

Development of Pulse Optical Spectrum Measurement Technology using Time Averaging

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[Summary]

Operators face continuing demand for higher network speeds due to the spread of teleworking, online entertainment etc. The high optical output of high-bit-rate LD chips supporting faster networks causes heat-generation issues at manufacturing inspection tests. There is increasing demand for spectrum measurement of optical pulse to solve this issue, but conventional methods do not permit both stable results and short test times. We have developed a stable and fast optical pulse spectrum measurement technology using a time averaging method with the Optical Spectrum Analyzer MS9740B.

1 Introduction

Recently, higher-output and higher-reliability Distributed FeedBack Laser Diodes (DFB-LD) are being investigated for applications in data-center high-bit-rate optical transceivers, optical-sensing light sources, Light Detection And Ranging (LiDAR), etc.

These high-output DFB-LD are evaluated using optical spectrum analyzers (OSA) but the increasing temperature of the LD chip while emitting light causes changes in the spectrum characteristics, such as wavelength drift and lower optical power level (Figure 1).

As a result, pulsed light measurement is used as a method to suppress rising LD chip temperature when evaluating peak wavelength, peak power, Side Mode Suppression Ratio (SMSR), etc.

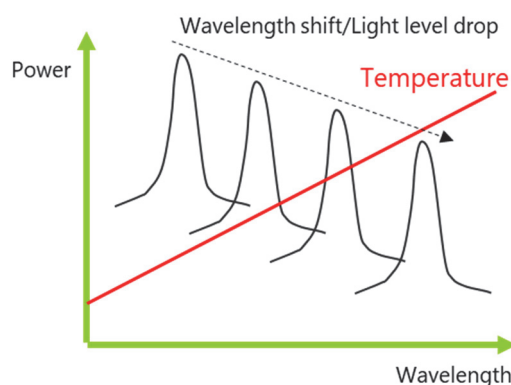


Figure 1 Changes in Spectrum Characteristics with LD Chip Temperature

Unlike Continuous-wave (CW) emission, increases in LD chip temperature can be controlled by emitting light periodically by turning the driving current on and off alternately (Figure 2).

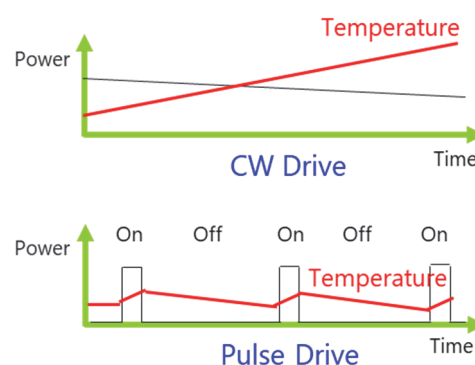


Figure 2 Change in LD Chip Temperature at CW and Pulse Driving

As future LD outputs become higher, this pulsed light emission will probably be essential when testing and evaluating optical spectrum characteristics. In particular, more accurate and faster SMSR testing at LD chip manufacturing inspection will be increasingly important in productivity improvement.

2 Optical Pulse Test Methods

There are three optical pulse test methods: external trigger, peak hold, and time averaging. Table 1 lists the advantages and disadvantages of each.

• External Trigger Test Method

Measures optical spectrum by synchronizing with emitted light timing

• Peak Hold Test Method

Measures optical spectrum by capturing maximum power within a constant period interval without requiring trigger signal

• Time Averaging Spectrum Test Method

Measures optical spectrum by averaging data captured over a constant period interval without requiring trigger signal

Table 1 Comparison of Optical Pulse Test Methods

Measurement Method	Advantage	Disadvantage
External Trigger	High-reproducibility measurement by synchronizing to optical pulse Supports peak power measurement	Long measurement time because requires repeated control and driving of diffraction grating in OSA
Peak Hold	Does not require trigger signal Supports peak power measurement	Increases noise level by holding of peak signal
Time Averaging Spectrum	Does not require trigger signal Fast stable measurement of optical spectrum by controlling measurement to optimize optical pulse	Cannot measure peak power but measures average power because uses additive averaging processing

3 Development of Spectrum Measurement Technology using Time Averaging Method

3.1 Need for OSA at LD Chip Manufacturing Inspection

LD manufacturing inspection requires productivity improvement by accurate and stable SMSR measurement. To meet these requirements, a pulse test method was selected because it measures SMSR quickly and stably.

3.2 Design Requirements

The important design points are listed below.

- 2.8 dB p-p SMSR reproducibility for pulses with 5 kHz-frequency and 1%-duty ratio
- Asynchronous measurement (trigger-less)
- Similar measurement time to CW light measurement
- Optimized for measurement system using MS9740B

3.3 OSA Functional Block Diagram

Figure 3 shows the functional block diagram for this system.

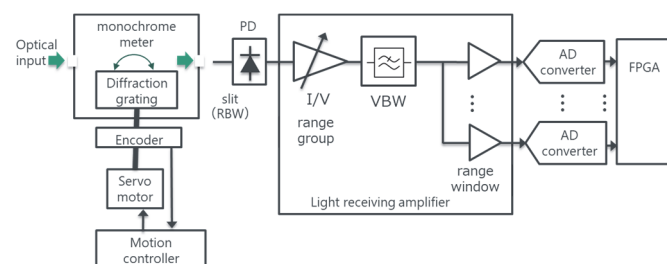


Figure 3 Optical Spectrum Analyzer Function Block Diagram

The light to be measured is diffracted by a diffraction grating and passes via a slit to a photodiode (PD) where it is O/E converted and the signal is amplified by the light receiving amplifier and is A/D converted. The measured wavelength is selected by rotating the diffraction grating.

To shorten measurement times using this developed system, the spectrum of the optical pulse is measured while wavelength sweeping (continuously variable wavelength).

Consequently, the timing of the wavelength sweeping and the asynchronous optical pulse measurement timing must be controlled.

Moreover, to shorten the measurement time also when using the light receiving amplifier, the simultaneous A/D conversion configuration with a wide level range (range window) is applied, which adjusts the signal gain (range group) depending on the power of the measured light.

3.4 Software Processing

Figure 4 shows the relationship between the pulse signal and averaging range. In the averaging range, values of the averaging points, which are specified by the software, are obtained and averaged for each period of reading the AD values (this is the averaging window).

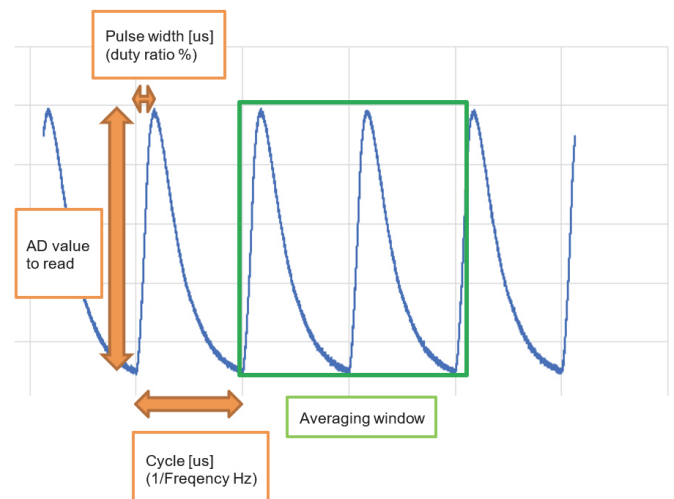


Figure 4 Relationship between Pulse Signal and Averaging Window

The number of averaging points is determined as the pulse period multiplied by an integer divided by the AD reading period. For example, the sampling interval is 4 μ s considering the sampling processing time per point when the measured light pulse cycle is 200 μ s (5 kHz pulse cycle), the pulse is 2 μ s (1% duty), and the VBW is 1 kHz.

The sampling time is set to be equivalent to the light pulse period multiplied by an integer, as shown in Figure 5, to shorten measurement time. In this time, we set the sampling time so that the number of averaging points (=100) was equivalent to two pulse period.

$$\text{Number of averaging points} = \frac{\text{Pulse cycle integer multiple time}}{\text{AD read cycle}}$$

Figure 5 Averaging Point Count Calculation

To minimize the times to switch the light receiving amp range to quickly measure a wide level range, the light receiving amp is configured for measuring a level range of 50 dB simultaneously and a range group that switches the range window in six steps with the difference of 10 dB, depending on the input level. Figure 6 shows the relationship between the range window and range group. This enables high-speed measurement from +10 to -90 dBm.

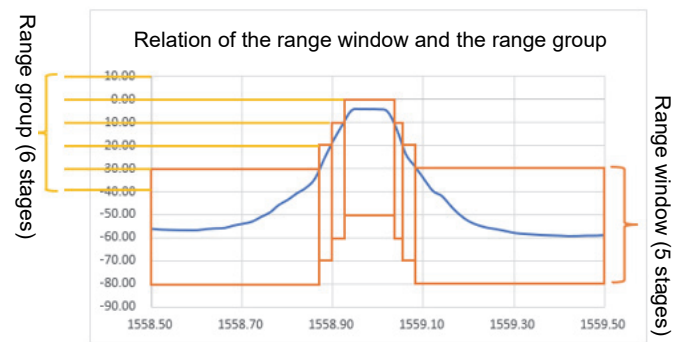


Figure 6 Relationship between Range Window and Range Group

To capture measurement data in the optimum range window, the average and maximum levels can be captured from the multiple sampling data at each measurement point, and the optimum level is determined based on the maximum level.

Obtaining process of the average (mean) and maximum level values are accelerated by a Field Programmable Gate Array (FPGA).

Additionally, we added a function for switching the Pulse Mode On/Off with the GUI. Figure 7 shows the setting screen when this option is enabled and Figure 8 shows the waveform display screen.

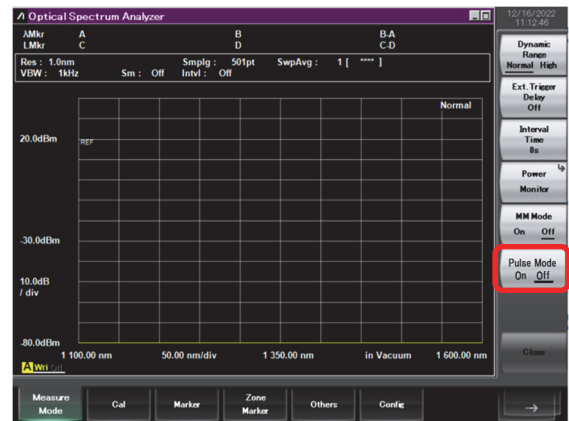


Figure 7 Added Pulse Mode Function

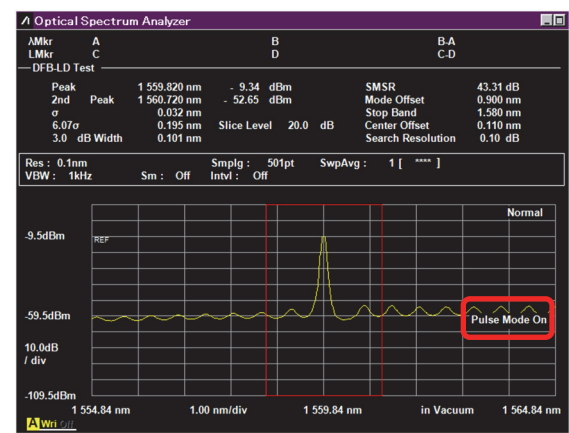


Figure 8 Waveform Display Screen

Based on the above functions, users can use the Pulse Mode just by updating the firmware version and by purchasing the option, without adding any hardware.

3.5 Time Averaging Processing using FPGA

Time averaging processing is handled by the FPGA. As shown in Figure 9, time-averaged sampling values are derived by averaging multiple AD data points obtained at a shorter cycle compared to the sampling points forming the total waveform (the measured optical signal level digital data value from the A/D converter is called AD data).

AD data points are used to average multiple points around a target sampling point on the time axis. For example, the temporal interval between AD data points is 4 μs and 100 points are averaged, as described in section 3.4. Under the measured pulse light conditions given in section 3.4, the two cycles of pulsed light shown in Figure 4 will be contained in the averaging window shown in Figure 9.

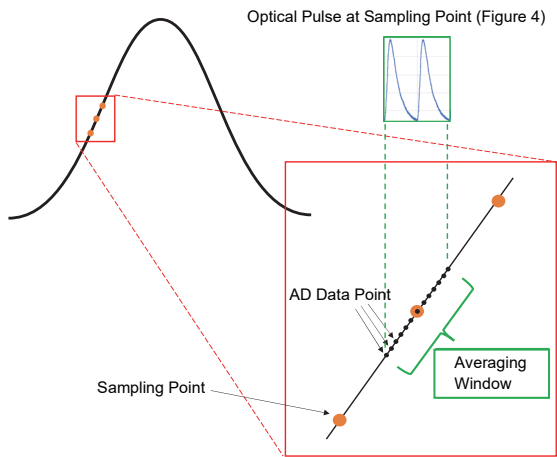


Figure 9 Time Averaging Schematic

The following section explains the FPGA operation for implementing the above-described operation.

As shown in Figure 10, the FPGA is composed of internal RAM for saving AD data points as well as RAM Controller and Calculation Process modules. The firmware handles the various settings for averaging processing.

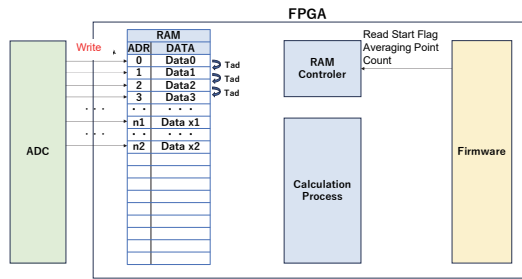


Figure 10 FPGA Internal Operation 1

Regardless of the firmware operation, the FPGA always reads values from the A/D converter at a fixed cycle T_{ad} and saves the result to RAM. The RAM uses a ring buffer structure and replaces the oldest data with latest data when it is full. Instead of using firmware timing, the FPGA independently writes AD data from the A/D converter to RAM, which enables the use of old saved AD data for averaging when a request for a data of a sampling point is received from firmware.

At the waveform sampling point acquisition timing, the RAM Controller receives information about the start flag and the number of averaging points from firmware. The RAM Controller then checks the address storing the latest AD data point at that point ($n2$ in Figure 10), and watches and waits until subsequent AD data points equal to half of the number of averaging points are added from the ADC.

Figure 11 shows the operation after the data write wait. Reading RAM starts when the write wait until address $n3$

ends. The data at the address $n1$ ($n2 - \text{averaging point count} \div 2$) to $n3$ ($n2 + \text{averaging point count} \div 2$) are read sequentially and transferred to the Calculation Process module. The Calculation Process module sums up the transferred data and the value is divided by the averaging point number, resulting in the average value. Additionally, the maximum value is also extracted from the data read from RAM. Both the calculated average and maximum values are passed to firmware and the maximum value is used for ranging processing by the firmware.

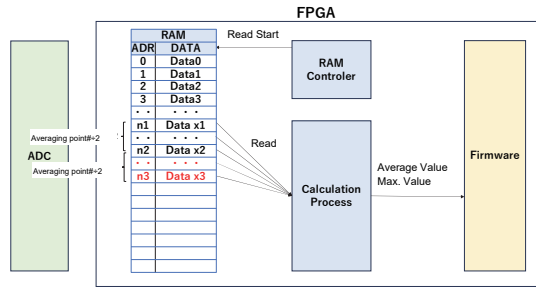


Figure 11 FPGA Internal Operation 2

Based on the above operation, averaging of multiple points in the temporal range around the sampling point is performed.

We consider the reason why the AD data points before and after the sampling points are averaged, from the perspective of processing time and the error between the theoretical value of the sampling points.

Table 2 compares the three methods: the AD data points for averaging are all before the sampling point, are all after that, and both before and after that.

Table 2 Advantages and Disadvantages Depending on AD Data Point Position Relative to Sampling Point

	AD Data Point for Averaging	Processing Time	Deviation from Theoretical Value
A	Before sampling point	○	△
B	After sampling point	×	△
C	Both before and after sampling point	△	○

From the viewpoint of FPGA operation, when the request of averaging comes from the firmware on reaching the sampling point, addition of data after the sampling point requires waiting time to write from the A/D converter to RAM. Consequently, using AD data only before the sampling point is fastest because no wait time is required. Conversely, using AD data only after the sampling point requires more time

because it is necessary to wait just for the averaging point number. When using AD data both before and after the sampling point, the processing time is midway between the other two methods because the averaging point number to be waited is half. Figure 12 compares the processing for each method when the sample number is n .

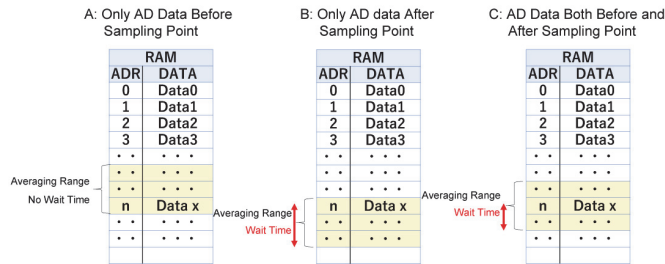


Figure 12 Processing Time Comparison

From the viewpoint of deviation from the theoretical value, although it depends on the averaging point number, the error rate is lowest compared to the theoretical value of the target sampling point's average power when the AD data is centered around (before and after) the original sampling point. When the AD data is either only before or after the sampling point, the average power is lower or higher than the theoretical value, compared to the first case. Therefore, the error is thought to be larger. Figure 13 depicts the comparison of the error from the theoretical value for each method.

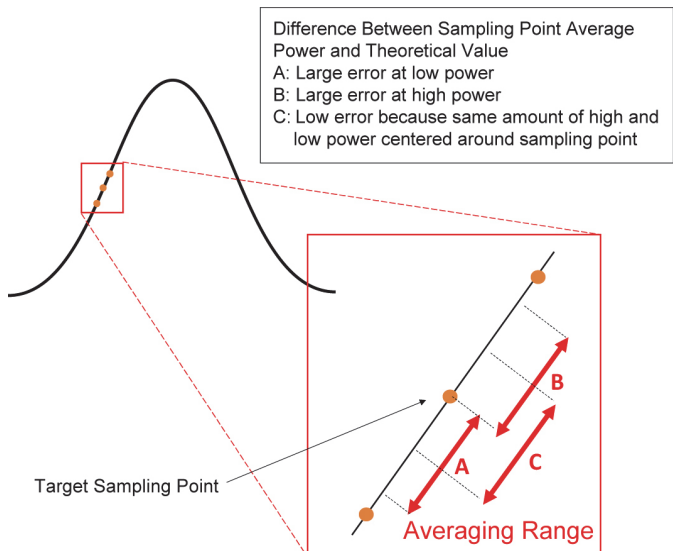


Figure 13 Sampling Point Average Power Theoretical Error Comparison

We adopted the type-C sampling method (AD data both before and after sampling point) in Table 2 because it satisfies both reasonable processing speed and low error rate.

4 Results

Table 3 and Figure 14 show the results with the time averaging method, as well as the conventional external trigger and normal sweeping measurement methods. SMSR stability was higher for the time averaging method than the normal sweeping method, and the measurement time was faster than the external trigger method. We confirmed the improved stability and measurement time with the time averaging method.

Table 3 Comparison of Time Averaging and Conventional Test Results

Optical Pulse Test Method	SMSR Value [dB]	SMSR Stability [dBp-p]	Measurement Time [s]
Time Averaging	44.00	0.31	0.482
External Trigger	43.94	0.10	1.172
Normal Sweep	31.92	46.82	0.450

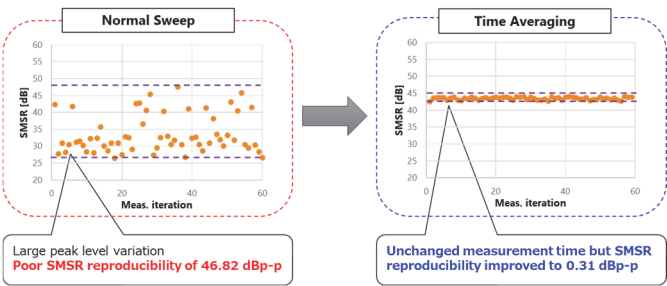


Figure 14 Comparison of Time Averaging and Normal Sweep SMSR Stability

5 Conclusions

Due to increasing demand from manufacturers for optical pulse measurements supporting high-output optical transceivers for faster and larger-capacity communications, we developed an optical pulse measurement technology using the time averaging method to support fast, stable optical spectrum measurements.

In the future, we aim to help optical network development by further improving optical pulse measurement methods.

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