# Fiber - Optic Communication Systems and Techniques

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## Lecture – 44
## Introduction to WDM components

Hello and welcome to NPTL, MOOC on Fiber Optic Communication Systems and Techniques. In this module we will start looking at the WDM components that make up an optical fiber communication system. And we specifically call this as WDM components, because WDM is a standard technology that is used in optical communication systems. The fiber bandwidth is divided into multiple bandwidths ok, each in the frequency domain or frequency division multiplexing way.

But because of the use of, you know wave length on the natural unit of light measurement light this one measurement. So, we normally talk about wavelength division multiplexing although the concept is essentially the same, because wavelength and frequency are related in a one on one manner. So, you could of course, talk about frequency division multiplexing, but because of the wide use of wavelength instead of frequency as the unit, we call this as WDM or Wavelength Division Multiplexing.

And this is wavelength division multiplexing as I said is because you take this total available band, and then you divide that band in to multiple you know short bandwidth sections,. And each bandwidth or each channel as we would now have will have a central carrier and an allocated bandwidth to it. This bandwidth can be represented in terms of the wavelength as I have told you or equivalently in terms of the frequency. We will switch between frequency and wavelength depending on the context hopefully that should not be too confusing to you.

So, you have this multiple channel so, this is channel 1, this is channel 2, channel 3, channel 4 a good optical fiber communication system which is well you know standardized can support up to 200 WDM channels with a spacing that goes anywhere from 50 to 100 gigahertz. So, there is this dense WDM systems with 50 gigahertz, but normal WDM systems are at about 100 gigahertz. Earlier they were about 200 gigahertz, even earlier before we could get to this WDM components right, there was also something called as coarse division multiplexing.

In the course division multiplexing the bandwidth separation was white quite large ok. Here the bandwidth separations are about 0.8 nanometer reduce to 0.4 nanometers in many cases, 0.4 nanometers in dense WDM case.

So, what are these WDM components that that we are talking about?

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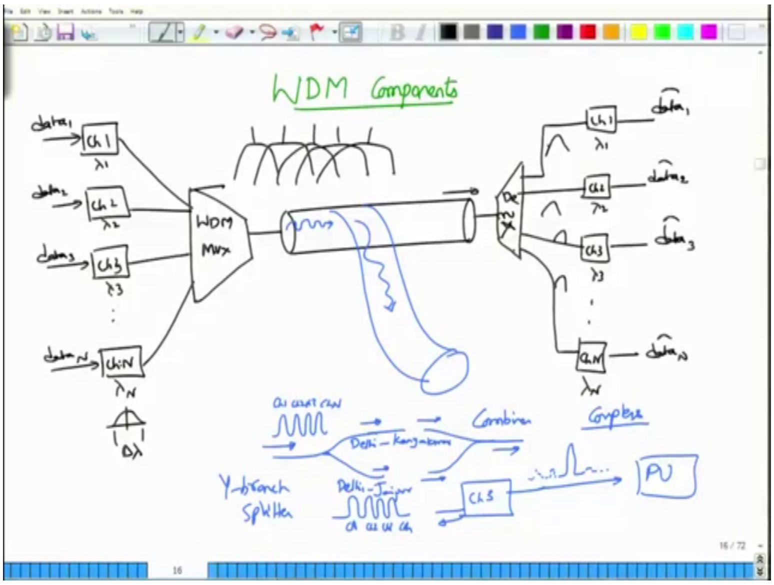


First if you look at the fiber itself. As I said, the fiber has the capacity of carrying many many channels. So, you have your channel 1 with some data that is coming in from a user or some other computer terminal or in aggregate data or voice data that could be coming in from. So, there are various data that from various sources you can actually get this data and then you have this multiple channels. Each channel of course, is centered at different frequencies or equivalently different wavelengths.

So, this wavelength say lambda 1, this is centered at lambda 2, lambda 3 and up to the last wavelength lambda n. Each of them has a certain bandwidth allocated to it. So, this is delta lambda, and we simply assume that this delta lambda is equal for each of the channel.

Of course each channel can have it is own user data or own data out there. And the objective of this WDM system is to somehow combine the data that is coming in from different channels and then to launch into the optical fiber; where at the receiver side you should again be able to demultiplex them, or you know remove their combinations, and individually you have these different channels.

Again these channels are settled at lambda 1, lambda 2, lambda 3 and so on up to lambda n. And you need to be able to get the data out. So, I will call this out data as data with a hat on top of it to indicate that. There are situations where this data may not be exactly equal to the data that you have transmitted because of the errors that have been made.

So, what technology can combine this? Or what is the device that can combine all these channels ? It turns out that there is a device called as WDM multiplexer. See, we just tag on the word WDM for many things. It is actually a multiplexer that we are considering. And this is a multiplexer that is multiplexing signals of various bands or various channels which are well separated in the wavelength domain. So, on the wavelength this channels are all separately occupying their own slots, that is data is occupying their own slots in their appropriate channels. What does WDM multiplexing will do is to combine all these optical signals into one stream, I mean it will launch into the optical fiber. And these are combined at the same time.

So, it is not like you first take this lambda 1, launch into it lambda 2, launch in and so on. So, they all combine at the same time ok. So, that is the WDM multiplexers job. And at the receiver there is something called as a WDM demultiplexer ok. So, WDM demultiplexer will demultiplex all the channels and thereby allowing you to obtain individual channels out there. So, you have a WDM mux and then you have a WDM demux.

This is not at all the end part of what is WDM. Suppose at some point I want to break off this optical fiber ok, or to actually get some of the signals that are instead of routing them through this way, I want to route them to another optical fiber right. So, if I want to do that one, I need to be able to first couple light which is traveling in this direction on this waveguide to be traveling on the other waveguide. So, what I need is some way of branching out an optical signal ok, and sometimes I do not want to branch out the signal, I want to actually combine the signal.

These 2 are complimentary divides. They are actually passive bidirectional devices, meaning that when you send in an optical signal in, this way the optical signals separates out into 2 components it will be the same information may be some phase change will happen, but essentially it is a same signal that is going in this one. So, this for example, is maybe say Delhi to Kanyakumari. So, this is the optical fiber that we are using there, but if I want to send the signal to say Jaipur, this would be the fiber that I have laid which will carry signals from Delhi to Jaipur ok.

So, the optical signals that are being carried or the WDM signal that are propagating from Delhi to Kanyakumari, if some of them have to be routed to Delhi to Jaipur, one way would be to copy the entire stream, there are better ways of doing this I will tell you the better ways of doing this one; is to first copy the entire different channel. So, these are all different channels so, this is channel 1, and channel 2, channel 3, channel n and so on.

So, same thing you copy everything here, and then you select only one of them. So, maybe only the lam channel 3 is supposed to go to Jaipur. So, you select only one of them, and then reject or suppress all the other wavelengths. So, you do not have any wavelength here no wavelength, and then this wavelength has been selected and again no wavelengths. And you pass it on to whatever the processing unit, local processing unit that is there in Jaipur route, ok.

So, this requires of course, to actually have the ability to have these devices; which will be able to copy the signal onto the other branch, maybe when they copy there will be some amount of delaying or some amount of phase shift that is possible. But it is still possible for us to actually make divides which will allow you to copy the information in more or less the same fashion. And these devices are called as y branch devices. One which actually splits the signal into 2 is called as the splitter, and the other one which combines is called as a combiner. Together, sometimes they are called as couplers.

These couplers as I have told you, a lossless coupler will actually take the input signal and split it into 2 equal parts or maybe different parts, but the total energy in each of them arms when you combine them will be the same, or if you individually calculate will be the same. A combiner will take input from 2 different optical fibers and then give you the single optical fiber which will carry the signal. So, this couplers is also very important device for us.

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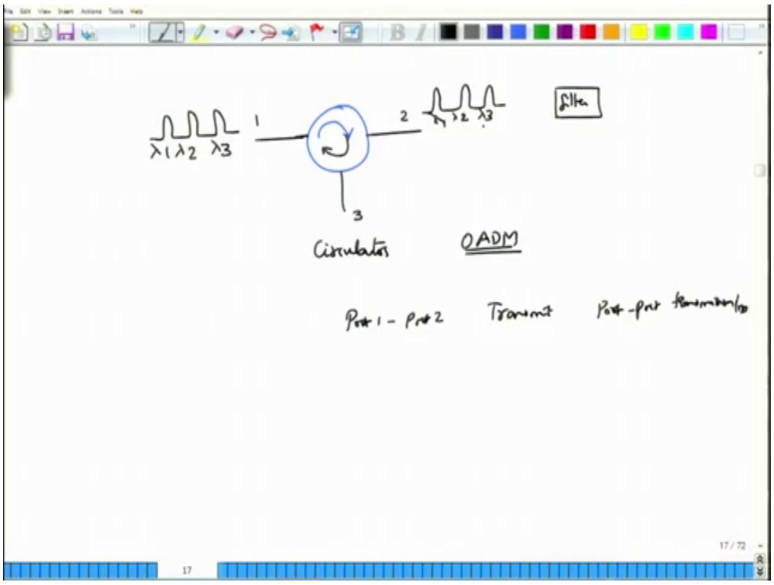


Now, instead of a coupler we might elect to use what is called as a circulator. A circulator is a very interesting device, what it does is, it actually has 3 ports. We will talk more about all these devices. I am just giving you an overall idea of what are the different WDM components that we use ok. So, this is port 1, port 2, port 3 and the working of this circulator is actually dependent on the direction of the arrow.

So, the direction of the arrow is seems to be like going from one to 2 which is correct, and then what is what it says is that, this arrow continues in this manner. So, it goes from 2 to so, this circulator ok, it is a very important device in what is called as optical add drop multiplexers ok. What is an optical add drop multiplexer? Suppose I have signals coming in from 3 different channels.

So, call them as channel 1, channel 2 and channel 3. What the circulator does; is to take these signals from port 1 to port 2, not to port 3. So, port 1 to port 2 is called the transmit port ok, there might be some loss which we will call as port 1 to port 2 transmit loss, or simply port to port transmission loss. So, port to port transmission loss is possible.

And this is the transmit port of course, now what happens? All these signals are copied onto 1 2, I mean second port the same signal. So, these are the channels that we are copied. So, let us make them lambda 1, lambda 2, lambda 3 to remove any confusion between the port numbers and the channel numbers.

Suppose here I put in a selection of filter or actually maybe we should have taken this one in a slightly different manner. So, let me just go back to it, circulator is fine. So, the way to put that one would be slightly different. So, I will actually have a circulator itself.

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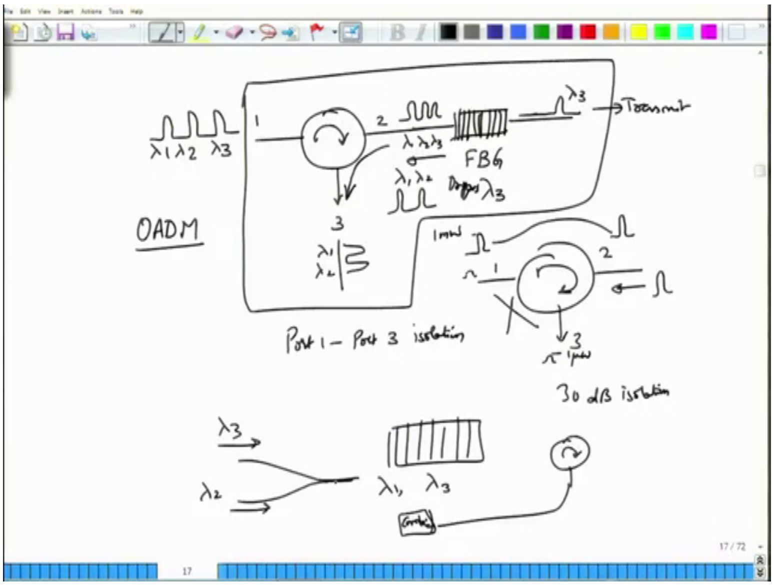


So, I will have a circulator here 1 2 and 3 ports ok. Now here I will have a filter, but I do not have any filter, I have a very specific filter which I will call as a fiber Bragg grating ok.

So, this is a grating actually which is created out of an optical fiber itself. And this is this specific grating is called as a fiber Bragg grating, and this will act as a filter or a selective component. And the characteristic of this fiber Bragg grating is that, it can be tuned to a particular wavelength. For example, I will tune this to say wavelength lambda 3 so that it will allow. So, you had this 1, lambda 1, lambda 2, lambda 3 incident on the fiber Bragg grating, but what this fiber Bragg grating will do after it has been tuned to lambda 3; is that it will allow lambda 3 to pass through lambda 1 and lambda 2 are not pass through or lambda 1 lambda 2 are rejected by the fiber Bragg grating.

So, it will actually carry only lambda 3 out ok, and it will actually push or reflect back lambda 1 and lambda 2. So, you have these 2 channels which are now reflected back, and then they start moving towards the circulator.

So, as they move to the circulator 2, will they go to port 1? No, they will go in the direction that is indicated by this arrow; which means that they will be copied back onto this line. So, out on this line you will have lambda 1 and lambda 2, and this is how the circulator will actually behave.

So, a circulator will take an output; sorry will take the direction in which the arrow is pointing. So, any signal that is launched along 1 will go to signal along 2, no signal will go from 1 to 3. Of course, in reality you cannot have that no signal will go through, there will be some amount of leakage signal onto lambda 1, and this is called as isolation of the circulator. So, we call this as port 1 to port 3, isolation. Isolation simply means that how much of the power in 1, that is port 1 is being rejected by port 3 or the device of course, it will still send out some residual power here, but how much is the difference here.

So, if you have launched one milli watt here, and you get just about one micro watt here, then this device has about one thousand order of magnitude or about 30 dB isolation between the 2 ports; 1 and 3 of course, it is the same notion that when you send in signal at lambda 2 no signal will go to lambda 1. Of course, in practice there will be some residual signal, from port 2 appearing in port 1, and that would again depend on what is the port 2 to port 1 isolation.

So, this device that we talked about which is a combination of a fiber Bragg grating and a circulator is called as optical add drop multiplexer. The reason why we call this as a optical add drop multiplexer is, because I am able to of course, at this point is just kind of rejecting kind of a thing or rerouting kind of a thing, but it can be converted into a add drop multiplexer as well. Here we call this as this is the transmit, and this is the this lambda 1 and lambda 2 are said to be dropped.

So, this is the one that is being transmitted and lambda 1 and lambda 2 are being dropped by this FBG. Of course, you can keep multiple FBGs ok, such that when you tune this to say lambda 3 you can tune this to lambda 1 lambda 3, or in between you can keep these circulators so that they can all come back appropriately spaced, and then you can combine all of those into a single this one device by using a combiner right. So, this is my combiner so, signals can come lambda 3 and lambda 2 may be for example, are being transmitted or are being dropped. And they can be picked up by a single fiber by this combiner.

This is another WDM component.

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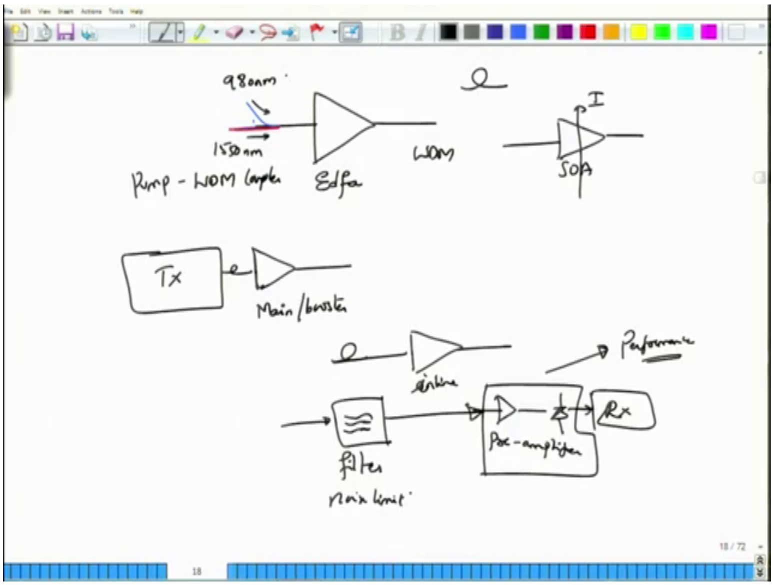


Of course, this component you have already seen, this is the fiber or this is the amplifier, this is the device I mean this is the symbol that we use we do not actually use the fiber symbol to denote the erbium doped fiber amplifier, but this is a fiber that we have seen. And this amplifier can itself occur in 3 different ways. So, you have this is also a WDM component by the way, and as we have also seen this Edfa to operate requires a pump right. And this pump is usually a laser diode sitting at 980 nanometer.

So, you need to have a signal coming in from 980 nanometer on this blue line. And the signal which is at 1550 nanometer should also come in on the red line. And you need to have a device, which can combine both 980 nanometer signal and a 1550 nanometer signal. And then pass it on to a single output, and such a device is called as pump WDM coupler.

Pump WDM coupler because pump is at 980 nanometer 1550 is as actually the WDM channels. So, you could simply call this as pump coupler or we call it as pump WDM coupler ok. So, that one, and this is the erbium doped fiber amplifier which of course, amplifies and things that you already have seen. So, we have talked about this erbium doped fiber amplifier. Of course, the same symbol is also used for semiconductor optical amplifiers. In this case there is no pump coupler requirement, because the pumping is done by the current of the semiconductor optical amplifier.

So, this is also a WDM component because it is used in WDM systems. And this Edfa is used in 3 different ways ok. So, first way is when you have a transmitter, write at the output of the transmitter you place a erbium doped fiber amplifier. This is called as a main amplifier. Somewhere in between the fiber you can use this is called as the in line amplifier ok.

Or sometimes called as the so this main amplifier is sometimes called as the booster amplifier, and this is the in line amplifier which will actually compensate for the losses. And at the receiver side, just before you place the photo detector. So now, this is the photo detector, and just before you place a photo detector, you can actually have a erbium doped fiber amplifier, and this Edfa here is called as the pre amplifier. We will see that the noise characteristic of pre amplifier followed by photo detector is a very interesting and important information, and this will affect our performance of the system, because it changes the noise characteristics totally. We will study that in detail once we kind of look at all the other WDM component.

So, this is something that we will revisit, the combination of an erbium doped fiber amplifier which is a pre amplifier and the photo detector. Of course, at all these places especially in when we are looking at this pre amplifiers or you are actually looking at amplification in general whether inline or booster, you normally also follow up, or you before you give signals to the optical amplifier, you will also actually put in a device called as a filter.

And this filter can be single band filter or it can be multiple band filter, and the ways to make these filters are WDM filters is also something that we are going to talk about it sometime later as we look at the WDM complements. And the job of this filter is essentially to limit noise.

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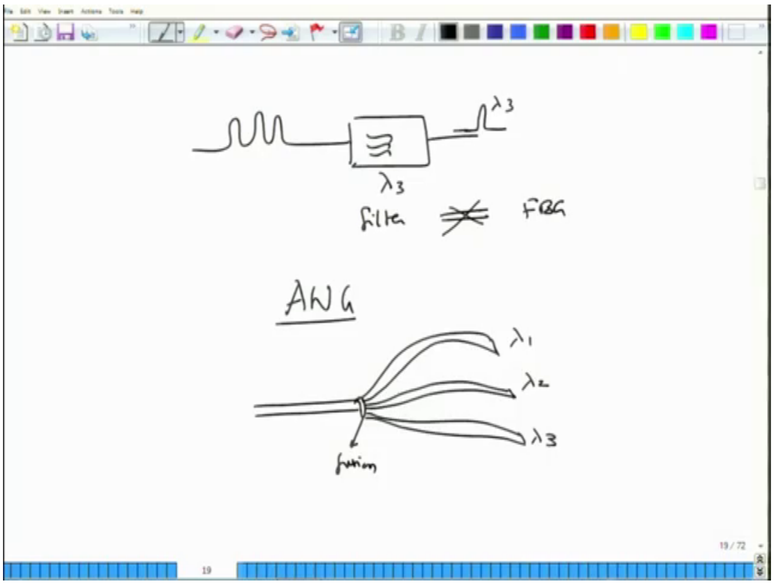


But as I said, you could of course take a WDM channel, and then select a particular channel. So, maybe this selection of the channel would be lambda 3. So, that others are suppressed and there is a lambda 3 which comes in at the output ok.

Of course the lambda 1 and lambda 2 are not being reflected back. So, this is different so this is just a filter, this is not the same as the fiber Bragg grating, because it does not reflect back anything, it simply absorbs the whole thing ok. So, the characteristic of this filter is not the same as that of the fiber Bragg grating.

So, we have seen these devices which you know all of these devices starting from WDM multiplexer demultiplexer. In fact, WDM multiplexer and demultiplexer are essentially filters themselves. So, this is how the multiplexer characteristic would typically look like, these are the central bands, and this is how the overlapping actually happens. So, one has to design a filter such that this overlapping can be reduced as much as possible.

And a demultiplexer also looks very similar to this one, except that there are these individual channels out. There at the outputs whereas, at the input you have on this single channel ok. You can separate them out by another WDM device called as an arrayed waveguide grating. This arrayed waveguide grating will actually be an array of different wave guides ok, of different waveguides that coming out there.

And the selectivity that is which grating takes upon which. So, there is the fusion out there so, you actually fused the input and output out there using a splicer or some kind of a fusion splicer. And each of these will be a different wavelength, because they will be having a certain orientation and they will be having a certain length adjusted according to this.

So, we talked about these devices also is time permits. Otherwise you just have to remember that arrayed waveguide gratings is another way of separating out the different components ok. We of course, have seen couplers which will be very important. Combined couplers can be made to work as splitters or they can be made to work as combiners, they are passive bidirectional, meaning, it does not matter which way you put them together ok. And we have seen this circulators, we have seen fiber Bragg gratings, there is another device WDM device which is kind of a grating itself or which is actually grating called as long period grating ok.

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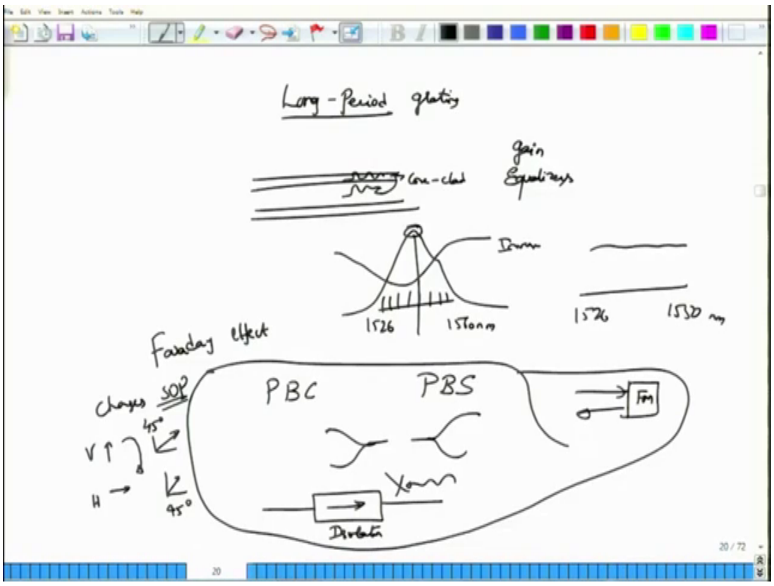


Long period grating as it is name would suggest has quite long periods ok period. Period means periodicity in the refractive index variation. And these are usually used to couple the modes from cladding to the core.

So, they actually do a core to cladding you know mixing up of the modes, and they are widely used as gain equalizers ok. What is the meaning of gain equalizer? We know that the erbium doped fiber amplifier has a gain cross section that looks something like this, from say about 1526 to 1560 nanometer. So, clearly the central one near 1550 is the one that is actually getting lot of gain, but the others are not really that equal in terms of the gain.

So, if you have multiple channels here, it is clear that the central channel where the gain is speaking will have the higher gain while the others will have a lower gain. But using these LPGS designed carefully you can actually have a gain profile equalized such that this will be the inverse filter which has almost same shape as the gain filter out there. So, that overall you will essentially have a uniform gain from 1526 to 1550 nanometer so you have to speak.

Additional WDM components are polarization beam combiners and polarization beam splitters ok. These are devices which are used to combine polarizations and to split polarizations. They are they will just be concerned with a polarization components, then there is also another device called as isolator. This is also very important device, because it can what the isolated does is, it will allow the light to propagate in the direction of the arrow, it does not allow the light to propagate in the reverse direction. So, if the light tries to travel from here, it will block this one.

Then there is what is called as a Faraday mirror ok. So Faraday mirror will simply reflect whatever the light that has been sent in on to the reverse side of it. So, this is another WDM component that will be very useful to us. So, you have an isolator you have a Faraday mirror, you have all these devices which are used. Interestingly this polarization beam combiners polarization beam splitters, isolators can exhibit some polarization dependencies, but they can be made to be polarization independent. And all these devices work on the basis of what is called as Faraday effect. Faraday effect changes the state of polarization.

So, if you send in a linear polarization in one direction, it may turn out to be linear, but with an angle 45 degrees at the output. But if you send in a 45 degrees at the other end of the fiber that is from the other end at the output it will not go back to the linear polarization. It will actually do one more 45-degree rotation and then you will actually get a light which is vertically horizontally polarized.

So, you started off with a vertical polarization, you got a 45-degree polarization, but you take the same 45-degree polarization and pass it through the device in the backward direction; well, it will turn out to be a horizontal polarization; which means that state of the polarization rotates only in a given direction, it does not change the direction.

So, these are all the different WDM components; have given you an overview of this components. We will look at the operating principles of some of these components starting with the coupler in the next module.

Thank you very much.