Keysight Technologies

Measuring the Dependence of Optical Amplifiers on Input Power Using an Attenuator

Application Note

Abstract

The important optical amplifier properties of gain and noise figure are generally dependent on the powers and wavelengths of the input signals. Testing this behavior requires control of the power of the input signals, which can include channels at many wavelengths, over several orders of magnitude. Using a spectrally flat attenuator provides a time-saving and accurate control of multichannel sources. This capability is further enhanced by including power monitoring with the attenuator.

KEYSIGHT TECHNOLOGIES

Introduction

The most important performance parameters for an optical amplifier are: the gain which characterizes the power increase of a signal, the output power which characterizes the amplifier capacity, and the noise figure which characterizes the degradation in signal-to-noise ratio resulting from the amplifier.

An important aspect of testing optical amplifiers is that their performance is dependent on the power of the input signals. The most obvious example of this is that the gain goes into saturation (dropping with increasing signal strength) for high input powers, because the output power reaches its maximum value. Another example is the decrease in broadband background light (amplified spontaneous emission, ASE) when the energy of the amplifier is depleted through the amplification of increasingly strong input signals. This effect influences the noise figure of the device in operation. Thus it is important to characterize amplifiers over the relevant range of input power.

For this reason, some of the specification parameters called for in international standards for optical amplifiers also characterize the input-power dependence of the device, including: output power range, small-signal gain, saturation output power, and multichannel gain tilt.

This application note describes how these parameters can be accurately determined using the basic building blocks of an optical amplifier test station, including optical spectrum analyzer, calibrated power meter, single or multichannel source, switches and optical attenuator.

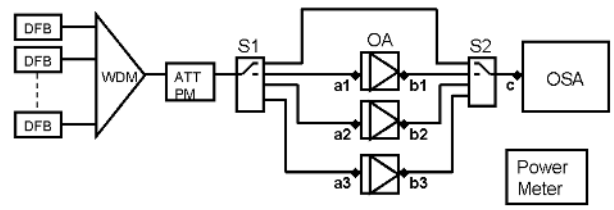
Setup

The basic setup for these measurements is shown in Fig. 1. In general, an optical spectrum analyzer is required for amplifier characterization because the amplifier produces light over a broad spectral range.

The OSA allows measurement of individual channel powers, as well as characterization of the broadband ASE produced by the amplifier. Keysight Technologies, Inc. 8614x series optical spectrum analyzers also include built-in application routines to make gain and noise figure measurements of optical amplifiers. These applications can be used manually or called by external programs to coordinate the measurements with the control of the other instruments.

Because the performance of the amplifier depends on the input signals, it is necessary to use a configuration of sources that well represents the intended application. Here, this is accomplished using a set of DFB lasers as a multichannel source (light at multiple wavelengths). The sources serve two functions: to simulate the signals to be amplified and at the same time to set the operational point of the amplifier. In this role they are often called "saturating sources", and their distribution of power over wavelength is important.

Example Optical Amplifier Test Setup



~~Figure 1. Basic setup for optical amplifier test with adjustable multichannel~~ input power. In this case, 3 amplifiers are connected at the same time. (The abbreviations are: DFB, distributed feedback laser, e.g. Keysight 81662A; WDM, wavelength-dependent multiplexer; ATT PM, attenuator with power control, e.g. 81577A; S1 and S2, switches, e.g. 81595A; OA, optical amplifier; OSA, optical spectrum analyzer, e.g. 86146B; optical power meter, e.g. 81630B.)

The lasers can be combined with either a broadband-coupler multiplexer or a wavelength-dependent multiplexer. The multiplexer based on broadband coupling has the advantage of flexibility in wavelength selection and avoids critical dependence of insertion loss and polarization dependent loss (PDL), on fine wavelength adjustment. The WDM generally provides much lower insertion loss, allowing higher signal powers at the device under test (DUT), and filtering of the broadband emission of the sources, which can influence the accuracy of amplifier noise figure measurements. At each channel wavelength, only the source spontaneous emission (SSE), of that laser channel is passed through the WDM. With broadband combining, the SSE of all the lasers are added at each wavelength and the total SSE can exceed acceptable levels, when using many lasers. When using a WDM, fine tuning of the DFB wavelength may be required to minimize IL and PDL. This can be achieved with the Keysight 81662A and 81663A DFB modules.

An optical attenuator can be used to control the input power to the DUT over a wide range, while allowing the lasers to operate at a constant and stable level. When testing with a multichannel source, it is generally desired to attenuate all of the signals equally. This requires a wavelength-flat attenuator, like the Keysight 8157xA modular instruments, which allow adjustment of total DUT-inputpower without the need to individually readjust the laser powers. Attenuation rather than adjustment of laser power also maintains the best ratio of signal to SSE for a laser, which generally has the best performance near maximum power.

Testing of optical amplifiers involves the comparison of signals into the amplifier with signals at the output. Thus good calibration and repeatability is required between these two measurements.

In the most demanding cases, this may require splicing the DUT- input and DUT-output fibers together (for example, connection a1 to b1 in Fig. 1) to make the source measurements, followed by measurements with the amplifier spliced in at this position. It will then be desirable to make all necessary source measurements consecutively, for example at the desired power levels, before changing the connection. This requires especially good stability of the sources as well as other instruments and it is useful to monitor this stability. This can be done, for example using a tap coupler after the attenuator to sample the source with a power meter. Such a power monitoring function is included in the power-control versions of the Keysight modular attenuators.

When splicing is not possible or desired, manual reconnection or switches can be used to make the comparison measurements. Switches are convenient and enable mounting more than one DUT at a time. In this case, it is important to properly calibrate the various measurement paths as well as to monitor the signal stability among the measurements. In the case of Fig. 1, the upper positions of the two switches, together with a connecting patch cord provide the “source measurement” path.

As optical amplifiers may emit short pulses of high intensity (transients) when the input signal power changes rapidly, it is recommended to only change the input switch, S1, when the output switch, S2, is not directing the corresponding DUT output to the OSA. This protects the OSA detector.

In order to make the necessary calibrations of the optical paths, and of the absolute power measurement of the OSA, a reference power meter is generally also required. The use of this instrument for calibration is described in the next section. An instrument capable of high-power measurements may be required, such as the Keysight 81630B sensor module or 81628B optical head.

In addition to this basic setup, addition functionality is also often required. A broadband source, such as an edge-emitting light emitting diode (EELED), or a tunable laser may be added to allow measurement continuously over wavelength, probably as a small signal while the operation point is set by the saturating sources. An instrument for polarization control of the sources may also be added to avoid errors due to polarization hole burning (PHB), or to measure the polarization dependence of the gain (PDG).

Calibration

The critical optical power measurements for characterizing signals and noise are made by the OSA in Fig. 1. From these measurements, the power levels at the input and output of the amplifier need to be determined. Thus an important part of the measurements is the calibration of the OSA readings for the various optical paths with respect to the values present at the actual points of interest. This involves comparison of the relevant path insertion losses, as well as a comparison of the power readings from the OSA with corresponding readings from the power meter.

This comparison between the OSA and the power meter is especially important for the optical noise figure measurement, because this depends on the absolute power density of the broadband ASE. This requires both accurate calibration of absolute power measurement and of the resolution bandwidth, since the measurement of the broadband intensity depends on the bandwidth of the detected light.

Since these calibration measurements involve comparisons of power at different measurement points, if they are made by the same reference instrument then they need to be made at different times with reconnection. Therefore it is valuable to have another power meter monitor the source power continuously during the measurements. This can be achieved in the setup of Fig. 1 by using the power control feature of the Keysight attenuator modules. For every measurement, power readings are taken with both the reference power meter and with the attenuator power monitor. This also allows calibration of the offset between the power reading at the attenuator and the power appearing at the DUT input.

A proposed sequence for calibration is described below. The calibration should be performed with a single-wavelength source. If the path losses are not sufficiently independent of wavelength, then the calibration should be performed at all wavelengths of interest.

This might involve sequential measurements with only one DFB turned on at a time. The values obtained by this calibration can either be entered as parameters in the OA-Test application of the OSA or used by the external program to correct the values obtained from the OSA.

When making these measurements with a power meter, it is important to be aware that the responsivity of the detector is generally dependent on wavelength. Keysight power sensors are calibrated in responsivity vs. wavelength and the wavelength parameter should be set to the correct value for absolute power measurements. In the case of the setup in Fig. 1, this means that the wavelength parameter of both the reference power meter and the attenuator should be set to the correct value.

The following calibration steps may be followed for the setup of Fig. 1:

Step 1. Connect the reference power meter to the DUT-input fiber at Point a1 and set the switch S1 to route the signal to this point.

For each desired wavelength turn on the respective laser and take readings with both the reference power meter, P_{a1}^{R}, and the attenuator power meter, P_{a1}^{A}. If a switch is used to provide multiple DUT connections, this step should be repeated for each DUT input.

Step 2. Connect the reference power meter to the OSA-input fiber at Point c and connect the fibers for the DUT input and output connections to each other, such as a1 to b1 (omitting the DUT) and similar for any other DUT connections. Set the switches to the measurement position of the DUT and for each wavelength turn on the respective laser and take readings with both the reference power meter, P_{b1}^{R}, and the attenuator power meter, P_{b1}^{A}. for each DUT switch setting.

Step 3. With the reference power meter still connected to Point c, set the switches to the "source measurement" position so that the source is routed directly to Point c. For each wavelength turn on therespective laser and take readings with both the reference power meter, P_{S}^{R}, and the attenuator power meter, P_{S}^{A}. for each DUT switch setting.

Step 4. Keeping the same switch position, connect Point c to the OSA and measure the power for each wavelength with both the OSA, OSA P_{OSA}, and the attenuator power meter, P_{OSA}^{A}. Use the same measurement parameters for the OSA as will be used during the measurements, especially the same resolution bandwidth.

These calibration readings allow correction of the OSA measurements for losses in the system to determine the power levels present at the input and output of the DUT. With the powers expressed in dB, the source path offset,

$$L_{S1} = \left(P_{a1}^{R} - P_{S}^{R}\right) - \left(P_{a1}^{A} - P_{S}^{A}\right) + \left[\left(P_{S}^{R} - P_{OSA}\right) - \left(P_{S}^{A} - P_{OSA}^{A}\right)\right]$$

and the amplifier path offset

$$L_{A1} = \left(P_{a1}^{R} - P_{b1}^{R}\right) - \left(P_{a1}^{A} - P_{b1}^{A}\right) + \left[\left(P_{S}^{R} - P_{OSA}\right) - \left(P_{S}^{A} - P_{OSA}^{A}\right)\right]$$

may be calculated. These offset values may be functions of wavelength. Since these offsets characterize the setup, the same values can be used for measurements of more than one DUT, so the values should be stored in a file for repeated use. An OSA measurement M^{OSA} of the input and output signals can then be corrected according to

$$M_{in}^{true} = M_{in}^{OSA} + L_S$$

and

$$M_{out}^{true} = M_{out}^{OSA} + L_A\,.$$

If an OA-Test application of the OSA is used, then the path offsets can be input directly into the measurement setup parameters and the gain and noise figure will be calculated according to this calibration. The same offset values are then used for all wavelengths of a multichannel measurement. If there is a significant wavelength dependence to the offsets, the gain correction can be adjusted outside of the OSA application. In this case, the offset parameters should be set to the average value in the application routine and the corresponding gain and noise figure results obtained from the routine. The gain should then be corrected for deviations from the average offsets according to

$$G^{true}(\lambda) = G^{OSA}(\lambda) + \Delta L_A(\lambda) - \Delta L_S(\lambda),$$

where

$$\Delta L_A(\lambda) = L_A(\lambda) - L_A^{ave} \text{ and } \Delta L_S(\lambda) = L_S(\lambda) - L_S^{ave}\,.$$

A similar correction to noise figure for the deviations with wavelength is more complicated. Determination of the parameter using the ISS method (defined in the Measurements section) is based both on the difference and the ratio between DUT-input and DUT-output measurements, which prevents complete correction with a simple offset. Using the TDE method (also defined in the Measurements section), the noise figure determination is based on a simple ratio between ASE power determined at the output and then gain. The correction for deviations can then be made according to

$$NF^{true}(\lambda) = NF^{OSA}(\lambda) + \Delta L_A(\lambda) - [\Delta L_A(\lambda) - \Delta L_S(\lambda)]$$
$$= NF^{OSA}(\lambda) + \Delta L_S(\lambda).$$

If the source path and amplifier path offsets are similar, or if the SSE is small compared to the ASE, then the same correction is also adequate for the ISS method.

The calibration steps described above distinguish between corrections due to insertion loss and the OSA calibration itself. The OSA calibration is represented by the terms in square brackets in the equations for the offsets. It is also possible to measure the two corrections together if this distinction is not desired. In this case, Steps 2 and 3 can be made directly with the OSA and Step 4 can be omitted. The square bracket terms should then also be omitted.

For accurate measurement and setting of the total DUT-input power with the Keysight power-control attenuator module, there are two calibrations to make for the power monitor.

The “power offset” parameter should be set to correct for loss between the attenuator measurement point and the DUT-input. This offset corresponds to

$$P_{offset} = P_{a1}^{A} - P_{a1}^{R}$$

and can be input either manually or from a computer program.

The offset data can also be entered as an array dependent on wavelength, so that the offset value corresponding to the value chosen for the wavelength parameter of the module will be used. This array is primarily useful for tunable single-channel sources. For a multichannel source, an average offset value should be used.

The offset can be different for multiple DUT positions, in which case either the offset can be changed at the module each time a different DUT is selected with the switch, or the difference can be accounted for by the controlling program. (An alternative “trick” that may be useful, especially for manually testing a setup, is to store the offset for each switch position in the offset data array of the attenuator, using a slightly different wavelength value for each position. For example:

[1550.001nm, Offset1; 1550.002nm, Offset2; etc.]. Then the correct offset can be chosen using the wavelength parameter.)

The second power-control related calibration is for the wavelength- dependent responsivity of the power monitor. When only a single wavelength is used, this is accomplished by setting the wavelength parameter of the module to this value so that the module can use the built-in responsivity calibration data. In order to extend this calibration for control of multiwavelength sources, the Keysight 81576A and 81577A power-control attenuator modules offer the possibility of calibrating the power monitor feature for the actual set of wavelength channels used in the measurement. This procedure is described in detail in the Appendix. This calibration depends on the relative distribution of power among the channels, so any equalization or pre-emphasis of the channel powers should be performed before the calibration. Such equalization may be used to obtain equal channel powers at the DUT input and may be performed by adjusting each laser power, based on the measurements of Step 1.

Measurements

With a calibrated test system, accurate measurements can now be made. These can be divided into relative and absolute power measurements. Relative measurements are based on the comparison of power, as is true for gain determinations. Absolute measurements, which are generally more demanding for the detector and calibration accuracy, are used for parameters like output power and especially importantly for noise figure.

Specification parameters for optical amplifiers are detailed as international standards in the IEC 61291 series documents. In particular, IEC 61291-1 provides definitions of parameters to use for optical amplifiers. IEC 61291-2 details performance specification templates for amplifiers in digital applications and IEC 61291-4, when published, will add definitions and templates specific to multichannel applications. Measurements of several of the parameters from these documents that rely particularly on input power control are outlined below.

Most measurements require distinguishing the optical power of the signal from light that the amplifier emits spontaneously. The spontaneous emission is usually distributed over a wide wavelength range so that the separation can be made with an optical spectrum analyzer. When multiple signals at different wavelength channels are used, these can also be separated with the OSA.

Gain is the primary function of the amplifier. It is defined in IEC 61291-1 as: “In an OA which is externally connected to an input jumper fibre, the increase of signal optical power from the output end of the input jumper fibre to the OA output port at a given input signal power, expressed in dB.” (Additional notes of clarification are also in the standard.) As is already made clear in this definition, the value of this parameter is based on the choice of input signal power.

Thus a gain measurement begins by setting and measuring the input signal power and wavelength. The power can be set using the calibrated variable optical attenuator. Based on the calibration measurements, the value of attenuation can be calculated and set directly. Using a power-control attenuator module allows the power itself to be set directly. The measurement of input signal power is usually made with the OSA, especially because multiple signals need to be measured separately. Also, both input and output signals are then measured with the same instrument, since the OSA measurement is needed to separate ASE from the output signals. The definition of gain is extended to multiple signals in IEC 61291-4 as channel gain.

Correct determination of output signal power also involves subtraction of spontaneous background optical power at the same wavelength as the signal, which can be estimated by interpolation of the background intensity at wavelengths near the signal. This correction is sometimes negligible, but is important for measurement of small-signal gain, which is described below. Further details for measuring gain with an OSA are given in IEC 61290-1-1.

The small-signal gain is defined in IEC 61291-1 as, “the gain of the amplifier, when operated in the linear regime, where it is essentially independent of the input signal optical power, at a given signal wavelength and pump power or bias current.” Determining this involves measuring the gain for an input signal power which is sufficiently reduced that the gain remains unchanged for further reduction. This level of input power can be found by making gain measurements over a series of input power levels. This same series of measurements can be used to determine other parameters, as described below. As is further noted in the standard, “this property can be described at a discrete wavelength or as a function of wavelength” and “also applies when the OA is saturated by single or multichannel signals.”

The noise figure characterizes the degradation in signal-to-noise ratio of the optoelectrically detected signal due to the amplifier. In many cases, this effect is dominated by the influence of the ASE, which causes beat noise with the signal. This influence can be determined from an optical measurement of the ASE spectral power density at the wavelength of the signal, which can also be measured with an OSA. Several methods have been developed to make this measurement. Interpolated-source subtraction (ISS) is supported with a built-in application on the 8614x-series OSA. Time-domain extinction (TDE) is a built-in application in the 86146B OSA and works in conjunction with the Keysight modular laser sources. These methods are described in Ref. [1]. The noise figure also depends on signal power and wavelength and the operating conditions at which the noise figure is specified should be given, as noted in IEC 61291-1.

Parameters that specify absolute power levels from the amplifier include output power range and saturation output power, both defined in IEC 61291-1. These parameters are based on output signal power, so they should not include the ASE power. This is most easily achieved by making the measurement with an OSA rather than a power meter that integrates power over the complete emission-wavelength band. For multichannel signals this means adding the individual signal power values together. However, a parameter for the individual signals is also defined in IEC 61291-4 as channel output power range.

Output power range is defined as the “range of optical power levels in which the output signal optical power of the OA shall lie, when the corresponding input signal power lies in the input power range, where the OA performance is ensured”, and can be measured by making a series of measurements, varying the input signal power over the desired range to be specified.

The saturation output power can be determined from the same series of measurements and is defined as “the optical power level associated with the output signal above which the gain is reduced by N dB (typically N=3) with respect to the small-signal gain at the signal wavelength. Once the small-signal gain has been determined, the input power at which the gain is sufficiently reduced from this level can be identified and the associated signal output power determined. The wavelength or configuration of multiple wavelengths for which saturation was measured should be stated.

The specification of maximum total output power is indicated in the templates of IEC 61291-2 as a parameter for safety aspects. This power includes all emitted power including the ASE so it may be determined using a power meter, if the wavelength-dependence of the responsivity is not excessive for detecting the broadband emission. For this test, sufficiently high input signal power is needed to strongly saturate the output power of the amplifier.

A parameter specific to multichannel applications is multichannel gain tilt. Gain tilt characterizes how the wavelength-dependence of gain changes with respect to input power. It is useful both for modeling the theoretical performance and for specifying the effect of input power changes on the gain flatness. Often, optical amplifiers are designed to achieve wavelength-flat gain for a specific operation level.

Gain flatness itself is described for multichannel applications by the parameter multichannel gain variation, which is defined in IEC 61291-4 as, in part, “the difference between the channel gains of any two of the channels in a specified multichannel configuration.” Normally this is specified as the maximum difference between any two of the channels, either for a certain stated configuration, or based on measurements at the minimum and maximum specified total input signal powers. Gain variation is expressed in units of dB.

Multichannel gain tilt is defined in IEC 61291-4 as, in part, “the ratio of the changes in gain in each channel to the change in gain at a reference channel as the input conditions are varied from one set of input channel powers to a second set of input channel powers.” Thus the gain tilt

$$GT_j = \left(G_j^{(1)} - G_j^{(2)}\right) / \left(G_r^{(1)} - G_r^{(2)}\right)$$

has a value for each wavelength channel of a multichannel source configuration, based on one of the channels that is chosen as the reference, r. For a channel j, the gain tilt is, where the (1) and (2) represent gain measurements at two specified sets of channel input power. Generally in Configuration (1), all channels are equal to the maximum of the allowed channel input power range and in Configuration (2) they are equal to the minimum of this range. Usually gain tilt is largely independent of the actual power levels used, which makes this a useful parameter. The unit for gain tilt is dB/dB and so has value 1dB/dB at the reference channel.

Gain tilt should not be confused with gain slope, which is the derivative of gain with respect to wavelength (under particular measurement conditions) and has units of dB/nm. Gain slope is a particularly important parameter for amplifiers used in analog signal applications, because gain slope causes distortion of such modulated signals. Another parameter defined in IEC 61291-4, somewhat similar to gain tilt, is multichannel gain-change difference, which also characterizes nonuniform changes in gain for changed input powers. This parameter is based on the

$$GD_{jl} = \left(G_j^{(1)} - G_j^{(2)}\right) - \left(G_l^{(1)} - G_l^{(2)}\right)$$

difference in gain change, rather than the ratio, and is defined for all pairs of channels rather than with respect to a reference channel. Thus for two channels, j and l,

which has units of dB. Input power of Configuration (1) is generally with all channels at minimum power and Configuration (2) is then with all channels at maximum power, but other configurations could be used and described with the product specification. Typically, the values of gain-change difference are condensed by specifying the maximum value.

As can be seen from this short summary of measurements, a well planned series of gain and noise figure measurements at different input power levels and using an appropriate configuration of source wavelengths can be used to determine many of the parameters indicated for performance specification by international standards.

Appendix: Multiwavelength Calibration

The Keysight modular optical attenuators with power control provide a convenient means of accurately setting and monitoring the total optical power provided to the DUT input. The power measurement has been factory-calibrated to provide accurate absolute measurements. The calibration incorporates the wavelength-dependence of the tap coupler and photodetector and is stored in the module as a responsivity factor vs. wavelength array.

Absolute power measurement of a multiwavelength or broadband light source needs to correctly account for the wavelength-dependence of the responsivity, which is only possible if the source spectrum is known. This spectrum (relative distribution of power over wavelength) can then be convolved with the responsivity spectrum to give an effective responsivity factor. Using this factor, an absolute total power measurement is then possible, as long as the relative spectral distribution of the light remains constant. This is the case when the intensity is controlled by a wavelength-flat attenuator like the Keysight 8157xA.

This appendix describes the algorithm for making this multichannel power calibration, for a given source spectrum. This is made particularly convenient by the VXIplug&play driver, but thenecessary data are also available for use by a user-written algorithm.

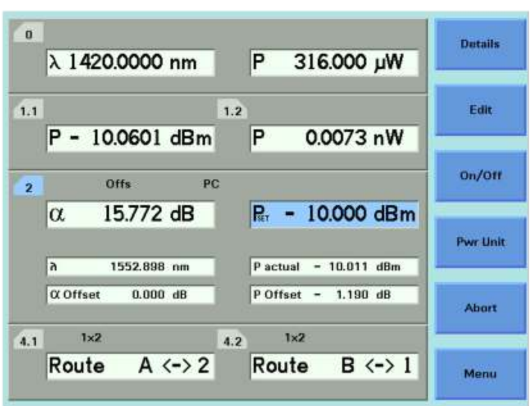


Figure 2. Instrument display showing power control parameter and calibrated effective wavelength of attenuator module.

Any channel equalization or pre-emphasis should be performed before making this calibration, and recalibration, or recalculation of the effective responsivity, may be necessary if the pre-emphasis or channel configuration is changed during the measurements.

Step 1. The spectrum at the output of the attenuator first needs to be determined. This will be expressed as an array with wavelength and power values, $A(\lambda_i, P_i)$. For the purpose of this calibration, the absolute values are not important; only the relative strength of each data point compared to the total power plays a role. The power values should be expressed in linear units like milliwatts.

This spectrum can be a set of discrete values corresponding to the wavelengths and powers of the individual channels, which is especially appropriate for multiple laser sources. However the spectrum can also be a continuous spectrum with many points, which could be used for a broadband source. Three possible methods for obtaining this spectrum are described here, but alternatives adapted to a particular measurement station can be easily substituted.

OSA Scan: After connecting or switching the attenuator output to the optical spectrum analyzer, a scan is made over the entire spectral range of the source and the wavelength and intensity data are read from the OSA. This method is advisable for broadband sources or if the OSA does not offer a channel analysis function.

OSA Analysis: When the source consists of multiple laser lines, it is convenient to characterize only the channels. Built-in OSA functions can be used for this purpose. The Keysight 8614x OSA series provides two applications that can perform this analysis. The WDM Spectrum routine can be used to automatically produce a table of channel wavelengths and powers, which can then be read out over the interface bus. Similarly the OA-Test routines themselves can be used to provide such source information, which is particularly convenient for recalibration between amplifier measurements, if necessary.

Spectrum Synthesis: The spectrum for a multichannel source can also be generated by making sequential single-channel measurements of each laser source individually using a wavelength-calibrated power meter. For this purpose, the readings from the built-in power monitor itself may be used, together with the known wavelengths of the laser sources. (The measurements should be made with the correct wavelength setting of the power meter for each channel.) This allows calibration in setups that do not include an optical spectrum analyzer.

The measured spectrum should be representative of the spectrum detected at the attenuator module for proper calibration. This means that wavelength dependence in the loss path should be avoided between the attenuator output and the receiver used to measure the spectrum. If this is difficult using the OSA as receiver, the spectrum synthesis method using the built-in monitor may be most convenient.

Step 2. Now the responsivity factor corresponding to the source spectrum can be determined and set in the attenuator module. This step can be conveniently performed by the VXIplug&play instrument driver as described here first. Use of the PnP drivers in programming is generally recommended for optimum use of Keysight instruments. The details of the step are then described in more detail for direct programming of the algorithm.

VXIplug&play function:
The PnP driver can be used to perform the convolution of spectrum and module responsivity to determine and set the effective responsivity.

This is done with the PnP function:
hp816x_spectralCalibration(//
instrHandle, //instrument handle
Slot, //input slot position of attenuator
Size_of_Spectrum, // input number of points in spectrum
Wavelength, //input array of wavelengths (meters)
Power, //input array of powers (watts)
Wavelength_Result, //output value effective wavelength
Error_Diagnose).

The PnP function will then upload the calibration data from the module, calculate the effective responsivity and set the module for this value by determining an optimally chosen effective wavelength, situated within the range of actual wavelengths and correspondingbto the required responsivity factor.

Direct programming:
Step 2 can also be programmed directly with the following details:

a) input the number of points N in the spectrum and the array $A\ (\lambda_i, P_i)$,
b) if necessary, sort the array A according to λ,
c) upload power calibration data "Resp ovr Wvl", using the instructions:
:SLOT[n]:HEAD[m]:WAVelength:RESPonse:SIZE?
to determine the number of points in the wavelength response table and
:SLOT[n]:HEAD[m]:WAVelength:RESPonse?
(binary format) or
:SLOT[n]:HEAD[m]:WAVelength:RESPonse:CSV?
(CSV ASCII format) to upload the values. These are referred to here as the array $B\ (\lambda_i, P_i)$,
d) calculate for each λ of the source spectrum array A, a factor f_i, using linear interpolation from the uploaded calibration data B (a simple interpolation using only the two neighboring points from B for each i should be adequate),
e) calculate the total power of the spectrum, P_T, according to:

$$P_T = \sum_i^N P_i \ ,$$

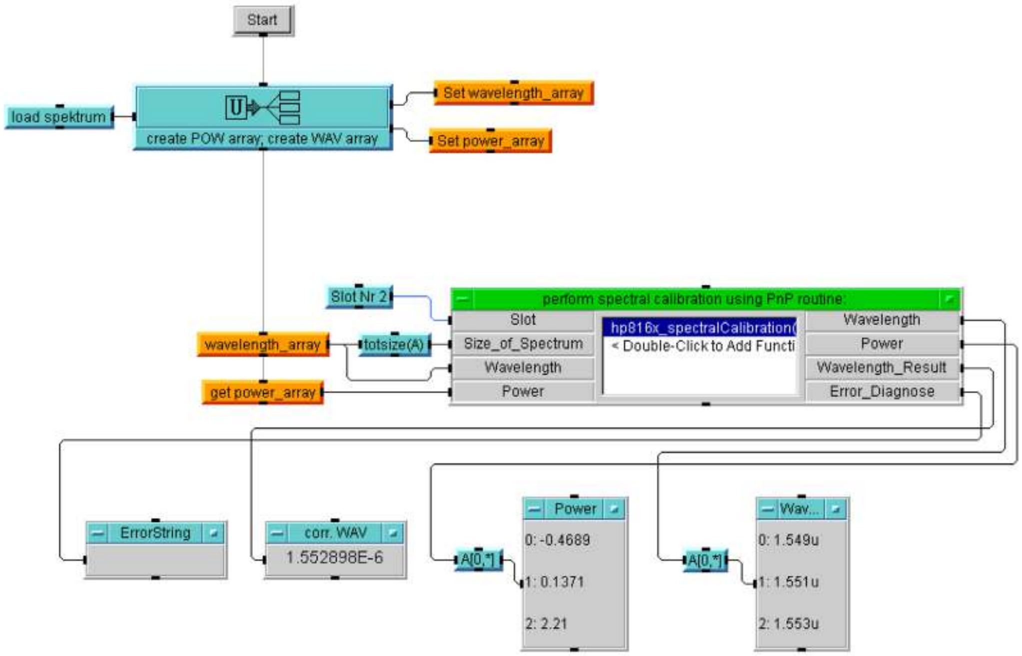
f) calculate the effective calibration factor, f_{eff}, according to:

$$\frac{1}{f_{eff}} = \frac{1}{P_T} \sum_i^N \frac{1}{f_i} P_i \ ,$$

g) find a value for the effective wavelength, λ_{eff}, for which $f(\lambda_{eff}(f_{eff}$, and set the module to this value with the
:INPut[n][:CHANnel[m]]:WAVelength
instruction. In general this must be done by searching the array B. B. It is recommended to choose a value of λ_{eff}, centered within the actual wavelength range of array A. The following procedure is suggested:

i) search the uploaded array of power calibration data B within the wavelength range of the source spectrum $A\ ($ j such that $\lambda_i^{min} < \lambda_{j+1}$ and $\lambda_i^{max})$ for all j such that f_{eff} is equal to f_j or between f_j and f_{j+1}; from this set of j, choose the value for which λ_j is closest to the center of the wavelength range in A, $(\lambda_i^{min} + \lambda_i^{max})/2$,
ii) determine the value of λ_{eff}, for which $f(\lambda_{eff}) = f_{eff}$, using linear interpolation between λ_j and λ_{j+1} for the chosen j, and
iii) set the wavelength parameter of the attenuator module to the value λ_{eff} .

Finished. The power control feature of the module is now calibrated for the multichannel source. The attenuator can be set to a chosen output power and this will be achieved using the calibrated feedback from the power monitor. Note that the calibration is only valid to the extent that the spectral distribution of power in the source remains constant. For further details please see the technical specifications and programming guide for the attenuator module, Ref. [2].



Related Keysight Literature

[1] Application note 1550-10:
Optical Amplifier Testing with the Interpolated Source-Subtraction and Time-Domain Extinction Techniques.

[2] Keysight 8156xA and 8157xA
Optical Attenuators Technical Specifications
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