Application Note

How to integrate switches and an optical attenuator in the amplifier test set-up

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Abstract

This application note discusses how to ensure an accurate characterization, and how to integrate the required measurement equipment, especially an optical attenuator for amplifier test and switches, into an amplifier test system

Introduction

Signal strength in WDM transmission links is attenuated by properties of optical components, such as multiplexers or demultiplexer, cross-connects or simply by the optical fiber that is used. To achieve a certain reliability of transmission, e.g. BER less than 10^{-9},the 'signal to noise ratio' of each channel has to be maintained, either by regenerating the signal or by amplifying the signal. Regeneration takes place by converting the optical signal to electrical, which is then used to modulate a new optical signal. Amplification is generally a more economical solution.

Amplification within the optical path uses optical amplifiers such as erbium-doped fiber amplifier (EDFA) and Raman amplification.
At the amplification point in the network, the various optical carriers can differ in intensity. This is caused by the wavelength dependence of every optical component used in a transmission link. These differences can also be caused by several other reasons. For example, the output power of the sources are not equal, or add-drop-multiplexes multiplexer have been used within the optical network to route one carrier out of the fiber and route a stronger signal into it.

This application note describes how to integrate the necessary measurement equipment to a test system to ensure an accurate characterization of optical amplifiers.

The discussion will begin with a description of an example test set-up. It will describe the components that are used, and analyze the advantages and disadvantages of these. After that, a standard measurement, the gain versus input power measurement, will be discussed in the context of this example test set-up.

Then the discussion will focus on how to calibrate the test set-up to compensate losses caused by it. The possibilities will be shown and their advantages and disadvantages highlighted, and example algorithms to perform these calibration steps will be shown.

A software application to handle this calibration data, after they have been collected, will be discussed. How to apply the calibration data onto the returned measurement values of the optical spectrum analyzer will also be discussed.

Then, the structure of the automated software will be sketched and access to Agilent hardware, such as the 8166B will be illustrated using function calls of the Plug and Play driver.

Basic Measurement Setup

One standard measurement will be used as an example. This is the common gain versus input power measurement. Figure 1 shows an example test set-up.
This example set-up consists of two Agilent mainframes: an 8164B loaded with modules for routing and conditioning the stimulus signals and an 8166B, loaded with up to 16 DFB laser modules to stimulate the DUT. For a higher number of stimulus channels, 2 or more 8166B's can be combined. Each of the DFBs emit power at a certain wavelength. For backup reasons, a modular tunable laser can be loaded in an unused slot e.g. in slot 17, which could replace one specific DFB in case of a fault. To meet the output power level, which could be provided by one of the DFBs, a high power tunable laser has to be used.

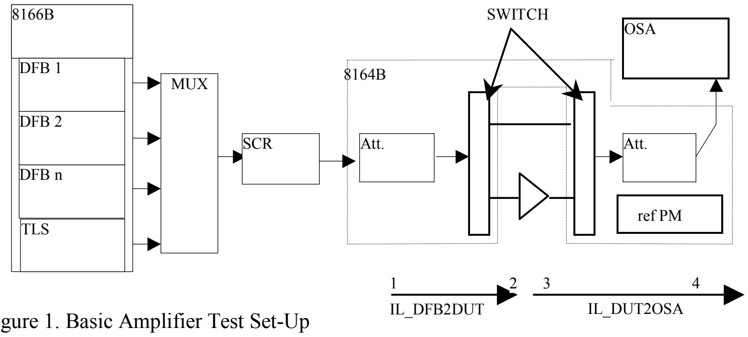


Figure 1. Basic Amplifier Test Set-Up

The multiplexer combines all optical carrier signals and passes the result into the common fiber.
There are two types of multiplexers existing, one is a wavelength dependent multiplexer, which allows combining several optical carriers in to one fiber with less loss. The essential element of this coupler is an arrayed wave-guide or a thin film filter, for example.
To ensure, that all carrier wavelengths fit into the ITU grid specifications of the wavelength dependent multiplexer, the DFB laser's

wavelength can be tuned within a limited but sufficient range.

As a second type of multiplexer, a wavelength independent coupler can be used. This coupler has a high insertion loss, as 3dB loss is added for each doubling of carrier number.

The WDM signal is fed into the polarization scrambler, e.g. 11896A. If a polarization scrambler is enabled during measurement, then it generates a fluctuating polarization state of the sources, which can be used to average out or to resolve polarization dependence.

To control the stimulus power to the DUT, an attenuator 81576/7A with integrated power meter is used. The characteristics of its internal attenuation filter are specially suited to amplifier test applications.
First, the filter can carry input power levels up to 2W total power. Total power means the sum of every carrier expressed in Watts (where n represents the carrier number):

$$\sum_{i}^{n} P_i(\lambda) = P_{total}$$

The attenuator contains an internal power meter, which is used, after calibration, to monitor the total power applied to the DUT. Therefore, a determined power can be applied to the DUT when a specific power level is desired. This is achieved by comparing the current power value with the desired value. The filter then sets a specific attenuation based on the difference. The calibration procedure will be discussed later and this attenuator is referenced as the primary attenuator in further discussion.
An additional important property of the attenuator is the spectral flatness of the filter element. This is important, as the attenuator has to attenuate a complete WDM spectrum equally. If an attenuation of 10dB is obtained, then every single channel in the WDM spectrum has to be attenuated by 10dB.
For example, if the attenuator's filter is not flat over wavelength, the first channels could be attenuated only by 9.8dB and the last channels about 10.3 dB, depending on the filter characteristics.
Figure 2 illustrates the differences between a attenuator with flat spectral filter properties versus a attenuator without flat spectral filter properties.

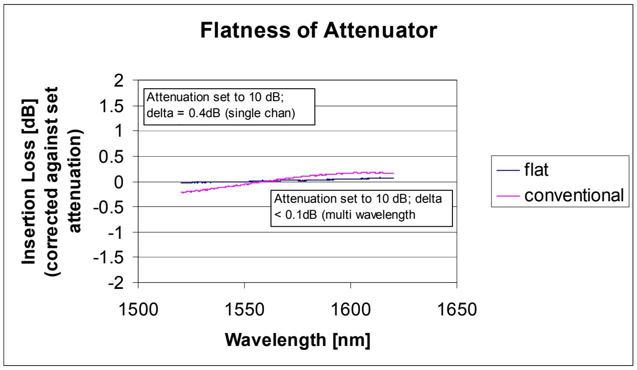


Figure 2. Filter characteristic versus wavelength

The graph shows an attenuation factor of 10dB being held constant over the complete operating wavelength, which ensures that each channel of a WDM signal is treated equally. This is the attenuator 81576A with flat filter properties. The crossing curve represents an attenuation factor of 10dB, which has its optimum at 1550nm. This curve was measured with the 81560A attenuator, which is designed for single-wavelength attenuation.

Refer to attenuator's user's guide for detailed information about verifying attenuators key parameters. (81560-90A12)

Modular optical switches, installed in the 8164B are used to apply sequentially a non-amplified (input) and an amplified (output) signal to the OSA. Figure 1 shows a dual '1X2' switch, which allows the connection of one reference line and one DUT within an optical path. If more than one DUT needs to be tested, then for example, 2 1X4 modules can be used. The first line is then also used as reference line, and the other 3 are used to connect 3 DUTs into the test set-up.

```
1.  Load ISS Application of OSA Set up measurement parameters
    including path loss offsets
2.  Open Shutters of all attenuators within optical path
3.  Enable all DFB sources
4.  For (all desired total power levels)
5.  {
6.  Set a specific total power level to the DUT input with attenuator
7.  Bypass the DUT using switch position to reference line
8.  Make Source Measurement of OSA test application
9.  Connect DUT into the optical path using switch position to DUT
    line
10. Make Amplifier Measurement of OSA test application
11. Load measurement result from OSA into controller
12. }
13. Apply calibration data onto measurement result for correction
14. Display measurement result
```

Figure 3: Algorithm of Gain Measurement with OSA intern. ISS App

The attenuator in front of the OSA is optional and can be used to prevent damage to the OSA by very high-power amplified signals.

The Optical Amplifier Test routine (ISS, which is an OSA built-in application, is used to measure the key amplifier properties, noise figure and gain. These measurements are performed in two steps. At the first step the OSA measures the input source power versus wavelength, and stores the data in its memory. For this measurement, the optical path goes from the multiplexer via the primary attenuator, via the reference line of the switch, and via the optional attenuator into the OSA. During the second step, the OSA measures the output power versus wavelength after the DUT has been connected into the optical path, by the switch. The gain is the difference in signal power, measured by the OSA without and with amplification, expressed in dB.

$$G = P_{amplified} - P_{nonamplified}$$

In Equation 1 this equation is displayed as a matrix, as matrices will be used later in the controller software. Note that the signal power measurements are corrected for the background light.

$$\begin{pmatrix} G_{\lambda 1} \\ G_{\lambda 2} \\ \cdots \\ G_{\lambda n} \end{pmatrix} = \begin{pmatrix} P_{Output\_\lambda 1} \\ P_{Output\_\lambda 2} \\ \cdots \\ P_{Output\_\lambda n} \end{pmatrix} - \begin{pmatrix} P_{Input\_\lambda 1} \\ P_{Input\_\lambda 2} \\ \cdots \\ P_{Input\_\lambda n} \end{pmatrix}$$

Equation 1. Gain calculation expressed in dB

Gain Versus Input Power Measurement Using OSA Internal OA Test Application

Here it is described how the controller software performs this measurement.

The OSA contains a routine called ISS that is launched to perform a gain and noise figure measurement. It is launched by the controller software, written in languages such as Agilent VEE, VC++, VB or any other programming environments that support the accessing of external library files such as the PnP driver. Figure 3 illustrates the steps performed during a noise figure and gain measurement.

Calibration of Test Set-up

During a measurement the power applied to and from the DUT are measured on the OSA, but the power levels at the OSA are influenced by the path losses of the system, so the insertion loss of the complete system must be known. For that purpose, the test set-up has to be calibrated.

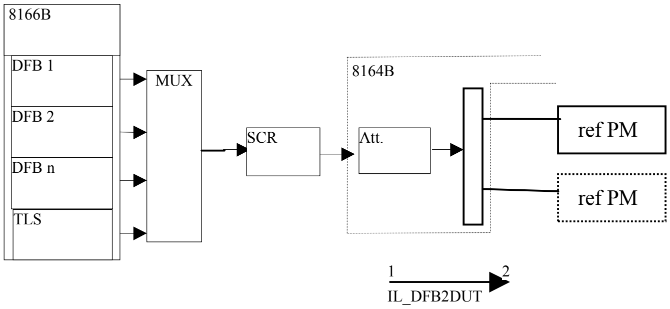


Figure 4. Connected Set-up during Insertion Loss Calibration from point 1 to point 2

In the example, discussed in this note, the test set-up consists of two optical paths. The first is from the sources through the coupler, scrambler, and primary attenuator, switch, ref line to switch and via the optional attenuator to the OSA. The second path is from the source through the coupler, scrambler, attenuator, switch, DUT, switch and via the attenuator to the OSA.

In addition, the power control feature of the attenuator can be calibrated for the multi-wavelength spectrum. This is used for example in measuring gain and noise figure versus input power levels.

DFB2DUT Calibration

In Figure 1, two arrows indicate 4 positions within the optical path, which will be measured during calibration. The first arrow labeled as ‘DFB2DUT’ represents the losses from the starting coupler tap (point 1) of the primary attenuator to the DUT input (point 2). The second arrow labeled as ‘DUT2OSA’ represents the losses starting at the DUT (point 3) and ending at the OSA input (point 4).
In addition to these 4 measurement points, it is necessary to calibrate the power reading of the OSA with the reference power meter.

To get all the necessary data for the 4 points described, two insertion loss measurements are needed. Both insertion loss measurements consist of a power measurement at the start and at the end of the path. The difference in the measured power levels is the insertion loss. This means:

```
Set power offset of attenuator to zero
For every optical path do
{
 Connect corresponding opt. path  via output of switch to power meter
 For (λstart, λstop, λstep)
         {
         Configure power meters regarding wavelength
         Apply wavelength source to optical path
         Get power reading from attenuator’s internal PM
         Get power reading from reference power meter
         Store AttiPM, refPM, and wavelength into matrix
         }
}
```

Figure 5. DFB2DUT_TLS_stepping

$$IL = P_{start} - P_{stop}$$

[dB] = [dBm]-[dBm]

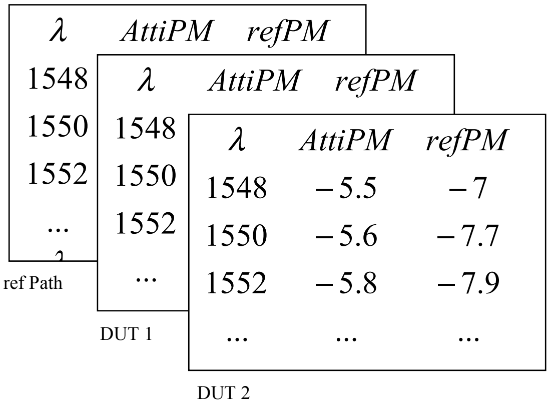
The first calibration procedure is used to measure the insertion loss from point 1 to point 2. Figure 4 shows the principle connection, where the reference power meter is connected one after another to the outputs of the first switch.

To make the measurement for multiple wavelengths, two approaches are:

- (a) Tunable Laser Source (TLS) stepping and polling power meter,
- (b) DFB sequential on/off and power meter.

a) TLS stepping and polling power meter
This approach uses the TLS or a compact tunable laser (CTLS), in the 8164 mainframe with step capabilities. While the TLS steps within a specified spectrum, the reference power meter and the attenuator’s built-in power meter measure the power at every specified step. This is done for every optical path. Figure 5 shows the algorithm.

Although the TLS 816XXB is able to perform a continuous sweep, the internal monitor diode of the attenuator cannot be triggered during this continuous sweep. Therefore, after reaching each wavelength point, the attenuator's internal power meter and the reference power meter need to be queried for power reading sequentially and stored in a calibration table. The insertion loss is then calculated from these two power readings. This includes only the insertion loss (IL) beginning at the coupler tap of the attenuator and ending at the DUT input. As the attenuator will be used to apply a certain total power level to the DUT input, this calibration suffices to ensure this functionality.



ref Path

λ	$AttiPM$	$refPM$
1548		
1550		
1552		
...		

DUT 1

λ	$AttiPM$	$refPM$
1548		
1550		
1552		
...		

DUT 2

λ	$AttiPM$	$refPM$
1548	-5.5	-7
1550	-5.6	-7.7
1552	-5.8	-7.9
...	...	...

Figure 6. Calibration table of DFB2DUT_cal

Figure 6 shows how the calibration data is handled. Every optical path is represented by one sheet, containing the operating wavelengths and the power values seen by the attenuator’s internal power meter and the reference power meter.

b) DFB on/off approach
This approach uses every used DFB laser source to apply the operational carrier to the optical path. Each DFB laser is sequentially turned on and off. During the on period, the internal power meter of the attenuator and the reference power meter are queried to perform a power measurement. Before the power meter is queried to perform a measurement, there is a waiting period that lasts until the DFB output power and wavelength become stable. This is configurable in the software. This data is stored, beside the current wavelength in a matrix. The algorithm in Figure 7 shows the procedure.

```
For every optical path do
{
 Connect reference output of switch to power meter
 for  (every used DFB laser source)
        {
        Query actual DFB for its wavelength
        Configure PM and atti internal PM  regarding
                                                       wavelength
        Turn current on
        Delay (); // Stabilizing wavelength, power
        Get power reading from attenuator's internal PM
        Get power reading from reference power meter
        Store AttiPM, refPM, and wavelength into matrix
        Turn current DFB off
        }
```

Figure 7: Algorithm of DFB2DUT_DFB on off

The result of both approaches is a zero-based array of matrixes. The first matrix contains the power value measured by the built-in power meter of the attenuator and the reference power meter, which is connected to the reference output of the switch, alongside the carrier wavelength. This is the first element and corresponds to the reference line. For the switch output to the first DUT, an identical structure is generated. The differences are the insertion loss values, as these represent the loss of the individual paths. As the array is zero based, comfortable access to the calibration data for the first DUT by index 1 and the second DUT by index 2 is obtained. To access data for the reference line, the index 0 is used. Figure 6 shows three elements of the generated array. These are absolute power levels, expressed in dBm. The calculation of the insertion loss will be performed 'on the fly' whenever this data is needed.

The power values labeled as AttiPM are measured at point 1 and power values labeled as refPM are measured at point 2, marked in figure 4

DUT2OSA Calibration

The second calibration procedure is used to determince the loss between Points 3 and 4. Figure 8 shows the positions in the test set-up.

During the calibration of DFB2DUT, the reference power meter was connected to the point of the DUT. Therefore this information is already known and does not need to be measured again.

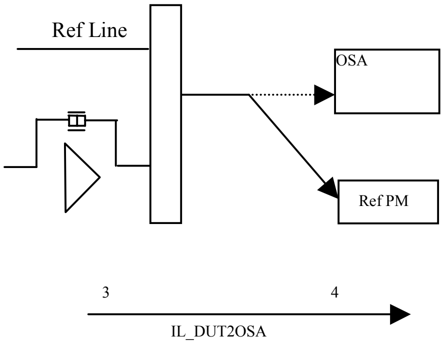


Figure 8. Set-up DUT2OSA calibration

For this 2nd calibration, these already measured "Point2" positions of the first switch are connected to the corresponding position of the 2nd switch, Point3. (For example, the two switch connectors that will be at the input and output of DUT1 are connected together.)

At the 'DUT2OSA' calibration, the reference power meter is connected instead of the OSA. As the input power applied to the system could have changes due to temperature effects, between these two calibration measurements, the input power needs to be monitored. At least the difference must be detected. For that purpose, the primary attenuator is queried for actual power, as we have seen during the DFB2DUT calibration. The difference between the observed power during the DUT2OSA measurement and that during the previous DFB2DUT measurement can be used to correct the calibration data, which results in higher accuracy.

Figure 9 shows the algorithm for this calibration procedure using the DFB on/off approach.

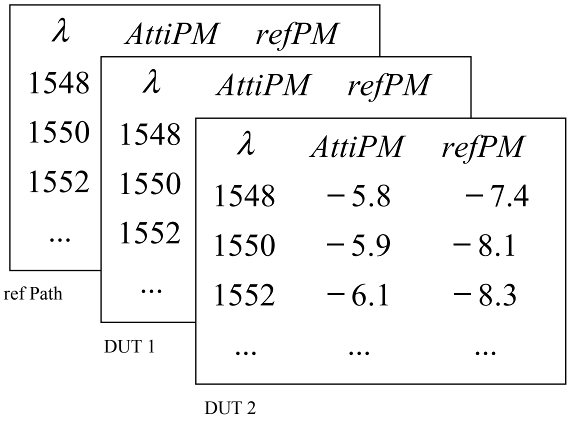
The delay time should allow the laser to stabilize, if necessary.

The resulting matrices of this calibration look identical to those in the DFB2DUT calibration.

```
For every optical path do
{
 for  (every used DFB laser source)
        {
        Query current DFB for its center wavelength
        Configure power meters regarding wavelength
        Turn current DFB on
        Delay ();
        Get power reading from primary attenuator
        Get power reading from reference power meter
        Store AttiPM, refPM, and wavelength into matrix
        Turn current DFB off
        }
}
```

Figure 9. DUT2OSA calibration using DFB on/off approach

The power values in Fig. 10 are randomly chosen to illustrate the case where the input power of the system has changed between the calibration procedures DFB2DUT and DUT2OSA. The power level decreases about 0.3 dB. Later in the section where it is described how to apply the calibration data to measurement results, this drop will be compensated.
The calibration data for the insertion loss is now known, and can be used within the controller software.



ref Path

λ	*AttiPM*	*refPM*
1548		
1550		
1552		
...		

DUT 1

λ	*AttiPM*	*refPM*
1548		
1550		
1552		
...		

DUT 2

λ	*AttiPM*	*refPM*
1548	−5.8	−7.4
1550	−5.9	−8.1
1552	−6.1	−8.3
...	...	...

Figure 10. Calibration table of DUT2OSA_cal

OSA P_{in} Calibration

As the OSA will be used to measure power levels, it is necessary to compare the power values seen by the OSA with those seen by the reference power meter. The power meter has higher absolute power accuracy. The controller software must also consider the differences between these two measurements.

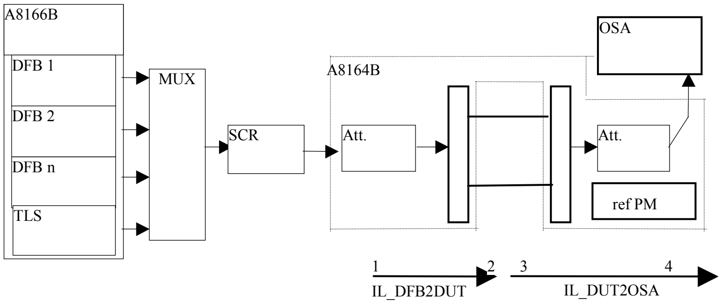


Figure 11. Basic Amplifier Test Set-Up during OSA P_{in} Cal

For this calibration, the test set-up is configured as shown in Figure 11, like in the previous step

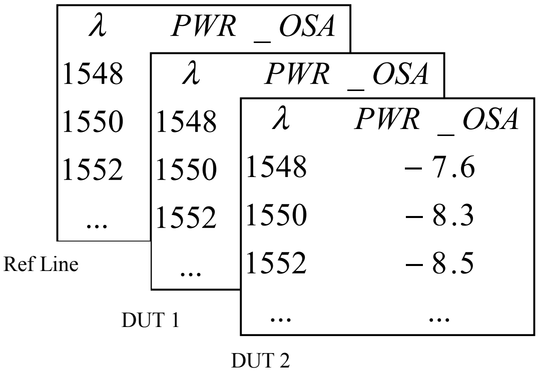
1. Launch WDM application of OSA
2. Set Resolution Bandwidth to value to be used in amplifier measurements (typ 0.2nm)
3. Open Shutter of attenuator
4. Turn on all DFBs which will be used
5. For every optical path do
6. {
7. Switch current path active
8. trigger WDM sweep
9. collect data from OSA
10. }
11. Unload WDM application of OSA
12. Turn off all used DFBs
13. Close Shutter of attenuator

Figure 12. OSA Pin calibration using OSA internal WDM application

but measuring the output with the OSA.
The 8614x OSA contains a built-in application routine called WDM Channel Analysis application. This routine enables measuring the peak power levels and peak wavelengths of a WDM signal. The difference between the peak power level and the power level seen by the reference power meter in the DUT2OSA calibration is then included in the correction mechanisms of the controller software.

Figure 12 shows the algorithm for the OSA Pin calibration. P_{in} stands for input power of OSA.

The resulting matrix of this calibration contains, the measured wavelength and peak power as shown in Figure 13.



λ	PWR _ OSA
1548	− 7.6
1550	− 8.3
1552	− 8.5
...	...

Figure 13. OSA Pin matrix

When DFB2DUT, DUT2OSA and OSA Pin Calibration have been performed, then all necessary data regarding loss and power calibration are available.

Note that the absolute power calibration of the OSA can also be set using an internal function of the OSA.

Attenuator Spectral Calibration

Before the use of the calibration data is discussed, one additional calibration is needed. It is called the spectral calibration for total power. This calibration applies only to the attenuator with power control function (Agilent 81576A, 81577A).

As already mentioned, the attenuator with integrated power meter is used to apply a desired total power level to the DUT's input. Therefore, the attenuator has to measure incoming power, and correct its attenuation to achieve the desired power level. The internal power meter consists of a photo detector, whose responsivity is calibrated with respect to wavelength.

```
ViStatus _VI_FUNC hp816x_spectralCalibration
   (ihandle,             // IN: Pointer to instrument
    Size_of_Spectrum,    // IN: how many datapoint
    Wavelength[ ],       // IN: array of input spectrum
    Power[ ],            // IN: array of input spectrum
    Wavelength_Result,   // OUT: calculated wavel.
    Error_Diagnose,      // OUT: in case error → msg;
    Slot );              // IN: Slotnumber of attenuator
```

Figure 14. Function 'spectral calibration'

As a multiwavelength signal is applied to the optical path during the measurement, the problem then arises in selecting the wavelength point the power meter has to be set to, in order to achieve the correct calibration.

A PnP driver function, which only requires a WDM spectrum as input, is used to calculate and set this value to the attenuator. It is named hp816x_spectralCalibration. The function prototype is shown in Figure 14. For developers preferring SCPI commands, this functionality can also be programmed via SCPI.

The WDM spectrum consists of two arrays. One is the power for every channel and the second is the wavelength of each channel. These arrays are already created during the DFB2DUT calibration routine. The power values measured by the reference power meter and the wavelength can also be used for this function. The function sets a wavelength that results in the correct calibration. For more information about the algorithm used, refer to <5988-5260>.

Since this calibration depends on the signal spectrum, recalibration is required if the distribution of power among wavelengths is changed.

Applying Calibration Data to Measured Results

In Figure 3 the algorithm of a gain and noise figure measurement is described. The trace-offset values of Step 2 are based on the calibration measurements. The results returned by the OSA, are indicated in Figure 15. These results may be further corrected for any wavelength dependence of the offsets (losses). These two levels of correction are discussed below.

λ	Gain	Noise	Power
1548	17 .1	4 .7	− 19 ,87
1550	17 .3	4 .5	− 19 ,18
1552	17 .5	4 .5	− 14 ,77
...	...	...	...

Figure 15. OSA ISS Application Result referred to as 'NoiseGainResult'

The example test set-up is used for measurement of one DUT, so all tables shown consist only of a table for the reference line and the second table for the DUT 1 line. In case other switch types, for example 1 by 4, would be used then the tables would be extended by values for up to three DUTs. Index 0 is for reference line and index 1 is for the first, and in this case the only, DUT. The result of the 'post processing' gives the corrected input power, the gain and noise figure of the DUT.

In following equations are listed, which show how calibration data are handled. Please be aware, that these data are stored in matrices. All matrices, which are added or subtracted to/from each other, must exist in same shape, which means same amount of rows and columns. For easier readability these matrices are not resolved, but only their names are mentioned.
In case of changes to measurement parameters, these conditions would not be fulfilled necessarily, so the application software should check the format of the matrices, before applying operations on these.

As already mentioned, between the DFB2DUT and DUT2OSA calibration the input power of the complete system could vary, especially since the lasers are turned off in between. Because the power can be monitored at the attenuator each time, this drift can be corrected as to determine the insertion loss between Points 3 and 4.
Defining the drift according to:

$$Drift = DFB2DUT.AttiPM - DUT2OSA.AttiPM,$$

Subtracting appropriate data arrays results in insertion loss between the points 3 and 4 for each channel:

$$ILDUT2OSA = DFB2DUT.refPM - DUT2OSA.refPM - Drift.$$

To calculate the insertion loss between the points 1 and 2, the following equation is used for each channel:

$$ILDFB2DUT = DFB2DUT.AttiPM - DFB2DUT.refPM.$$

From the *ILDFB2DUT* value for each channel, the average is calculated, which should be used as the power offset parameter in the attenuator. This value is a scalar $\boldsymbol{P_{offset}}$. Each DUT position may have its own value. Please note that this average insertion loss is a positive value, because it is treated as loss. The attenuator, and its power offset feature demand an offset. Which means, that a positive loss has to be entered as a negative offset to the attenuator $\boldsymbol{P_{offset}}$.

The measured data returned by the OSA amplifier test application is stored labeled with an identifier 'Noise Gain Result', for example (Figure 15). These contain a subset of peak power levels, gain and noise figure values.

The OSA_Pin calibration data must also be applied to correct the difference between the results of the reference power meter and the OSA. This additional offset is calculated by:

$$OSA_{correction} = DUT2OSA.PM - OSAPin.PWR\_OSA.$$

When switches are used, the insertion loss for the source measurement with the reference line is different than for the amplifier measurement with the DUT line.
If the insertion loss of the reference path is 0.5dB bigger than the insertion loss of the DUT path, then during the source measurement the OSA sees a signal that is 0.5dB weaker than during the amplifier measurement. This difference must be considered.
As suggested above, the calibration is now separated into two levels. The first level is the most important and uses the average values of these corrections over wavelength as input parameters for the built-in OSA application. The results returned by the OSA for source power, gain and noise figure at each channel are then corrected for these average offsets.
The control software may then further correct the OSA results in a second level for any wavelength dependence of the path losses. Note that the control software could also perform both levels of correction together for the gain measurements, but this is not practical for the noise figure measurement, where the internal calculations of the OSA are more complicated.

For the first level correction, the Source Path Trace Offset and the Amplifier Path Trace Offset parameters need to be calculated and used in the OSA application Measurement Setup. These two offsets will in principle be different for each DUT position, if the test system includes switching among multiple DUTs.

The Amplifier Path Trace Offset (scalar: ***APTO***) is calculated in two steps a) APTO over wavelength:

$$APTO(\lambda) = ILDUT2OSA_{DUTPath} + OSA_{correction}$$

And step b) the average of $APTO(\lambda)$:

$$APTO_{scalar} = avg(APTO(\lambda))$$

The Source Path Trace Offset (scalar: ***SPTO** $_{scalar}$*) is calculated as:

$SPTO_{scalar} = avg(SPTO(\lambda))$ while the wavelength resolved SPTO is:

$$SPTO(\lambda) = ILDFB2DUT_{refPath} - ILDFB2DUT_{DUTPath} + ILDUT2OSA_{refPath} + OSA_{correction}.$$

These values are calculated for each DUT path and stored. The correct values are then sent to the OSA for each DUT measurement.

After the measurement the OSA returns to the software, the corrected gain, noise figure and source power values, related to the average offset values.

```
…
void correct_Psource_OSA(
            int amountchannel,     // amount of DFB used
            float SPTO[], float Psource_OSA[],  // returned result
            float SPTO_scalar, float * NEW_Psource)  // Output
{
float *deltaSPTO= new float[amountchannel); // deltavalues
float delta=0;
int channel=0;
float *newPsource = new float[amountchannel]; // new Psource

// calculate delta between SPTO(λ) and SPTO_scalar (average)
For (channel=0; channel < amountchannel; channel++)
  {
  delta = SPTO[channel] – SPTO_scalar; // calc difference
  *(deltaSPTO+channel) = delta;             // save in array
  }

// differences are added to the P sourcevalues:
For (channel=0; channel < amountchannel; channel++)
  {
       *(newPsource+channel) =
              *(Psource_OSA+channel) +*(deltaSPTO+channel);
  }

// now return new Psource_OSA
memcpy (NEW_Psource, // destination
            newPSource,   // source
            sizeof(newPSource)*amountchannel); // amount bytes
// tidy up….
Delete newPsource;
Delete deltaSPTO;
}
```

Figure 17 Example code for P_source correction 2nd level

The second level of correction is to achieve a higher accuracy in the returned (wavelength resolved) results by correcting these regarding wavelength dependencies of the path trace offsets. This is done, by adding the difference between wavelength-resolved loss and average loss on to the returned results in the manner shown.

In the following, the *source power* result is corrected, and then the gain.
For this the scalar ***SPTO** $_{scalar}$* is compared to the actual wavelength resolved source path loss *SPTO(* λ). The difference in these, is applied on to the corresponding wavelength source power returned by the OSA. A possible implementation of the algorithm is shown in Figure 17.

These calculated data are displayed using visualization objects, such as “MS Chart”, or similar.

To check, if the desired total power levels have been applied to the DUT, the peak values can be summed together linearly.

Correcting the gain values to a second level is done using the same principle as for source power. Here the scalar ***APTO*** and once again the scalar ***SPTO*** are compared to the wavelength resolved ***APTO(λ)*** and ***SPTO(λ).*** Their difference is obtained and the resulting wavelength resolved values are added to the gain values, returned by the OSA. Figure 18 shows a possible implementation of this algorithm.

After completing the discussion of the implementation principles of the test set-up, the discussion now moves on to the practical implementation.

```
…
void correct_Gain_OSA(
            int amountchannel,     // amount of DFB used
            float SPTO[], float SPTO_scalar
            float GAIN_OSA[]  // returned result
            float APTO[], float APTO_scalar,
            float * NEW_Gain_OSA)  // Output: corrected result
{
float *deltaSPTO= new float[amountchannel]; // deltavalues
float delta=0;
float *deltaAPTO = new float[amountchannel]; // deltavalues
int channel=0;
float *newGain = new float[amountchannel]; // new Psource

// calculate delta between SPTO(λ) and SPTO_scalar (average)
For (channel=0; channel < amountchannel; channel++)
  {
  delta = *(SPTO+channel) – SPTO_scalar; // calc difference
  *(deltaSPTO+channel) = delta;            // save in array
  }

// calculate delta between APTO(λ) and APTO_scalar(average)
For (channel=0; channel < amountchannel; channel++)
  {
  delta=*(APTO+channel) – APTO_scalar; // calc difference
  *(deltaAPTO+channel) = delta;
  }

// subtract delta of each other and add the result to gain result
For (channel=0; channel < amountchannel; channel++)
{
  *(newGain+channel) =
      (*(deltaAPTO+channel) - *(deltaSPTO+channel)) +
      *(Gain_OSA+channel);
}

// now return new newGain
memcpy (NEW_Gain_OSA, // destination
           newGain,   // source
           sizeof(newGain)*amountchannel); // amount bytes
// tidy up….
Delete newGain;
Delete deltaSPTO;
Delete deltaAPTO;
}
…
```

Figure 18. Example Code for 2nd level correction of GAIN result

Structure of the Controller Software

In this section, the controller software structure will be discussed. It won't be discussed in all details; only the major structures are sketched up and illustrated. However, this is an example structure and is intended only as a suggestion of how things could look. On special instrument modules, such as the attenuator or the switches, the specific functions are highlighted.
The example code shown simply demonstrates the principle; they are only fragments and are not executable.

The controller software has to check that the minimum system requirements are fulfilled, after the available instruments and their loading are analyzed. These minimum requirements have to be specified, e.g. using a test set-up scheme as shown in Figure 1.
In addition, it has to apply measurement parameters and available modules to measurement algorithms, as well as the main task of controlling the instruments and storing the measurement results.

To keep the software clear, a few specifications have to be made. For example, in the test set-up discussed, it could be specified that two mainframes, an 8166B and an 8164B, beside an OSA are the minimum hardware that must be available. An optional external polarization scrambler could also be installed. All stimulus modules – this means all DFB modules – have to be installed in the mainframe 8166B. Modules used to condition or guide the signals – as the attenuator and switches - are installed in the 8164B. The reference power meter can be installed in either the 8164B or the 8166B.

After launching the software, it checks immediately for these conditions. If one of these conditions is not fulfilled, then the software notifies the user and stops executing.

```
hp816x_listVisa_Q
    (interface,                 // IN: e.g. GBIBxx::YY::INSTR
    select,                     // IN: All or 816x instr.
    numberOfDevices,            // OUT: amount found devices
    listofAddresses[]           // OUT:InstrumentsList
    );
```

Figure 19. Function hp816x_listVisa_Q

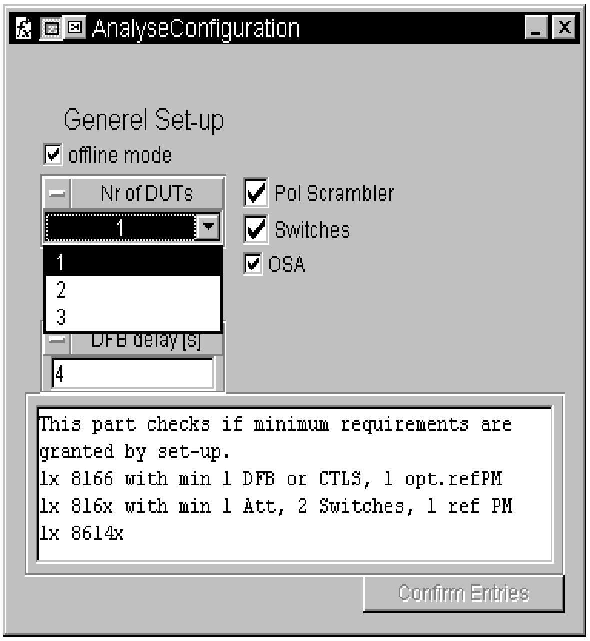
The function 'hp816x_listVisa_Q' returns an address list of all instruments connected to the GPIB interface. Each element list can be sequentially fed into the function 'hp816x_getInstrumentID_Q' to retrieve the specific instrument type, which can be entered in a look up table, which is referred to by other parts of the controller software.

After all connected instruments are identified, the first check can be implemented, while comparing the generated 'available Instrument List' with a pre-defined or definable instrument list.

```
hp816x_getInstrumentId_Q
(ViString busAddress,          // IN: Instrument Adress
 ViCharIDNString[ ]);          // OUT: Instrument String
```

Figure 20. Function hp816x_getInstruemtnID_Q

In case of error, the program has to inform the user by displaying an error message.



☑ offline mode

Nr of DUTs: 1 (1, 2, 3)

☑ Pol Scrambler

☑ Switches

☑ OSA

DFB delay [s]: 4

```
This part checks if minimum requirements are
granted by set-up.
1x 8166 with min 1 DFB or CTLS, 1 opt.refPM
1x 816x with min 1 Att, 2 Switches, 1 ref PM
1x 8614x
```

Figure 23. Example of UI for hardware "Configuration"

Before the discussion moves to the mainframe's loading check, the generated data about the availability of instruments can be stored in a look-up table.

```
ViStatus _VI_FUNC hp816x_getSlotInformation_Q(
ViSession ihandle,                  // Session Handle
 ViInt32 arraySize,                 // IN: Amount of Slots
 ViInt32slotInformation[ ]);// OUT: results
```

Figure 21. Function hp816x_getSlotInformation_Q

For common instruments, such as the OSA 8614x and the polarization controller 11896A, this kind of checking is enough.

In contrast to these, for the free configurable modular systems such as the 8164B and 8166B, the program must also check the mainframe loading.

To check the mainframe loading, the function 'hp816x_getSlotInformation_Q' is used to retrieve a table of module types installed in the queried mainframe. A function prototype is shown in Figure 21 and in the example directory of the PnP installation, a demo program can be found, which illustrates this kind of checking.

The list can be verified for specific modules, which grants the minimum configuration of the complete test set-up, for example the availability of an attenuator 81576A and modular switches, such as the 81592A.
Every element found is also entered beside the slot position in the look-up table of the controller software. If the detected modules don't match the demanded modules, the controller software should display an error message.

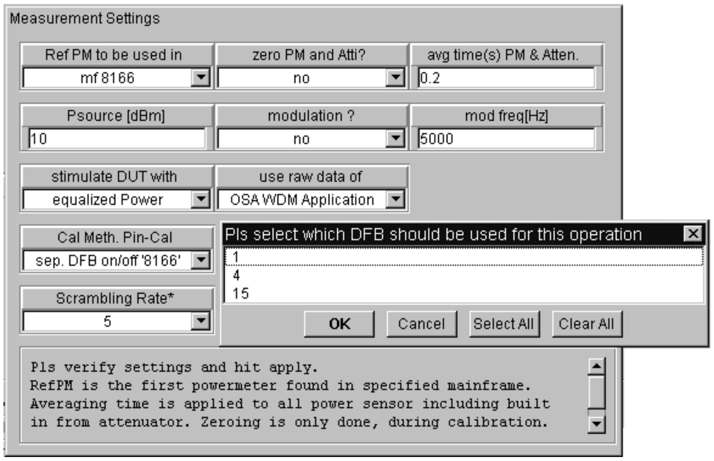
```
Struct Module
{
int TableSlotNumber[20];
int NrAvailable;
int Type;
};
Struct Mainframe
{
Module DFB;
Module Switch;
Module Atten;
Module PM;
Module TLS;
};

Mainframe mf816x;
Mainframe mf8166;
```

Figure 22. Instanced type mainframe mf as A816x

The aforementioned 'look-up table' is a record/structure containing arrays, Boolean variables and other types. A possible implementation for the 8164B / and or 8166B could look like that shown in Figure 22.

For the stand-alone instruments, such as the OSA 8614x and the polarization controller 11896A, variables also exist that describe the availability and the type. These are used to determine whether they are available or not.



Measurement Settings

Ref PM to be used in	mf 8166
zero PM and Atti?	no
avg time(s) PM & Atten.	0.2
Psource [dBm]	10
modulation ?	no
mod freq[Hz]	5000
stimulate DUT with	equalized Power
use raw data of	OSA WDM Application
Cal Meth. Pin-Cal	sep. DFB on/off '8166'
Scrambling Rate*	5

Pls select which DFB should be used for this operation

1
4
15

```
Pls verify settings and hit apply.
RefPM is the first powermeter found in specified mainframe.
Averaging time is applied to all power sensor including built
in from attenuator. Zeroing is only done, during calibration.
```

Figure 24 Example UI for Measurement Setting

In Figure 23 an example GUI is shown. The selected items are checked on the data retrieved from the mainframe loading check routines.

As the software has already got all the data about the hardware configuration, it needs data about specific measurement parameters.

```
Struct measDFB
{
float mod_frequency;    // modulation frequency
int modulation;         // bool: 1-enable, 0-disable modulation
float Psource;          // Output power of DFB
int tbl_used[17];       // Array of used DFB;
};
Struct measDUT
{
int amount              // Amount of DUTs
int stimulationmode;    // equalized, ramp, non equalized
};
Struct measPM
{
float avgtime;          // used averaging time of power meter
int zero;               // 1-zeroing before meas; 0-no zeroing
int Slotnumber_ref;     // location of reference power meter
int refPMMf;            // in which mainframe is ref power meter
};

Struct Measurement
{
measDFB DFB;
measDUT DUT;
measPM PM;
};
Measurement Meas;       // creating  LookUp Table
```

Figure 25 Look Up Table for measurement settings

For example, if the DUT has to be stimulated, then the software needs to know, if the sources should be modulated, which sources have to be used, which power they should be set to and so on.

For calibration purposes, the user wants to decide if a dark current calibration of the power meters is performed before the actual calibration routine starts. For some reasons it could be interesting to stimulate the DUT with special pre-emphasized input signals. This means that all channel powers, applied to the DUT input, are equal, or with either a rising or a falling slope. To control the switches and the iterations during measurement algorithms, the number of DUTs and the installed switch type must be known.

All this kind of data must be gathered in the user interface, and then stored in a look-up table containing measurement-preconditioning data. An example user interface is shown in figure 24. A possible look-up table could be implemented as shown in figure 25.

Use of Look Up Tables Applied on Implementation of Gain Versus P_{in} Measurement

As example measurement, the Gain versus P_{in} measurement will be used to show how to use the look-up tables. This measurement measures the behavior of gain if the input power to the amplifier is changed. During the gain versus P_{in}

```
…
Atten_OpenShutter();
DFB_TurnOnAllUsed();
Scrambler_TurnOn();
for (Pactual, Pstart <= Pstop, Pstep)
{
        Switch(ref);
        Atten_SetPower(Pactual);
        OSA_DoSourceMeasurement();
        Switch(DUT);
        OSA_DoAmplifierMeasurement();
        ReadDatafromOSA();
}
Atten_CloseShutterAtti();
DFB_TurnOffAllUsed();
Scrambler_TurnOff();
…
```

Figure 26. Gain versus Pin

measurement, the routine for gain and noise figure, as discussed earlier, is performed for every input power measurement point. To apply a signal with certain strength the calibrated attenuator is used.

```
…
int DFB_TurnOnAllUsed(void)
{
for (int I=0; I<sizeof(Meas.DFB.tbl_used); I++)
{
hp816x_set_TLS_laserState(
   ihandle,     // pointer to instrument
   Meas.DFB.tblused[I], // TLSSlot
   ON);                 // Turn it on)
}

return 0;
```

Figure 27 Function to turn all used DFB lasers on

The basic algorithm is shown in Figure 26, on which the access to the look-up table will be

```
Switch(int position)
{
   switch (A816x.Switch.NrAvailable)
   {
   case 0: query user for manual connection
        break;
   case 1:
   {
// send command to switch
// e.g.
// hp816x_set_SWT_route(
        hp816x_set_SWT_route
        (ihandle,
        816x.Switch.TableSlotNumber[0],
        Input,
        Output)
        ;
        break;}
   }
}
```

Figure 28 Function Switch (pos.) Inside

demonstrated.
In Figure 27 the look-up table is used to turn all DFBs on and Figure 28 shows how a switch is set to a specific position.

For details on how to include the PnP driver function into a programming environment, please refer to 5988-2790EN. To get more information about the actual functions, refer to the 816x.hlp help file saved in the VXI PnP installation directory.

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Related Agilent literature:

Agilent 8163B Lightwave Multimeter
Agilent 8164B Lightwave Measurement System
Agilent 8166B Lightwave Multichannel System
Technical Specifications
p/n 5988-3924EN

App Note:
How to use VXI Plug &Play Driver with Agilent Vee,C/C++, Visual Basic, Labview, and LabWindows/CVI 5988-2790EN

Measuring the Dependence of
Optical Amplifiers on Input Power
Using an Attenuator
5988-5260EN