Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – I
Module – 0
Overview of Fibre – Communications

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Hello all and welcome to this first module of optical communications mook course in this module I will give you a brief overview of optical fiber communications the idea is not be very comprehensive if you do not understand one or two topics here or if you d not understand most of the topics here do not worry the entire course is for this expanding up on what we are going to cover today we will be revisiting all the topics that we discuss in a very brief manner the idea of this over view is t tell you what is optical communications.

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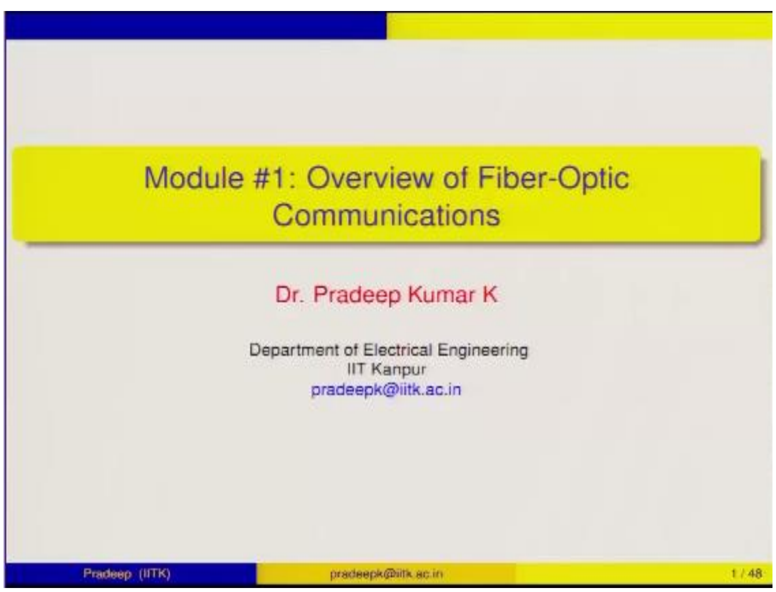

Capable of doing and how it performs this function that it is very well known for that and we will also discuss the course plan suggested text book and references and we will began with considering the overview of optical fiber communications my name is Pradeep Kumar K and I am department of electrical engineering IIT Kanpur my email ID is given here on the screen so feel free to contact me once the course starts we can talk about the questions that you will have. So the outline here for the overview is that we will first motivate the requirement for optical fiber communications and then we talk about the point to point.

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Optical communication link I will talk specifically about modulation and transmission also introduce you to receivers finally I will discuss optical fibers remember all these topics are going to be covered in the entire detail for the rest of the course the idea here is to familiarize due with what is optical fiber communications and how is it currently deployed and what are the elements that going to making in optical fiber communication system.

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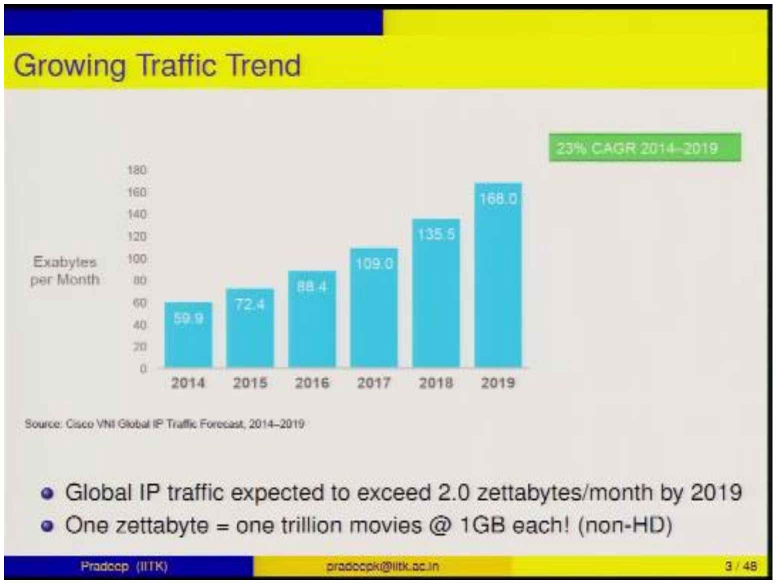

Now before we get into optical fiber communications here is a slide which I want to show you this slide was taken from Cisco global IP traffic forecast which was couple of years ago it was published and it is it makes very interesting reading here you can see that the data traffic or the global IP traffic keeps on increasing from the values around 60 exabytes/ month to the projected 170 or 168 exabytes/ month by the year 2019.

We are already in the year 2016 and the exabytes/month of the global IP traffic is already touching 100 exabytes/month now this is just a IP traffic if you look at global traffic the global data rates are expected to exceed 2 zettabytes /month by the year 2019 in another 3 years we are expected to reach more than 2000 more than 2 zettabytes/ month to put this number zettabyte into context 1 zeetabyte allows you to store one trillion movies each movie assuming at 1 gigabytes that is a non HD format most movies are available with 1 gigabytes of the size and you can store one trillion movies this is the entire movie in all of the different movie industries in the world put together this number would not be exceed.

So you have you see that by the 2019 this is the kind of data traffic that this expected to be there for the entire world and this traffic implies that then world must be connected with very high speed data network.

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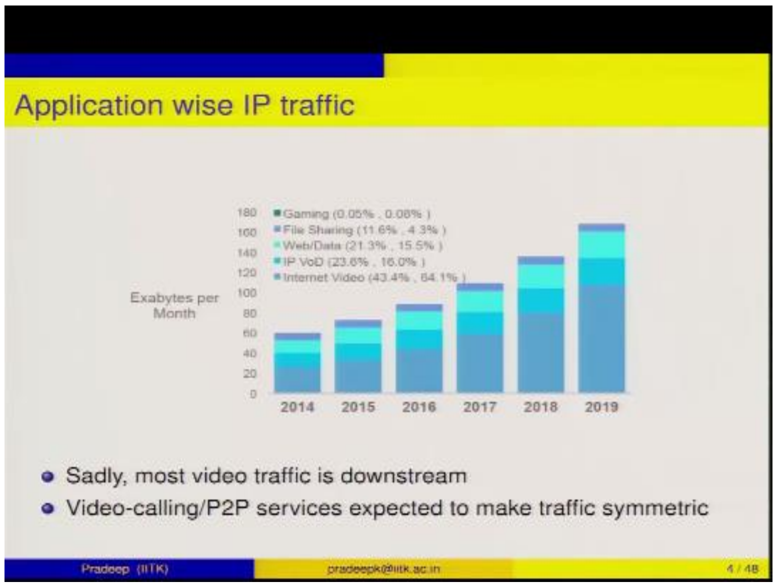

If you look closely at what applications drive this IP traffic you will see that much of the application is by the internet video something that you would appreciate it including this online lecture that is that you are viewing currently comes and into the category internet video and you can see that there is about 40% or 45% of the entire traffic is excepted to be that but by the year 2019 this number is excepted to go up to 64% so we expect that internet video will become is already dominating.

It will become even more dominating as the years go by the next application that is consuming lot of data is IP video on demand then there are web data and file sharing with which you know can share files to your friends you can share some documents that comes up and finally there is gaining which does not really see much of a improvement out there, so this applications all consume enormous amount of data and these applications are also sensitive to delay.

You do not want to view a video in which one frame of the video comes now and the next frame of the video comes 1 or 2 seconds later that kind of delay is unacceptable so once the steaming starts you want the entire video to be delivered to you are streamed to you unfortunately this video traffic is not always up steam that is this video traffic is almost always consumed by the consumers rather than consumers putting out videos and you know putting down the connection from the other end.

However we also expect such certain novel applications to come up such video calling and pear to pear services they are expected to make traffic symmetric so that the load on the network distributes evenly between consumers as well as the data centers if you look at the context of India internet in India is one of the rapidly expanding recourse and it is very clear why that is so because now more and more people are getting connected through internet by either private networks or though public sector networks which are governed by the government of India.

And this internet traffic is expected to go even more higher because of such initiatives by the government such as online course which is are again expected to increase rapidly in addition t that consumer data traffic also drives the internet traffic in India and India is one of the fastest growing country in terms of internet traffic we expect that IP traffic are when I say we actually I mean the Cisco expects Cisco networks expects that the IP traffic in India will exceed 2 exabytes/ month by the 2017.

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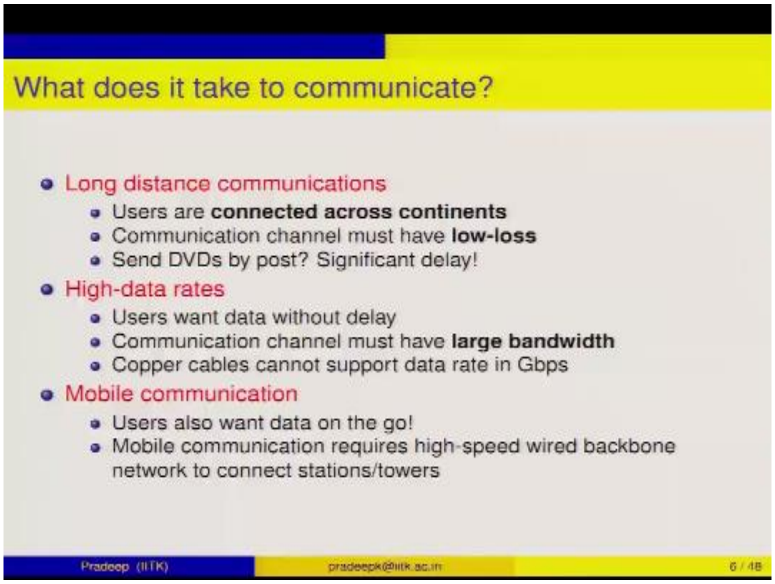

Okay now we ask well we are seeing lot of data being communicated now what actually does it take to communicate what infrastructure is required for me communicate at such high data rates and possibly with very low delay that is the network or the infrastructure must be fast enough in order to perform all these functions to transfer the data it must also calls no delay okay well two characteristic of communication come up very naturally one is that you are looking at long distance communications.

Why are we looking at long distance communications remember your data centre might be located in the united states and you might be sitting in India and accessing some data from the data centre which means that you are on two different continents and you are now connected though a infrastructure communication infrastructure, it is of course not only two users there are millions and billions of users who are connected where internet and this internet spans continents right.

In order to have long distance communication you also want the communication channel to have very, very low loss what happens if the communication channel has a high loss then what ever data that you are transmitting in certain form that will be lost before it reaches the destination and we are talking about thousands of kilometer of transmutation of data from one point to another point therefore in order sustain this long distance communication the communication channel that you use in the network infrastructure must have low loss.

Well there was a very interesting idea that someone suggested to as to why should you have a communication channel at all what if you possible that you take All the DVD's whatever data that you want to communicate put all the DVD's and post it or carrier then to the destination well it can be done the data rate will be certainly very high you can imagine you know a truck load of DVD's being delivered to you and the data in each DVD would be around 4 or 5 gb let us say so that entire data is available to you at the instance.

Right when it is delivered to you however this transporting DVD form one point to another point when you are far way across the continents will involve significant delay so you cannot have 10 frames of CD of a move arriving to you by post toady and the reaming 20 frames arriving in the next post so that is a significant delay in this idea so that is that brings up to another aspect of communication we want communication at long distances you know contentedly connections.

However we want this communication to happen rather fast we do not want significant delay in this communication also because it is suppose to carry a large data rate the communication channel most have a large band width right so large bandwidth less delay are two other characteristics of long distance communications that you would like to have the traditional communications which were happening over copper cables.

I do not think you would find copper cables anymore and for a very good reason is because data rates cannot be supported in the range of gigabytes / second and when we say gigabytes/ second this is on the low ball that we are looking at low ball park that we are looking at the data rate typically that current communication infrastructure supports is around 10 of gigabytes/ second.

So it is clear that copper cables or any other solution you can think of satellite you can think of the acoustic way kind of communication none of those communication technologies are able to support data rates in gig bits per second, the third and one of the recent match characteristic of communication that has now come to all of us is that users also want the data on go.

That is I have a smart phone you are the smart phone and you want to watch video not sitting at a home or not turning on your PC or connecting to the television via internet what you would like to have is that you’re walking or your running and you want to also watch video or you are travelling from this one point to another point and you want to watch video that is tram that is streamed to your smart phone.

This is what we call as data on the go, however for this to happen the infrastructure must support mobile communications and this mobile communication which is implemented in the form of wireless technology today still requires a high speed wired backbone network in order to give you mobile communications as when.

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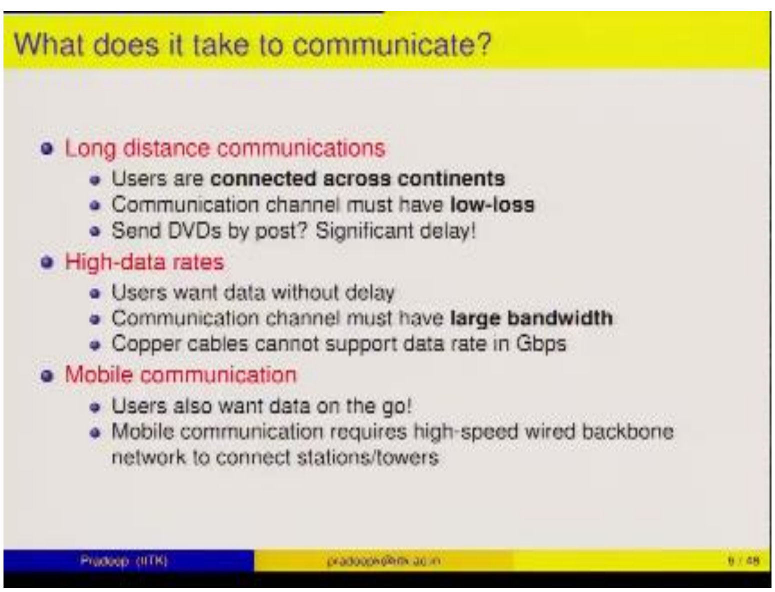

So this backbone network connects to stations and towers that are used in the wireless communication systems.

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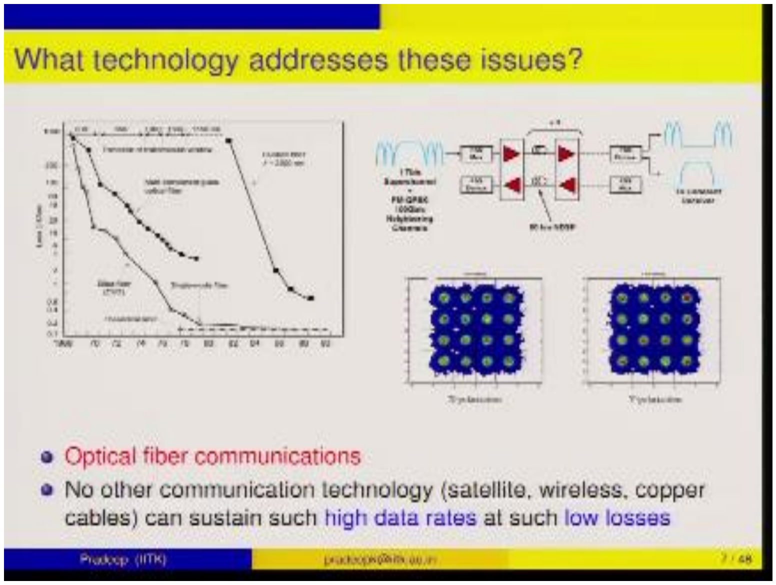

Now if you ask what technology addresses all these issues there is only one technology which is currently making all these communication that I talked about with all the nice attractive features of long distance, low loss, high data rate, low or a less relay is made possible by fiber optic communication and fiber optic communication today can support data rates in excess of one tera but per second super channels well these are lap demonstration they are not have been operational in the actually world.

But data rates of 40 Gbps are currently available so much of the new network that private network operators are setting up is running a 10 or its next cousin at 40 Gbps. So there is already 40 GBPS available and if you look at the aggregate data the aggregate data rates are in excess of tera bit per second, now this is very importunate to aggregate data is in tera bit per second, okay.

1 tera bit is 1000 times billion so you can imagine the kind of data rate that is possible with current optical communication technology, no other communication technology such as satellite, warless, copper cable whatever communication technology that I can think of can provide such high data rate at such low losses, okay.

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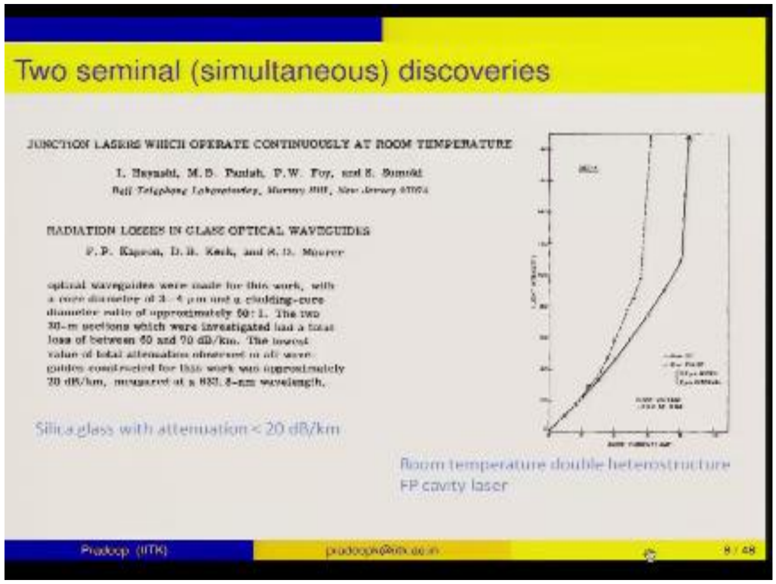

Now how optical fiber communications was made possible? Well optical communications has been in existence since around 1917 and two discoveries which were made simultaneously these two seminal discoveries made optical fiber communications possible, the first one was the fabrication of glass optical wave guides or what are now known as optical fibers which allowed us to reach the so call magic number of 20Dp/km and this work was performed by certain group of people at conic laboratories.

Where they fabricated a silica glass with attenuation less than 20 degree per kilometer, now magic number of 20 degree per kilometer comes from the older technology where the copper cables add this kind of loss the copper cables that used that per used for communication for telephony and other things. They had this loss of 20 degree per kilometer therefore there was a rush to try and get to that magic number of 20 degree per kilometer with optical fibers.

So if the fiber could deliver attenuation of less that this number then copper cables would be replace because silica is cheap is abundantly available glasses can be made with very little loss, now that is another interesting point us to how this losses where reduce and losses per initially very high, losses were at 1000 degree/ kilometer when this concept of optical fibers where suppose and then the loss steadily decrease and now it was now in the 1917 it was around 20 degree/ kilometer.

From there the loss has been reduced to the theoretical limit of around 0.15 degree/ kilometer today loss are around 0.15 degree/ kilometer therefore you can kind of forget about loss as a major impairment in optical communication systems, loss is almost not unimportant issue today. The other thing that made possible optical communications was the fabrication of a room temperature laser, now laser if you, you know think about laser first thing that would come to your mind is the huge helium, neon lasers or kind of different carbon dioxide lasers, these lasers you know all work a different wavelength they all emit light at different wavelengths.

But one of the characteristic that comes to our mind when we say laser is that, these are very bulky, they occupy large area and they have to be cool always, so if you look at carbon dioxide laser there is a cooling liquid such as water that is flowing around, also in order to cool the placing medium. So this kind of operation made that you could not really use this laser in conjunction with optical fiber and that is where semi conductor laser's fabricated.

These are known as double hetero structure fabric diode cavity lasers and these lasers have distractive features that you can control the lasing power by simply varying the current to the laser and this came in a very small form factor and most importantly, this did not require external cooling mechanism and they were able to work at room temperature. So they did not require this huge in stuff but they were able to work at room temperature and these two together now you have a laser optical source and you have a optical fiber which is the guiding mechanism, so you can take light from the laser modulate, so that you can put the information on the optical source.

And then couple that one to the guiding medium, there at the receiver end, you put up a photo diode, which is again a semi conductor device which can again be fabricated on the chip and then the corresponding circuitry can be arranged on the chip, as well and then you have your full optical communication link, so you have the source in the form of a laser, you have an optical fiber which is the guiding mechanism at the end you will have a photo diode or photo detector.

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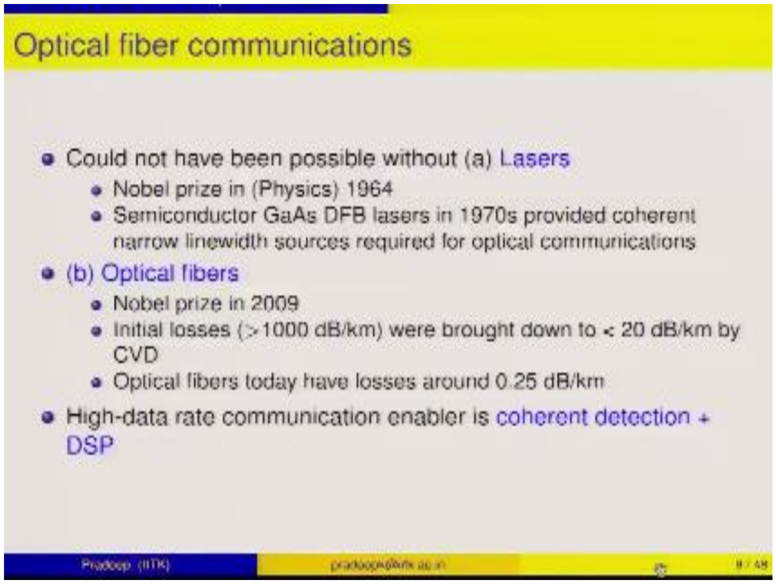

So optical fiber communication suggested was not possible without having this room temperature lasers and the development of low loss optical fibers. The concept of optical fibers was not really, in fact the concept of optical communication was not really new, long time ago I know about hundreds of years, two thousand of years ago people use to communicate by you know with this smoke signals, if something happened you burn some wood and then the smoke signal go up, the person at some other distance can view the smoke signal and then say that something must have happened.

This kind of visual communication by the smoke signal or by lighting up torches and then relying the information was known, people used light for communications. But, of course the thing with that those communications are there extremely low data rate and they are susceptible to lot of problems because of the channel and weather conditions and the distance between which you could perform the communication was limited. So you light up a torch, it can only go so far before that other person cannot see anything.

So these were characterized by very low data rates, they were characterized by short distances and high amount of loss because of the weather condition, things started improving and people in the 1960's came up with the idea of using optical wave guides or with the idea of glass fibers, you know these fibers which are very thin or suppose to guide light using the mechanism of total internal reflection, so this was proposed however, load of optical fibers were not available, because the fabricated optical fiber at significant impurities from the w3ater content in the fabrication.

Then people refined the fabrication process and finally what came was a low loss optical fiber, throughout this 10 year journey where optical fibers proposed and their losses were reduced in the year 1970. There was couple of people who were campaigning the cause of optical communications and one of this person was Charles Kao who jointly won noble prize for campaigning the cause, for popularizing the cause of optical fiber communications.

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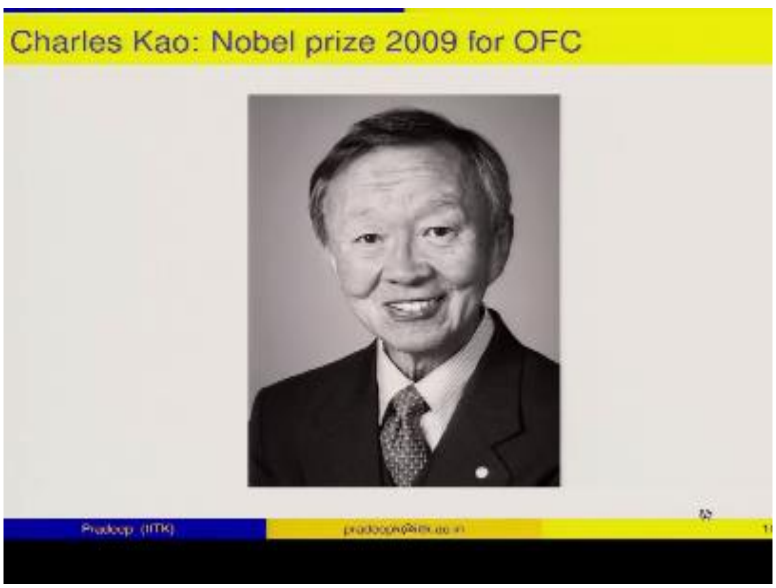

He won a noble prize in the year 2009, today however low loss optical fibers are available, lasers are available and then high data rate communication is enabled today in addition to fibers, lasers, detectors all this improvements, today there is a significant communication technology enabled in the form of coherent detection plus digital signal processing, coherent detection was used in the first three generations of the optical networks, however there coherent detection was very difficult top scale up for higher bit rates, today coherent detection is combined with digital signal processing which makes the data rates at 100 Gbps and next now the next technology at 400 Gbps and beyond.

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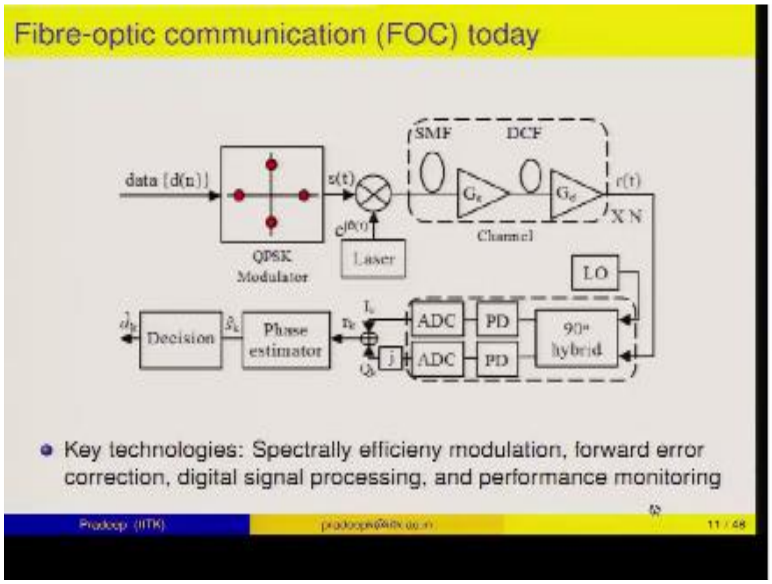

If you look at how a typical optical communication looks, this is how it looks, of course I dint put all the components necessary over here. We have a data that is almost always digital, this data is mapped to appropriate, by using an appropriate mapping technology we will talk about what is mapping is and what is modulation methodology is later, in this case it is called as Qpsk modulator, from this Qpsk modulator you take the map data, this is still in the base band or in the digital domain, this is still that data needs to be over the optical fiber.

In order to transmit it over optical fiber you need to modulate this data onto a laser, laser is the optical source, optical carrier; you modulate the laser and then transmitted over the fiber you can choose to compensate for certain fiber impairments inside the link itself this is known as in line dispersion compensation do not worry if you do not understand dispersion compensation we will talk about it later so this is the standard single more fiber whose loses are pretty low and this will work in the wave length range 15, 15 nanometer so this current optical communication technology was in the range of 15, 15 nanometer and these GS and GD are the optical amplifiers these are use to overcome whatever the losses that are there in the channel okay so you will have multiple fetch what is called as span so these spam consisting of a single mod optical fiber.

And an amplifier so you have multiple such spans forming together to the channel at the receiver you have a local oscillator which will mix with the incoming signal and then produce in face and quarter components these in face and components are analog signals are these are the currents are voltages in the electrical domain they will which are continuous but they will be sampled using very high speed analog to digital converters once we have sampled to combined the digital samples and perform the rest of the signal processing.

It could be face estimation it could be carriers frequency offset estimate it could be anything else you perform all the signal processing eventually you try to recover the data of course so the not always be able to recover the data because lot of things can go wrong in this communication system and you are one of the objectives of optical fiber communication system the design objective is to minimize the error between what you are sending and what you are receiving we will quantify more stringent error criteria in the next module okay so key technologies that are driving optical fiber communication.

Today or spectrally efficient modulation you want to modulate your data on to the carrier in such a way as to minimize the total occupied bandwidth okay so for a given bandwidth you want to sequencing as much as data as possible then you also have to do come preprocessing at their transmitter side by performing some error correction this is called as forward error correction.

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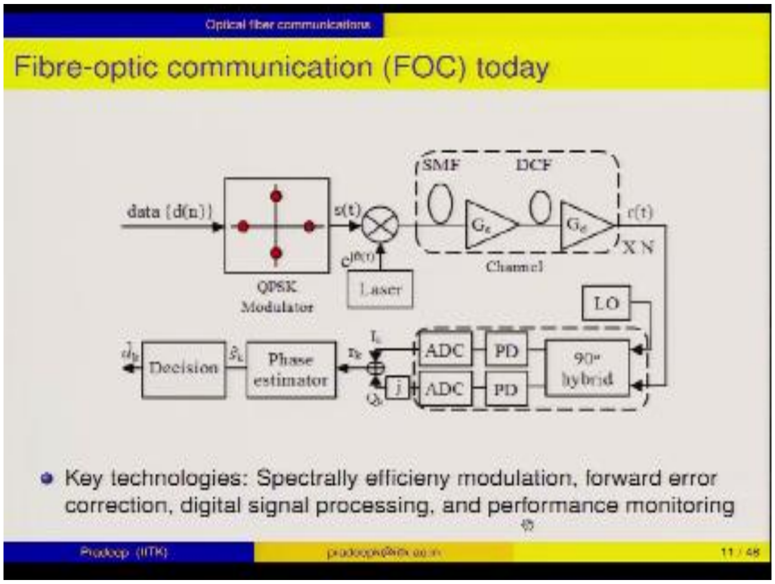

This is in anticipation of things that can go wrong in the channel you also performed digital signal processing at the end and then you also need to performance monitoring or in it actively monitor the performance of various blocks in this optical communication system so as to consistently deliver high data rates.

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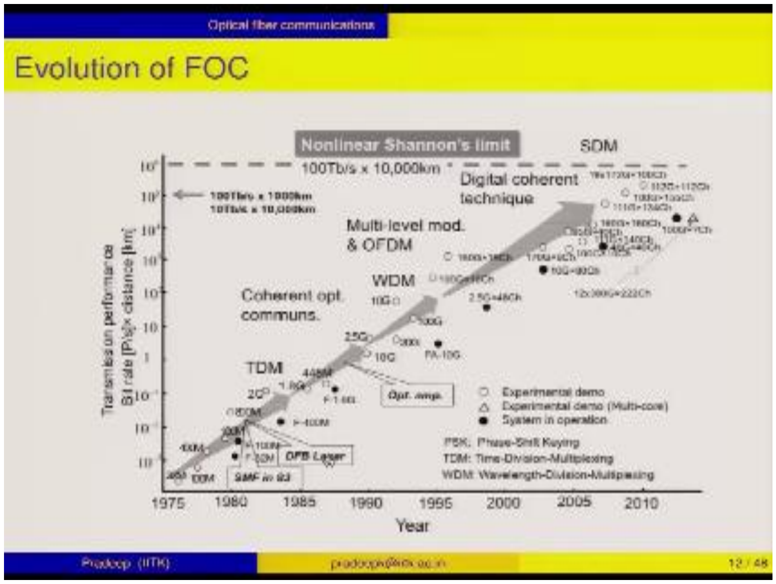

If you look at hoe optical fiber communication involved at the beginning you had in the 1970s the first generation optical fibers they were working in the 800 nanometer reign the data rates were pretty small and the distance over which you could communicate was also small SMS was introduced in 83 at the same time DSP laser was also introduced of course before that the laser that were used for fabric cavity laser so we will talk about them later and once SMS was introduced at the wave length was push to 15, 15 nanometer the data rate became 2.5gb PF that was the third generation optical network the first generation was working with 800 nanometer and multi mode fibers.

They were not very fast or they did not have pretty high data rate the rate were in some 40 to 45 mega bits per second later in the second generation optical communications systems the operating wave length was move to 1300 nanometers because that happens to be a smaller attenuation compared to 800 nanometers however this smaller attenuation actually this smaller also has 0 dispersion there single more optical fiber then so called 652 de optical fiber has 0 dispersion wave length or 1300 nanometer which means that you do not have to worry about dispersion in that band.

And that was made very attractive later lot of other problems came up and the attenuation was not as small has be through so there was one more window which opened up at 15, 15 nanometer that was a third generation opt6ical communication systems were the data rate sorry where the attenuation was at is lowest at 15, 50 nanometer the attenuation is lowest dispersion is not low but it can be but it can be managed okay so this third generation data rate was 2.5gb PS the detection mechanism for coregent action so you had to have a local oscillator and we have to control the face of the local oscillator and you have to control the fact of the local oscillator very accurately with respect the incoming optical signal.

This was a very challenging task but the advantage was that the sensitivity can be pushed up to 628DB okay so third up to third generation current detection systems were very widely used something very radical happened in the late 80s where people discovered an optical amplifier that to take fiber that would be couple with fiber at the input and it produce a five I mean it would produce an output through the fiber that could be coupled at the output and the amplifier itself was made of fiber.

Which could be easily pumped by having one more optical element at the input called a pump diode laser or a pumped diode okay pump laser now this amplifier is called as Erbium diode amplifier it is structure I very similar to the single mode fiber however this single mode fiber when you dope with this Erbium irons will allow you to amplify optical singles the best part of this optical amplifier that is the erbium dope optical amplifier was that you did not have to convert your input optical signals into electrical signals and then amplify this was in all optical amplifier you have multiple.

Multiple channels coming in and all this channels could be amplified simultaneously by using the Erbium doped fiber amplifier so you could use this Erbium dope fiber amplifier to amplify optically all the signals that also let to the concept of w DM systems that is instead of sending only one carrier in the optical fiber communication you now break up the available spectrum into multiple channels you modulate each channel with data communication from different sources you put all of them together into an optical multiplexer.

And then send it over the fiber if the fiber is getting I mean if the data is getting loss because of the fiber loses you simply put an optical amplifier in the form of an it for amplify all the channels simultaneously and then transmit over the next or the remaining part of the fiber network so this advantage of having WDM systems and later to dens WDM system so DW DM systems meant that you could be pack in lot many channels and each contributing data rates of at least 2.5 to 10gb PS of the data rate so you have an aggregate.

Data rate which was already going up this WDM technology was the one which made possible internet connections because it delivered very high data rates to the users were connected very far away distances of course from there you see that the data rates have pushed up.

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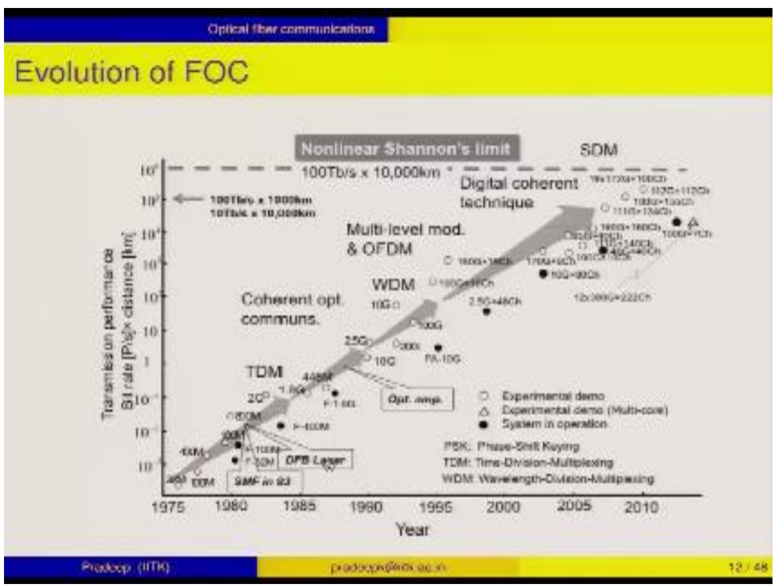

Increasing and increasing and this is a figure which is quite old now this is up to the year 2010 but you can see that already at 2010 you have systems demonstration such as 112 Giga bits per second and there are 112 channels in the aggregate so the total data rate is 112/112 the experimental reach already came in the system operation already came with 100G that is now going to be standardized very shortly so in between you had 2.5 10GB PS from 10 it when to an intermediate 40GB PS stage from 40 we are now at 100G.

So current technology is at 100 Giga bits per second technology so we will see what makes the current technology and enables the current technology as we go along with the.

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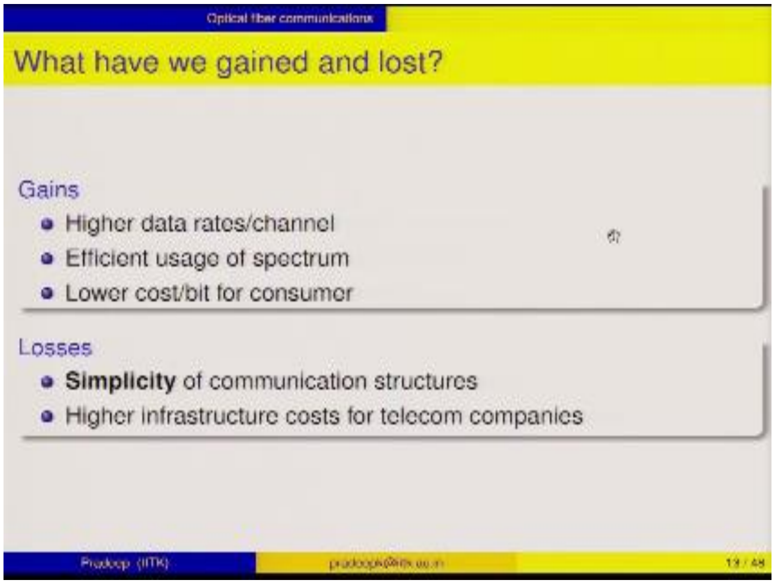

Course now one thing which I would like to emphasis is that optical communications earlier work quite simple if you take a standard text book on optical communications which was published in the year 90s or 80s you would see that modulations implement changing the laser current according to the signal that you want to sent and detections implement you put a receiver photo detector and then follow it up whether receiver amplifier so this is all your receiver consistent of a detector and amplifier.

So in a way the communication system was very simple you had a simple transmitter you had a simple structure for receiver however with this you know the current trends in optical communications which show that high data rates can be achieved what they have done is that in order to get this high data rates per channel and not a efficiently utilize the spectrum and to lower the cost per but for the consumer we have lost that simplicity the moderator structure is now complicated the receiver structure is even more complicated and the enabling technology all have to go in order to ensure that higher data rates per channel are achieved and of course the.

Advantages is that if you do this higher order higher data rates per channel then you are efficiently utilizing the spectrum and so as a consumer there will be less amount of cost per bit that you consume or that you transmit over the network so higher infrastructure cause go for telecom companies which they will then recover by appropriately pricing their strategies okays so the point I want to make was we have increase the data rate at the cost of simpler transmitter sent receivers.

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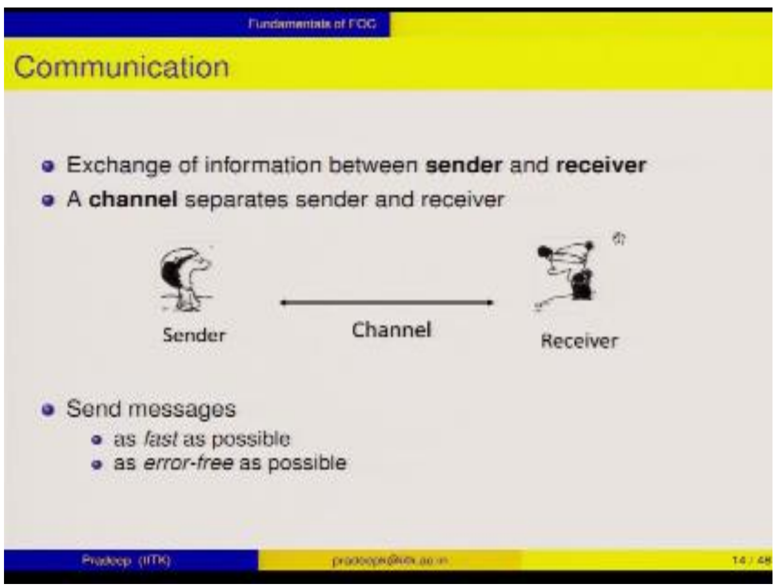

To get back to what communication means communications is a very old concept even now I am communication of course this is a one way communication because I am talking and your listening and hopefully my ideas which have been speaking for the last 20 30 minutes it is going into you so this is one kind of communication a which requires a person who is communication a medium which is internet in this particular lecture series and a listener who will listen and interpret what the sender is saying so you have a sender you have channel and the receiver of course the receiver can also.

Send something back not at the same time so you have these two parties which can communicate over the channel in a by lateral way so sender can become a receiver, receiver can become a sender after sometime, the idea for the sender would be to send messages as fast as possible and make as many less errors as possible so the communication channels must ensure which the communication channel will separates the sender and the receiver must ensure that messages are be delivered faster and they are being delivered with almost no errors.

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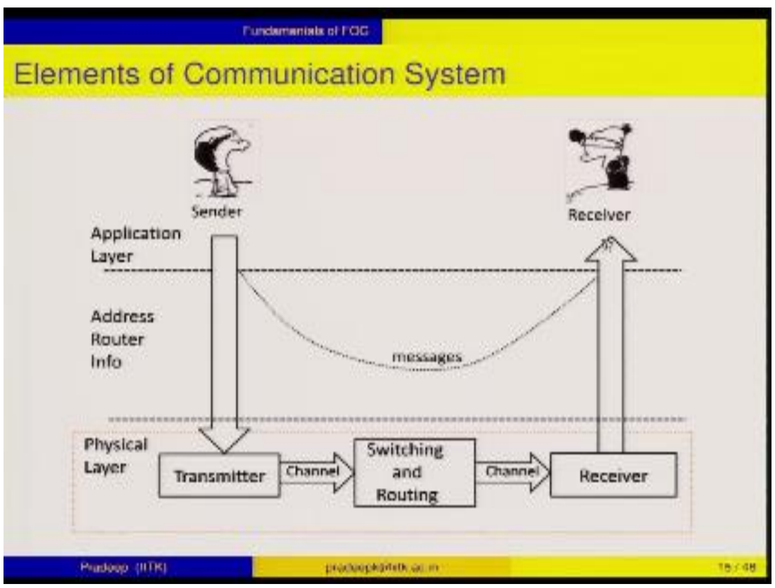

If you look at a typical communication system there are certain layers in which the communication system is organized in order to much, in order to facilitate the entire communication process at the top you have an application layer for example, if I am typing an email to be send out to my friend who does not reside in India but resides let say in United States I type something on the on my computer and then say put it into a email program and then send hit but I press the hit but send button and this message is then transmitted to my friend.

This layer which completely shields me away as to what is happening inside, how it is possible that I put up or if I press a button here the message is delivered almost without any delay to my friend that entire mechanism is invisible to me and this mechanism in which I am only concern with how to utilize this application is called as the application layer, so on the application layer we are completely obvious to the mechanism of communication.

So if you want to understand how communication is happening you need to go down one level below this is sometimes called as a network layer, so what happens is that the message that needs to be communicated to the receiver must be tagged appropriately think of you know posting a letter, when you post a letter without mentioning the address it can go anywhere, it can go anyplace it wants but it does not always go to the receiver.

So in order to make it go to the intended receiver you need to put in the address router all this information needs to be you know it needs to be put in. So the email that I entered which is just a strop of keys you know from the keyboard will be converted into bits because most communication systems are digital so they will converted into bits and this bits are tagged with addresses in order to make it go to the resend intended recipient, okay. Of course this again shields the exact way in which this bit transfer is occurring, right so one can take this bits and then carry physically over to the receiver but that is not what we normally mean by communication system.

So if you go one level below you will see that these bits actually are input to a device called as transmitter which will then prepare this information which it has received into a form that is suitable for transmission over the channel and based on what address and router information has been given this way forms which are suitable for the channel and they are carrying the information that needs to go from sender to receiver will be switched routed and placed appropriately at the receiver side you have the physical layer receiver which will receive the information from the channel and converted into a form that is suitable for the receiver to read.

If you receive 1s and 0s or if you receiver currents and voltages you would not be able to understand what is being transmitted, so this voltages and current have to be converted in the form that you can understand and the form that you can understand is perhaps the language that we are speaking right now. So this entire thing has to performed at the physical layer for someone who is sitting at the network layer it seems that some bits are going in and some bits are coming out with occasional errors.

So this entire physical layer will look like a bit pipe, okay so bits go in bits comes out, so this sometimes they would be errors but this bit pipe encapsulates whatever the function that are necessary to convert bits which are abstract entities into actual voltages or currents or light waves which can then be transmitted over the channel.

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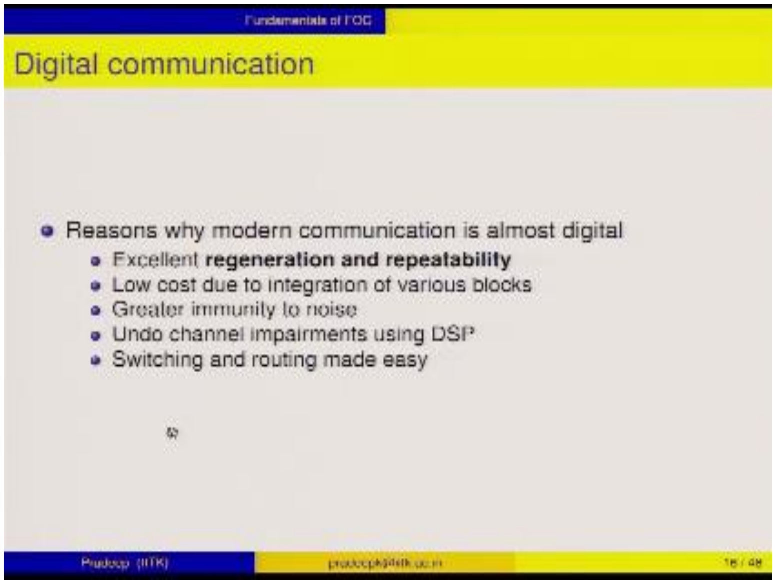

Now as I mentioned mush of communication happens today by digital means there are very few analog links that are available even the analog communication system such as AM and FM use analog only at the front end and at the back end, the remaining ends are all digital, okay so if you go to a AM station or a FM station only at the front end everything is analog the, and the transmitting and where your the wave forms are going as AM or FM, but once you have come to the actual circuits after the initial front end all the remaining circuits are all they are in the digital domain.

So why if it that everything has gone digital there are several reasons why it is so, one of the important reasons is that digital signals are immune to noise because they can be regenerated and this information can be repeated, so this regeneration and repeatability which are excellent for digital communications compute to analog communications makes it very attractive for us to work with digital communication systems, and there are various blocks that one can use when you are operating things digitally and they can be purchased at very low cost because they have been nicely integrated by the VLFI technology.

As I said this regeneration repeatability comes because digital signals have a greater immunity to noise the channel impairments can be easily you know we can easily undo the channel impairments using digital signal processing you can use all kinds of DSP algorithms very sophisticated and this algorithms allow you to overcome the channel impairments and switching and routing operations are very easy with digital communication system, they are very difficult with analog communication systems, they are very easy you can tag headers you can tag footers you can tag whatever that you want and in order to switch and route the appropriate bits or packets.

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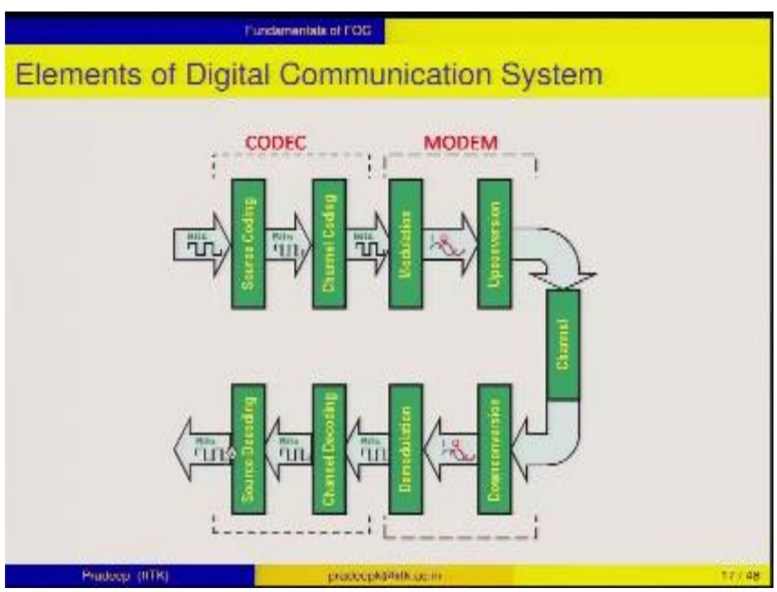

If you look at elements of digital communication system you will see a CODEC you know at the input side which consists of the bits, bits are coded in order to reduce the redundancy amongst them and then these bits are then further encoded in order to deal with the channel impairments which is called as channel coding and they have to be of course converted into a form that is suitable for transmission that can be performed by a modulation block and normally this block that you see after modulation has data in its base band as we would call this base band data must be converted into pass band using an up conversion process.

For example, this could be an electrical signal but my channel would be optical channel so I need to convert this electrical signals on to optical signal, so I can do that by up conversion process the channel will then carry the appropriate wave form at the receiver side you demodulate and recover back your base band signal which you then demodulate, sorry down convert and recover back your electrical signal use then demodulate you perform channel decoding source, decoding lots of performs and signal processing operations to recover your bits, okay.

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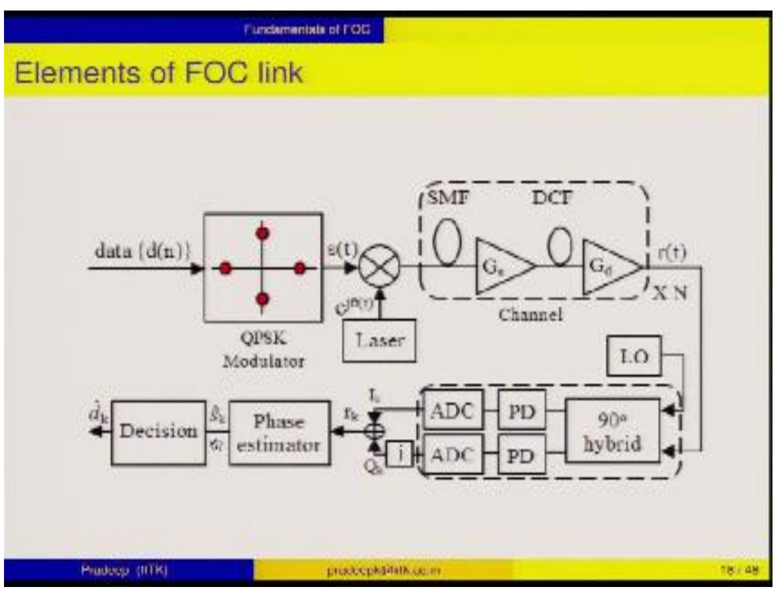

As I said this is just an optical fiber communication that could exists today this could be an example of 100 gigabits per second, single channel optical link, okay it is not an optical network at a single channel optical link.

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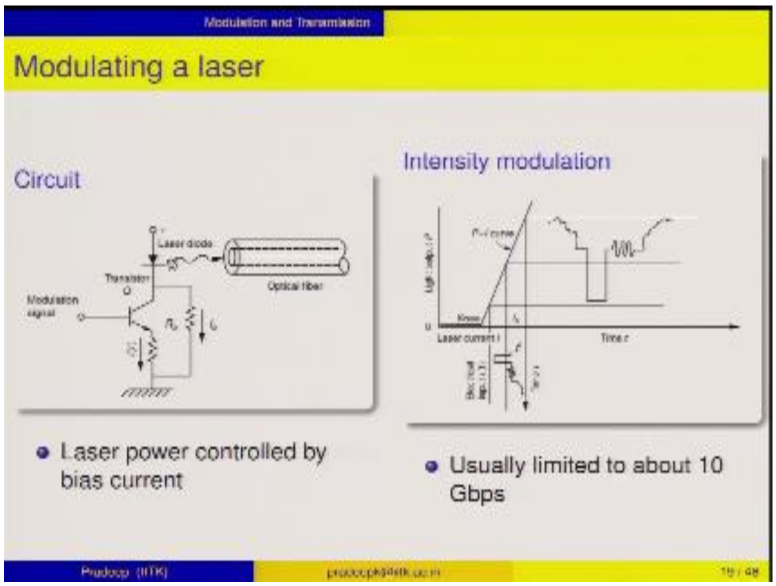

If you look at what is required to modulate this data you will see that you have a laser diode, laser diode normally emits lights which is continuous wave that is it is like an oscillator which is oscillating with the particular wave form however if you want to modify the characteristics of this wave form you need to modulate its amplitude, frequency, phase or any of this combinations, normally we modulate the amplitude and phase this is called as quadrature amplitude modulation.

If you simply choose to modulate the amplitude or equivalently intensity this is called as intensity modulation. What you would like to do well, I know that this is a wave form which I want to send let us say and I know this is the laser light output as a function of the current so imagine this as a diode and this electrical signal is driving the current, so if the current increases the volt, the light output power will increase if the current here at the input decreases the light power decreases, so whatever the variation that are happening at the electrical side will be carried over to the optical side, this is called direct modulation of the laser and this was the technology that was used in the first four generations of optical communications for data rates up to 10gbps.

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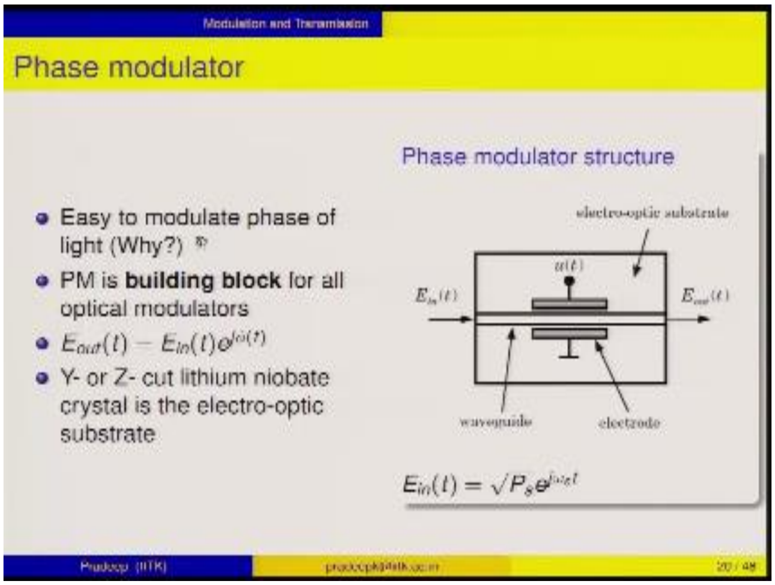

Now instant of using only intensity modulation if you want to pack in more and more data on to the same bandwidth you want to use modulators which can perform phase modulation, you want to modulate not only amplitude you want to modulate phase as well, so that you can put in more information and in some sense we will see later optical phase modulation is one of the easiest things to perform rather than optical amplitude modulation, okay.

So phase modulator is the building block including an optical modulator, so all external modulators include phase modulator as one of its unit, you can play your own with the phase modulator to come up with amplitude modulator structures as well. In today's technology Y or Z cut lithium niobate crystals are the substrates that are used for optical phase modulation, okay. we will study more about how phase modulation occurs and what is the physics behind this phase modulation as we go ahead with the other parts of the course.

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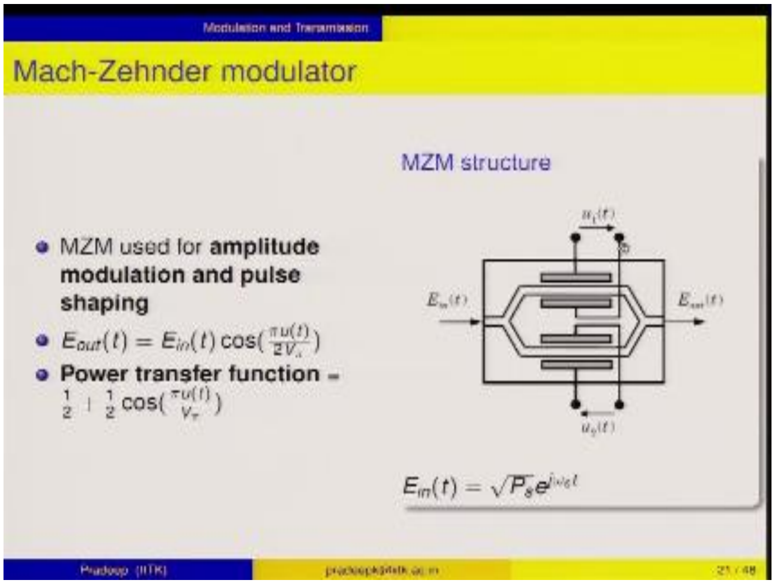

You can combine phase modulators put them together to form a Mach-Zehnder modulator which consists of two phase modulators you can see one phase modulator at the top, you can see one more phase modulator at the bottom you can drive it with two signal this is called as a dual drive Mach-Zehnder modulator, and the transfer characteristics of this which you can see here.

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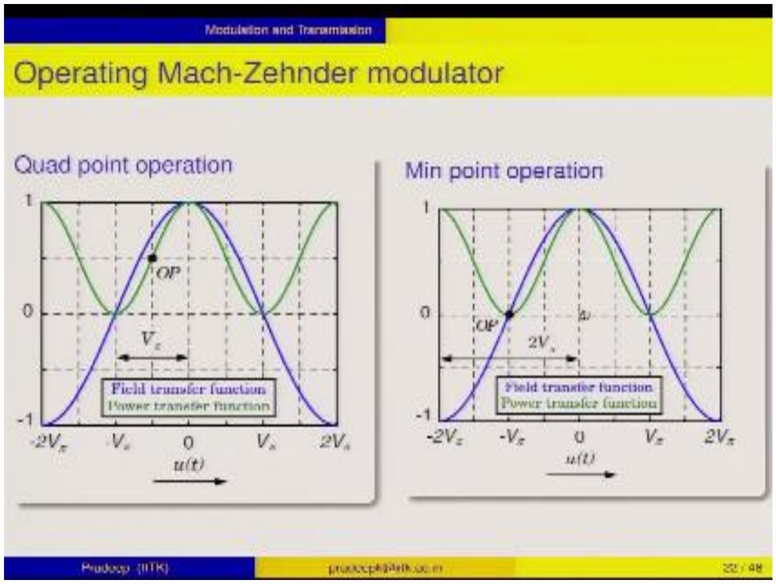

Shows that it is a non linear transfer characteristic but if you want to operate in the linear region that is if you what to send in analog signals you would like to operate this in the linear region which is called as the quad point operation you but your bios point at the dot that is shown here, if you want to operate digitally you operate either at the minima or at the maxima of the signal and then drive from minima to the3 maxima, okay. So this Mach-Zehnder modulator allows you to perform analog modulation as well as digital modulation, it also allows you to create pulses out of contentious wave light .that we will see later.

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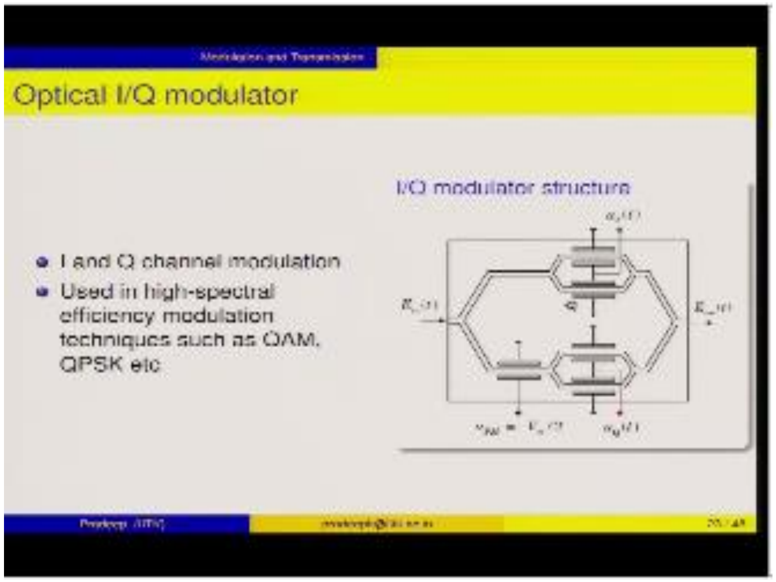

You can put together, to such mach-zehnder modulators and one phase modulator, in order to perform what is called as quaderature amplitude modulation, with quaderature amplitude modulation you are able to perform both amplitude as well as phase modulation combined together, okay.

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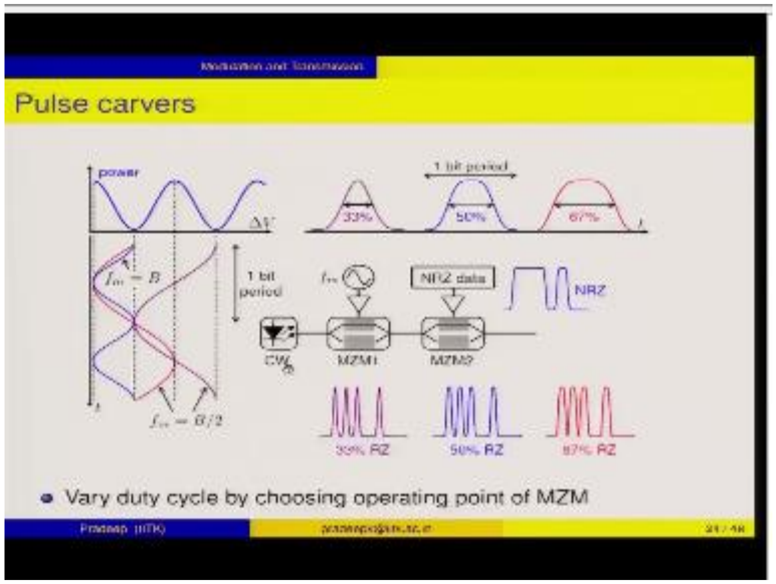

As I said you can use mach-zehnder modulation for pulse carvers various duty cycles or various area under the pulses can be archived, this is the 33% duty cycle, this is 50% duty cycle, and this 67% duty cycle for the way form, where in you send in the contentious wave signal and outcomes your pulsed wave form, okay. We will see how you can perform all this pulsed wave form or you can generate this pulses later as we go to the course.

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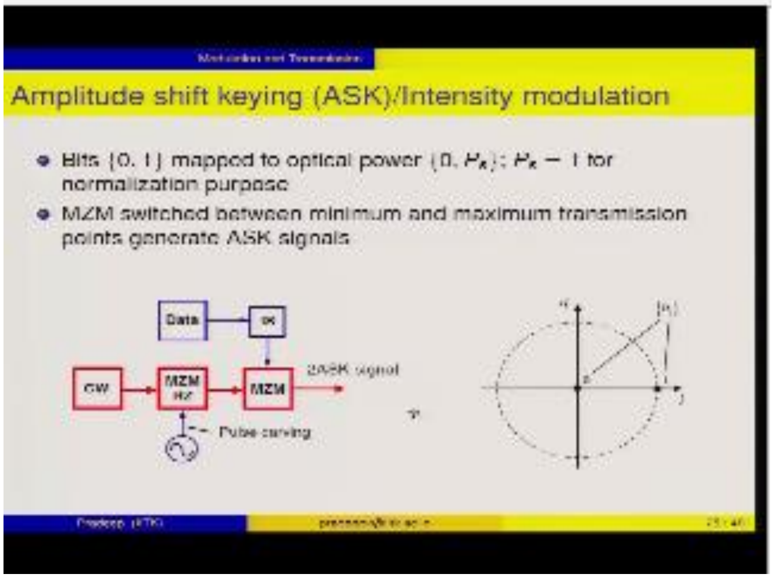

As I said you can modulate amplitude, if you simply choose to modulate the amplitude of the carrier this is equivalent of density modulation, you can either turn on the light source or turn off the light source, when you turn off the light source the amplitude of the light going is 0, when you turn on the light the amplitude could be something or the power could be something, we will normalized it and called this amplitude to be equal to 1.

So this is called as amplitude shift keying modulation this is inherently digital modulation, your data comes in the forms of 0’s and 1’s ,to send a 0 you send nothing ,to send 1 ,you send some amount of light for a short duration.

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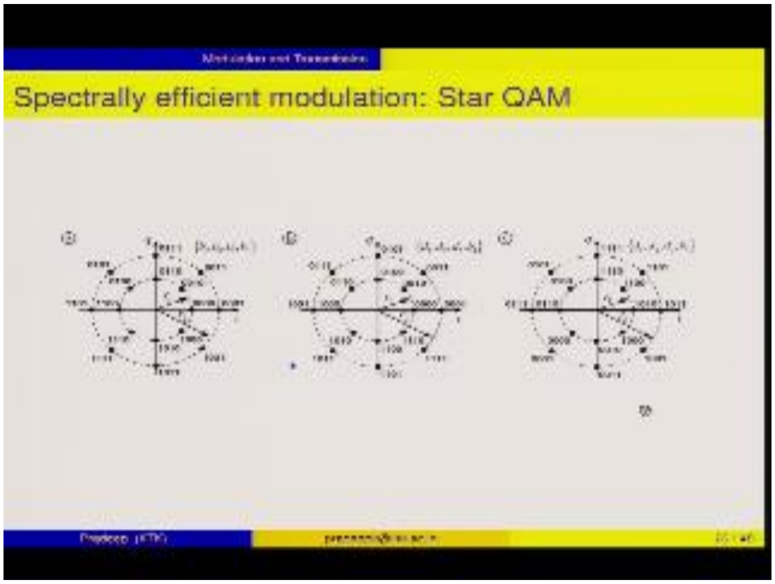

Specially efficient modulation would require you to modulate both amplitude and phase ,this is an example of a star quaderature amplitude modulation ,you can see that there are 16 states in this so there are 16 possible bit combination that you can transmit, if for example you want to transmit the bit sequence 1111 then you transmit an amplitude of some r2 at the same time you also have the phase of 90^0 , so this is the in phase access is the quaderature access we will come to that when we discuss modulation phases in the next few modules, okay.

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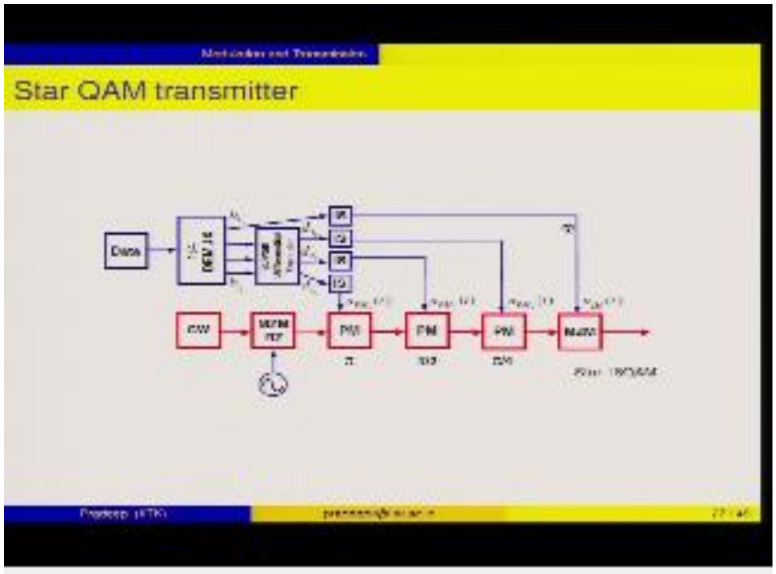

So this is an example of a transmitter.

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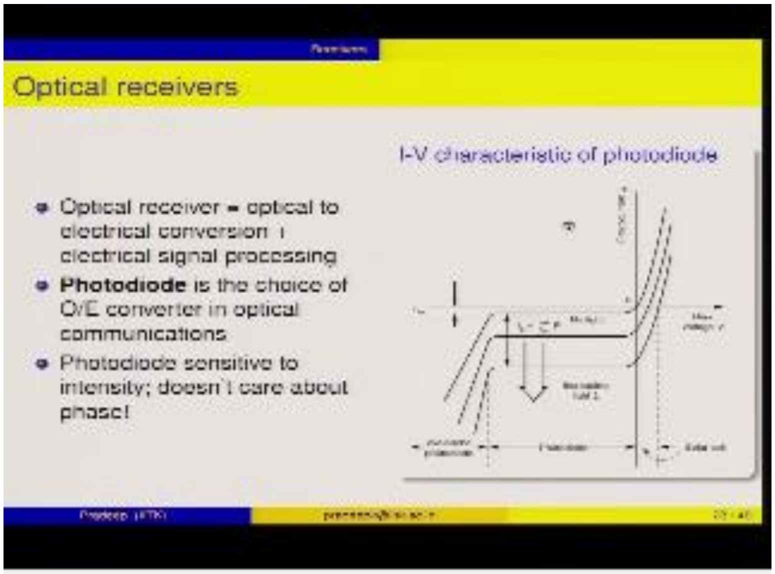

Now you come to receiver an ordinary PN junction can act like a receiver, okay, however if you want to make good qualities receivers, then you have to do some additional things to the PN diode, and do additional things are in the form of the structure, in the form of toping concentration, in the form of the structure, the device itself.

This entire thing we will discuss later the device which responds by changing its electrical current to the incoming light is called as a photodiode, and this photodiode will allow you to convert optical variations in to electrical variations, the fact about photodiode is that there only sensitive to intensity that don't really care what is the phase of the input signal, Okay and.

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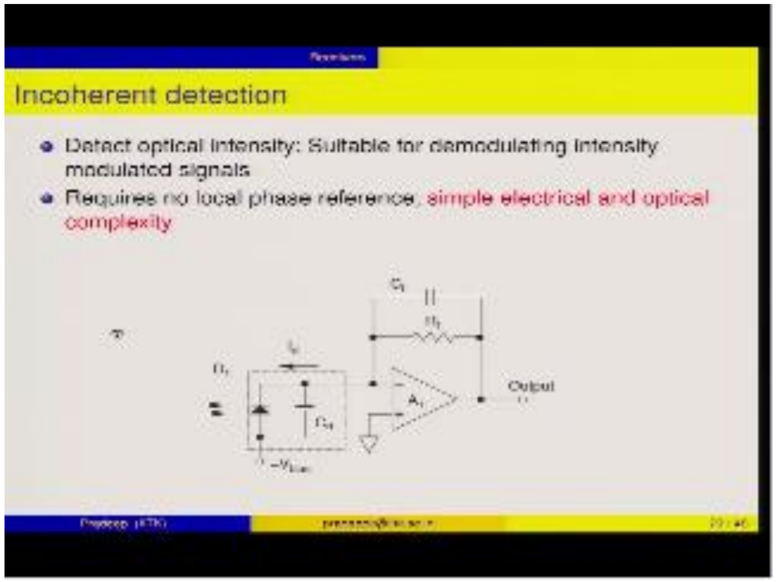

As such they can be used what is called as incoherent detection, in this method of detection which is also called as direct detection you are only concern with the optical intensity, so your data is coming in either some light pulse or no light pulse, and you put in the detector, if there is no input the detector will produce 0 ideally, and if there is some light pulse the detector will produce a certain current which will then be converted in to voltage and amplifier, okay.

There is no requirement of controlling the phase there is no requirement of controlling the polarization, everything is very simple this as the electrical and optical complexity, of course it’s not suitable for demodulating or detecting phase modulated systems.

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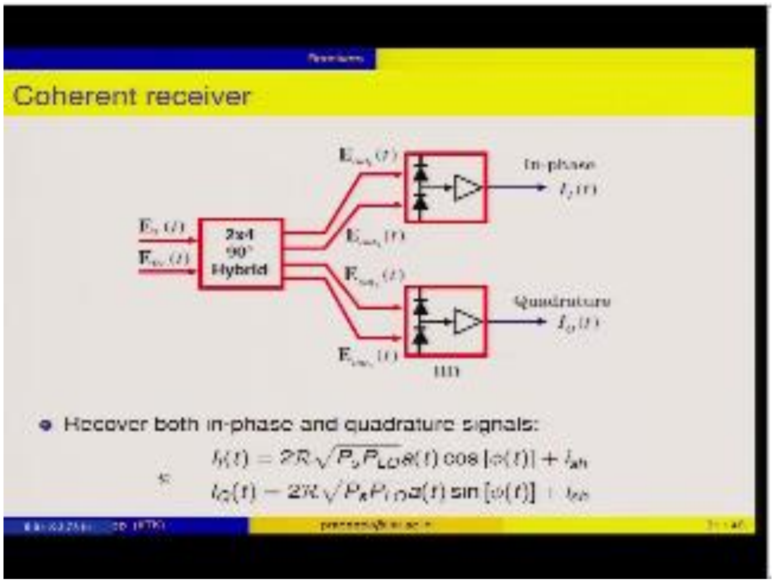

So in order to detect phase from the incoming signal, you have to use what is called as a coherent receiver, a coherent receiver is the one which mixes the incoming signal which have represented as Es with the local oscillator signal E_{lo} and after a mixing you put them through, the photo detectors take the difference in the photocurrents and then amplify it.

You will be able to recover both the in phase as well as quaderature components of course when you recover the in phase and quaderature components also going to look at some noise in the receiver system and that noise will be part of your detected currents. The information that you have transmitting resides in the amplitude A(t), and in the phase I(t) ,both can be recovered by this coherent receiver.

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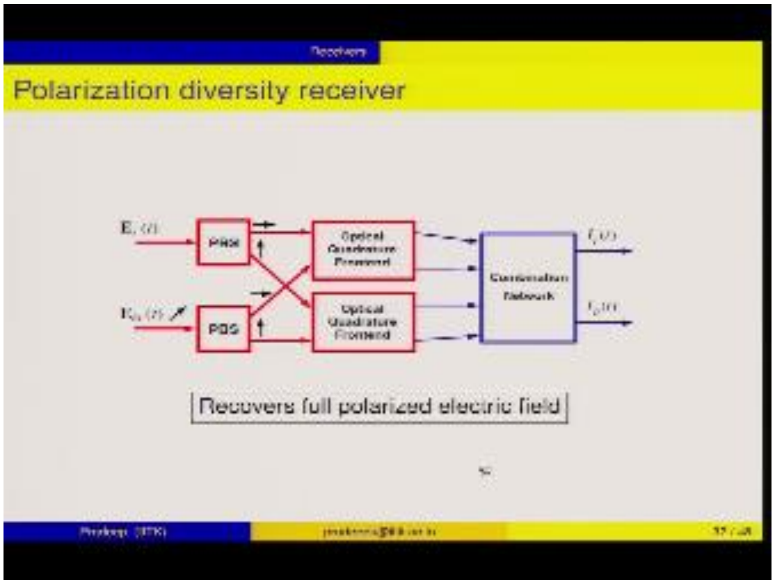

You can do one step better then a coherent receiver, you can split the incoming signal in to two parts because we will later learn that fibers can support two polarizations and it is criminally wasteful to just waste one polarization, so we normally modulate both the polarization degrees of freedom.

You can recover this entire polarization of the incoming signal by splitting the input signal into its respective or polarized components mix them with the local oscillator component, which is again split into to two or tonally components, and perform IQ de modulation at the two ends and then combine appropriate to obtain the full polarized electric field. So you have got a full information about whatever that has been transmitted.

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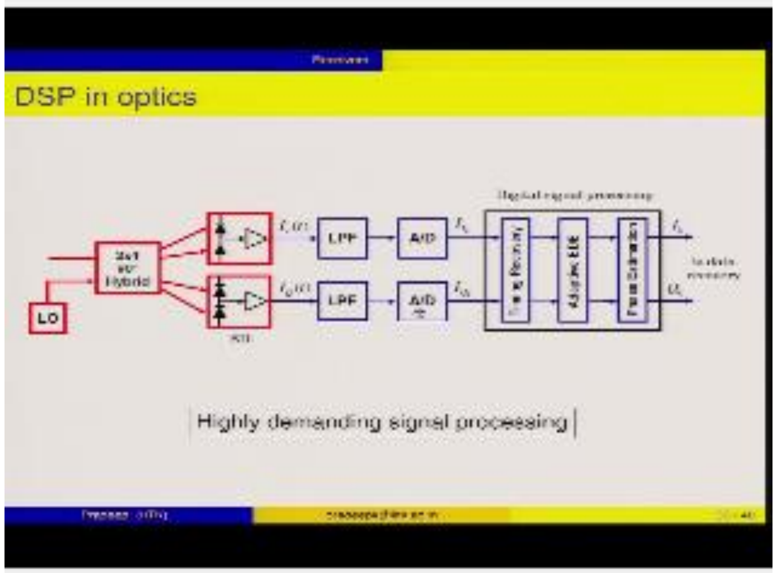

As a final point, I would like to tell you that this process by which opening the currents ,by in phase and quaterature currents are not the end of optical communication systems ,infect for high data rate system that is just the beginning ,from here you perform low pass filtering in order to remove some noise and other components at a lot of interest ,then you convert this contentious time signal into discrete time signal by sampling them through a high speed analog to digital converter ,once this samples are available you can then perform operations such as timing recovery, adaptive equalization ,you can perform phase estimation in order to obtain the carrier in order recover the carrier phase. You can do all this by using highly sophisticated digital signal processing algorithms, okay.

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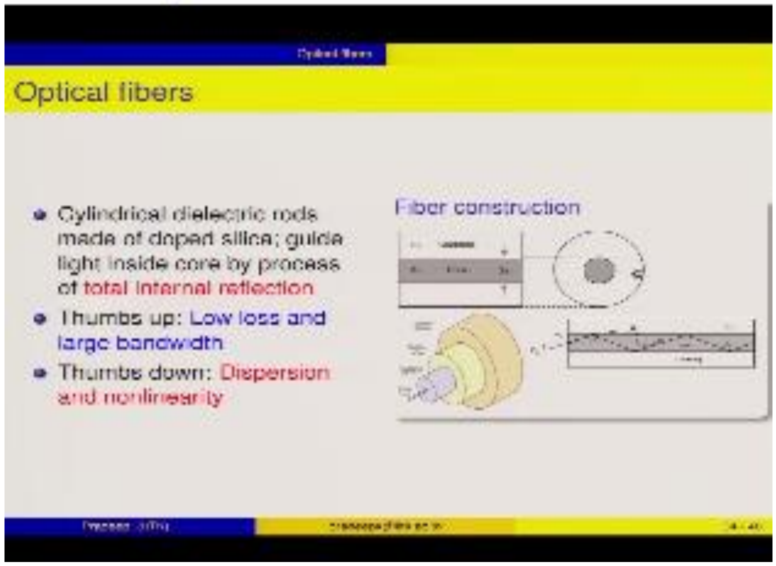

The next and the last part which i would like to show you now, is the optical fiber in a optical fiber is the guiding layer which allows you to take data from one point to another point, in its impressed structure an optical fiber consists of a cylindrical core and a cylindrical cladding that is surrounding, the core has the higher refractive index, the cladding has the lower refractive index, and light in a very simplified analysis can be considered as in guided by total internal reflection.

What are the good things about this optical fiber, the optical fiber has no loss and large bandwidth ,however two impairments which are common to optical communication systems because of the fibre are ,dispersion and non linearity, so we will spend some time discussing dispersion and non linear compensation schemes.

If you look at the structure of a single mode optical fiber, the core diameter is around 8 micron or the core radius is around 4 micron, the cladding is standardize to 125 micron, covering the cladding is the buffer 250 micron and finally the jacket at around 400 microns, okay.

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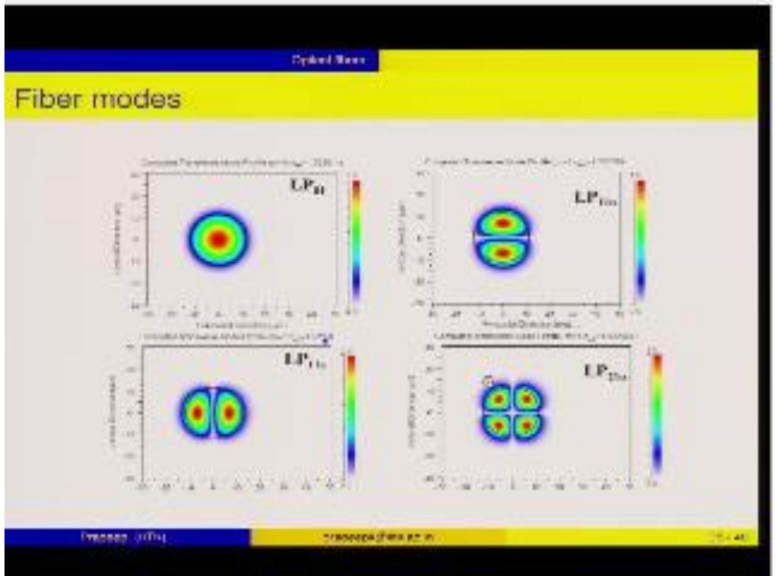

So these are some of the modes in the optical fiber when you send light, light arranges itself in this fashion the intensity here is at the centre is maximum, the intensity keeps dropping as we move away from the centre in this mode this is the fundamental mode this is called as LP_{01} mode, then you have higher order modes which are all the different pattern which selected fields can be found inside an optical fiber. We will discuss fiber modes and tell you how to obtain these beautiful colored pictures later in the course.

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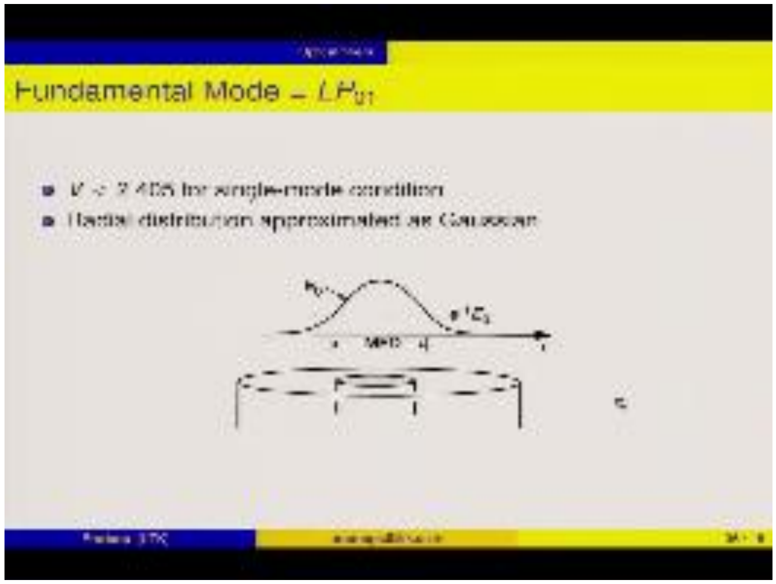

This is the fundamental mode as I said the core has its larger intensity and the intensity of the light starts should drop of as you move away from the core, the effective content of the energy inside the core is measured by what is called as the mode field diameter, which is the distance over which the light is concentrated by its height is higher than 1/E, so it’s around 90% of the power is concentrated inside this mode filled diameter of the fiber.

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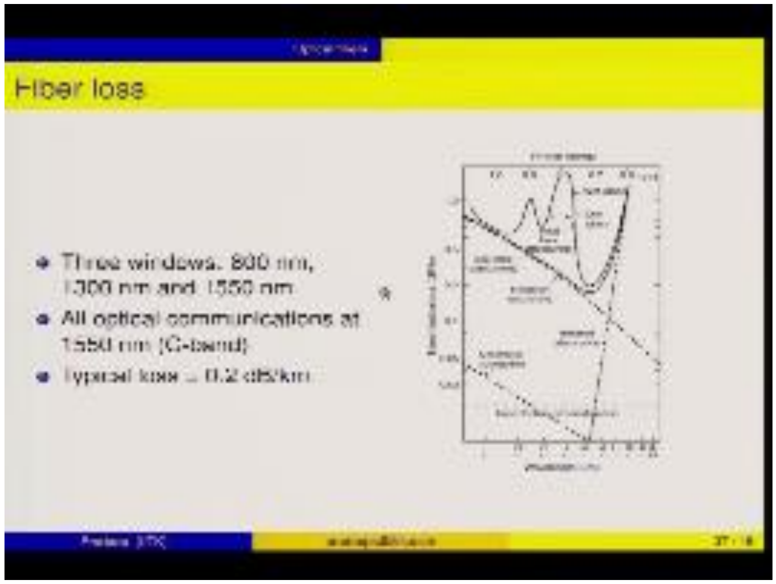

So earlier transmission of optical fiber happened the first generation happened 800 nanometer because the loss here was at its lowest then came 1300 nanometer window which is this one ,and sorry! This is the 1300 nanometer window and finally you have the window at 1550 nanometer which is the lowest loss, and the typical loss in fiber on 0.2dB/km.

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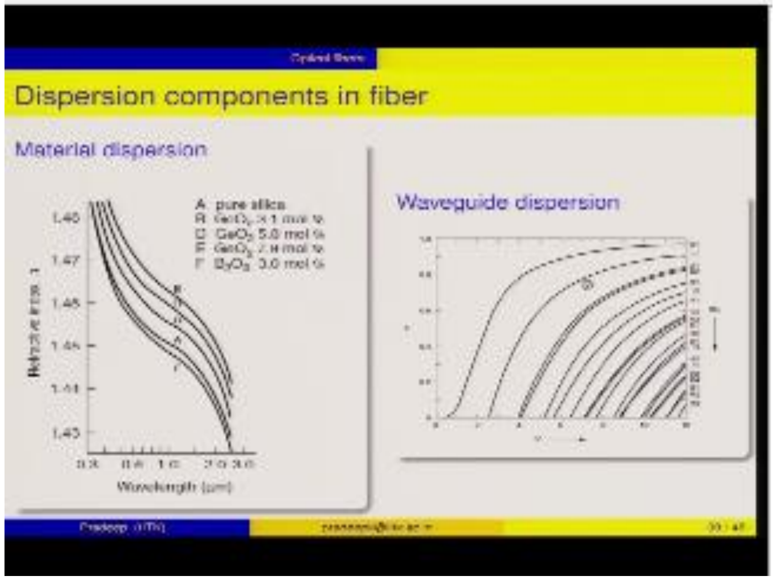

As I said dispersion is a major impairment in the fibers there are two kinds of dispersion, one is called as material dispersion this occurs because of the silica molecules, and then there is waveguide dispersion which is because of the cylindrical construction of the optical fiber. The total dispersion is the sum of these two and for standard single mode fiber.

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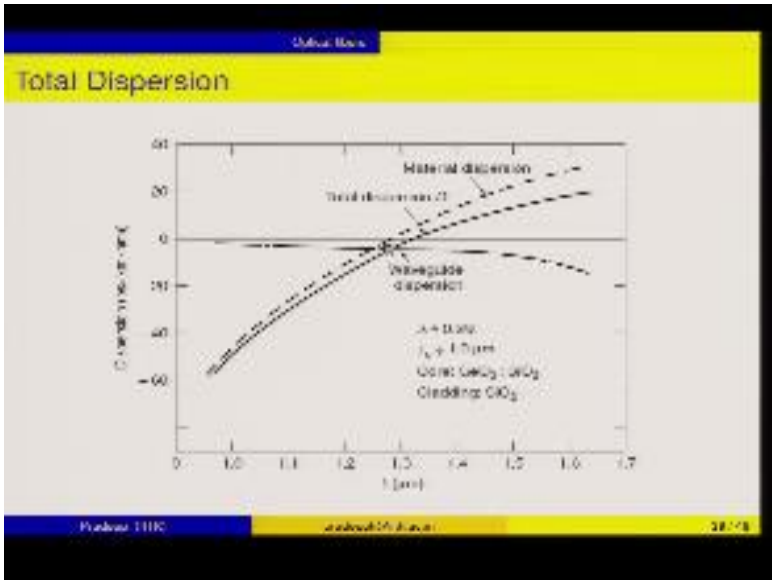

Zero dispersion occurs at the 1300nanometres however this dispersion can be move the zero dispersion windows can be moved to 1550 nanometer by appropriate dividing the material dispersion.

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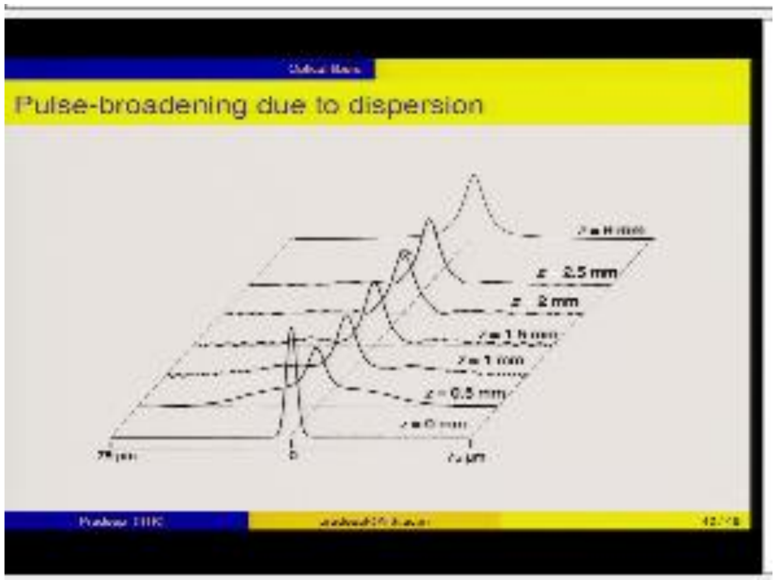

What is the effect of dispersion? The effect of dispersion is to basically broaden the pulse, as the pulse start to spread, no as the pulse starts to propagate to the fiber it starts to broaden, why should be care about that pulse? You are not going to send only one Pulse you will be sending one pulse immediately to will be sending one more pulse, it is a certain distance between the two, so if the first pulse spreads out and then you know occupies the slot for the second pulse then the second pulse and the first pulse will talk to each other, and then you will not be able to recover which pulse corresponds to what.

So you will actually have what is called as inter symbol interference, one symbol is interfering with the other symbol and finally optical fiber at.

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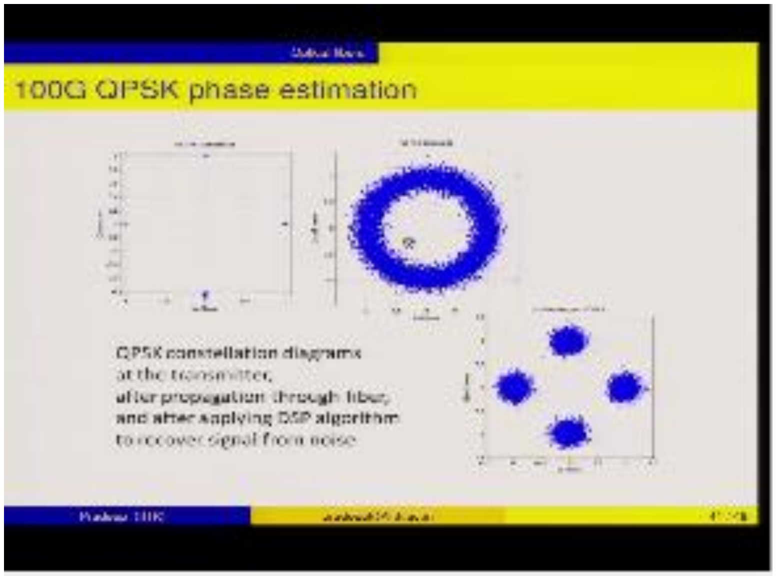

Low launch powers low optical powers are very good linear channel, however this linearity is lost as soon as you start pumping in larger optical power, because an optical fiber itself a very small structure you know the core diameter is 4 micron the power density, even if you put just 1 mille what the power density inside an optical core is very high and that will give raise to non linear effect.

One of the major impairment of this non linear effect to disturb the phase of the input or the transmitting signal so at the transmitter if you have this constellation we will talk about what will constellation in the next module this constellation gets degraded as it propagate to the fiber and you can almost make out nothing from this but this can be restore by some good digital signal processing algorithms in order to I mean from the good digital signal processing algorithms to recover what you have been transmitting.

So this is an example of a 16.phase estimation again you can see that you can almost distinguish nothing here in the middle diagram and then you can recover almost all of the symbols that you have transmitted after performing digital signal processing.

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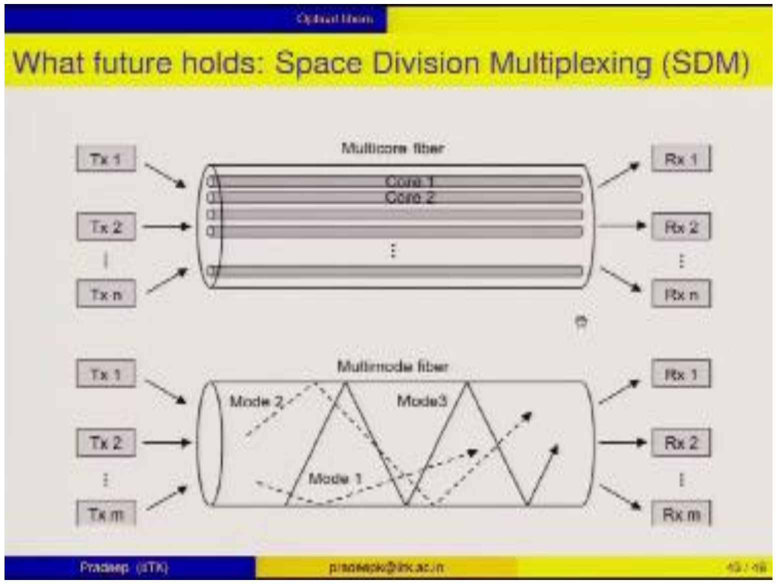

In future or it is almost already current people are looking at multi core fibers where there are multiple course data can be introduce in to each core it is like multiple antennas at the input and the multiple receivers at the output end you can also use a multi more fibers and launch light in the different modes of the fiber okay.

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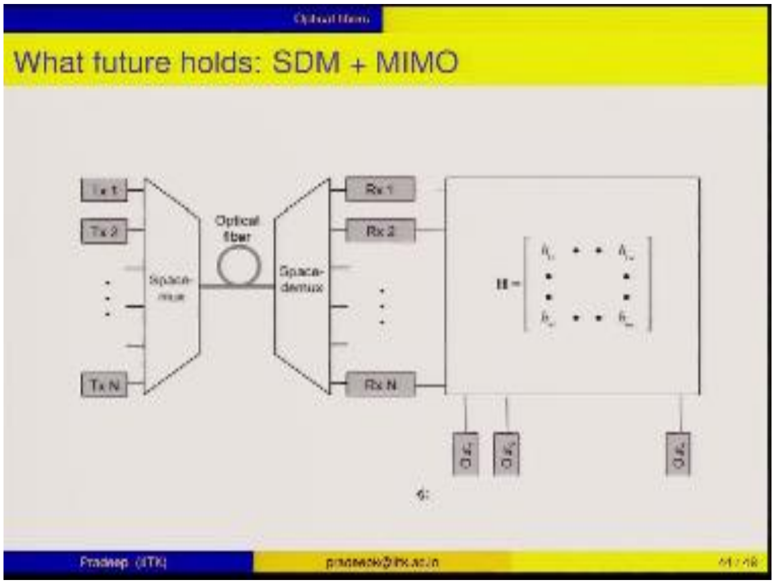

And you can combine them with proper digital signal processing algorithms to form what is called a SDM MIMO SDM stand for space tuition multiplexing and MIMO stands for multiple inputs and multiple outputs.

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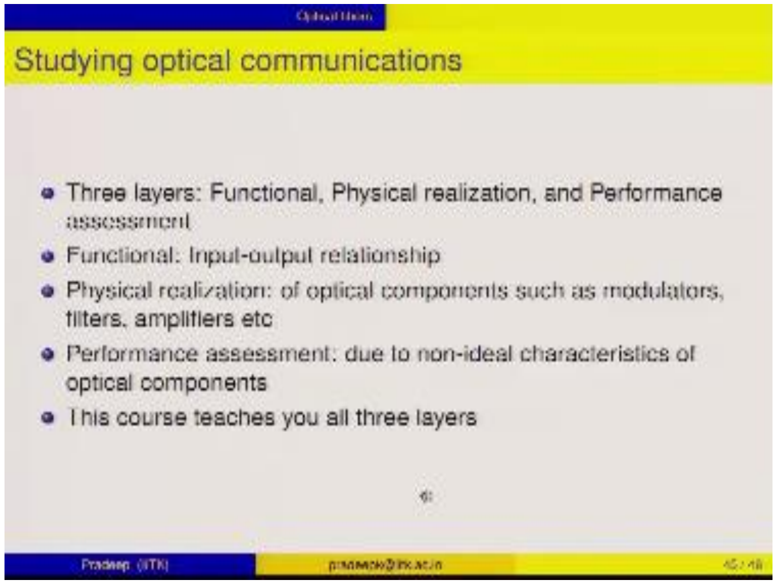

If you want to study optical communications you have to understand 3 layers one at the functional level you want to know what a functional blocked does what does the modulator do what does a laser do what does it input characters take it what does it output characters take what should I feed in to control this then you have to know how a laser is made how a modulator is made how a photo detector is made what are the things that can go wrong when you make them.

So you want to perform you want to assist the performance of this optical elements when they are placed in the appropriate optical communication links we understand functional realization and performance assessments in this course by first focusing on the functional then talking about the physical realization and finally putting them together to unsets the performance of this blocks.

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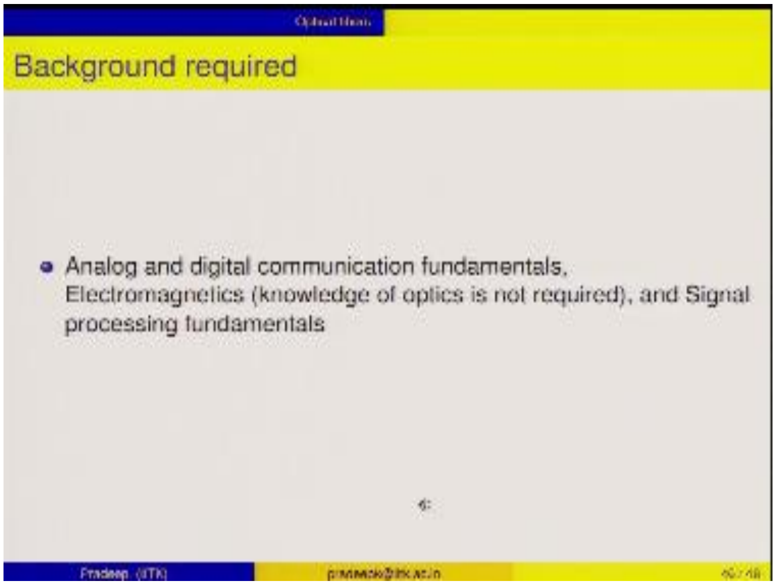

What background if required for a good for taking this course and to extract the maximum benefit out of this course I assume that you are familiar with analog and digital communication basics I will review some fundamental of digital communication and analog communication but remember this is just a review I would appreciated if you would read up analog digital communication fundamental before listening to these lectures I also assume that you have taken electromagnetic.

You do not have to know optics I will teach you whatever the optics that is necessary electromagnetic at the level of introducing you have maximum equation is what I assume so I hope that you would brush up that part and you should also know little bit about signal system and digital signal processing fundamentals I will cover all these topics as and when they are required but my coverage will be slightly rapid because my focus is not on this my focus is on how they can be apply for optical communication system.

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The course plan that I am following will be to first talk about optical fiber communication we have already talked about that then I will talk about some digital communication fundamentals some line coding pull shaping which is common to both analog and digital communication systems we will talk about optical transmitters optical receivers lasers optical amplifiers optical fibers and fiber modes what are the WDM components like multiplexers filter arrived wave guide gratings fiber brag grating all those thing we will talk and finally we will talk about DSP in optical communications for most part of this the text book that I would following.

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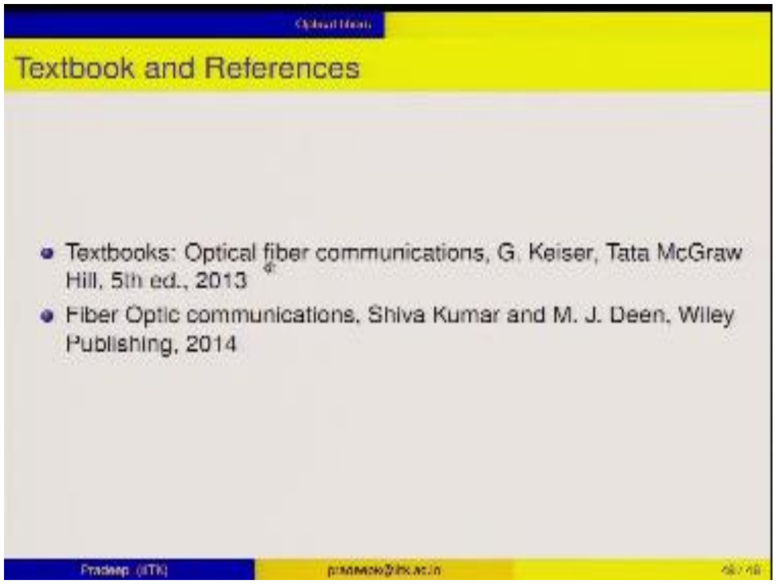

Is optical fiber communications by Keiser of fifth low cost addition is available in India and there is another book I would follow to time to time I will let you know when I am following the text book if fiber optic communication by Shiva Kumar and team this unfortunately to my knowledge does not come in a low cost paper bag addition so with this I close this module and I look forward to discussing some fundamentals of analog and digital communications and then moving on to the functional description of the optical transmitter blocks and how optical communication can be use to perform analog and digital modulation, thank you.

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