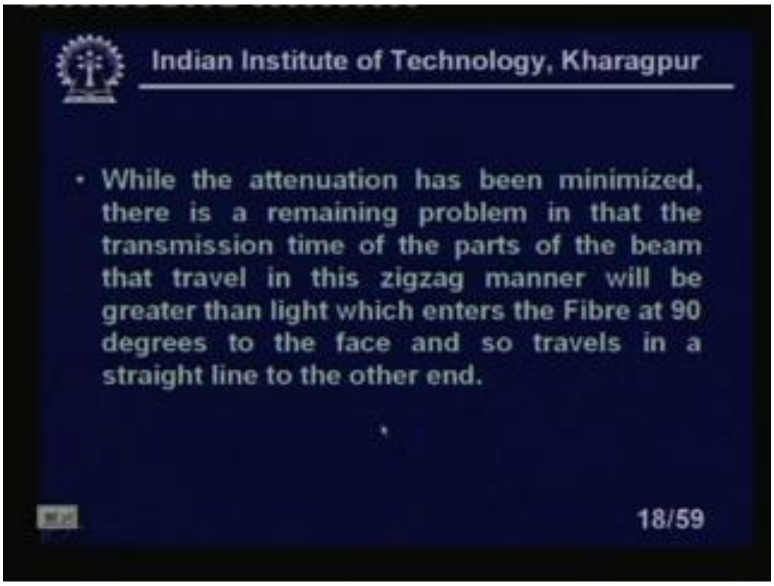

While the attenuation has been minimized, there is a remaining problem in that the transmission, time of the parts of the beam. That travel in the zigzag manner will be greater, than the light which enters the fibre at 90 degrees to the face. And so travels in a straight line to the other end. So obviously, if it falls on a 90 degree is not, it if the light falls on a 90 degree, because we are talking about. So, much you see if I take a dark 1.

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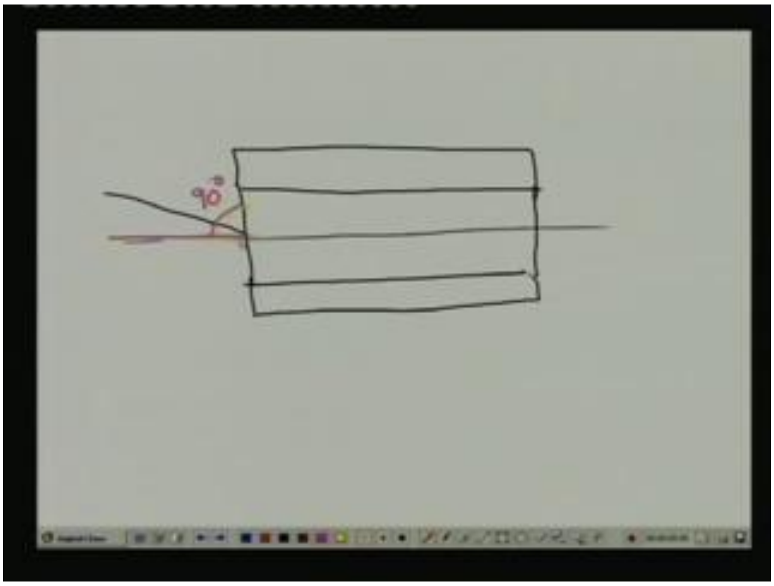

So, we are talking about like this one this is our fibre and we have a cladding here. So, this is our central, so light is falling like this one right. But at the same time light may fall on a straight line, if it falls in straight line. So, the angle of incidence is 90 degree is not, it is not very good, I can take this one. This is 90 degree, then is not it does not matter, because it is even in that case. Even it falling on perpendicular to the face, but the angle of incidence theta a in that, case will be 0 degree is not it theta should be always, less than that value. Otherwise there will be no total internal reflections anyway let us go back.

While the attenuation has been minimized, there is a remaining problem in that that the transmission time of the parts of the beam. That travel in the zigzag manner, will be greater than the light, which enters the fibre at 90 degrees quite obviously. A light travelling in a zigzag fashions, with the total internal reflections. It will have some time, where the light? When the light? I mean, travels straight away, through the fibres. When the light falls with the theta equal to 0 degree; obviously, in that case, it will take less time is not it.

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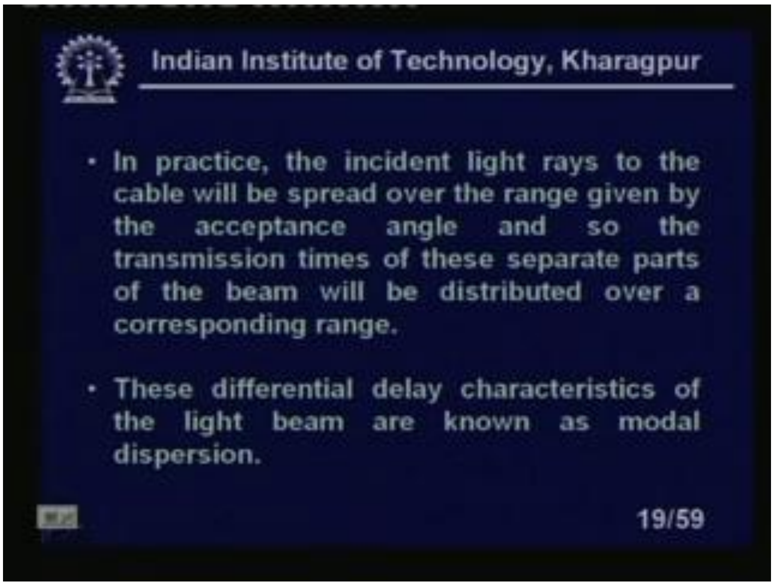

In practice, the incident light rays to the cable will be spread over the range given by the acceptance angle and. So, the transmission times of these separate parts of the beam, will be distributed over a corresponding range, right. It will be distributed transmission times, of different ray, so in the case of multimode fibre, so this will be very predominant. These differential delay characteristics of the light beams are known as a modal dispersion in a optical fibre. So, is the dispersion of light, so lights are getting more and I mean, time is not equal time, it reaches at the end, but this I mean, problem can be eliminated in the case of graded index fibres. So, it, because this problems, what we have talked about is a multimode fibre? Multimode step index fibres will, this will be more you will find easy to see this one in the graded index fibres right. It will not the problem, not be there at this modal dispersion, will almost eliminated in the case of the graded index fibre.

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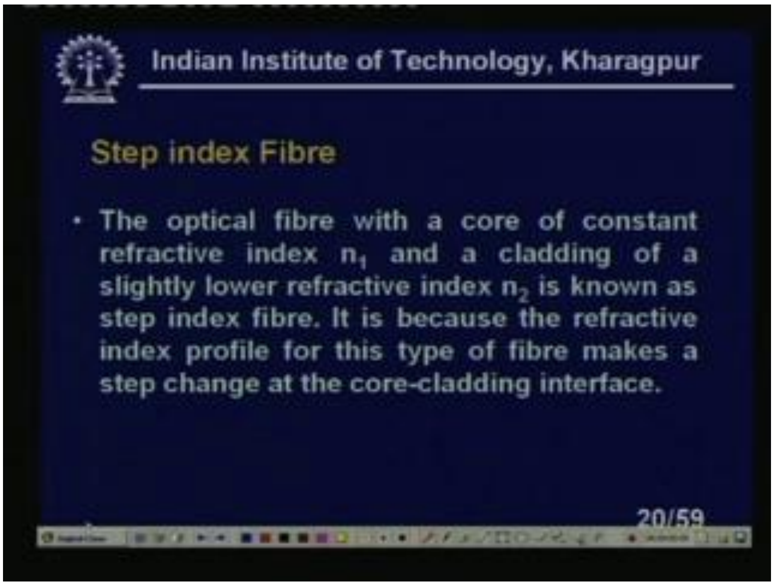

Now, step index fibre the optical fibre with a core of constant refractive index n 1. And a cladding of slightly lower refractive index n 2 is known as a step index fibre as simple as that. It is, because the refractive index profile for this type of fibre makes, a step change at the core cladding interface clear. So, let us look at that type of I mean, step index fibre or step index fibre. So, this step index fibre can be 2 type, it can be monomode can be multimode. So, let us look at first monomode.

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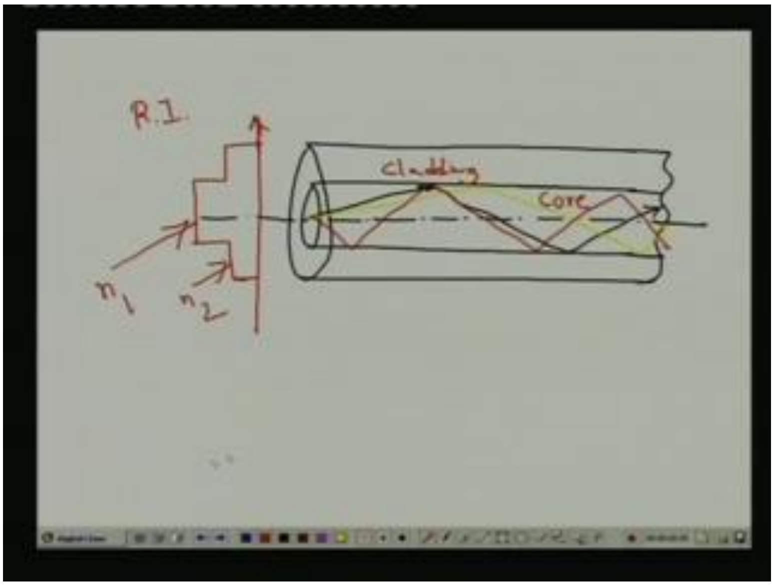

Let us take white page say, it will look like this you see, that I have a I can take a large dark pen. A cladding here, I have a fibre here. Let me draw, one the end joining and the center line, which we studied in the first year the drawing like this one right. So, what will happen? You see here, this is the cladding both side cladding and center. We have a is a cylindrical in shape, what will happen? In the case of multimode fibre. So, light will travel in these various directions. So, it will travel like this, then it will travel like this right. It will like this one. It can also travel like this, it can travel like this it can travel or it can go like fashion, it can go in a more like this right in all these different cases. Now, the index profile; that means, refractive index profile, we look like this one, it will have a step change; that means, you see it will look like here. So, actually, it will look like this one right, so this will right.

So, let me get back the pen again and see it will look like this right. So, here the refractive index here, is n 1 and here the refractive index is n 2 right. So, this refractive index, we are plotting RI refractive index, we are plotting. So, this is the multimode fibre, so this is core, this is cladding, this is multimode fibre. And in the case of step this is say please note, there is a there is a step change of the refractive index, RI is not it. There is a step change here, at this point there is a step change that is a reason, we are calling step change multimode fibre right. We have a step and we have a, we have a single mode fibre also right, so its look like this.

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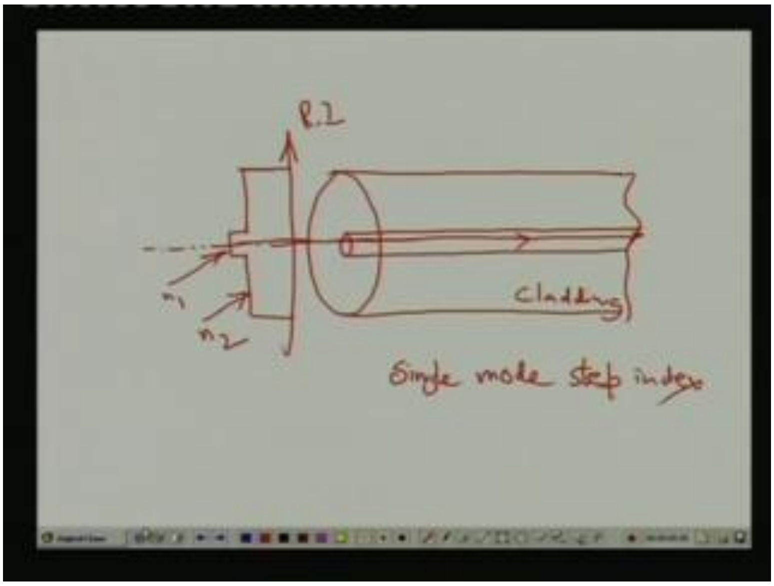

So, I have a core as before then I have. So, in the case of multimode fibre I am sorry in the single mode fibre the core diameter is extremely, small. So, that is the problem, we need different sort of source here, while I mean, directional sources. So, the light will travel in this case the refractive index profile. If I plot the refractive index RI, it will look like I have a small change here. So, this is our n 1 this is our n 2, so this is our central line. So, the light also travel to this one, like this one this is core and this is cladding as before. This, I talked about the single mode fibre, single mode step index fibre, these are we called again the step there is step index. There is a step change of the refractive index see, index means basically, we are talking of the refractive index please note.

So, there is a step change of the refractive index, that is the reason, we are calling its single mode step. I mean, index fibre, because there is only 1 mode light can transmit to the core core diameter is usually, very small right let us go beck. So, this is about the step index fibre clear, So, the optical fibre with a core of constant refractive index n 1. And a cladding of slightly, lower refracting index n 2 is known as a step index fibre. It is, because the refracting index profile for this type of fibre makes a step change at the core cladding interface.

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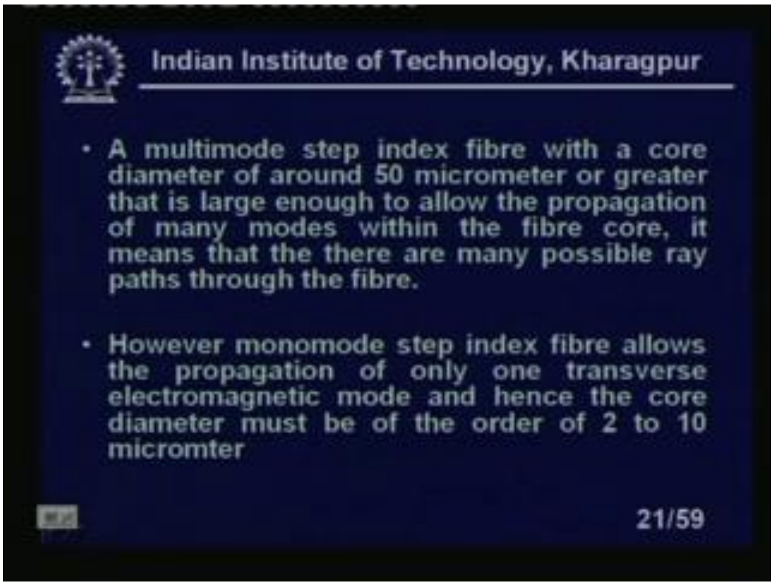

Now, a multimode step index fibre with a core diameter of around 50 micrometer. Or greater that is larger enough to allow the propagation of many modes in many incident situations. Many modes within the fibre core, it means that the there are many possible ray paths through the fibre. Multimode is basically, there is a different ray paths or multiple ray paths, through the fibre, that is we are calling multimode. However monomode step index fibre allows the propagation of only 1 transverse, electromagnetic mode and hence the core diameter must be of the order of 2 to 10 micron or micrometers right. It is quite small, we have seen that if find graded index, it is in between the 2 right, it is we will come to that.

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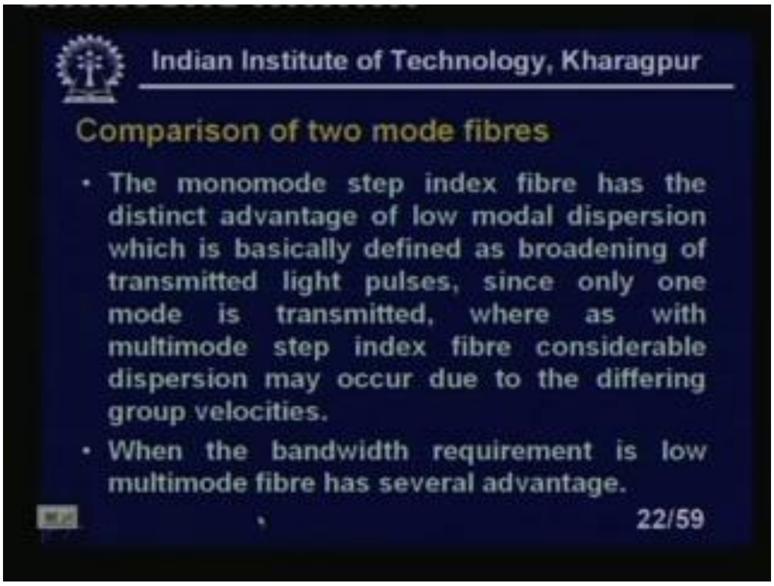

Now, comparison of the 2 modes 2 modes of fibre, if I compare the 2 modes the monomodes step index fibre has a distinct advantage of low modal dispersion. As I told you earlier, which is basically, defined as a broadening of transmitted light pulses. Since only 1 mode is transmitted whereas with the multimode step index fibre, considerable dispersion may occur due to the different, differing group velocities. As we told you, because there is a I mean, light ray which is going straight to the along the axis, that is one speed of watts is going towards total internal reflection. Because in there is large, I mean I mean, incidental or, so that we will have different group velocities. So, that the end will there is a modal dispersion right. When the bandwidth requirement is low the multimode fibre has a several advantage. Now, again the problem is that in the case of multimode fibre; obviously, the bandwidth will be narrower right as several advantage.

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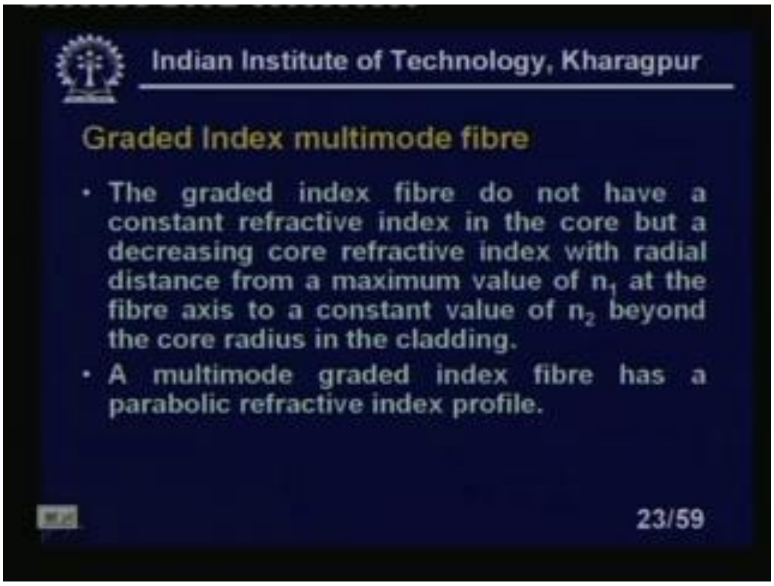

Now, what are the advantage? If I look at the advantages, that you will find that in the case of multimode fibre, we do not have any restrictions on the transmitter. Because we have to transmit light either you have to use a lead or light emitting diode or laser sources. Since the light emitting diode has a little disperse though I mean, the ray will be dispersed that can be used for transmission of lights in the cases. So, we do not need any very stringent requirements of the coherent sources and all those things, which is necessary in the case of single mode fibre. So, this is a great advantage, because the cost of the transmitter will be reduced, even though for the low. So, therefore, the, if the bandwidth requirements is low; obviously, we go for the multimode fibre.

Because what will happen that I can save the money on the actually they on the transmitters. Whereas, in the case of single mode fibre, we cannot use lead light emitting diodes, we have to use the laser sources, which is very coherent and all those things right. Now, graded index multimode fibre; the graded index fibre do not have a constant refractive index. That is no step change of the refractive index in the fibre, but a decreasing core, refractive index with radial distance from a maximum value of n 1 at the fibre axis to a constant value of n 2 beyond the core radius in the cladding right. So, that is step change, we will find there is some tremendous advantage. So, for that modal dispersion is concerned, we will get.

So, we are getting the advantage of the graded index fibre, you see that we can use the same the light sources. But I am mean, you can use the here lead, but the bandwidth will be slightly better I mean, because here what advantages that there the light will reach at the end. Even whether it is going in a straight the core or through a refractive total internal reflections in different angles is does not matter, it light will reach the end of the fibre at the same time. So, this, the great advantage, so a multimode graded index fibre has a parabolic refractive index profile, So, let us look at that what is that actually talking about? Let us take a white page.

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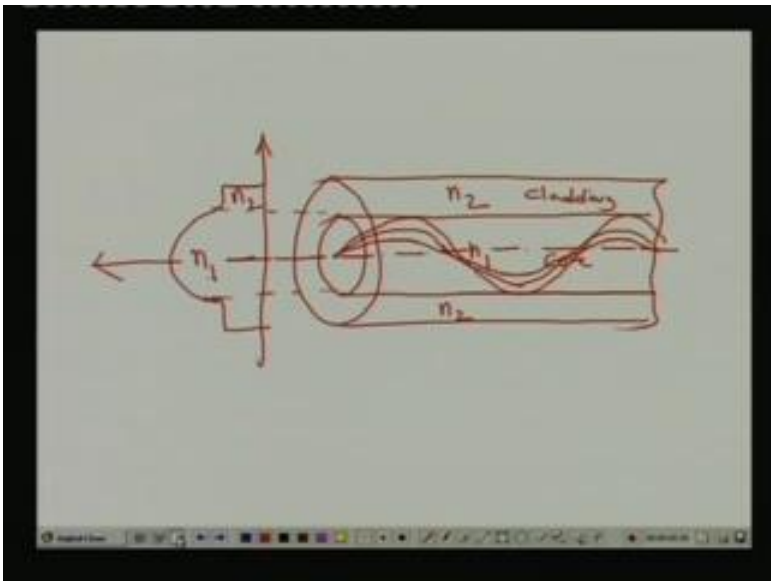

It will look like this; that means, you see the refractive index profile will look like this, we have is a multimode fibre. So, it has its look like, this is going like this, this is n 2 n 2 and this is refractive index n 1, but please note this n 1, I should should not write here actually, there is a. So, actually what will happen? You see that n 1 is at the at the center point n 1 actually, if I look at. So, it will the refractive index n 1 is at the center point here actually. So, the refractive index will slowly, decrease to the n 2 value as I go from a center to the cladding, because this is the cladding and this is a core. So, at the center the refractive index is here you know as I move towards the cladding. The refractive index slowly, changes slowly decreases at the up to the at the point n 2, it is at the point the clad the this whole junctions it is now n 2, right.

So, that is now, the refractive index profile, if I plot it will look like this one no more step change. So, it will look like this, so I have, so it is parabolic like this one right. So, this is our n 1 at the center, so I can erase again. So, I can, so , so here it is n 1 and here is it is actually, this will be like this 1 this is n 2 right. So, this is how light will travel like this? One you see light fall and it will travel like bend path like this one, because slowly light will bend right that is a reason, we are calling it right. So, light will come like this, one. So, do not need say that it is to be go to the at the cladding is not necessary, because before in the ((Refer Time: 32:58)) angles between the layer, because there are multiple layers. So, it will move like this one clear, this is a difference. So, this is core, this is cladding clear; that means, if I draw it will looks like this one.

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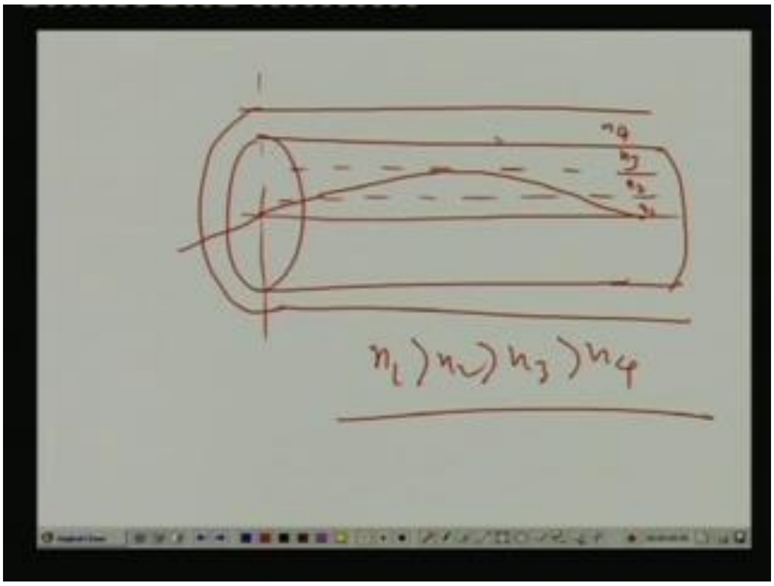

That means if I draw, if I have a fibre like this one. So, the light will fall, this is our axis, so I have a several layers. So, suppose this is n 1 this is n 2 now, a ultimately it is coming to the cladding. So, this is our cladding, so light will fall like this, it will bend again to this one, this will bend again, until and it is gets a total internal reflections clear. So, this is a some I mean, I can write n 1, n 2, n 3 and n 4 right. So, n 1 is greater than n 2 greater than n 3 greater than n 4 this ((Refer Time: 33:56)) I mean, for visualizations or understanding the, what is greater, how the greater get into server box? These way we are dispersing. So, it is not necessary, all the race with go at the at core cladding interface in between, it may have a total internal reflection, if the incidence angle is more than the critical angle clear. So, multimode graded index fibre has a parabolic refractive index profile the gradual decreases in the refractive index from the center of the core to the cladding creates many refractions.

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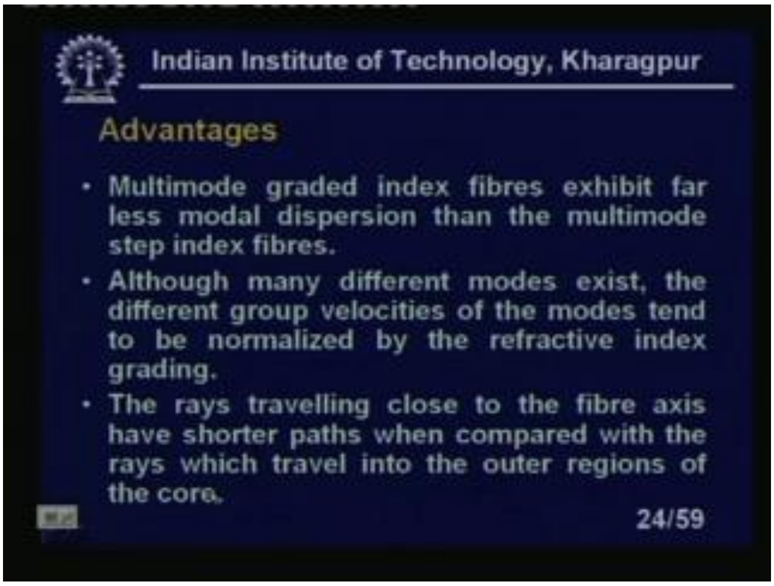

Advantage what are the advantage? The multimode graded index fibre exhibit for the less modal dispersion, than the multimode step index fibre reason. I will show tell you although, many different modes exist. The different group velocities of the modes tend to be normalized, by the refractive index grading. Because of the refractive index grading, because you see the light which is travel at the center at along the axis of the fibre core ((Refer Time: 34:53)). So, ((Refer Time: 34:54)) if it goes to the extreme I mean, a core cladding interface, it has a higher speed, because the refractive as you know, the refractive. If the refractive index increases a speed of life also decreases, the rays travelling close to the fibre axis, that I what I told you have shorter path. When the compared to with the rays, which is travel into the outer regions of the core, this is path is shorter, but the speed will be lower. So, ultimately, the, I mean the at the same time it will reach. So, the modal dispersion is not be there, right.

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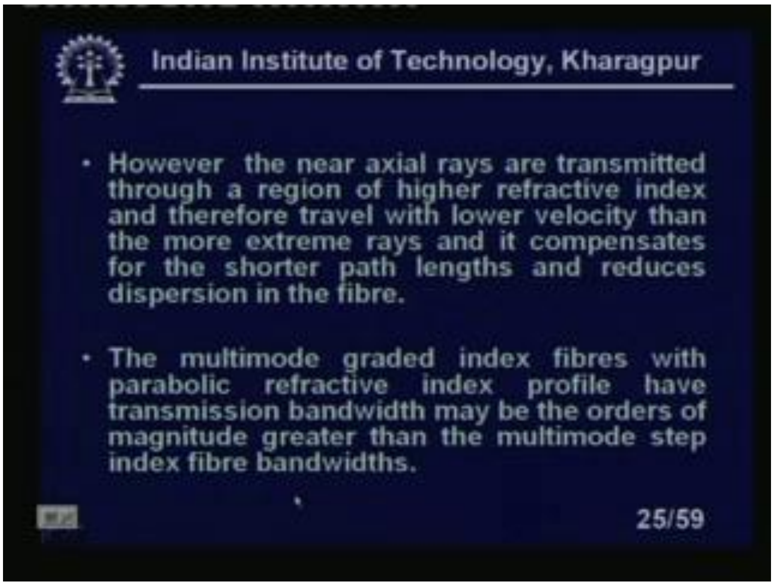

However, the near axial rays are transmitted through, a region of higher refractive index. And therefore, travel with lower velocity, then the more extreme rays and it compensates for the shorter path length and deduces dispersion of the fibre which is going at the end, which has a I mean, less days. I mean it will take I mean less time, because even though, it is getting total internal reflection that the refractive index is less. So, the speed of light will be higher those case. The multimode graded index fibres with the parabolic refractive, index profile, which we have shown have transmission bandwidth may be the orders, of magnitude greater than the multimode step index fibre bandwidth. So, this is a great advantage of this one.

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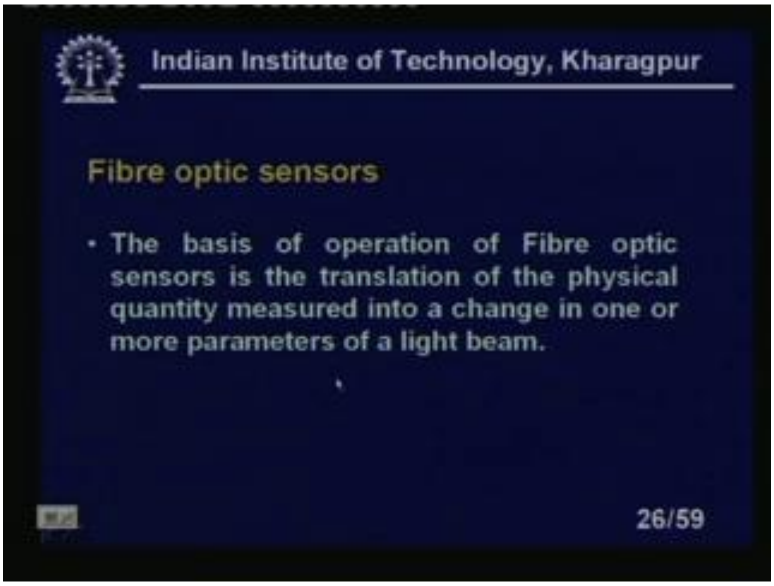

Now, let us come to the fibre optic sensors. Now, there are basis of the operation of the fibre optic sensors is the translation of physical quantity measured into a change in one of the ((Refer Time: 36:19)) or more parameters of a light beam.

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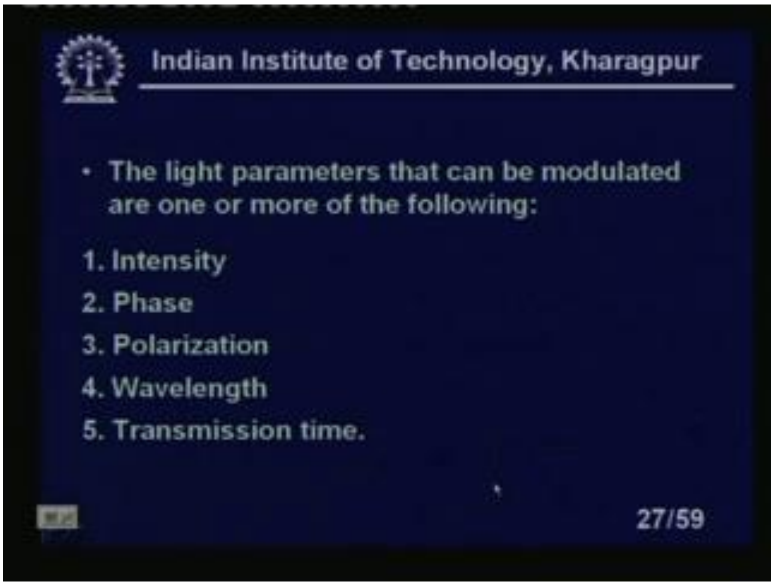

The light parameters that, can be modulated are one or more of the following intensity can be modulated, phase can be modulated, polarization will be there wavelength can be modulated and transmission time. ((Refer Time: 36:42)) see in most of the case, we find the intensity of light is very easy to be modulated, we will some sensors we will discuss where the intensity of light is modulated.

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Fibre optic sensors usually, incorporate either glass or plastic cables, because now, all plastic cables are coming up very fast a glass is a cheaper than, the silica based I mean, fibre. So, we must give some emphasis on the all plastic cables, because it is loss is more though in the case of all plastic cables, but it is cheap also, it is a mechanical strength is better than the all glass fibre. All glass types are rarely used, because of their fragility and plastic cables have particular advantages for the sensor applications. Because they are cheap and have a relatively, large diameter 0.5 to 1 millimeter making connection to the transmitter and receiver easy using multimode, there is no problem.

So, the connection transmitter and the receiver transmitted to the cable, to the to the fibre optic cable also from the again, from the cable to the receiver is easier. No in the case of monomode fibre, it is most difficult to launch light I mean, to couple a transmitter and the light itself, because is a small diameter due to small ((Refer Time: 37:52)) where is in the case of plastic cables we can have a larger diameter. So, the launching of the light is easier. So, that type of ((Refer Time: 38:00)) will not be there.

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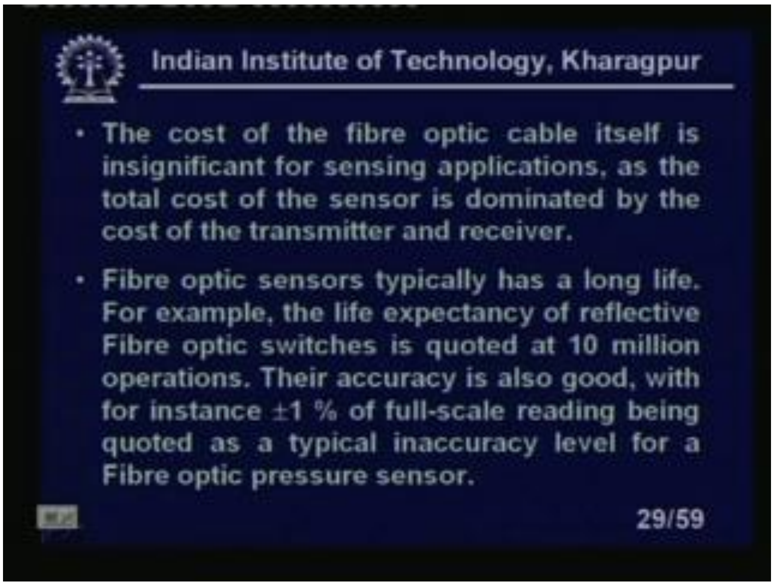

The cost of the fibre optic cable, itself is insignificant for sending the applications for sensing applications as a total cost of the sensor is dominated by the cost of the transmitter and receiver. So, always preferred lead light emitting diode and photodiode for a which are to be used as a transmitter and receiver respectively. Fibre optic sensors typically, has a long life for examples, the life expectancy of reflective fibre optic switches is quoted as 10 million operations. Their accuracy is also good with for instance plus minus 1 percent of full scale reading being quoted as a typical inaccuracy, level for a fibre optic pressure sensor.

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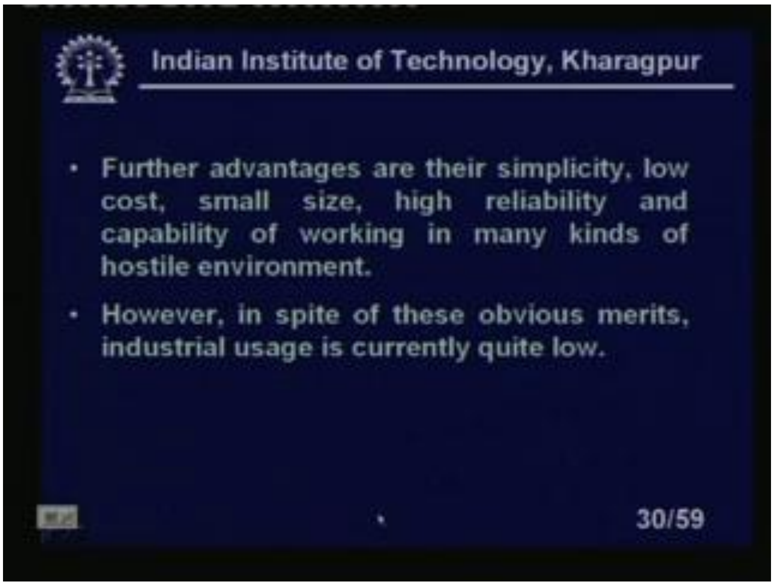

Further advantages are their simplicity, low cost smaller size and high reliability and capability of working in many kinds of hostile environment. So, hostile environments I mean, where is there is dust? When there is a chance of a large electromagnetic field. Where the electrical connection is very ((Refer Time: 38:58)) or some you cannot use electrical taking suppose. I have a thermocouples. And there is a it is ((Refer Time: 39:04)) I mean, transformer where it is large one it ((Refer Time: 39:07)) influence, because if there is a surges or something in transforms, that will affect our readings, so right. And, so if we route at the strip ((Refer Time: 39:15)), which is recording the temperature that also will create problem. So, that type of problem does not come in the optical fibres.

So, that is a great advantage of this type of fibres more over, please note in many, many process industry. This is it is forbidden to use a high voltage; I mean especially, the electrical cables voltage should be around 40 volts and especially, in hydrocarbon industry which is highly inflammable industry, with that type of applications of fibre optic sensors. Though previously use people are using a pneumatic system where the safety is very high, but the pneumatic system has high it is rugged and I mean it is rugged. Obviously, but it is very large in size all those things are problems and the maintenance is difficult. Whereas, if you use fibre optic sensors in that type of situations which will I mean satisfy both the thing that means, which is safety will be there. Because since it is very low voltage and entire transmission is like through light there is no electrical connection as though right.

However in spite of these obvious merits industrial usage is currently quite low that is we must admit right even though this is. Because there might be there is some vicious circle; that means, people those who are are using the conventional sensors whether the new additions. These was not I mean, not new, when the, we are using pneumatic sensors in the process industrial pneumatic system, process in the industrial. When the electrical system came, which is now, converting all through 15 PSI of control signal to 2 4 to 20 millions, but there is also lot objections, but later on we slowly, we found over the details. All this I mean, pneumatic system were replaced by the by the electrical system like, where is the current is 4 to 25. Similarly, we also hope that in future, this also this all will be replaced by the fibre optic sensors.

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Now, fibre optic sensor, let us look at 2 major classes of fibre optic sensors are exist, what is the intrinsic sensors and extrinsic sensors. In intrinsic sensor the fibre optic cable itself is a sensor whereas, in the extrinsic sensors the fibre optic cable is only used to guide a light, to and from the conventional sensor right right. So, that is not actually, sensor or such I mean, I am talking of the extrinsic sensors. But we are using actually, the extrinsic sensors that the cable to take out some light actually, to the, the conventional sensors, which is might be far away right, we will see some that type of typical situation, one of the example is the measuring the Jet engine exhaust temperatures.

I can use a optical and pyrometer, but it is very difficult one line measurements right, because jet engines I mean, jet is running at a all digit of four 40 thousand feet's and it is one line measurements is difficult. So, I have to install optical fibre where the, which is send the light to the transmitter at the receiving end. I can use one optical pyrometer might be, it is happening ((Refer Time: 42:10)) time to measure the engine temperature, because the thermocouple will not for, because this a temperature is extremely high.

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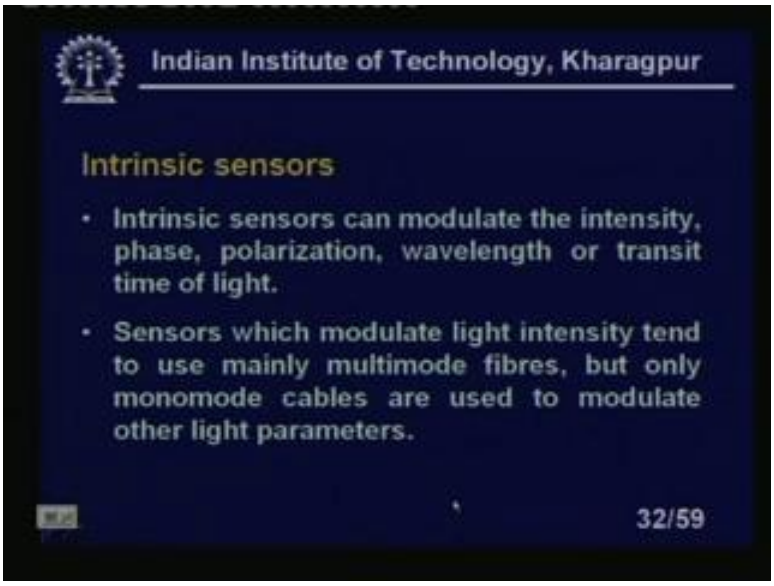

Now, intrinsic sensors, Intrinsic sensors can modulate the intensity phase polarization, wavelength or transit time of the light right. This one sensors, which modulate light intensity tend to use mainly, multimode fibres, but only the monomode cables are used to modulate to other light parameters.

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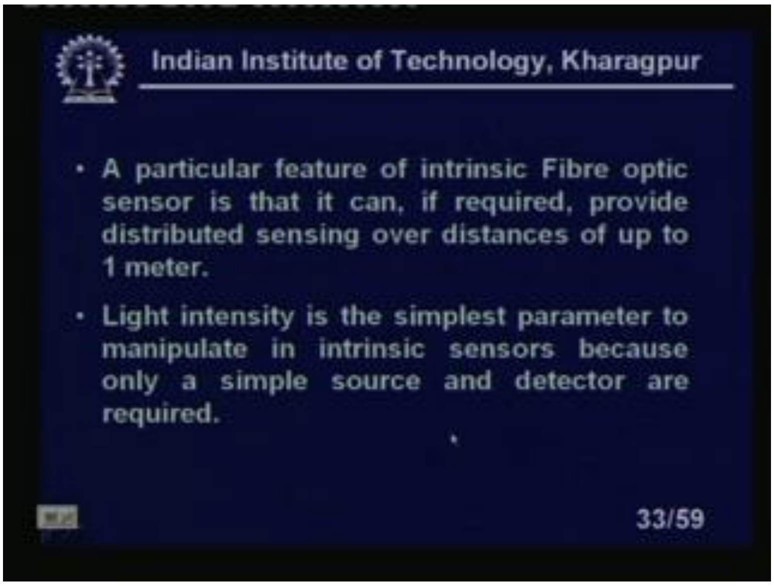

A particular features of intrinsic fibre optic sensor is that, it can if required provide distributed sensing over the distances of up to 1 meter. Light intensity is the simplest parameter to manipulate in intrinsic sensor, because only a simple source and detector are required right.

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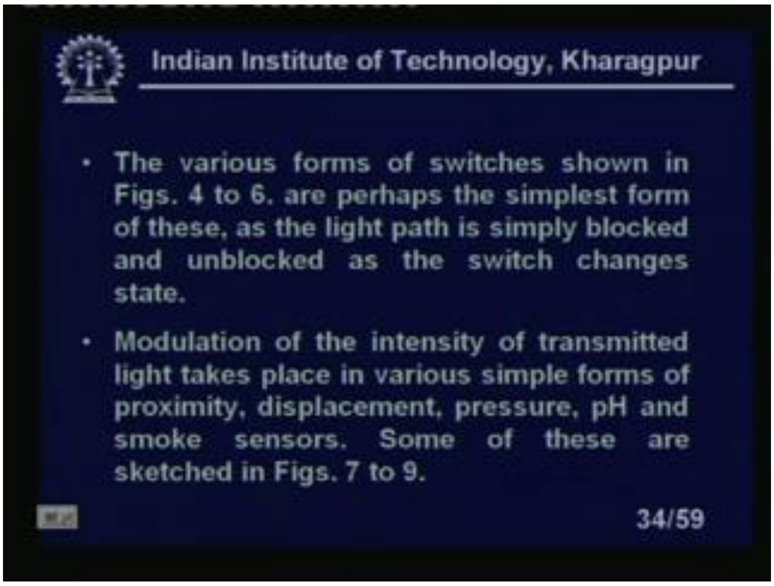

The various forms of switches shown in figure 4 to 6 are perhaps the simplest form of these as the light path is simply, blocked and unblocked as the switch changes position right changes state. Let us, look at modulation of the intensity of light of the transmitted light takes, place in various simple forms of proximity, displacement pressure pH and smoke sensors. And some of these are sketched in figurers 7 to 8.

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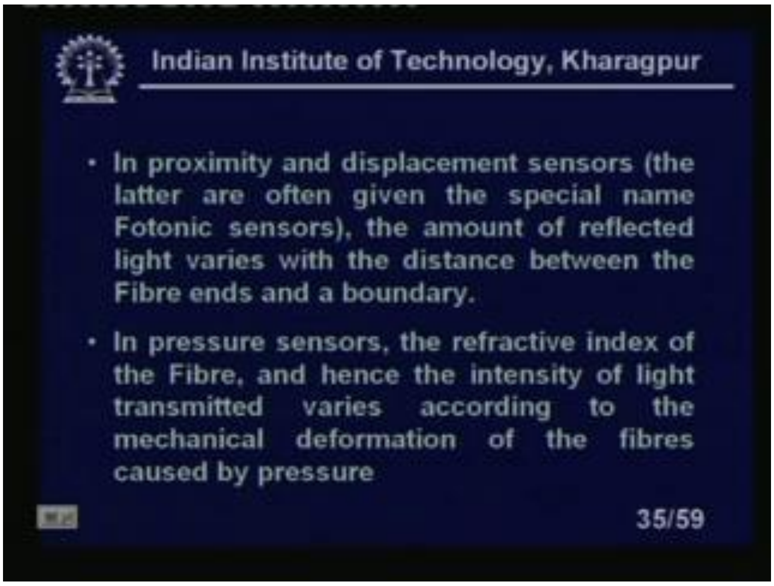

Let us look at in proximity and displacement sensors the latter are often given to the special name Fotonic sensors. And the amount of reflected light varies with the distance between the fibre ends, and a boundary in pressure sensors. The refractive index of the fibre and hence the intensity of light transmitted varies, according to the mechanical deformation of the fibres, caused by the pressure, we will show some example.

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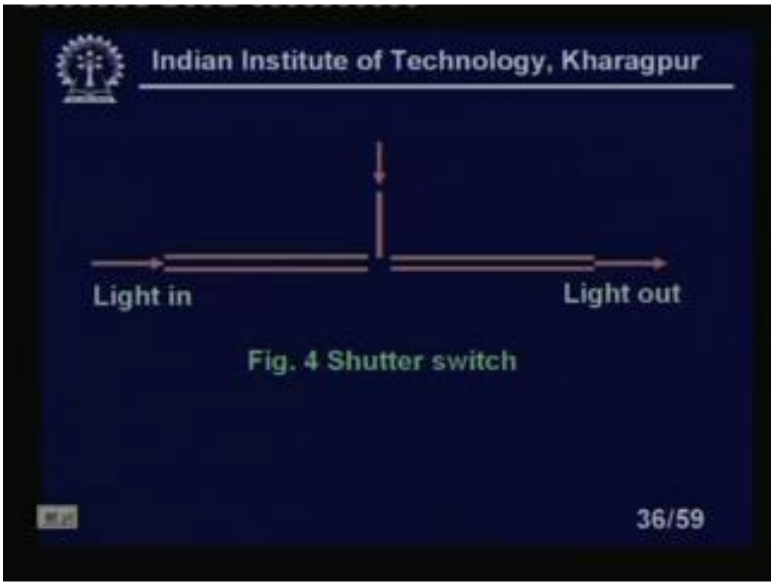

This is you see, the, a simple shutter switch; that means, if the shutter comes down; obviously, will find if the shutter comes down. The shutter comes down like, this one what will happen? You see there it will modulate the light, because if the light is coming intensity would not get in here. So, this is this is a shutter switch.

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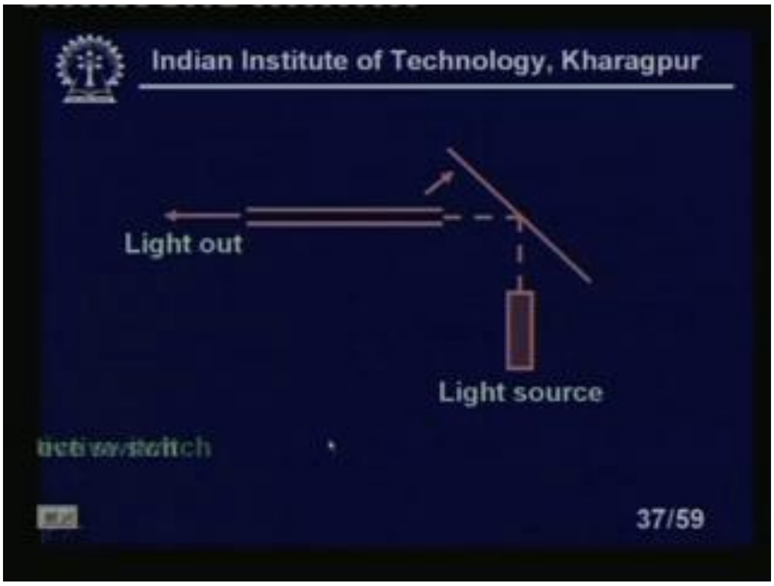

This is the reflective switch, if the switches changes positions, suppose if the switches changes position like this one. Then what will happen? In the switches position, switches come to this positions so; obviously, the light sources or the light switches light positions light source will not get in light I mean, light out. So, at the receiver, we would not get get any light. So, this is reflective switch this is also can be used for the as the switch for the fibre optic sensors.

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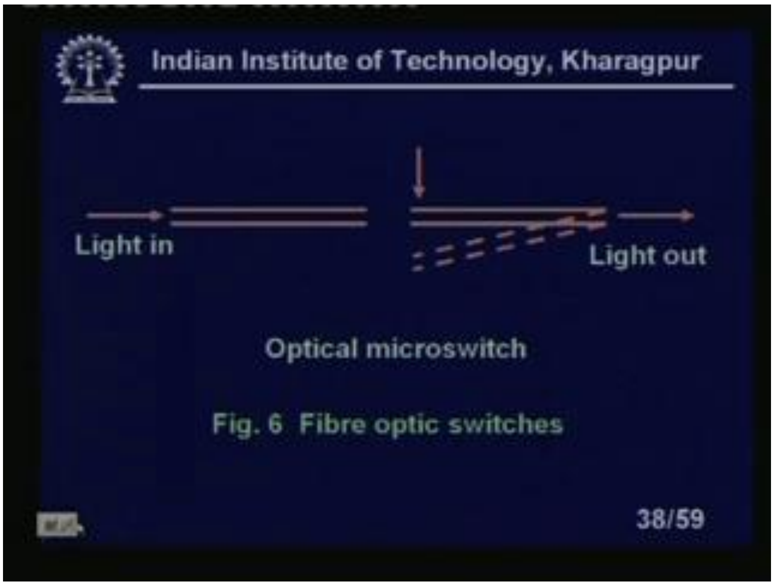

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This is the fibre optic switches; that means, is optical micro switch; that means, if I the fibre bends like this one the fibre bands in this directions. So; obviously, if the light have a light sources, have a light receiver, so obviously I would not get in get a light output. So, this is all the use of optical micro switch right. So, this is also a example of fibre optic switches.

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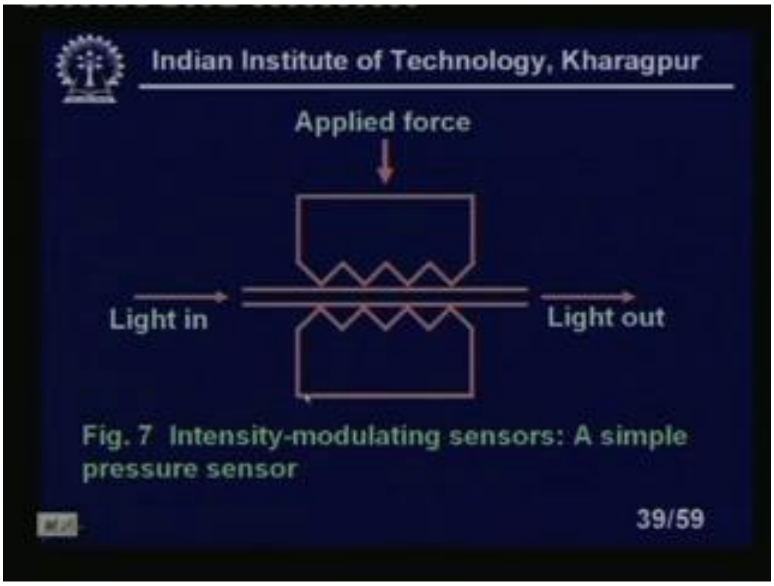

This is you see, the applied force we are using a which as we say the some sensors is a force measurement. What will happen? If the light falls on this one this straight light fibre is the fibre . So, this will be corrugated in shape is not it if it is in corrugated in shape. So, the; obviously, light intensity will be modulated, by looking. So, if it is the more and more pressured, it will be more and more corrugated. So, the intensity light here, which will receive if it is straight; obviously, I will get more light. So, if it is I mean, bends like this one less light, so obviously the sensing the intensity of light can be caliberated iin terms of forces right.

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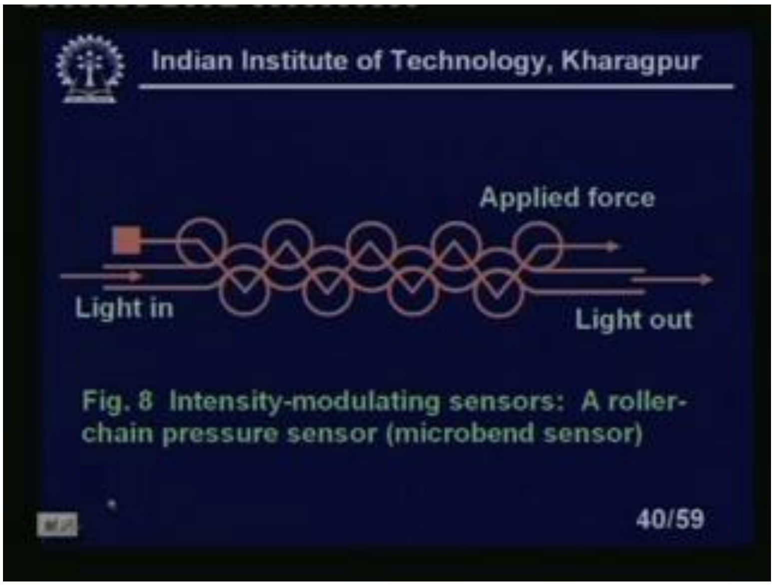

This is example intensity modulating sensors a roller chain pressures sensor you see that with the chain pressure is higher then what will happen this the roller chain pressure is higher and higher. This is the same example if you whatever pressure four sensors we have discussed the more and more bending of the light being here. So; obviously, I will less less light will received at the we at the end. So, that can be caliberated in terms of the pressure. So, the how much is the chain pressure can be calculated by you can intensity of light receiving at the receiving end.

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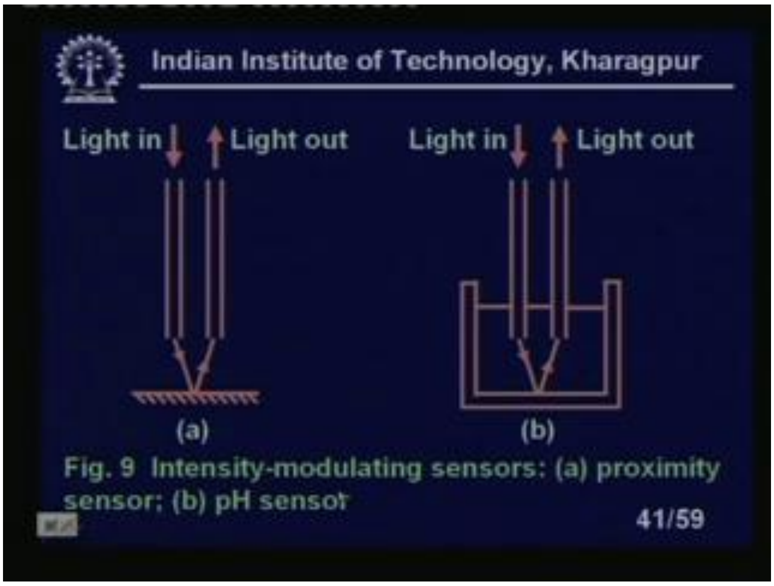

You see this is the some with these intensity modulating proximity sensors if the light goes if the light is coming through this one and it is getting reflected and it is light is coming out if it is coming more and more. So, if it have a reflecting surface here so; obviously, I will receive more and more light if it is far away. So, I will get less light, so the intensity of light again here it is modulated according to the position of the, this proximity sensors right here. It is pH sensor, which will be the principles will explain after sometime.

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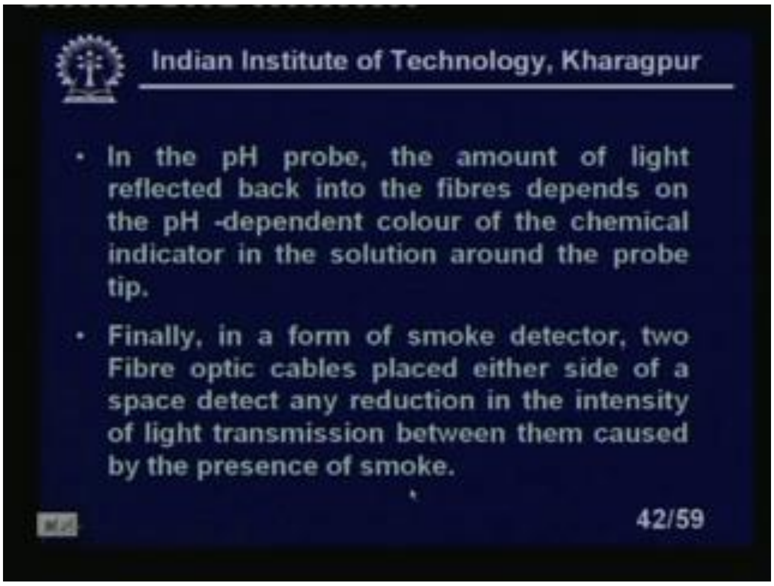

In the pH probe, the amount of light reflected back into the fibres depends on the pH dependent colour of the chemical indicators in the solution around the probe tip right. What we are launching and what we are receiving? Obviously, the intensity will not be same finally, in the form of smoke detectors, 2 fibre optic cables placed either side of a space detect any reduction in the intensity of light transmission between them caused by the presence of smoke. Very simple suppose I have a I mean I have a light source here.

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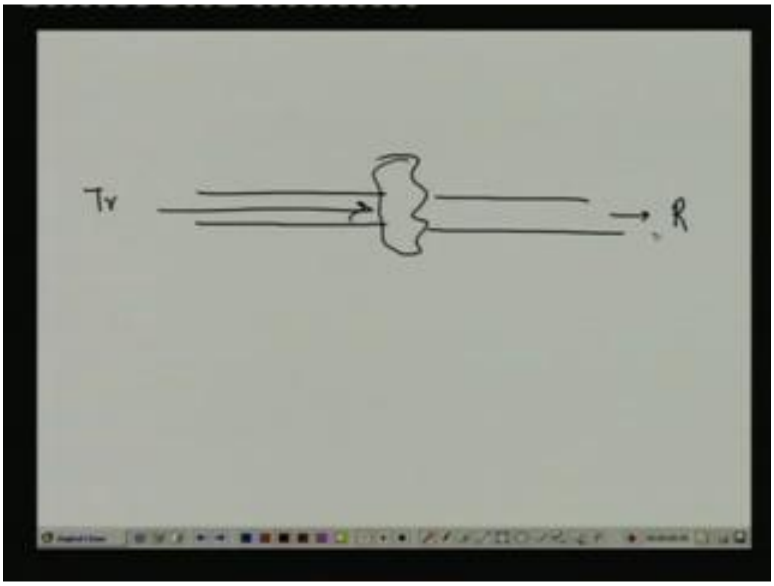

And sorry let me take it is I have a fibre here and I have a fibre here. So, I am getting the smokes comes here what will happen the intensity of light received at this end this is the transmitter and this is our receiver. So, what will happen intensity of the light will be decreased since the smoke will; obviously, decrease the intensity of light. So, the; obviously, this can be used as the smoke detectors. So, it will turn on some alarm or some announciation right.

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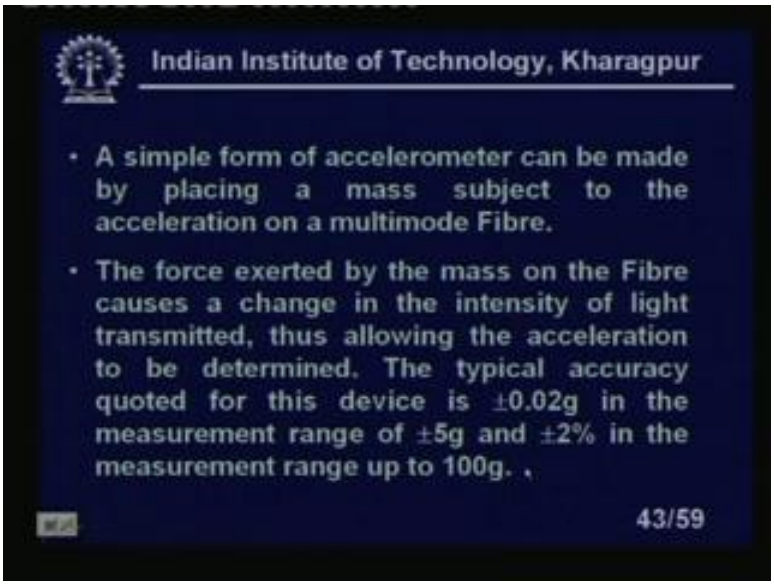

Now, a simple form of accelerometer can be made by placing a mass subject to the acceleration on a multimode fibre. The force exerted by a by the mass on the fibre causes a change in the intensity of light transmitted. And thus allowing the acceleration to be determined and the typical accuracy quoted for this device is plus minus 0.02 g in the measurement range of plus minus 5 g 6 extremely good. I should say and plus minus 2 percent in the measurement range up to 100 g.

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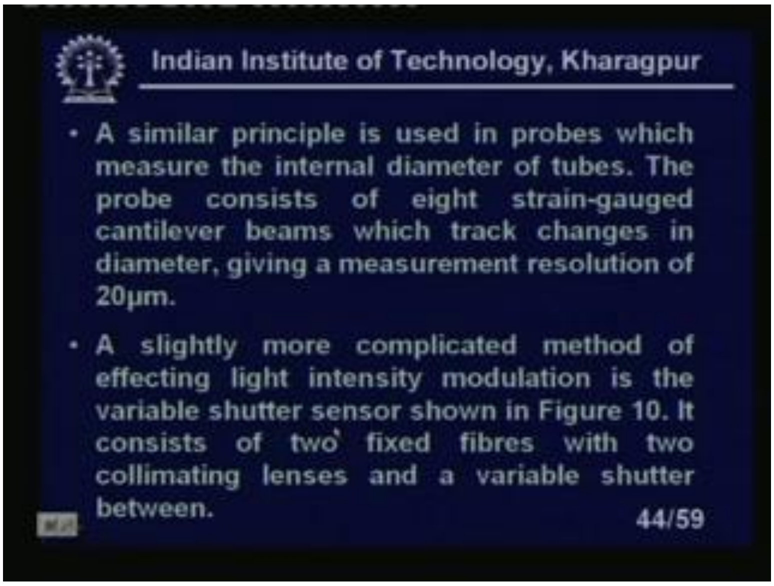

A similar principle is used in probes, which measure the internal diameter of the tubes the probe consists of 8 strain gauged cantilever beams which track changes in diameter giving a measurement of resolutions of 20 micron right. So, in many situations we need this term. A slightly more complicated method of effecting light intensity modulation is the variable shutter sensor shown in ten where it consists of 2 fixed fibres with 2 collimating lenses and a variable shutter between.

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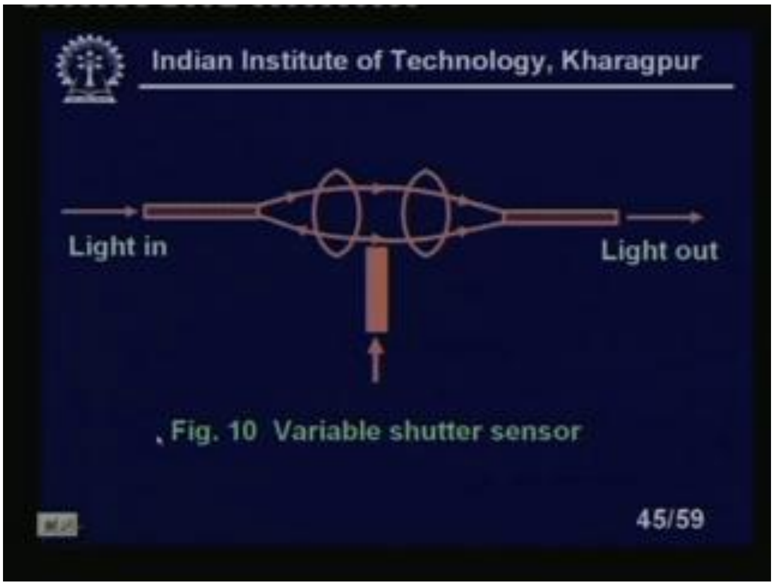

It looks like this you see what will happen, you see that this movement I can get from many places I can get from the pressure sensors and I can get from the Burdon tube we have already discuss the Burdon tube. Now, we will discuss that in some details light is falling in I have a collimated lens. So, if I can put the shutter here; obviously, at the output also will be less right. Because if you use a collimated lens; obviously, there will be no dispersions of the light from the, at that light end. So that I can use a simple lead light emitting diode in the multimode fibres right further as a transmitter.

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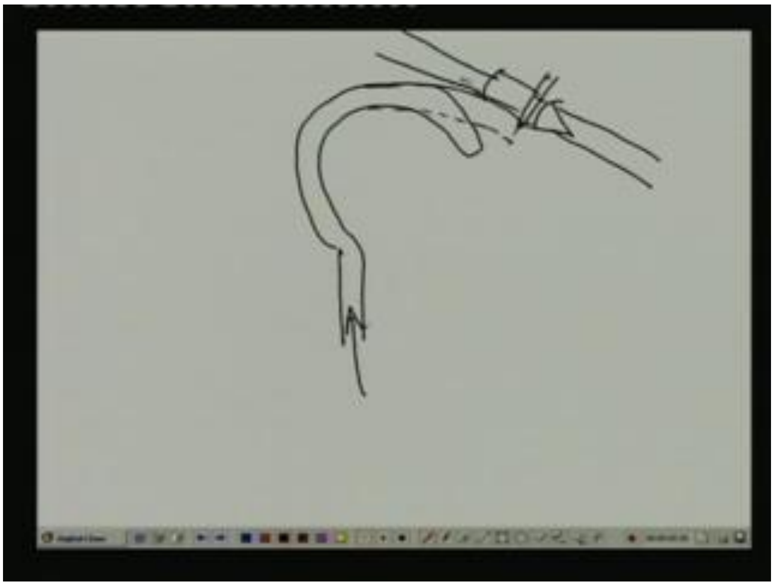

You see why I am saying this shutter can be used you see that is A suppose I have a, you have started the Burdon tube see tips looks like this is not it. So, the pressure increase we have seen that this tip moves like this one this with the some arrangement. We have connected to the needle or pointer and that dial is calibrated in terms of pressure here you see this movement I can put on a shutter, is not it? So, light is coming in and the light is coming out with the call emitter lens and all these things whatever we have. So, light is coming parallel like this one it is from then I think it is coming to the right then what will happen if it moves? So, the this shutter will move inside the shutter will move inside this I should draw like this one; that means, that if the tip moves; that means, if the shutter will all will go inside. So, it will their intensity light will modulated. So, if it is goes entire end. So, I can show I should say it has reached the large scale. So, this intensity of light also will be varied according to the pressure which is giving inside the Burdon C-Tube. So, that can be calibrated in terms of pressure, right.

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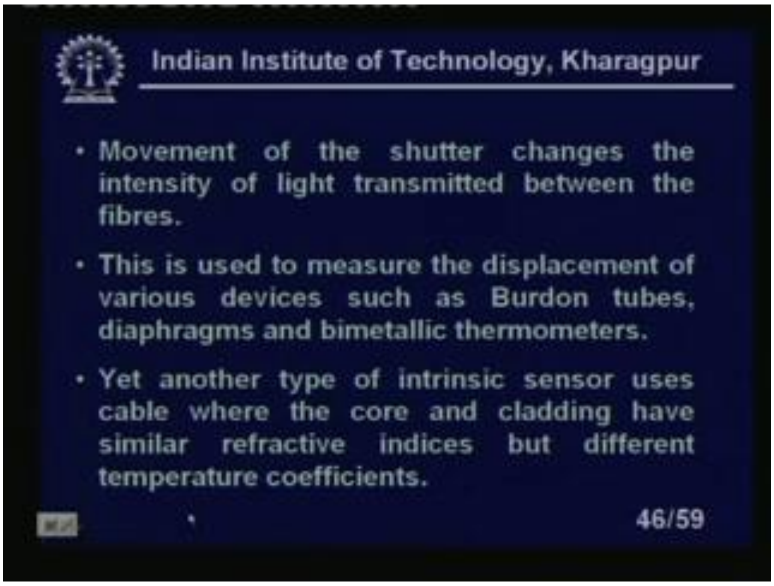

Now, moment of the shutter changes the intensity of light transmitted between the fibres this is used to measure the displacement of various devices as I told you Burdon tubes. Burdon tubes actually we know that we have basically tip movement is an with a some sector and all those things we will find it is converted to a a circular movements on a scale. And we can use it for a diaphragms also for the bimetallic thermometers same intensity, but diaphragms what will happen we know that very easily. We now have a diaphragms.

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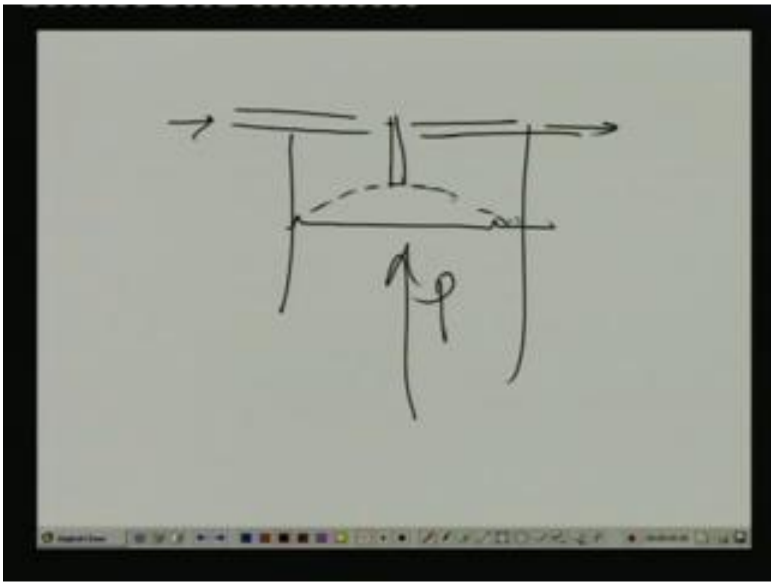

So, with pressure in diaphragms stretch diaphragms it look like this. So, if there is pressure increase it moves like this one. So, if I now include a shutter here and again lights will come here lights are coming out light in light out. Then what will happen the shutter the position in the shutter will give you the intent will modulate the intensity of light. So, this intensity of light can be calibrated in sound of pressure, because here I am giving the pressure. So, diaphragms will bend like this is not it also in the case of bimetallic strip.

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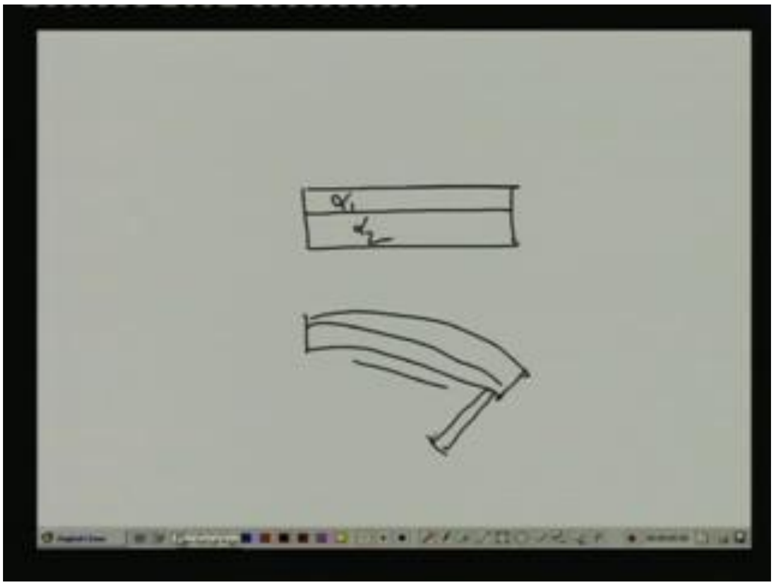

As we know the bimetallic strip what will have which is used for the measurement of temperature also for it can be switched if the temperature increase because of the 2 different alpha 1 suppose this is alpha 2; that means, different coefficients expansions its bends like this one right. So, now if this strip is moved connected to a shutter so; obviously, what will happen? You will find that this will be modulated right. So, this is the one of the way of doing that thing. See yet another type of the intrinsic sensor uses cable where the core and the cladding have similar refractive indices, but different temperature coefficients.

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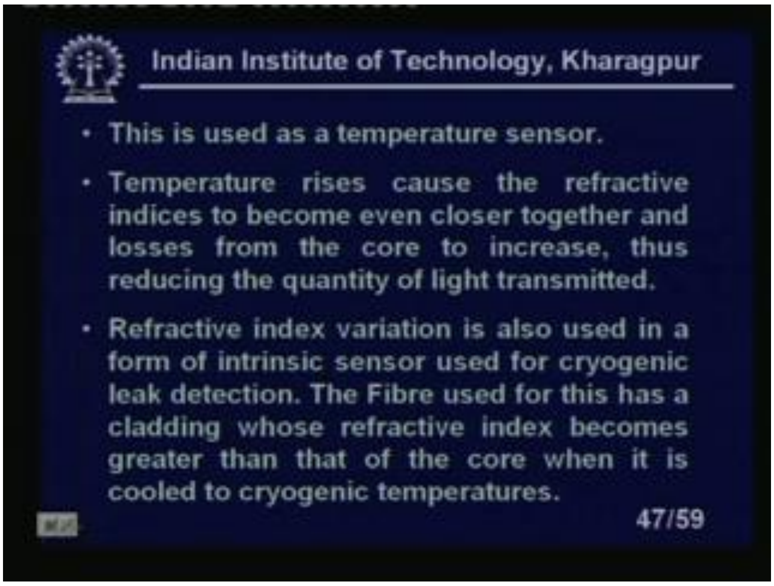

This is used as a temperature sensor. Temperature rises causes the refractive indices to be even closer together and losses from the core to increase. Because if the refractive index is almost same there will be more and more lost to the cladding there will be no total internal reflection. So, thus reducing the quantity of light transmitted at the, which we receive that is the. Refractive index variation is also used in the form of intrinsic sensor used for cryogenic leak detection. The fibre used for this has a cladding whose refractive index becomes greater than that of the core when it is cooled to cryogenic temperatures.

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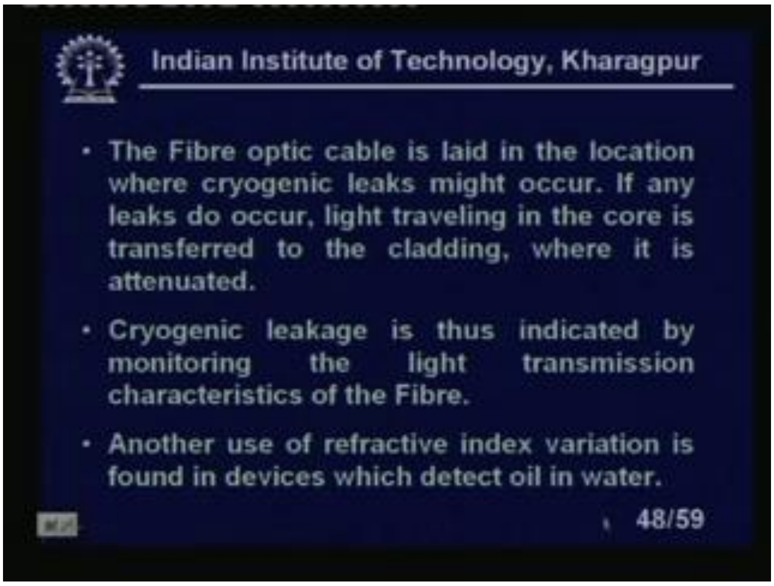

The fibre optic cable is laid in the location where cryogenic leaks might occur. If any leaks do occur light traveling in the core is transferred to the cladding, where it is attenuated. Cryogenic leakage is thus indicated by monitoring the light transmission characteristics of the fibre. Another use of the refractive index varation is found in the devices which detect oil in water in many case it is nesscery to detect.

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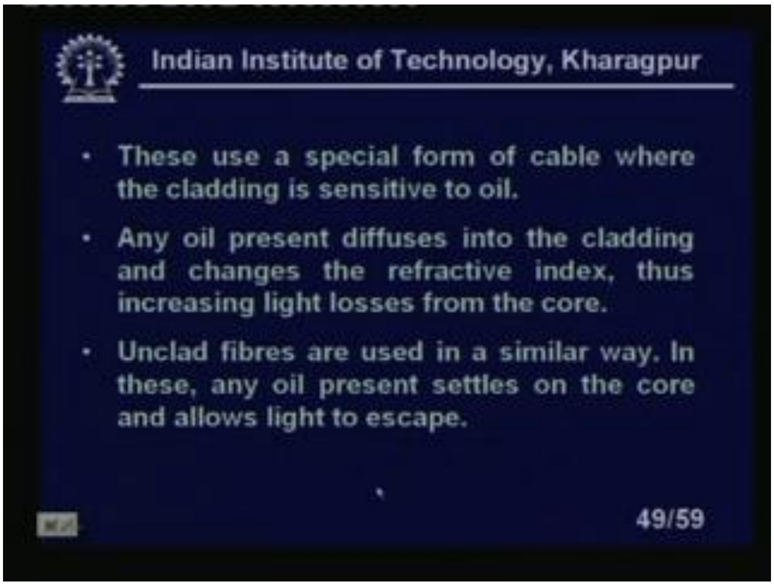

So, that case what is the principle you see these uses a special form of cable where the cladding is sensitive to oil any oil presents diffuse diffuses into the cladding. So, oil will be diffused in the cladding and changes the refractive index of the cladding. So; obviously, light again will be light will be if the is refractive index changes. So, it will change the transmission of light because a light will, because in the multimode fibre; obviously, there will be total internal reflection. So, that will prevent the total internal reflection. So, at the receiving end whatever the light we will receive that will be less intensity right unclad fibre are used in the smilar way in these any oil present settles on the core and allows the light to escape right. So, that is another thing.

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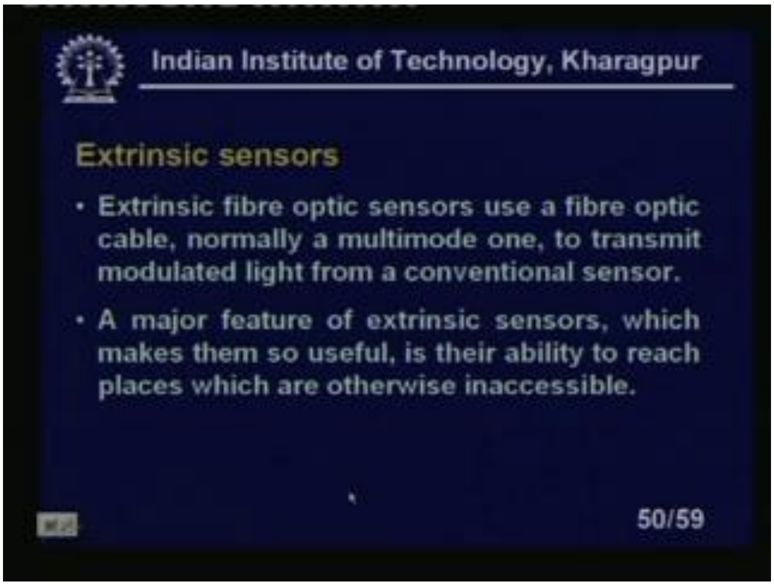

The extrinsic sensors then extrinsic sensors. Extrinsic fibre optic sensors use a fibre optic cable normally a multimode one to transmit the modulated light from a conventional sensors. As I told you just given a example that, the in measurment of a temperatures of a jet engine exhaust jet engine where we can use an optical pyrometer. But the light is to be transmitted to the optical that is the type of sensors we are calling it extrinsic sensors instead of a intrinsic sensors. So, let us not fibre optic as a sensors as such, but the transmission of the light from the in the optical mode to the conventional sensors. A major feature of the extrinsic sensors, which makes them so useful is their ability to reach places which are otherwise inaccessible. As I told you in jet engine which is traveling at a height of 40000 feet and it is a inaccessible. So, it is in that case optical fibre is very suitable.

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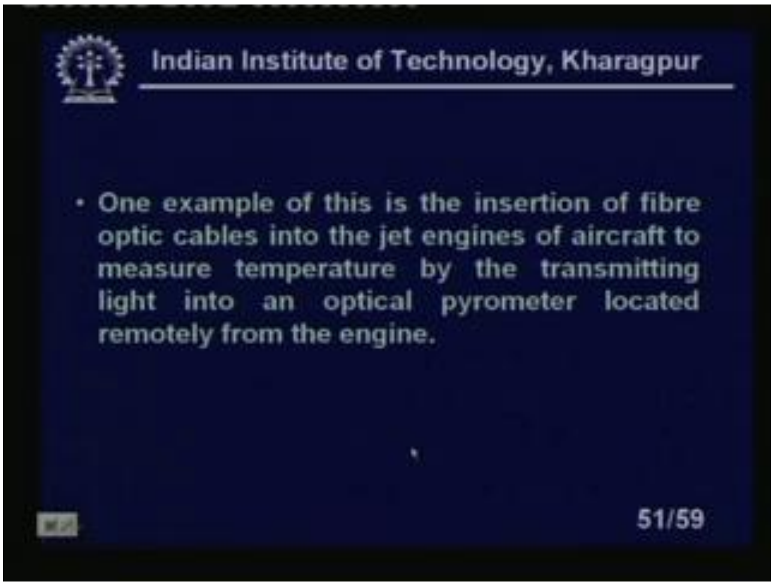

One example of this is insertion of fibre optic cables into the engines of aircraft to measure temperature by the transmitting light into an optical pyrometers located remotely from the engine.

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Extrinsic fibres optic sensor provide excellent protection of measurement signals against noise corruption. So, that is inherent to the any optical fibre sensors it is immune to the electrical noise a surge anything. It does not matter and moreover 2 optical fibre can go side by side without having any crossed or this is not possible in the electrical fibre. If I take the thermocouple lead wires to thermocouple lead wires goes parallel then if there is surge in one that will affect the other thermocouple lead wires also. So, obvious that will affect the output which we will receive unfortunately the output of many forms of conventional sensor is not in the form which can be transmitted by a fibre optic cable. Conversion into the electrical form must, therefore take place prior to transmission.

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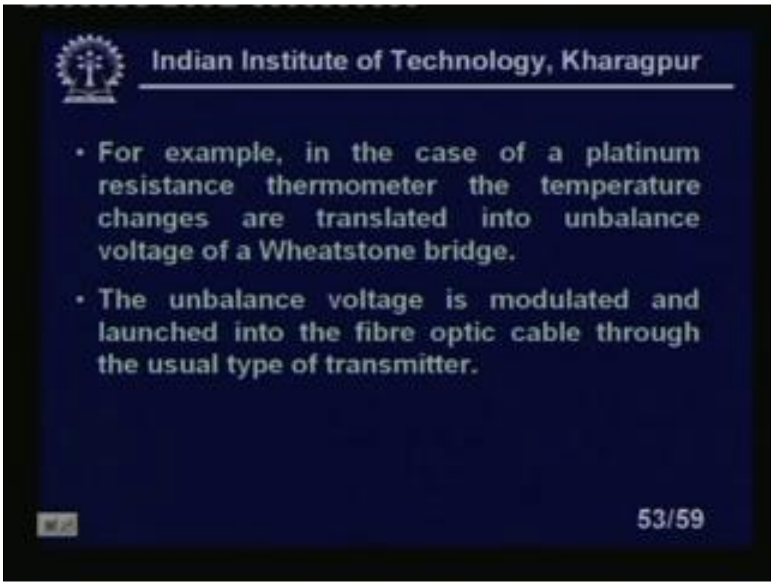

For example in the case of a platinum resistance thermometer temperature changes are translated into unbalanced voltage of a Wheatstone bridge right. The unbalanced voltage is modulated and launched in the fibre optic cable through the usual type of transmitter. Because the unbalanced voltage I can unbalanced voltage also will always keep the measurement of temperature. But that would can be modulated that can be converted through a, that voltage and later accordingly it will give the light intensity. So, the intensity of light we will be modulated will be depended on the unbalanced voltage. So; obviously, the intensity of light can be measured of temperature of the object which we put.

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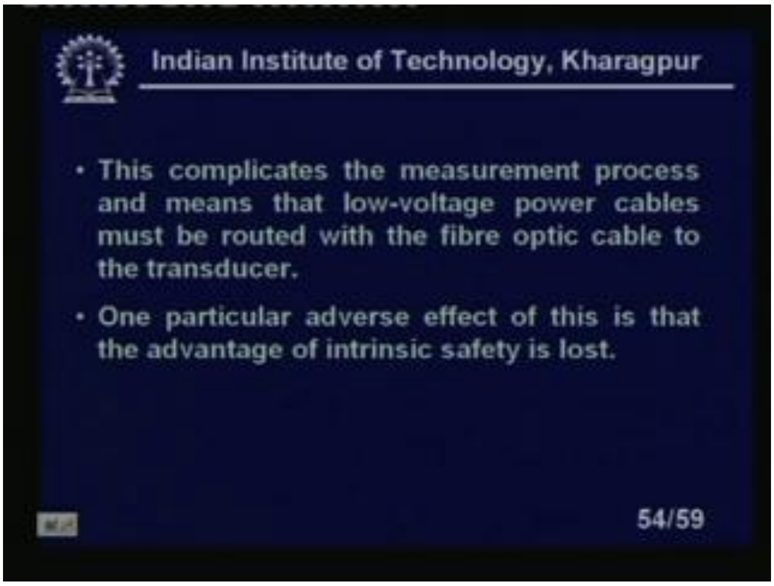

This complicates the measurement process and means that the low voltage power cables must be routed with the fibre optic cable to the transducer. One particular adverse effect of this is that the advantage of intrinsic safety is lost because we are using the electrical system. So, that intrinsic safety which we talked about, so much of the optical fibre that is lost there.

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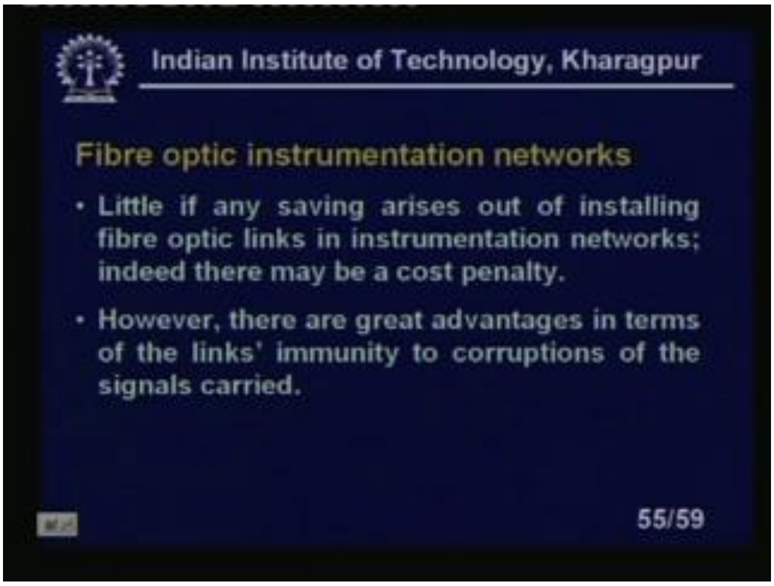

Now, fibre optic instrumentation networks looks like this that little or any saving arises of the installing the fibre optic links in instrumentation networks indeed there may be a cost penalty. Because many sensors we are using; however, there are great advantages in terms of the links immunity to corruptions of the signal carried.

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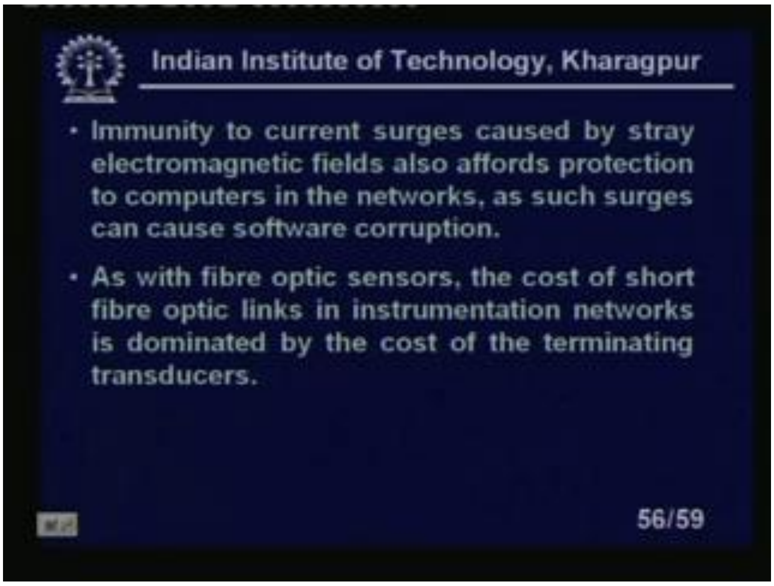

Immunity to current surges caused by the stray electromagnetic field also affords protection to computers in the networks as such can causes software corruptions. As with the fibre optic sensors the cost of the short fibre optic links in instrumentation networks is dominated by the cost of the terminating transducers that is the problem. That means, everywhere I need a transmitter and receiver that it means the use of the increasing the cost, but in some applications as I told you safety is most important. So, in that type of situation we should not consider for the cost right. However as a length of the fibre link becomes greater the cost of the fibre optic cable becomes more significant.

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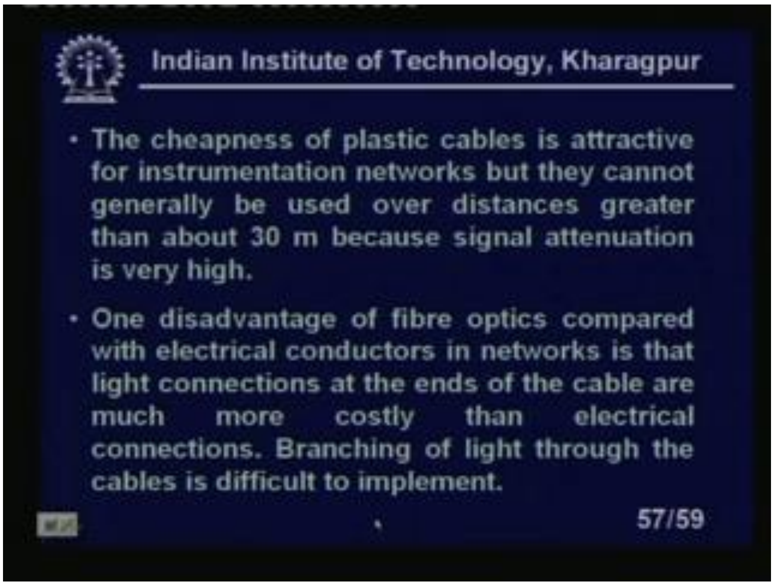

The cheapness of the plastic cables is attractive for instrumentation networks, but they cannot be generally be used. Because it has a large loss as I told you is a large signal attenuation in a plastic cable, but in the short range it is very useful. Because that will reduce the cost of the fibre though as I told you repeatedly the cost of the fibre is insignificant compared to cost of the transmitter and the receiver. One disadvantage of the fibre optics compared with electrical conductors is a networks is that the light connections at the ends of the cable are much more costly. Then the electrical connections and branching of the light through the cables is not is is difficult to implement. What is that you see it is very simple what its look like this.

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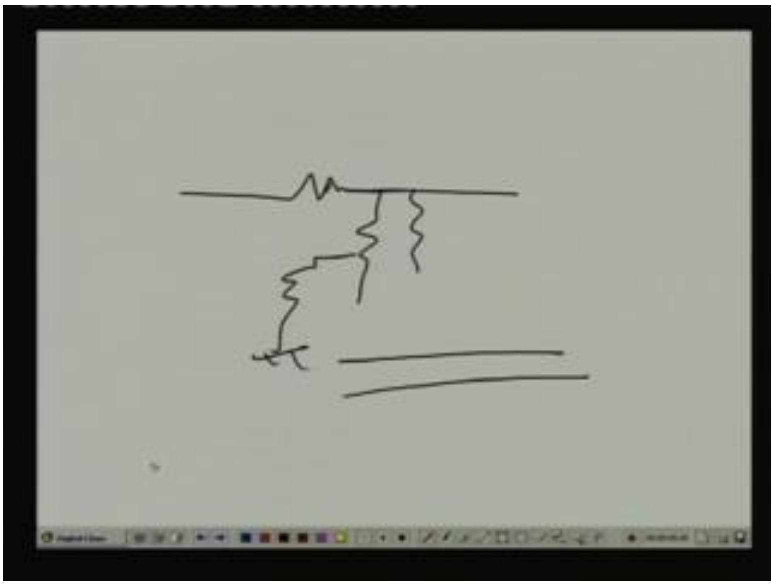

I have a electrical circuits like this one I can have branch it I can make a another branch I can make another branch or I can make another branch like this one. I can do like this one I can put like all the different branches in possible where in the optical fibre it is very difficult if I need branching I need another transmitter there . So, the bend of the light is not possible which is very easy in the case of optical in the electrical systems.

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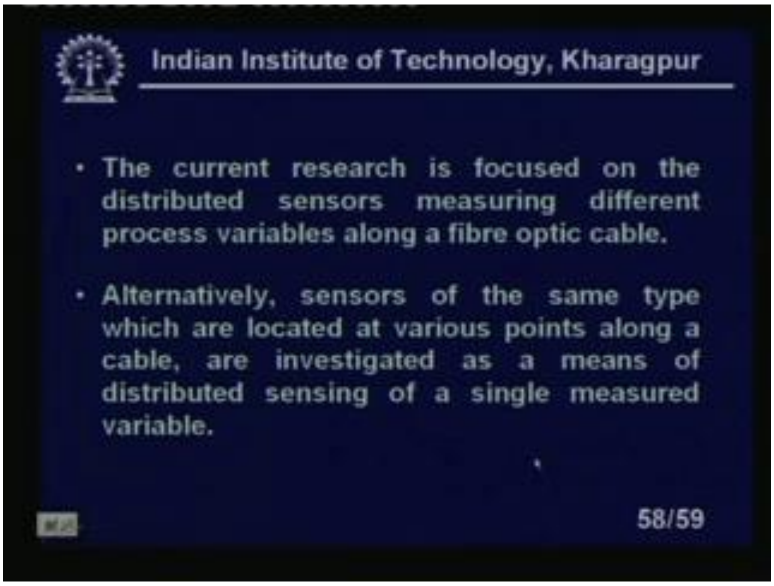

The current research is focused on the distributed sensors measuring different process variables along a fibre optic cable. Alternatively, sensors of the same type, which are located at various points along a cable are investigated as a means of distributed sensing of a single measured variable. That is only possible, but it it coming out the fibre optic sensor are coming up very fast. When you we think that in the in few decades I think within next decade, the fibre optic sensors will dominate. It will replace all the electrical sensors or electrical transmission system in the instrumentation networks in any process industry. With this I come to the end of the lesson 29 of industrial instrumentation.