Computer networks
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Fiber Optic Components
Lecture -10

Good day. Today, we will be speaking about fiber optic components and fiber optic communication.

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His lecture as well as the next couple of lectures will concentrate on fiber optic components. We have looked at some of the physical layer components of fiber optic systems before, so we will quickly review that. Some of the stuff we will be talking about today is going to be common and then, from that point, we will take up WDM systems, details of how wavelength division multiplexing is done and how systems are handled in fiber optic domain. The fiber optic domain happens to be very crucial because a lot of traffic in terms of volume may be as much as 40–50%, actually follows the fiber. As days are going by and as more and more demand for bandwidth is coming up, fiber optics is becoming more and more important. So we will be talking about fiber optic components today.

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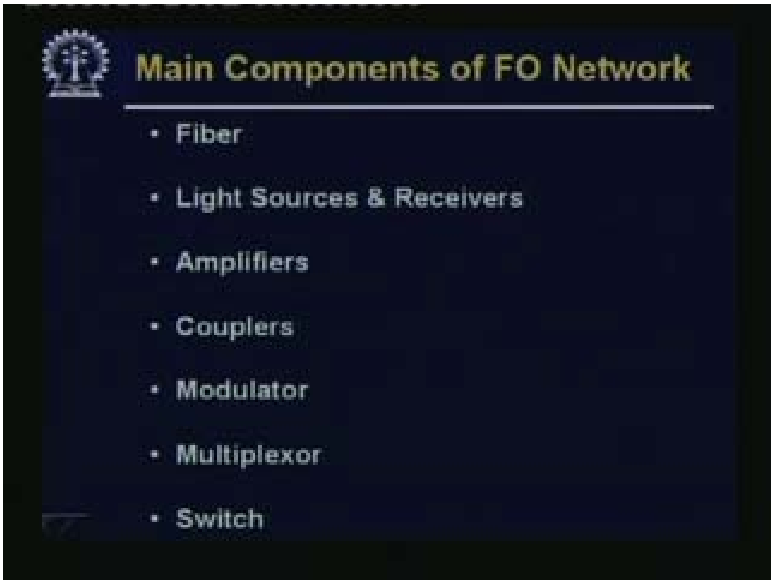

So in fiber optic component, of course, the basic fiber is there; we have already talked about it, so we will talk little bit more about this. Then we have light sources and receivers on two ends because we know that in fiber optic cables, light are the carrier of information. Then we require these different components like amplifiers, couplers, modulators, multiplexers and switches. So we will look at these components one by one. Then we will start our discussion on wavelength division multiplexing.

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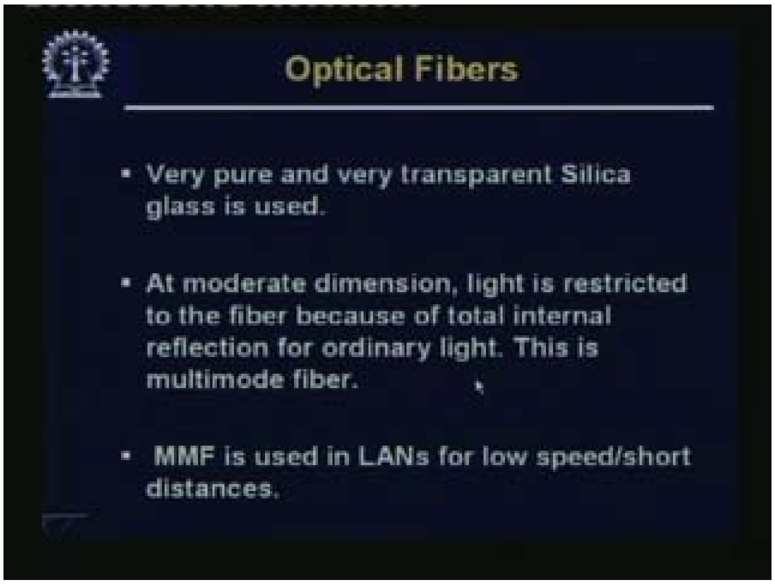

So optical fiber as mentioned earlier is very pure and very transparent silica glass is used. At a moderate dimension, the light is restricted to the fiber because of total internal reflection for ordinary light; this is a multimode fiber. MMF is used in LANs for low speeds or short distances. MMF may be used in LANs; that is another kind of fiber. But the multimode fiber happens to be the cheaper variety and this is used in LANs, but this is good only for low speed. When I say low speed I mean comparatively low speed, for this say 100 mbps or 155 mbps may be a low speed and by short distances may be couple of kilometers at the maximum.

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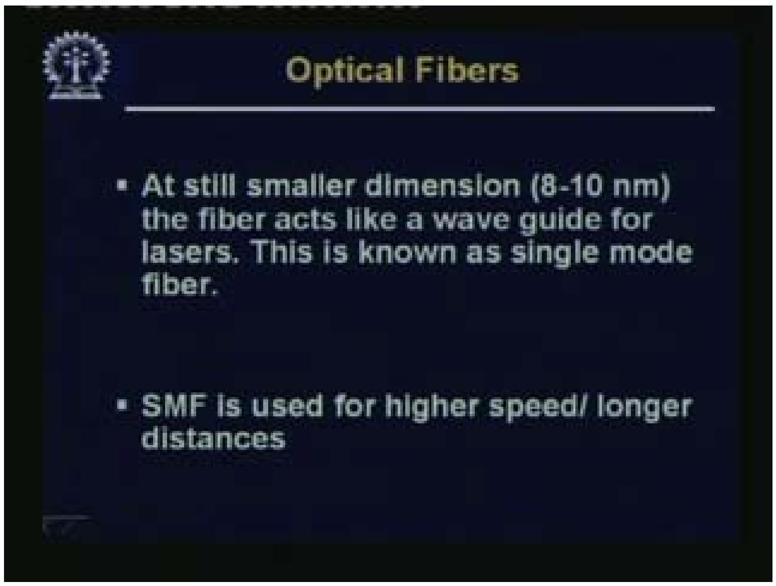

At a still smaller dimension, that part of the fiber that actually carries the signal – if you remember our discussion about, the fibers in physical layer, we have shown some diagrams regarding the cross section of a fiber, so at the very core – is a very thin strand of glass fiber. This is surrounded by a cladding, which is also made of glass; actually, we will not be able to see the actual part of the fiber, which is carrying the signal. The surrounding is also made of glass and that is again coated or covered etc., by outer protection. So if that strand happens to be even smaller, say 8 to 10 nanometer range, then it acts like a wave-guide and a single mode of operations.

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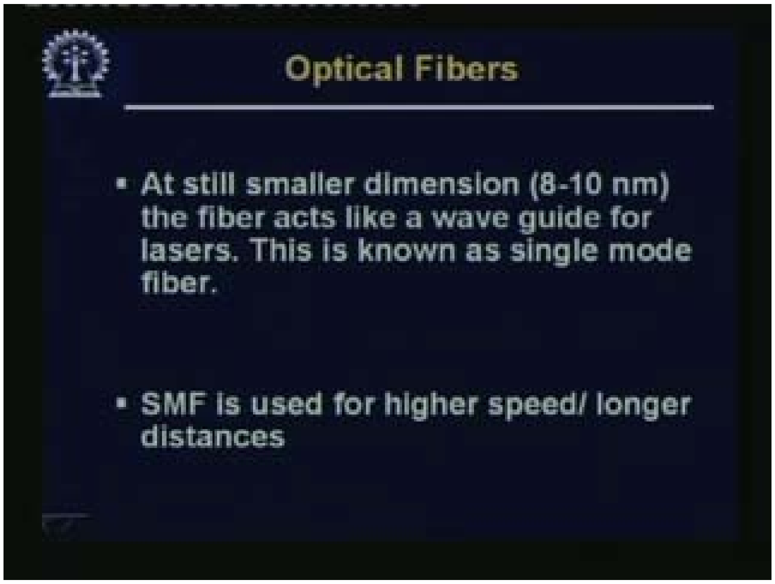

We will not go in details of Electro Magnetics and wave-guide propagation of optics to this fiber, but any way, the support of the single mode of propagation is called single Mode Fiber. SMF is used for higher speed, so all these speeds of 2.5 GB/sec or 10 GB/sec etc., are possible on Single Mode Fiber and it also goes over longer distance and nowadays, we have fibers, which span across oceans. We have fiber from one continent to another, which is really a marvel of engineering and technology. So these fibers are actually single mode fibers. There are a few transmission windows like 1310 and 1550 nm bandwidth etc.

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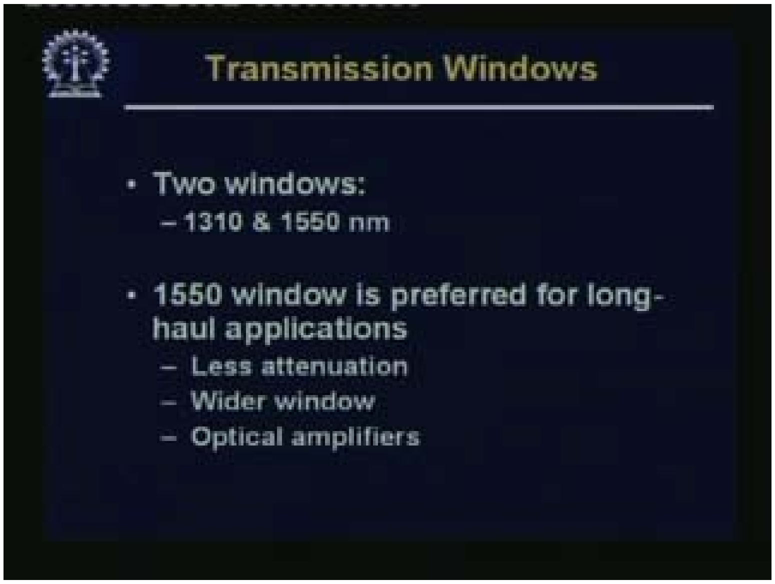

1550 nm window is preferred for long haul applications because it has less attenuation, wider window, and we can get very easily get good optical amplifiers in this range.

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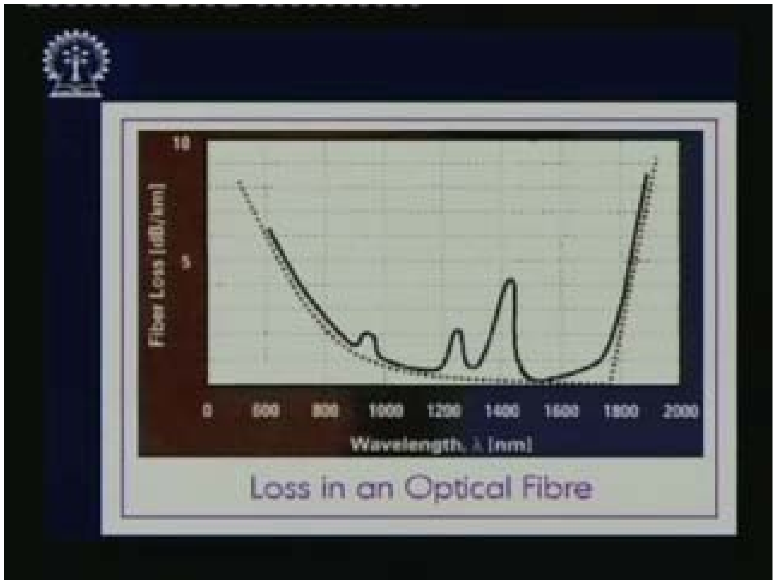

This is the diagram you have seen before, so you will see that at around 1550 nm range, we have some kind of low attenuation. Similarly, 1310 nm is another window, but this window is quite wide. Although it may not look very wide in this diagram, in actual practice, this is quite wide. So this is the wider window and we get good optical amplifiers. We will come back to this point when we discuss optical amplifiers.

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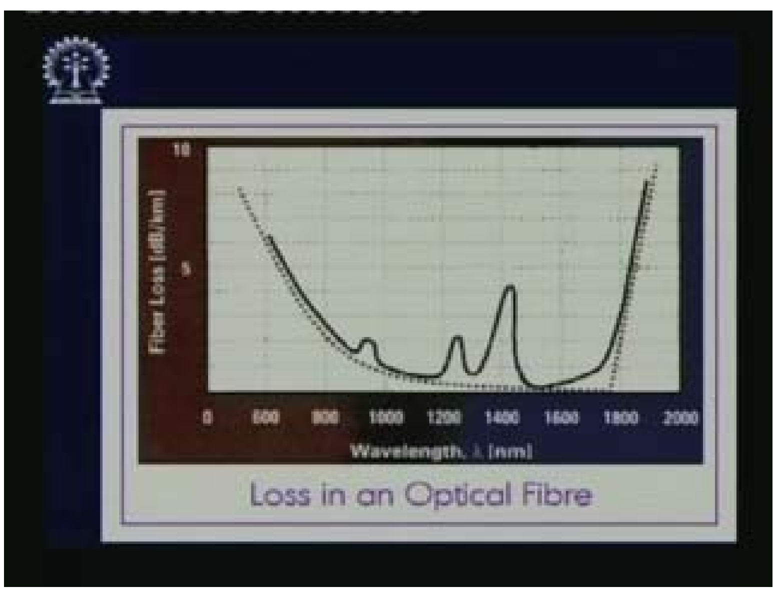

Why do we require optical amplifiers, because there are losses in fiber, may be due to various reasons: One, of course, the main thing is absorption. That is what we showed in the previous diagram; it loses energy to the atom and absorbs some of the photons. So we get lower magnitude or lower strength of the light signal, as we go to longer and longer distances. Then there is scattering of photons by the medium. So there is Rayleigh scattering, due to slight changes in the refractive index of glass; then there is Mie scattering due to imperfection of the cylindrical structure, it's made to rigorous specification, but it's never exact in the engineering world – it can never be exact. So we get all these different types of scattering, absorption, etc., leading to losses in fiber.

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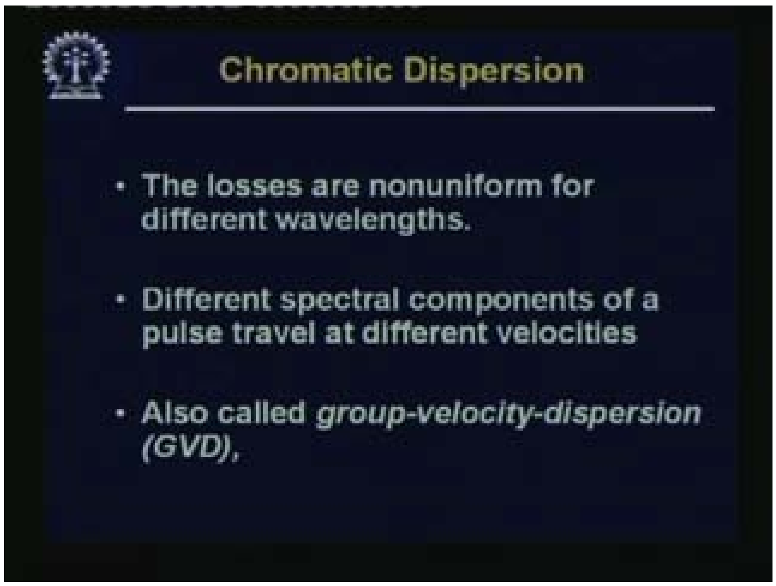

Apart from these just lowering of signal strength, one problem is that the losses are in no uniform for different wavelengths. The loss may be more for one particular frequency and may be less for another frequency. The trouble is, when you take a waveform, specially a digital waveform, which is a square waveform and if you analyse it, you will get a lot of spectral component. If you do a fuller transformation on that, you will get the different harmonics or components of that particular wave shape. And for the perfect square shape to come up, these different harmonics have to be at specific strengths compared to each other. Due to differential losses at different frequencies, what would happen is that their balance would get disturbed. What you will actually see is that your pulse shape has changed.

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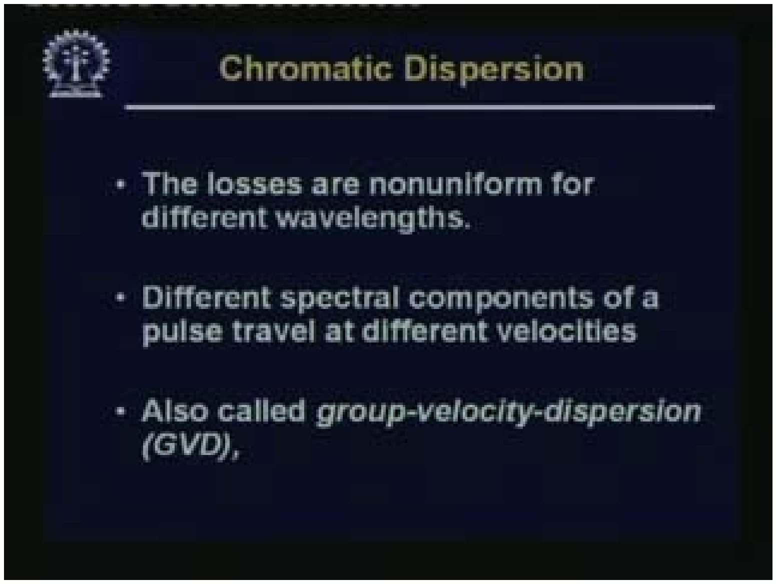

This is known as chromatic dispersion – chromatic because it depends on the wavelength or frequency, or the color of the light that is why it's called chromatic. Different spectral components of pulse travel at different velocities. This is another problem and there is something called group velocity dispersion. We get some kind of velocity for all these different components and this leads to some kind of dispersion.

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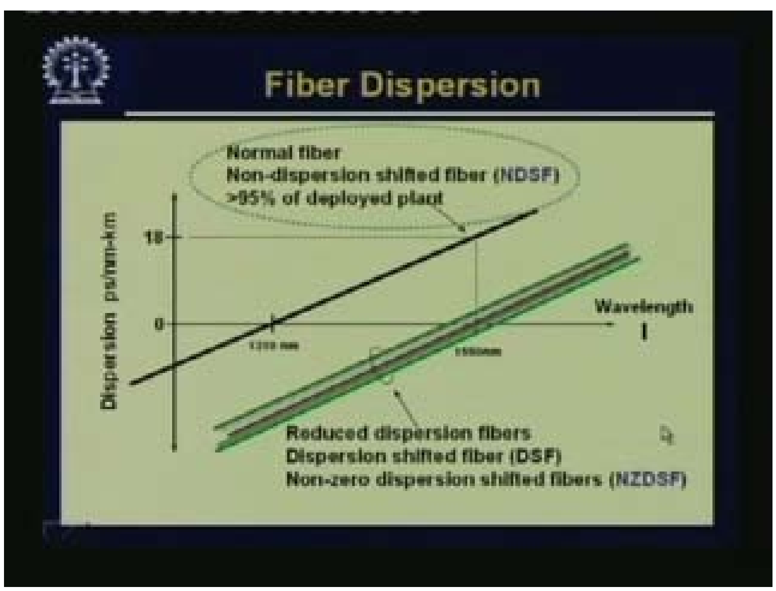

So this is an example of chromatic pulse – we need not go into the details of this, but this is the input pulse whereas in the output pulse, it has a much more flattened shape because these different components have been attenuated differently as they went along the fiber.

For compensating these dispersions, nowadays some special types of fibers have come up; we cannot go into details of these – one is the reduced dispersion fiber. By dispersion-shifted fibers, we mean the natural dispersion that is sort of acted on nonzero dispersion shifted fibers. Anyway, the point is that normal SMF is there in most of the places, say, more than 95% of the deployed plant. Dispersion is measured in pico second per nanometer kilometer; so dispersion is much lower. For some of the interesting areas or the window, we get an almost zero dispersion for these fibers. So we can get very special fiber these days, which may be utilized for very long haul applications, where dispersion becomes a problem. By the way, for short haul- applications, when you travel through a few kilometers, then the dispersion is not much of a problem and we need not bother about dispersion shifted characteristics of the fiber because in ordinary fiber, whatever the dispersion it gives in that small distance, will not matter so much.

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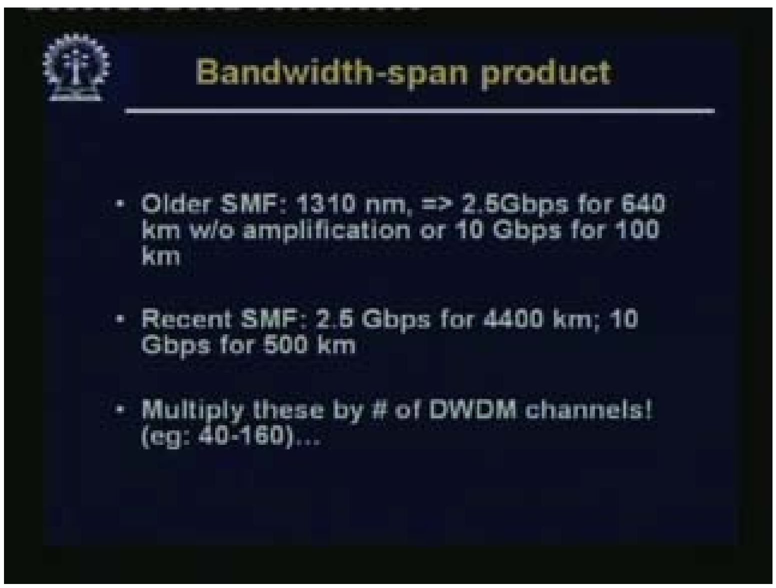

We have a bandwidth span product; that means, how much bandwidth for what kind of distance. This is very common in almost all kinds of transmission lines. So a transmission line, which operates at a particular speed quite well for some distance, will not operate that well if you either increase the rate at which you are pumping in the data (increase the frequency) or if you keep the data rate constant and increase the length. That would also not work very well. So for any kind of medium, we get the bandwidth distance product, which tends to be more or less sort of constant. A fiber, which is good for at a particular speed for 2 kilometers, may be just good enough for 1 km when you double the data rate. For older kind of SMF at 1310 nm, we get high speed – these are some typical figures, they are not exact figures; these are some typical figures to get some ideas. So we can operate at 2.5 gb/sec for 640 kms without amplification, or 10 gb/sec for, let's say, 100 kms. A decent SMF can take up to 2.5 gb/sec for 4400 kms, which spans from one continent to another or 10 gb/sec for 500 kms.

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Of course, you should multiply these figures for DWDM. We will talk about WDM presently, where it gives you a large number of channels, may be 40 channels. So you can see that you can realize really tremendous data rate, very high data rate, using this fiber optic communication and that is the major advantage of fiber. There are, of course, other advantages like you are not susceptible to electromagnetic radiations; that is one good thing because nowadays with so many gadgets all around and so many things moving around, we get all kinds of very noisy electromagnetic ambience; but fiber is immune to all that. That is the good point about fiber.

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Next, from fiber, we come to light source that is the LED. Light source is of course of two types, depending on whether we are using multi mode fiber or single mode fiber. Usually, we would use ordinary light in a multi mode fiber and the source of the ordinary light would be LED. One good thing about the LED is of course that it is very cheap. So the good thing about multi mode fiber is that it is cheap; the only thing is that it will not scale up very well with that bandwidth distance product. An LED is just a forward biased pn-junction; what happens is that recombination of injected minority carriers by spontaneous emission produces light and it is a broad spectrum up to gain bandwidth of the medium; so that is an LED.

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It is usually of a low power. You remember that for power you have to divide it by time. Although you might get a continuous source of light, it will be comparatively low power like 20 dbm, of low internal modulation. So you can internally modulate it. with hundreds of mega bits/sec, which of course, for some applications, may be more than enough speed. But then again,, when you are talking about the core of wide area network, then it may not be very low speed. So obviously, in the core of a wide area network, we will not be using multimode fibers or LEDs. LED slicing is LED plus a filter. It gives some power loss; we need not bother about that at the moment.

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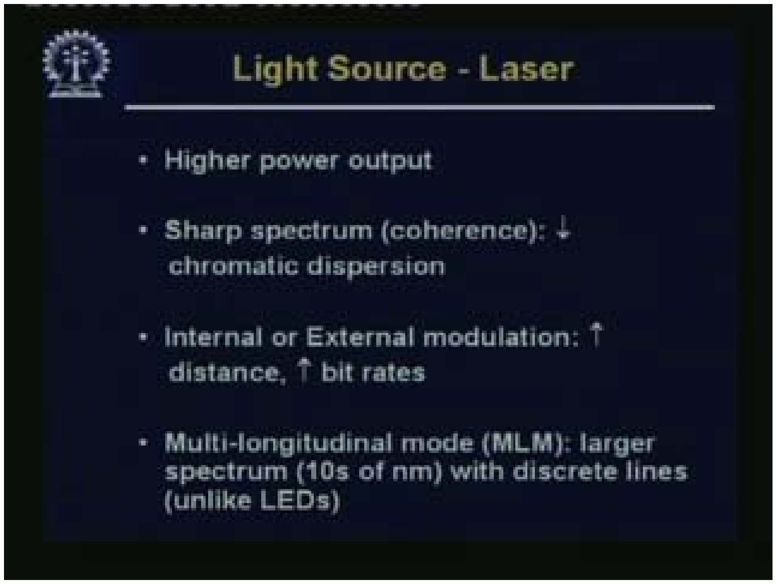

The other kind of light source, which is very important, is the laser; of course, we use semiconductor lasers here almost always. It gives much higher power output. So in a short duration of time we get quite intense pulses of light. That is very good; it has a high power output; it has got a sharp spectrum; it is coherent; that is, it is not at the wide range of spectrum.

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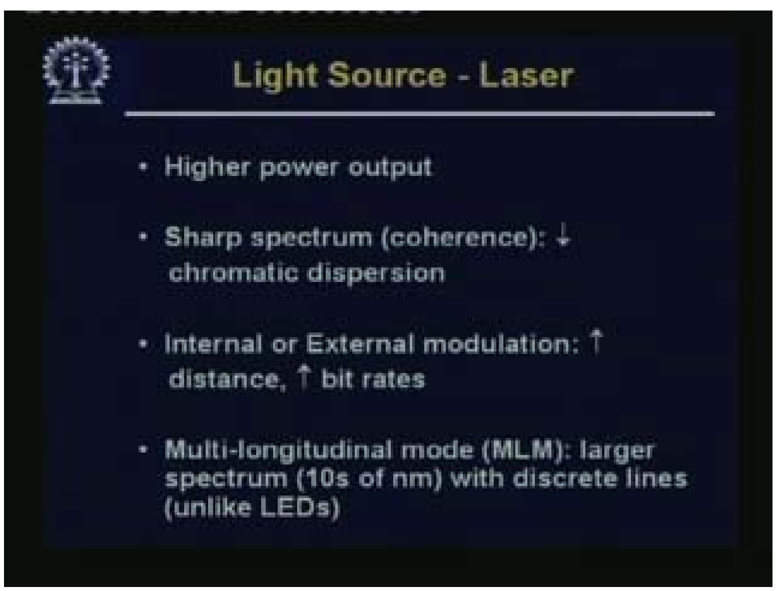

So it is sharp spectrum, which is the property of a laser that reduces the chromatic dispersion. It can be modulated either internally or externally, so that is also a good point. It is good for longer distances and larger bit rates compared to MNF.

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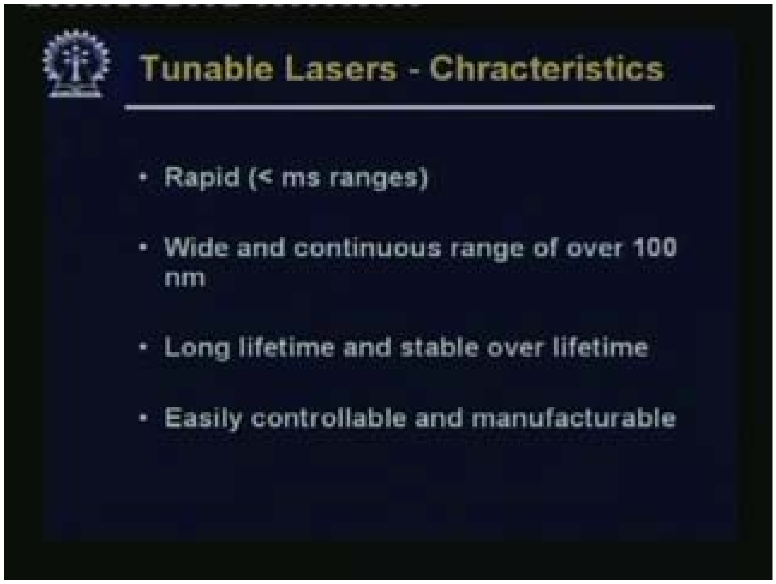

We need not bother about MLM. We have some special kind of devices, the tunable lasers. Tunable lasers means a laser, but we can change the color of light over a certain range. And as we will see later, the tunable laser may be quite important in some cases. We will see what kind of time we require for tuning; it's fairly rapid in the sense that it is in less than milliseconds' range. In the order of milliseconds, we can change the frequency emitted by the lasing system. It has a wide and continuous range of over 100 nm; has a long lifetime and is stable over lifetime; and it is easily controllable and manufacturable. These are the good points about the tunable lasers.

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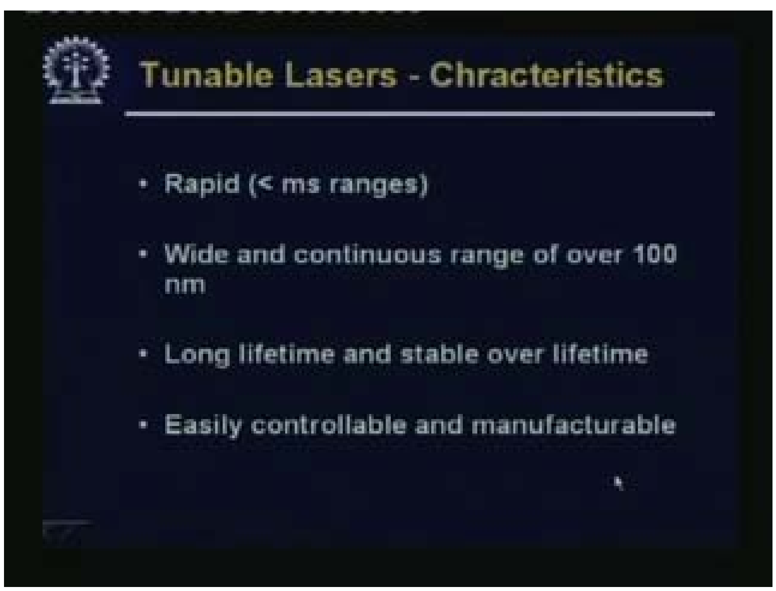

The methods could be Electro optical; changing the refractive index by injecting the current or applying an electromagnetic field. So that is one way; it could be temperature tuning although it is not much preferred. First of all its range is narrow and then it may degrade the lifetime of a laser if you want to do it through temperature; or mechanical tuning using MEMS. This is compact but one problem of this tunable laser is that it is costly; it is quite costly and that is why this is not very common; also, it is slightly more complex to manage. But in some instances, it gives some advantages. We will mention this point later on when we discuss WDM.

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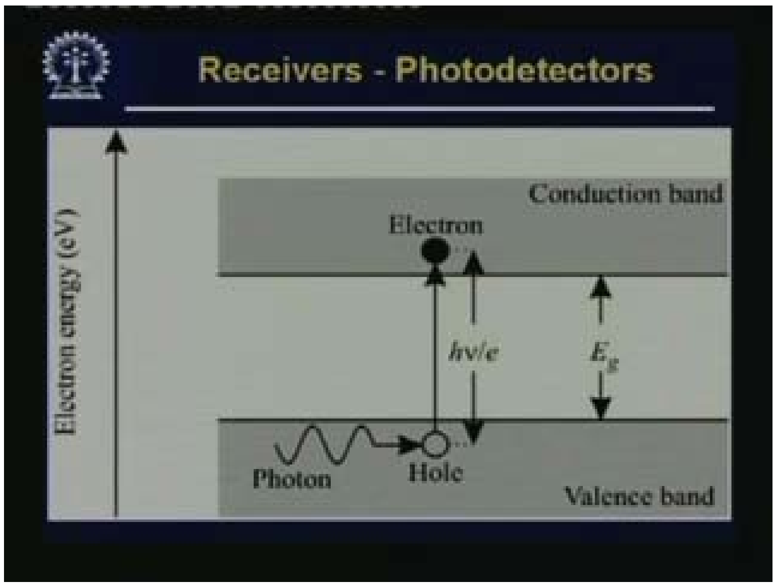

We come to receivers of course the light pulse coming will have to be detected by something: whether a pulse has come or whether the pulse has not come, whether it’s 1 or a 0. So if an photon comes, it will sort of push up an electron to a conduction band. So that is the standard photo detector, which you must have studied at school. So if it is sort of higher than this gap, this energy gap, then we get the electron in the conduction band, which will naturally show up by conducting; so that is the easiest thing.

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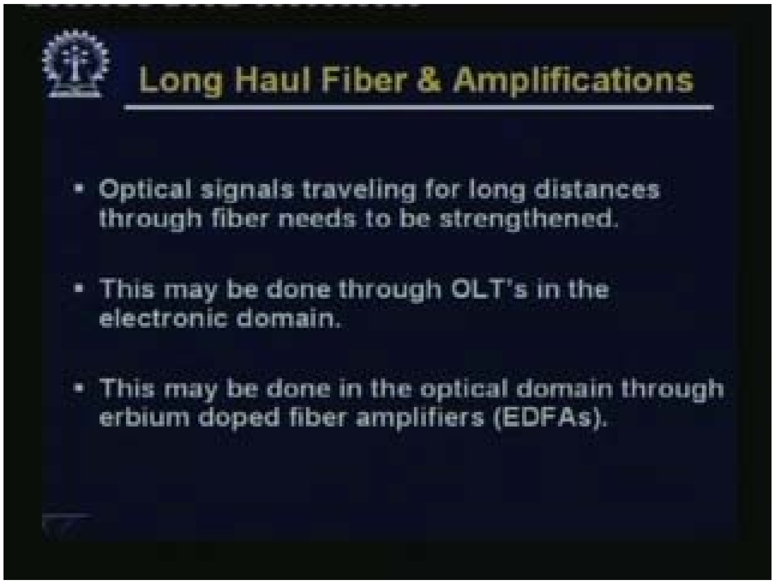

I was mentioning that nowadays we have fibers running for thousands of kilometers. So if we have such long haul fibers, what would happen is that naturally, after some distance, what you have to do is that your signal will become weak, so you have to amplify this. Previously this distance would be something of the order of 4–5kms. Nowadays 5 kms is very common, you can go hundreds, or in special cases, you can go even up to many hundreds of kilometers; you can go without amplification. But whatever it is, after some distance if, because of this loss, absorption, dispersion, etc., you will have to amplify the signal.

For optical signals traveling long distance through fiber, it needs to be strengthened. This may be done through OLT, which was the older technology. In OLT, what was done was that, the optical signal was converted back to the electronic domain. And then you amplify the signal and then push it back to the optical domain. Obviously this has quite a number of disadvantages, main disadvantage being cost and the speed; that means cost is higher and speed is lower that has some advantages also. I will mention it later; this may be done in optical domain. The idea was the that, it could be done in optical domain through erbium doped fiber amplifiers. There are other kinds of dopers that I will mention; we will see that.

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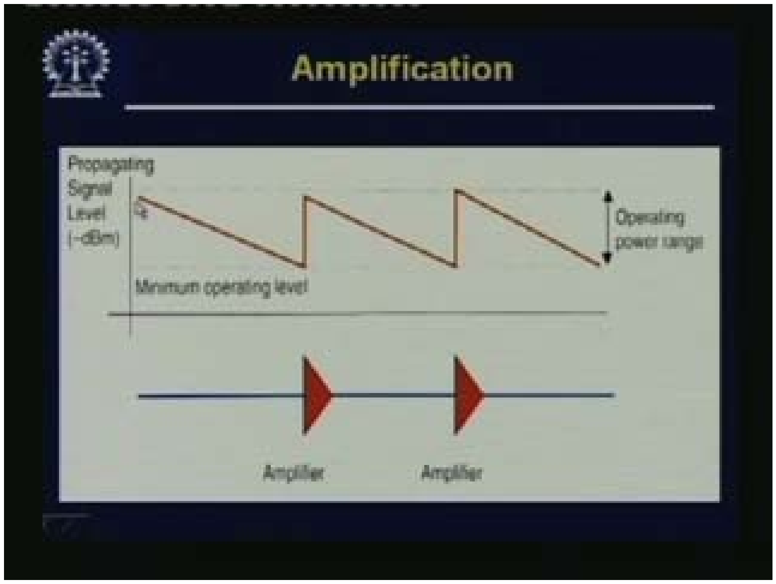

So this is the scenario – we have this light propagating and as it propagates with distance, the signal level comes down. When it comes down to minimum operating level, at that point, we will have an amplifier that will amplify the signal back; and then again, after sometime, it will sort of decay and then we again amplify. So these are some kind of repeaters.

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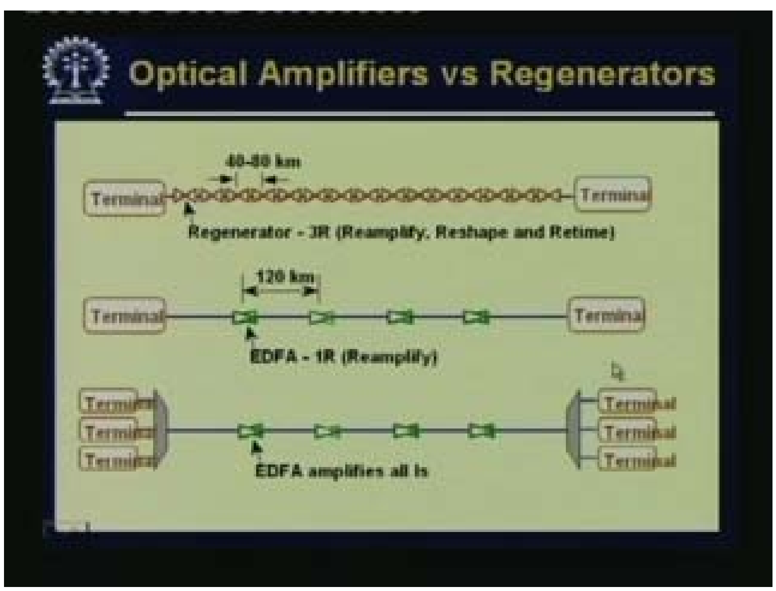

We come to one point where simple amplification is not always enough; sometimes we require regeneration. These are the so-called 3Rs: reamplify, reshape and retime.

As far as absorption is concerned, if you simply amplify, that means increase the size, the strength of the signal is good enough. So the absorption loss or the loss of strength can be handled that way. But when you talk about very long distances, due to chromatic dispersion, etc., wave shape will become distorted as we have seen. In very long distance, on the other side there will be tremendous amount of errors that may not be acceptable. So we have to get a wave into shape.

Now there are some special kinds of fibers; try to do it in optical domain. But more commonly they are deployed today to bring them to electronic domain and then give them the right square shape once again. So that is the second R; and the third R is the timing; that means how do you keep all the clocks synchronized. Because, after all, some TDM signals, etc., are traveling; so you will have to have a very strict control over the time. So these reamplify, reshape, and retime, are the 3 R kind of regeneration. Sometimes we only do with 2 Rs or simply 1 R, which is simply reamplify, which can be done simply with an EDFA, that is, the erbium doped fiber amplifiers; and at certain distances, we simply reamplify this.

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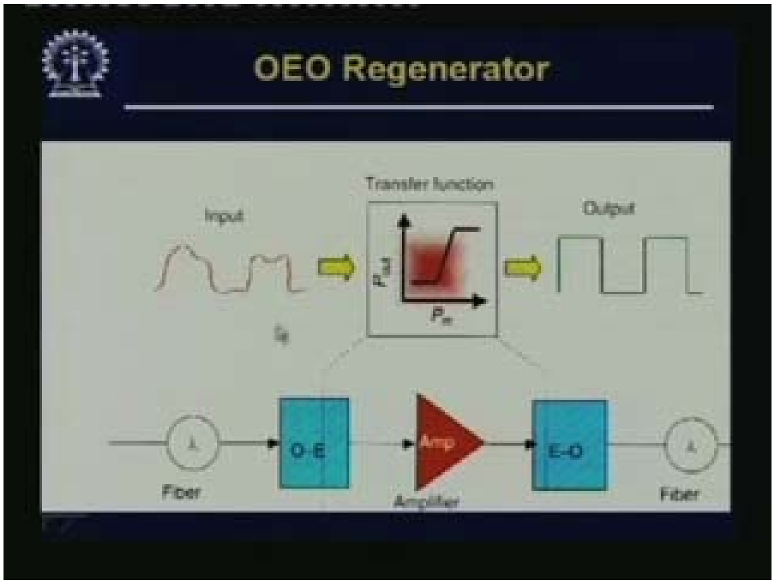

If you want to do some reshaping, suppose this is the input shape, which has come. This goes through the OE transformation, the optical domain, and we come to the electronic domain. We amplify this; shape this properly; and then again push it back from the electronic domain to the optical domain. So we again get a nicely shaped pulse and the output, which has been strengthened as well as reshaped. The problem of this is that, naturally, we can do the reshaping as well as amplification at the same time. But one problem that we face in this case is that the cost is high; and the other problem is that optics inherently can operate at a very high speed. But we can get fairly high-speed electronics also. But it becomes more and more difficult in the electronic domain as the speed becomes higher and higher.

And when that happens we would like to do it in optical domain if we could and there are a number of schemes today for handling this in the optical domain. For example, we can have some very specially shaped optical waves, whose shape will not change over a distance. They are called solitons; they are sort of done in a way that different spectral components are mixed in such a manner that after dispersion, they cancel out each other. Similarly there are fibers which give the dispersion in the opposite direction to the standard fiber so that it can be brought back to shape. So these are all the atoms to handle this reshaping in the optical domain, but the most widely deployed system as of today is to take it to the electronic domain and do it there.

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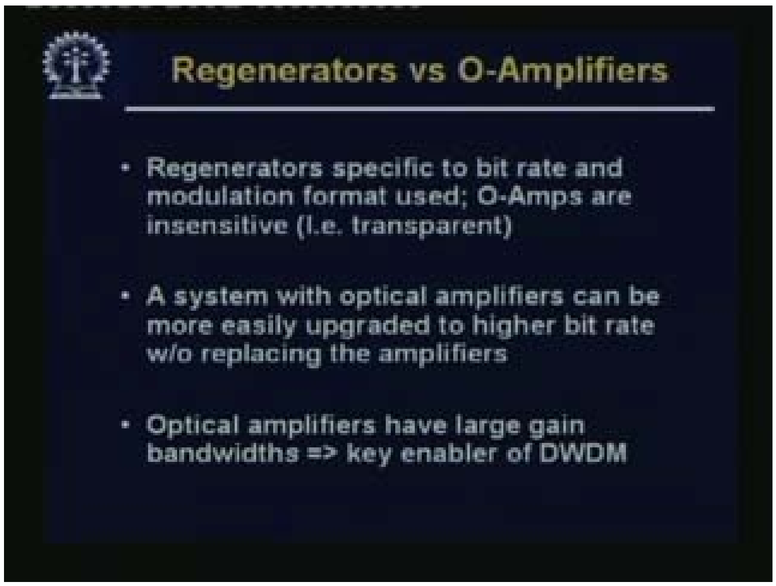

Regenerators are specific bit rate, so that is another problem with the electronic domain. It is an opaque unit; that means. it has specific bit rate and modulation format that is used; whereas optical amplifiers, in optical domain whatever is coming is being amplified. So it is transparent to the bit rate, the modulation format, the protocol, etc.; it is transparent to all that. Whatever is coming, is simply amplifying. so that is the good thing about optical amplifiers. The system with optical amplifiers can be more easily upgraded to higher bit rate, without replacing the amplifiers. If you are going to use the same infrastructure for higher bit rate as service providers often want to do, in that case, if you are taking it to the electronic domain, you have to replace. Optical amplifiers have large gain bandwidth; they are also key enablers of dense wavelength division multiplexing.

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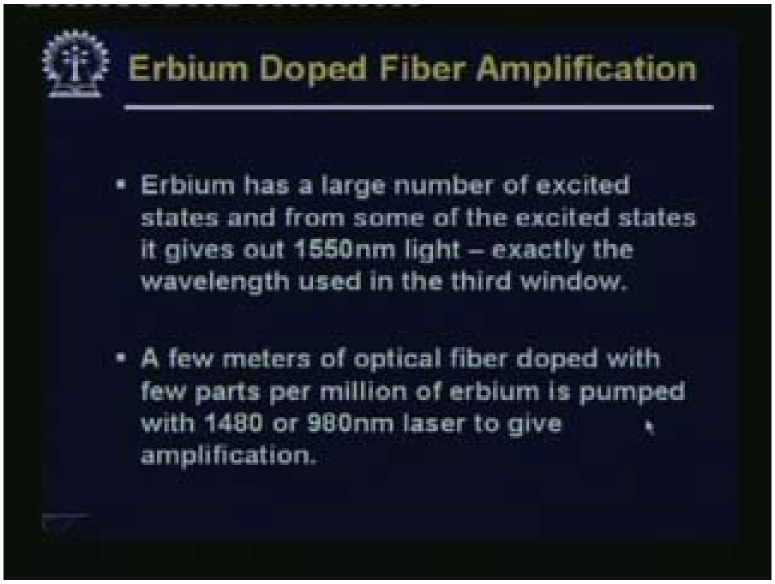

One of the standard kinds of fiber amplifiers, which is very widely deployed, is the erbium doped fiber amplification – we have talked about this earlier. Erbium has a large number of excited states and from some of the excited states, it gives out this 1550 nm light, exactly the wavelength used in the third window. A few meters of optical fiber doped with a few parts per million of erbium is pumped with 1480 or 980 nm laser to give amplification.

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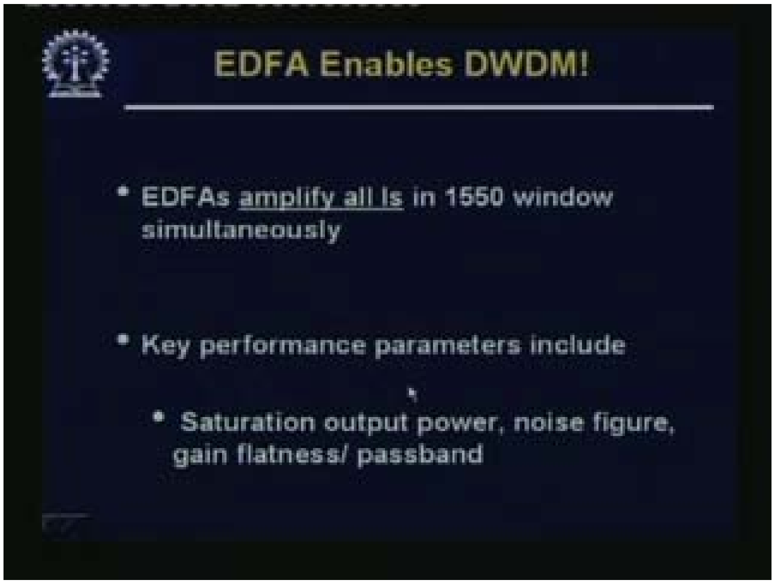

So EDFAs amplify all lambdas in the 1550 window simultaneously. So key performance parameters include saturation output power, noise figure, gain flatness, pass band, etc.

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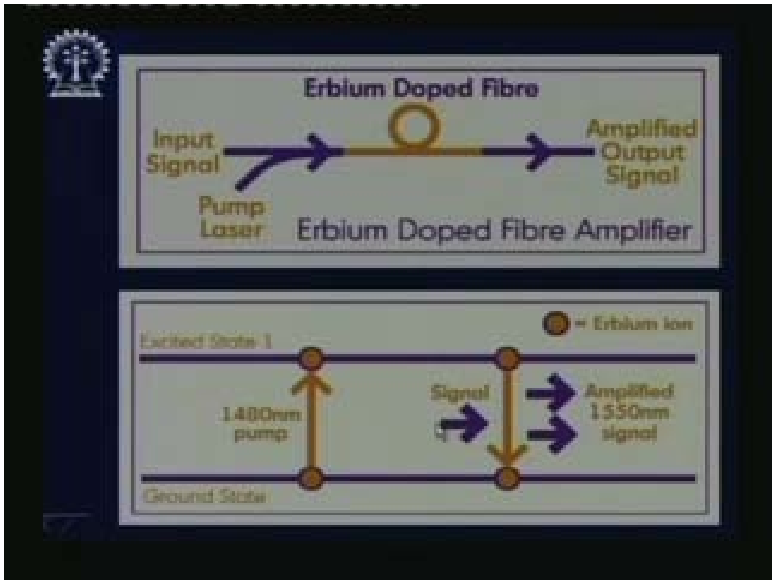

We have input signal coming through regular fiber and this is the part which is erbium doped and you pump some laser. So these are combined using some kind of couplers; I will be talking about couplers later on. Because of the pumping laser, the erbium ions become excited and when the incoming signal hits these, they fall back to the ground state may be emitting more photons, so the signal is amplified.

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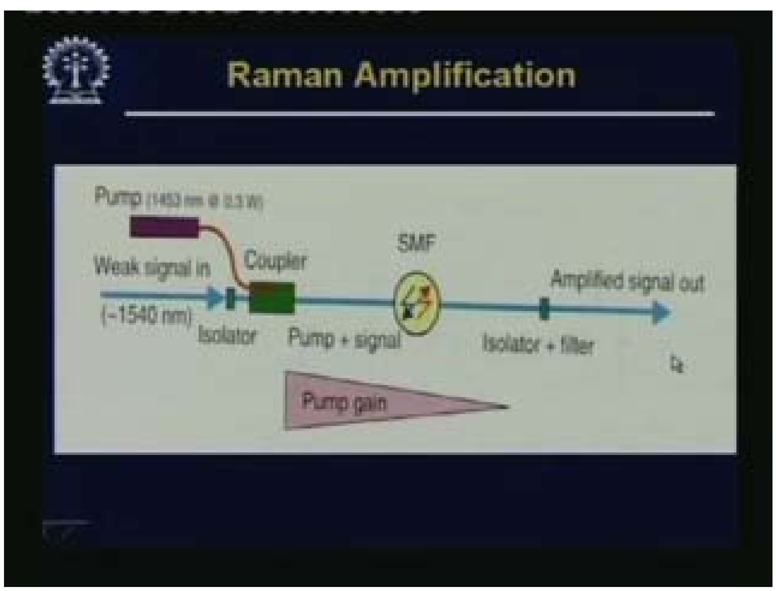

There is another kind of amplifier called Raman amplifier, which uses longer lengths of fiber. This has other advantages, basically using Raman scattering, so we are not going to the details of this once again. It has pumping through some kind of pump and signal. This pump may be in the same direction as the signal is going or it may be counter pumped in the other direction; the whole point is that, this pump keeps the atoms excited and, due to Raman scattering, so more and more photons come out, so we get an amplified signal finally.

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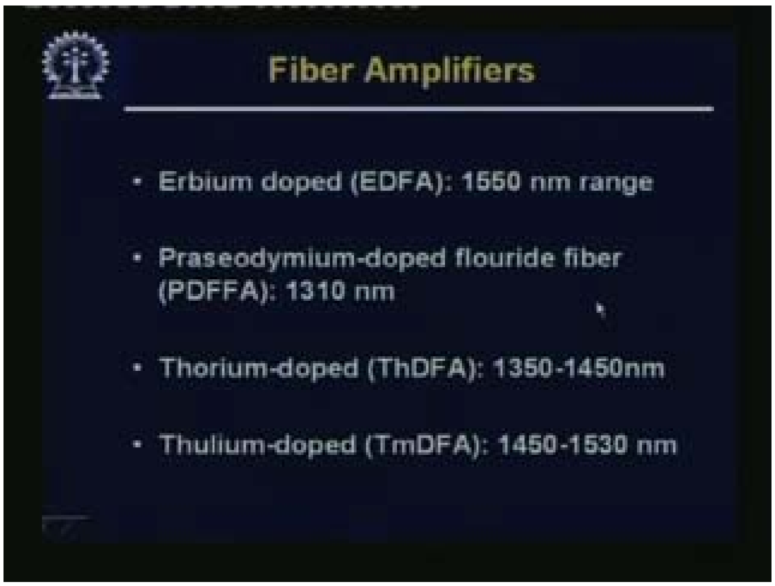

We have other kinds of dopants also: erbium doped for 1550 nm range, praseodymium doped fluoride fiber (PDFFA) for 1310 nm, thorium doped for 1350–1450 nm, thulium doped – well, this is somewhat more academic, because thulium is considered as a rare material; it is not easily available. And even if it is available, it is quite costly. Anyway this is in the 1450–1530 nm range, tellerium erbium doped fibers in 1532–1608 nm range.

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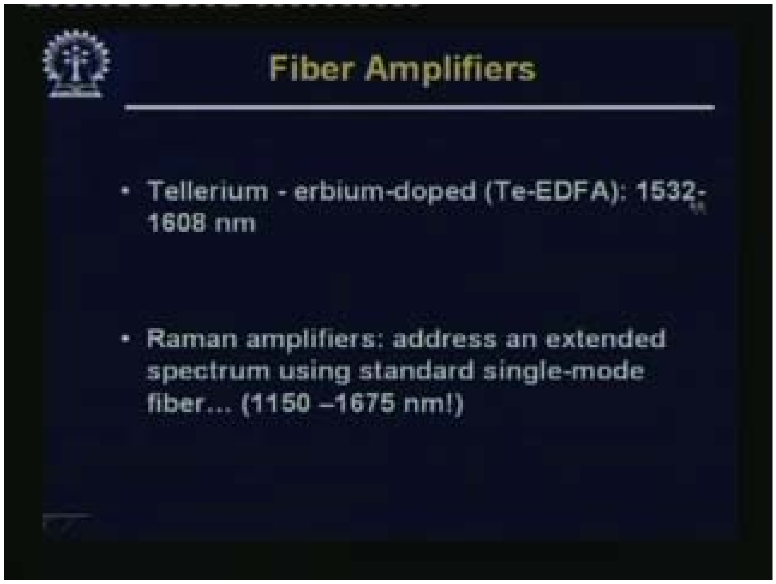

Raman amplifiers address an extended spectrum using standard single mode fiber. That is the good thing about Raman amplifier.

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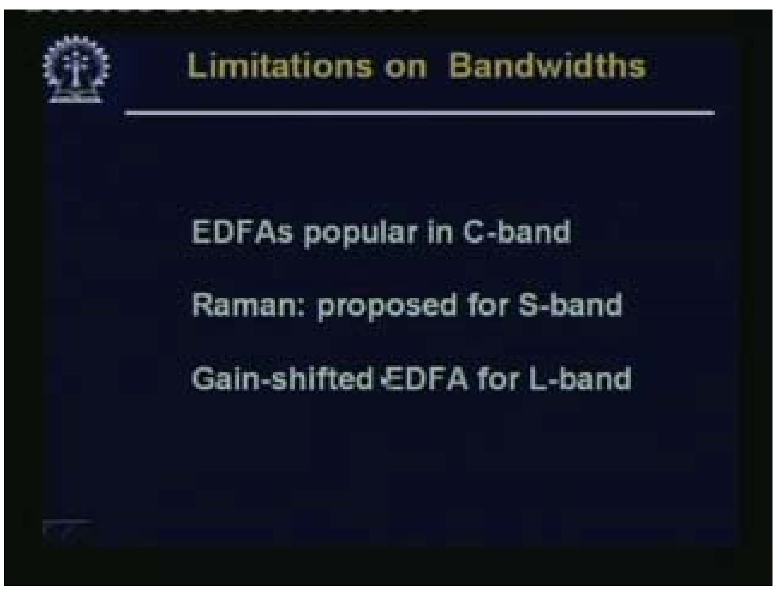

So EDFAs are popular in C-band, Raman are proposed for S-band, and gain shifted EDFA for L-band etc.

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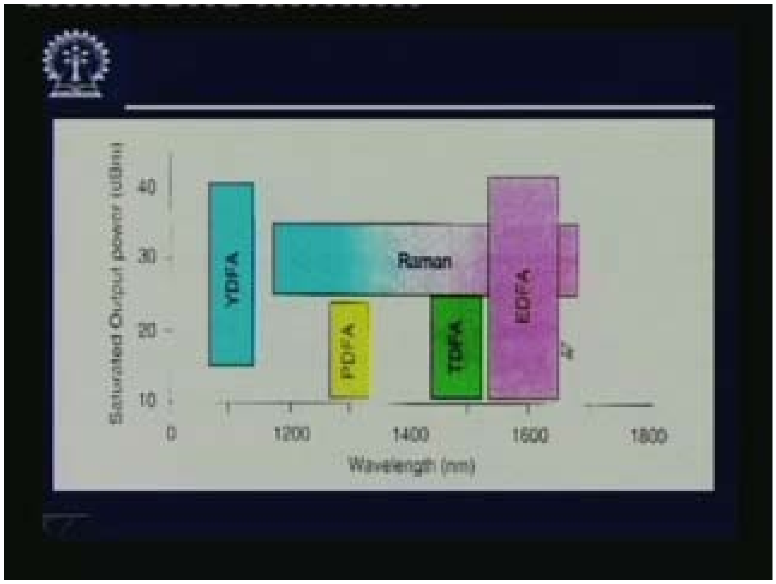

We can have a look at this – depending on the wavelengths, different kinds of doped and different kinds of fiber amplifiers become is more relevant, like EDFA for this range from 1550 etc., TDFA, PDFA, Raman amplification for this entire range, etc. Now we talk about some more components: the first component we talk about is some sort of passive device called a coupler.

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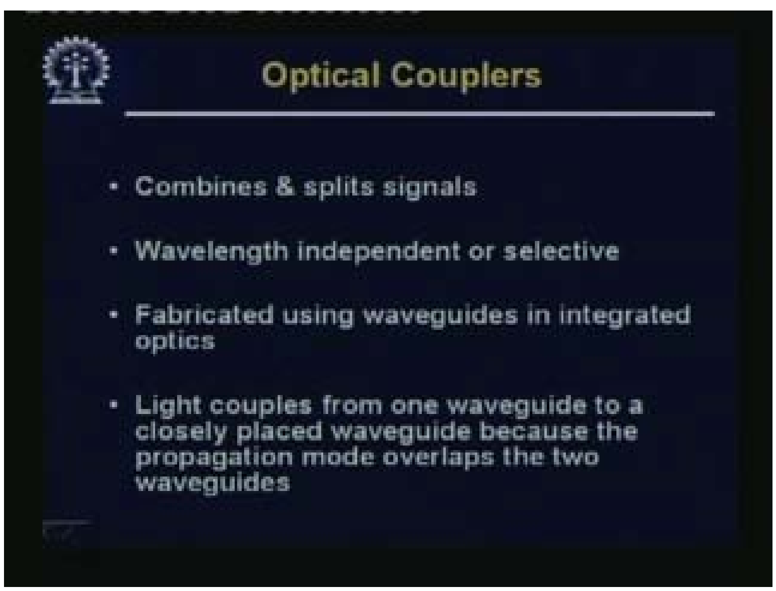

Optical coupler combines and splits signal wavelengths independent or selective; that means, the coupler can be wavelength independent as well as wavelength selective; fabricated using waveguides in integrated optics.

Light couples from one waveguide to a closely placed waveguide because the propagation mode overlaps the two waveguides.

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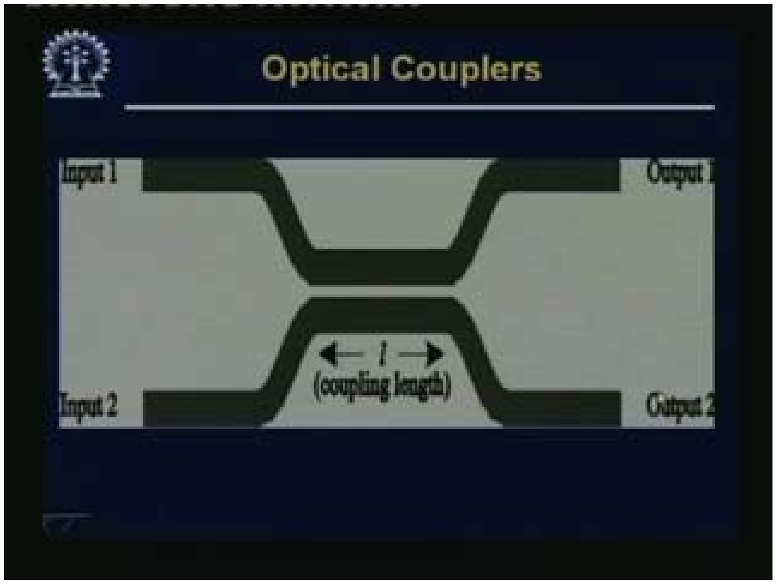

So this is the picture: we have an input waveguide coming in and another input may come; and there are 2 outputs. So what might happen is that it may be used as a coupler; that means, 2 signals joining together, like we wanted to do when we tried to put in a pump in the EDFA amplifier. Or it may be used for splitting the signal coming from one and it is getting split into two directions. So this can be used in various ways.

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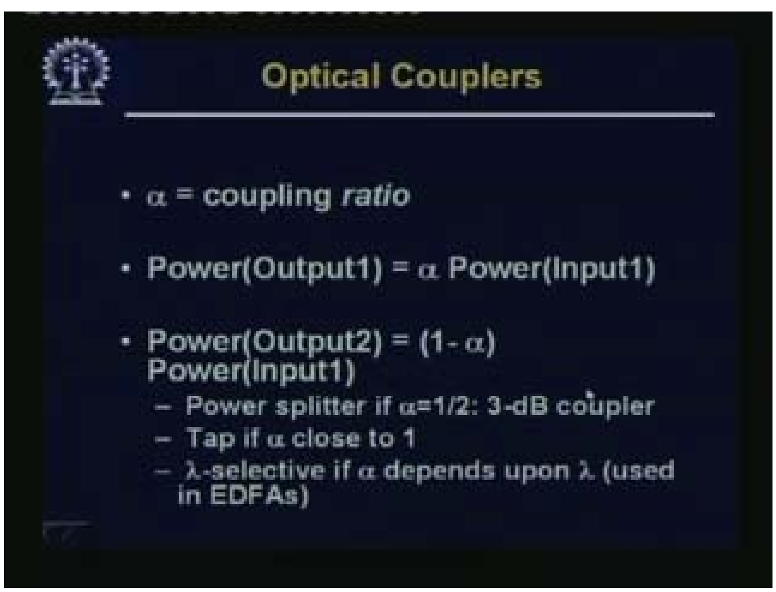

So if α is the coupling ratio, power output 1 is α times power of input 1. Whereas power output 2 is 1−α times power of input 1. So you see that together the input power is split into two parts if you want to have α is equal to ½. These are so-called 3-dB couplers. We put half the power in input 1 and half the power in output 2. If you want to broadcast the same signal to two different destinations, you can use a 3dB coupler. As I said, light couples from one waveguide to a closely placed waveguide,

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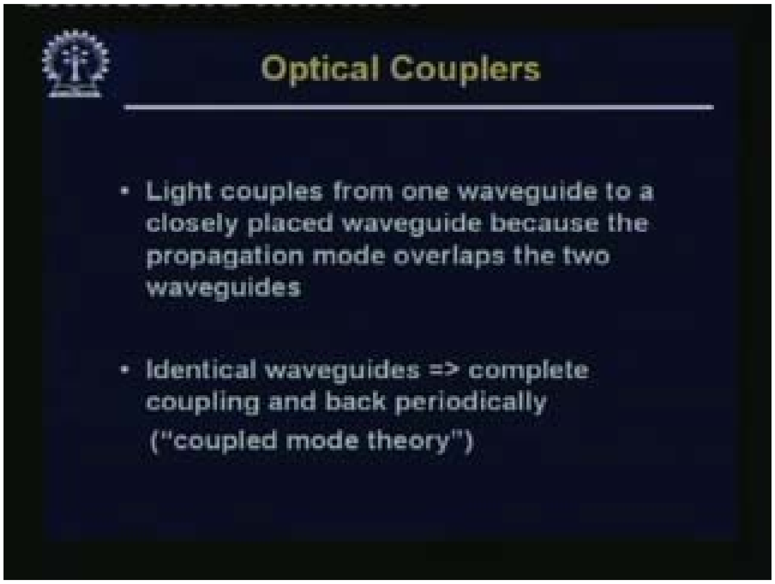

Identical waveguides complete coupling and back periodically. So this is the couple mode theory.

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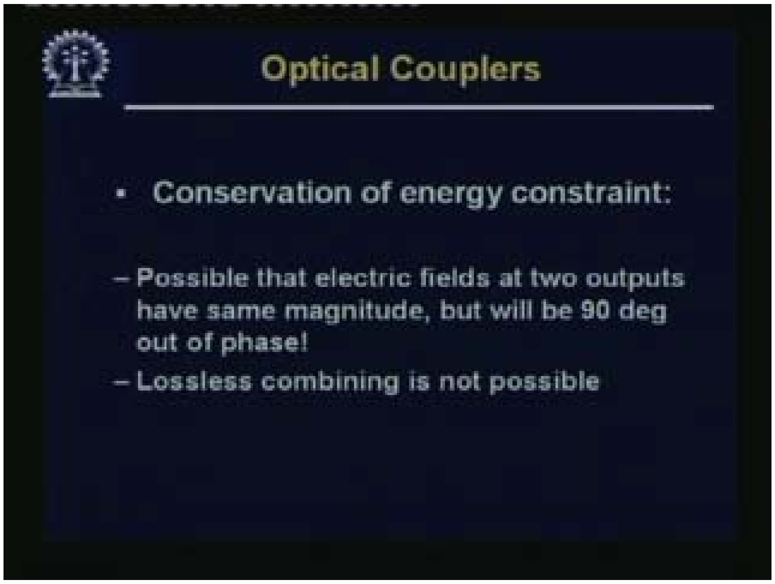

Of course we have to follow the conservation of energy constraint so you cannot get more – since this is a more passive device, we cannot get more out of it. Then when you put in actually you get less, so it is possible that electric fields at two outputs have the same magnitude. So they are exactly the same, but will be 90° out of phase and lossless combining is not possible, so nothing is really 100% efficient.

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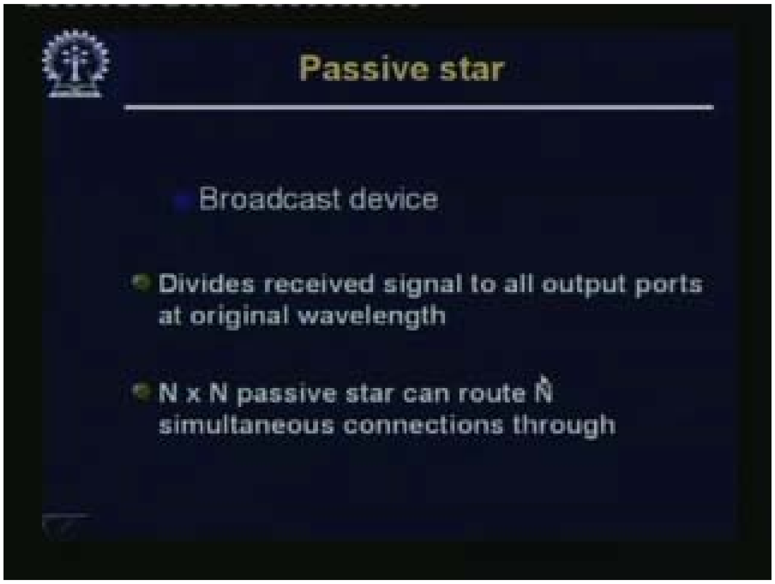

Passive star is a sort of generalization of this. It’s a broadcast device to more than one recipient. It divides the received signal to all output ports at original wavelength; of course, if you divide the same signal into so many different signals, the received strength of the signal will be proportionally less. You have to handle it by either amplification or some other thing, or maybe, weak signal is good enough for your application etc. So N into N passive stars can route N simultaneous connections through.

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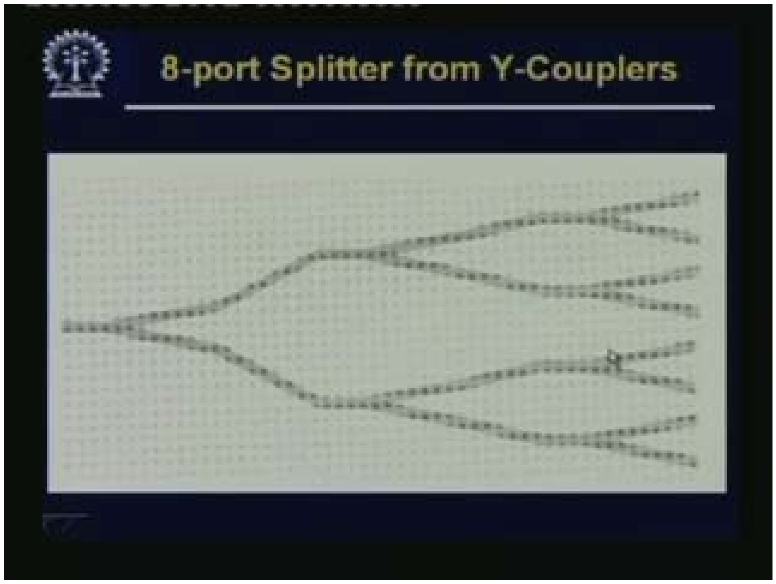

This is an example of an eight-port splitter. Whatever signal is coming, it is getting divided into two and again divided into two. So we get eight signals over here; we can actually use some 3-dB couplers to form this eight port splitter from Y-couplers.

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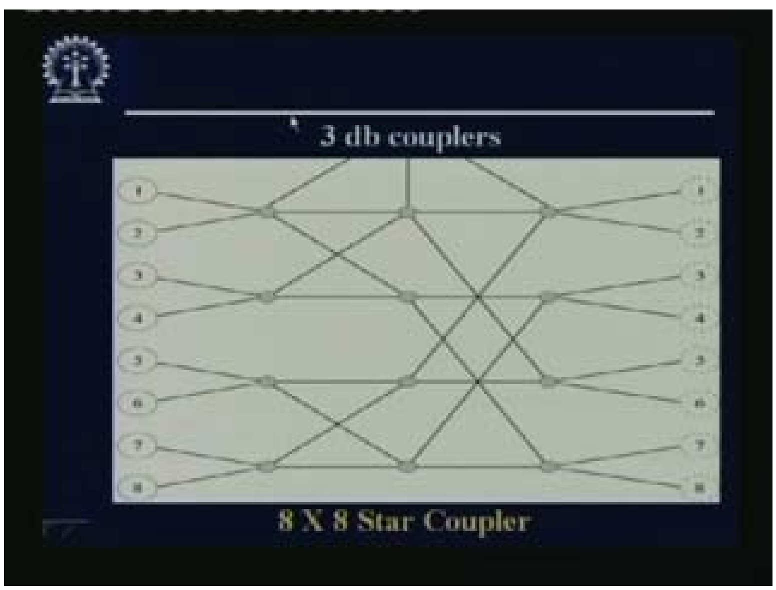

This is another example of an 8 into 8 star coupler. There are 8 lines; any of these might communicate something which will be broadcast to all the other seven ports. So such things are used for broadcasting.

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We now come to optical modulation; that means how we modulate it. Of course the simple modulation scheme – since we are talking only about digital systems – is on/off keying, that means either on or off or 1 or 0. There are two types of modulation techniques, namely, direct modulation versus external modulation. In modulation, the extinction ratio of output power for bit is equal to 1 to output power for bit is equal to 0 is very important. We want this to be as high as possible. Some lasers cannot be directly modulated; that is one problem.

Another problem with direct modulation is that you are modulating at the source, modulating at the same place, from where that light is being generated. Whatever diode or whatever you are using for generating it, we want to modulate through that only. So that is the direct modulation, whereas in indirect modulation, what we will do is that there is a continuous source of light and just as the light comes out, we will modulate it. We will put it on or off by making it go through something. So that is the external modulation.

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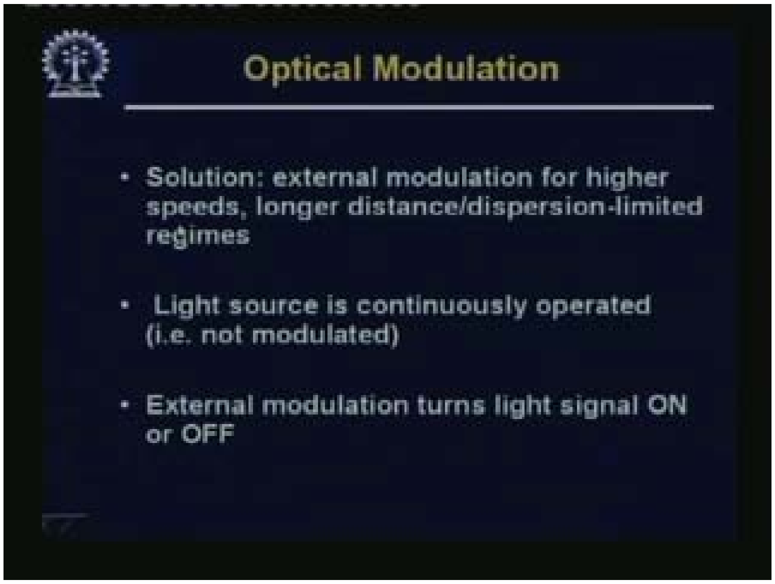

So the solution is – naturally since direct modulation has the problem about the chirp, etc. – external modulation for higher speeds, longer distance dispersion, limited regimes, etc. We prefer external modulation. The light source is continuously operated. External modulation turns light signal on or off; so this is the optical modulation.

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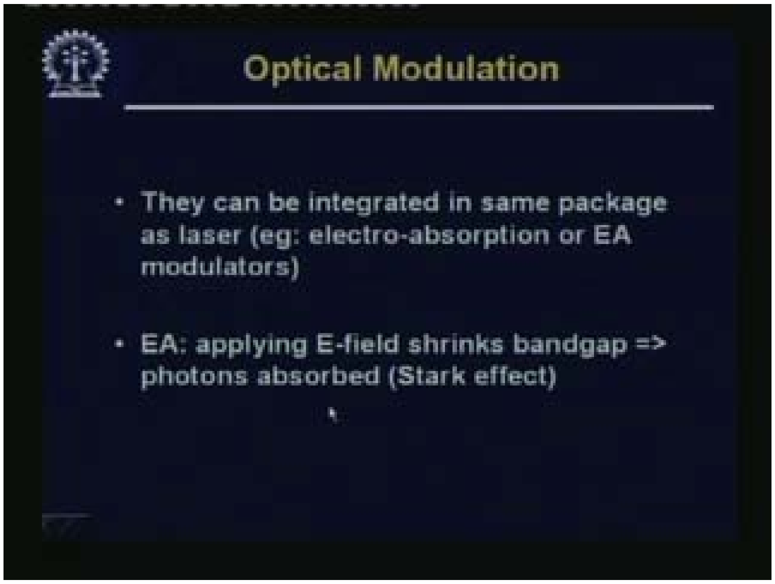

They can be integrated in the same package as laser; the laser source is there and the modulator is external, but they can be packaged. Electro absorption or EA modulator is one important kind of modulator; it applies an electric field, shrinks the band gap and photons are absorbed.

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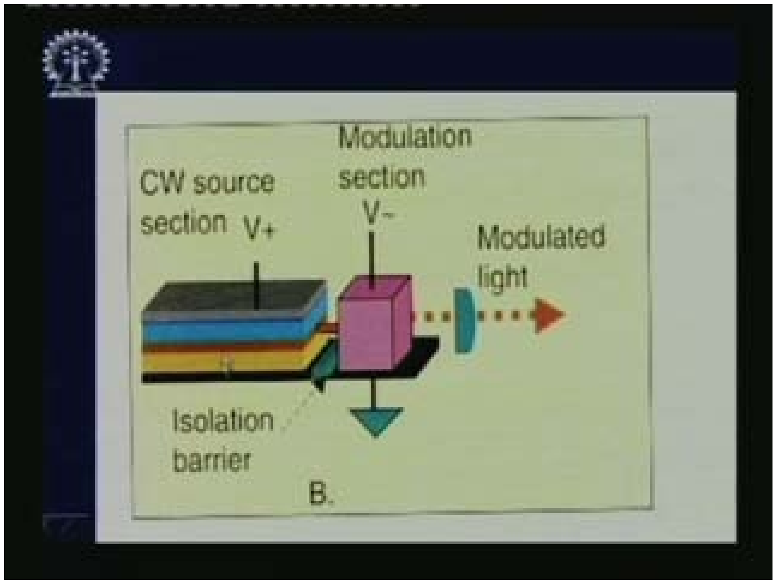

So this is the picture, this is the continuous source of this light, which is being modulated, that is, being put on or off depending on whether you want to transmit 1 or 0.

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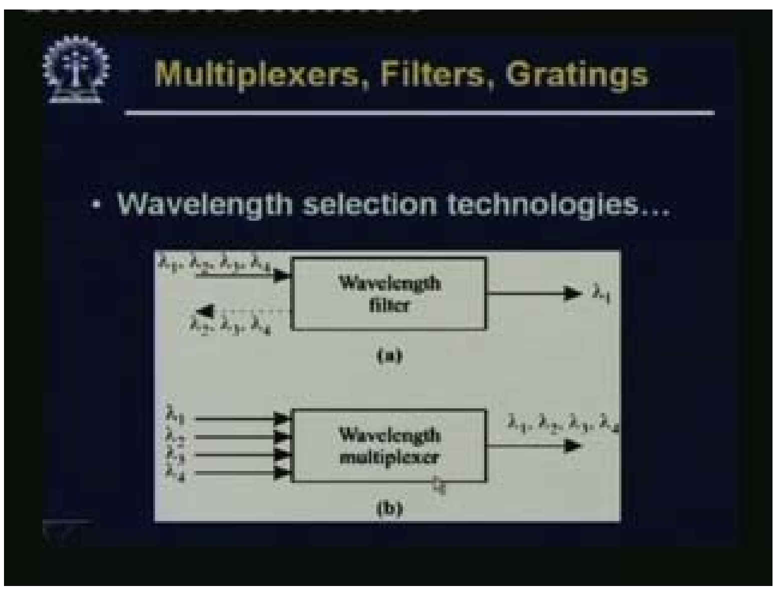

The next set of components are multiplexers, filters, and gratings. We will talk a little bit about it. If you look at this, these are all wavelength selective devices: multiplexers, filters, and gratings. In a wavelength filter suppose λ_1, λ_2, etc.

So many λs are coming, but I want only λ_1 out. λ_2, λ_3, λ_4, etc., are absorbed; whereas if you are a multiplexer, I want the different λs coming in different lines. I want all to be mixed together and use the same line. That is a wavelength multiplexer.

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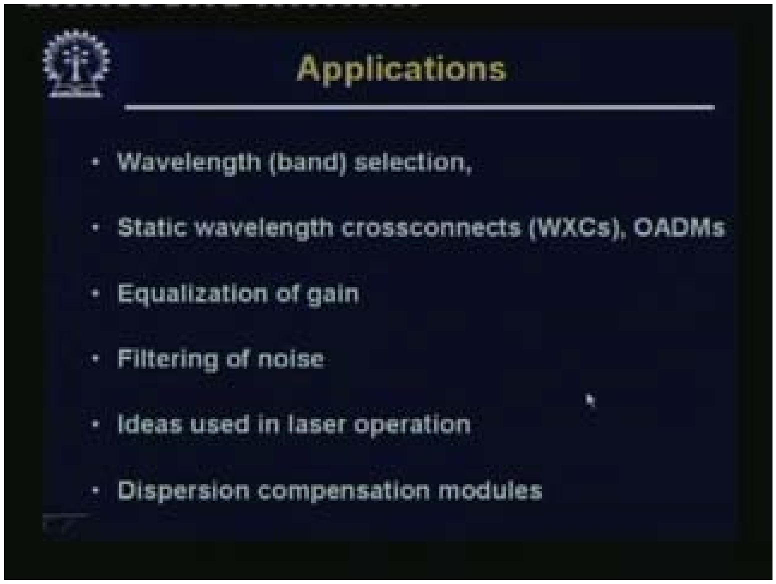

So the application could be particular wavelength or a particular wave band selection. Wave bands are nothing but some contiguous, operating wavelengths, which all are side by side. In the operating window, whatever be the window you are using – 1550 or whatever – you can have a number of λs, all side by side. There is a guard band between each of these operating λs – the IQT has specified how much guard band etc., you will have to have.

You can have large number of λs, all grouped together in the same window. Now you can select a band out of that, a bunch of frequencies out of that, instead of selecting only one; that is wavelength band selection. Static wavelength cross connects and OADMs (optical add drop multiplexers): you have come across this term, optical add drop multiplexers in the context of SONET, but in the optical domain we require optical add drop multiplexers; we will come to that. Equalization of gain: that is another application; filtering of noise; ideas used in laser operation and dispersion compensation modules etc. These are the different applications.

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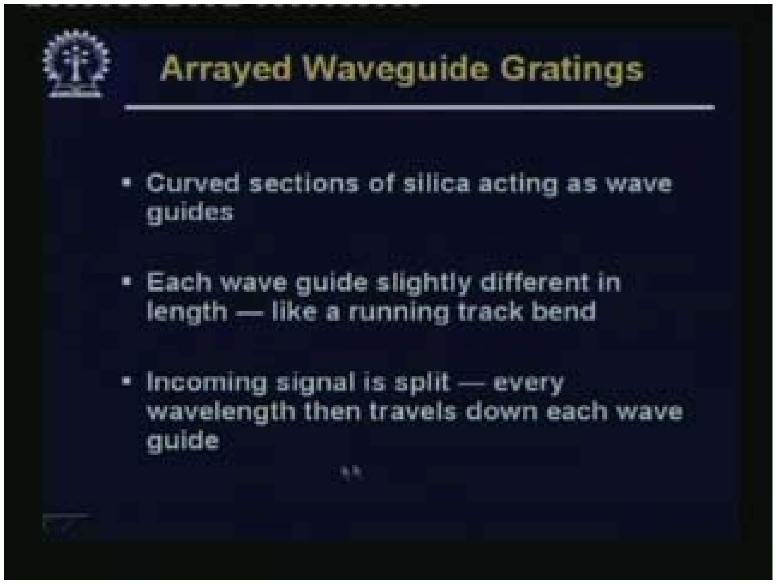

One of the standard wavelength selective components is arrayed waveguide gratings. These are curved selection of silica acting as waveguides. Each waveguide is slightly different in length. The incoming signal is split. To be slightly different in length is like a running track bend – in a running track you know that the outer track, in any athletic event, in an 800 m race or something, the outer track is longer than the inner track. That is why athletes are given proper handicap, because we want to make all the distances same. Here deliberately, we want the distances to be different. If they are different, they are going to sort of arrive out of phase at the output. The incoming signal is split; every wavelength then travels down each waveguide.

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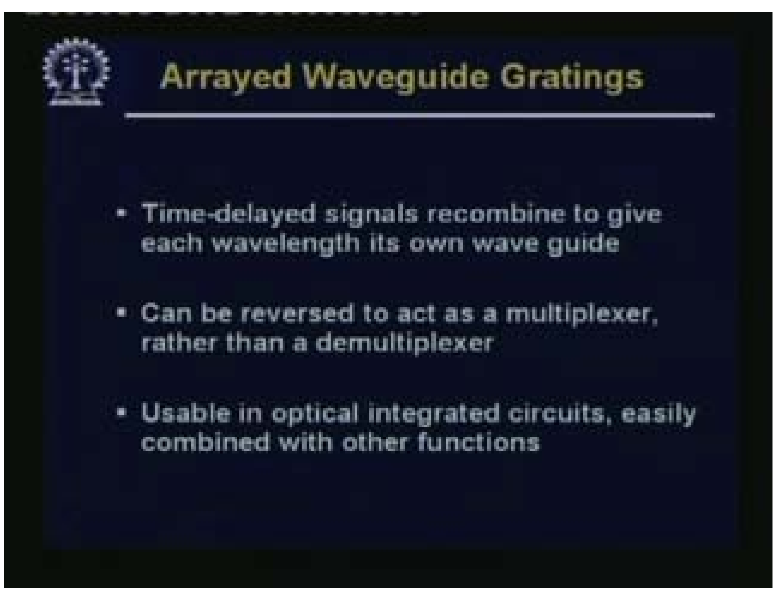

Time delayed signals recombine to give each wavelength its own waveguide; can be reversed to act as a multiplexer rather than a de multiplexer; usable in optical integrated circuits; easily combined with other functions.

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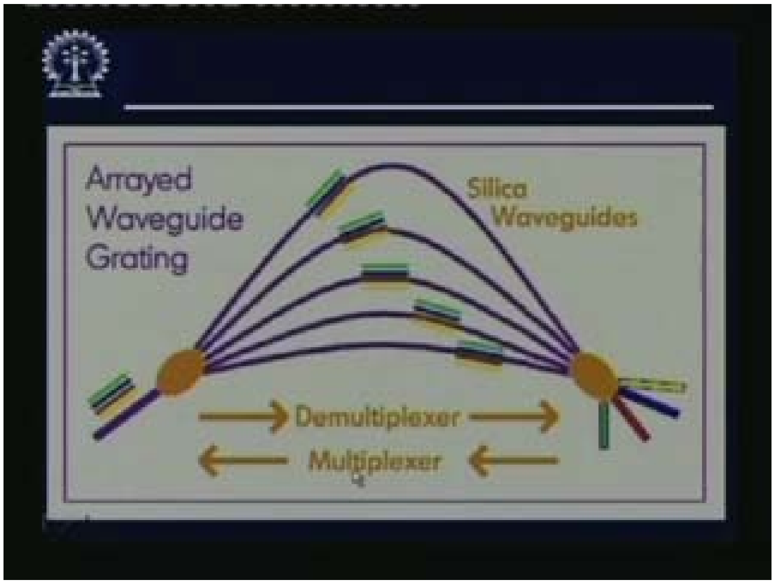

This is the picture we had seen earlier: if your light is going in this direction, what you are doing is that you are de multiplexing. One bunch of frequencies are coming; we want all these different colors to get separated out. So that is the de multiplexing action going on. If different wavelengths or different colors of light are coming in the other direction, it’s just the direct opposite thing, and we will get a multiplexer, so it is an AWB acting either as a multiplexer or de multiplexer, depending on how you operate.

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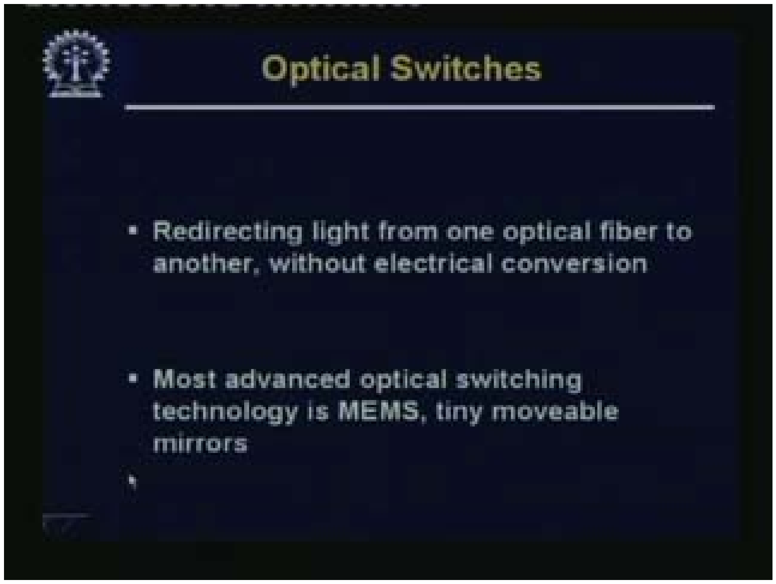

We come to optical switches; we have seen electrical switches. Now we will talk little bit about optical switches. What is optical switching? You remember electrical switching? In electrical switching, there are some one input lines coming in line i and I want to get that signal out through line j. So we want to operate the switch. Through the switch or something, want to connect the ith line and jth line. The basic idea was that the signal coming down from ith line has to go out of the jth output line. That was the simple switching element. It is the same thing here also; some wavelength is coming through some fiber, that is, one input port. We want to get it out of another fiber.

For the time being, we do not have any wavelength conversion kind of thing, thus the same wavelength has to push it to another fiber. So that is my switching at the optical plane redirecting light from one optical fiber to another without electrical conversion. So we are always harping on that without electrical conversion, we can operate it at a much higher way and higher speed. Secondly it may be cheaper also, to operate at high speeds; it will be cheaper and then if you upgrade eventually, this is going to be transparent. This does not depend on the underlying protocol, etc., that is being used at the higher layer. These are the other advantages of doing at the optical plane. Now, the most advanced optical switching technology is MEMS, that is, tiny movable mirrors. So this is the crossbar switch 4 into 4 switch.

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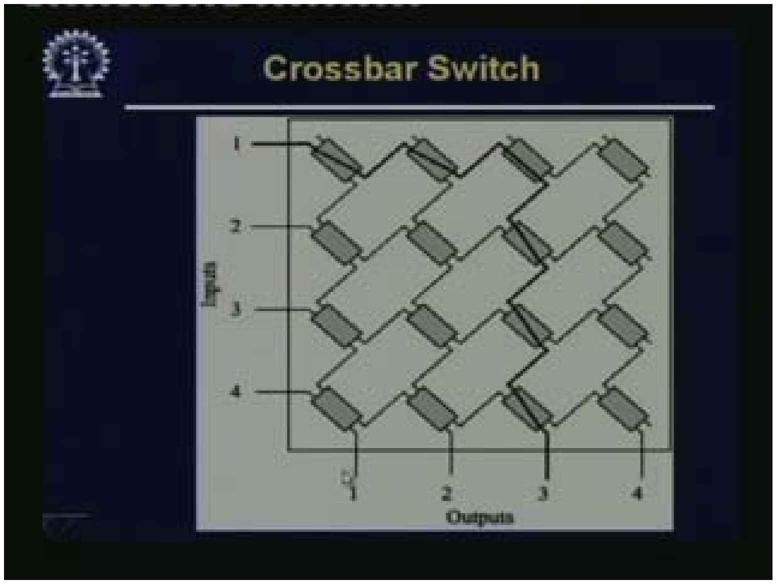

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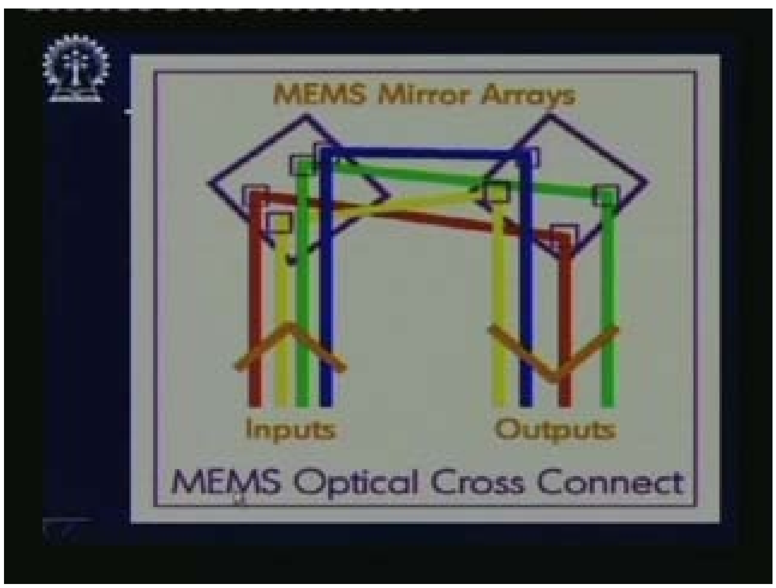

We have seen this picture also. That is a MEMS optical cross connect. You see that these are all tiny mirrors; what I can do is that, to follow the red line which is coming, we are using these two mirrors to push it to line number 3 over here – from line number 1 to line number 3. This way, by just adjusting the angles of the mirrors which we can do through the MEMS technology, we can have a simple and elegant kind of switch. The light goes and bumps off a couple of mirrors and goes out the other fiber. Whatever signals it is carrying, what protocol it is carrying is immaterial; similarly, the data rate also is immaterial. This is a MEMS optical cross connect.

Now all this technology sort of enables what is known as the WDM technology, which is a wavelength division multiplexing. As I was mentioning when we were discussing multiplexing, wavelength division multiplexing is nothing but frequency division multiplexing; that means, you want different channels to come at different frequencies. It's just the opposite of optical domain. In wavelength division multiplexing, different wavelengths and different λs are getting together and light with different wavelengths can very well mix together and go to the other end. For example, sunlight has all the frequencies that are mixed up to appear as white light to us; if you send this through a prism, all the frequencies split up so we will get some kind of a de multiplexing action.

So you want to use this property for wavelength division multiplexing for achieving very high data rates. There are two kinds of wavelength division multiplexing, or WDM, that people talk about. Mostly in the backbone, people use DWDM. DWDM means dense wavelength division multiplexing. By dense we mean that we put a lot of channels, lot of λs side by side, so we get a lot of channels. Of course, DWDM would not usually be deployed in a LAN because DWDM is costly. But then, at the backbone, where you are talking about very high speed that cost is effective; whereas another kind of wavelength division multiplexing is coming into LANS, which is called CWDM or coarse wavelength division multiplexing. There the wavelengths are not so closely packed; they are sort of more sparsely placed, which is a good thing because then, the stability of these laser sources, detectors etc., are less of an issue. So CDWM tends to be cheaper than DWDM and CWDM is coming into use these days. We will start our discussion on wavelength division multiplexing in this lecture and then we will continue in the next lecture with the details of wavelength division multiplexing.

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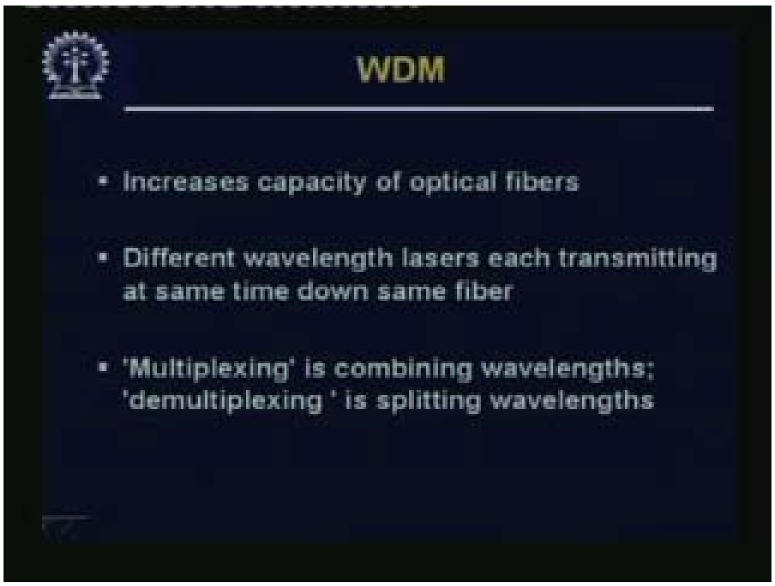

WDM increases the capacity of optical fibers; different wavelength lasers, each transmit at same time down the same fiber; multiplexing is combining wavelengths; de multiplexing is splitting of wavelengths.

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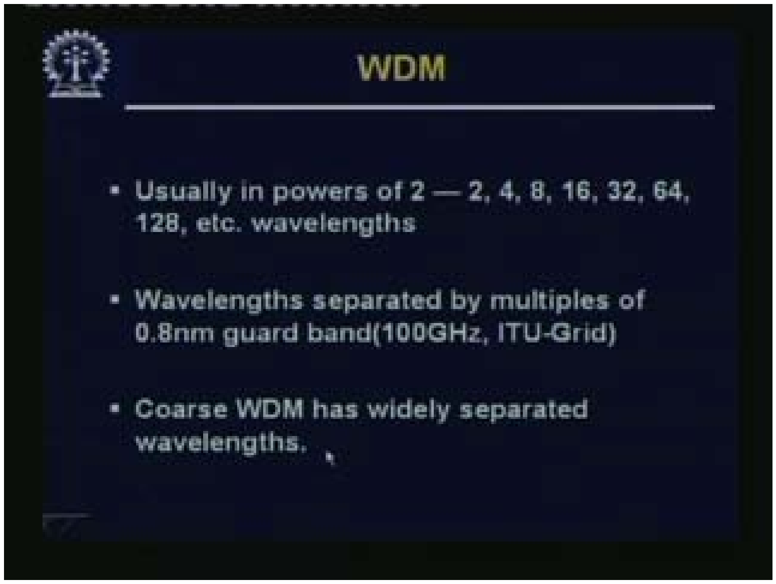

Usually the number of wavelengths is in the power of 2, 4, 8, 16, 64, 128, etc., things like 32, 64 etc., are big. 16, 32, 64 are deployed; now people are talking about hundreds of wavelengths, may be even thousands. Wavelengths are separated by multiples of 0.8 nm guard band: I mentioned this is equivalent to 100 GHz. There is 100 GHz separation between two λs; that is the minimum separation, which is mandated by the ITU standard. Coarse WDM has widely separated wavelengths so that the components can be little less sophisticated and much more cheaper.

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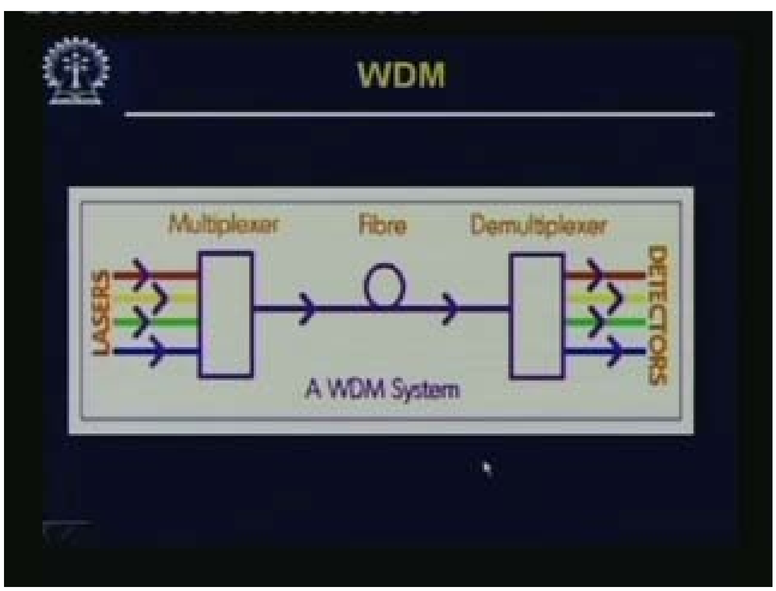

This is a WDM system; different lasers of different lights coming together to the multiplexer, flowing down the same fiber at the same time, being de multiplexed on the other end. The multiplexer, de multiplexer could be an AWG or some other.

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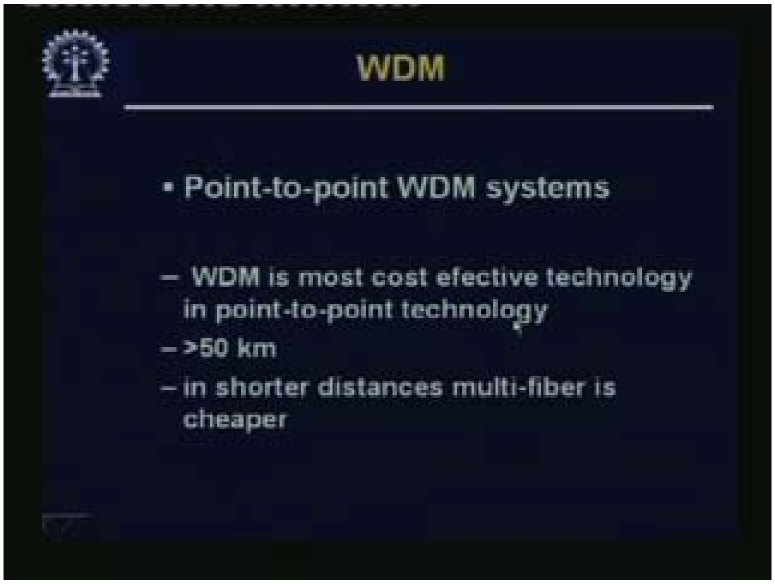

In point-to-point WDM system, one point is connected to another point through multiple wavelengths. WDM is the most cost-effective technology in point-to-point technology, where the distance is about greater than 50 kms. In shorter distances, multi fiber is cheaper because in DWDM naturally your end equipment tends to become quite costly. If you have some extra strands of fiber, then that may be a cheaper option.

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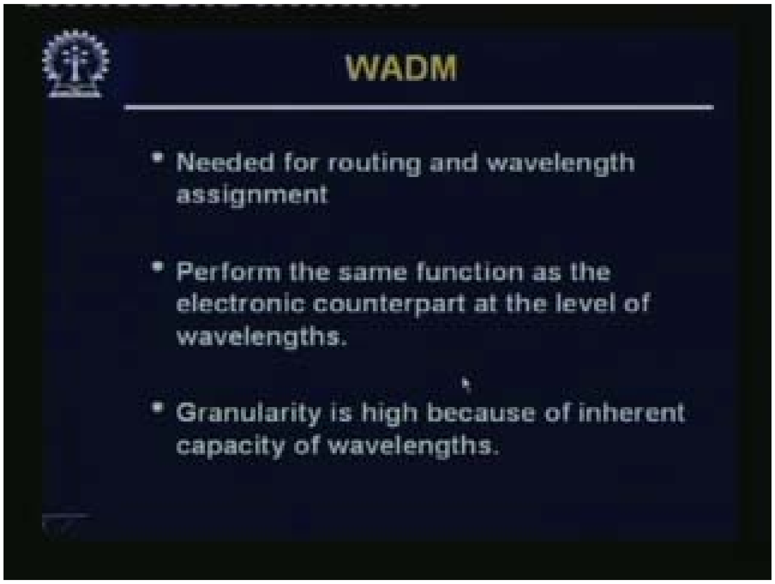

Wavelength add drop multiplexer is one thing we require, when we want to add on to a stream of WDM that is going through a fiber, or we want to add on some extra wavelengths on the wave or we want to take just one wavelength out and let the others pass through. So that is a wavelength add drop multiplexer needed for routing and wavelength assignment. It performs the same functions as the electronic counterpart at the level of wavelengths. We had come across its electronic counterparts like ADM in SONET; the same thing happens in the optical domain. One problem is that granularity is high, because of inherent capacity of wavelengths; so even if you take out one single wavelength out of a whole bunch of wavelengths, that one single wavelength can carry a large amount of traffic, let us say, 2.5 gbps – that is a high amount of traffic. If there are small amounts of traffic, which you want to add or drop, then this is not a very effective technology.

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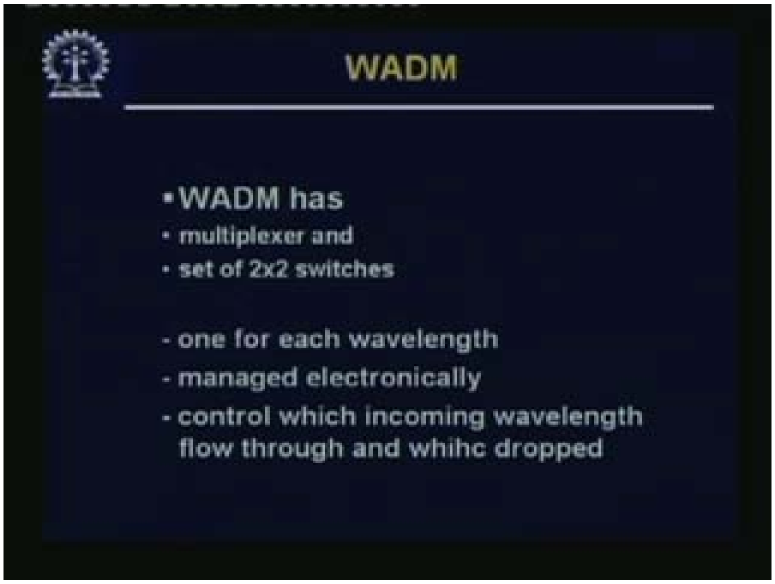

WADM has multiplexers and a set of 2 into 2 switches, one for each wavelength. They are managed electronically; that means, these switches, etc. are programmed electronically to control which incoming length flows through and which is dropped.

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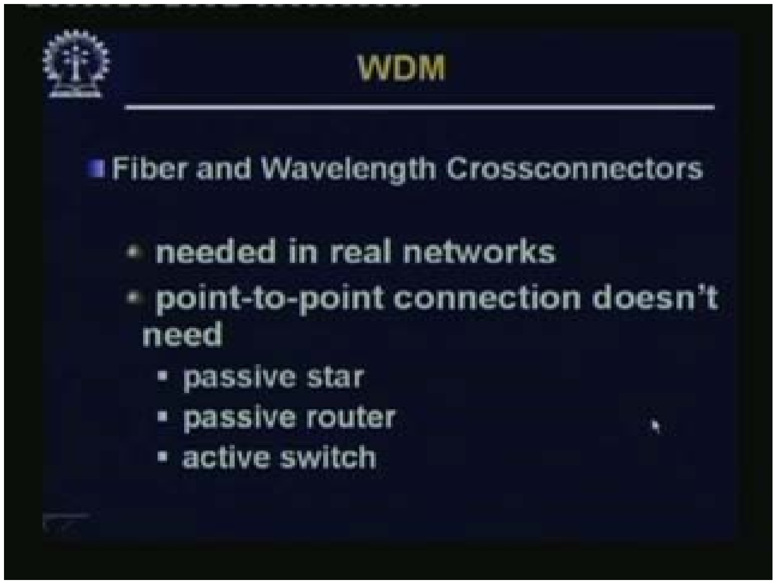

So fiber and wavelength cross connects are important components of this WDM, needed in real networks. Point-to-point connection does not need a passive star, or a passive router or active switch, but in WDM, we may require all these for an entire communication network. We have discussed this.

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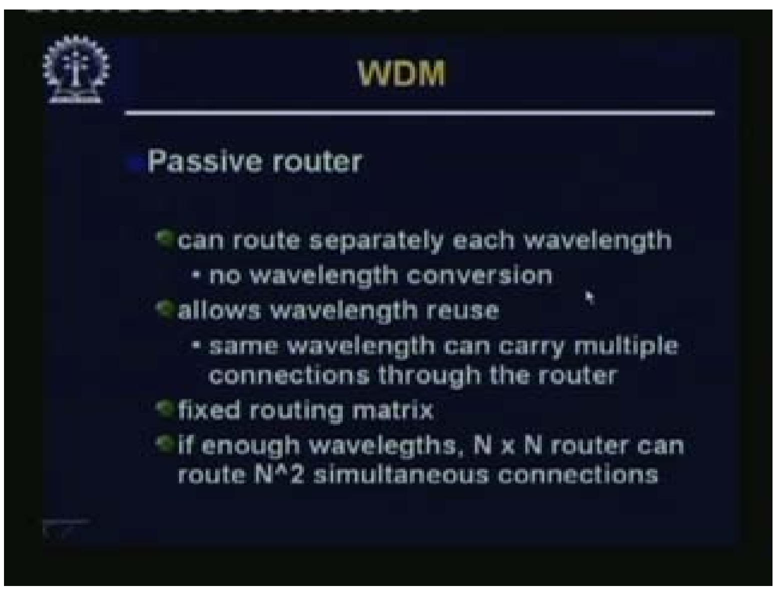

Passive router: It can route separately each wavelength, no wavelength conversion; it allows wavelength reuse, same wavelength can carry multiple connections through the router.

For example, the same wavelength coming from fiber 1 going through fiber 3 and the same wavelength coming in from fiber 2 and going out through fiber 4 is perfectly possible. If enough wavelengths are there, N into N router, can route N2 simultaneous connections; some routing issues are there. We will discuss the routing issues in the next lecture.

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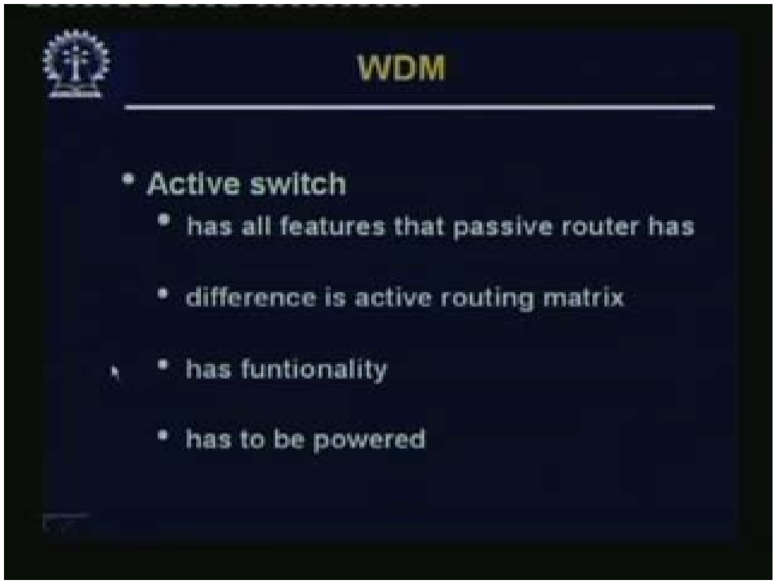

Finally, we may have some active switch, which has all the features that a passive router has. The difference is that active routing matrix, which has some functionality, has to be powered. This is of course an issue when you are talking about a very long haul.

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With this we conclude our initial portion of our discussion and in the next lecture we are going to discuss the details of WDM; that is, how different wavelengths are routed through the network how we can get an entire network output. Thank you.

PREVIEW OF NEXT LECTURE

Computer networks
Prof: Sujoy Ghosh
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur
Lecture 11
Routing and Wavelength Assignment
In WDM all optical networks

Good day, In this lecture, we are going to continue our discussion on wavelength deviation and multiplexing. Specifically we are going to talk about routing and wavelength assignment.

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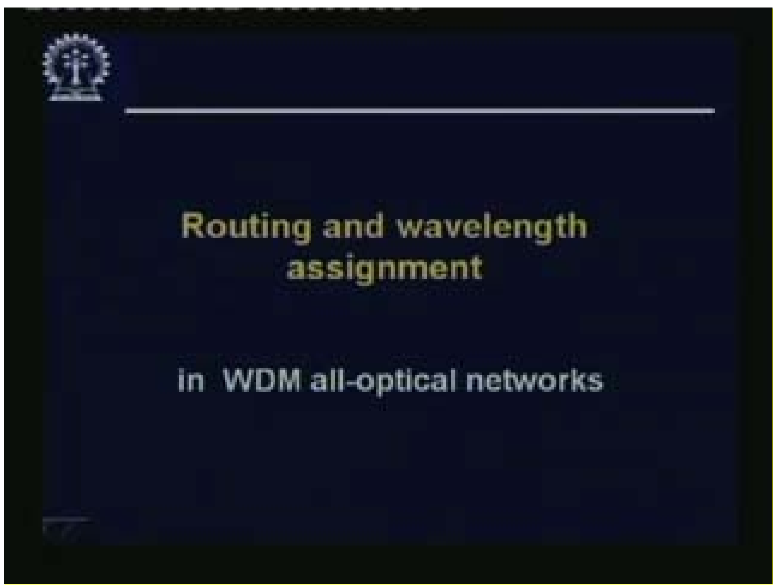

Routing and wavelength assignment to what? Well routing and wavelength assignment means that we have some stream of packets or whatever data or whatever communication is going on from one source to one destination. These sources and destination, point to point connection is point-to-point connection directly sends the fiber that is simple but in general, they will not be directly connected. They will go through a network; they go through some intermediate notes to reach the destination. So for this stream, we have to route one problem and the other thing is that maybe they are all the stream right some particular wavelength for the time being. Let us assume that it is continued on the same wavelength. So we have to assign one wave length, so we have this problem of routing and wavelength assignment.

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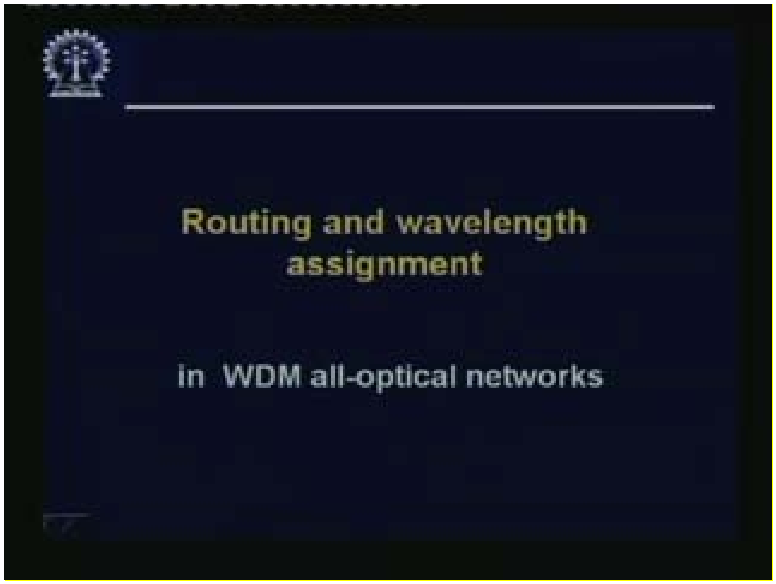

in WDM all optical networks of course routing etc., very easily in the electronic domain, routing in the electronic domain how it is done etc., we are not discussed it, In the these series of lectures but routing, I mean we are talking about a simple kinds of routing problem here. So we will talk about routing and wave length assignment.

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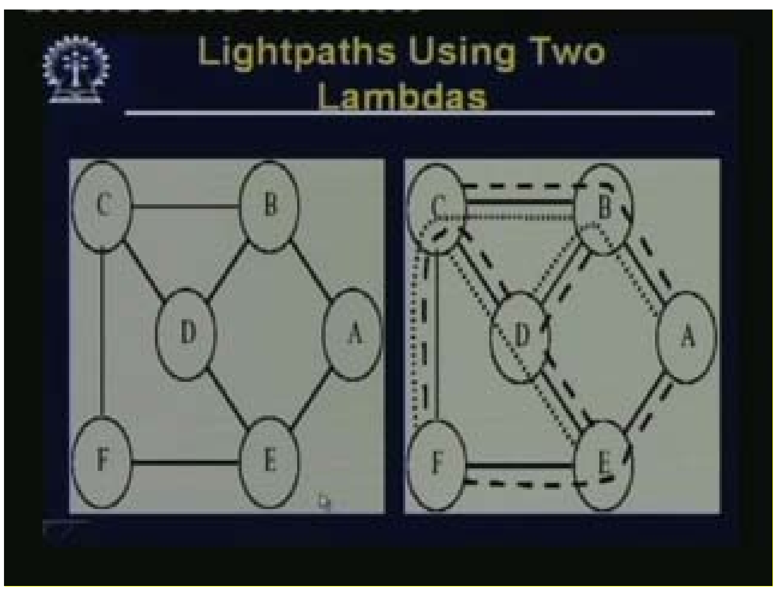

So this is an example of light path establishment, suppose you have these ABCDE these are connected. In the first part, the left half of the figure what we have is the physical connection from A to B, there is a connection and B to D there is a connection and so on. In this one-RW, routing and wavelength assignment has already been done and some of the wavelengths and some of the links have been used. So here only 2 wavelengths are used, let us say a A to B they are not connected say A to C the A to C light path has been established via B so A to B, there will be a switch which will switch the [noise] and suppose this dashed line is the LAMBDA 1. So the LAMBDA1 coming through this fiber from A to B that is switched to lambda one LAMDA 1 using the same wavelength to the outgoing fiber from B to C.

We have light a path-established between B to C. similarly C to D, there is a light path B to D, there is a light path D to E there is a light path E to F there is a light path D to F, there is a light path and so on, using the same LAMDA 1 then I want to connect E to C. I cannot go from E to C after say LAMDA 1 has been assign I cannot go, but from E by LAMDA 1 to anywhere because all the outgoing fibers the LAMDA 1s have been used up this side, for a this side for B and this side for F So in order to connect from E to C, I use the another wavelength. Which LAMDA 2, which connects me higher D and the D cross, connect this particular LAMDA from this fiber to this fiber. We will get a direct ~~[noise]~~ light path from E to C. Similarly, we will get a light path from B to F using LAMDA 2A to B using LAMDA 2 and this way, they are all connected.

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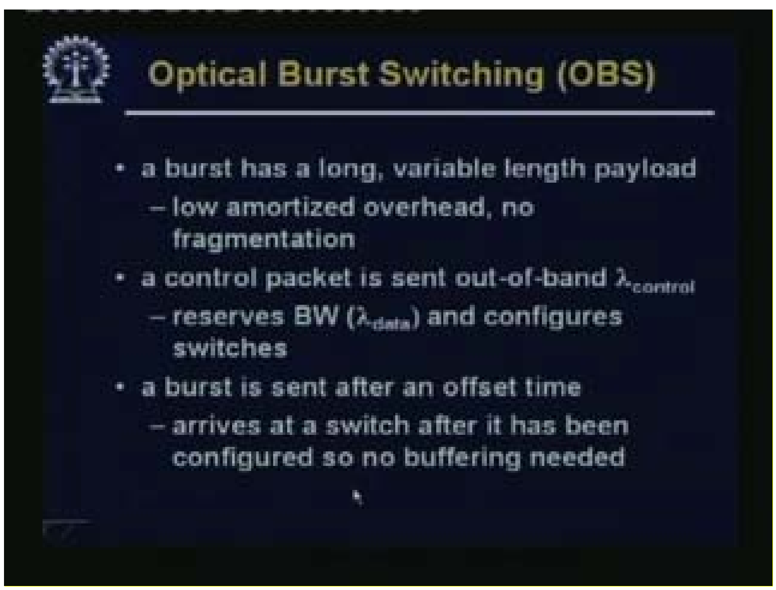

A burst has a long and variable length payload; if it is long, low amortized overhead no fragmentation. A control packet is sent out of band that means using some other lambda LAMDA control and reserves bandwidth that is LAMDA data reserves a particular bandwidth along a particular path and configures the switches. So it is like a setting up temporary light path from the source to the destination burst is sent after an offset time, it arrives at a switch after it has been configured. So no buffering is needed, so our original problem is of not having optical buffer. So buffers in the optical domain that is avoided in this fashion.

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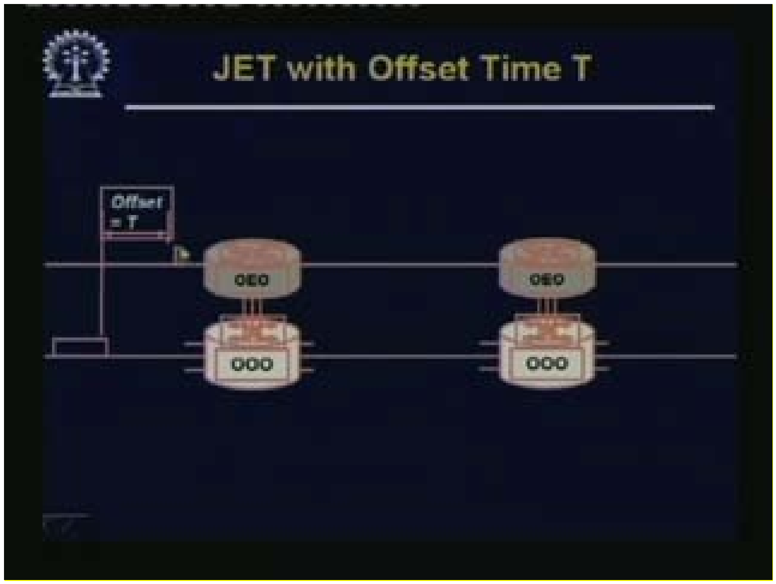

So what will happen is that, this will now moving towards the other end to the next node and here this will again go through the O to E and then switch configuration and then again E to O and go to the next half and this delay etc., is calculated in such a fashion that when the burst arrives, what happens is that we when the burst arrives at the intermediate node, the switch fabric is already configured. So you do not have to store it, you simply passes through the optical domain. So that is

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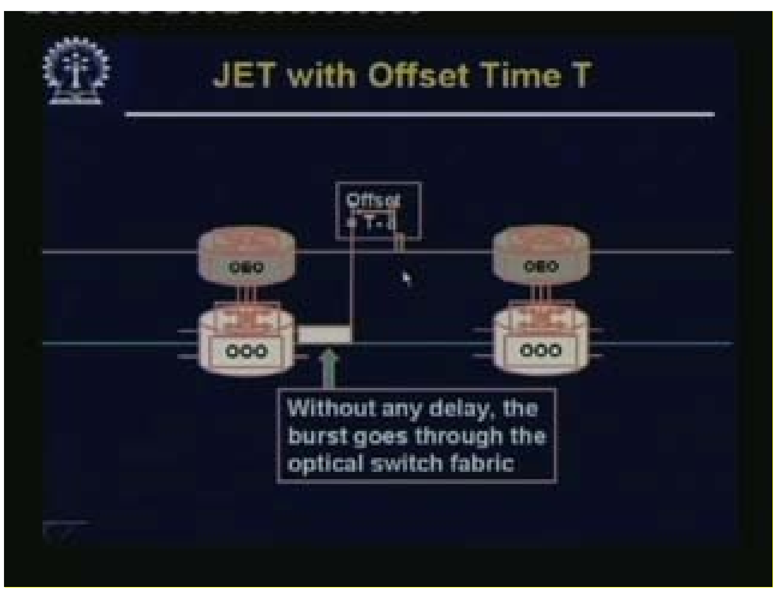

So that is nice so offset of course is now T-λ, because it spent λ amount of time over here. So without any delay, the burst goes through the optical switch fabric, so depending on how many intervening notes are there, you have to have this original T, so that finally when the T is exhausted offset but you have also reached your destination.