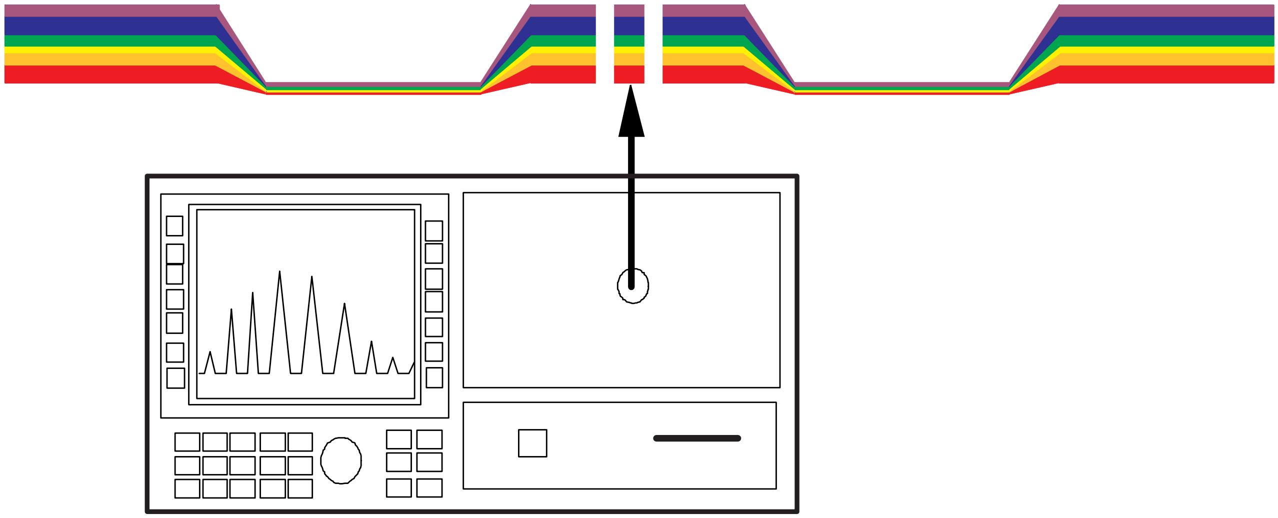
Pulsed- or Time-Dependent Optical Spectra Measurements

Product Note 71452-4

Agilent 71452B
Optical Spectrum Analyzer



Agilent Technologies
Innovating the HP Way

Table of Contents

Introduction

The rapid progress of lightwave technology constantly leads to measurements of more complex optical signals. In a variety of applications, the power or the spectrum of the light changes within a short period of time. For example, a pulsed laser has to be measured differently than a continuous wave signal. In a re-circulating loop incorporating optical amplifiers, the spectrum changes significantly within a fraction of a second. Agilent's family of optical spectrum analyzers (OSAs) support a variety of measurement features which allow accurate characterization of time-dependent optical spectra.

This product note first discusses how the Agilent OSA synchronizes its internal activities with external signals. Then it shows how major applications can take advantage of it.

Product information:
Agilent 71450B / 71451B / 71452B (or 70950B / 70951B / 70952B):
All information in this document is applicable without exception.

Agilent 71450A / 71451A (or 70950A / 70951A):
Triggered sweep, gated sweep and ADC Sync Output are standard. Many older instruments have a limitations of the analog bandwidth and the analog slew rate. The analog-to-digital conversion trigger modes and the TRNZLCK function require additional hardware.

To improve the analog and timing hardware, and to get the firmware functions offered in the "B" version, contact your local Agilent sales office and order the Agilent 70953A Time Domain Extinction upgrade.

References:

[1] Optical Spectrum Analysis Basics, Agilent Application Note 1550-4 (Agilent literature number 5963-7145E)
[2] EDFA Testing with the Time Domain Extinction Technique Agilent Product Note 71452-2 (Agilent literature number 5963-7147E)
[3] EDFA Noise Gain Profile and Noise Gain Peak Measurements Agilent Product Note 71452-3 (Agilent literature number 5963-7148E)
[4] Agilent 71450B/1B/2B Optical Spectrum Analyzers User's Guide (Agilent part number 70950-90049)
[5] Agilent 71450B/1B/2B Optical Spectrum Analyzers Reference (Agilent part number 70950-90051)

OSA Block Diagrams

Measurements of optical spectra require a complex combination of optics, electronics, and firmware. Figure 1 shows a simplified model of an OSA. Agilent's actual implementation is much more complex than the models shown in this document to illustrate the timing and synchronization issues.

If the light at the OSA input changes with time, then the signal to be measured must be described as a function of wavelength and time. However, the operation of the instrument depends on time too – the optics inside the OSA filter the spectrum. In order to measure all spectral components, the grating rotates so that different wavelengths are brought to the slit. The OSA function sweep time (ST) and the wavelength range (CENTER, SPAN) control the speed of the grating.

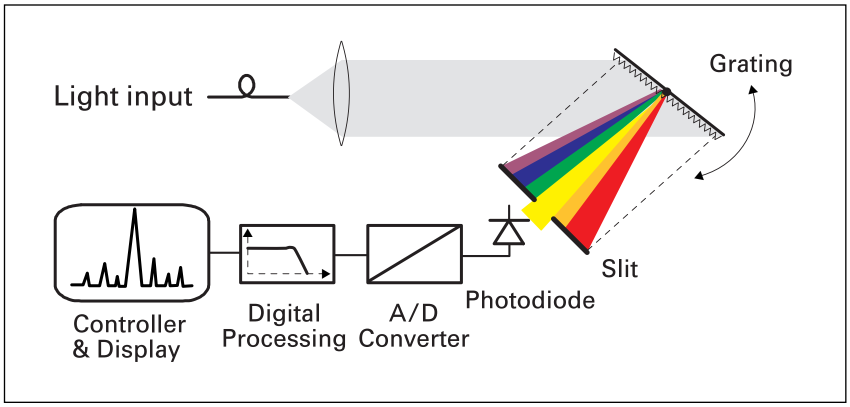


Figure 1. OSA Principle of Operation

The grating together with the slit behaves like an optical bandpass. Such a combination is called a monochromator. Its spectral filter characteristic (mainly center wavelength) changes with the grating motion. The photodetector receives a power that can be described as a convolution of the input signal and filter function of the monochromator. Independent of the wavelength, the photodetector converts all the light coming to the slit into an electrical signal that is amplified and then sampled. The analog-to-digital conversion (ADC) occurs every 37.5 µs. In best case, it takes trace length times ADC conversion time (800 x 37.5 µs = 30 ms) to scan a given wavelength range.

After the ADC, a digital signal processor (DSP) further processes the data. For example, the video bandwidth (VBW) function is implemented in the digital processor. Finally, the data is log-converted (dBm) and transferred to a display unit.

In many cases the spectrum at a given point within the modulation period is more meaningful than the average spectrum. A TTL signal at the trigger input of the OSA can synchronize a variety of the electronic blocks (Figure 2). For example, the signal can (mutually exclusive):

- start the grating motion (Triggered Sweep)
- sample and A/D convert a data point (ADC Trigger Mode)
- tell the DSP when the optical spectrum is valid (Gated Sweep)

Because there is only one trigger input connector, the timing unit block has to distribute the trigger input to either the motor control, or to the analog-to-digital conversion, or to the digital signal processor. If the grating is triggered, then the analog-to-digital conversion runs freely. If the ADC is triggered, then the grating moves independently of any external signal. The DSP can't be triggered directly (it has to synchronize its activities both with the ADC and the grating). However, the trigger input tells the DSP how to handle the data from the ADC.

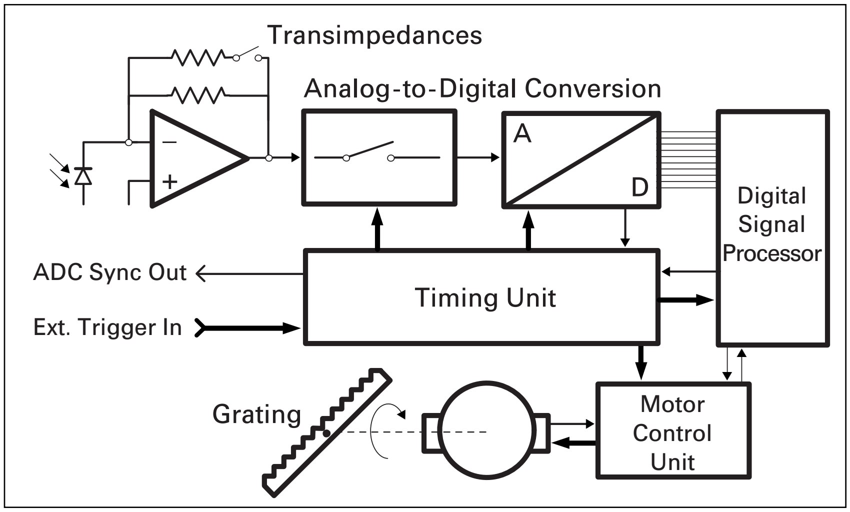


Figure 2. Trigger Signal Distribution

Before the next section discusses the various trigger modes in detail, let us first look at how the OSA operates independent of any external signal.

Free Run Mode

This is the basic mode. The grating sweeps through the selected wavelength range (Figure 3). When the sweep has been completed, the grating moves back into the start position. This cycle repeats itself as long as continuous sweep is active.

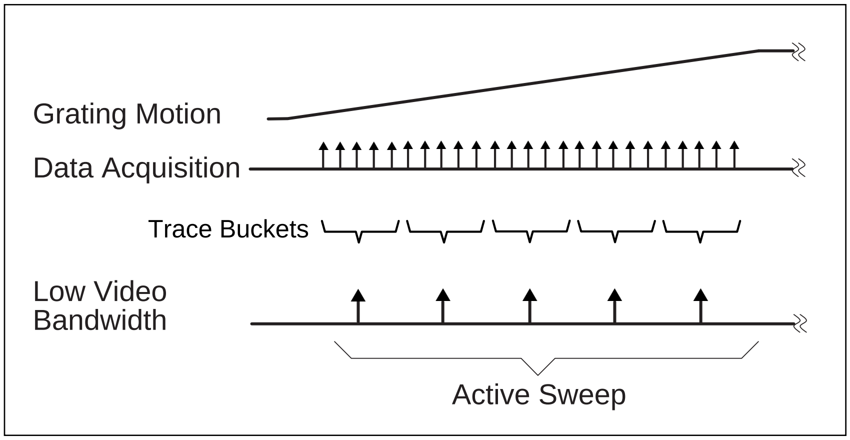


Figure 3. Free Run Mode

If the input power and spectrum are constant over time, then only the grating motion and the digital filters in the DSP must be synchronized to generate an accurate trace on the screen. In this case, the grating speed mainly depends on the wavelength range to be covered and the required sensitivity[1]: the slower the grating rotates, the more samples from the ADC can be averaged by the video bandwidth (VBW) function into one trace point on the screen. Sometimes such a trace point is called a "trace bucket" because it actually combines several ADC values.

If the signal is modulated then the OSA still can measure the average spectrum without any external synchronization. The VBW must be significantly smaller than the lowest modulation frequency component, otherwise the signal can look very distorted (Figure 4).

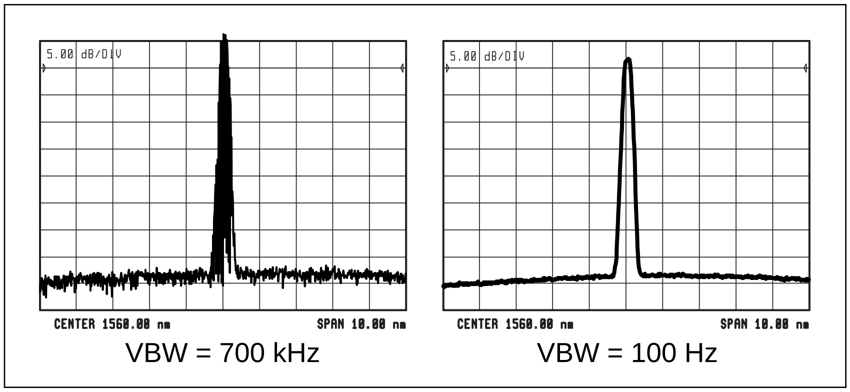


Figure 4. Video Bandwidth Effects

---

[1] The OSA can also increase its sensitivity by changing a different amplitude range (i.e., by selecting a different amplifier gain in the analog path). Because this can cause additional problems with modulated signals, we assume that ranging does not occur during the measurement. Several trigger and gated sweep modes turn off AUTO RANGE automatically.

Zero Span Mode

If the span is zero (i.e., start wavelength = stop wavelength), then the grating remains at the angular position representing the center wavelength. Therefore, the rest of the OSA behaves similar to a digital oscilloscope. The x-axis on the screen represents the sweep time. The sampling period is 37.5 µs. If the sweep time is longer than trace length times sample rate, then a trace bucket represents the average of several ADC values.

Besides looking at a low frequency (< 10 kHz) modulation, this mode has a major speed benefit for an accurate power measurement at one wavelength: Instead of placing a marker at a desired wave-length and then reading its power level, use zero span at that wave-length and then read the average power of the whole trace (remotely: "MEAN TRA?;"). Because a trace consists of many points, the mean trace power has averaged the noise or modulation, even if the sweep time is very short. To achieve the same noise or modulation suppression for a sweep with span > 0, the video bandwidth (VBW) must be very low, and therefore the sweep time becomes very long.

OSA Trigger Modes

Triggered Sweep

In this mode, the grating waits in a position according to the start wavelength[2] until it receives a trigger pulse (Figure 5). Then the grating starts to move in the same way as in the free run mode. There is no difference in building trace buckets or averaging the signal by a low video bandwidth. However, after the sweep the grating stops at the start position and waits for the next trigger event.

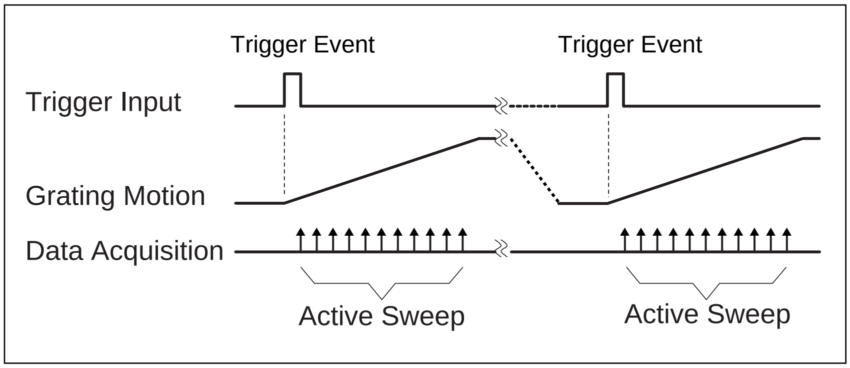


Figure 5. Triggered Sweep Mode

Each sweep results in a trace which can be processed further. For example, the MAX HOLD function will take the trace displayed before, compare each trace point with the new data, and then displays only the greater value of each point. Often, a swept source such as a tunable laser triggers a sweep after each wavelength step (see Figures 14 and 15 later in the application section).

During the whole sweep cycle including any processing of the data by markers or built-in application personalities, the OSA ignores any additional trigger pulse. Therefore, the repetition period of the trigger signal must be longer than the sweep time (plus some overhead if the CPU has to process many calculations).

Triggered sweep also works in zero span mode. In this case, a trigger edge causes the start of the data acquisition for an entire trace.

ADC Trigger Mode

The ADC trigger mode samples the raw data between 2 µs and 6.5 ms after a positive or negative edge of the signal at the trigger input (Figure 6). The grating runs continuously but the data acquisition is synchronized. If there is a trigger event, then the OSA will sample the data after the specified delay and digitize it.

The analog-to-digital conversion lasts 37.5 µs. The DSP needs additional time (up to 80 µs) to process the data. Trigger edges occurring in the meantime are simply ignored.

---

[2] Because the grating has to accelerate from zero to its measurement velocity, it actually waits at a position before the start wavelength. Acceleration can cause a delay between the trigger edge and the first data sample in the order of 10% of the sweep time.

There is also a relation between sweep time and the longest time period between trigger events: in order to get at least one valid sample for each trace point, the maximum time between trigger events must be less than sweep time divided by trace length. If the grating passes from one trace point (which represents a specific wavelength) to the next one without a trigger, then the OSA reports the error “Sweep time too fast.” In this case, adjust the sweep time manually to 1.2 .. 2 x trace length x maximum trigger period (the factor 1.2 .. 2 allows some time for processing overhead).

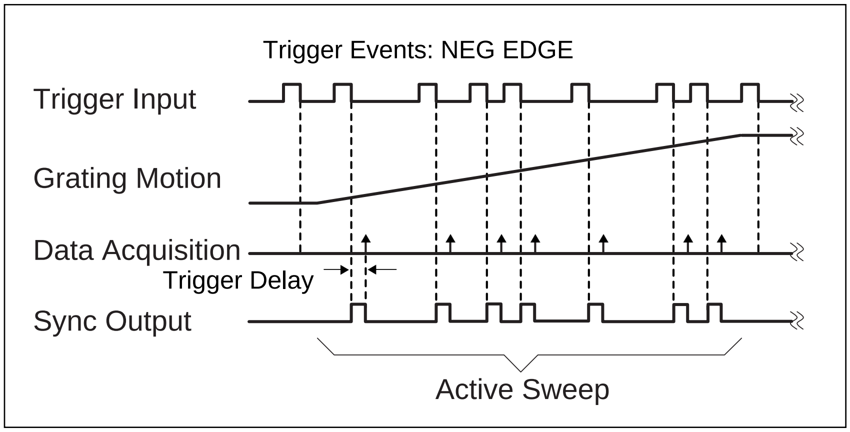


Figure 6. ADC Trigger Mode

Two additional aspects should be kept in mind when using the ADC trigger mode (or ADC AC Mode discussed below): the impact on the effective video bandwidth, and the amplitude range setting.

Because the VBW filter is implemented as part of the DSP firmware, the OSA displays a VBW value based on the assumption that the sampling period is 37.5 µs. If the trigger period in the ADC trigger mode is longer, then the effective VBW is accordingly lower. The effective VBW can be calculated as the displayed VBW times 37.5 µs divided by the trigger period.

ADC trigger is available in all ranges, including the more sensitive ones. If the input signals characterized with the ADC trigger modes have higher modulation frequency components, then the transimpedance amplifier between the photodiode and the ADC must have enough bandwidth. Because the sensitive gain ranges are slower[3], the OSA must stay in the two fast gain stages. The easiest way is to turn on the function TRNZLCK (transimpedance lock) and to turn off AUTORANGE.

---

[3] Bandwidth of the OSA ranges: 700 kHz, 600 kHz, 60 kHz, 20 kHz, 2 kHz and 200 Hz bandwidth.

ADC AC Mode

Similar to the ADC trigger mode, ADC AC samples the data delayed after a trigger event. While the first one triggers on either a positive or a negative edge, the ADC AC mode alternates between positive and negative edges (Figure 7). In addition, the DSP processes the data differently: it calculates the absolute difference between the samples acquired after the positive trigger edge and the ones acquired after the negative edge. The resulting trace point represents only the modulation amplitude, so that any constant light or light modulated at a different frequency cancels out.

In this mode, the DSP runs two VBW filters on the raw data from the ADC (one for the positive and one for the negative samples). Therefore, it reduces random noise without affecting the true amplitude of the signal.

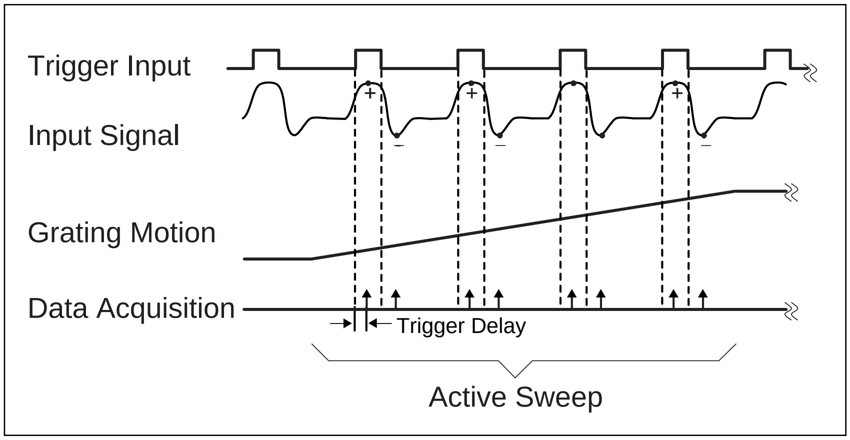


Figure 7. ADC AC Trigger

The ADC AC mode is similar to lock-in techniques. It measures the modulation portion of the light only, and it suppresses light which is not modulated. The impact on the effective video bandwidth and the amplitude range setting considerations discussed above apply to the ADC AC mode as well.

Applications for this mode include tests for systems incorporating EDFAs (see Figure 19), or open beam setups which use a 270 Hz modulation in order to suppress ambient light.

Gated Sweep Mode

The gated sweep mode tells the DSP when to retain or ignore the data coming from the ADC. Both the grating and the ADC run without synchronization to any external signal. If the trigger input is high, then the DSP takes the ADC value as a valid data point. Otherwise, it replaces the sample by the value -200 dBm. In both cases it continues processing according to the functions selected (e.g., video bandwidth, max hold, etc.).

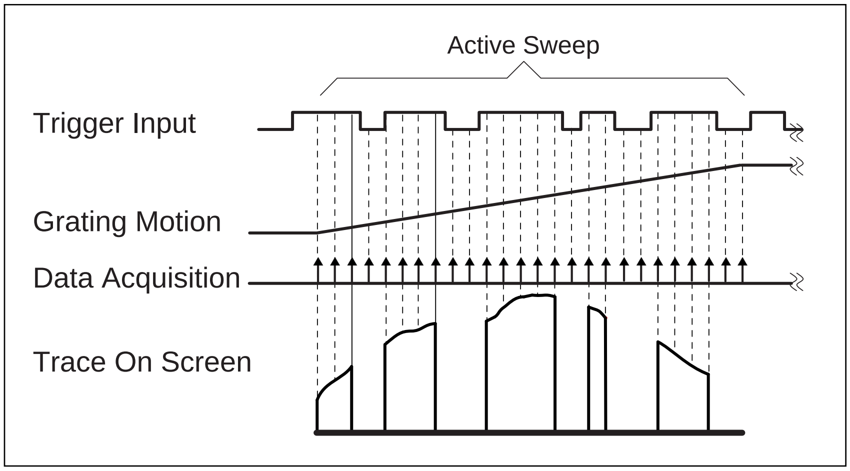


Figure 8. Gated Sweep Mode

If the time of the low level is longer than the time needed for the grating to move from one trace point to the next one, then the trace will have gaps (Figure 8). There are two alternatives to close the gaps: either increase the sweep time to at least 1.2 .. 2 x trace length x longest “low level” period, or activate the MAX HOLD function and let the OSA sweep several times. In the first case, the DSP will have at least one data sample marked valid (high level) per trace point. In the second case, multiple sweeps fill the gaps because the high and low levels of the gating signal occur independently of the grating position.

Gated sweep has no time limit for the high or low level. Therefore, it can be used to characterize pulses as narrow as a few microseconds, or obtain a spectrum whose timing exceeds the maximum 6.5 ms delay of the ADC trigger mode. This can occur in applications as shown in Figure 20.

Application Examples

Pulsed Light Signals

There is a great variety of pulsed light sources. Many applications fall into one of these categories (or at least have similar requirements):

1. High bit rate signals (34 Mb/s to 10 Gb/s)

2. Solitons (pulse width << 1 ns, repetition frequency > 1 GHz)

3. Test/control signals (pulse width 1 µs to 1 ms, duty cycle 10 to 90%)

4. Active component tests (lasers on a chip, etc.)

High Bit Rate Signals

The signals of this category have little modulation frequency components below 10 MHz. The best case analog bandwidth of the OSA is about 700 kHz. Therefore, the OSA measures only the average spectrum of typical telecom traffic signals.

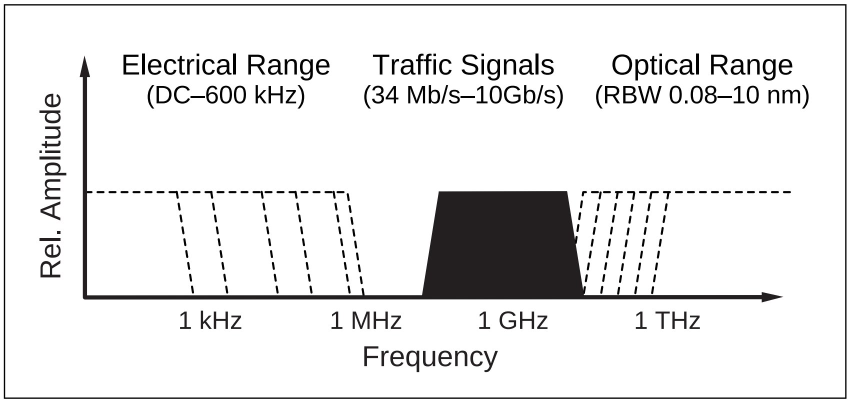


Figure 9. OSA Frequency Ranges

Solitons

Signals using solitons and other picosecond pulses also have a frequency spectrum mainly in the gigahertz range. Similar to the case above, the analog bandwidth of the transimpedance amplifier averages the pulses so that the signal looks like a continuous waveform to the OSA.

Test/Control Signals

Agilent’s family of OSAs offers the most variety to characterize test signals from components, sensors, subsystems or other light sources modulated in the frequency range approximately between 10 Hz and 250 kHz. Again, it is possible to measure only the average spectrum by choosing a low video bandwidth (Figure 10). Even if the analog bandwidth is higher than the modulation of the signal, the VBW function will low-pass filter the samples.

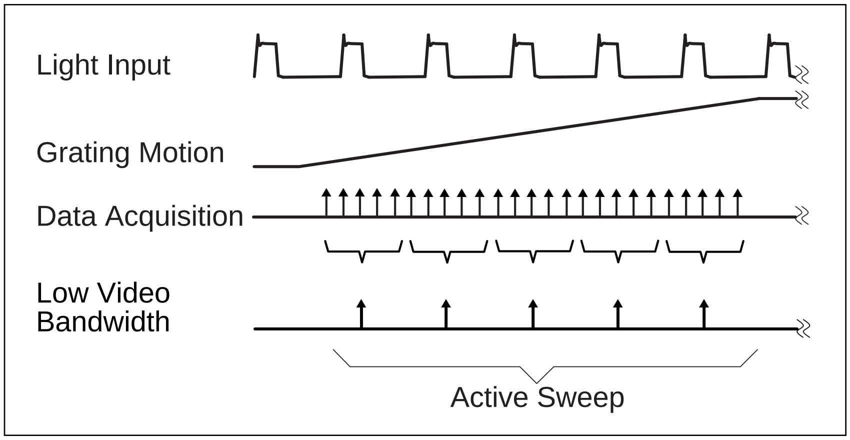


Figure 10. Pulsed Light Signal (measuring average)

Alternatively, the ADC trigger modes allow you to look at the spectrum for a specific point within the modulation period. The measurement in Figure 11 triggers at the positive edge and samples the light after a delay entered by the user. The OSA can delay internally between 2 µs and 6.5 ms. If an application requires longer delay times, then for example a Agilent 8110A / 8112A pulse generator can handle the extended timing requirements.

Note that the OSA is unable to trigger on the light input by itself. The analog receiver sees the modulation only when the grating is tuned to the wavelength of the modulated light. Other parts of the spectrum may not be modulated at all. If the light source does not provide an electrical trigger signal, then put a 10:1 coupler and a receiver[4] in front of the OSA's monochromator input. The receiver's insertion loss and dependence on wavelength should be low. It has to be taken into account for precise spectral measurements.

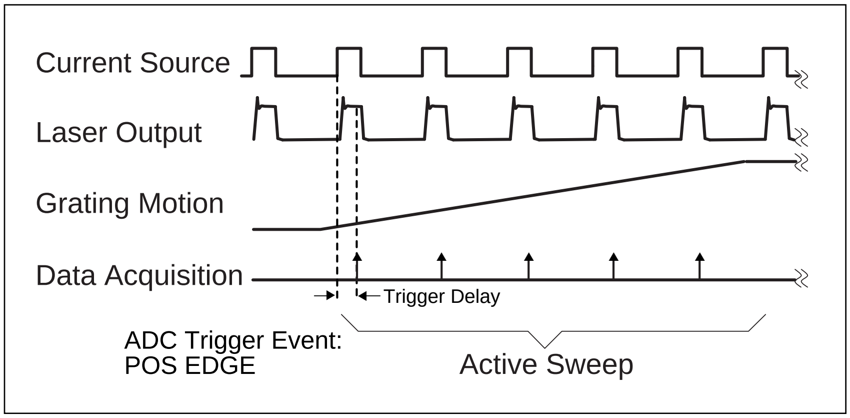


Figure 11. Pulsed Light Signal (synchronized data acquisition)

---

[4] The receiver has to provide a TTL-compatible output signal, and its frequency response should cover at least 5 kHz to 500 kHz.

Pulsing a Laser

Testing a source component, such as a laser or LED on a chip, is a common OSA application which often allows the OSA to control the modulation of the light source. Agilent's family of OSA offers personalities to characterize the spectrum of an LED, FP or DFB laser. Optionally, a current source can drive the component up to ±200 mA (Figure 12).

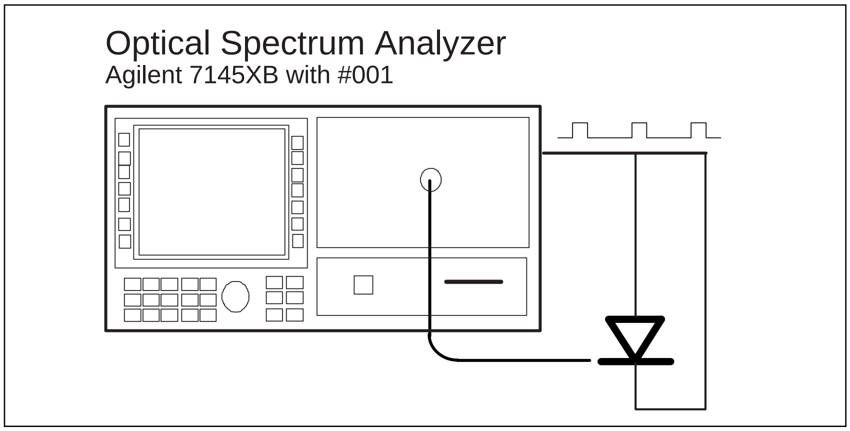


Figure 12. Pulsing a Laser With The Built-In Current Source

The OSA provides current pulses according to the selected pulse width. Because the OSA synchronizes the current source pulses with its data acquisition timing requirements, the actual duty cycle of the current may be slightly lower but never higher than the value entered by the user.

If the device under test needs more current than available from the OSA, or if the OSA does not have the current source option, then it is still possible to control the light pulses by using the ADC sync output (Figure 13): this output connector provides the timing infor-mation which otherwise modulates the optional current source. The width of that TTL-compatible pulse and its maximum duty cycle can be chosen in wide ranges. The OSA will always sample a data point immediately before the falling edge of the sync output pulse.

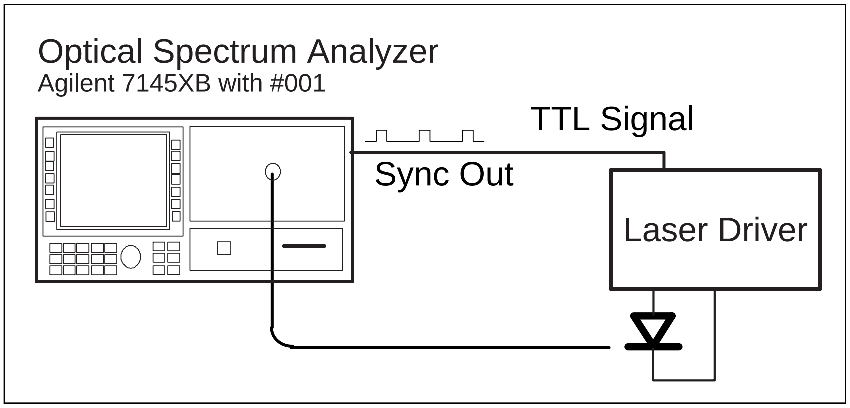


Figure 13. Synchronizing an External Laser Driver

When the OSA controls the timing, measurement speed is at its optimum because the OSA allows just enough time to acquire the data before it continues. There is no time lost while the OSA waits for a trigger signal, nor does the OSA miss or skip a trigger.

Synchronizing the OSA With a Tunable Laser

Many advanced measurement setups use a tunable laser source (TLS) and an OSA. For example, passive optical components such as deep, narrow filters require a swept source and a wavelength selective analyzer. The EDFA test option 051 of the OSA depends on a TLS to characterize the gain and the noise figure.

The TLS in Figure 14 makes a wavelength sweep step-by-step, i.e., it turns the laser off, moves the internal mechanics to the next wavelength, and turns the laser on again. The TTL-compatible modulation output goes low before the laser is turned off, and high after the laser is on again. Each rising edge of that signal triggers an OSA sweep. It is essential that the TLS dwell time (i.e., how long it stays at the wavelength before it makes the next wavelength step) is long enough so that the OSA can complete the sweep and return back to the start point. The more calculations the OSA has to make, the longer the dwell time. As a rule of thumb, choose the TLS dwell time greater than 1.5 x ST + 0.3 s (ST = displayed sweep time) for passive component tests, and 2 x ST + 5 s for the EDFA test personality (option 051).

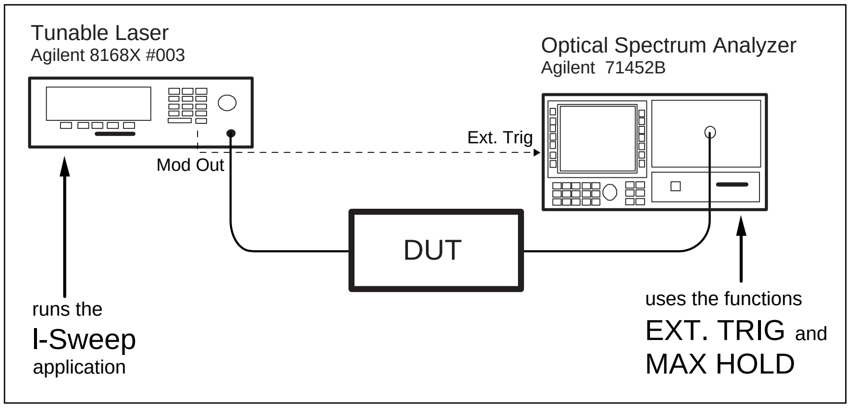


Figure 14. Synchronizing the OSA with a Tunable Laser

The TLS and OSA combination is often used in conjunction with the MAX HOLD function of the OSA. For each wavelength step, the TLS provides only one narrow laser signal (plus some source spontaneous emission). Therefore, each OSA sweep results in only one “needle”. MAX HOLD builds the wavelength dependence of the DUT by collecting the maximum of all sweeps. For illustration purposes, the step size of the OSA in Figure 15 is much greater than the resolution bandwidth (RBW) of the OSA. If the step size is smaller than the RBW, then the peaks combine and the obtained trace continuously shows the characteristic wavelength shape of the device under test.

In order to watch the effects of the min and max function on the OSA's color display, choose CLEAR/ WRT A, MAX HOLD B, and MIN HOLD C. Trace A displays each sweep at the top, and traces B and C hold the maxima and minima reached over time.

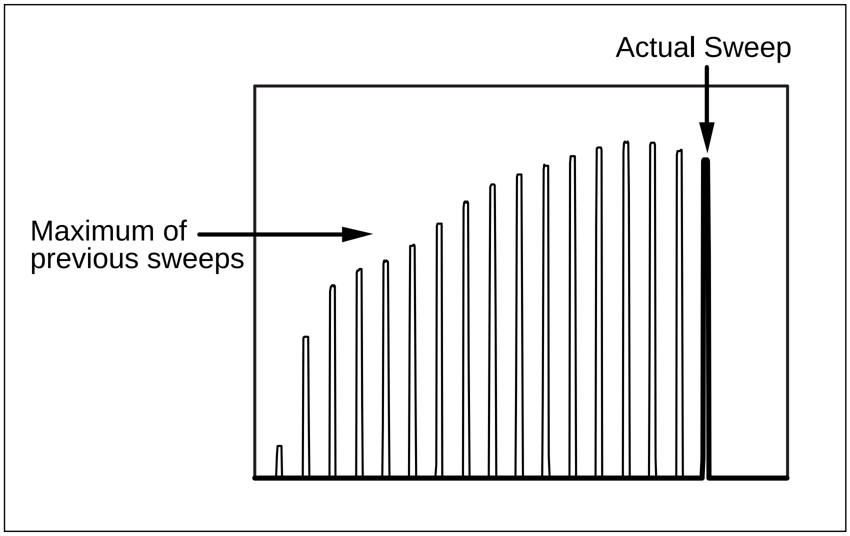


Figure 15. MAX HOLD Function

Time Domain Extinction

Time domain extinction is a technique to characterize Erbium-doped amplifiers (EDFA). It takes advantage of the relatively slow relaxation time of Erbium. One point of interest is the question how an EDFA amplifies a small signal such as noise in the presence of a large one. In Figure 16, the TLS drives the amplifier into its oper-ating point, and an Edge Emitting LED (EELED) provides the probe signal. Because the OSA has to measure the amplified EELED only but not the TLS signal, the TLS is modulated and the measurement occurs only in the break of the modulation. The EELED is modu-lated as well, so that its average power has only a negligible impact on the operating condition of the OSA.

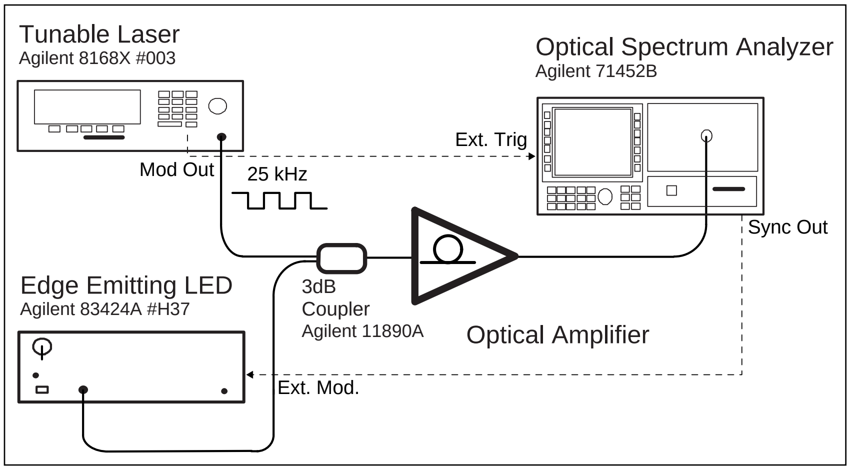


Figure 16. Noise Gain Profile Setup

In the example shown, the OSA uses the ADC trigger mode. When the OSA recognizes the negative trigger edge, then it switches the ADC Sync Output high, which turns the EELED on (Figure 17). Ten microseconds later, the OSA samples a data point and then immediately resets the ADC sync output.

At the sampling time, the TLS is off. With a locked transimpedance, the OSA has enough time to recover from the strong laser pulse. Therefore, the OSA measures only the spectrum of the amplified spontaneous emission and the amplified EELED. (For a further discussion of this measurement, see product note 71452-3).

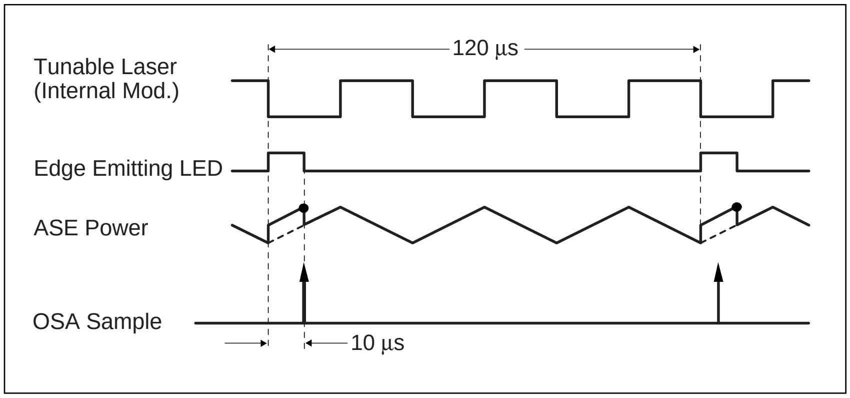


Figure 17. Noise Gain Profile Timing

The time-domain extinction technique is also a useful method to look at systems, even if the ends of the link are at different locations (Figure 18). While the signal from the transmitter side is square-wave modulated, the amplified spontaneous emission from the amplifier is not. The trigger receiver shown contains an optical coupler (10:1) and a receiver that re-creates the modulation clock.

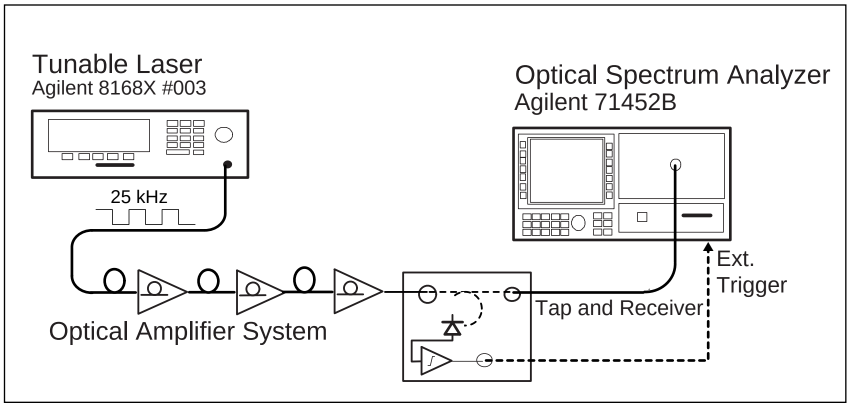


Figure 18. AC Mode Setup For Installed Systems

Depending on the ADC trigger mode and delay, it is possible to look at the combined or individual spectral components. Without any synchronization and a low VBW, the OSA measures the total average spectrum consisting of the amplified signal and the ASE. When the ADC triggers on the negative edge with 10 Ês delay time, then the trace shows only the noise (ASE) spectrum. However, when choosing the ADC AC modes, then the unmodulated ASE cancels and only the modulated signal appears. Note that the signal ampli-tude on the OSA screen is 3 dB higher in this mode. The ADC AC mode measures the full amplitude of the square wave while the low VBW measures only its average.

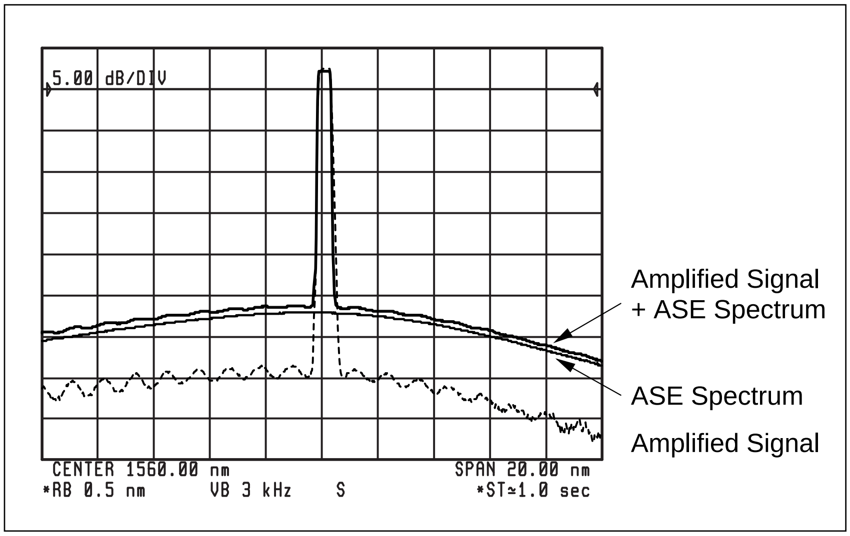


Figure 19. EDFA Output Separation

Re-Circulating Loop

In order to observe how an optical spectrum can change significantly when traveling along thousands of kilometers and through many optical amplifiers without actually building such a system, the setup in Figure 20 uses a loop technique. Typically, the loop consists of only a few EDFAs with 30 to 70 km long fibers between them, and one circulation lasts about 0.2 to 2 ms. Several circulations of a signal then simulate how that signal would behave on a very long link.

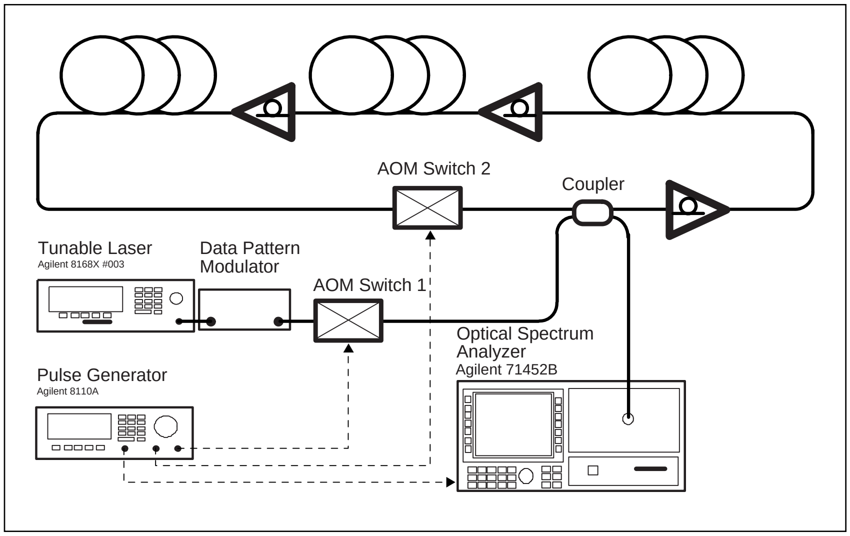


Figure 20. Re-Circulating Loop Setup

A pulse generator controls the timing. First, the acousto-optic modulator (AOM) 1 is open and AOM 2 is closed (Figure 21). At this time, the TLS in conjunction with an external modulator fills the loop with a pseudo-random bit pattern. Second, switch 1 closes and switch 2 opens allowing the pattern to circulate adequately (about 5 ms per 1000 simulated kilometers). Third, the OSA measures the spectrum at a variable delay (i.e., at a variable simulated distance). The three steps are repeated until the OSA has built a complete trace.

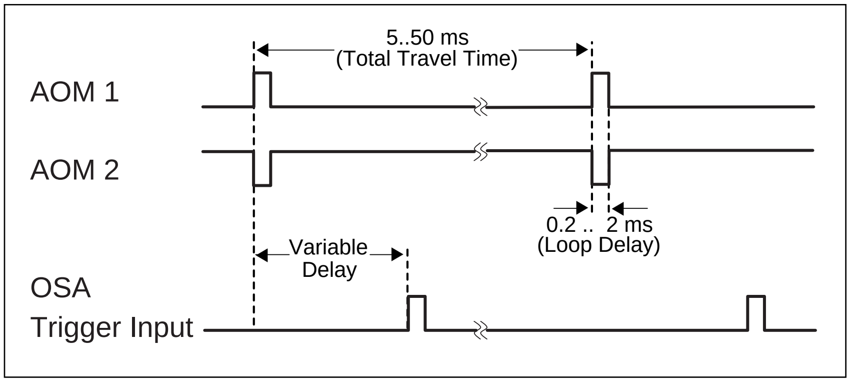


Figure 21. Re-Circulating Loop Timing

To measure the spectrum at a given distance, two trigger techniques may be used: ADC trigger or gated sweep. When using ADC trigger, the OSA samples only one data point per trigger but the time of the sampling is very well known. The OSA sweep time must exceed the total travel time times the number of trace points (e.g., 50 ms x 800 = 40 s. To allow processing overhead, choose 50 to 80 s).

When using gated sweep, the OSA keeps data samples as long as the OSA trigger is high. If the sweep time is as long as above, then the trace will be completed within one sweep. Otherwise, use MAX HOLD, so that several sweeps can close the gaps caused during the time the ADC trigger input is low. Gated sweep also provides the advantage that the OSA measures spectrum of a longer piece of the bit pattern (i.e., over the width of the gating pulse).

Under control of a remote program and by using a spreadsheet or math program, it is possible to create a three-dimensional (3-D) graph showing the signal and ASE amplitude as a function of wavelength and distance. There are two basic methods, each having their own advantages and disadvantages: scanning along the wavelengh axis, or scanning along the time axis.

Wavelength Scan

The OSA repetively measures the spectrum for subsequent variable delays. Each time the trace data is transferred to a computer which finally creates the 3-D plot (Figure 22). Because it typically takes about a minute to acquire one trace (see above), the total measurement time is in the order of M minutes (M = number of different delays, typically 10..30). The default trace length is 800, so this method provides good wavelength resolution. However, a fine distance resolution requires a large M and therefore a long total time.

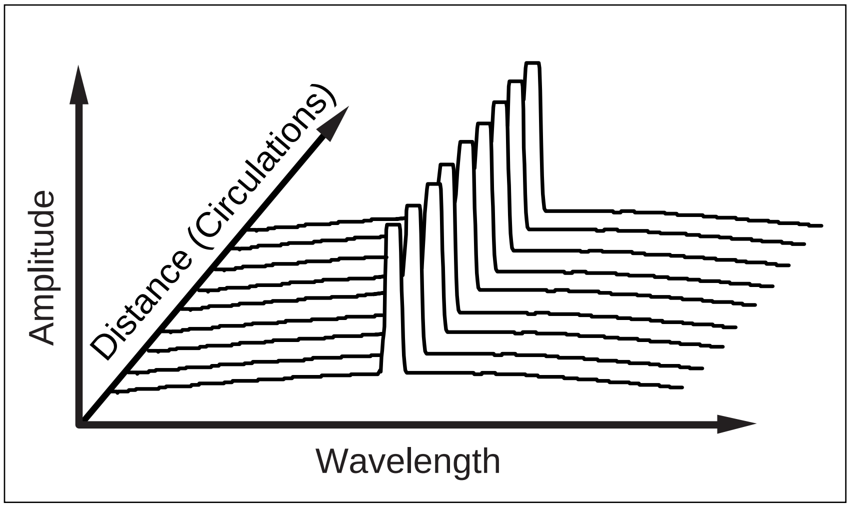


Figure 22. Three-Dimensional Loop Spectrum

<u>Time-Domain Scan</u>

When the OSA span is set to zero, then the grating behaves as a filter with fixed center wavelength. If the signal going to AOM 1 triggers a sweep, then subsequent ADC values represent the power versus time of the center wavelength of the OSA. With 50 ms sweep-time and 800 points / trace, the distance resolution is about 7.5 km[5]. This measurement has to be repeated for N wavelengths (typically 50 to 200) in order to create the 3-D plot (Figure 23). N and the span to be covered determine the wavelength accuracy. Assuming that a trace transfer to a computer lasts only few seconds, the data acquisition for this 3-D plot takes several minutes.

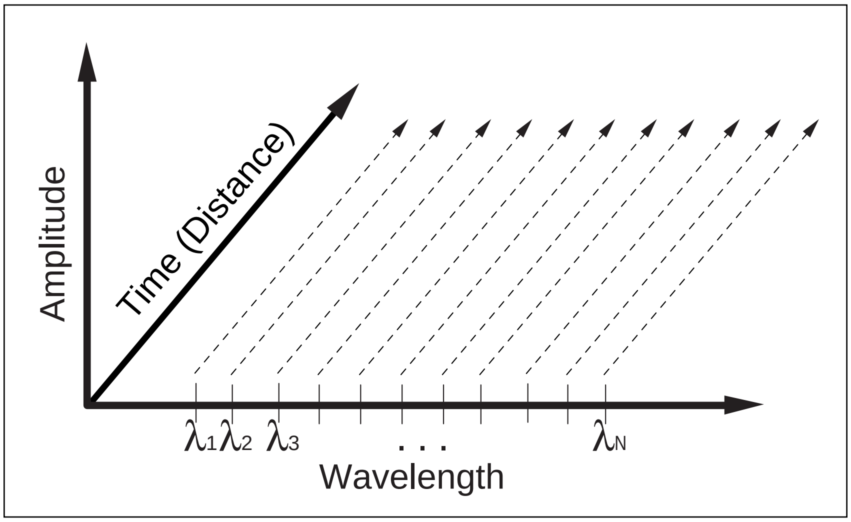


Figure 23. 3-D Scan Using the Zero Span Method

---

[5] Distance resolution = (sweep time * speed of light) / (trace length * refractive index)

Appendix

This section lists important keystroke sequences required for the examples shown. For a detailed description of these functions, see the Agilent 7145X User's Guide.

The notation below uses a bold font for **front panel keys** and a regular font for softkeys.

Always after power on and warm-up:
Provide light to the monochromator input and hit **AUTO ALIGN**.

To reset the instrument and start a new measurement:
INSTR PRESET, **AUTO MEAS.**

To define measurement ranges:
Use **START**, **STOP** or **CENTER, SPAN** to select the desired wavelength range. If necessary, adjust **RBW**, **SENS**, or **REV LEVEL**.

To use traces effectively:
MENU, Traces, CLEAR WRT A, MAX HOLD A, MIN HOLD A, STORE A / VIEW A, trace B, .. , MORE, MORE, TRACE LENGTH.

To control the sweep and video bandwidth:
MENU, BW Swp, CONT SWEEP, SINGLE SWEEP, VIDEO BW, SWPTIME. In most cases SWPTIME = AUTO works fine. Use SWPTIME MAN only to make it longer than the value calculated automatically.

To select various trigger modes:
MENU, BW Swp, MORE, TRIGGER EXT, TRIGGER FREE, .. , MORE, GATESWP ON/OFF, adc trigger, ADCTRIG POSEDGE, ADCTRIG DELAY. Lock the transimpedance when using any ADC trigger mode.

To lock the transimpedance amplifier:
MENU, Amptd, MORE, AUTORNG OFF (to keep the gain in the path determined by the reference level), TRNSZLCK ON (to lock it always into the high speed path).

To turn the current source on (OSA with option #001):
MENU, State, current source, PULSE WIDTH (set the pulse width before the duty cycle), DUTY CYCLE % (the ADC Sync Output becomes active if the duty cycle is less than 100 %), IGEN x mA (enter a positive or negative current), IGEN ON.

To turn on the ADC Sync Output (OSA without #001):
MENU, State, sync out, PULSE WIDTH, DUTY CYCLE %.

To watch the VBW as a function of the ***REV LEVEL****:*
MENU, Amptd, LOG dB/DIV, MORE, AUTORNG OFF, BW Swp, VID BW Auto.

To analyze the spectrum of a LED, Fabry-Perot or Distributed Feedback Laser:
USER, LED or FP or DFB

For more information about Agilent Technologies test and measurement products, applications, services, and for a current sales office listing, visit our web site,

www.agilent.com/comms/lightwave

You can also contact one of the following centers and ask for a test and measurement sales representative.

United States:
Agilent Technologies
Test and Measurement Call Center
P.O. Box 4026
Englewood, CO 80155-4026
(tel) 1 800 452 4844

Canada:
Agilent Technologies Canada Inc.
5150 Spectrum Way
Mississauga, Ontario
L4W 5G1
(tel) 1 877 894 4414

Europe:
Agilent Technologies
Test & Measurement
European Marketing Organization
P.O. Box 999
1180 AZ Amstelveen
The Netherlands
(tel) (31 20) 547 2000

Japan:
Agilent Technologies Japan Ltd.
Call Center
9-1, Takakura-Cho, Hachioji-Shi,
Tokyo 192-8510, Japan
(tel) (81) 426 56 7832
(fax) (81) 426 56 7840

Latin America:
Agilent Technologies
Latin American Region Headquarters
5200 Blue Lagoon Drive, Suite #950
Miami, Florida 33126, U.S.A.
(tel) (305) 267 4245
(fax) (305) 267 4286

Australia/New Zealand:
Agilent Technologies Australia Pty Ltd
347 Burwood Highway
Forest Hill, Victoria 3131, Australia
(tel) 1-800 629 485 (Australia)
(fax) (61 3) 9272 0749
(tel) 0 800 738 378 (New Zealand)
(fax) (64 4) 802 6881

Asia Pacific:
Agilent Technologies
24/F, Cityplaza One, 1111 King's Road,
Taikoo Shing, Hong Kong
(tel) (852) 3197 7777
(fax) (852) 2506 9284

Printed in U.S.A. 9/00
5964-6416E

Agilent Technologies
Innovating the HP Way