**Introduction to Photonics**
**Department of Electrical Engineering**
**Indian Institute of Technology, Madras**
**Fiber Laser**
**Lab Demonstration**

Hi all, so last week we saw how to make an optical amplifier. So today we are going to go slightly advanced and build our first laser okay this week you are going to make optical fiber laser okay so how do you make the laser? So how do you make a normal oscillator? So laser is a oscillator right so how do you make a normal oscillator? You give a feedback to a amplifier right you give a positive feedback to amplifier. So you are following the exact same principle in making a optical fiber laser.

So what we do? We take optical fiber amplifier first, and we give feedback to this amplifier, you say optical loop for plotting the feedback and you get a laser, so we call it the fiber laser. So you would have learned about semiconductor lasers, then of course Helium–neon lasers, gaseous lasers are there I mean Helium–neon is (())(1:07) gaseous laser, then you have the semiconductor laser.

And now we see something which is a slightly more interesting, this is a fiber laser, how it is interesting? There are a few advantages which none of these other lasers have, like you know the fiber laser produces laser within the fiber itself. So the light is which is already confined within the fiber, so you can easily take the light, you can easily take the laser to different areas for processing. So where does it find the applications? It find applications in you know it is readily high power, fiber laser can really provide a lot of power.

So it is used in application which should require a lot of power like material processing, material processing cutting, drilling, welding all these things you can make use of the advances of fiber laser and then even medical applications like you know all the fiber is already the laser is already confined fiber where you can easily take it to different places where you need the laser to be so of course it does have a lot of medical application and even defence you can use fiber lasers.

So when it comes to defence and aviation industry or in any anywhere where a light witness is of advantage, fiber is a very good solution because fiber is of course as we know fiber is very small strand of glass, so it does not have that much of weight and it can it is easily it is very portable, it is lightweight and the size form factor is so small and it is devoid of all the electromagnetic interference that can affect to your system. So all this properties make it a very good solution for different applications or different lasers. So these are the main advantages of fiber lasers.

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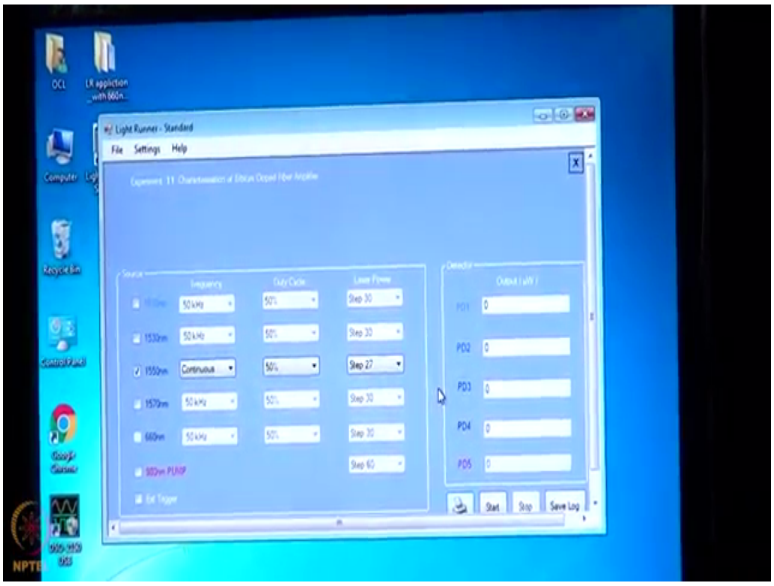


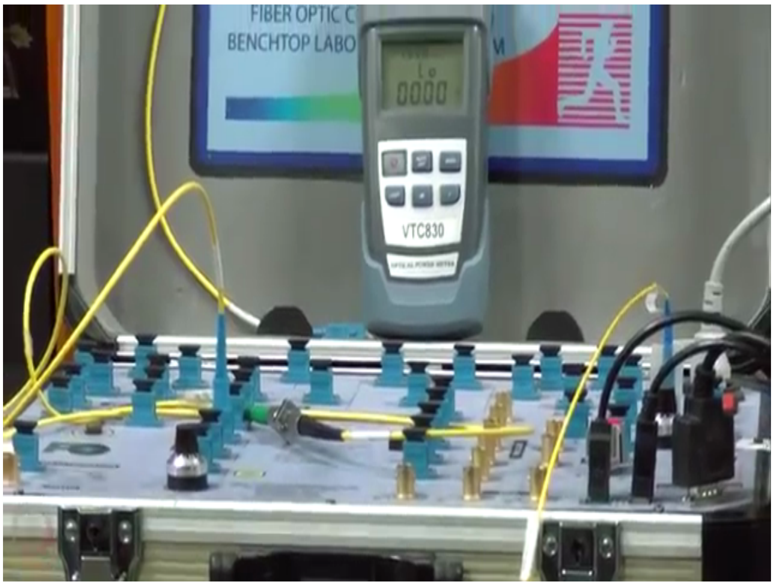


So now we will see how to make one of these lasers the fiber laser. Now so if you remember we are going to use the same kit from last day you remember this kit right this is the fiber optic light (())(2:59) you know you remember this from the last experiment the optical amplifier experiment. So in this what we did is, we made a optical amplifier last time right so there was no feedback there okay.

So this time around will give a feedback to that amplifier and get the laser that is all and we will have a in a different instrument here this is as you can see this is a spectrum analyser this is a really I will say compact spectrum and laser we have here.

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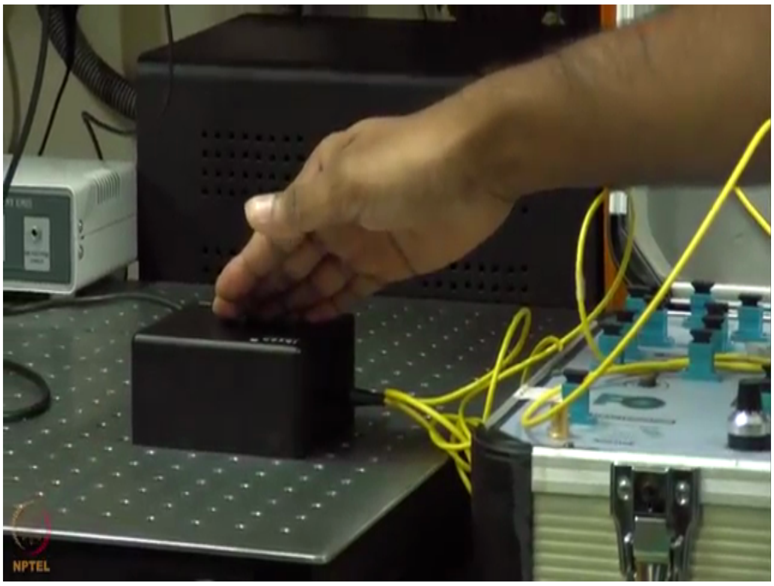


So if you can see this small black box here this black box you can see yeah that is the heart of that particular equipment. So it is it is the Epson IMON integration monitor it is basically what it does is it is a spectrum analyser first of all, so what is this shows is it shows what all frequency components are there in the laser okay. So as you see in our particular experience we have 1510, 1530, 1550, 1570 lasers. So if we put all of them in a (())(4:05) setup you will see multiple peaks multiple peaks in 1510, 30, 50 and 70 like this right.

So now that is what the spectrum analyser is doing that means if you have a like you know we will quickly see how it works the integration monitor. So what is how is a dispersive element? So what does dispersive element does? It disperses the different frequency into different spatial points, so that theory have already learnt, right. So a dispersive element you know it disperses the different frequency into different special elements.

Now at the spatial element we have a CCD, so basically what you have is a CCD array and each CCD array pickups them the amount of light that is falling on it. So you know if the if a pixel is easily a pixel is at 1550 and a lot of light of 1550 comes then the dispersive element makes sure that 1550 light 1550 wave falls in that particular section of CCD only so that a sharp peak is from there.

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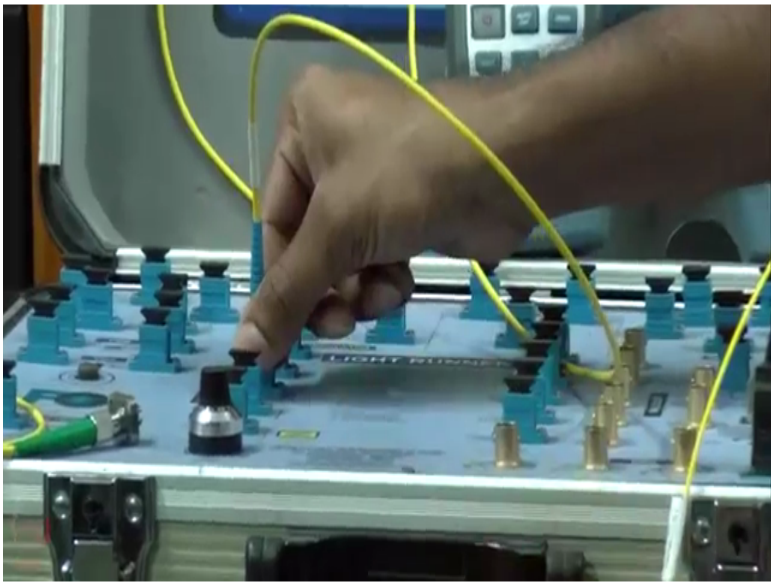

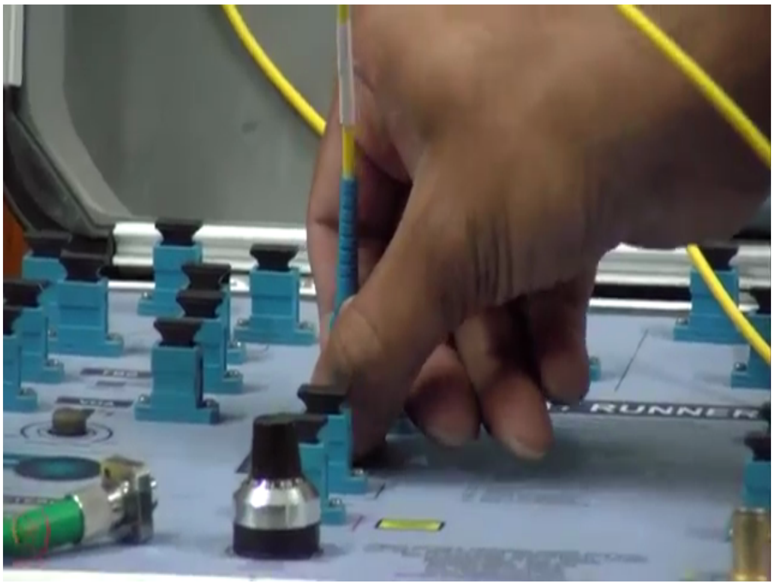

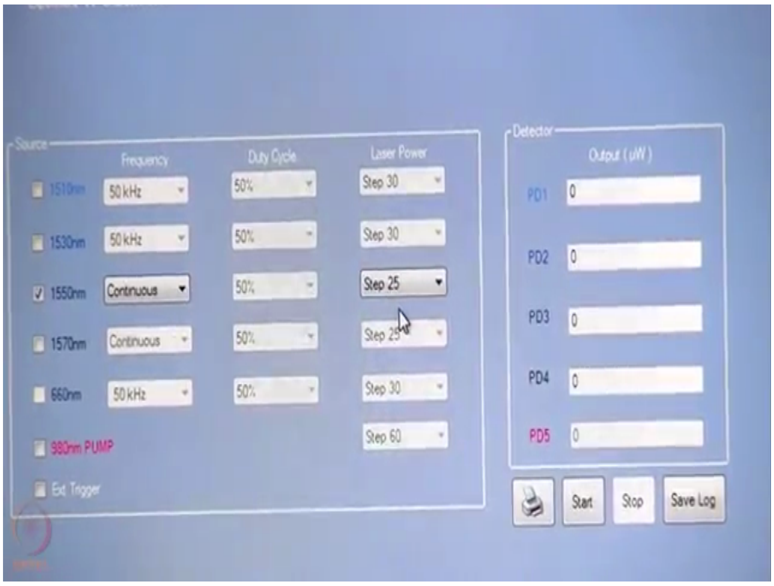
Source
Frequency
Duty Cycle
Laser Power
1510nm
50 kHz
50%
Step 30
1530nm
50 kHz
50%
Step 30
1550nm
Continuous
50%
Step 25
1570nm
Continuous
50%
Step 25
660nm
50 kHz
50%
Step 30
980nm PUMP
Step 60
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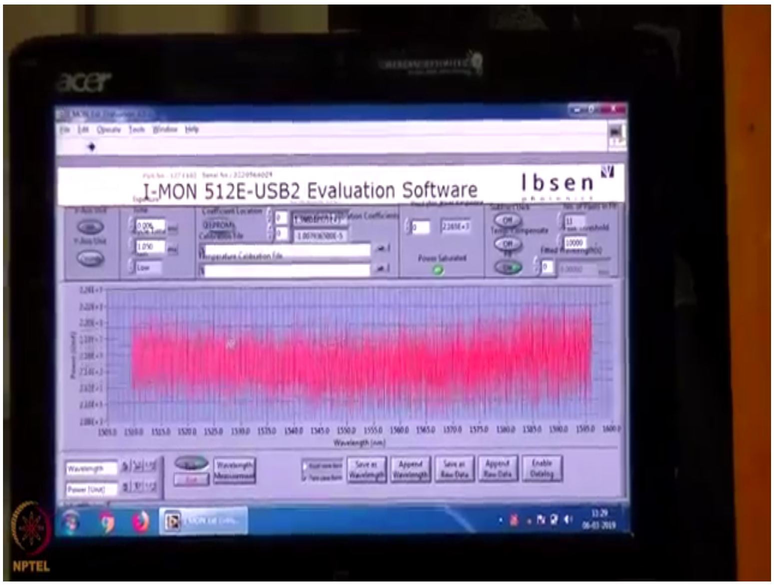


So now we will see how we use the spectrum analyser for that we will use a laser output from the light runner kit so we start with 1550 laser okay connect our fiber to 1550 and the thing is the spectrum analyser this one can handle a power only up to minus 20 DBM, so it is quite a fable devices as in we cannot handle too much of a power. So we have to make sure that we do not put a lot of power into the spectrum analyser, so ideally you have to use it attenuator before giving power to the spectrum analyser, but in our case as the light runner kit has a assess software control of power we will put a power which is less than the minus 20 DBM.

So I have already checked it it is around in the step 25 in the step (())(6:06). So first I will start with 1550 laser (())(6:09) in the continuous mode operation and the step is 25 which is less than it is almost minus 21 DBM okay and we see how the output in the in the in this software is changing.

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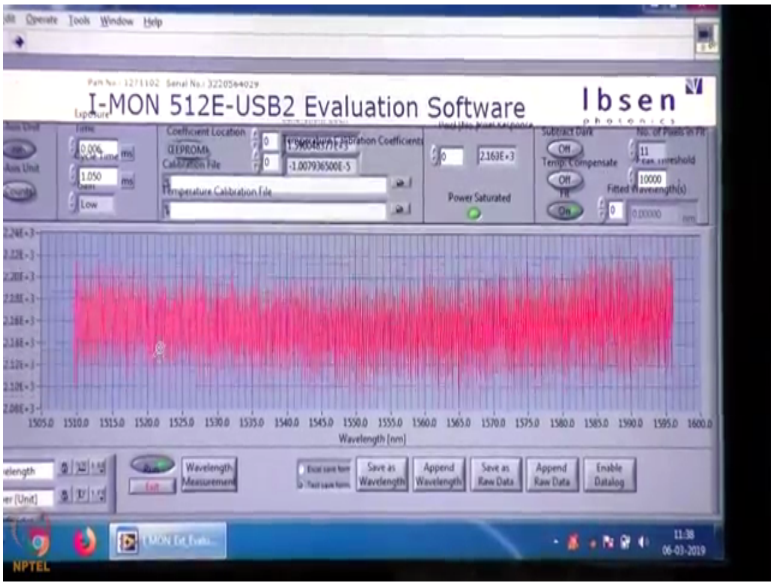


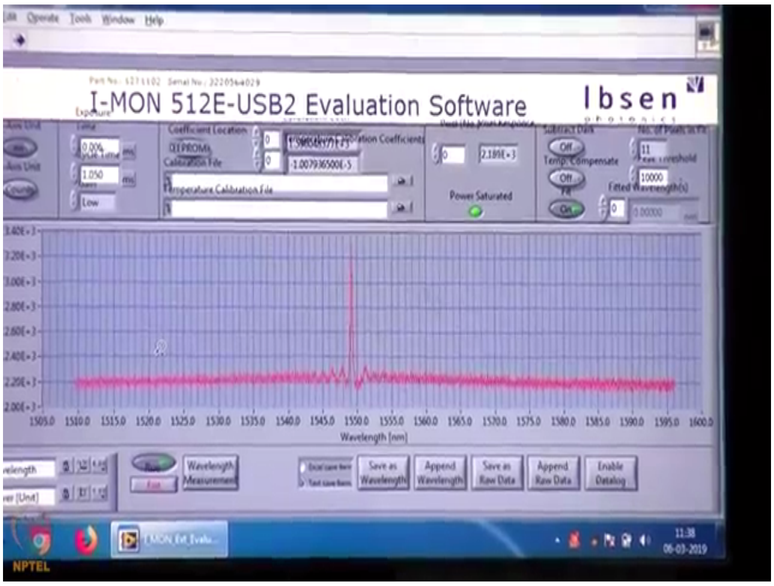


So how it is happening is that CC here is output is given to the software here this I-MON 512E-USB2 evaluation software, so that software will show you what is the power levels of of each wavelength that is input on that. So now again you can see just know some noise now so I am going to turn on the laser now, okay so I am going to start, so I am turning it on now, so laser is ON so you can see that at 1550 around 1550 we have a peak that signifies that the there is a placing that happens at that wavelength.

So as you can see there is now particular frequency that is specific there that is mostly no is there so I am going to turn ON the laser now, I am going to turn around 1550 laser in continuous mode operation at step 25 which is around minus 21 DB of power I am going to start now. So yeah now you can see that a peak has appeared and all the noise has been suppressed, not suppressed the peak is so high that you do not see the noise that clearly, so 1550 nanometer you can see it is around (15) I think 1549 probably, so that is what is being raised.

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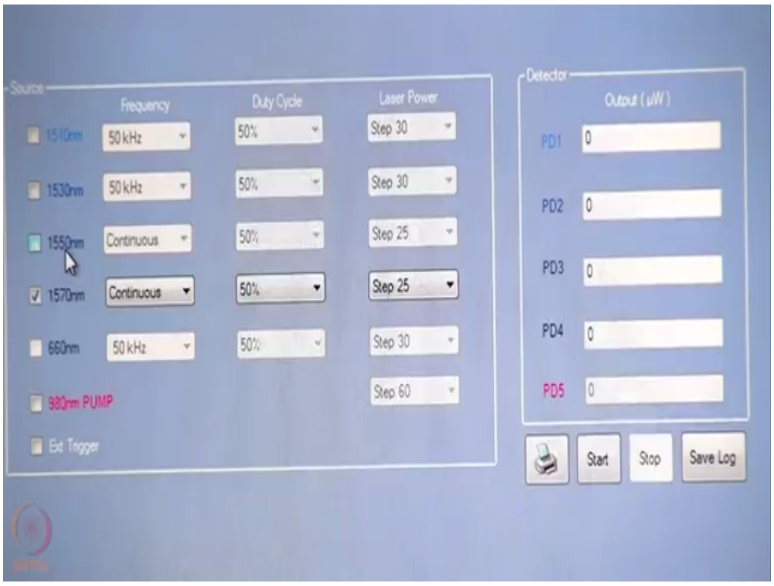


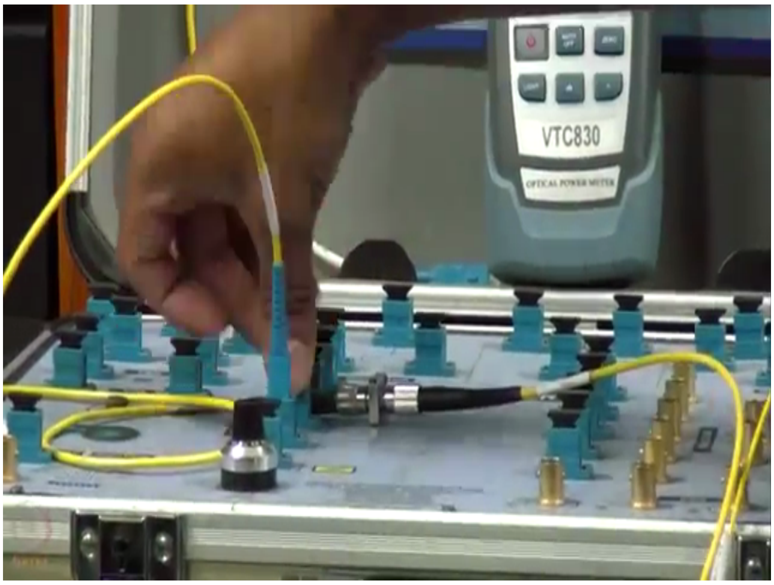

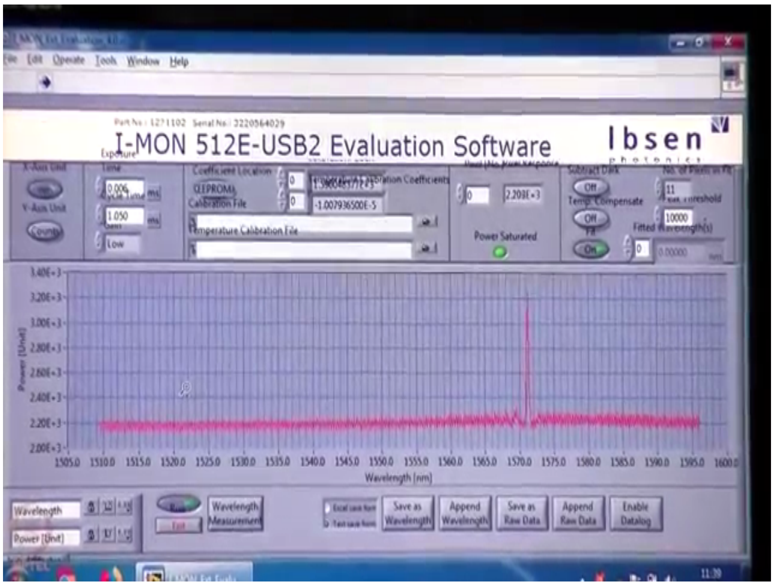



Now we will try and see how the spectrum changes when I change the laser. So I'm going to view a 1570 nanometer laser I am going to select it from the light runner kit, I am going to change the connections here, I put 1570 now, spectrum is slightly beyond 1570 that is it for you like see how the spectrum analyser works it can discriminate in different frequencies and it can also discriminate if you give both of these frequencies together if you put a WDM MUX and then you give you the (())(8:12) it will be able to show two peaks in there okay. So that is basically that is what the spectrum analyser does.

So how are we going to make use of this spectrum analyser because we want to see which wave in this being raised okay so be this time here instead of you making use of these lasers that is provided in the kit we are going to make use of the amplifier right the amplifier that is present in this kit and build our own laser okay. So we want to make we want to know which wavelength we are (())(8:44) which wavelength we are our laser which we are going to build is going (())(8:48).

So we have to of course use a spectrum analyser, you know all the other experiments we are already using a laser whose wavelength was known, so in most of the case we could do away with a spectrum analyser but not in this experience because we want to know which is the wavelength that is being (())(9:00). So yeah now will go straight and do building our first laser.

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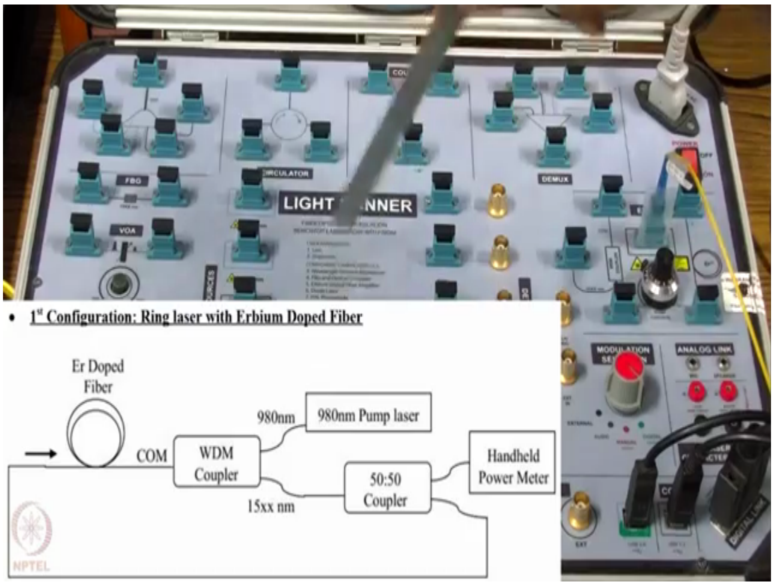


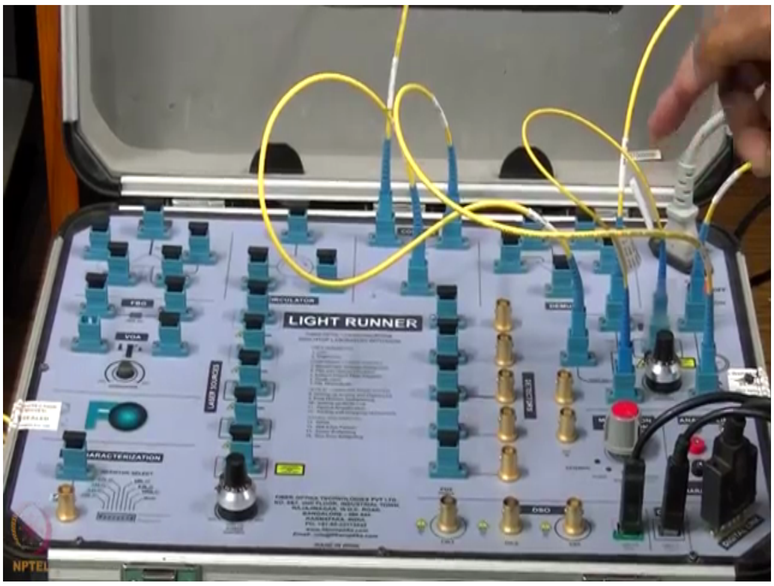

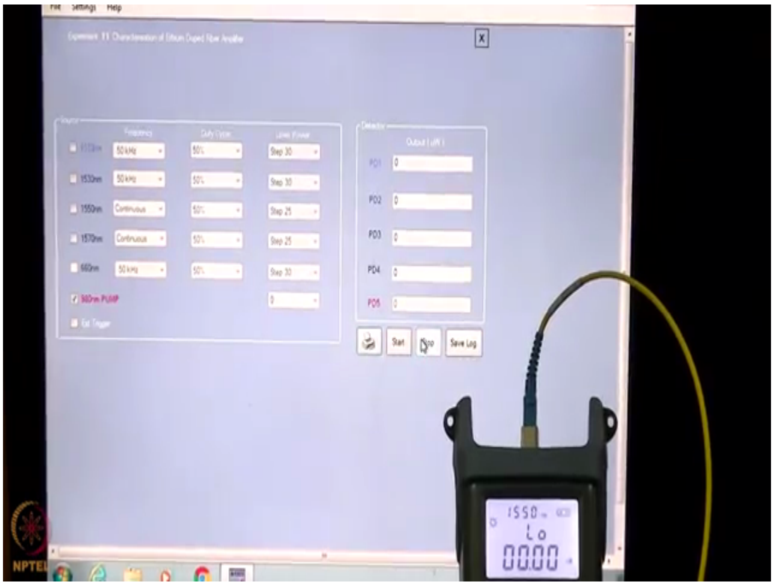

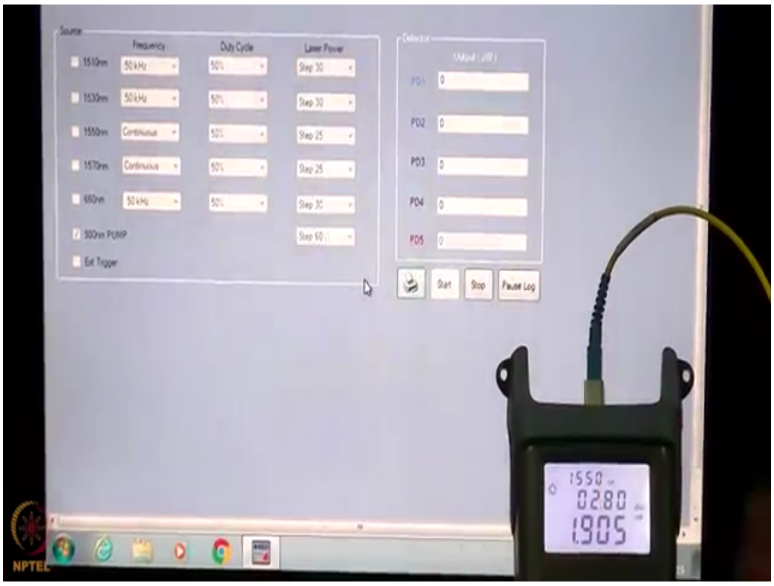

So now we will see how to make the connections here, you are already familiar with the fiber amplifier connection right. So there is only slight modification in that connection so all you have to giving is a feedback, so feedback you had to split the for you for the feedback you have to split the output into two, you have to use a coupler for that, so there is a coupler section, so this is input and input is this is a 50-50 coupler so half of the input comes from the output here and the other half will come out through here, so this is the coupler section.

So you will be using this coupler section along with the EDFA and the half of the output that is taken out from this coupler is used to view how much of the how much lasing is obtained okay and the other half is used for the feedback right. So that is what is (())(9:54). So as you can see in the connection diagram there is no input that is used in this section, so we are going to make a lesser right there is no need of any input, the only input is the pump that is used here that means this section is totally unused and the heart of the section is this which is the EDFA.

Now in the centre lies the EDFA pump, the pump has to be connected to the 980 pump input port in the WDM coupler right here you had to connect it here and the COM port needs to be connected to the EDFA output this is the EDFA air build of fiber this is the fiber and fiber orbit it has to be connected to this COM port and the output so our 1550 lasing or whatever wavelength is being raised is going to come out through this portion right I did because it is the 15 XX port wavelengths around that 1550 region will come out through this part.

So we are going to give that output to this coupler input and we are going to and it will have two outputs this one output 1 and output 2, output 1 you will see we will use for monitoring on a on a power meter and output 2 we will use for feedback, so you will take this output from here, take it and give here as the input of the EDFA and there is internal question that is the erbium doped fiber sitting below this and then you had to connect from connect the EDFA output to the COM port here, so that is all the connections we are going to make now.

As we can see the connections are all set now, now we are going to turn ON the pump laser, okay for turning ON the pump laser we will go back to our software interface here. So as we can see here we have deselected the 1550 nanometre laser because there is no need of any input, this is a oscillator so there is no input, this lesser so there is no need of any input and we have the only input is the 980 nm pump laser. So we have giving a 00 step means there is 0 power and we can discharge the experiment and of course there will not be any output as you can see in this power meter there is 0 output okay.

Now what we are going to do is we are going to increase the pump power, we are going to increase the pump power in steps of 10 or 20 or something and you will see how the output laser power looks like. So as we know laser is a threshold waste, so until a particular amount of pump is there laser will not turn ON okay after a particular point in this pump power you will see that laser gets turned ON and then after beyond it the power of power meter should show a very linear increase in power with the increase in the pump, so you see whether that happens now.

So if that happens we will successfully claim that we have made our first laser right. So we will see by increasing the pump, so at zero you can see that there is going to start experiment there is 0 output, okay so I will at step 10 step 10 we see step 10 so again 0 it is, we see it step

20 but you know step 20 is also not giving any output. So because the pump laser itself starts giving very good power only after step 25 and all.

Let us see step 30, the step 30 we should we should start seeing some output power, so because now the pump is there so some lasing should have happened it was standard to them okay so you can see minus 26 is there. So again this might or might not be lasing probably this is the amplified spontaneous emission that maybe there and then, but these are the AC is the one which gets fed feed fed back and which causes lesser. So the question is whether you have enough feedback?

Now we will go for step 40, okay the step 40 we have minus 2 that means that minus 2 is pretty very pretty impressive person almost 0.5 mainly (())(14:24) of power right so that is pretty very good power. So that means that your laser is ON, okay. Now from here on you should have an increase in power with increase in the pump power, see you have 1.3 DB that is pretty high and then this is step 60 or 3.2 DB DBM power. So that means that this we have made a laser which is more powerful than the inbuilt lasers that is already present in the light runner kit. So that is it we have successfully build the first our first (())(14:59) laser.

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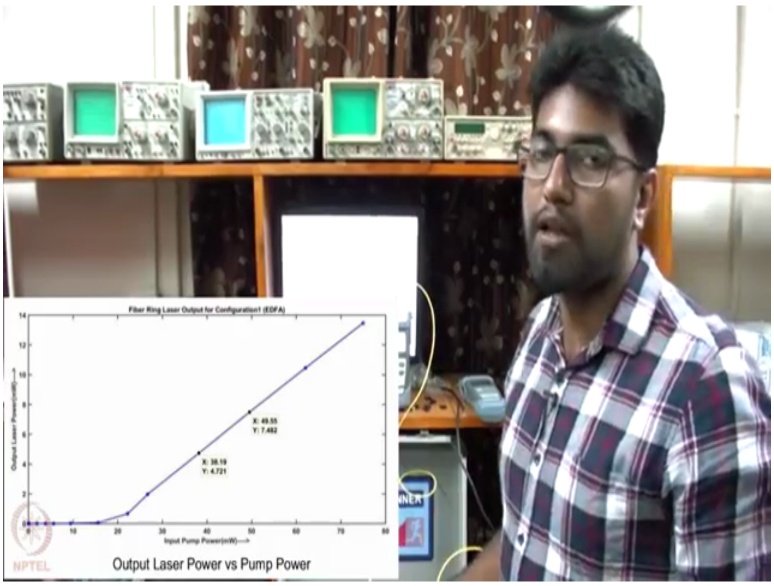


So now what you are going to see you had plot the step increase in the pump power with the output per, as you plot the increase in the pump power with output power what you see is like you know it will be almost 0 and suddenly in starts rising like this, so it is a threshold kind of operation, so that some result should be a flash in the screen now and after this the next part of characterization would be to see what is the wavelength that is raised okay.

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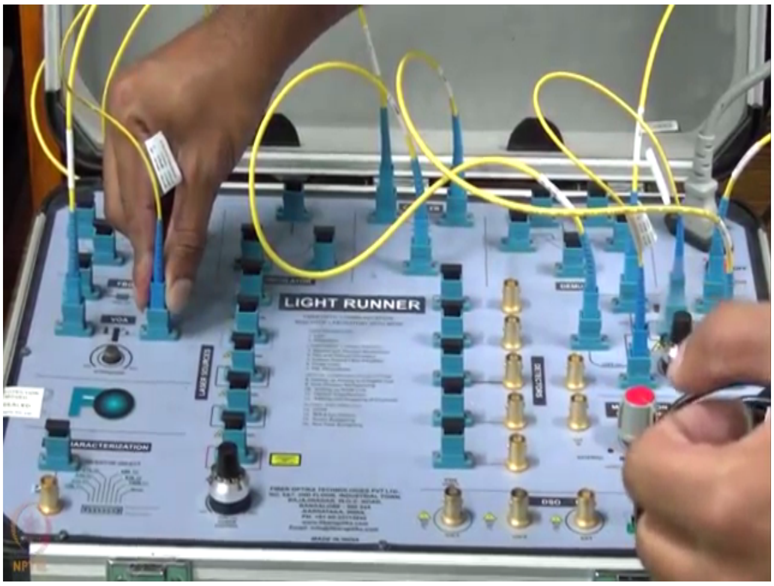


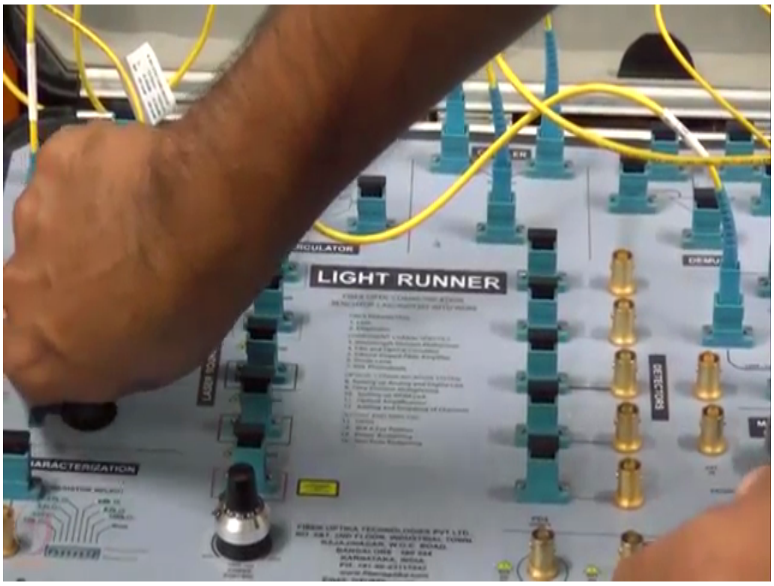


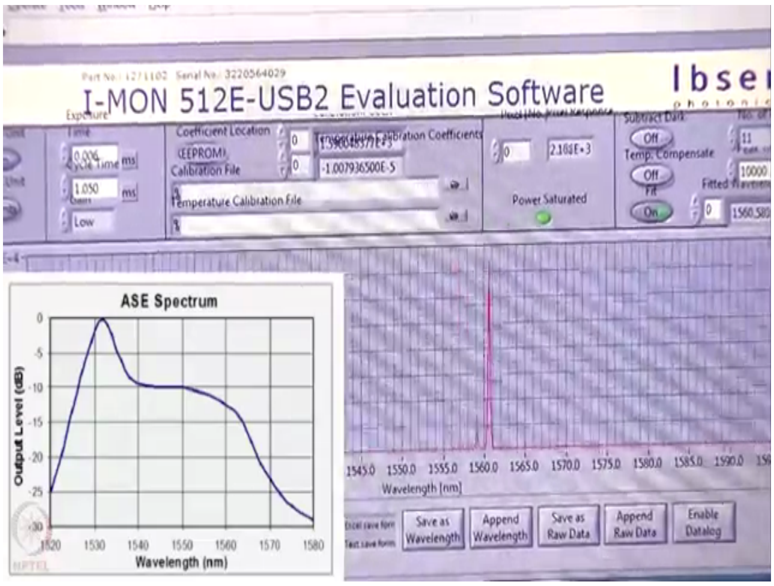

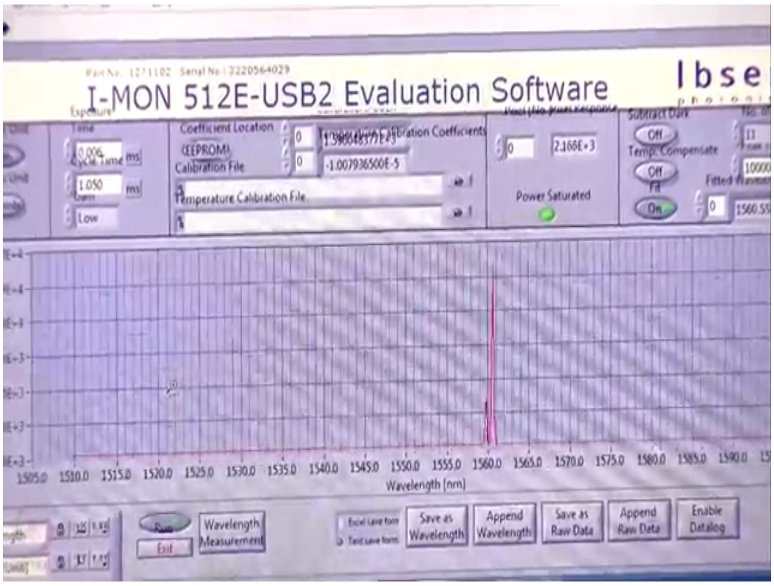


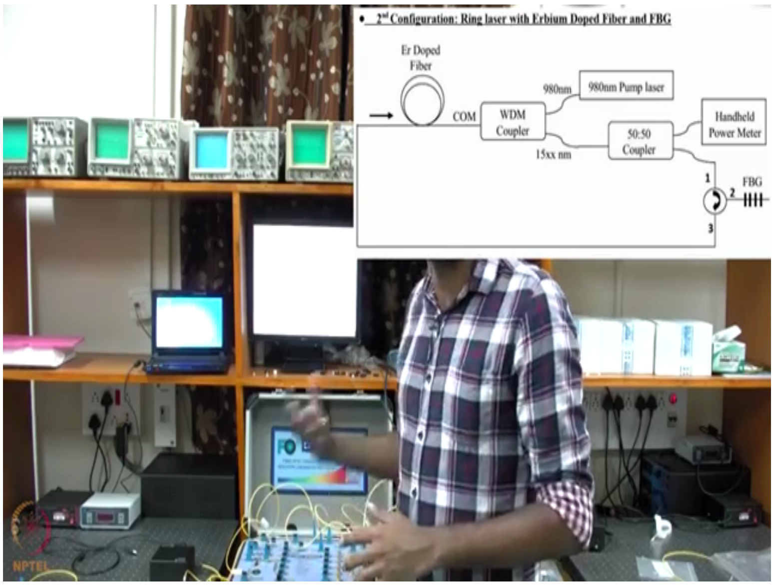


So for that we had to connect this set up to the spectrum analyser there okay. So for that we will stop this experiment now and we will make the connection to the spectrum analyser. So before making that connection one thing I had to make sure is that you have to use something known as a variable optical attenuator that is placed here, the (())(15:48) cannot take power more than minus 2 D DBM, so you have to attenuate the optical power that is coming out of the fiber laser.

So as we know we have almost 3 DBM of power, so we have to use something known as a optical attenuator, so we are taking out the output from this port, this is the output port and then connecting to the input port of the VOA okay and from the output port of the VOA you are connecting it to the power meter okay here we have the power meter I am going to turn

ON the light okay. So now it is turned OFF, I am going to turn ON the pump and hence turn ON the laser that we have built okay.

So pump is ON, so the lasing would have started now, so the knob is already in some position so I am going to rotate it further, (for more rotation you have to) for more attenuation you have to turn clockwise, so you can see the attenuation is increased right so you can put minus 21 DB of power so yeah I think this should be enough minus 20.9 or slightly high 21 you can put in the I-MON.

So that is it in the output we have minus 21 DB and input you know of course is almost 3 DB right so I am going to take this output from this parameter and connect to the I-MON input. Now we will see the output in the screen how things are happening. So now that pump power is OFF, now I am going to turn ON the pump and see how the output is going to be obtained, so I am going to start the pump now started see you can see there are a few wavelengths that is lasing okay so it is not a single wavelength okay sometimes it is a round 15 is around 1560 so in that range we have multiple wavelengths that is getting generated like this okay so that is because there is no wavelength selective element in this particular setup. As you know the EDFA spectrum, you can see the spectrum here it can you gain to multiple wavelengths.

So there is a chance that multiple peaks will get the gain they will fight for gain and sometimes a particular wavelength will be like this like this one and sometimes other wavelengths will also compete and win like this, so we cannot really say that which wavelength we are going to obtain from this setup. For that will go for a slightly more advanced setup in the next section of the experiment.

So in the last part of explain what we saw is that we can make a laser but you do not have much control about the wavelength at which it lasers because the EDFA has a flat spectrum, we can raise in most in a particular wavelength actually but it varies right with different factors. So in this part of the experiment we are trying to stabilize that or we are going to fix that wavelength, we are going to say that this is the particular wavelength at which I want lasing, for that what do you make uses something want to say FBG Fiber Bragg Grating, Fiber Bragg Grating is just a refractive index pattern.

So basically fiber has a core and cladding right the core refractive index is made in a pattern such that there is a pattern of high end low refractive indexes. So suppose that has a capital lambda spacing, then the wavelength that is reflected well how 2 into effective refractive index into capital lambda will be the therein that is reflected back of the grading. So they make of that make use of that principle to constrict a cavity or a loop fiber loop which is selective to a particular frequency.

So the wavelength that is reflected by the (())(19:42) is called the Bragg wavelength and we call it lambda B okay so if you can construct a cavity such that the lamp we get a particular lambda B that is reflected back from that grating which is the only wavelength that is allowed to propagate in the loop, then we will be able to sustain that particular wavelength in the particular loop.

So it is a very simple thing we are going to do in here, so what do you do is we are going to add a FBG to this query cavity to this to this loop fiber look. So what you do is that how we do that we have a FBG in our kit right so the thing is we cannot put it in like you know in a series way in the in the circuit what you do is that you had to get the lambda be reflected back from the FBG right so for that you will use a particular setup diagram schematic like shown here. So yeah from that we will move into connecting the particular setup.

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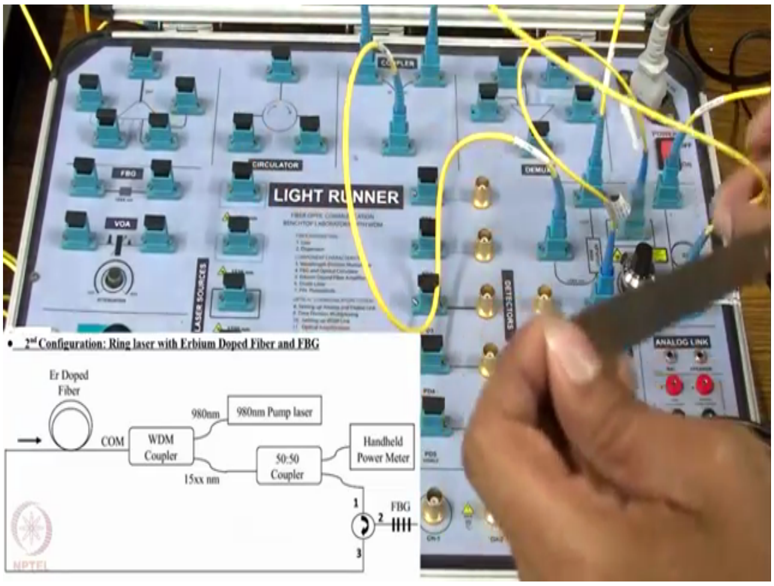

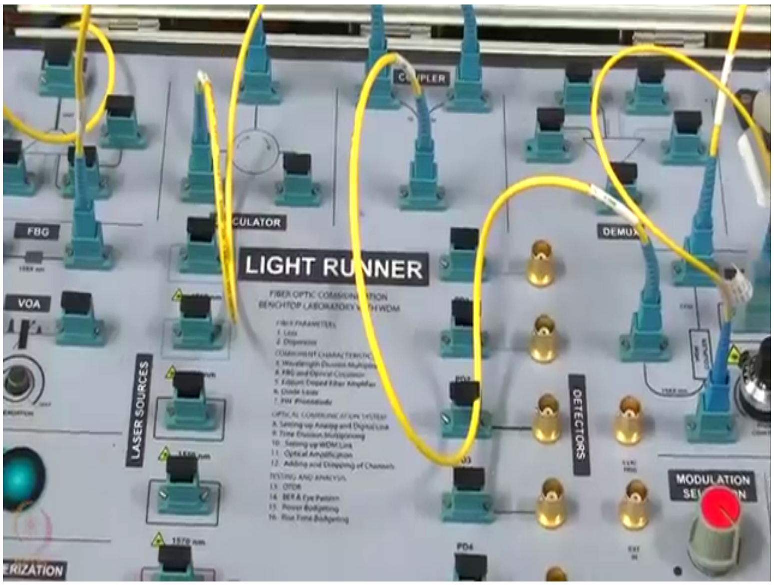


So as e can see in the schematic that is displayed the only difference in the setup is that we are adding an extra circulator and an FBG into this particular setup. So the difference is that the output of the laser which we are taking from this coupler output so which was earlier fed back to the EDFA like this is now being redirected to the circulator. So before making the connection setup I will tell you how the actual setup works.

So how a circulator works is that if you circular has three ports, port number 1, 2 and 3 okay so if you have a input at port number 1 it will come out through port number 2 if with some insertion loss and similarly this is a case with the port number 2 any input in port number 2 will come in port number 3, then (())(21:36) is port number 1 will not by pass anything to 3 and 3 will not bypass anything to 1 that is the case of optical circulator.

So any input that is present in 2 will be obtained at our port number 3, so that is the working of a circulator and FBG as I told before will reflect back a wavelength which is 2 times of effective reflective index into the grating period so that is the wavelength that is reflecting back. So how are you going to use this set? Now we are going to make the outputs to go and do the circulator first so the laser is going to come out of port number 2 because the connection is now 1, the output is going to be in port number 2, port number 2 we have to connect the output to the FBG okay now what happens here is what happens here is the laser that is coming out of coming into the port number 1 is going to into port number 2 and there is a FBG is there okay.

So only the wavelength only 15 so it is a here 1550 okay only 1550 gets reflected back through that port from that FBG so that will come out coming through so that will come in back through this fiber into port number 2. So that is a input at port number 2, so that input is redirected to port number 3 here so all you had to do is the all you have to do to finish the loop is connect this port number 2 to the input of this EDFA, so that is what you are going to do right now, we are going to take a fiber and connect make the connection.

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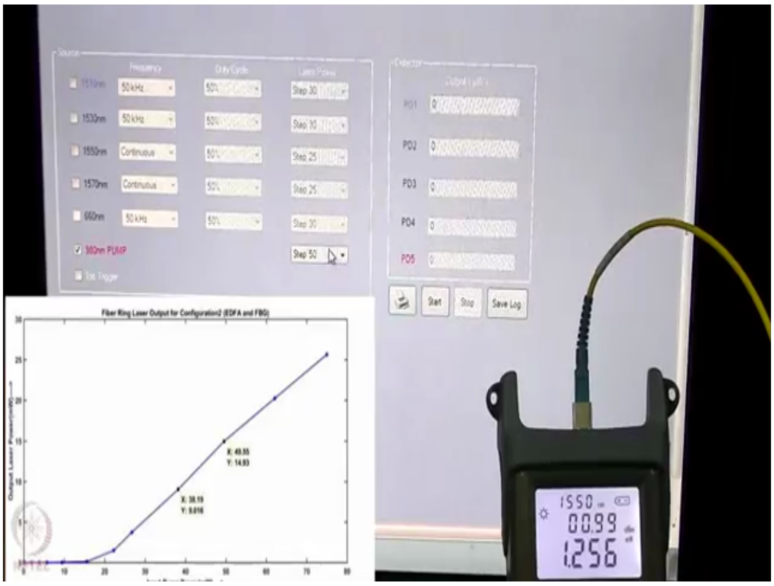


So now we are done with the connection diagram now what you are going to do is we are going to do the same characterization we did for the other laser, so we are going to increase the pump power from 0, step 0 to step 60 and see how much output is going to produced, okay it will be interesting to guess what is going to happen right. So as I told this is a wavelength selective element right so we are going to get a lot of lasing in a particular wavelength but does that mean that your total output power is going to reduce?

Let us see whether your total output power is going to reduce. So at step 10 again we do not have any outputs, step 20 we might we still do not have (any input) any output that is any lacing that is not happening and step 30 will we should have some yeah we have minus 26 DB of power output that is there.

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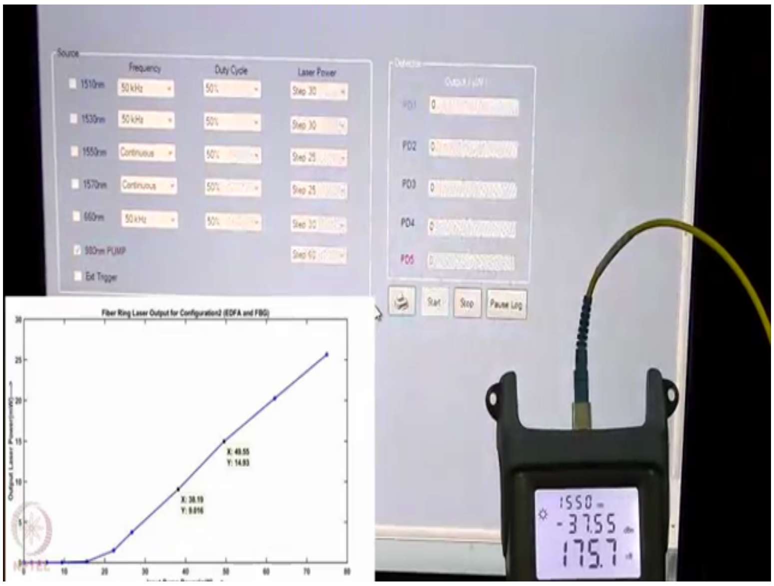


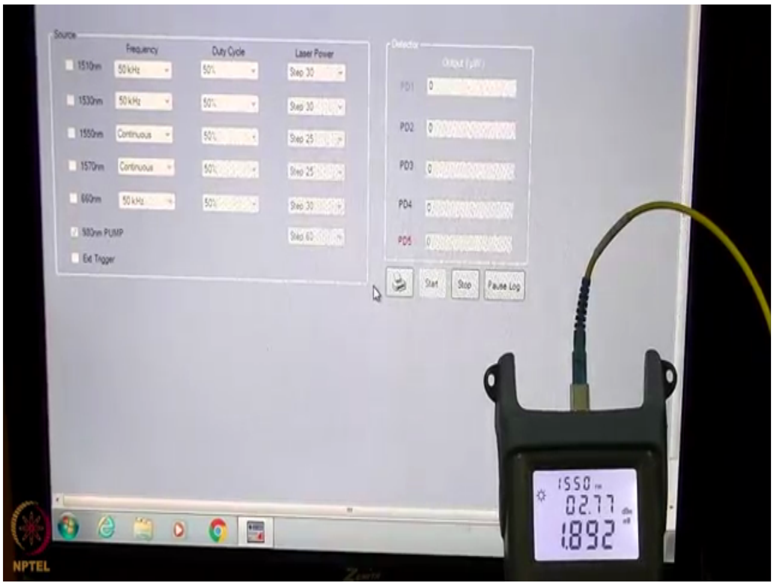


Now we are going to increase the power to step 40 let us see yeah we have minus 3 DBM so the pattern is not following not exactly following the other case but still we can see that after threshold we are almost getting a linear kind of increase in the power and with step 60 we can see that what we can see we can see that we got almost 3.04 DBM. So what this means that the total amount of power that is generated in both cases is almost the same except for some additional losses that is happening here probably because of the circulator but mostly the net output is comparable, so what it means that all the lasing power is concentrated in the 1550 wavelength now okay.

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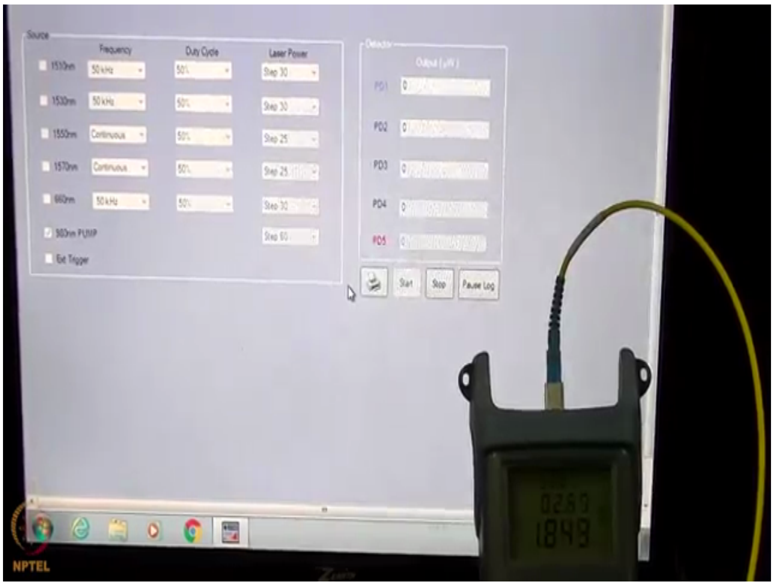

So we will see we will try and see the spectrum of this particular of a particular laser in the IMON right. So what we have to do we have to disconnect it from this power meter and then connect it to the IMON, so we are going to do that now.

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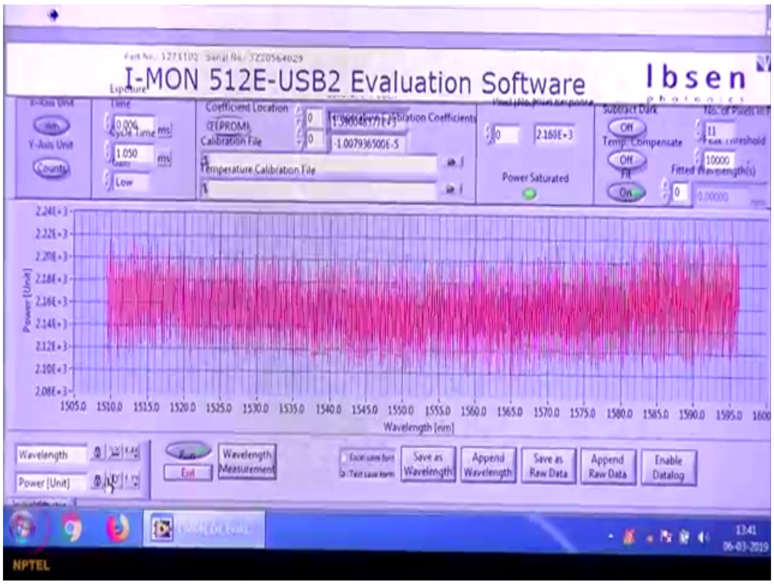


Now we will see the spectrum in the IMON, for that what we do is we will take the output from the coupler, pass it through the VOA so that we attenuate it to minus 21dB and send the signal to the VOA to the IMON input okay IMON is here and we can see that I have not turned ON the laser I mean turned ON the pump laser right so there is no output. So right now I am going to turn ON the pump here okay I am going to start the experiment I am going to start.

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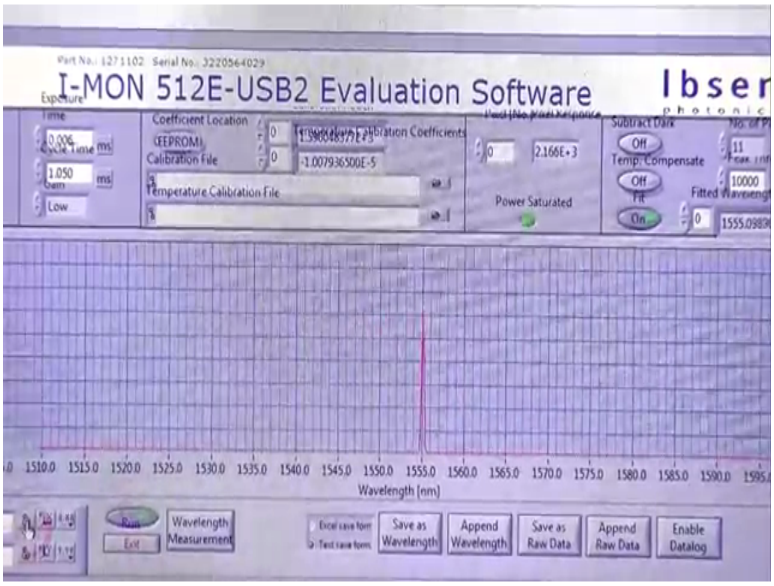


So I start the experiment let us see what is happening there so we can see that there is a single wavelength that is chosen, there is no different wavelengths that is coming and it is sharply at 1550, you can see how sharply it is at 1550, so there is no other wavelength that is lasing at that particular and in this particular scenario. So what does it mean that this FBG is reflecting only 1550 and only that 1550 is getting enough feedback to be sustained in the cavity, so that is why we are able to get a single wavelength in the output in the IMON like that okay, so that concludes the second section of the experiment.

Of course you can characterize the laser by for finding the threshold pump power and all but this is probably the more modern result here, we can see the frequency selectivity of FBG.

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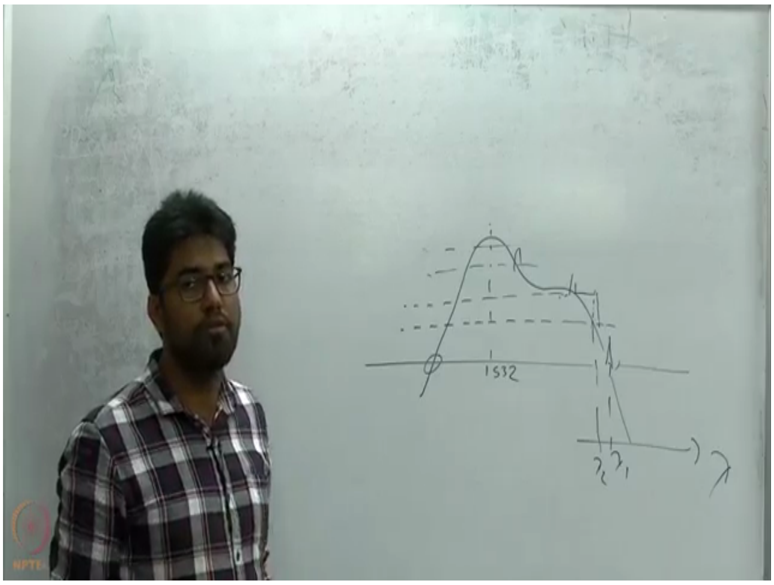

Now you have learned how to get a single wavelength lasing, the question arises like can you change that single wavelength, can we tune the wavelength the output from a laser? So a laser is of course a single wavelength or it is always a single wavelength that is being lased but that wavelength can change across with the time or with losses or with some thermal effects or something. So now the question is can we manually or can we use some mechanism to tune the output wavelength of a particular laser?

So this is in the third part of experiment we are doing going to do the exact same thing, we are going to make the laser tuneable, so how can we do that? We are going to use the losses in the cavity to this effect, so how do you do that? So assume this is the EDFA spectrum look something like that okay and imagine this is the net losses in the cavity okay the losses is independent of the wavelength so it is the wavelength here lambda and losses is independent of the wavelength mostly okay.

Now where does the lasing happens? Lasing happens at either this point or this point right so preferably lasing happens at this point because of the higher with lower absorption and higher emission so that the contrast between emission cross and emission and absorption cross section is slightly high here, so we will get it is preferably to get a lacing here. So that is how we end up with the lasing at this point okay we will get something like this. So intuitively we can guess that if you can increase the losses in the cavity right if you can keep increasing it something like this we should be able to get a lasing at this particular end which is a different wavelength, which is different values compared to the first case this is maybe lambda 1, maybe lambda 2 right.

So if we keep increasing the wavelength will end up having like lasing at only 1530, 1532 is the peak gain for a EDFA okay so by adding extra excess losses the cavity we can actually tune where the lacing is going to happen right. So if we keep on increasing too much losses then a point will come that only the peak most gain point that 1532 can only lase. So this is a way of tuning the wavelength the output from a laser from this particular fiber laser.

So we are going to do the exact same thing, so instead doing the cap restoration with pump power and the output power we go straight and see the spectrum, okay.

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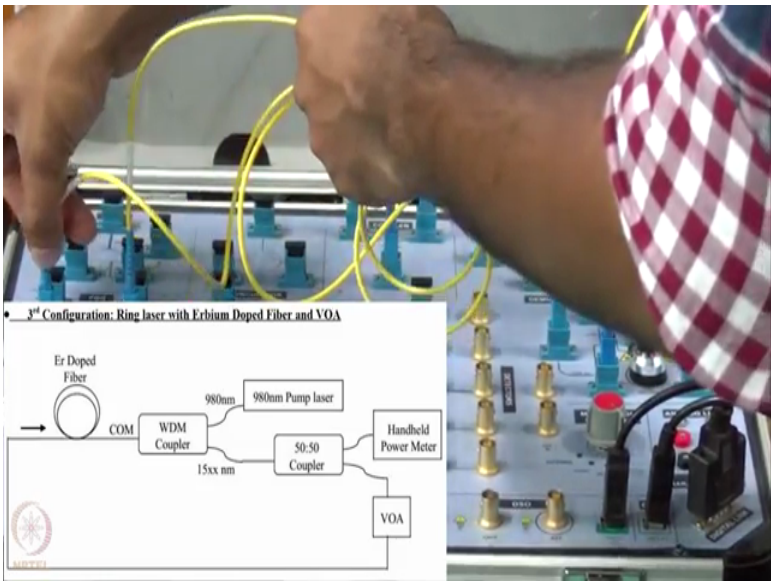


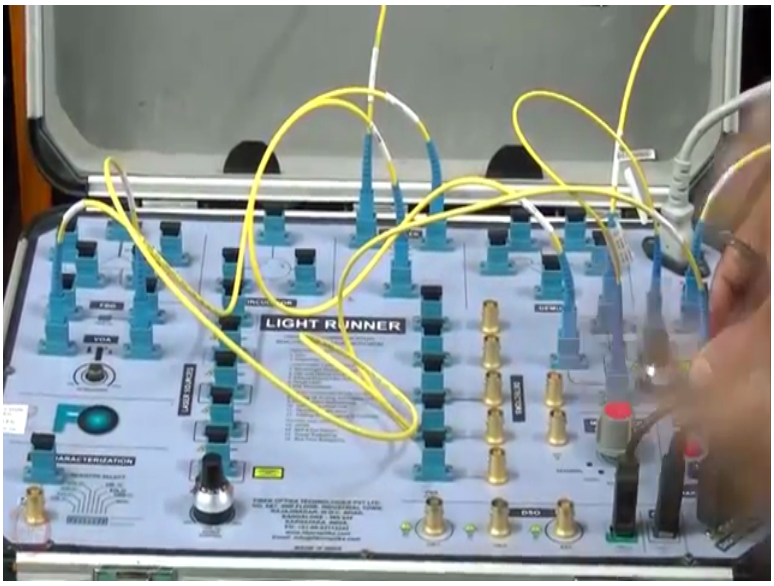


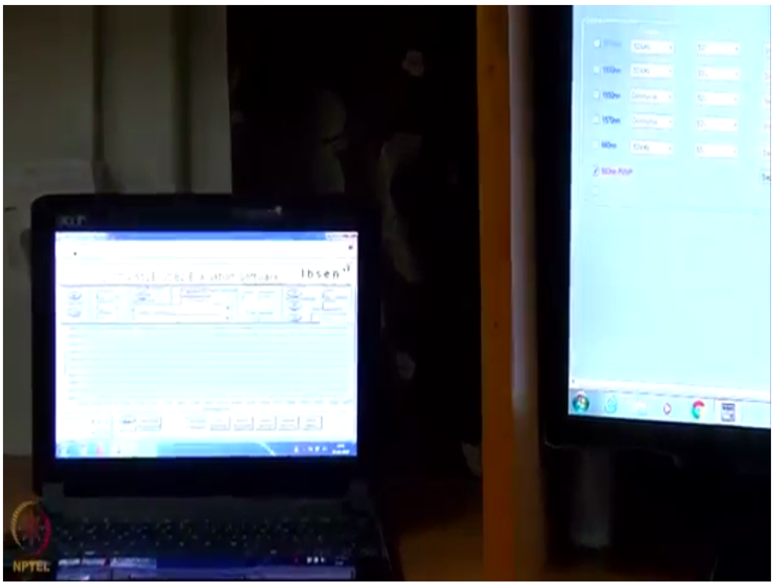

So now we will make the connections as seen the schematic, so the only change that is happened here is it from the output of the coupler the VOA is connected like this from the output of the VOA is connected back to the EDFA. So it is a similar simpler set compared to last one okay so that is all the change that is made here. So now the (())(29:46) optical attenuator is within the cavity within the cavity okay and here we can see the pump is OFF, I am going to start okay with the maximum pump I am going to start okay.

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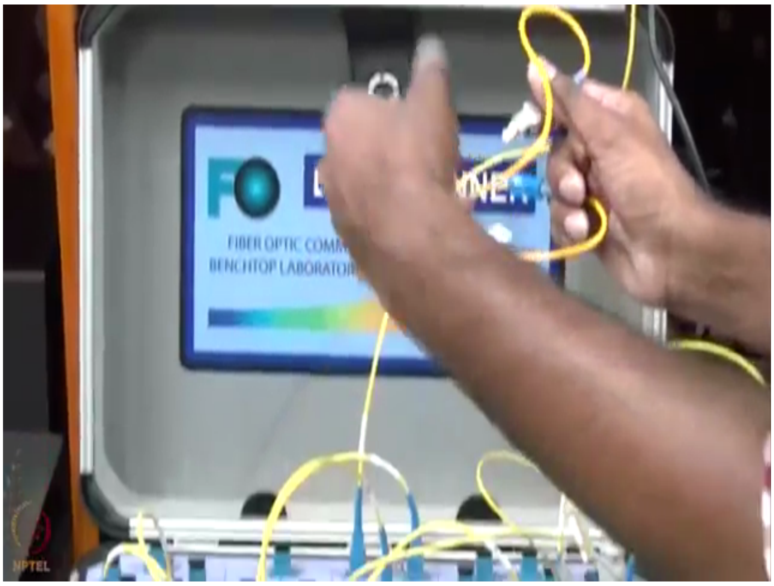


As you would have noticed we have only one VOA that is in the setup right so we as there is no VOA that is current library within the kit we are going to use something known as a fix attenuator this is a 20dB fixed attenuator okay so you can easily plug it in like this so this block is (())(30:17) block okay so it will add 20dB of attenuation to your signal. So that we do not want to use a VOA from another kit or something, so we can plug it in, so the output to be given to the IMON needs to be less than minus 20 right so it is almost 30 almost 3dB so we will add some minus 20dB of attenuation.

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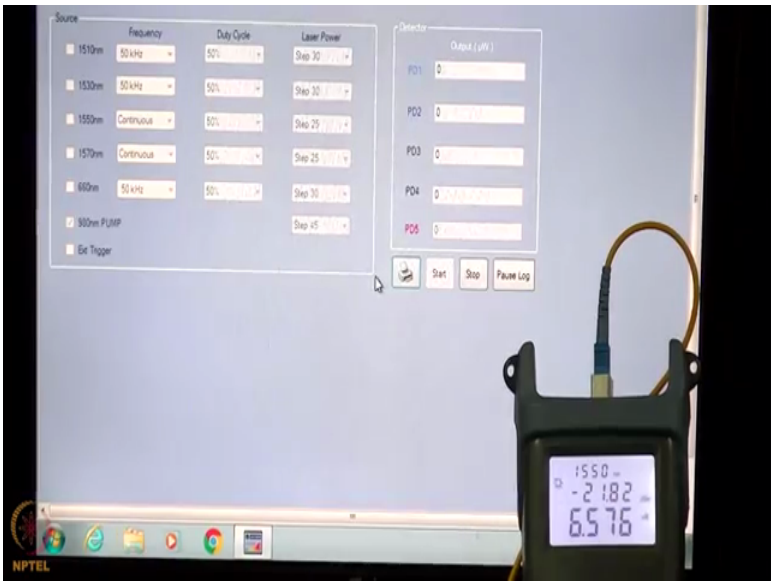


So we will connect it to the input of the IMON we will connect it here like this okay. So you would have notice the problem right you have 30dB output of laser and you have only 20dB of attenuation that means you have minus 17dB power that is coming out of attenuator also which is too high for the IMON. So what we do is we decrease the pump power a bit, we are putting step 44 instead of 60 so that we get a power output of minus 21 which can be given to the IMON safely.

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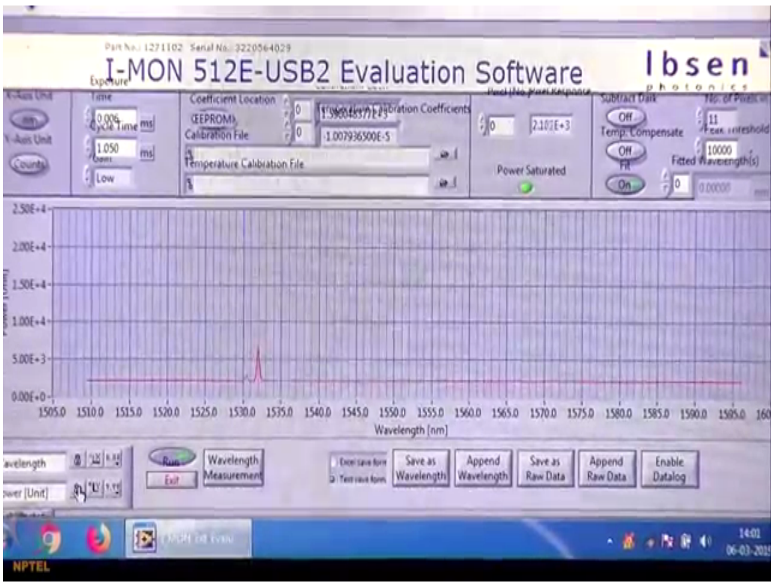

So the laser is turned OFF now and the attenuation in the loop is at the minimum point okay so we will see what is the spectrum going to be like, you can see the spectrum is at 1560 this is 1560 and you have multiple peaks of course there is not a wavelength there is not a wavelength fixing element there, so there will be some multiple modes around that particular wavelength, so it is around 1560 you can see multiple wavelengths that is lasing multiple modes that is lasing, multiple modes are lasing around that 1560.

So if you increase the loss we should see the wavelength shifting, so I increase in the losses in that attenuator, you can see that it is slightly shifting so you can see the shift right shifting and see now multiple wavelengths are supported at simultaneously and suddenly shifted to 1530 you can see that it is are going to 1530 where it has a maximum gain.

So today you should be proud of building our first laser so you build a fiber laser for the first time and you saw that the wavelength can be tuned, you saw that it has a threshold at a particular point and from beyond which there is a linear increase of the optical output, coming to wavelength part there are two ways of controlling it, you can use a wavelength fixing element like a FBG for getting the particular wavelength output and if you want tuneability you can use it VOA for tuning the wavelength that laser lases.

So I hope that is a very enriching session for you guys and hope it improves your knowledge and curiosity in learning more of optics and I especially thank my friends Nirjar here and Bhagat for assisting me with this very fast session and thanks for our cameraman Akshay also from our team we say our all the best you to you guys.