Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – VII
Module – II
Passive WDM components-II

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Hello and welcome to this module on passive WDM components we will continue the discussion.

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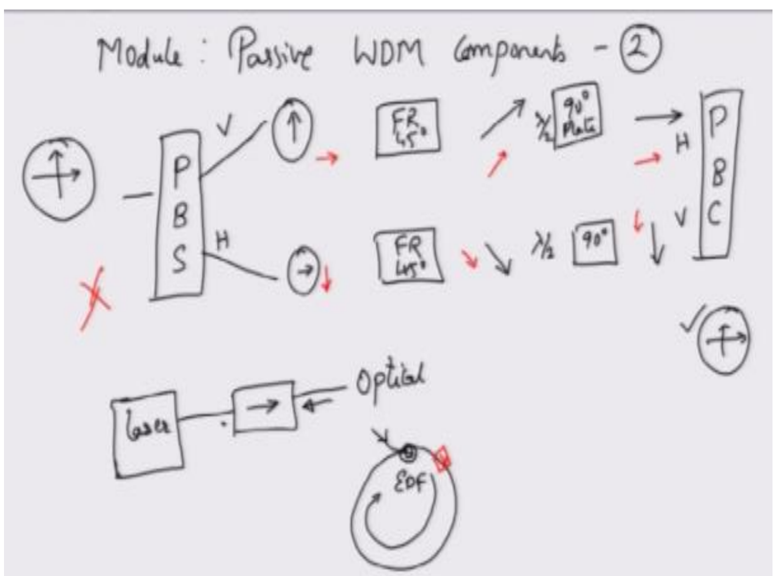

Isolator in the earlier module we have looked at isolator which is polarization dependent but clearly I cannot use a polarization dependent isolator because I do not know what the input polarization will be so the simple thing that you can think of would be to actually use two polarization dependent isolators the big idea is that I do not know what is a input polarization but

I can assume that this can be represented in terms of it horizontal and vertical polarizations correct.

I can always break up any incoming polarized light into it is horizontal and vertical Polarized light so I put one faraday isolator for the horizontal polarized light one for the vertical polarized light and that would be my polarization independent isolator let us look at the construction of that so we start with arbitrary polarized light which I can represent in this particular way you have to remember that this means that the input polarization can be expressed as linear combination of horizontal and vertical.

Then we use what I called as a polarization beam splitter which is a device which separates the incoming polarization into it vertical and horizontal polarizer's this can be implemented by a crystal especially a birefringence crystal or a prism okay and once you have separated them into vertical and horizontal polarizer's so you can put in a faraday rotator so let us say we have 45º faraday rotator for both arms.

So I have a similar 45 º polarizer so the polarize after faraday rotation the polarization state will be rotated by 45 º so this would be the polarization state next I put in a 90 º plate or what is called as a λ/2 plate will change my 45 º linear polarization into a horizontal polarization here similar if I put in one more λ/2 plate okay this is another 90 º so which means that the angle again will be rotated by 45 º okay so I put in here the angle gets rotated and 45 º this way polarized light will become a vertically polarized light now.

So I have a horizontal and a vertical put I can use what is called as a polarization beam combiner which will work exactly in the opposite way right it will combine a horizontal and a vertical polarized light into a single polarized beam it contains both horizontal and vertical polarized light so this is a simple polarization independent operation of course if you try and trace what happens from the other side so let us say you start with this in general polarized light this as to be converted into horizontal and vertical.

So you get horizontal and vertical here and at the output of the 90 º plate so this is how you get the conversation and what happens at this point is that this 90 º plate will rotate in a counter clockwise direction right so it will then change from horizontal to this 45 º plate this will again change in the counter clockwise direction in this way right now faraday rotator is a device which is not reciprocal it does not care which way you are input signal is coming in because it will always rotate clockwise by 45 º.

This is a 45 º rotator so this will become horizontal now right and this will become vertical because after clockwise rotation this would become vertical this would become horizontal now this horizontal is going into the vertical arm and vertical is going into the horizontal arm which means the polarization beam splitter will not combine them so PBS or PBC are you know reciprocal devices they can split an incoming polarization into horizontal and vertical they can also combine in horizontal and vertical into a single linear polarized light okay.

So this is how a polarization independent isolator works one of the major uses of polarization independent isolator is in protecting the optical devices especially you want to protect a laser so you put a laser and then put an isolator so that if I have any other optical element that might reflect some light that reflected light will not be reaching the laser and causing instabilities in the laser operation of course sometimes you want to create necessarily some instability in the laser but that is a different point normally want to avoid any signal being reflected back into the laser otherwise it will simply damage the laser, okay. So anywhere wherever you want to put some isolation you can out a isolator, let us consider this very interesting set up, okay.

So here I put what is called as an optical amplifier in the form of a fiber which is called as a Erbium doped fiber and I pumped this erbium doped fiber we will talk about what this means when we talk about active WDM components, okay. So this is an optical amplifier, now I somehow want to create Unidirectional propagation that is I want my signals to propagate only clockwise.

What I do is, I simply put a isolator here which will carry signals only in this way because any reflection will be filtered out but the isolator, so this is essentially where isolators are extremely useful, we will now go to one of the most useful devices called as wavelength filters.

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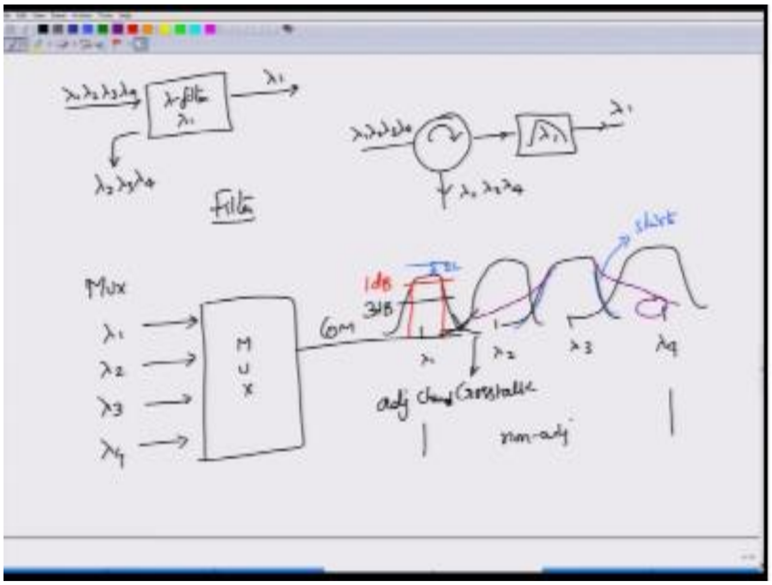

A wavelength filter is a very simple device, suppose I have a wavelength filter which is designed for filtering λ1 which means that I might come in with a set of spectra which has λ1, λ2, λ3 and λ4 at the output what I get is λ2 sorry at the output I get only λ1 because that is the on which is selected by this wavelength filter and all these other wavelengths λ2, λ3 and λ4 are reflected, now if you do not want them to go back to the source right you can put a circulator, right. So you can actually send signals through a circulator so that when a group of wavelengths come in to the wavelength filter which is a λ1 wavelength selection the λ1 will go out whereas onto this port 3 of the circulator you will get λ2, λ3 and λ4 therefore they are not going back into the original direction and no giving rise to some cross talk.

You can so this is called as wavelength filter, okay. YOU can also find what is called as a multiplexer in market, what is a multiplexer for a WDM system to a multiplexer is a very interesting device, it takes in signals of different wavelengths so let us say these are at wavelengths λ1, λ2, λ3 and λ4 and then combines them into the single output called as the Comb output or the common output, okay.

It does so .by having multiple sorry it is not very nicely drawn but is excuse my figure problems but this is λ1, λ2, λ3 and λ4 so it actually combines signals from λ1, λ2, λ3 and λ4 and then passes all of these signals on to the common port, so this is the multiplexing operation in order to create good multiplexers yo0u have to create a nice spectral pass bands okay, you have a band and the width of this pass band is normally determined by one 1dB bandwidth.

That is to say you look at two wavelengths at which point the power would have dropped from to 1dB of the maximum value and that would be the pass bandwidth of course the traditional way of talking about the bandwidth is to talk about 3dB bandwidth 1dB gives you the flatness of the filter bandwidth, the 3dB is the more common way of specifying the bandwidth, you can also see here that a portion of the signal goes into the second region, right.

So this is causing what is called as the crosstalk that is if I have a signal at λ1 a portion of the energy at λ1 goes into λ2 because λ2 is adjacent to λ1 this is called as adjacent channel crosstalk okay assuming that these are all different channels then this is called as adjacent channel crosstalk, okay. Sometimes you will also see what is a non-adjacent channel crosstalk okay, non adjacent channels are those which do not like they are besides each other they are lying far away from each other.

Finally these filters or multiplexers also have what is called as an insertion loss so this is the amount of insertion loss for a typical multiplexer this insertion loss will be anywhere about 0.5 to 1dB, okay. Sometimes slightly more than that but 1dB is a very typical insertion loss these carets which you can see right so you can see here these are the skirts of the pas band these skirts is their quite long, right.

So for example I might have a hypothetical filter which has this kind of a skirt, right. This is bad for me because it means that there is a significant amount of crosstalk into the neighboring channels. The goal of multiplexers would be to try and make this pass band scart in fact for the filters also to make the pass band scats as narrow as possible. One other problem that actually occurs with filters is that.

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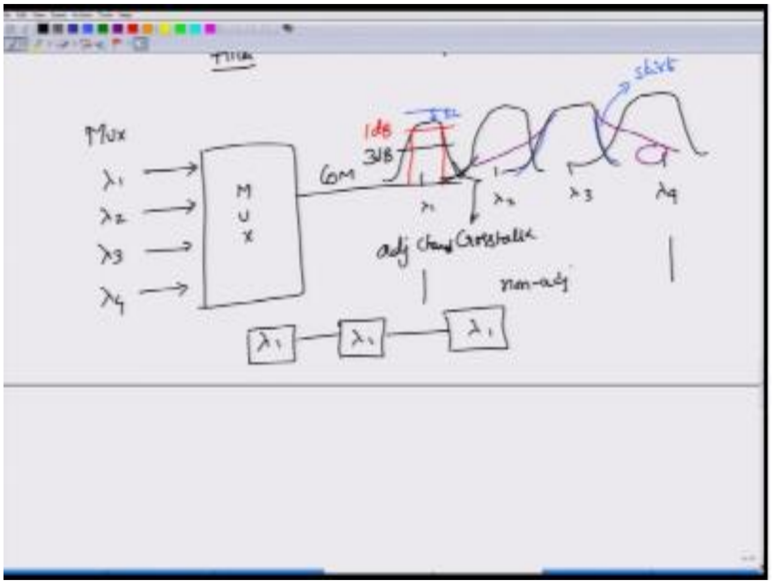

If I consider the same wavelength filter but I case cast them as and when something that happens when you are looking at a long distance transmission at each span just before the inline optical amplifier you will put an optical filter in order to limit the amount noise entering into that particular wavelength. So overall if you see over say 10 or 20 spans of propagation there are about 20 filters and if you now look at the overall response of the filters, the overall response would have narrowed down, so it might actually cut down some of the input signals spectrum.

In order to avoid this problem you have to have a flat response and this flatness of the response is measured by the 1 dp band width of the filter, okay. So this is one of the things that you will have to take care when you are looking at system design for a n span optical communication system, alright. So we will now look at some technologies which are used to implement multiplexers and de-multiplexers, de-multiplexers do they exact operation, I mean do the exact opposite of the multiplexing operation, okay.

So we will look at some techniques which can be used for implementing this wavelength filters and multiplexers.

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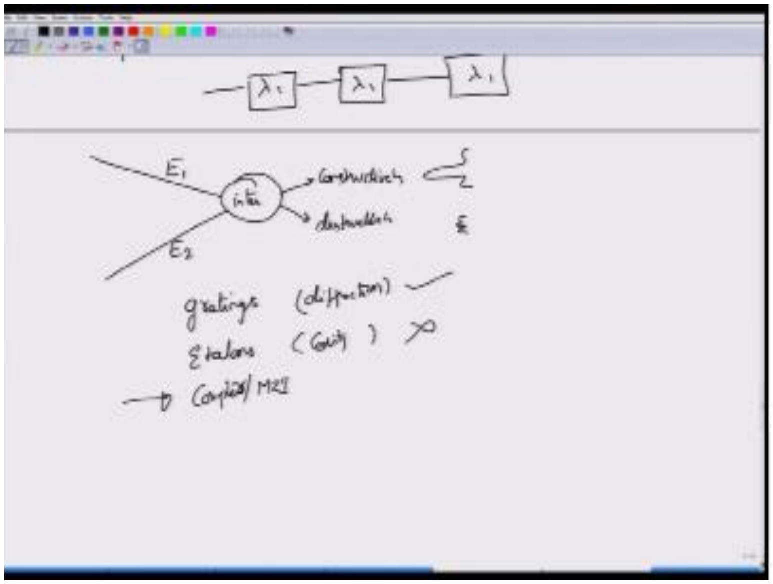

All these techniques can be taught of as based on one simple idea all though the idea is simple in practice they are quite difficult, the idea is that when two waves come in, okay so let us call this is as waves E1 and E2 of typically the same frequency they can interfere, okay interfere constructively or destructively. If they interfere constructively intensity will be maximum here, if they interfere destructively then the intensity will be minimum here, okay.

So this simple phenomenon of constructive and destructive interferences is the basis of many wavelength filters. Filters wavelength filters can be classified in two types which based on the physical principle involved gratings are typically diffraction based once, okay and you have what are called as etalons, etalons consist of a cavity constructive and destructive interferences of wave inside the cavity and then you have coupler or MZI based devices that is Mack Zehnder interfere meter based devices which is implemented by putting two couplers and a path link difference between the two.

We have already covered this last one so I am not going to talk about that in the previous module we have covered this, so we will look at gratings etalons again are kind of little difficult to talk about, I mean to derive the equations it little DTS so we will not derive equations for this, but I will give you the final results which you can use for designing the fabry perot etalons, fabry perot etalons being the most popular type of etalons, okay. You all are familiar with a grating idea, right what is a grating idea.

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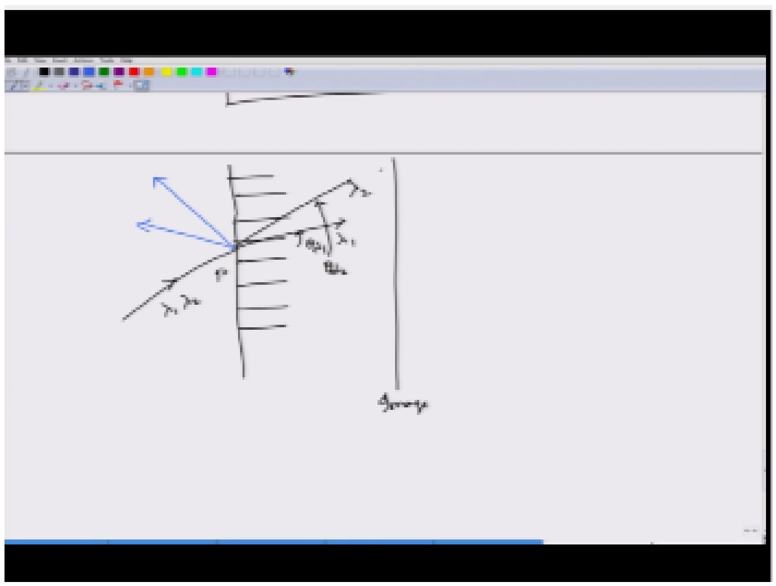

You that if I take two slits, right if they are separated by certain distance and then I send in light assume that light is coming off from a far away regions, so that it essentially approaches it as a plane wave, okay. So we will also assume that this slit width is very small, the slit width is this fellow is very small here, okay light can come in at certain angles and these rays which are coming in are essentially making an angle of θi, okay so these are making an angle of θi and then from here they will diffract with an angle of θd.

This angle is measured both rays of course will diffract with the same angle because they are coming with the same incidence angle θi. The distance between the two slits is what is called as the pitch of the grating, okay P is what I denote as pitch of the grating θd is the diffraction angle again as this rays propagate, okay they are essentially parallel to each other then they will interfere at what is called as the image plane, okay so they will interfere at the image plane. Now what is the result of this interference at the image plane well look at this?

They are essentially parallel because we are assuming that image plane is quite far away and the slit width is very, very small that is the slit width w is very, very small compared to the pitch P which itself is compared very small compared to the wavelength that I am sending in, okay, the pitch itself is very small, compare to the wavelength because we are looking at wavelengths of 1.5 micron propagation right? This is the 1550 nm window, the pitch is typically about $1/10^{th}$ of this, so it’s about 0.15 micron.

The slit width W is about one order magnitude less than 0.15 micron, which would be about 0.015micron, or very nearly in the nanometre range, okay. So what is the result of this interference of this two waves well in order to find out the result of the interference you have to find out what is the angel over which the extra propagation is happening correct? So this angel is, sorry, Distance over which extra propagation is happening.

This extra propagation comes by looking at this one so this is the extra distance for the refracted wave, and this is the extra distance for the incident wave, right? we know that the extra distance here can be written in terms of angel θ d, this is θd , so this angel will be 90/ θ d, this is the hypatanious for this triangle, so you have P*sinθ d, because this would be cause of 90- θ *p will be equal to the adjacent side over here, correct? So this is coming from or Δ d, this is coming from the out diffracted light.

And this is the input condition, similarly for the incident case you have P sin θ i = Δ i ,the total path length difference is of course the sum Δ d and Δ I, right? we will call this as PLD = Δ d- Δi or Δi –Δ , it doesn’t really matter, okay so this path length difference when you multiply this one by the propagation constant will be equal to the total phase shift that you are going to obtain, okay.

So if i assume that the propagation constant is $2\pi / \lambda$ and this is the λ for which I am designing disk rating, then the overall phase shift can be either $2m\pi$ for constructive interference or it can be an odd multiple of π, so that you get a destructive interference, suppose I consider constructive interference then I can remove this 2π on both sides and write down what is Δ d- Δ i, that is actually p*sin θ i- sin θ d also, doesn't really matter here, okay.
So this must be equal to m*λ this equation is called as the grating equation, okay if you look at typical construction there one be two such slits.

There will be multiple slits, okay these are all the multiple slits and this "p" is the pitch of the grating, okay the slit widths are almost neglected light comes in here if you have two wavelengths λ 1, λ 2, then you will have one refraction for λ 1, at an angel of θ d1 so this would be for θ d1, at a different angel which is θ d2 the light for λ 2 will be refracted, so this would be there on the image plane.

This is called as a transmission grating, sometimes you will also look at what is called as reflective gratings so there will be a reflected at two different angels, so that is called as the reflective grating, one interesting way in which you can create a grating, is what is called as fibre bract rating or in general a bract rating.

You are familiar with this bract rating phenomenon from your, x-ray diffraction study in case you have done so, right so you would take two planes and then imagine light falling here one light comes in gets reflected then the light penetrates to the second after the first interface hits the second interface comes back right, it's the second this one the electron goes to second latest plane hits the second latest plane comes back and the comes up again.

So these two will then be interfering with each other, they might again interfere constructively or destructively, okay. Similar effect can be obtained if you considered

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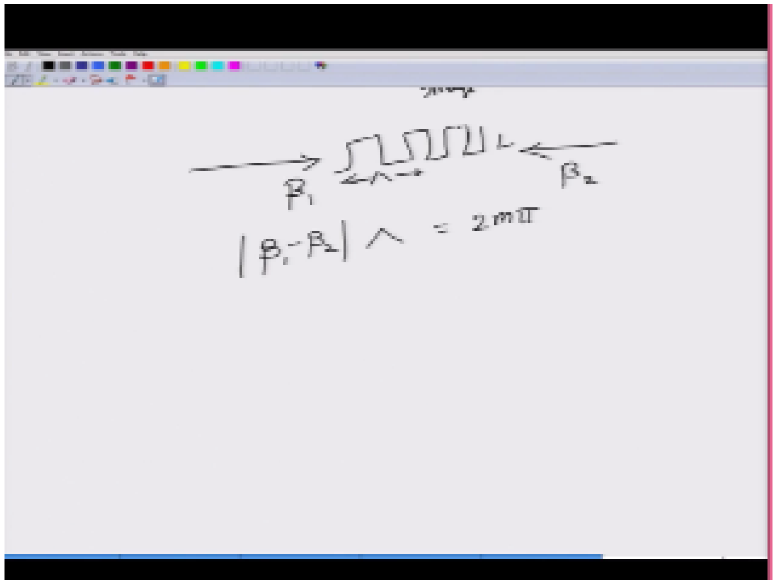

Counter propagating waves, okay of propagation constants β 1 and β 2 for this case the effective propagation constant difference β 1- β 2 if this would be the propagation difference and if this , if there propagate in a region which has a certain length λ okay or a certain periodicity λ this would be the overall phase change.

Remember propagation constant time distance is the phase change right? If this phase change is equal to some 2m π then they will interfere constructively, for the same wavelength $\beta_1=\beta_2$, they are just propagating in the opposite direction, for the wavelength λ_0 the propagation constant is β_0, $\beta_2= - \beta_0$ because β_2 is in magnitude equal to β_1 but in phase is equal to 180 degree. So this is equal to 2 $\beta_{0,}$ so you substitute that into the equation, you get 2mл, let's take m=1 as our solution, then you replace β_0 by λ, of course the actual propagation constant has to be written in terms of the effective diffractive index.

Because this effective diffractive index will be the effective diffractive index over this entire region, so you 2 into 2л /λ neff=2л, 2л cancels on both side, 2neff into λ, this capital λ is the periodicity, this must be equal to λ. This is called as the brag creating equation, this is the brag creating equation and in a fiber you can create, what is called as fiber brag. Fiber brag creating basically comes by creating the index difference inside the core.

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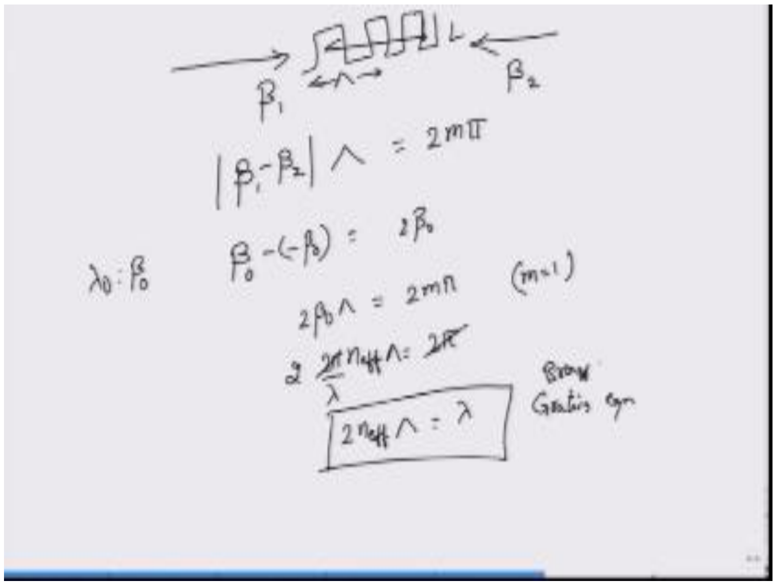

So you can create the index difference with this, so you have high index, low index, high index, low index. How can I obtain this? I can actually take two interfering UV beams, and because the core of the optical fiber contains the photo sensitive material, if you dope the core with germanium, in order to increase the refractive index, it is extremely photo sensitive to the UV light. So when you sending two UV lights which are interfering with each other there will b regions of, you know they are interfering, therefore there will be regions of maximum, minimum, maximum, minimum.

So wherever you get maxima, there will be a increase in the refractive index, wherever it not required it would be a decrease in the refractive index. In fact it would be a gradual decrease, you can also create in fact fiber brag gratings by sing phase make, you can do those phase masks, only those regions which are exposed will be higher index those which are not exposed will be of lower index or the other way around, it really doesn't matter.

The net effect is that, the refractive index in the core is now a function of the distance, which than couples the counter propagating waves, as the wave propagates, there will be an reflection and then it will create a partial wave into the second medium, let s look at it. Suppose I consider this as the high low refractive index, so this is the high refractive index region, low refractive index region, index high and low, this is the period of the grating, so this is my period of grating.

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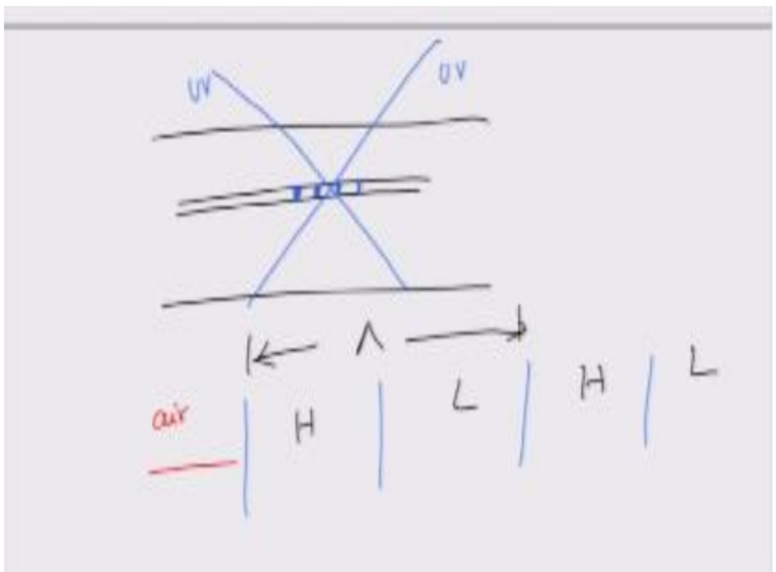

Let' assume that I'm coming with certain wave, this is air for now, this is the simple way of understanding what brag creating does, as this wave comes in, because it sees a different refractive index, there will be a reflection, but remember you are going from lower refractive index to higher refractive index, which means that there will be a 180 degree phase shift upon reflection. So this reflected wave as picked up a 180m degree phase shift.

Then this wave goes into the second medium when it's accumulating a certain phase shift depends on the length of this high index region. If I tailor the length of the high index region such that the phase shift will be 90 degrees, then it will accumulate a 90 degree phase shift. When you go from H to L region, there will be a reflection but there won't be any phase shift picked up the light.

However while propagation there will be another 90 degree phase shift, then this light will come out into the second region, with an overall phase shift of 180 degree with respect to the incident wave. This is the incident wave, with respect to incident wave, reflected wave is 180 degrees, this is 180 degrees. These two are now in phase with each other, these reflected components are in phase with each other, you can see what happens to the other wave here, this goes into the second region, picks up s90 degree phase shift, picks up 180 degree phase shift here, propagate back picks up 90degree phase shift, picks up one more 90 degree phase shift and then comes out.

What would be the phase of this one? Add up 90 + 90 is 180, 90+180 is 360, +90+90 is basically 360 degrees +180 degrees, again the relative phase difference between these two is 2л, 2л phase difference is equivalent to 0 phase difference. So all this three waves are now interfering constructively, you can then imagine that there will be one more way which would also come back and interfere.

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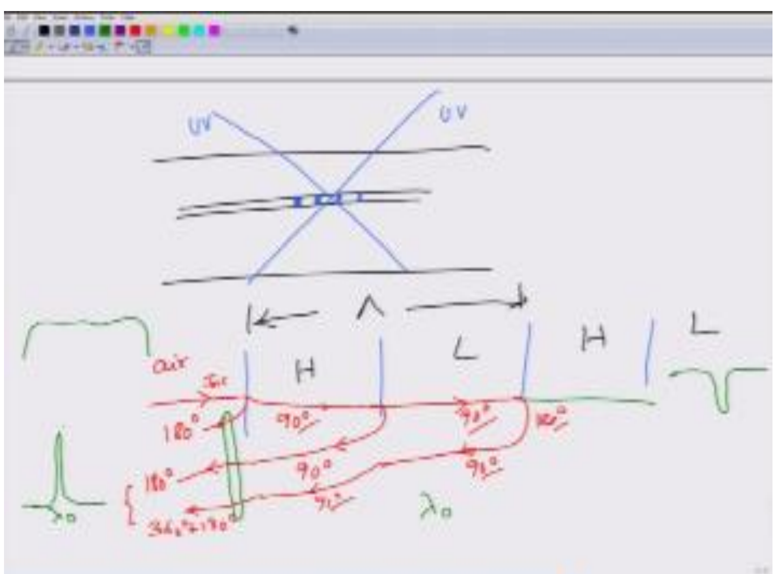

You can then imagine that there will be one more way which would also come back and interfere so given a certain broad wave length band and if I have designed this grating for δ 0 wave length then the reflected wave length will be at or the reflected signal will be at δ0 gets reflected whereas all these other wave lengths get transmitted okay, so this is the transmitted portion and this is the reflected spectrum. Of course the reflected spectrum would not exactly look like this.

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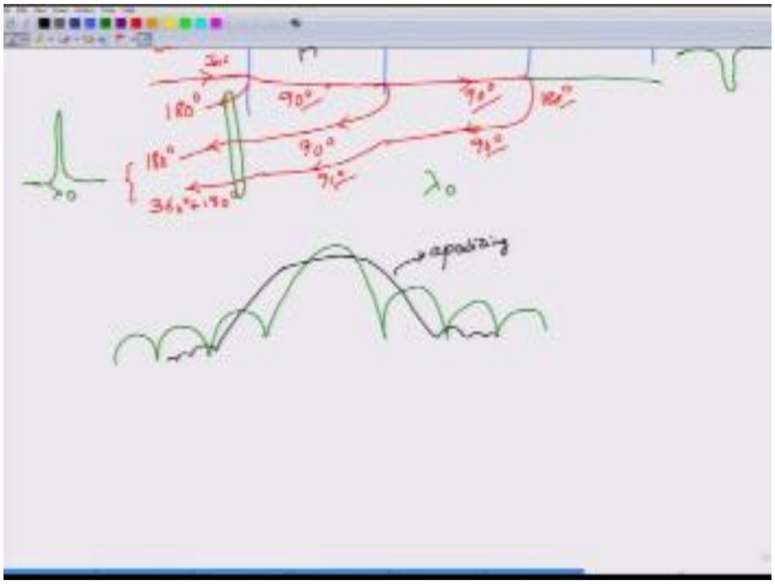

Actually if you take in db it would look like this these are all the side lops okay this side lops is coming because of the refractive index variation this is in fact the furrier transform of the refractive index profile okay if you play around with the refractive index profile then you can actually obtain a slightly better profile okay you can reduce all this side lops at the expense of increasing the main lope width okay.

This process is called as appetizing or this is such a grating is called as aphorized gratings. Okay so this is how of our fiber grating works there is one more devise which is very important for amplifier situation.

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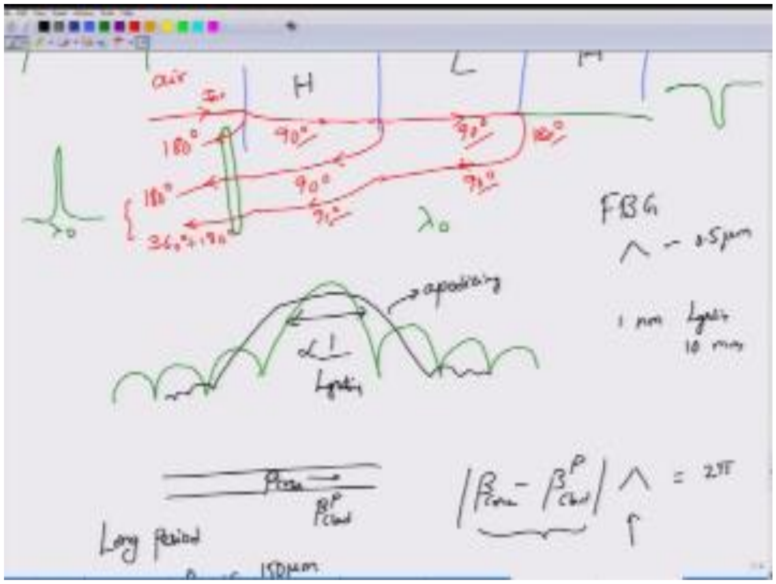

This is called as a long period grating in the long period grating you have the core propagation mode okay coupling to the cladding modes so cladding modes can be an infinite number of cladding modes of which you have to pick a particular cladding mode I mean the construction actually determines all that picking stuff so is you look at the difference between these two in the β in the core and the P^{th} cladding mode.

And if this difference times δ which is the period of the grating if this is equal to 2π or 2mπ then you are going to satisfy this constructive interference and the mode basically gets coupled in to that okay. These are called as long period gratings because if you look at the difference between core and cladding this difference is actually quite small in order to create a 2π phase shift you have to make δ to be very large.

Okay so this long period grating has δ in the order of about 150 to 200micron remember this is the period the length of the grating is different okay, whereas for the fiber back grating for the fiber brad grating or the short fiber brag grating which is implement entirely in its core refractive index by changing the core refractive index this δ is about 0.5 micron however the width of the main in lope of the gratings is inversely proportional to the length of the grating.

In order to obtain say around 1nm lope width main lope width you have to take the grating length to be about a few mm so let us say around 10mm or something. So this is the length of the grating versus pitch of the grating so that has to be remember pitch is the period okay, period is 0.5micron for a short fiber brag grating. So this completes our discussion of WDM components this can be implemented I mean these operations of filtering and multiplexing can also be implements using multi thin layer films you know thin layer optical films.

You can also use what is call as arrived wave guide gratings this also have comparable performance with respect to the traditional things that we have discussed but discussion of these components is kind of beyond the scope of this course so we will take leave here we will stop discussing this passive WDM components in this module. Thank you very much.

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