UNIVERSITY *of* GLASGOW

SCHOOL OF ENGINEERING

ELECTRONICS AND ELECTRICAL ENGINEERING DEPARTMENT

ANALYSIS OF AUTOMATED OPTICAL TEST EQUIPMENT

FINAL YEAR PROJECT

INDUSTRIAL ENGINEERING: ELECTRICITY

Project 45

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ABSTRACT

The present projects aims to characterise the performance of an optical test equipment system. The existing system consists of a c-band tuneable laser and an optical spectrum analyser, which are automated by a computer through LabVIEW software.

The test system is analysed in terms of accuracy and precision and a dynamic calibration is explored to improve the performance of the system. Specifications are discussed and recommendations are made on how to improve the device test procedure with the available equipment.

Finally several optical devices manufactured in the James Watt Nanofabrication Centre are tested within the analysed system. The stopband and its variability according to different injected currents are characterised in terms of reflectivity, where finally the calibration is applied to achieve more precise results. Matlab code is implemented for users of the system.

CONTENTS

1. Introduction

The present project is located within the optical instrumentation area, specifically in the automation of test equipment and calibration of optical systems.

As the use of optical networks and devices has dramatically increased during the last years, the automation of optical test equipment has been of vital importance during the whole development process and still is in current research.

Automation importance mainly lies in both a cost saving policy as a result from the time saved and in the necessity to provide robust and more reliable data exempt from human error and with quantified equipment performance ranges.

Calibration of optical equipment is a common practise to improve the accuracy and precision of the collected data, this project aims to get data able to describe the behaviour of an optical device itself, by accomplishing a dynamic in situ calibration of the whole system without the device connected. Thus it will be possible to quantify the system error (without the device) in order to subtract it from the data obtained when the device is connected.

2. Previous Work

For the purposes of the project there are two virtual instruments (VIs) programmed in LabVIEW which were made by two previous MSc students from Glasgow University. Despite one is conceived as an expansion of the other, different functionalities and performances are provided by each one and therefore they will be used according to them.

In general terms, the first one “Main VI v5.vi” is able to perform and record quick wavelength and power sweeps of a tuneable laser by using an OSA and allows the use of an attenuator within the system. On the other hand, “MAIN_OPLAB OTDR.vi” was designed to include a controllable voltage source in the system but it was conceived at the expense of sweeps’ speed.

These VIs will be analysed in terms of their actual characteristics and its performance will be specified focused on the calibration of the system.

3. Equipment

For the purposes of this project a c-band tuneable laser Anritsu MG9638A [1], and an optical spectrum analyser (OSA) Agilent 86140B [2] are used.

These devices are connected through a high speed GPIB/USB [3] connectors and commanded by a laptop via LabVIEW [4]. Several virtual instruments (VIs) exist with different functionalities and performances, which are to be used throughout this project. Matlab software [5] will also be involved for our post processing purposes.

4. Experimental Arrangement

Firstly, a test was performed to characterise the laser power and wavelength behaviour in terms of accuracy. To accomplish this, the main output of the laser was directly connected to the OSA using a multi-mode cable.

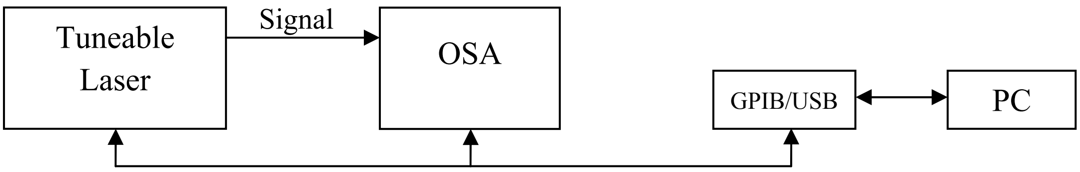


Figure 1.Connection of the equipment

5. Analysis of Results

5.1.Accuracy analysis

Figure 2 shows 15 sweeps within the range [1500, 1580] nm with 1 nm step, thus covering the entire range of the laser power input [8, -20] dBm in 2 dBm steps. Notice that despite the power input resolution allows changes of 0.01 dBm the laser output only responds to the manual input changes shown in Table 1.

Table 1.Quantification of laser Power output [dBm]

7.17	6.16	5.21	4.26	3.08	2.25	1.44	0.61	0.15	-0.9	-1.66	-2.44
-3.24	-4.03	-4.80	-5.56	-6.38	-7.12	-7.84	-8.60	-9.37	-10.20	-11.05	-11.91
-12.74	-13.51	-14.27	-15.01	-15.80	-16.48	-17.09	-17.83	-18.70	-19.40		

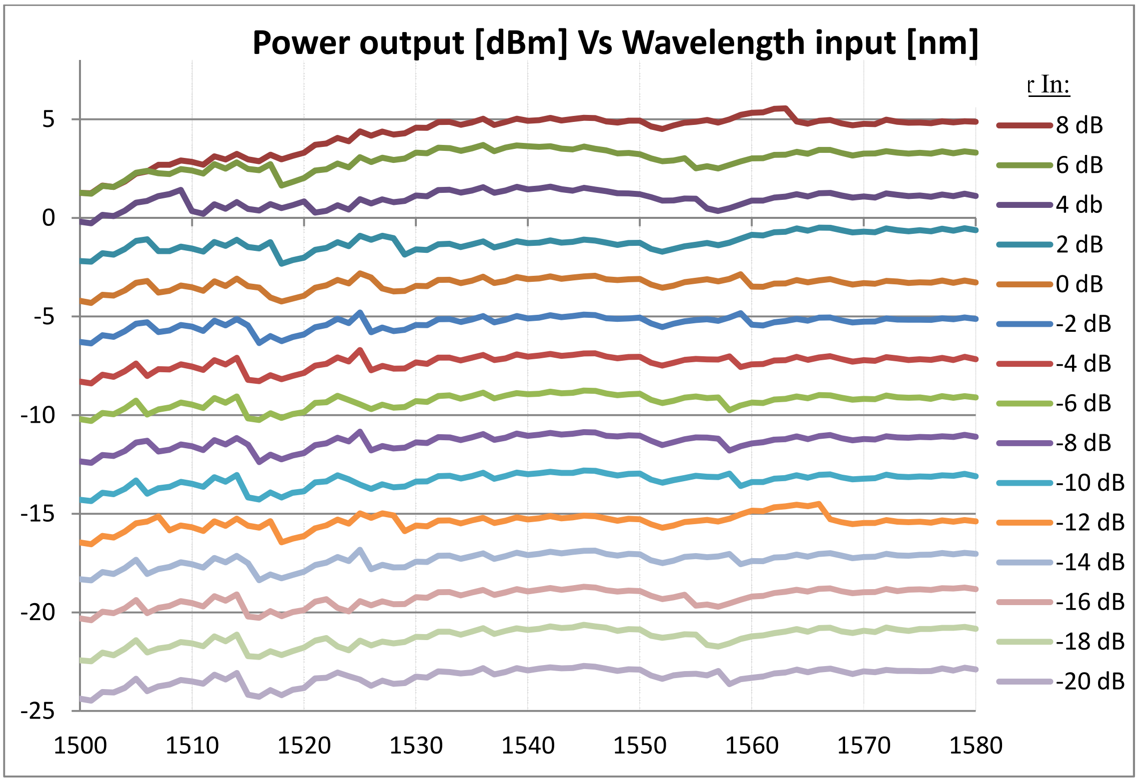


Figure 2.Power laser output for different powers selected during sweeps of 1nm step.

The laser power output is limited for short wavelengths ($\lambda < 1520$ nm) when using high power inputs ($P_{in} > +5$ dBm), that is the reason why the manufacturer cautiously states to provide a power output of at least +4 dBm and allows to set it up to a maximum of +8 dBm. Furthermore, there is a range of wavelengths where the power output fluctuations are smaller ($1532 < \lambda < 1550$ nm) where there is a minimum flatness of ±0.25 dBm (typ. = ±0.2 dBm). For the whole wavelength range the power flatness turns out to be 4 times larger being ±1 dBm and therefore, does not meet the specifications provided by the manufacturer said to be less than ± 0.2 dB. Is it important to notice that for $\lambda < 1530$ nm there are power fluctuations larger than 1.2 dBm.

Figure 3 shows the absolute value of the difference between the wavelength output measured with the OSA and the one set in the laser for a power input of 8 dBm.

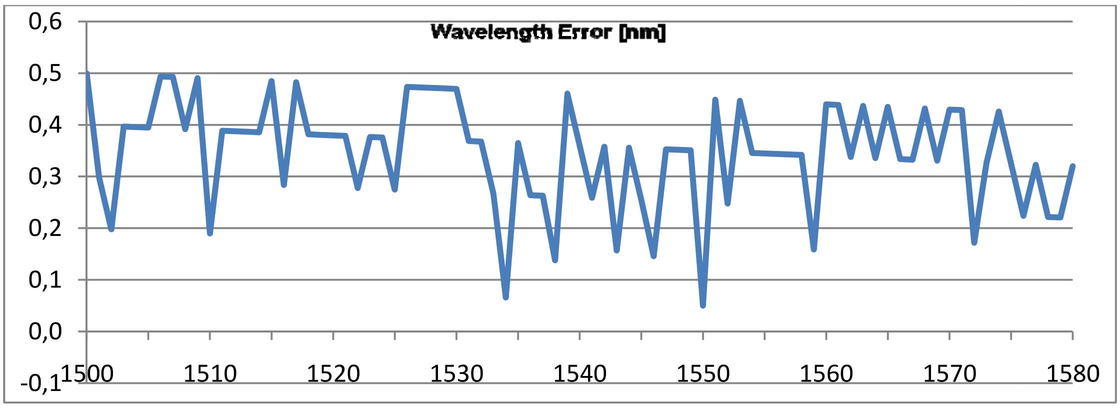


Figure 3.Wavelength error [nm] Vs Wavelength input [nm] for 8 dBm

The average error for the whole sweep is 0.346 nm. It is important to notice that the resolution expected for the measured wavelength is much higher than the recorded one as only one decimal is properly registered. As the laser wavelength resolution has been checked to respond to input steps of 1 pm this lack of resolution is associated to the OSA when it registers peak values during wide windows sweeps. For this case, where 81 samples were taken in a 1nm step, the actual program records up to 6 decimals where the following five decimals are filled with series of invaluable data. This behaviour is related to the span set in the OSA, and will be analyzed further in depth.

In Figure 4 it is possible to identify 6 linear tendencies in the error when an 8 dBm power is set, five of them with a negative slope (red) and one with a positive slope (green), this last one corresponds to the negative values of the wavelength error and therefore, it indicates that the wavelength provided is lower than the required, which occurs a substantially lower number of times.

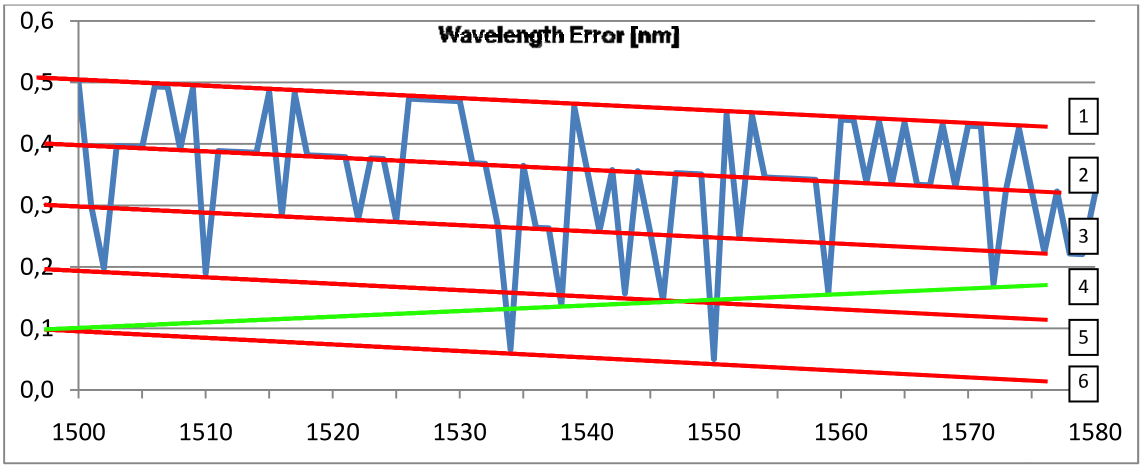


Figure 4.Absolute Wavelength error [nm] Vs Wavelength input [nm] with tendency lines.

Figure 5 shows the error analysed for the whole set of powers. It confirms the previously described behaviour for all of them, where in some cases the errors belong to up to twelve linear functions with the same absolute slope. When the wavelength value is manually changed it is possible to check with the OSA that the laser wavelength resolution is 1 pm as expected from the specifications. Therefore, this behaviour seems to be due to the way the wavelength value is either storage and sent to set the laser or read and recorded from the OSA.

As all the errors belong to negative slope lines if we keep the sign of the error, it is possible to assume that the wavelength is more accurate for long wavelengths measured within the same sweep and also within a set of sweeps performed with similar OSA parameters. Moreover, Figure 6 shows the average wavelength error for every sweep made at different powers, where it is possible to appreciate how the wavelength is more accurate for lower powers as well.

These assumptions are discussed in detail in the Wavelength Error Analysis study carried out within the precision analysis at page 13.

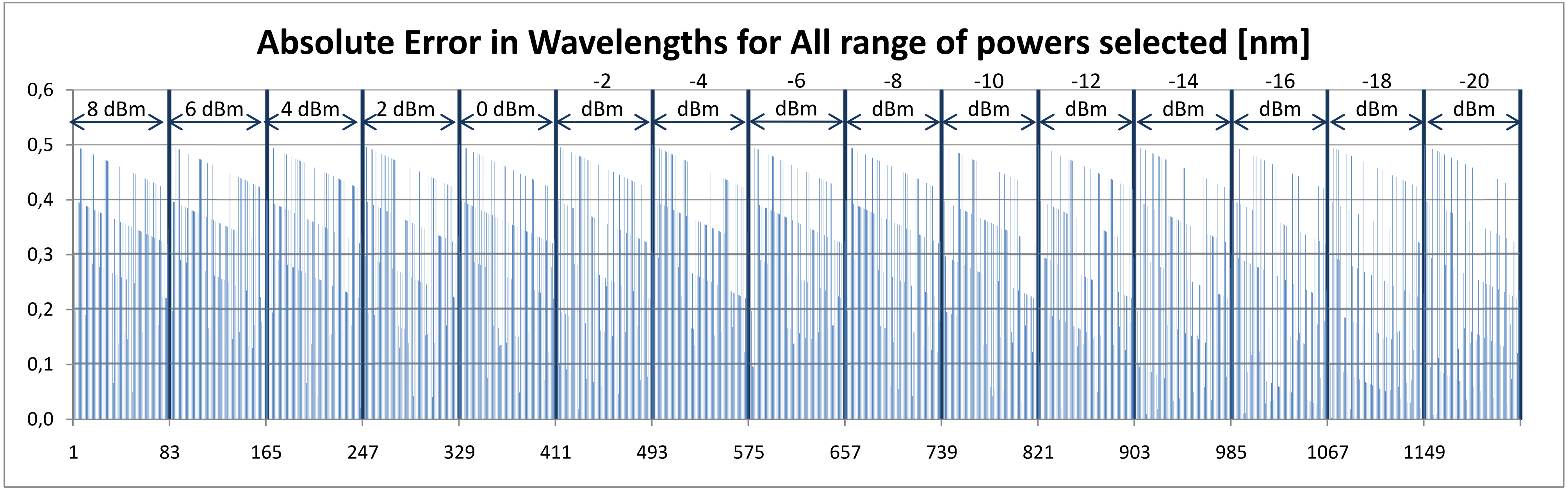


Figure 5 Error in Wavelength for different powers selected [nm]

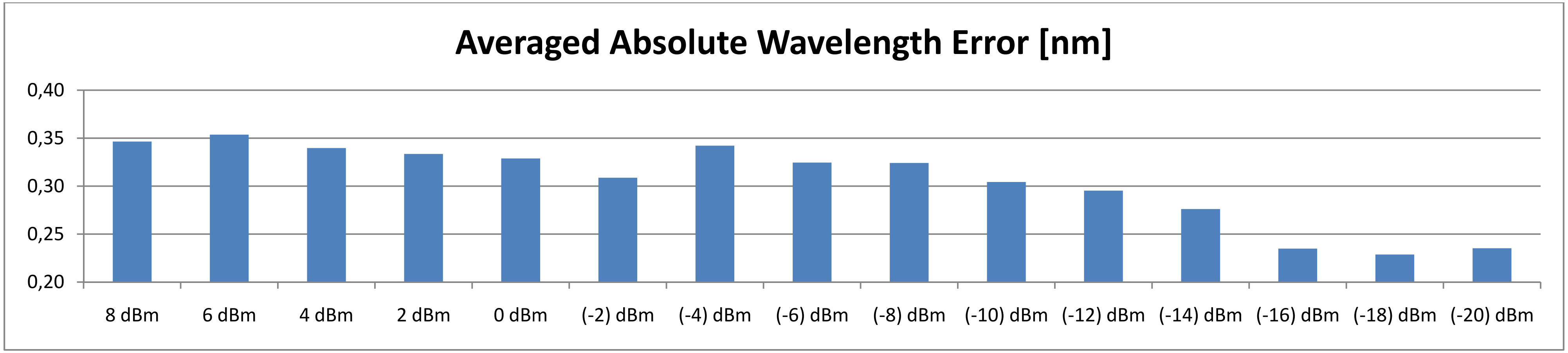


Figure 6.Averaged Absolute Wavelength Error for different powers selected [nm]

5.2.Analysis of the Precision

After analyzing the accuracy of the system, an analysis of the precision based on the repeatability is performed. Figures 7 to 14 show the laser power output for 15/20 sweeps at +6.00, +3.00, +1.00, -2.00, -5.00, -10.00 and 0.00 dBm input respectively. Data from Figures 7, 10 and 14 was collected in a different day than the others; every sweep was made at constant room temperature (22ºC) and at an interval of less than 2 minutes.

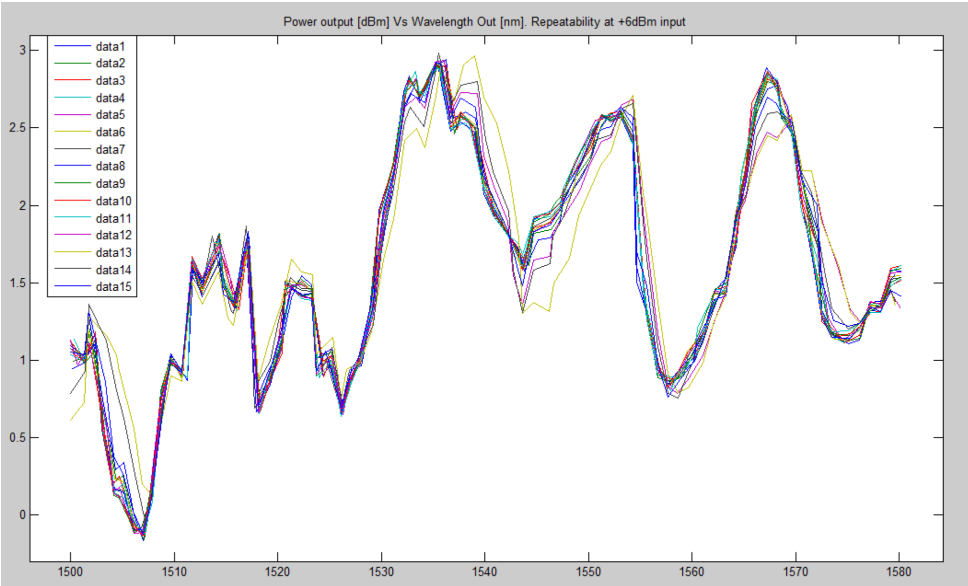


Figure 7.Laser power output at 6 dBm for 15 sweeps. [dB]

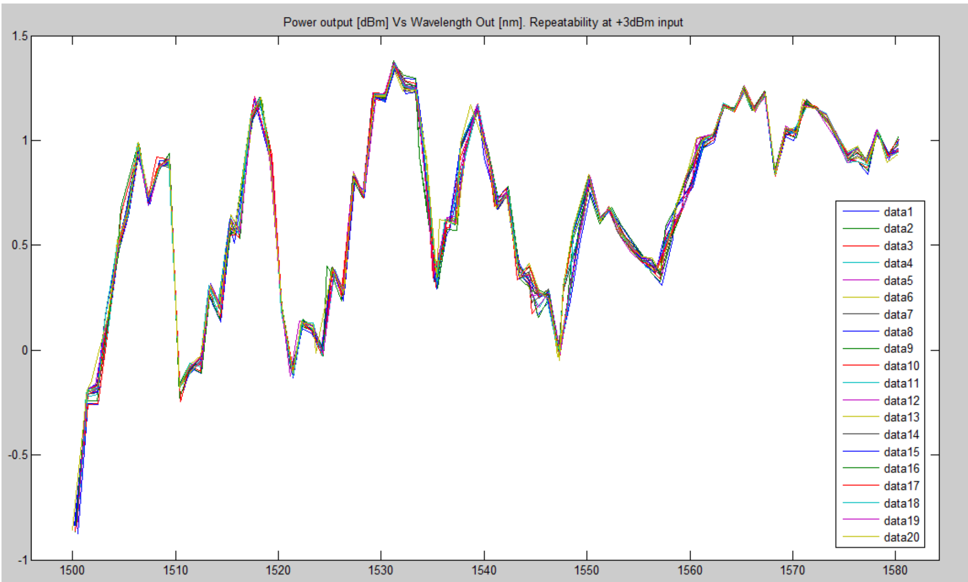


Figure 8.Laser power output at +3 dBm for 20 sweeps. [dB]

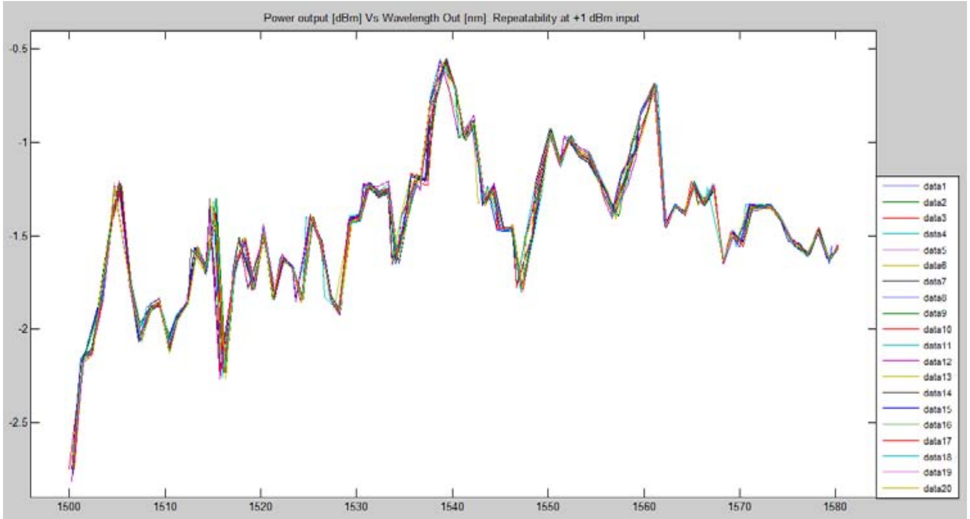


Figure 9.Laser power output at +1 dBm for 20 sweeps. [dB]

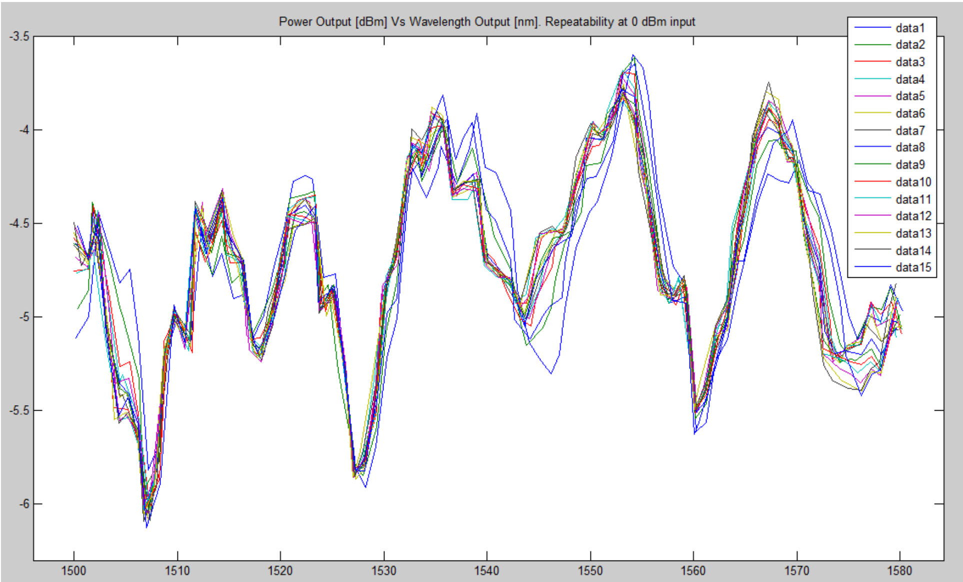


Figure 100.Laser power output at 0 dBm for 15 sweeps. [dB]. Case 1.

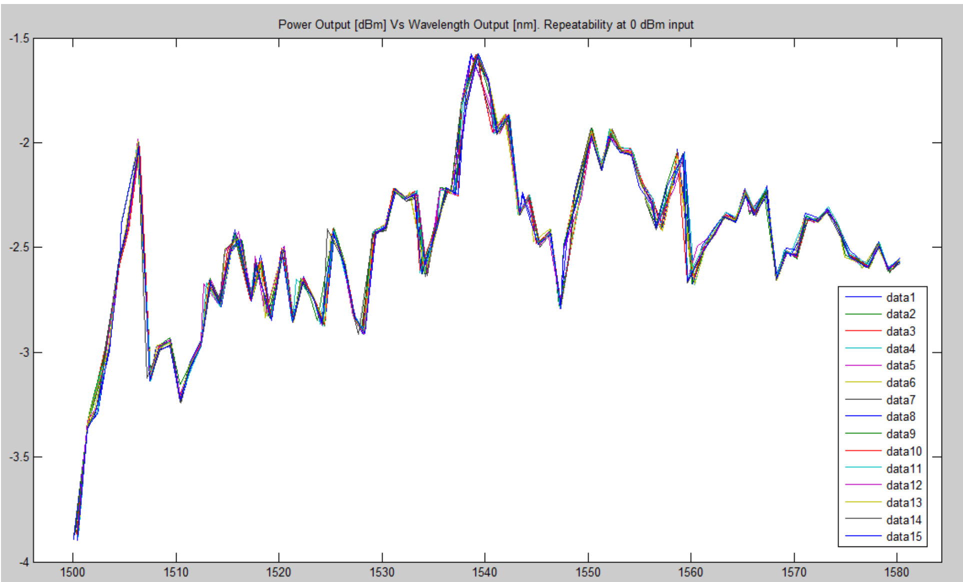


Figure 111.Laser power output at 0 dBm for 15 sweeps. [dB]. Case 2.

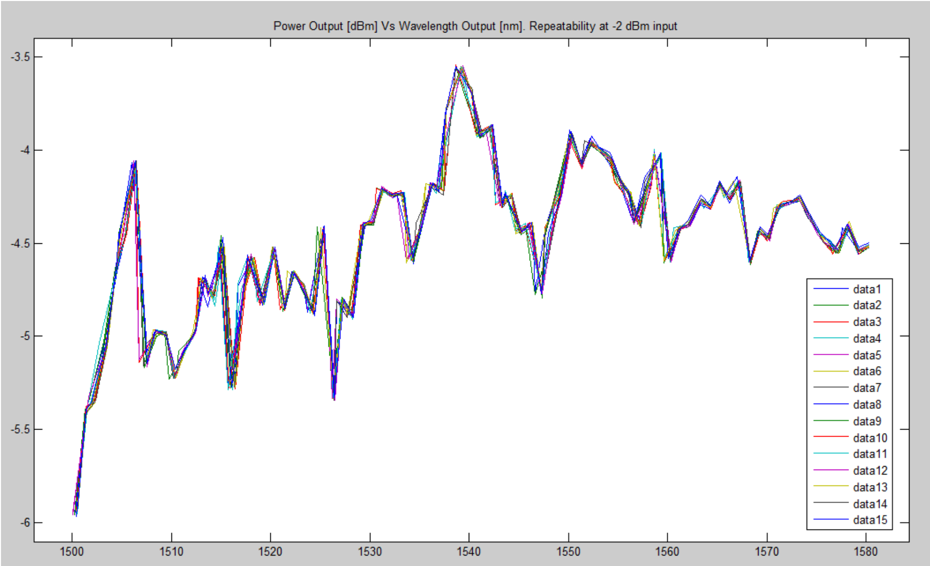


Figure 122.Laser power output at -2 dBm for 15 sweeps. [dB]

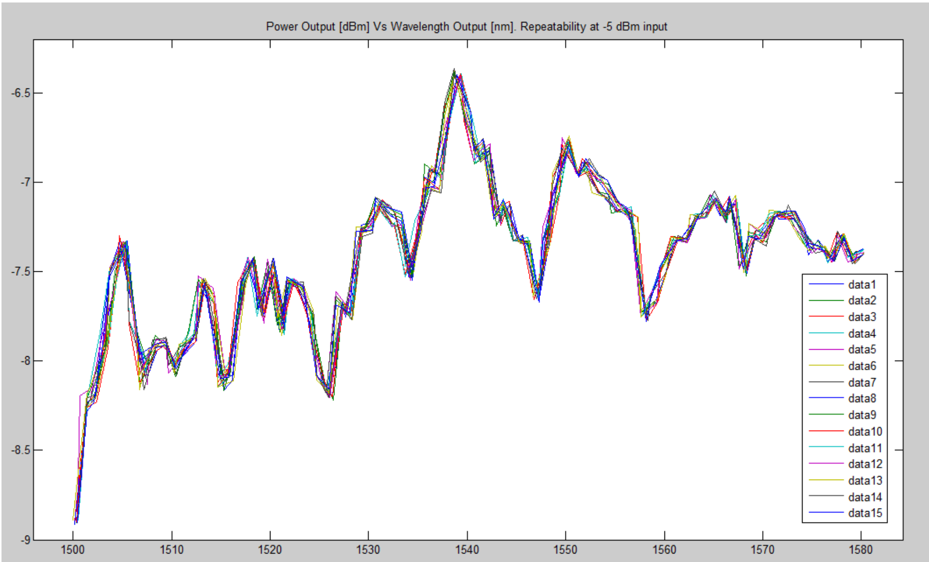


Figure 133.Laser power output at -5 dBm for 15 sweeps. [dB]

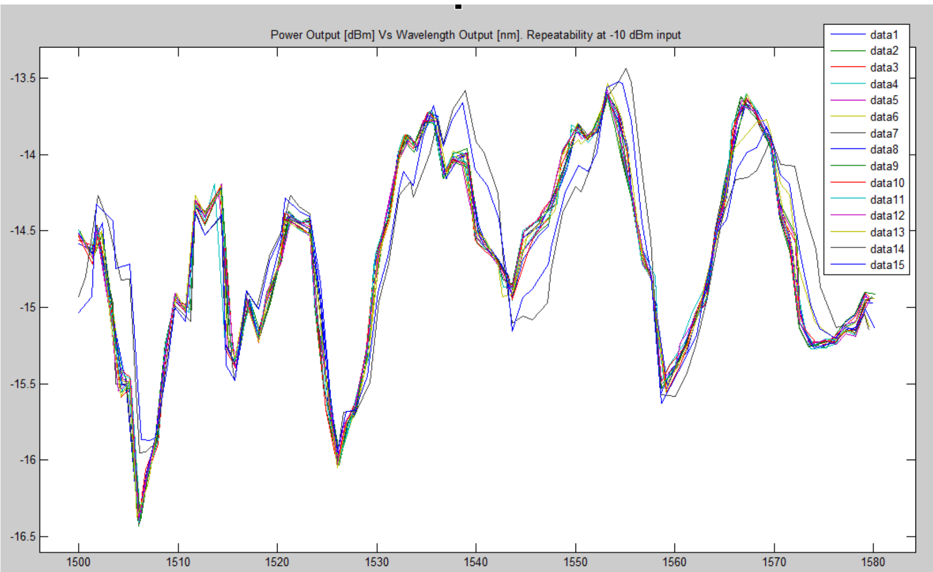


Figure 144.Laser power output at -10 dBm for 15 sweeps. [dB]

First of all, it is remarkable that the data registered in first place (Figures 7, 10 and 14) have some common characteristics among them. These Figures share the same shape, which is different from the one the others have, and also present a small number of abnormal sweeps which removal could be considered a proper way to proceed during calibration. The origin of these abnormal sweeps is not certain, though they might be due to human error as they are present in the first or last sweeps of each set. Figures 9, 11, 12 and 13 share their own particular shape and as Figure 8, don't show any abnormal sweep. As these last repeatability measurements were taken in a different day without deviated sweeps it also opens the possibility of the previous deviated ones being due to setting arrangements or methodological issues at the time the data was being registered.

Taking into account the variability noticed between the measurements taken in different days, in order to perform a suitable calibration it is necessary to calibrate the system the closest in time possible to the accomplishment of the measurements. Figures 10 and 11 show 15 sweeps each, performed at the same input power of 0 dBm. This is a clear evidence of that not even for the same power a calibration can be used as the error introduced might be higher than the error of the system itself.

The differences among the general behaviour of the laser in terms of amplitude are reasonably small. The use of a calibration acquired at a different power is possible, as due to the shared shape shown won't be significant differences. This way of calibration may be allowed just by knowing the corresponding offset between the input powers. However, the use of an optical attenuator is highly recommendable when more precise data was required, it would substantially increase the quality of the acquired data as it would allow using a single calibration for any power desired.

The recorded data shows that the highest precision cannot be guaranteed to be smaller than ± 0.1 dBm at any power within the wavelength range. However, it is important to notice that for any power input, the repeatability obtained in the power output depends on the wavelength selected and it is possible to identify both constant areas with a higher precision and others that present larger variations. The amplitude of the power peaks and its wavelength positions also remain constant for the different sweeps.

Table 2.Maximum Flatness values

Power [dBm]	Overall Flatness [dBm]
+ 6	**3.1**
+ 3	2.1
+ 1	2.4
0.a	**2.6**
0.b	2.4
- 2	2.4
-5	2.4
-10	**3.0**

Table 2 shows how the overall flatness is higher for the set of powers that present abnormal sweeps (+6, 0.a and -10 dBm), this is an easy way to identify whether the performed calibration contains sweeps liable to be rejected or not.

5.3. Determination of the number of sweeps for Calibration

The study of the repeatability of the system supplies the information required to accomplish the calibration of the system. Ideally, the more number of samples we have, the more precise is going to be our calibration, but in reality, despite the automation of the process involved in collecting determined sweeps, it takes long time to register the data and we are in the need of taking a fixed number of sweeps to make the process feasible.

In order to establish a robust number of averages to take, the following algorithm was followed for each set of powers:

powOUT: Matrix with output powers in the form [sweep_1, sweep_2, ..., sweep_m], where sweep_m is a vector containing the output power at each wavelength value (from 1500 to 1580 nm).

AvgPow: Matrix of k averages for a different number of sweeps: [Avg_1sweep, Avg_2sweeps, ..., A_ksweeps]

Subs: mean(abs(sweep_1-Avg_1sweeps)), mean(abs(sweep_1-Avg_2sweeps)), ..., mean(abs(sweep_1-Avg_ksweeps))

mean(abs(sweep_2-Avg_1sweeps)), mean(abs(sweep_2-Avg_2sweeps)), ..., mean(abs(sweep_2-Avg_ksweeps))

... .

mean(abs(sweep_m-Avg_1sweeps)), mean(abs(sweep_m-Avg_2sweeps)), ..., mean(abs(sweep_m-Avg_ksweeps))

AvgError: Calibration Power Error: [mean(N_{i1}), mean(N_{i2}), mean(N_{i3}), ..., mean(N_{ik})]

Which programmed in Matlab is:

```
%Matrix with the averages for a different number of sweeps
Add = powOUT;
AvgPow = powOUT;
for j=2:nsweeps
    Add(:,j) = Add(:,j-1) + Add(:,j);
    AvgPow(:,j) = Add(:,j)./j;
end

%Substracting each sweep from a different number of averages
for k=1:nsweeps              %k is number of averages
    for m=1:nsweeps          %m is index of sweep
        Subs(k,m) = mean(abs(powOUT(:,k) - AvgPow(:,m)));
    end
end
AvgError = mean(Subs);
```

Figures 15 and 16 show how the Calibration Power Error follows a function that decreases exponentially. Now it is easier to determine the order of the number of sweeps to use when calibrating any system with our equipment without unnecessarily waste time on redundant calibration sweeps just by setting a percentage of risk we want or are allowed to take.

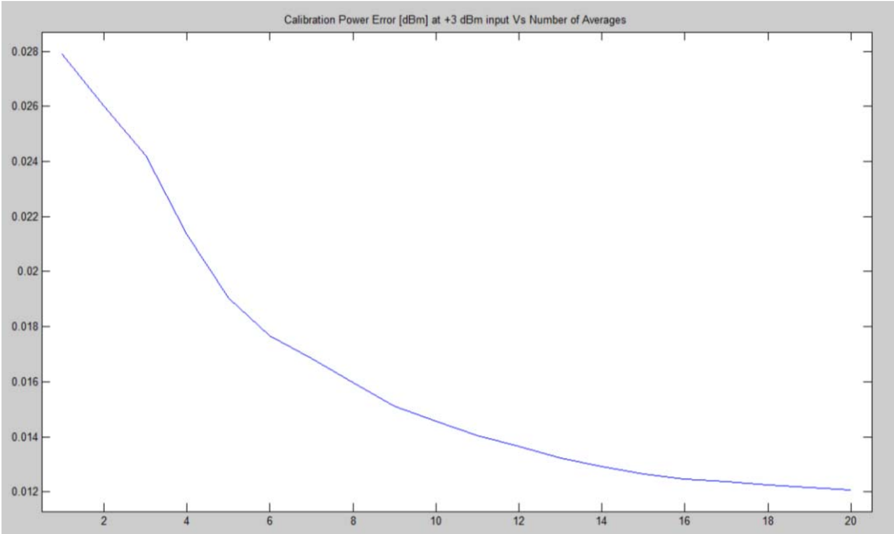


Figure 15.Calibration Power Error [dBm] at +3 dBm input Vs Number of Averages Used for Calibration

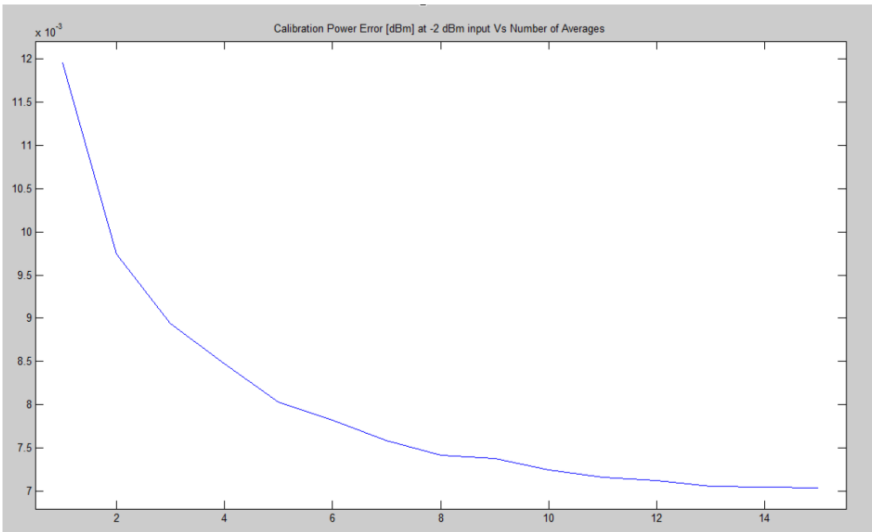


Figure 16.Calibration Power Error [dBm] at -2 dBm input Vs Number of Averages Used for Calibration

From the Figures above it is reasonable to establish 10 as the number of sweeps to use when calibrating for our purposes. Table 3 shows the averaged absolute power error from 15/20 sweeps when just ten of them are used as calibration

Table 3.Averaged absolute power error from 15/20 sweeps when 10 sweeps are used as calibration

Power [dBm]	Calibration Power Error [dBm] after 10 samples
+6	0.05976
+3	0.01456
+1	0.00905
0.a	0.07972
0.b	0.00663
-2	0.00725
-5	0.02000
-10	0.05202

5.4.Wavelength error analysis

Figures 17 and 18 show the wavelength error of 2 sets with 20 and 15 sweeps each performed at + 1 and -10 dBm respectively. Despite some similarities, it is not possible to treat it as an offset or any other function to establish a pattern to use as calibration which by subtraction would reduce the wavelength error.

On the other hand, we can state that the higher the wavelength or the more advanced is the sweep the lower are the positive wavelength errors (wavelength output higher than input) and the higher are the negative ones.

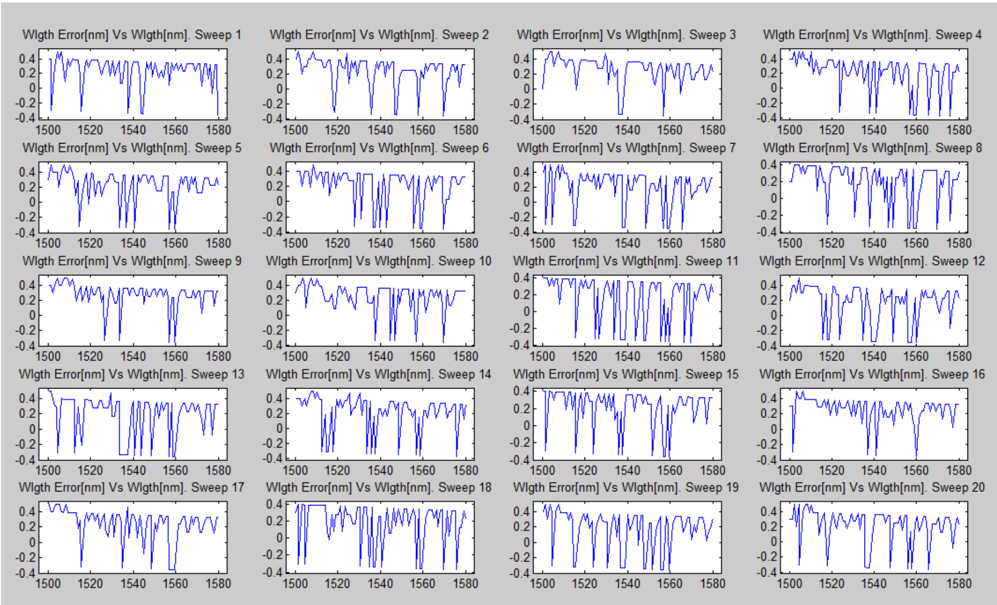


Figure 17.Wavelength Error [nm] Vs Wavelength [nm] from 20 sweeps at + 1 dBm

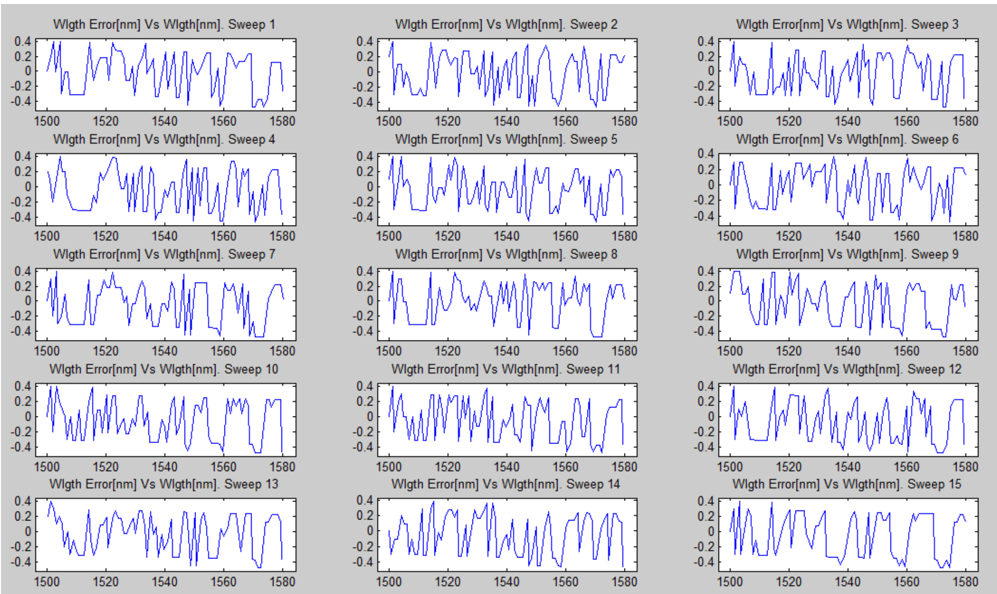


Figure 18.Wavelength Error [nm] Vs Wavelength [nm] from 15 sweeps at -10 dBm

Figures 19 and 20 show the previous individual sweeps concatenated in order look for more general similarities. From the y-axes of these figures we can see that the wavelength error is limited, which also happens with the other power sets. Hence we are able to specify a precision of ± 0.5 nm for sweeps taken within the window 1500-1580 nm, where the span of the OSA was set to 100 nm. This resolution meets the Resolution Bandwidth provided by the OSA and captured from the VI in the text file.

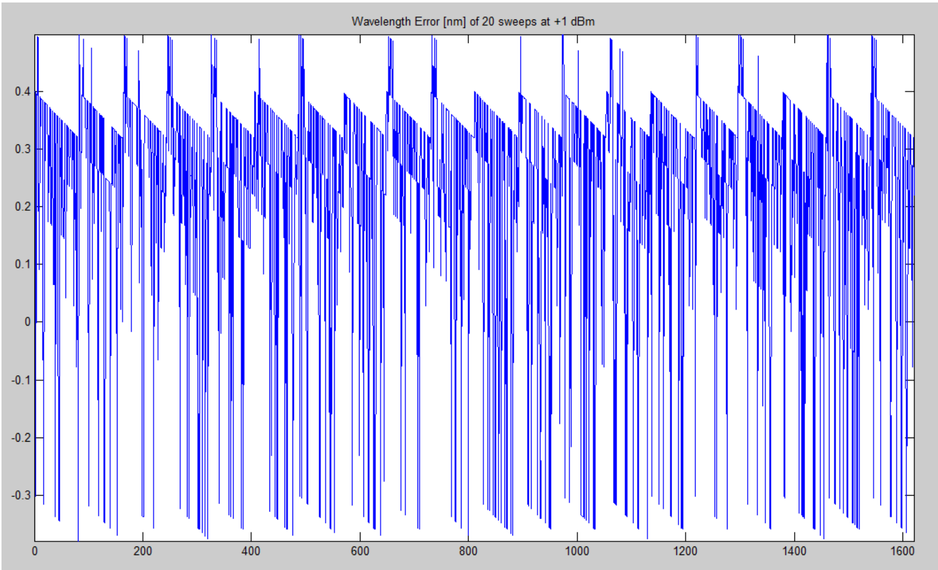


Figure 19.Wavelenth Error [nm] from 20 sweeps at + 1 dBm concatenated Vs Number of sample

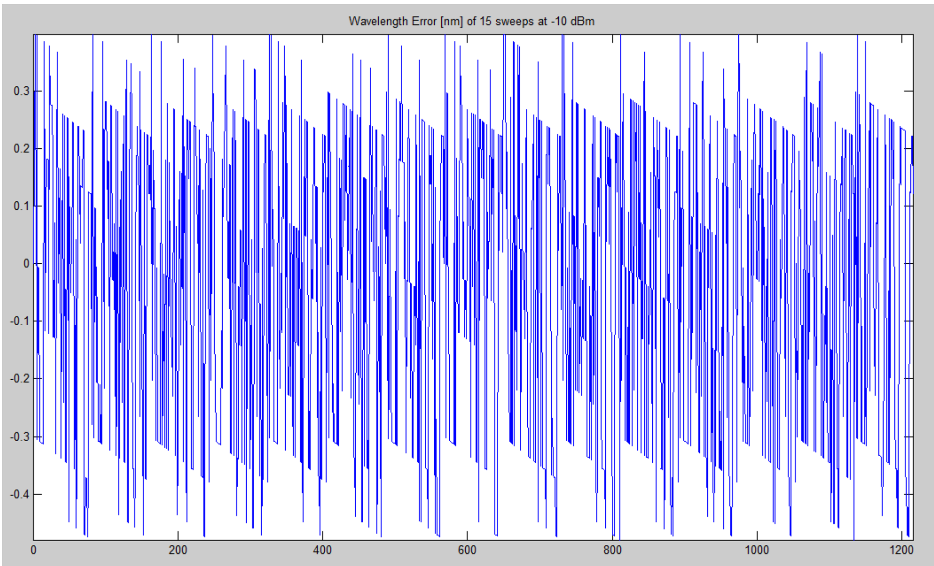


Figure 20.Wavelenth Error [nm] from 15 sweeps at - 10 dBm concatenated Vs Number of sample

Figures 21 and 22 show the average of the absolute wavelength error during the whole range of wavelengths of each sweep (1500 to 1580 nm). They show an important variability of this parameter from different sweeps at the same power, therefore the assumption previously made extracted from Figure 6 is not consistent and it is not possible to establish a relationship between the wavelength error and the power input.

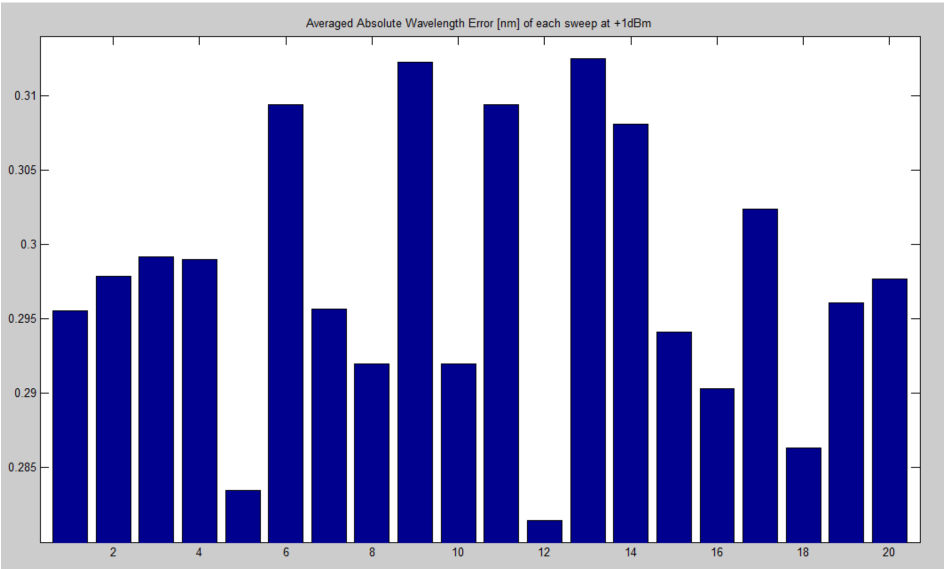


Figure 21.Averaged Absolute Wavelength Error [nm] of each sweep at + 1 dBm

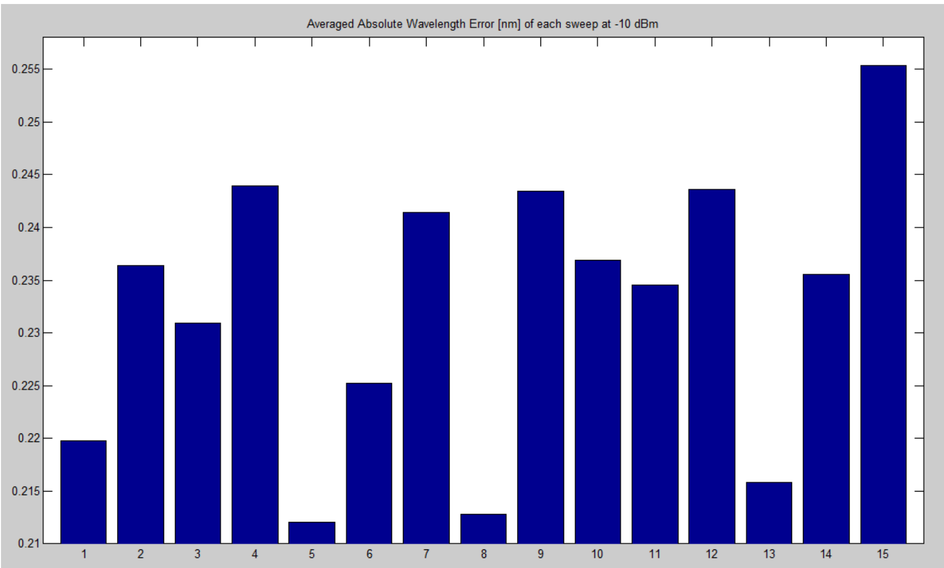


Figure 22.Averaged Absolute Wavelength Error [nm] of each sweep at -10 dBm

Before concluding the wavelength error analysis, in terms of precision for a set of sweeps performed with the same characteristics of power, wavelength range and wavelength step size for the laser and span, reference level and resolution for the OSA, an effort has been made to determine which of those parameters influence the error under study. To achieve consistent results the information obtained has been organized taking into account the parameters shown in Table 4.

Table 4.Error Wavelength Analysis. Span Dependency

SPAN [nm]	Bandwidth Resolution [nm]	Averaged Absolute Wavelength Error [nm]	Wavelength Error Step size [nm]	Comments	Time
Sweep 1520 to 1525 nm at 10 pm steps (501 samples)					17/12/2010
6	0.06	0.142	0.022	Sloped	13:36:02
Sweeps 1520 to 1520.08 nm at 1 pm steps (81 samples/sweep)					14/12/2010
0.2	0.06	0.156	0.022	Flat (2 levels)	13:54:39
2	0.06	0.156	0.023	´´	14:03:57
Sweeps 1520 to 1520.03 nm at 1 pm steps (31 samples/sweep)					14/12/2010
5	0.06	0.154	0.025	´´	14:07:57
10	0.1	0.165	0.028	More values	14:09:34
Sweeps from 1520 nm at 2,5, 50 pm steps respectively (51 S/sweep)					17/12/2010
0.2	0.06	0.150	0.005	Sloped	12:45:13
0.5	0.06	0.150	0.004	Sloped	12:49:47
5	0.06	0.145	0.012	Sloped	12:52:02
Sweeps 1520 to 1520.05 nm at 0.001 nm steps (51 samples/sweep)					17/12/2010
0.2	0.06	0.15	0.005	-	12:24:44
0.5	0.06	0.15	0.005		12:26:44
5	0.06	0.14	0.006		12:28:35
10	0.1	0.13	0.012		12:29:53
20	0.2	0.11	0.029		12:31:26
50	0.5	0.15	0.122		12:33:32
70	0.5	0.12	0.149		12:35:36
100	1.0	0.31	0.243	+	12:37:43
200	2.0	0.70	0.050	Very sloped	12:39:27

SPAN [nm]	Bandwidth Resolution [nm]	Averaged Absolute Wavelength Error [nm]	Wavelength Error Step size [nm]	Comments	Time
Sweeps 1520 to 1545 nm at 0.5 nm steps (51 samples/sweep)					17/12/2010
30	0.2	0.10	0.070	Flat	13:13:14
40	0.5	0.14	0.136	´´	13:14:53
50	0.5	0.11	0.109	´´	13:16:25
60	0.5	0.10	0.064	´´	13:17:50
70	0.5	0.11	0.091	´´	13:19:27
80	1.0	0.27	0.379	´´	13:20:57
90	1.0	0.26	0.387	´´	13:22:19
100	1.0	0.24	-0.055	´´	13:24:04
200	2.0	0.59	0.715	´´	13:25:55
500	5.0	2.09	1.016	´´	13:27:18

Table 4 shows how the wavelength error highly depends on the span selected on the OSA. The relation between both parameters is direct (by increasing the span, the error also increases), but once again (see Figure 23) it is not possible to determine a function to describe it. From the experimental data obtained the error sometimes can be assumed to be linear and therefore eliminated, although this assumption cannot be generalized as could induce high increments on the wavelength error.

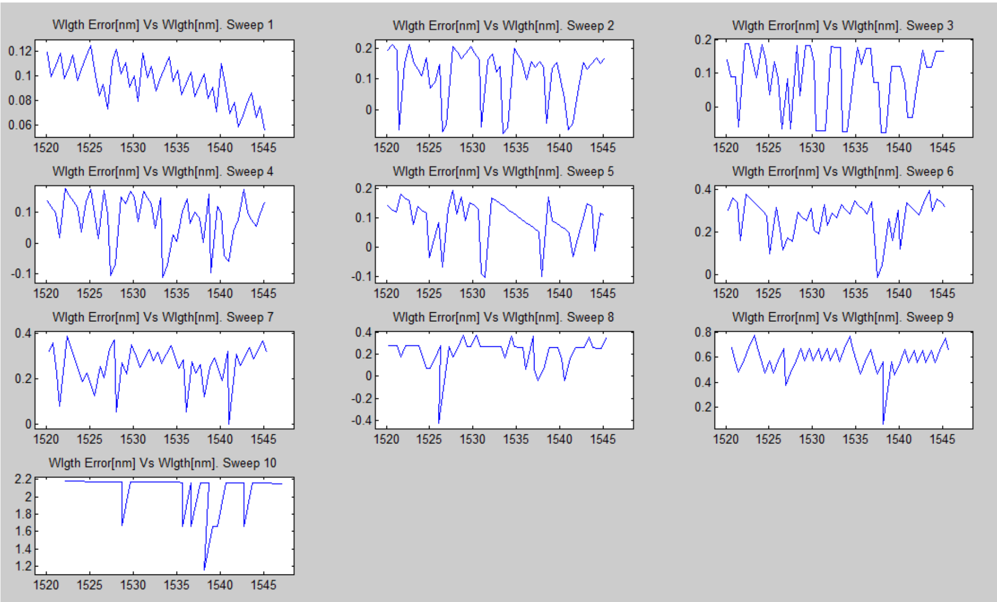


Figure 23.Wavelength Error [nm] for the last set of sweep in Table 4 taken with different spans

Figures 24 and 25 show the wavelength error concatenated (left) and its absolute value averaged (right) for the last two set of sweeps registered in Table 4. They show how the span change directly affects the wavelength error, both in DC and noise levels.

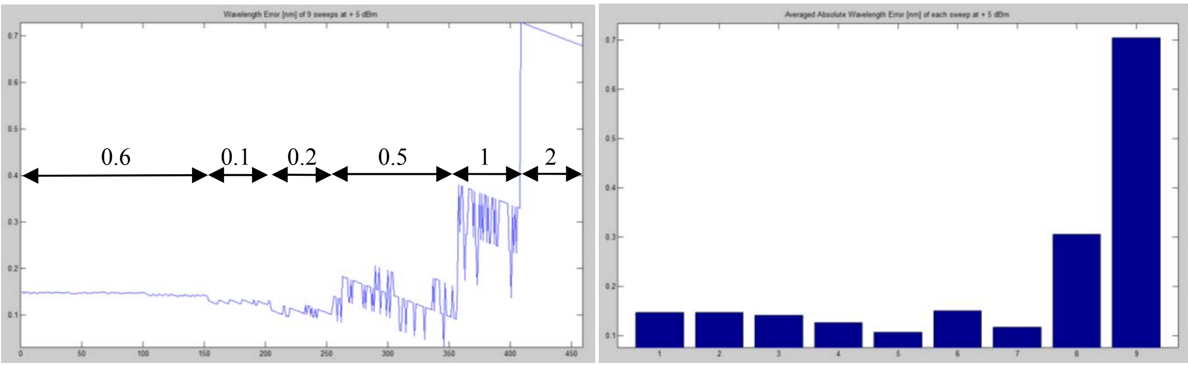


Figure 24.Wavelength Error [nm] Concatenated (left) and Averaged (right) for penultimate set of sweeps in Table 4 taken with different spans. The arrows indicated the Resolution Bandwidth.

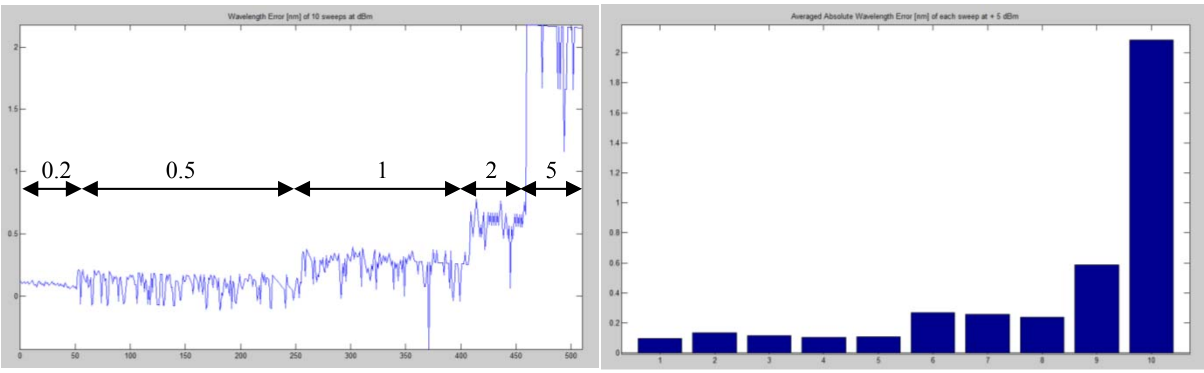


Figure 25.Wavelength Error [nm] Concatenated (left) and Averaged (right) for last set of sweeps in Table 4 taken with different spans. The arrows indicated the Resolution Bandwidth.

From all the data registered in order to understand the behaviour of the wavelength error it is shown that the OSA is the main responsible of it, and that there is not much to do to improve the wavelength error apart from using smaller spans. Therefore we focus our efforts in improving the amplitude accuracy.

6. Test of Optical Devices

6.1. Description of the device

The devices under test (DUTs) have been designed and manufactured in the James Watt Nanofabrication Centre (JWNC) at the University of Glasgow. They are made of Indium Phosphide and have three areas to distinguish:

1) Optical laser
2) Gratings
3) Semiconductor Optical Amplifier (SOA)

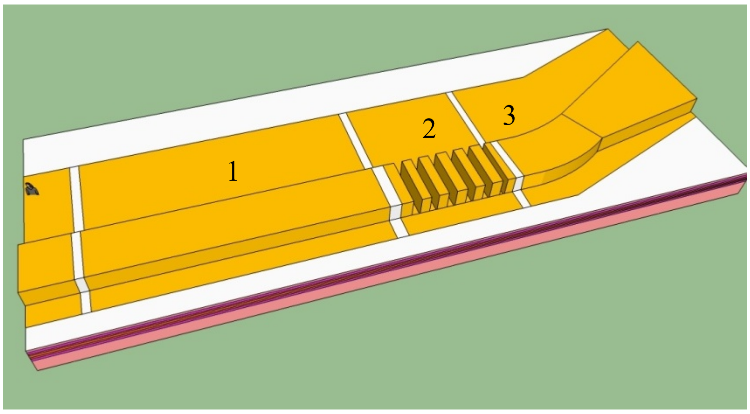


Figure 26.Model of optical device

The devices used are straight in the SOA area and correspond to the devices DBR734, DBR732 and DBR730 of the Bar 1.7B shown in Figure 27.

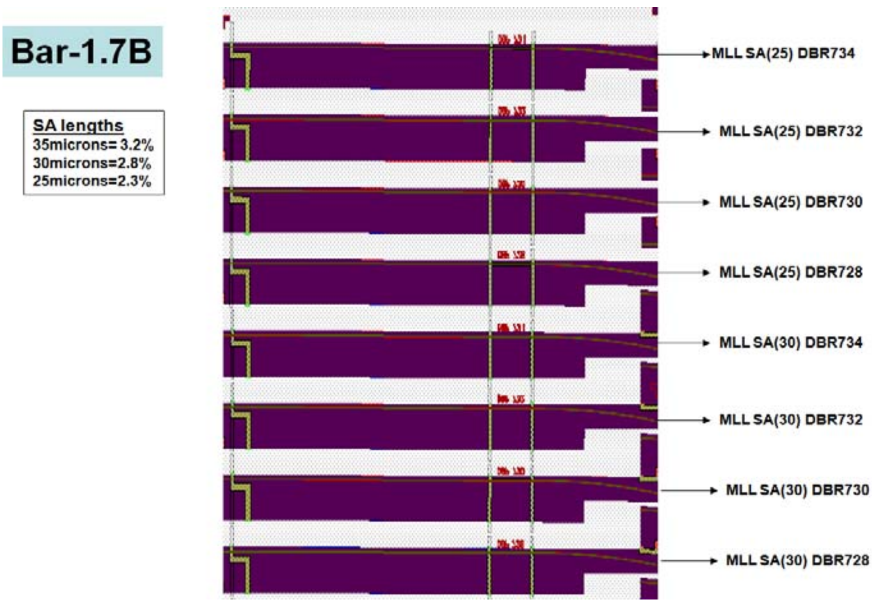


Figure 27.Bar 1.7 with the devices used on the top

6.2.Test Description

The purpose of the test is to characterise the Stop-Band of these devices by analysing the reflexion of light at determined wavelengths.

When current is applied to the device's gratings section, the stop band is expected to move towards lower λs. The parameters under study are therefore: wavelength of maximum reflexion (λ_{max}), maximum reflected amplitude ($P_{\lambda\ max}$) and bandwidth of reflection (BW_{refl}). In order to register these parameters properly, current is injected into the SOA. Figure 28 shows the setup of the test. In order to separate the reflected signal in the fiber from the signal coming from the laser an optical circulator is used.

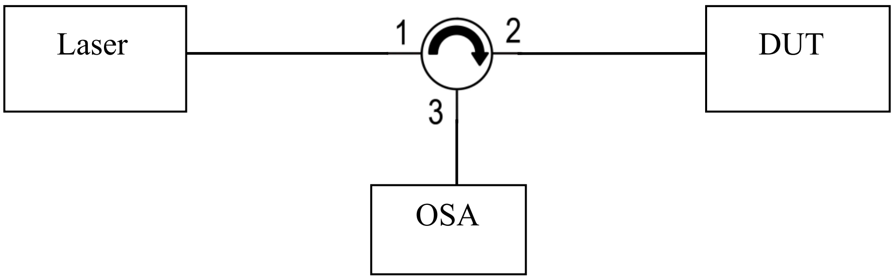


Figure 28.Setup used for the test

Figure 29 shows the reflected wavelength captured by the OSA when different currents are injected into the SOA. It is possible to appreciate that the higher the currents are the clearer the stopband is shown. Hence, 150 mA will be injected into the SOA to characterise their behaviour when different currents are applied to the gratings section.

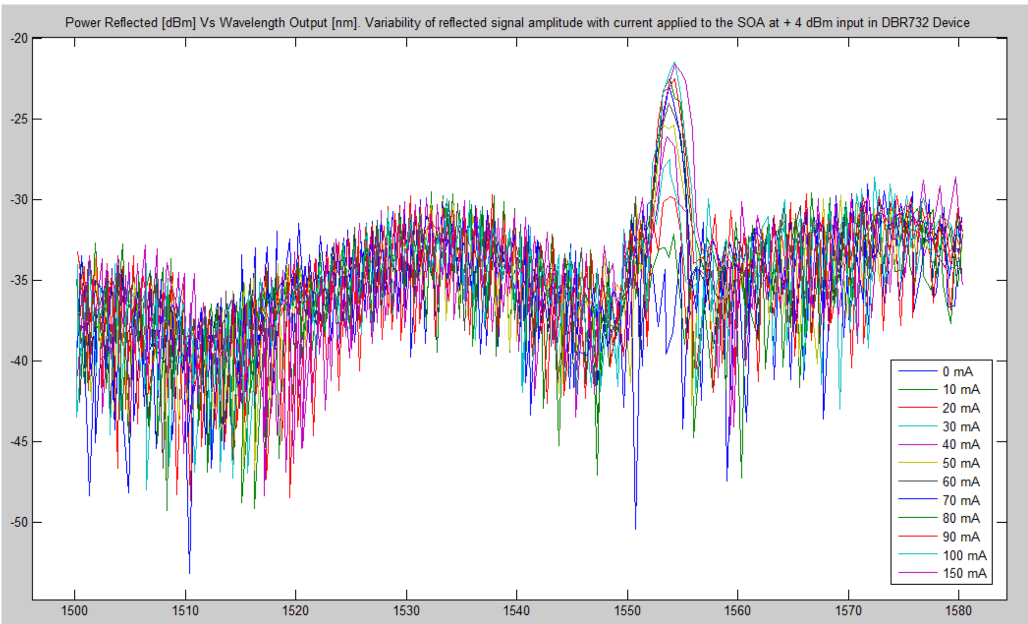


Figure 29.Device DBR732. Variability of the reflected signal for different currents applied to the SOA at + 4 dBm input. Power Reflected [dBm] Vs Wavelength [nm]

Figures 30, 31, 32 show the average of the different currents applied to the SOA in order to get a clearer view of the stopband by getting rid of the noise. However, Table 5 uses the highest current applied to determine the parameters of each device. It shows how for every device Pλmax is achieved at a different wavelength.

Table 5.Devices stop band

Device	λ_{max} [nm]	$P_{\lambda\ max}$ [dBm]
DBR734	1555.8	-19.029
DBR732	1553.8	-22.486
DBR730	1549.3	-19.078

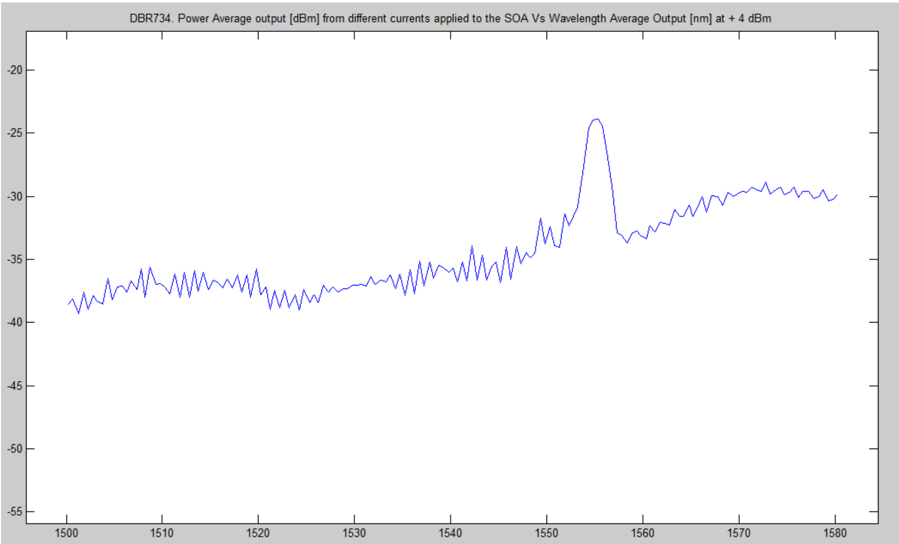


Figure 30.DBR734. Power Average output [dBm] from different currents applied to the SOA Vs Wavelength Average Output [nm] at + 4 dBm

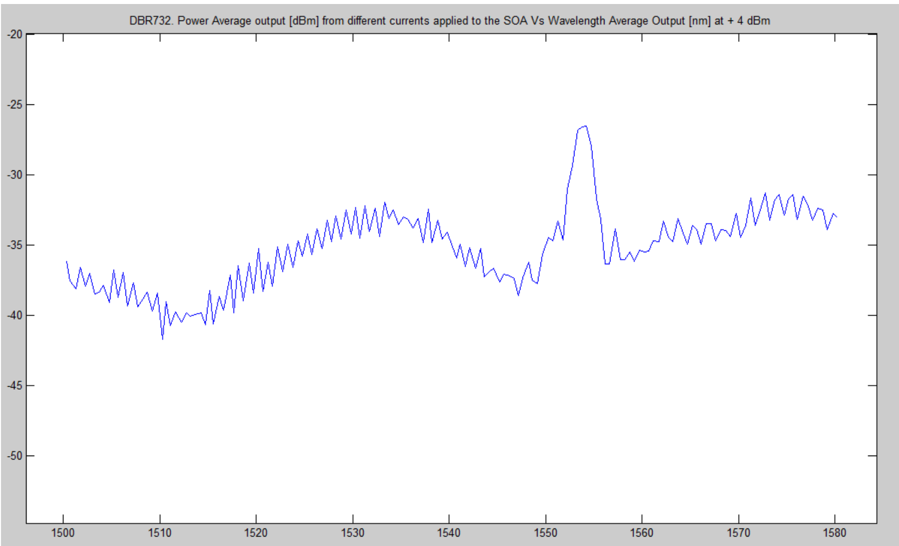


Figure 31.DBR732. Power Average output [dBm] from different currents applied to the SOA Vs Wavelength Average Output [nm] at + 4 dBm

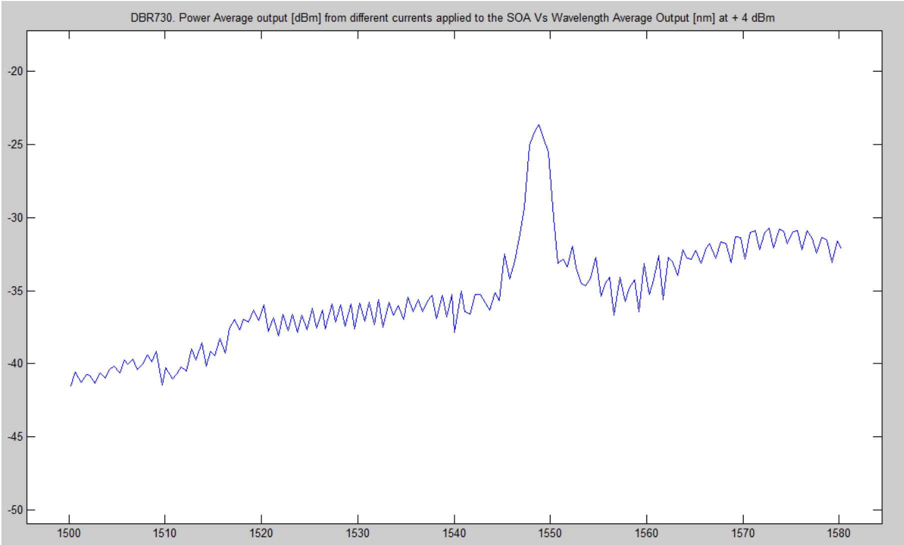


Figure 32.DBR730. Power Average output [dBm] from different currents applied to the SOA Vs Wavelength Average Output [nm] at + 4 dBm

Figures 33, 34 and 35 show the variability of the stopband when different currents are injected into the grating area for the devices DBR734, 732 and 730 respectively, where the span of the window has been reduced by a factor of 8. As previously indicated the current applied into the SOA is 150 mA and the laser amplitude was set to + 4 dBm.

Some undesired wavelength jumps appear in these plots, this is due to the fact that out of the stopband sometimes the noise level is higher than the reflected signal at certain wavelengths.

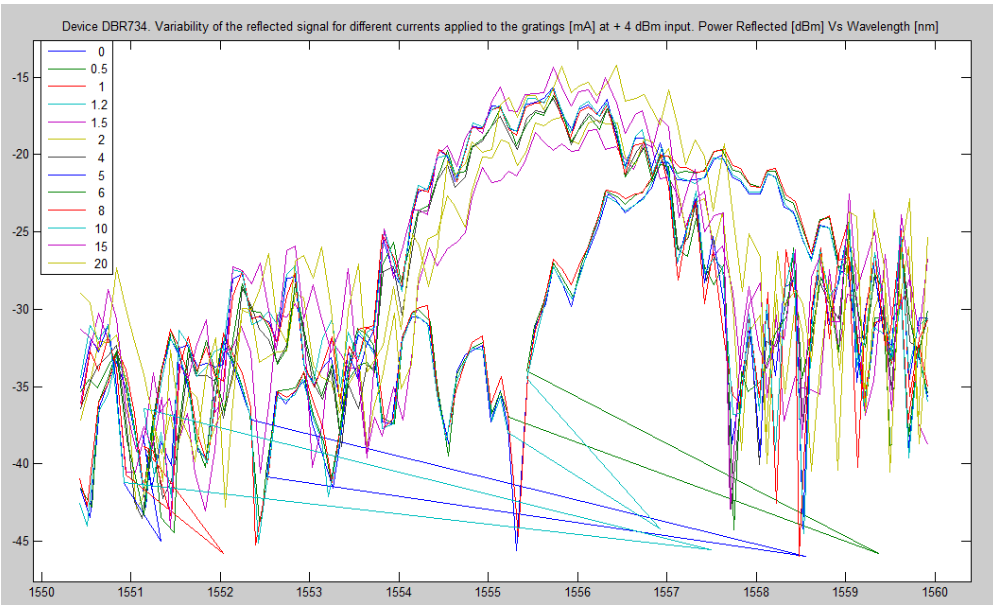


Figure 33.Device DBR734. Variability of the reflected signal for different currents applied to the gratings [mA] at + 4 dBm input. Power Reflected [dBm] Vs Wavelength [nm]

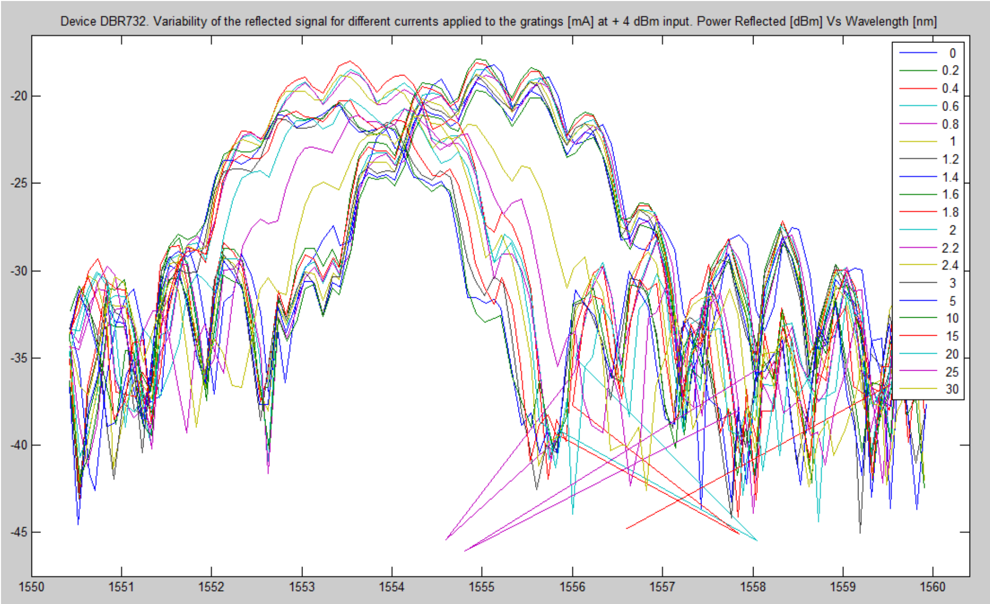


Figure 34.Device DBR732. Variability of the reflected signal for different currents applied to the gratings [mA] at + 4 dBm input. Power Reflected [dBm] Vs Wavelength [nm]

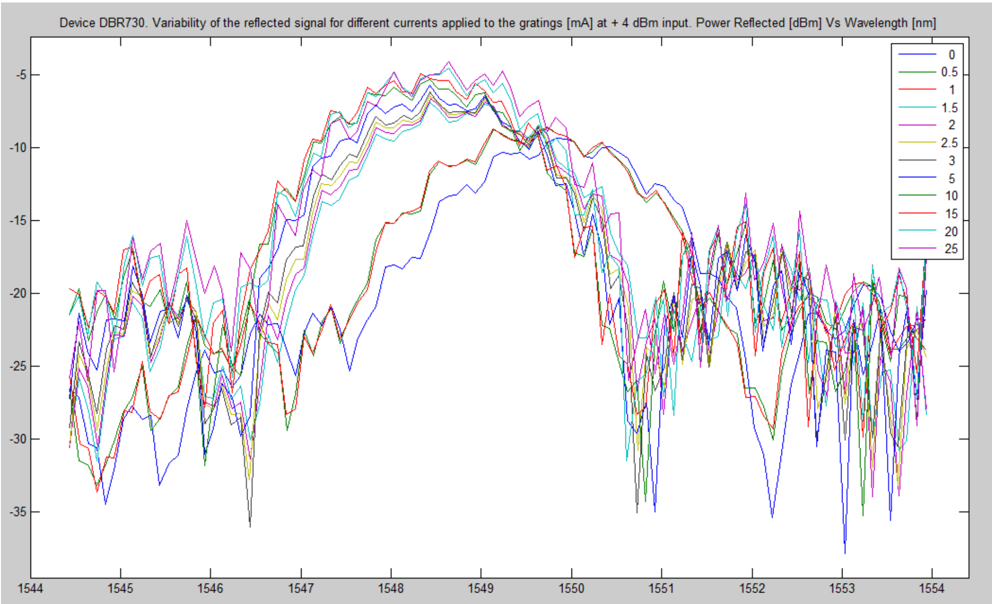


Figure 35.Device DBR730. Variability of the reflected signal for different currents applied to the gratings [mA] at + 4 dBm input. Power Reflected [dBm] Vs Wavelength [nm]

Tables 6-8 extract the parameters aimed to characterise the devices, the reflection band has been establish at a -3 dBm drop at both sides.

Table 6. DBR734. Stopband characteristics at different currents injected in the gratings

	Current [mA]	Wavelenth Peaks [nm]	Power Peaks [dB]	Reflection Band [nm]
1	0.00	1557.6	-20.0280	1.6683
2	0.50	1557.6	-19.6466	1.7782
3	1.00	1557.6	-19.6969	1.8781
4	1.20	1557.5	-20.1967	1.7782
5	1.50	1556.2	-18.3531	1.6084
6	2.00	1555.8	-17.5919	1.3287
7	4.00	1555.7	-16.3495	0.6094
8	5.00	1555.7	-15.6118	1.6783
9	6.00	1555.7	-16.2055	1.2188
10	8.00	1555.7	-15.8253	1.1788
11	10.00	1555.7	-15.6816	1.7882
12	15.00	1555.7	-14.3542	1.5984
13	20.00	1556.4	-14.2217	1.6084

Table 7. DBR732. Stopband characteristics at different currents injected in the gratings

	Current [mA]	Wavelenth Peaks [nm]	Power Peaks [dB]	Reflection Band [nm]
1	0.00	1555.1	-18.2128	1.6983
2	0.20	1554.9	-17.9082	1.7083
3	0.40	1554.9	-18.1067	1.7982
4	0.60	1554.9	-18.4881	1.7982
5	0.80	1555.0	-18.8224	1.6983
6	1.00	1554.9	-18.7625	1.7982
7	1.20	1554.9	-18.8244	1.7083
8	1.40	1554.9	-19.2491	1.7982
9	1.60	1554.9	-19.6918	1.7982
10	1.80	1553.5	-17.9995	1.8082
11	2.00	1553.5	-18.4881	1.8082
12	2.20	1553.5	-18.6242	1.8082
13	2.40	1553.4	-18.7860	1.7982
14	3.00	1553.4	-20.4331	1.6983
15	5.00	1553.4	-20.5256	1.7982
16	10.00	1553.4	-20.3975	2.2078
17	15.00	1553.5	-20.2408	1.7982
18	20.00	1553.5	-20.1376	1.8182
19	25.00	1554.1	-20.7394	2.2178
20	30.00	1554.3	-21.0731	1.7882

Table 8. DBR730. Stopband characteristics at different currents injected in the gratings

	Current [mA]	Wavelenth Peaks [nm]	Power Peaks [dB]	Reflection Band [nm]
1	0.00	1549.8	-9.3701	1.7982
2	0.50	1549.7	-8.6366	2.2977
3	1.00	1549.7	-8.5631	2.1878
4	1.50	1548.4	-6.9341	2.0979
5	2.00	1548.4	-6.6694	2.0979
6	2.50	1548.4	-6.4719	1.7982
7	3.00	1548.4	-6.1623	1.8981
8	5.00	1548.4	-5.7463	1.7982
9	10.00	1548.4	-5.3361	1.6883
10	15.00	1548.3	-4.9641	1.7882
11	20.00	1548.6	-4.5478	1.7982
12	25.00	1548.6	-4.1065	1.5984

As we can see, the stopband does not change linearly against the current applied to the gratings. It is possible to distinguish four areas show in Figures 36-38. The first one is the result of applying low currents, where the stopband seems to remain constant. The second area from 1.0 to 2.4 mA decreases the λ max in a dramatic step of less than 2 nm. Then the stopband remains constant until the current gets to 15 mA when it starts to move to towards higher wavelengths again.

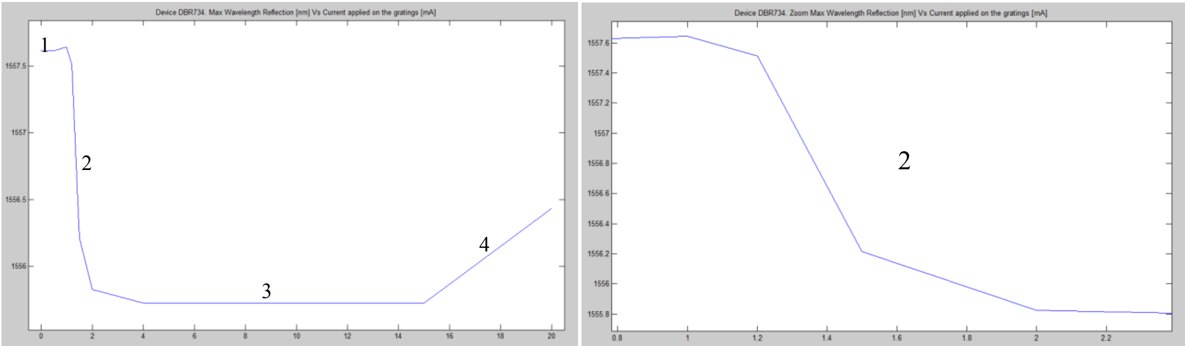


Figure 36.Device DBR734. Max Wavelength Reflection [nm] Vs Current applied on the gratings [mA]. Zoomed (right)

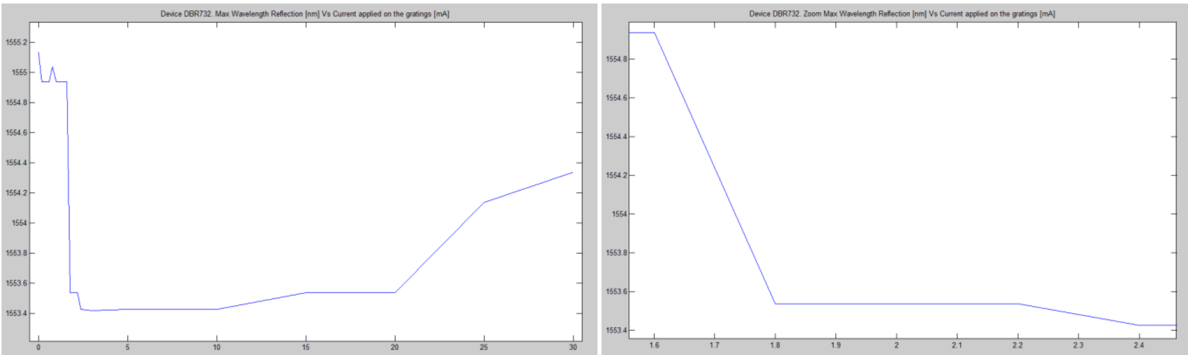


Figure 37.Device DBR732. Max Wavelength Reflection [nm] Vs Current applied on the gratings [mA]. Zoomed (right)

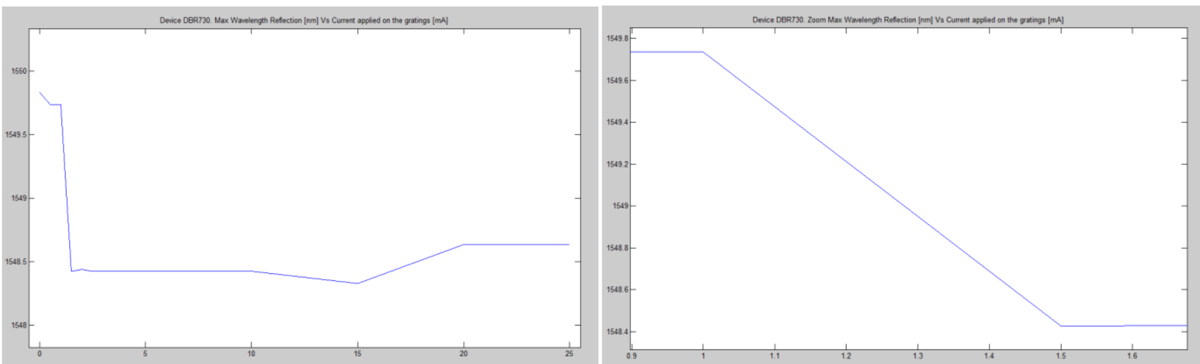


Figure 38.Device DBR730. Max Wavelength Reflection [nm] Vs Current applied on the gratings [mA]. Zoomed (right)

The behaviour shown in the first region suggests that the current provided by the current source which displayed a resolution of 0.1 mA, is not suitable for the characterization aimed due to its lack of reliability at low currents, although its behaviour has not been tested.

Finally, Figure 41 shows the calibrated variability of the stopband for the device DBR734. To achieve this calibration the circuit shown in Figure 28 was split into two circuits show in Figure 39. In the first one the laser is connected to the circulator in the same way it was during the characterisation of the devices and the OSA takes the place of the device in order to characterise the loses between these two parts, where 10 sweeps are recorded. Finally the laser is connected to port no. 2 of the circulator in order to characterise the losses between this point and the original location of the OSA, where other 10 sweeps are again recorded, see Figure 40.

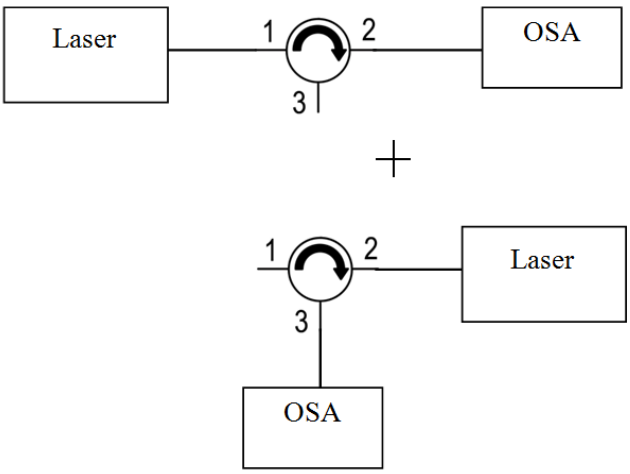


Figure 39.Setups used for the calibration of the devices

In the original circuit the losses could be summarised as follows:

$$\Delta\varepsilon_{TOT} = \Delta\varepsilon_{Laser} + \Delta\varepsilon_{Fib\ L-1} + \Delta\varepsilon_{Circ\ 1-2} + \Delta\varepsilon_{Fib\ 2-DUT} + \Delta\varepsilon_{DUT} + \Delta\varepsilon_{Fib\ DUT-2} + \Delta\varepsilon_{Circ\ 2-3} + \Delta\varepsilon_{Fib\ 3-OSA} + \Delta\varepsilon_{OSA}$$

In the circuits used for calibration:

$$\Delta\varepsilon_{CALI\ 1} = \Delta\varepsilon_{Laser} + \Delta\varepsilon_{Fib\ L-1} + \Delta\varepsilon_{Circ\ 1-2} + \Delta\varepsilon_{Fib\ 2-OSA} + \Delta\varepsilon_{OSA}$$

$$+$$

$$\Delta\varepsilon_{CALI\ 2} = \Delta\varepsilon_{Laser} + \Delta\varepsilon_{Fib\ L-2} + \Delta\varepsilon_{Circ\ 2-3} + \Delta\varepsilon_{Fib\ 3-OSA} + \Delta\varepsilon_{OSA}$$

$$\Delta\varepsilon_{TOT\ CALI} = 2 * \Delta\varepsilon_{Laser} + \Delta\varepsilon_{Fib\ L-1} + \Delta\varepsilon_{Circ\ 1-2} + \Delta\varepsilon_{Fib\ 2-OSA} + \Delta\varepsilon_{Fib\ L-2} + \Delta\varepsilon_{Circ\ 2-3} + \Delta\varepsilon_{Fib\ 3-OSA} + 2 * \Delta\varepsilon_{OSA}$$

Assuming: $\Delta\varepsilon_{Fib\ L-1} = \Delta\varepsilon_{Fib\ L-2} = \Delta\varepsilon_{Fib\ L}$

$\Delta\varepsilon_{Fib\ 2-OSA} = \Delta\varepsilon_{Fib\ 3-OSA} = \Delta\varepsilon_{Fib\ OSA}$

Then:

$$\Delta\varepsilon_{TOT\ CALI} = 2 * (\Delta\varepsilon_{Laser} + \Delta\varepsilon_{Fib\ L} + \Delta\varepsilon_{Fib\ OSA} + \Delta\varepsilon_{OSA}) + \Delta\varepsilon_{Circ\ 1-2} + \Delta\varepsilon_{Circ\ 2-3}$$

This model used for the calibration is an approximation that involves the error due to the laser and the OSA twice, which is twice the times involved in the actual circuit. This is acceptable as seen in the previous characterisation of the equipment for the span window used.

Once the 20 sweeps are registered, the next stage is to add them; the resultant sum is then subtracted from the 4 dBm input in order to obtain the system losses. Finally, the calibrated data will be the result of adding the registered data to the system losses. These operations require the prior transformation of the dBm amplitudes into mW carried out through the following formula:

$$P[mW] = 10^{\frac{\mathrm{P[dBm]}}{10}}$$

The actual data will be, once the described operations finished, rescaled for its representation into dBm.

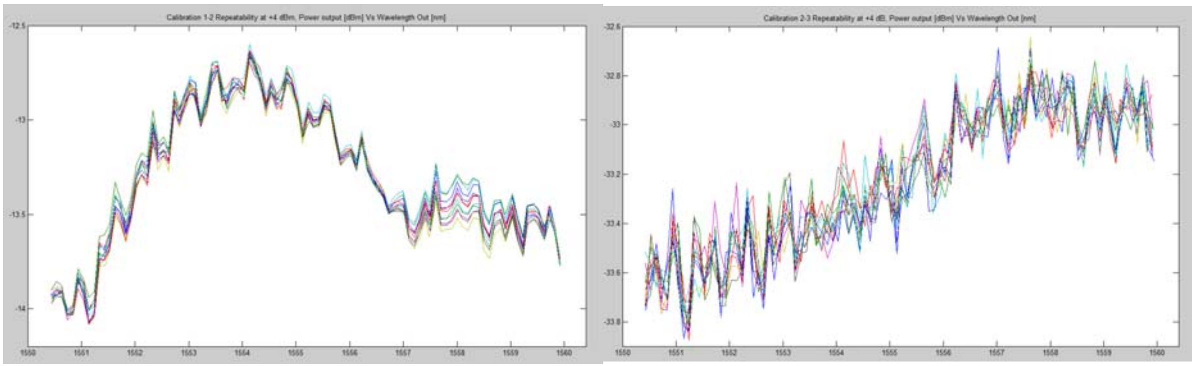


Figure 40.Calibration sweeps ports 1-2 (left) and ports 2-3 (right). Reflected Power [dBm] Vs Wavelength [nm]

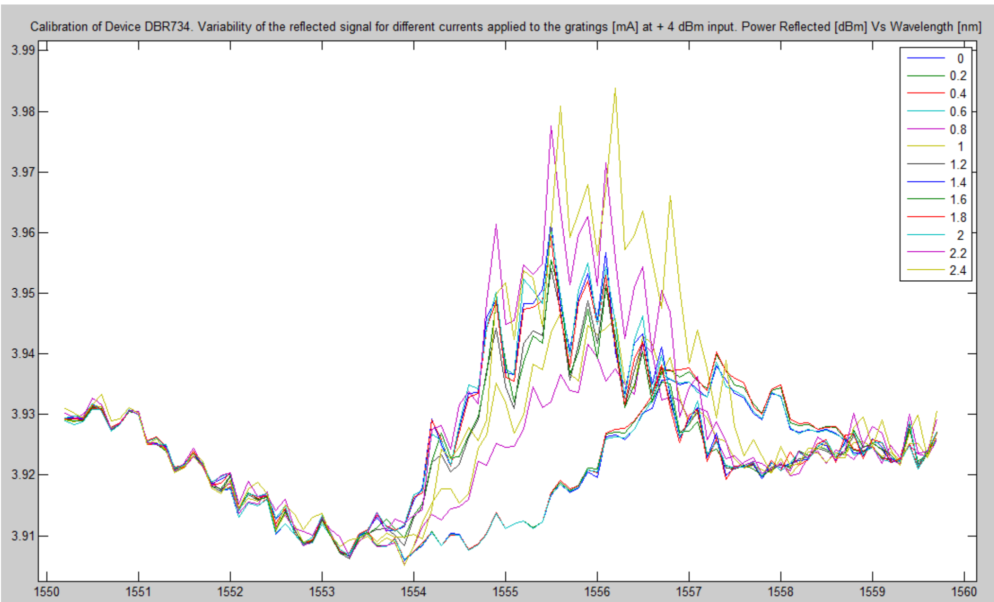


Figure 41.Calibration of Device DBR734. Variability of the reflected signal for different currents applied to the gratings [mA] at + 4 dBm input. Power Reflected [dBm] Vs Wavelength [nm]

7. Conclusions

The output signal is saturated in its lower wavelength range when high powers are selected; hence it is recommendable to set the power output to values no higher than 5 dBm. Furthermore, despite the power input resolution allows changes of 0.01 dBm the laser output only responds to the manual input changes shown in Table 1.

For smoother power output behaviour it is recommended to work in the range 1532-1550 nm especially behind the 1532 nm. The higher the wavelength or the more advanced is the sweep the lower are the positive wavelength errors (wavelength output higher than input) and the higher are the negative ones.

Although at an initial state of the study the wavelength error seemed to be smaller for lower powers it cannot be guaranteed. The OSA is the main responsible of the wavelength error and it can be reduced by applying the lowest possible spans.

Despite it is not possible to use data calibrated registered in one day for a different one, it is possible to use data calibrated at one power for other powers. However, the use of an optical attenuator would increase precision.

The amplitude precision is tested to be ±0.1 dBm although is out of range for some sweeps which might be due to human action due to setup sensibility.

As regards to device characterisation, three optical devices have been explored in terms of stopband. The stopband does not change linearly against the current applied to the gratings and it is possible to distinguish four areas, although higher precision current sources should be used to clarify this point.

8. Suggestions for further work

Improve the VI so that the OSA is able to set a smaller and adapted window for each wavelength set instead of using a large span for the whole sweep if the wavelength error is to be improved.

Use higher precision current sources to test the optical devices and independently measure the injected current for a improved device stopband variability characterisation.

9. References

[1] Anritsu MG9637A/MG9638A Tunable Laser Source. Remote Control. Operation Manual, Second Edition. Document No.: M-W1214AE-2.0. October 1997

[2] Agilent 86140B Series. Optical Spectrum Analyzer. User's Guide. Agilent Part No. 86140-90068. January 2002

[3] GPIB Controller for Hi-Speed USB http://sine.ni.com/nips/cds/view/p/lang/en/nid/201586

[4] LabVIEW. Getting Started with LabVIEW. August 2006

[5] Matlab Documentation. http://www.mathworks.com/

10. Appendices

10.1. Matlab analysis script

```
function analysis_individual_project

clear all
format shortG;

currents = [0; 0.2; 0.4; 0.6; 0.8; 1; 1.2; 1.4; 1.6; 1.8; 2.0; 2.2; 2.4; 3;
5; 10; 15; 20; 25; 30];
sweeps = dir('*.txt');
nsweeps = length(sweeps);
for i=1:nsweeps
    A = importdata(sweeps(i).name, '\t', 21);  %Imports, skips file header
    wavIN(:,i) = A.data(:,1);
    powOUT(:,i) = A.data(:,2);
    wavOUT(:,i) = A.data(:,3);
    wavERROR(:,i) = wavOUT(:,i) - wavIN(:,i);
end

%Matrix with the averages for a different number of sweeps
Add = powOUT;
AvgPow = powOUT;
for j=2:nsweeps
    Add(:,j) = Add(:,j-1) + Add(:,j);
    AvgPow(:,j) = Add(:,j)./j;
end

%Substracting each sweep from a different number of averages
for k=1:nsweeps                 %k is number of averages
    for m=1:nsweeps             %m is number of sweep
        Subs(k,m) = mean(abs(powOUT(:,k) - AvgPow(:,m)));
    end
end
AvgError = mean(Subs);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  NUMBER OF AVERAGES

figure(1)
ymin1 = min(min(AvgError));
ymax1 = max(max(AvgError));
yrange1 = ymax1-ymin1;
labelymin1 = roundn(ymin1 - 0.05*yrange1, -4);
labelymax1 = roundn(ymax1 + 0.05*yrange1, -4);
labelxmax1 = nsweeps + 0.5;
plot (AvgError);
axis([0.5 labelxmax1 labelymin1 labelymax1])
title('Calibration Power Error [dBm] at dBm input Vs Number of Averages')

['Average Power Error after 10 sweeps calibration = ' num2str(AvgError(10))
' nm']
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  REPEATABILITY

figure(2)
ymin2 = min(min(powOUT));
ymax2 = max(max(powOUT));
yrange2 = ymax2-ymin2;
labelymin2 = roundn(ymin2 - 0.05*yrange2, -1);
labelymax2 = roundn(ymax2 + 0.05*yrange2, -1);

xmin2 = min(min(wavOUT));
xmax2 = max(max(wavOUT));
xrange2 = xmax2-xmin2;
labelxmin2 = roundn(xmin2 - 0.05*xrange2, -1);
labelxmax2 = roundn(xmax2 + 0.05*xrange2, -1);
plot (wavOUT, powOUT);
axis([labelxmin2 labelxmax2 labelymin2 labelymax2])
title('Repeatability at dBm, Power output [dBm] Vs Wavelength Out [nm]')
legend(num2str(currents));

figure(3)
POWAVERAGE = mean(powOUT,2);
WAVAVERAGE = mean(wavOUT,2);
plot (WAVAVERAGE, POWAVERAGE);
axis([labelxmin2 labelxmax2 labelymin2 labelymax2])
title('Power Average output [dBm] Vs Wavelength In [nm] at dBm')

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  WAVELENGTH

%Wavelength error key values
minwavERROR = min(wavERROR,[],1);
maxwavERROR = max(wavERROR,[],1);
stepERROR = maxwavERROR - minwavERROR;
info_wavERROR(:,1) = [stepERROR];
info_wavERROR(:,2) = [minwavERROR];
info_wavERROR(:,3) = [maxwavERROR];
[info_wavERROR]

figure(4)

if (nsweeps <= 20)
    rows = 5;columns = 4;
    if (nsweeps <= 15)
        rows = 5;columns = 3;
        if (nsweeps <= 12)
            rows = 4;columns = 3;
            if (nsweeps <= 9)
                rows = 3;columns = 3;
                if (nsweeps <= 6)
                    rows = 3;columns = 2;
                    if (nsweeps <= 4)
                        rows = 2;columns = 2;
                        if (nsweeps <= 2)
                            rows = 2;columns = 1;
                            if (nsweeps <= 12)
                                rows = 1;columns = 1;
                            end
                        end
                    end
                end
            end
```

```
        end
    end
end

for p=1:nsweeps
    ymin4 = min(wavERROR(:,p));
    ymax4 = max(wavERROR(:,p));
    yrange4 = ymax4-ymin4;
    labelymin4 = roundn(ymin4 - 0.05*yrange4, -2);
    labelymax4 = roundn(ymax4 + 0.05*yrange4, -2);
    subplot(rows,columns,p);
    plot(wavOUT(:,p), wavERROR(:,p));
    axis([labelxmin2 labelxmax2 labelymin4 labelymax4])
    title(['Wlgth Error[nm] Vs Wlgth[nm]. Sweep ' num2str(p)])
end

AvgWError = mean(mean(wavERROR));
maxWError = max(max(wavERROR));
minWError = min(min(wavERROR));
['Average Wavelength Error = ' num2str(AvgWError) ' nm']
['Max Wavelength Error = ' num2str(maxWError) ' nm']
['Min Wavelength Error = ' num2str(minWError) ' nm']
%['Average Wavelength Error after 10 sweeps calibration???

figure(5)
allwavERROR = wavERROR(:);
plot(allwavERROR);
axis([0 length(allwavERROR) min(allwavERROR) max(allwavERROR)])
title(['Wavelength Error [nm] of ' num2str(nsweeps) ' sweeps at dBm'])

figure(6)
abswavERROR = abs(wavERROR);
avg_abs_wavERROR = mean(abswavERROR,1);
ymin6 = min(avg_abs_wavERROR);
ymax6 = max(avg_abs_wavERROR);
yrange6 = ymax6-ymin6;
labelymin6 = roundn(ymin6 - 0.05*yrange6, -3);
labelymax6 = roundn(ymax6 + 0.05*yrange6, -3);
bar(avg_abs_wavERROR);
axis([0.3 (nsweeps+0.7) labelymin6 labelymax6])
title(['Averaged Absolute Wavelength Error [nm] of each sweep at dBm'])

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  CALIBRATION SUBTRACTION

BlueWhite = 10.^(POWAVERAGE1./10);
RedBlue = 10.^(POWAVERAGE2./10);
AddedCalibration = RedBlue + BlueWhite;
AddedCalibrationdB = 10*log10(AddedCalibration)
LossesP = 10^(4/10)-AddedCalibration;
LossesMP = LosesP*ones(1,nsweeps);
calibrated_powOUT_P =powOUT_P + LossesMP;
calibrated_powOUT_dB = 10*log10(calibrated_powOUT_P);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%  STOPBAND ANALYSIS

%%Wavelength of maximum reflection and its power
%     %From average
[Peak_avg, Peak_avg_index]= max(POWAVERAGE);
Wav_Peak = WAVAVERAGE(Peak_avg_index);
['Max Power Reflection from Averaging different currents = '
num2str(Peak_avg) ' dB at ' num2str(Wav_Peak) ' nm']
     %At each current
[Peaks, Peaks_index]= max(powOUT);
for m=1:nsweeps
    Wav_Peaks(m) = wavOUT(Peaks_index(m),m);
end

%%Stop-band limits -3dB
    %At each current
for r=1:nsweeps
    PowCuts(r) = Peaks(r) - 3;
    for n=1:length(powOUT(:,r))
        if (powOUT(Peaks_index(r) - n, r) <= PowCuts(r))
            Cutoff_LOW_index(r) = Peaks_index(r) - n;
            Cutoff_LOW(r) = wavOUT(Cutoff_LOW_index(r));
            break
        end
    end
    for q=1:length(powOUT(:,1))
        if (powOUT(Peaks_index(r) + q, r) <= PowCuts(r))
            Cutoff_HIGH_index(r) = Peaks_index(r) + q;
            Cutoff_HIGH(r) = wavOUT(Cutoff_HIGH_index(r));
            break
        end
    end
end
Reflection_Bands = Cutoff_HIGH - Cutoff_LOW;
Reflection_at_every_current(:,1) = [currents];
Reflection_at_every_current(:,2) = [Wav_Peaks];
Reflection_at_every_current(:,3) = [Peaks];
Reflection_at_every_current(:,4) = [Reflection_Bands];
[Reflection_at_every_current]

figure(7)
cnames = {'Current [mA]','Wavelenth Peaks [nm]','Power Peaks
[dBm]','Reflection Band [nm]'};
t =
uitable('Data',Reflection_at_every_current,'ColumnName',cnames,'Position',[
20 20 500 300]);

figure(8)
plot (currents, Wav_Peaks);
axis([(min(currents)-0.5) (max(currents)+0.5) (min(Wav_Peaks)-0.2)
(max(Wav_Peaks)+0.2)])
title('Max Wavelength Reflection [nm] Vs Current applied on the gratings
[mA]')
```

10.2. Catalogues

TUNABLE LASER SOURCE
MG9637A/9638A
1500 to 1580 nm

For Evaluation of WDM, Optical Devices and Optical Fiber Amplifiers

GPIB

The larger transmission capacity required by multimedia applications has seen increasing use of wavelength division multiplexing (WDM) using optical fiber amplifiers in every field from R&D to commercial operation. As a consequence, key WDM optical devices such as optical fiber amplifiers, couplers, and isolators require even higher performance and stability.

The MG9637A/9638A design meets these requirements through excellent wavelength repeatability, achieved by self-calibration and improved reliability using a new external cavity technology. The MG9637A/9638A utilize an external optical automatic power control (APC) module, the MG9637A has an Lithium Niobate modulator in the APC section to provide excellent output power stability and S/N ratio. The MG9638A uses a semiconductor amplifier providing a high-power output of at least +4 dBm.

Both laser sources are ideal for evaluating the wavelength loss characteristics and polarization mode dispersion (PMD) of optical devices (couplers, filters, etc.), as well as the gain and noise figure of optical fiber amplifiers and PMD used in dense wavelength division multiplexing (DWDM) systems.

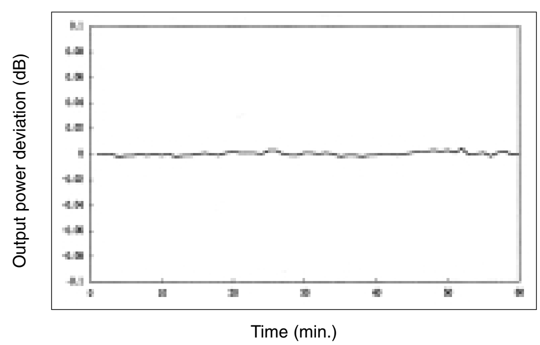
Features

- Single moded emission
- 1 pm wavelength setting resolution
- ±7 pm max. wavelength repeatability
- +4 dBm or more output
- Two output ports

Performance

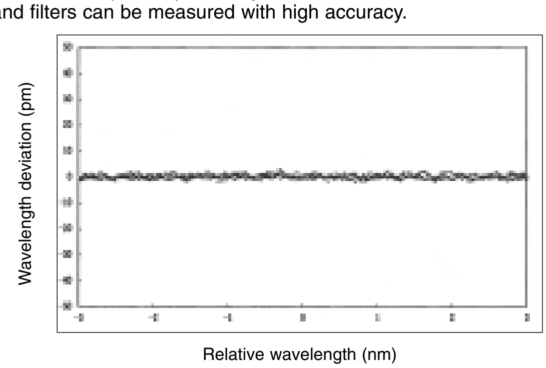
• Stable output power

The power of Output 1 of the MG9637A has been stabilized to ±0.01 dB using the APC function, permitting easy and stable wavelength loss measurement of optical devices. In addition, the wavelength flatness is within ±0.1 dB, enabling high-accuracy measurement of wavelength loss without normalization of the output power of the laser source.



• Wavelength repeatability

The wavelength repeatability is about ±5 pm when the calibration function (applications for patent) is used. Consequently, the full width half maximum (FWHM) and stop-band loss characteristics of narrow band filters can be measured with high accuracy.



• Polarization maintaining fiber output
Output 1 uses a polarization-maintaining fiber to guarantee a polarization extinction ratio of more than 18 dB at the output side. This is very useful for measuring the polarization characteristics of optical fiber amplifiers and external modulators, as well as for measurement at a constant polarization.

• Coherence control function
When measuring the wavelength loss characteristics of an optical devices with a narrow linewidth, interference due to reflect from the optical device reduces the level stability and causes ripple over wavelength. The coherence control function broaders the linewidth to about 50 MHz eliminating level fluctuations due to interference and permitting accurate measurement.

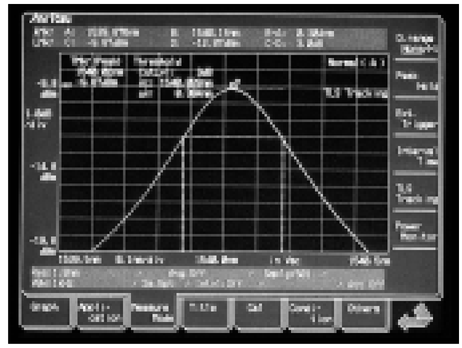
Functions

• Fast measurement of narrow-band filters
DWDM communications currently being commercialized use wavelength multiplexing at an interval of 0.2 nm to several nm. As a consequence, wavelength band pass filters for these applications require a narrow bandwidth and large loss in stop-band loss.

The MG9637A/9638A achieve improved wavelength repeatability and high-speed sweeping using self calibration function (applications for patent). When combined with the MS9710B Optical Spectrum Analyzer or ML9001A Optical Power Meter, wavelength loss characteristics can be measured quickly with high accuracy and a wide dynamic range. For example, high-speed measurement (51 points) is possible in less than 30 seconds.

• Wide dynamic range measurement with optical spectrum analyzer
The MG9637A/9638A can be linked with the MS9710B Optical Spectrum Analyzer just by an RS-232C cable, with no need for an external controller. Measurement is made simple by using the MS9710B soft keys. Furthermore, measurement results including transmission loss, FWHM, and stop-band loss characteristics can be analyzed easily using the MS9710B marker, trace, and smoothing functions.

The following screens (A, B) show examples of measurements of a high performance filter with a center wavelength of 1540 nm. Screen A is a FWHM measurement example: since the wavelength repeatability is within ±7 pm, the FWHM can be measured accurately. Screen B shows a pass-band and stop-band loss characteristics measurement example: wide dynamic range measurement of better than 70 dB is possible by setting the MS9710B resolution bandwidth to 0.2 nm.



A: FWHM measurement (MS9710B display)

B: Wide dynamic range measurement (MS9710B display)

Specifications

Model		MG9637A	MG9638A
Wavelength range		1500 to 1580 nm	
Wavelength setting resolution		1 pm	
Absolute wavelength accuracy		<±0.1 nm	
Wavelength stability		<±100 MHz/h*1	
Wavelength repeatability		±35 pm (80 nm range), Typical: ±7 pm (at ±3 nm, after calibration)	
Side mode suppression ratio*2		>45 dB (1520 to 1570 nm) >40 dB (1500 to 1580 nm)	>40 dB (1520 to 1570 nm) >35 dB (1500 to 1580 nm)
Linewidth (typical value)		700 kHz (coherent control: Off), 50 MHz (coherent control: On)	
Wavelength switching time (typical value)		100 ms/1 nm, 150 ms/10 nm, 500 ms/80 nm	
Output 1	Max. output power	>–10 dBm (1520 to 1570 nm) >–13 dBm (1500 to 1580 nm)	>+4 dBm (1520 to 1570 nm) >0 dBm (1510 to 1580 nm) >–5 dBm (1500 to 1580 nm)
	Min. setting output power	<–20 dBm	<–10 dBm
	Power stability*1	<±0.01 dB/h	<±0.02 dB/h
	Power flatness*3	<±0.1 dB	<±0.2 dB
	Polarization extinction ratio	>18 dB	
Output 2		Output power: >–10 dBm	
Internal modulation		200 Hz to 20 kHz (square waveform), Duty: 50%	
External modulation*4		1 MHz to 3 GHz	1 to 300 MHz
Interface		GPIB, RS-232C	
Main functions		Wavelength calibration, single-step sweep	
I/O Connector		Frequency control input, external modulation input, sweep signal output, sweep trigger signal output, internal modulation sync signal output	

Continued on next page

Warm-up time	<1 h
Laser safety	FDA21-CFR: Class 1 IEC-825: Class 3A
Ambient temperature	Operation: +10˚ to +35˚C, Storage: –20˚ to +60˚C
Dimensions and mass	319 (W) x 177 (H) x 450 (D) mm, ≤16 kg
Power supply	AC 85 to 132/170 to 250 Vac, <190 VA
EMC	EN55011: 1991, Group 1, Class A EN50082-1: 1992
Safety	EN61010-1: 1993 (installation Category II, Pollution Degree II)

Note: Typical values are not guaranteed.
*1: 1 hour at constant temperature
*2: Ratio of peak levels over the peak wavelength range ±0.5 to ±2.5 nm, measured using an optical spectrum analyzer with a wavelength resolution of 0.1 nm.
*3: Room temperature
*4: 10 dB down from the reference point at 10 MHz

Ordering information

Please specify model/order number, name, and quantity when ordering.

Model/Order No.	Name	
	Main frame	
MG9637A	Tunable Laser Source	
MG9638A	Tunable Laser Source	
	Standard accessories	
	Optical connector adapter*1:	2 pcs
J0017	Power cord, 2.5 m:	1 pc
F0013	Fuse, 5 A:	2 pcs
S0001	Optical output control key:	2 pcs
W1213AE	MG9637A/9638A operation manual:	1 copy
W1214AE	Remote control operation manual:	1 copy
B0329G	Front cover:	1 pc
	Options	
MG9637A-27	E2000 connector*2	
MG9637A-31	EC (Radial) connector*2	
MG9637A-37	FC-PC connector*2	
MG9637A-38	ST connector*3	
MG9637A-39	DIN connector*3	
MG9637A-40	SC connector*3	
MG9637A-43	HMS-10/A (Diamond) connector*3	
MG9638A-27	E2000 connector*2	
MG9638A-31	EC (Radial) connector*2	
MG9638A-37	FC-PC connector*2	
MG9638A-38	ST connector*3	
MG9638A-39	DIN connector*3	
MG9638A-40	SC connector*3	
MG9638A-43	HMS-10/A (Diamond) connector*3	
	Peripheral instruments	
MS9710B	Optical Spectrum Analyzer	
ML9001A	Optical Power Meter	
MA9611A	Optical Sensor (for ML9001A)	
MA9714B	Optical Sensor (for ML9001A)	
MN9610B	Programmable Optical Attenuator	
MN9611B	Programmable Optical Attenuator	
MF9630A	Optical Wavelength/Frequency Counter	
	Application parts	
J0654A	RS-232C cable, 9P-9P	
J0655A	RS-232C cable, 9P-25P	
J0007	GPIB cable, 1 m	
J0617B	Replaceable optical connector (FC)	
J0618D	Replaceable optical connector (ST)*4	
J0618E	Replaceable optical connector (DIN)	
J0618F	Replaceable optical connector (Diamond HMS-10/A)	
J0619B	Replaceable optical connector (SC)*4	
J0635B	FC • PC-FC • PC-2M-SM (FC • PC optical fiber cord, 2 m, SM)	
Z0282	Ferrule cleaner	
Z0283	Replacement reel for ferrule cleaner (6 pcs/set, for Z0282)	
Z0284	Cleaner for optical adapter (stick type, 200 pcs/set)	
B0335C	Hard carrying case	

*1: Any of the listed connector options can be fitted as standards if specified when placing the order. If no connector types is specified in the order, FC-PC connectors (MG9637A/9638A-37) will be fitted.
*2: Factory option
*3: User-replaceable type
*4: The optical output off function is not available when no optical fiber cord is connected to the ST or SC replaceable optical connector.

Agilent 86146B
Optical Spectrum Analyzer
Technical Specifications

November 2005

- **Full-Feature Optical Spectrum Analyzer**
  Exhibits excellent speed and dynamic range with convenient and powerful user interface.
- **Filter Mode**
  Wavelength - filtered signal can be coupled to a single-mode fiber output for tunable-filter and channel-drop applications.
- **Dispersion penalty calculation**
  Dispersion Penalty calculation software combines 86146B and 86100C to measure time-resolved chirp and calculate dispersion penalty.

Agilent Technologies

Specifications

Characteristics and Specifications

The distinction between specifications and characteristics is described as follows:

- Specifications describe warranted performance.
- Characteristics provide useful, but non-warranted information about the functions and performance of the instrument.

The **specifications** apply to all functions, with video bandwidth autocoupled, over the temperature range 0 to 55° C and relative humidity <95% (unless otherwise noted).

All specifications apply after the instrument's temperature has been stabilized after 1hour continuous operation and the auto-align routine has been run. Unless otherwise noted, specifications apply without USER CAL.

Standard operation mode (not filter mode)

T(#) indicates temperature range and dependence.

Wavelength	**Agilent 86146B**	**Notes**
Range	600 nm to 1700 nm	
Reproducibility	±0.002 nm	With applied input fiber 9/125 µm; ≤ 1min
Span Range	0.2 nm to full range and zero span	
Accuracy After calibration with internal source and with enhanced wavelength calibration for specified range. 1480-1570 nm 1570-1620 nm	 Typ ±0.01 nm Typ ±0.025 nm	At room temp; with applied input fiber 9/125 µm
After calibration with external reference source(s) ±10 nm of calibration reference point(s)	 Typ ±0.01 nm	At room temp, with applied input fiber 9/125 µm
After user calibration over full wavelength range (600-1700 nm)	±0.2 nm	T(20-30°C), with applied input fiber 9/125 µm
Absolute Accuracy	±0.5 nm	Factory cal. 2 yr. cycle; T(20-30°C); with applied input fiber 9/125 µm
Tuning Repeatability	±0.002 nm	With applied input fiber 9/125 µm; ≤ 1min
Span Linearity 1525-1570 nm for spans <40 nm	 Typ ±0.01 nm, Typ ±0.02 nm	T(20-30°C); with applied input fiber 9/125 µm
Resolution Bandwidth (RBW)		
FWHM (3 dB Bandwidth)	0.06, 0.07, 0.1, 0.14, 0.2, 0.33, 0.5, 1, 2, 5, 10 nm	Resolution of 10 nm is available for first order grating response only; with applied input fiber 9/125 µm
Noise Marker Bandwidth Accuracy using noise markers 1525-1610 nm ≥0.5 nm 0.2 nm 0.1 nm 0.06 nm	 ±2% ±3% ±7% ±12%	 T(20-30°C)

Amplitude	**Agilent 86146B**	**Notes**
Sensitivity		Sensitivity is defined as signal value > 6 x RMS noise value.
600-750 nm 750-900 nm	-60dBm -75 dBm	T(0-30°C), 2nd order
900-1250 nm 1250-1610 nm	-75 dBm -90 dBm	T(0-30°C)
1610-1700 nm	-80 dBm	T(20-30°C)
Maximum Measurement Power		Resolution bandwidth setting < channel spacing.
1525-1700 nm 600-1000 nm 1000-1525 nm	Typ +15 dBm per channel, +30 dBm total Typ +15 dBm per channel, +30 dBm total Typ +12 dBm per channel, +30 dBm total	
Maximum Safe Power Total safe power Total power within any 10 nm portion of the spectrum	 +30 dBm +23 dBm	
Absolute Accuracy at –20dBm, 1310 nm/1550 nm	 ± 0.5 dB	For resolution ≥ 0.1 nm, with applied input fiber 9/125 µm
Scale Fidelity Autorange off Autorange on	 ± 0.05 dB ± 0.07 dB	Excluding amplitude errors at low power levels due to noise, T(20-30°C), with applied input fiber 9/125 µm
Display Scale (log scale)	0.01-20 dB/DIV, -120 to +90 dBm	
Amplitude Stability (1310 nm, 1550 nm), 1 minute	 ±0.01 dB	For signals within 8 dB of top of screen, with applied input fiber 9/125 µm
15 minutes	±0.02 dB	Typ., with applied input fiber 9/125 µm
Flatness 1290-1610 nm 1250-1610 nm	 ±0.2 dB ±0.7 dB	With applied input fiber 9/125 µm Absorption of light by atmospheric moisture affects flatness at 1350-1420 nm
Polarization Dependence 1310 nm 1530 nm, 1565 nm 1600 nm 1250-1650 nm	 ±0.12 dB ±0.05 dB ±0.08 dB ±0.25 dB	For resolution ≥0.2 nm, at room temp, with applied input fiber 9/125 µm
Dynamic Range		
In 0.1 nm Resolution Bandwidth		Excluding multiple order grating response, With applied input fiber 9/125 µm
1550 nm at ±0.8 nm (±100 GHz at 1550 nm) at ±0.5 nm (±62.5 GHz at 1550 nm) at ±0.4 nm (±50 GHz at 1550 nm) at ±0.2 nm (±25 GHz at 1550 nm)	 -60 dB -58 dB -55 dB Typ -40 dB	Average of all states of polarization
Monochromator Input	**Agilent 86146B**	**Notes**
Input Return Loss Straight connector (9/125 µm)	>35 dB	Depends on the quality of the attached connector; With applied 9/125 µm straight connector

Sweep		
Max. Sweep Rate	Typ 40 nm/56.3 ms	
Max. Sampling Rate in Zero Span	Typ 50 µs/trace point	
Sweep Cycle Time 50 nm span, auto zero off 50 nm span, auto zero on 100 nm span 500 nm span	 Typ < 180 ms Typ < 340 ms Typ < 400 ms Typ < 650 ms	
ADC Trigger Accuracy Jitter (distributed uniformly) Trigger delay range	 Typ < ± 0.5 µs Typ 2 µs-6.5 ms	
Pulse Mode Accuracy		
Turn On (≥2 µs after rising edge)	Typ. <±0.2 dB	(starting from dark)
Turn Off (≥10 µs after falling edge)	Typ. <±0.2 dB (30 dB extinction)	

Operation using Filter Mode

Insertion Loss Stability

1550 nm,15 minutes	0.5 dB	Immediately following enhanced single point auto align, at constant temperature

Insertion Loss

1550 nm	Typ. 10 dB	At room temperature

Filter Bandwidth: (From 1530 nm to 1610 nm)

	0.5 dB	**1.0 dB**	**3.0 dB**
RBW Nominal Setting	**Actual Bandwidth (nm)**		
0.04 nm	Typ 0.016	Typ 0.023	Typ 0.039
0.05 nm	Typ 0.019	Typ 0.026	Typ 0.045
0.07 nm	Typ 0.033	Typ 0.044	Typ 0.063
0.1 nm	Typ 0.076	Typ 0.089	Typ 0.115
0.2 nm	Typ 0.134	Typ 0.147	Typ 0.173
0.3 nm	Typ 0.257	Typ 0.270	Typ 0.297
0.5 nm	Typ 0.421	Typ 0.434	Typ 0.460
	±20%		

Filter Bandwidth: Adjacent Channel Rejection (at 1550 nm)*

	12.5 GHz	**25 GHz**	**50 GHz**	**100 GHz**
	±0.1 nm	**±0.2 nm**	**±0.4 nm**	**±0.8 nm**
0.04 nm	Typ 40 dB	Typ 50 dB	Typ 55 dB	Typ 55 dB
0.05 nm	Typ 40 dB	Typ 50 dB	Typ 55 dB	Typ 55 dB
0.07 nm	N/A	Typ 50 dB	Typ 55 dB	Typ 55 dB
0.1 nm	N/A	Typ 40 dB	Typ 50 dB	Typ 55 dB
0.2 nm	N/A	Typ 40 dB	Typ 45 dB	Typ 55 dB
0.3 nm	N/A	N/A	Typ 45 dB	Typ 55 dB
0.5 nm	N/A	N/A	Typ 45 dB	Typ 50 dB

*Adjacent Channel Rejection limited to 60 dB below total integrated power

Filter Bandwidth: Polarization Dependence

1550 nm	Typ ±0.2 dB	for 0.2 nm filter bandwidth and greater, at room temperature

Computer Interfacing	Agilent 86146B	Notes
Remote Control	Web enabled controls	
Compatibility	IEEE-488.1, IEEE-488-2 (100%)	
Interfaces	LAN, GPIB, Parallel Printer Port, External VGA Monitor, Keyboard and Mouse (PS/2)	
Floppy Disk	3,5” 1.44 MB, MS-DOS	MS-DOS is a U.S. registered trademark of Microsoft Corporation
Data export	Spreadsheet and Word Processor Compatible (CSV ASCII)	
Graphics export	CGM, PCL, GIF	
Instrument Drivers	Universal Instrument Drivers (PNP), Compatible with VEE, Labview, Visual Basic and C++	Labview is a U.S. registered trademark of National Instruments.

General Specifications	
Dimensions	222mm high x 425mm wide x 427 mm long
Weight	16.5 kg
Environmental	
Temperature*	Operating 0°C to 55°C, Storage –40°C to 70°C
Humidity	Operating <95% RH, Storage: Noncondensing
EMI	Conducted and radiated interference is in compliance with CISPR pub 11, IEC 801-3, IEC 801-4 and IEC 555-2
Power Requirements	
Voltage and frequency	90 Vac to 260 Vac, 44 to 444 Hz
Maximum power consumption	230W

*Floppy disk and printer operating temperature range 0°C to 45°C

Options and Accessories

Options (available on new instruments only)	Agilent 86146B
Current Source	86146B-001
White Light Source *	86146B-002
Built-in 1310 & 1550 nm EELED Source *	86146B-004
Wavelength Calibrator	86146B-006
DWDM Spectral Analysis Application	Included
Passive Component Test Application	Included
Amplifier Test Application	Included
Source Test Application	Included
Connector Interface	FC/PC: 81000FI SC/PC: 81000KI DIN: 81000SI ST: 81000VI E2000: 81000PI LC: 81002LI MU: 81002MI
Certificate of Calibration	Included

* 86146B-002 and 004 are exclusive.

OSA Fiber Sizes

Model Number	Optical Input	86146B-002* (White Light Source)	86146B-004* (1310/1550 EELED)	86146B-006 (Calibrator)	Photodiode Input	Mono Output 1
86146B	9 µm	62.5 µm	9 µm	9 µm	50 µm	9 µm

* 86146B-002 and 004 are exclusive.

Options and Accessories: Specifications

86146B-001 Current Source	Agilent 86146B
Range	0 to ±200 mA (source or sink)
Resolution	Typ 50 μA steps
Accuracy	2% ±50 μA
Clamp Voltage (nominal)	±2.7 V
Noise Density at 1 kHz	Typ <4 nA/√Hz
Stability Within 30 Minutes	Typ <100 ppm ±500 nA
Temperature Drift	Typ <(100 ppm ±500 nA)/K
Pulse Mode Pulse Range Pulse Resolution Duty Cycle Range	 10 μs to 6.5 ms 100 ns Pulse width/1 s to 100%

86146B-002 White Light Source	
Wavelength*	900 nm to 1700 nm
Minimum Output Power Spectral Density** (9/125 μm fiber) 900 to 1600 nm 900 to 1600 nm 1600 to 1700 nm	 -67 dBm/nm (0.2 nW/nm) Typ -64 dBm/nm (0.4 nW/nm) -70 dBm/nm (0.1 nW/nm)
Minimum Output Power Spectral Density*** 50/125 μm fiber 62.5/125 μm fiber	 Typ -50 dBm/nm (10 nW/nm) Typ -46 dBm/nm (25 nW/nm)
Output Stability**	Typ ±0.02 dB over 10 minutes
Lamp Lifetime, Mean Time Between Failures** (MTBF)	Typ >5000 hours

* filtered below 850 nm
** with applied input fiber 9/125μm
*** typ; includes power in full numerical aperture of fiber

86146B-004 EELED Sources	
Minimum Spectral Power Density 1300 to 1320 nm, 1540 to 1560 nm 1250 to 1620 nm	 >-40 dBm/nm (10nW/nm) Typ >-60 dBm/nm (1nW/nm)
Return Loss With straight connector	 Typ >25 dB
Stability (ambient temp. <±1°C) Over 15 minutes Over 6 hours	 Typ <±0.02 dB Typ <±0.05 dB

86146B-006 Wavelength Calibrator

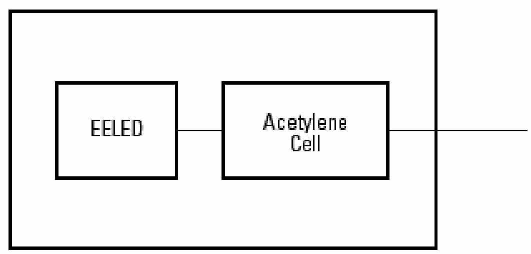


Figure 1: Wavelength calibrator block

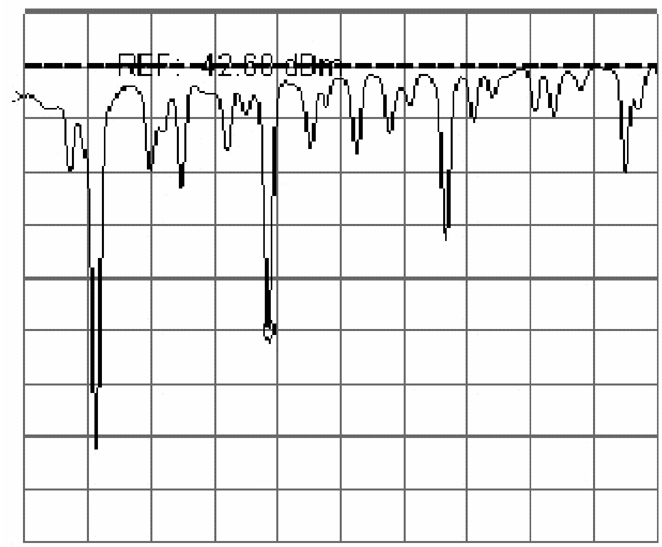


Figure 2: Wavelength calibrator absorption spectrum

The wavelength calibrator option provides an onboard wavelength reference that can be used to automatically calibrate the optical spectrum analyzer. The calibrator is based on an EELED and an Acetylene gas absorption cell, Figure 1. The Acetylene absorbs light at very specific wavelengths based on the molecular properties of gas. The cell is illuminated by an EELED and the OSA uses the absorption pits to perform a wavelength calibration, Figure 2. Since the absorption of the Acetylene gas is a physical constant it never needs calibrating.

The wavelength calibrator enhances the OSA to achieve better than ±10 pm wavelength accuracy and removes the need to use a tunable laser source and multi-wavelength meter as an external reference.

Additional Parts and Accessories	**Agilent 86146B**
Printer Paper (5 rolls / box)	9270-1370
Additional Connector Interfaces	See Agilent 81000 series
9 µm Single Mode Connector Saver	Standard
Rack-mount Flange Kit	86146B-AX4
Transit Case	9211-2657
BenchLink Lightwave Software*	Standard

* Agilent N1031A BenchLink Lightwave allows transfer of measurement results over a GPIB Interface to a PC for the purposes of archiving, printing and further analysis. Not usable with Windows XP.

Definition of Terms

Wavelength

- Absolute Accuracy (after user cal) refers to the wavelength accuracy after the user has performed the internal wavelength calibration using a source of known wavelength.
- Reproducibility refers to the amount of wavelength drift, which can occur over the specified time while the OSA is swept across a source of known wavelength.
- Tuning Repeatability refers to the wavelength accuracy of returning to a wavelength after having tuned to a different wavelength.

Resolution

- FWHM refers to the Full-Width-Half-Maximum resolutions that are available. This indicates the width at half power level of the signal after passing through the resolution slits.

Amplitude

- Scale Fidelity refers to the potential errors in amplitude readout at amplitudes other than at the calibration point. This specification is sometimes called linearity.
- Flatness defines a floating band, which describes the error in signal amplitude over the indicated wavelength range. (This error may be removed at a given wavelength by performing the user amplitude calibration).
- Polarization Dependence refers to the amplitude change that can be seen by varying the polarization of the light entering the OSA. This is not to be confused with amplitude variations caused by the varying distribution of energy between the different modes in fiber that are multimode at the wavelength of interest.

Sensitivity

- Sensitivity is defined as the signal level that is equal to six times the RMS value of the noise. Displayed sensitivity values are nominal. Slightly lower values may have to be entered to achieve specified sensitivity.

Dynamic Range

- Dynamic Range is a measure of the ability to see low-level signals that are located very close (in wavelength) to a stronger signal. In electrical spectrum analyzers, this characteristic is generally called shape factor.

Sweep Time

- Maximum Sweep Rate refers to the maximum rate that the instrument is able to acquire data and display it. This rate may be limited by multiple internal processes when using default number of trace points.
- Sweep Cycle Time refers to the time required to make a complete sweep and prepare for the next sweep. It can be measured as the time from the start of one sweep to the start of the next sweep.