

Fiber Optics
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Lecture – 01
Introduction

Let us start asking ourselves a question: what comes to our mind when we hear this term fiber optics. What is optical fiber, where do you see it, do we see it in our daily lives, can we recollect some things where we see optical fiber? I have a few things to show to you; let us see.

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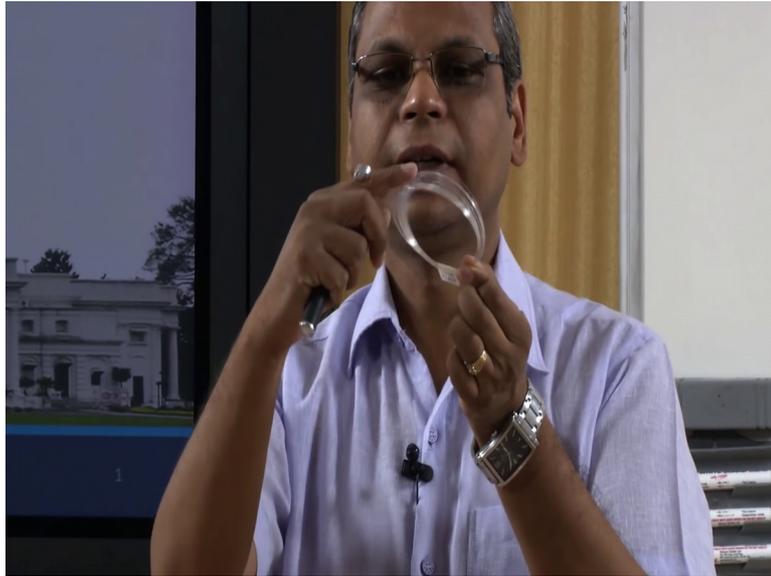


You might have seen something like this in which if I put light then you can see it glowing everywhere. I have used a multi colour LED to illuminate it and you can see that different pieces of fibers are glowing and the colours are changing.

This is a kind of fiber which people use for decorative purposes. I also see a fibers something like this way in which if I put light inside I can see light coming out of the other end. This looks like a normal wire, but it guides light you can see; what a flexible structure it is and it can take light around all the curves over a long distance, over the entire length of this piece of wire. So, this is another form of optical fiber.

We also see fibers something like this.

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This is really hair thin structure and I can very carefully couple light into it and light can come out of the other end. It can guide light over kilometers length.

We also see something like this. This is a fiber which is jacketed, it is a similar fiber which I showed you earlier it is jacketed. You can notice the colour, its colour is yellow the colour of the jacket is yellow and it signifies it is single mode fiber.

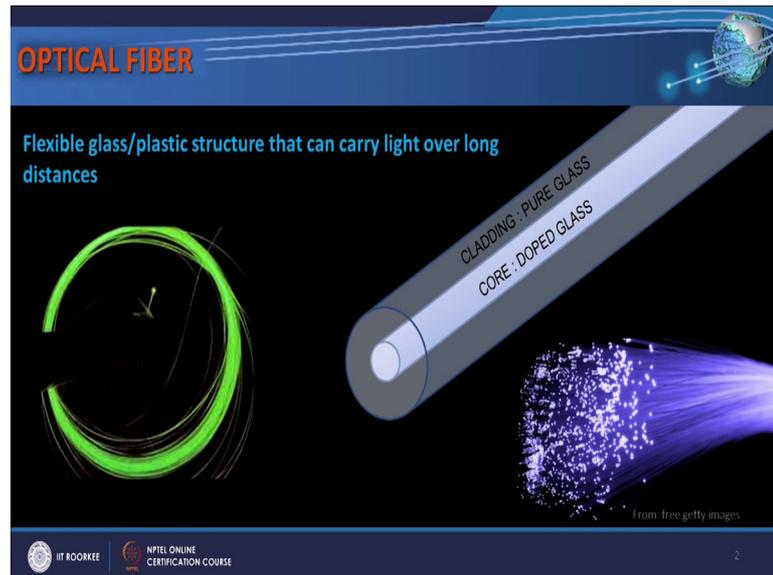
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Well, what is a single mode fiber? We will learn as we go along. This is another similar kind of fiber, but it has an orange colour jacket, it is known as multimode fiber. Again

this term multimode we will understand as we will go along. You may have also seen something like this. This is a very flexible cable, but it takes light along it. So, if I put light into one end you can see light coming out. So, if I take light from here it can be eliminated. So, I have different types of fibers, you also think where do you see fiber, what comes to your mind when you hear this term fiber optics or optical fiber.

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Let us look at where do we see fiber in our lives, and how does the fiber look like. Let us first have how the fiber look like what exactly is optical fiber. So, it is having a very thin core in the centre which is made of certain material, here I have shown it is made up of doped glass. And it is surrounded by another material which is called cladding. This material can be for example pure glass, and this region is called cladding. And this forms a flexible structure which can carry light over very long distance. And the material can be glass or plastic.

This is typical glass fiber eliminated by green laser light, and this is typical plastic fiber bundle which is eliminated by white light. Where do we see fibers in our daily lives? Well, the very first use of optical fiber was in endoscopy. The bundle that I showed you here this is the kind of bundle of fiber which is used in endoscopy. What does it d? Well, you can slip in this kind of fiber inside the human body and image it inside. You can see the elements which I have hafting inside.

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FIBER IN OUR LIVES

MEDICINE



Endoscopy
is used to image inside the human body

Laproscopy
is used to carry out minimum invasive surgery

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And if you put a laser beam through it you can even do surgery; this is minimum invasive surgery. What you have to do only puncture some small holes in the human body, slip in the fiber, put the laser light, image it do the surgery, and treat the elements. This kind of surgery is known as laparoscopy.

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FIBER IN OUR LIVES

MONITORING CIVIL STRUCTURES



✓ 24x7 real time monitoring is possible

✓ any defect can be detected at the initial stage and precautionary measures can be taken

✓ can be used to monitor health of flyovers, railway bridges and buildings

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Where else do we see fibers? Fiber can be seen in flyovers, installed in flyovers to sense the any straight to sense any straight or stress developing in the structure. So, you can use fiber sensors to monitor the health of civil engineering structures. You can do 24 by 7

real time monitoring, any defect can be detected at the initial stage itself, and the precautionary measures can be taken. So, it can be used to monitor the health of the flyovers, railway bridges, and building. And you can do real time monitoring of the health of these structures.

This is one example of Taiwan's first ever all round full bridge fiber optic monitoring system.

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The slide features a blue header with the text "FIBER IN OUR LIVES" and a globe icon. Below the header, the title "TAIWAN'S FIRST EVER ALL-ROUND FULL-BRIDGE FIBER-OPTIC MONITORING SYSTEM" is displayed in red. The main content area includes a photograph of the Dazhi Bridge, a close-up of fiber optic cables, and a computer monitor showing monitoring data. A list of three bullet points describes the system's capabilities. At the bottom, there are logos for IIT ROORKEE and NPTEL ONLINE CERTIFICATION COURSE, along with a small number "5".

FIBER IN OUR LIVES

TAIWAN'S FIRST EVER ALL-ROUND FULL-BRIDGE FIBER-OPTIC MONITORING SYSTEM

Dazhi Bridge

- ✓ Capable of performing 24-hour all-round bridge monitoring
- ✓ Any abnormality detected is immediately notified to the bridge management unit by means of computer or smartphone via the cloud
- ✓ The system can also be combined with traffic signals to immediately prohibit use by vehicles or pedestrians

NAR Labs, Newsletter, issue 25, 2013/04/30

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It is capable of performing 24 hour all round bridge monitoring. If there is any abnormality detected then the bridge management unit is immediately notify it by means of computer or Smartphone and precautionary measures are taken. This system can also be combined with traffic signals to immediately prohibit use by vehicles or pedestrians.

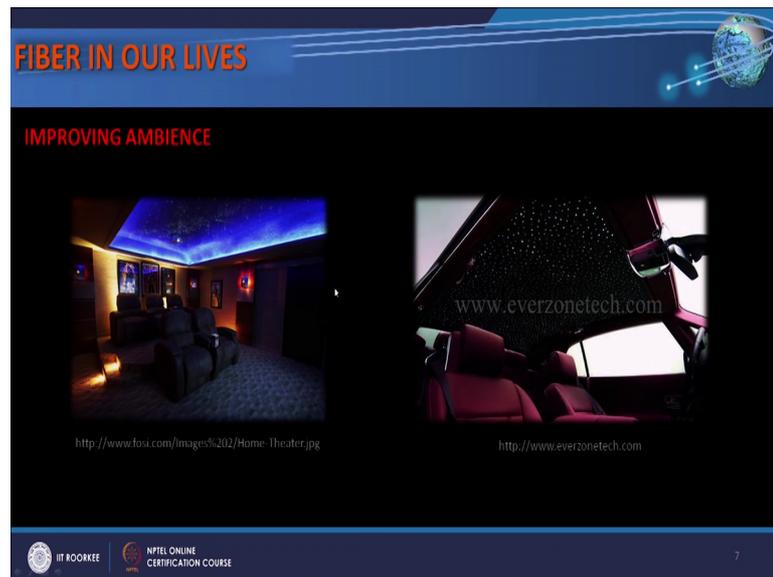
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Another application that I see is in eliminating the places, like museums, caves, or where you have very precious artworks. Why do we need this? Well, in these kinds of places we have artworks which are very sensitive to thermal radiation and if we eliminate them using ordinary lamp then these lamps do not only give light, but also heat the artworks. So, these kinds of lamps degrade the quality of artworks. So, to prohibit that to address this issue what can be done? You can put the lamp outside; for example in this Ajanta caves you put the lamp outside, take the light using optical fiber bundle through this the fiber is running along this and then take this fiber bundle inside the cave and eliminate it. You can see the blazing light coming out of fiber bundles and the whole structure is eliminated.

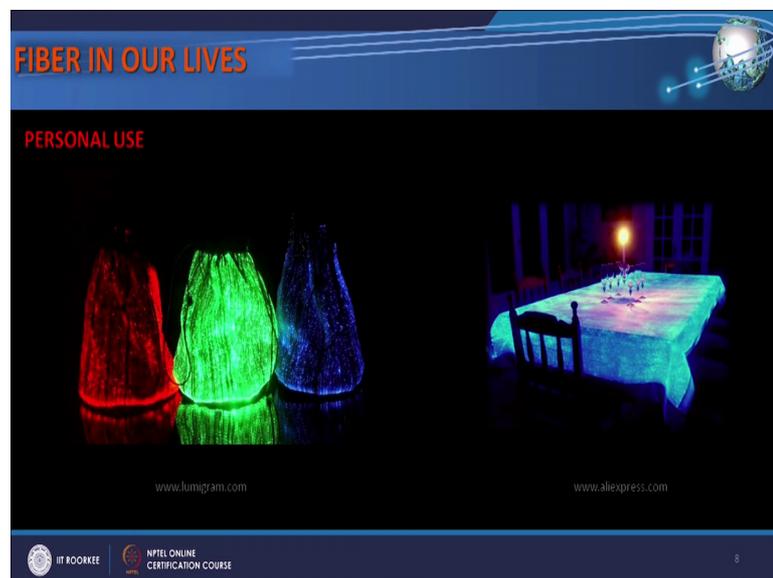
In this way you can only transport light through optical fibers, but not the heat. So, your artworks are protected.

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You can also use optical fibers for improving our ambience. For example, you can make a ceiling of hotel lobby like this, or you can make the ceiling of your car like this, you can also use optical fiber for your personal use.

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Like, you can make a fabric using optical fiber, you can basically we win the optical fiber which side emitting and then eliminated using different colours. So, you have colour changing fabric. You can turn on light if you use this kind of a bit. But of course, the very important use and the most important use of optical fiber is in

telecommunication. It is really wonderful to see from where we started and where we have come. What a tremendous advancement of technology has happened.

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We started with telephone something like this and now we have a Smartphone; very small phone which has all the capabilities, you can do whatever you want. We started with internet it is something like first generation internet in 1981 using that we could just browse few websites, use internet email perhaps. And now we are heading to 5G- maybe in 2020 or before.

In initial days we had computers which looked like this and now we have computers which are hand held; on your palm top you can do everything. We used to watch television on very big CRT screens, now television can be mounted on wall. We can even watch videos over on our mobile phones, over on our tablet computers. We can watch television over internet. And all this could happen because of tremendous advancement in technology in the area of photonics and particularly in the area of fiber optics.

Today we are connected globally. The world has become really very small.

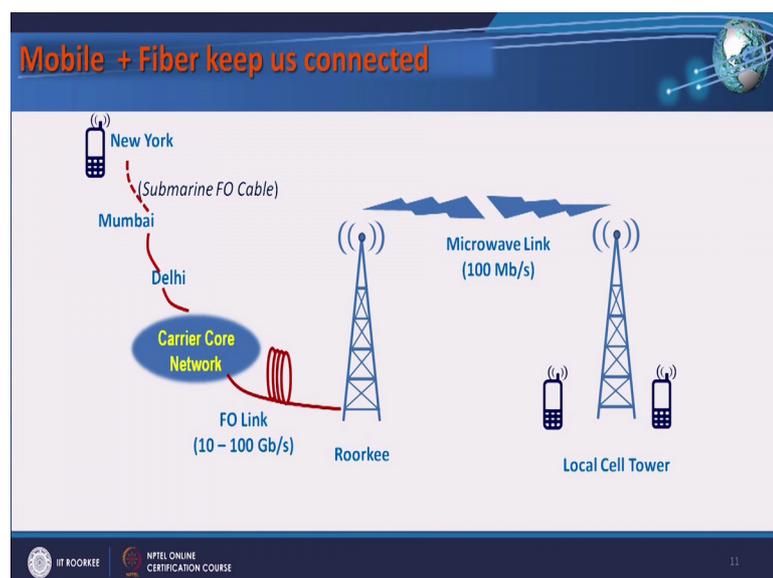
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We are connected to our friends to our families wherever they are: using various social networking sites, emails, internet, etcetera and the credit goes to fiber optics

You will wonder that I am saying that you are talking on mobile phone then where the fiber optics come to picture. You are browsing internet where I am using optical fiber, I am sending message using Whatsapp, where I am using optical fiber. Well, what we see basically is this domain.

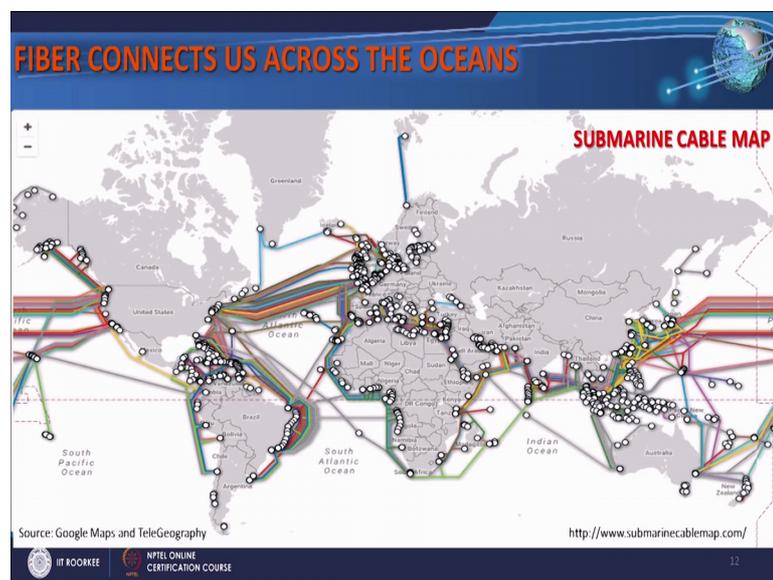
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We use our mobile phones which communicate to this local cell tower. You might have seen these kinds of cell towers in your localities. Now if I want to send a message to a mobile which is in New York, how does this data go? Well, this local cell tower is connected to another tower which is connected to optical fiber and carrier core network, but the connection between these two towers is using microwave link. The connection between your mobile phone and this tower is also through microwave link. This microwave link has a limited data transmission capacity which is about 100 megabits per second.

So, you send data from this tower to this tower at 100 mbps over a few kilometers, and then fiber takes over. This data goes into optical fiber to for example, Delhi this fiber is buried under the ground, and then from Delhi to Mumbai, and then from Mumbai to New York using optical fiber. You will say how go from Mumbai to New York using optical fiber; well, there are submarine fiber optic cables. Cables are buried on sea bed something like this.

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This is a submarine cable map; it shows that millions of kilometers of optical fiber is buried on sea bed is lying on sea bed connecting the whole world. Here you are in India and then you can go to Europe and to the US, ok.

So, it is this fiber which takes your data from Mumbai to New York. It is this fiber which downloads data from Europe to your computer in Roorkee.

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FIBER OPTICS : SOME HISTORICAL FACTS

The term **Fibre Optics** was coined by



<http://www.sikhfoundation.org/people-events/dr-narinder-kapany-the-man-who-bent-light/>

N S Kapany
Born in [Moga, Punjab](#), India and educated in [England](#).
His was the first Ph. D. Thesis on "Fibre Optics" from the University of London in 1955
[H. H. Hopkins and N. S. Kapany, "Transparent fibres for the transmission of optical images," *Optica Acta 1*, No. 4, pp. 164-170, Feb. 1955.]

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Well, now there some historical facts. This very tough fiber optics was coined by Narendra Singh Kapany, he was born in Moga Punjab and educated in England and his was the first PhD thesis on fiber optics in the year 1955 from University of London. The fibers on which Professor Kapany worked could be used to transmit image only over a meter or so. The fiber was very lousy, he use the bundle of optical fibers which could transmit image over a meter. But at that time people were not able to transmit light over long distances, not even up to 10 meters forget about kilometers, because the fiber was very lousy.

And remember I am talking about mid 50s or late 50s; at that time liver was not available. So, it was not possible to use optical fiber for telecommunication.

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LASER

Birth of LASER

May 16, 1960: Theodore Maiman demonstrated the first laser at Hughes Research Laboratories in Malibu.

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a wide range
sandy changed

any American
singly. In many
for example—
ble technology

December 12, 1960: Ali Javan made first helium-neon laser at Bell Labs the first laser to emit a steady beam.

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<https://en.wikipedia.org/wiki/File:Mems-laser.jpg>

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14

Then what happened a revolution happened: the Laser was born. In May 1916 Theodore Maiman demonstrated the first laser, it was a ruby laser, he demonstrated it in Malibu. And few months later Ali Javan demonstrated first helium-neon laser at Bell Labs. And this mark the revolution in the area of photonics: in the way we live, in the way we communicate to each other, in several other things; because this laser was very special source of light, it was very powerful, directional, coherent, monochromatic, all these things in one single source it was a miracle.

And using this kind of source people started playing with it; find to do whatever came to their minds. And they also tried to use these lasers for telecommunication, because they were very directional. So, they thought that they can use these lasers by open air or open atmosphere communication, but of course there were limitations, because if you are using a laser through open atmosphere you are doing communication; for example your transmitting some music signal you are listening to music and suddenly a bird causes the laser beam and your music stops. Suddenly fogs settles in and you beam is attenuated. If there is thunderstorm the dust particles this scatter light re visit innovated.

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LASERS FOR TELECOMMUNICATION

- 1962–1963: Experiments showed high loss when sending laser beams through atmosphere.
- Fibers already showed too high loss to be used for telecommunication.
- America led the world in developing lasers and optical fibers, but it virtually ignored the idea of fiber-optic communications.

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15

So, in the years 62 to 63 experiments showed high loss when sending laser beams through open atmosphere. And fibers already showed too high loss to be used for telecommunication. So, during this time in early 60s people had lost interest in using optical fiber for telecommunication, they thought that it can never be used for communication.

At that time America was leading the world in developing lasers and optical fibers, but for different applications. America virtually ignore the idea of fiber optic communication. So, it was put in a cold bed. At that time a young Chinese engineer Charles K Kao he was still pursuing this idea of communication using optical fibers.

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FIBER COMMUNICATION TAKES OFF

In 1965 at Standard Telecommunication Laboratory in England a young Chinese engineer **Charles K Kao** was still pursuing the idea of optical communication through hair thin fibers

At that time the fiber had a loss of **1000 dB / km**
(only 1% light remains after 20 m long fiber)

With the laser power available at that time and the sensitivity of the detector Kao and Hockham in 1966 made a daring conclusion in a historic paper

A fiber with 20 dB/km loss can realize the dream of optical communication
(Loss : $10^{100} \rightarrow 10^2!$)



Photo Courtesy Nortel
Collection by Richard Epworth
Source: <http://www.goforich.co.uk/>

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And at that time let me tell you the loss of optical fiber was 1000 dB per kilometer. It means that if you send light through 20 meters of optical fiber then only 1 percent light remains. It means that if you put 100 millivolt of light at one end of 20 meter long fiber at the output end you will be left with only 1 millivolt; but 100 millivolt is huge, you do not use 100 millivolts.

So, only 1 percent light remains after 20 meter this was the kind of loss in optical fiber at that time. Charles K Kao and George Hockham they very carefully studied everything what was available at that time; the lasers and their power available at that time. The detectors, and the sensitivity of detectors, what is the weakest level of light intensity or light power the detectors could detect. And the fiber itself; how fiber is made, what are the sources of losses in optical fiber, all these things they studied in very detailed manner and made it daring conclusion in a historic paper.

And just look at this conclusion which they made the proposition which they made in 1966 and it was a fiber with 20 dB per kilometer loss can realize the dream of optical communication. 20 dB per kilometer loss what does it mean? It means that you are bringing down the loss factor from 10 to the power 100 to 10 to the power 2; I hope it is not a joke. Bringing down the loss factor from 10 to the power 100 to 10 to the power 2, but there is study was very extensive and some people took it very seriously.

And then there was another revolution.

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FIBER COMMUNICATION TAKES OFF

In 1970 Corning Glass Work produced a fiber with 16 dB/km loss at 633 nm wavelength

Within a decade the fiber loss could be brought down to ~ 1 dB/km

Today we have fibers with loss < 0.2 dB/km

Kao is widely regarded as **Father of Optical Fiber Communication** and has been awarded **2009 Nobel Prize in Physics**



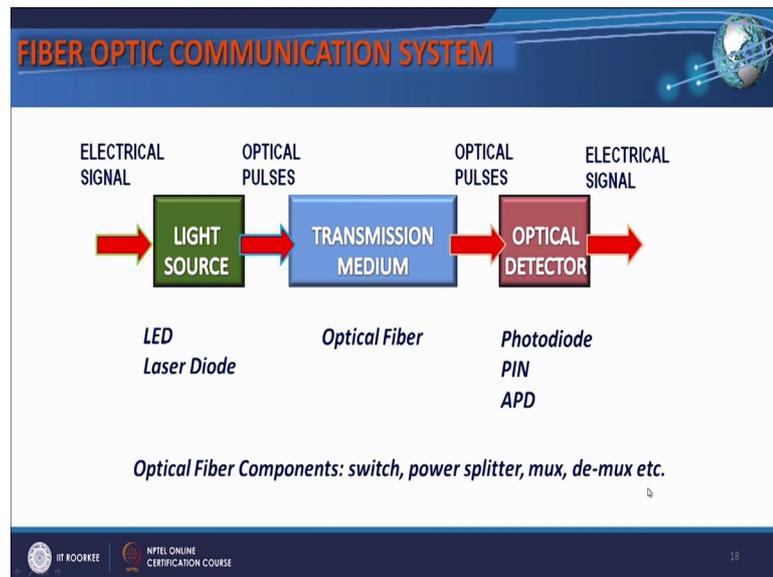
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In 1970 Corning Glass work produced a fiber with 16 dB per kilometer loss at 633 nanometer wavelength. And within a decade the fiber loss could be brought down to about 1 dB per kilometer. And it was just the beginning, today we have fibers with loss less than 0.2 dB per kilometer which is approximately the theoretical limit

So, whatever today we have is because of Charles Kao, because of his daring proposition the optical communication; fiber optic telecommunication could take off. And today all these social networking sites, internet, television, all these things which we are enjoying is because of this. So, far his tremendous contribution in the area of optical fiber communication Professor Kao is widely regarded as Father of Optical Fiber Communication and has been awarded 2009 Nobel Prize in Physics.

Now, let us look at fiber optic communication system and what we are going to do in this course.

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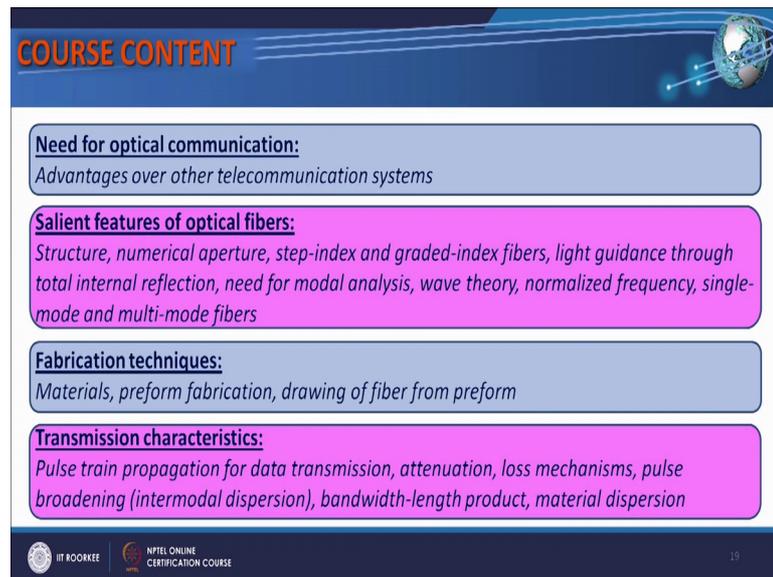


This is a typical block diagram of optical fiber telecommunication system where we have electric signal; so whatever data we want to send it is converted into electric signal whether it is voice data, image, or a video. So, we have electric pulses, these electric pulses drive light source and produce optical path pulses. These optical pulses are send through transmission medium and they are received at the output end by optical detector, where they are converted into electric signal again.

So, we have three primary components here: light source, transmission medium and optical detector. And we are going to study about this. We are going to study individually the light source, transmission medium and optical detector and then the system as a whole. The transmission medium is optical fiber, so we are going to study what are the transmission characteristics of optical fiber, what are the light sources which are used in telecommunication. So, we are going to study about light emitting diode and laser diodes, then what how the optical pulses are detected at the output end. So, we are going to study about photodiode; PIN detector and avalanche photodiode APD.

Apart from these we will also study various components which are required in telecommunication system; for example; power, splitter, polarizer, multiplexer, de multiplexer, all these components which are made up of fiber itself.

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COURSE CONTENT

Need for optical communication:
Advantages over other telecommunication systems

Salient features of optical fibers:
Structure, numerical aperture, step-index and graded-index fibers, light guidance through total internal reflection, need for modal analysis, wave theory, normalized frequency, single-mode and multi-mode fibers

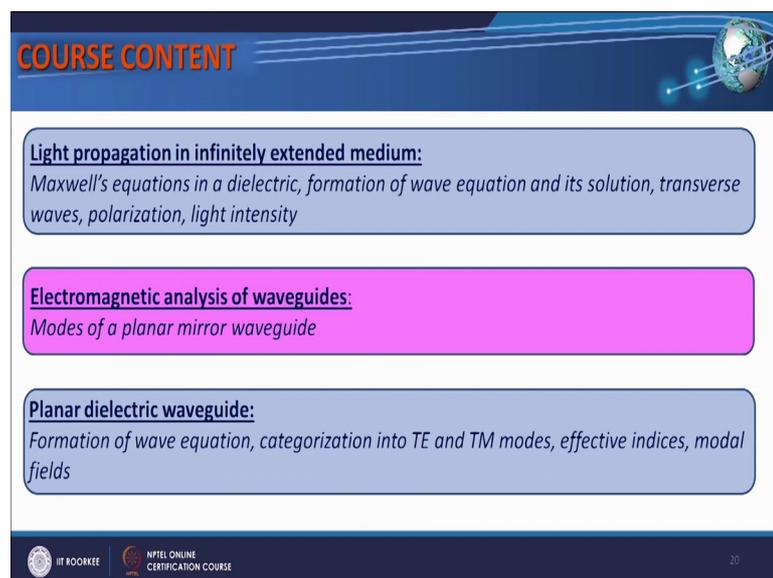
Fabrication techniques:
Materials, preform fabrication, drawing of fiber from preform

Transmission characteristics:
Pulse train propagation for data transmission, attenuation, loss mechanisms, pulse broadening (intermodal dispersion), bandwidth-length product, material dispersion

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So, this is a course contains: we will start with need for optical communication. Why at all we need optics or optical waves for communication. Then what are the salient features of optical fibers; what is the structure, how the light is guided. Then how an optical fiber is fabricated, what are the materials used what are the techniques for fabrication of optical fiber, what are the transmission characteristics, when these optical pulses go through optical fiber what happened to them, and what causes the distortion of optical pulses.

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COURSE CONTENT

Light propagation in infinitely extended medium:
Maxwell's equations in a dielectric, formation of wave equation and its solution, transverse waves, polarization, light intensity

Electromagnetic analysis of waveguides:
Modes of a planar mirror waveguide

Planar dielectric waveguide:
Formation of wave equation, categorization into TE and TM modes, effective indices, modal fields

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And to understand the transmission characteristics of optical fiber first of all we should understand how light propagates in a room like this. So, how light propagates in an infinitely extended medium. Then we will study the light guidance mechanism in a very simple optical waveguide which is a slab waveguide, which is something like this. If you have things like this is very thin if you have a thin slab of glass for example, and you silver it here and here then you send light, then because you have silvered it on the top and the bottom then light will bounce back and forth and will be confined in this structure.

So, this is a very simple planar mirror waveguide. So, how light goes through this, and then we will move to planar dielectric waveguide. If we do not put any metal coating or silver the top and bottom of this kind of structure then also it can guide light. This is a planar dielectric waveguide. So, how does this guide light. And then we will understand how optical fiber propagates light through it in a cylindrical geometry.

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COURSE CONTENT

Optical fiber waveguide:
Need for scalar analysis, weakly guiding fiber, LP modes, mode cut-offs, effective indices, modal fields, modal field patterns, degeneracy

Single-mode fiber:
Cut-off wavelength, empirical formula for propagation constant, mode field diameter, bend loss

Splice loss:
Mode mismatch loss, losses at the joint of two fibers, transverse, angular and longitudinal off-set losses

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We will talk about single mode fiber, properties of single mode fiber which is primarily used in long distance telecommunication. Then since, this fiber is used over 100s 1000s of kilometers, so it is natural that we will have to join two fibers together at some point. When we join two fibers together then what happens at the joint, what are the kind of losses at the joint they are called splice loss. So, we will study about them.

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COURSE CONTENT

- Waveguide dispersion:**
Group delay, waveguide dispersion coefficient, total dispersion
- Optical fiber components and devices:**
Directional coupler, power splitter, multiplexer, de-multiplexer, fiber Bragg gratings, long-period fiber gratings, polarization controllers
- Attenuation management:**
Optical fiber amplifier, basics of erbium-doped fiber amplifier
- Dispersion management:**
Dispersion shifted fiber, dispersion compensating fiber

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Then waveguide dispersion which is one of the mechanism responsible for broadening of pulses in optical fiber components and devices which include power splitter, multiplexer, de multiplexer. Then how do we manage the attenuation of pulses in an optical fiber. Then how do we manage broadening of pulses in an optical fiber; that is dispersion management.

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COURSE CONTENT

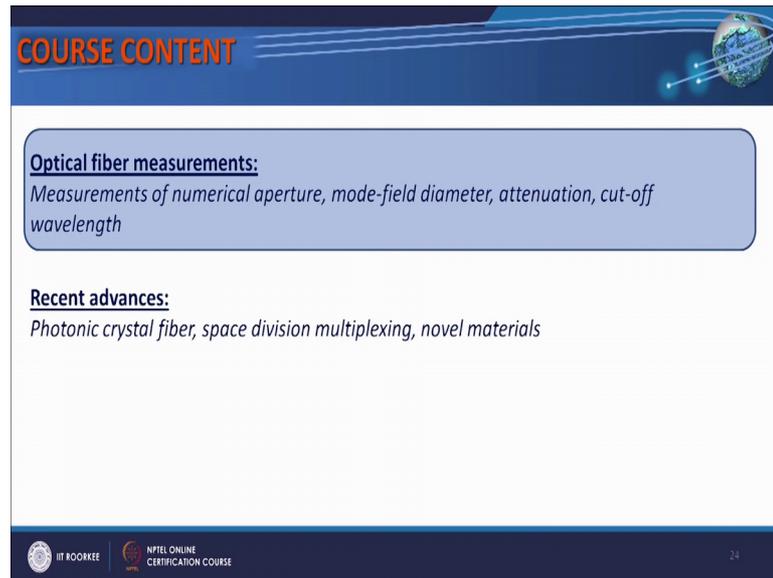
- Sources for optical communication:**
Light emitting diode, efficiency, responsivity and basic characteristics, laser diode, basic characteristics, modulation
- Detectors for optical communication:**
Light detection mechanisms, p-n junction photodiode, efficiency, responsivity, p-i-n detector, avalanche photodiode, noise
- System design:**
Dispersion limited system, attenuation limited system, error rate, power budgeting

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Then sources for optical communications; what are the properties of light emitting diodes, what are the properties of laser diodes. Then detectors for optical

communication; how light is detected in a photodiode, what are their basic characteristics, what are their efficiencies. And then after doing all this then we will be able to do system design. The design of the system as a whole; what are dispersion limited system, attenuation limited system, power budgeting of the link all these things we can do.

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COURSE CONTENT

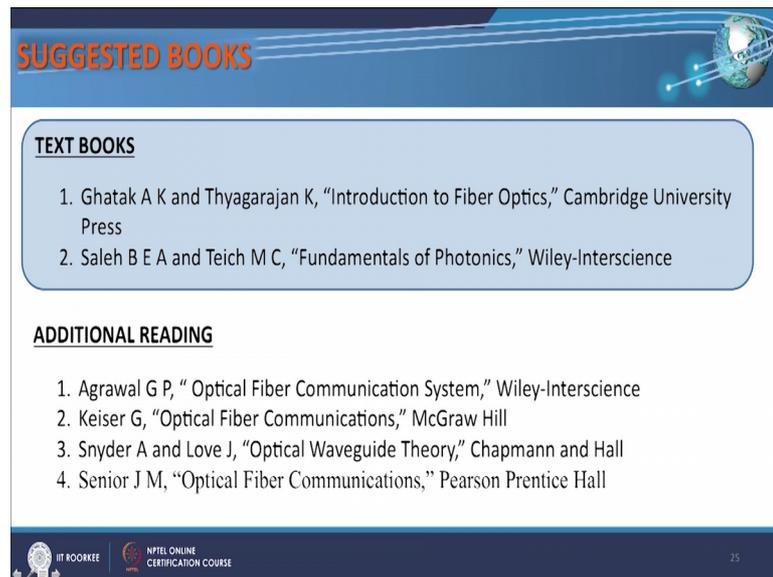
Optical fiber measurements:
Measurements of numerical aperture, mode-field diameter, attenuation, cut-off wavelength

Recent advances:
Photonic crystal fiber, space division multiplexing, novel materials

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Then we will also learn few techniques of measurements of different properties and parameters of optical fiber. And lastly what are the recent advances in fiber optics. This would include weekly assignments in the form of multiple choice questions.

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SUGGESTED BOOKS

TEXT BOOKS

1. Ghatak A K and Thyagarajan K, "Introduction to Fiber Optics," Cambridge University Press
2. Saleh B E A and Teich M C, "Fundamentals of Photonics," Wiley-Interscience

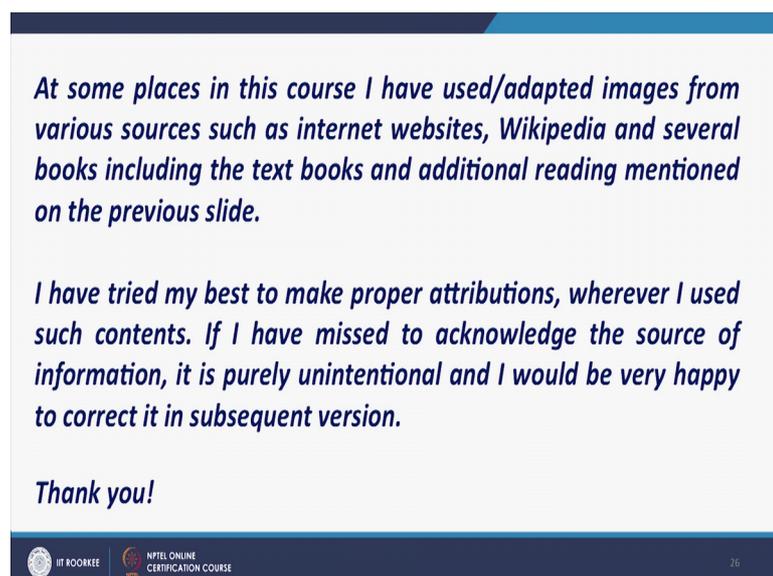
ADDITIONAL READING

1. Agrawal G P, "Optical Fiber Communication System," Wiley-Interscience
2. Keiser G, "Optical Fiber Communications," McGraw Hill
3. Snyder A and Love J, "Optical Waveguide Theory," Chapman and Hall
4. Senior J M, "Optical Fiber Communications," Pearson Prentice Hall

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The suggested text books are: Ghatak and Thyagarajan, "Introduction to Fiber Optics" and Saleh and Teich, "Fundamentals of Photonics". In addition to these two text books there are four books recommended for additional reading these are: GP Agrawal, "Optical Fiber Communication System". G Keiser, "Optical Fiber Communications". Snyder and Love, "Optical Waveguide Theory". And Senior, "Optical Fiber Communication".

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Thank you!

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