81910A Photonic All- parameter Analyzer

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Preliminary Product Note

Abstract

Fiber optic network technology is taking a big step forward with the tremendous transmission capacity offered by dense wavelength-division multiplexing (DWDM). These developments bring new challenges to the testing of today's passive optical components as it is not sufficient to test devices for loss only, but also for their phase or dispersion properties.

The 81910A Photonic All-parameter Analyzer tests and measures components and modules for Insertion Loss, Polarization Dependent Loss, Group Delay, and Differential Group Delay.

This product note is intended to introduce the product's basic concepts and features.

Agilent Technologies

Introduction

Today DWDM is the fiber optic method of choice for cost-effective data transfer. Prospects to satisfy the increasing demand in bandwidth is either to move to higher network speeds, narrower channel spacing, or both.

Testing of fiber optic components for DWDM applications has become increasingly challenging.

- Channel spacing has constantly reduced and has driven a demand for new test parameters, as polarization dependent loss or dispersion.
- Higher data transfer rates force the manufacturers to design and manufacture closer to physical limitations.
- Beside that, the huge demand for fiber optic components is forcing manufacturers to optimize their production strategy. Thus, easy test setup and reduced test times are main drivers in the market.

During this evolution path it turned out that it is no longer sufficient to test optical components for loss only but that precise characterization and control of the dispersion properties of all devices becomes mandatory.

For an detailed description of definition and physical origin of Loss and Polarization Dependent Loss (PDL) as well as Group Delay (GD) and Differential Group Delay (DGD), we refer to related literature [1, 2, 3].

The philosophy behind the 81910A Photonic All-parameter Analyzer

As networks move to 10 Gbps and beyond, run time properties of the signal become important and all components must fulfil stringent requirements for four parameters: Insertion Loss (IL) and Polarization Dependent Loss (PDL), but also Group Delay (GD) and Differential Group Delay (DGD). Up to now the measurement of loss and delay (dispersion) was treated as separate tasks and addressed by separate solutions [3].

Today, components can lead to system penalties or even failure by not meeting specifications of any of the four parameters.

The 81910A Photonic All-parameter Analyzer is designed to have an instrument which allows for precise characterization of all relevant device parameters equally important, not only for a subset or with focus on a single parameter (see Figure 1). In addition, this should be possible in a single setup using just a single connection in order to minimize test uncertainties.

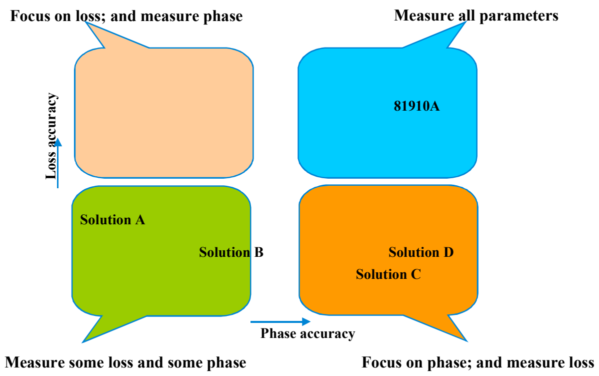

Figure 1: 81910A Photonic All-parameter Analyzer in a loss – phase accuracy specification matrix

In addition, recent research indicates that narrow-channel devices challenge today's most widely applied methods to determine dispersion properties. These limitations can be overcome by interferometric setups, especially swept homodyne interferometry [3, 4]. To address both loss and dispersion measurement properly, the 81910A Photonic All-parameter Analyzer combines a tunable laser source with low-noise output for loss measurement [5, 6] and interferomerty for measurement of dispersion properties.

The 81910A is intended to help customers that develop, test or manufacture passive optical devices and modules like Fiber Gratings, AWGs or add-drop modules. Test of all parameters is most important for 10G and 40G as well as for narrow-band components.

Measuring "all parameters"

Any modulated signal is spread over a wavelength range minimum as wide as the applied modulation frequency itself (see Figure 2). As a consequence, test of parameters characterizing a device must be considered over a wavelength range, not just at a given wavelength.

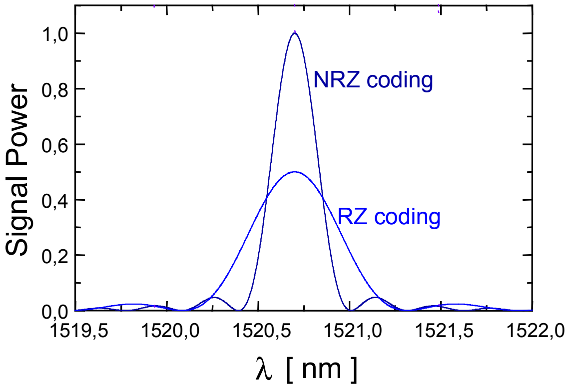

Figure 2: Signal width of a 40Gbps signal for Return to Zero (RZ) and Non-Return to Zero (NRZ) signals.

A typical device that requires "all parameter testing" is a Fiber Bragg Grating (see Figure 3). Design goal is to have a controlled response both for loss and dispersion in the relevant wavelength range of the signal. In this example, the loss trace is designed to be flat and symmetrical over wavelength but the Group Delay trace is designed to have a gradient over wavelength. This device can operate as a channel dispersion compensator with special target requirements regarding gradient and ripples of Group Delay. This example shows that for advanced modules loss and phase characteristic or closely connected. An “all-parameter” look is needed here to judge if a device is capable for use in a high-speed optical network.

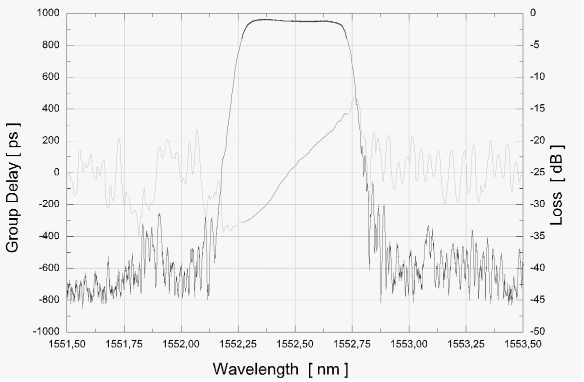

Figure 3: Insertion Loss and Group Delay of a reflected channel of a Fiber Bragg Grating.

A new innovative approach

The Agilent 81910A Photonic All-parameter Analyzer uses a new innovative method to determine dispersion properties. Within the test head the optical signals are mixed all-optically, leading to higher resolution than standard methods.

In so-called “swept wavelength homodyne interferometry” a laser source is wavelength tuned, while the arm lengths of the interferometer remain fixed (see Figure 4). One arm includes the device under test.

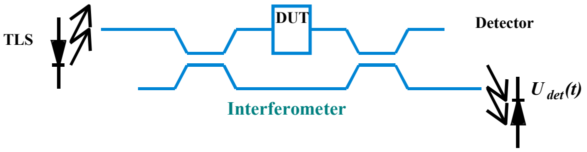

Figure 4: Principle setup for swept homodyne interferometry.

After the signal has passed the arms, the signals get combined onto a detector. Referring to Figure 4, in the detector plane an interferogram of the kind

$$P(\omega) = E_{LO}^2(\omega) + E_{dut}^2(\omega) + 2\ E_{LO}(\omega)\ E_{dut}(\omega) \cdot \cos\varphi(\omega)$$

Figure 5: Signal as function of laser frequency ω

will be observed, with E_{LO} specifying the local oscillator and E_{dut} the field amplitude that passed the DUT.

The phase information φ of the device under test can be extracted by mathematical means and translated to Group Delay.

As of today, modulation phase shift (MPS) is the standard method to measure delay and dispersion [3]. Beside some advantage in speed, the motivation to apply swept homodyne to measure delay and dispersion is to gain higher resolution. There are advantages and limitations for both methods. It is important to understand that MPS is most accurate for highest modulation frequencies; typically modulation frequencies in the range of GHz are applied. As the signal gets sinus modulated, side modes widen the signal spektrum. The offset between the main signal and the side modes is determined by the modulation frequency and can take values of 2*24pm for a frequency of 3GHz. If the dispersion properties of the device vary in a scale comparable to the modulation signal bandwidth, they can hardly be resolved. This can happen for so-called group delay ripple and at the edges of a filter passband (see Figure 6). Interferomerty can help here to resolve fine details.

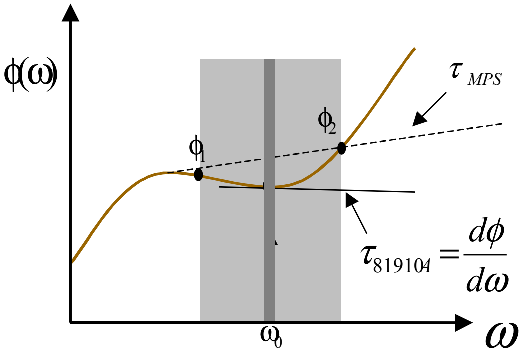

Figure 6: Resolving local Group Delay gradients by swept homodyne interferometry

As a drawback, swept homodyne interferometry in first priority is not targeted to measure long devices like fibers.

To summarize up to here, the principle of swept homodyne interferometry gives advantage for the 81910A Photonic All-parameter Analyzer to be best optimized for narrow-band components, but with a good leverage into broadband devices.

81910A Photonic All-parameter Analyzer: The setup

The complete package 81910A Photonic All-parameter Analyzer consists of a 8164A mainframe with 81640A tunable laser, a 8169A polarization controller, licensed software, accessories, a system controller and the optical test head (see front cover). Three 81634A power meters are included in the mainframe and are used for measuring loss. The system controller is used to record the phase data. It is connected to the customer’s PC by a standard interface card.

For those customers who already own equipment (81640A, 8169A), options allow an easy upgrade path to add the optical test head and software. This requires a specially calibrated laser source.

Loss: Measurement principle

The 81910A Photonic All-parameter Analyzer uses the full range of all features and capabilities to measure loss with high accuracy and highest dynamic that are supported by the 81640A laser, the 81634A power meters, and the software package [1, 5, 6]. For measurement of Polarization Dependent Loss, the Mueller - Stokes method is applied [1, 2, 3].

Dispersion: Measurement principle

As all lightwave signals travel as a group, not at a single frequency, Group Delay τ is the parameter of interest. Group Delay is closely connected to phase delay and takes the spectral neighborhood of a signal into account; so Group Delay is how phase changes with wavelength (on a very small wavelength scale), see Figure 7. Group Delay unit is time (ps).

$$\tau(\nu) = (1/2\pi) \cdot d\phi(\nu)/d\nu$$

Figure 7: Calculating Group Delay from Phase Delay derivative

In some cases Chromatic Dispersion (CD) is used to characterize a component. CD describes the slope of Group Delay versus wavelength [3] and is usually measured in ps/nm.

Differential Group Delay (DGD) is defined as the difference in Group Delay for two orthogonal input polarization states and reflects the birefringence properties of the device's material. To measure DGD two traces for Group Delay are recorded with orthogonal polarization states and subtracted (Figure 8 and 9).

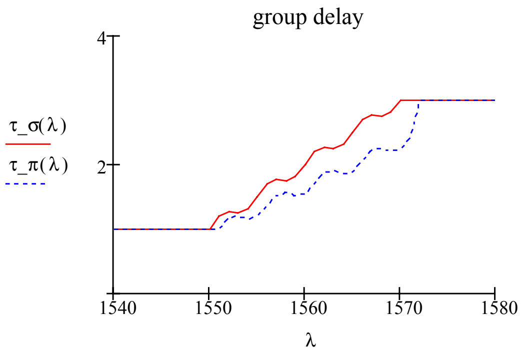

Figure 8: Measuring polarization resolved Group Delay

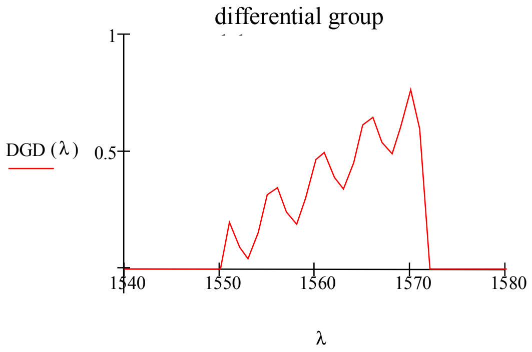

Figure 9: Calculating Differential Group Delay from polarization resolved Group Delay measurements

It is worth mentioning that PMD (Polarization Mode Dispersion) and DGD sometimes are used to describe the same phenomenon; but PMD is best used in context with fibers, as this parameter is of statistical nature. For components the DGD is best applied.

Preliminary specifications

The 81910A Photonic All-parameter Analyzer combines a power meter based approach to determine loss and an interferometer to measure phase to enable measurements with high accuracy, resolution and dynamic range. The setup allows the complete polarization resolved FBG characterization at a fast measurement time at high accuracy. A measurement accuracy of less than 50fs for Group Delay, 80fs for Differential Group Delay and 10mdB for Loss and 30mdB PDL is obtained with the current setup. Accurate Group Delay and Differential Group Delay measurements with a resolution bandwidth of 1 pm can be obtained.

Measurement examples

The initial offering of the 81910A Photonic All-parameter Analyzer is targeted to measure two-port devices in transmission and reflection; so eight traces are recorded simultaneously.

As a representative device under test we chose a Fiber Bragg Grating (FBG). Figure 10 and Figure 11 show loss measurements with 5pm resolution of a non-apodized, non-symmetric FBG in reflection and transmission mode. The grating period exhibits a slight polarization dependency causing a shift of a few pm between the loss spectra for the principal states appearing as PDL for the sharp structures. The loss values have been calculated as the average of the polarization resolved measurement [3].

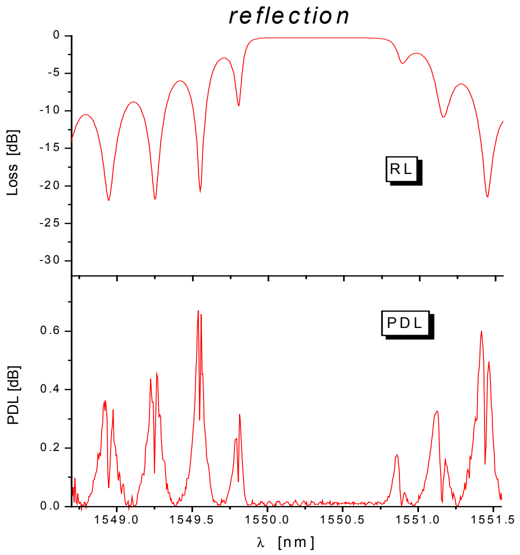

Figure 10: Loss and PDL properties of a FBG in reflection

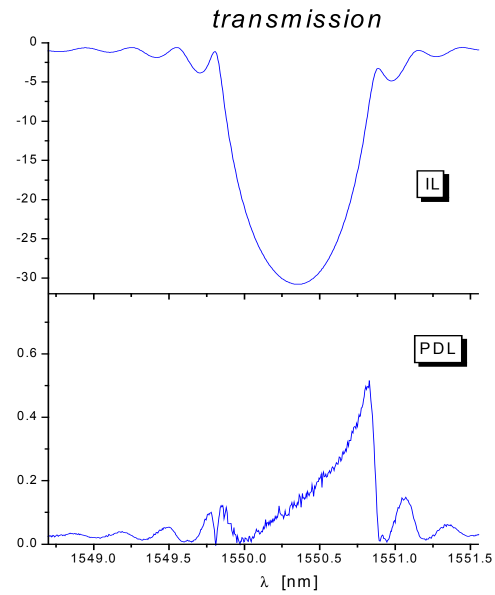

Figure 11: Loss and PDL properties of a FBG in transmission

For the phase measurement the sweep speed of the TLS is set to 40 nm/sec. Measurement time of a single sweep including numerical analysis is in the range of a few seconds. Averaging of individual traces can be used to improve SNR. The presented results use an average of ten measurements. A sliding spectral window (bandwidth β) can be applied to further reduce the noise floor. The bandwidth β can be adapted to the shape of the spectrum to minimize signal influences, but values much more below the convolution kernel of standard phase modulation methods show good results.

Group delay spectra in transmission have a smooth spectral characteristic (Figure 13). Birefringence and hence DGD is also present in transmission mode of the grating. Increasing the bandwidth β can also be used to improve the SNR.A bandwidth of 50 pm is sufficient here to resolve the spectral phase properties of the grating.

The birefringence of the grating period also causes a spectral shift of group delay spectra. GD peaks are accompanied by a sharp double-dent DGD structure with a centered minimum where the GD value is identical for both PSPs (see Figure 12). To resolve these fine DGD structures the data resolution as well as β were set to 1 pm.

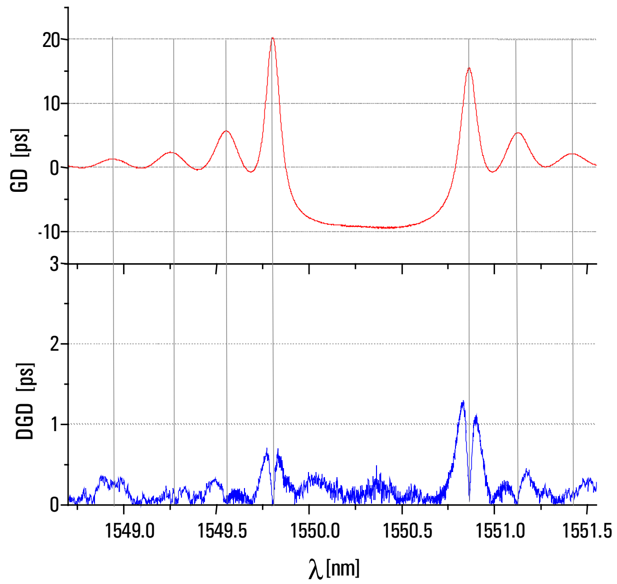

Figure 12: Group delay and DGD of the FBG in transmission (resolution 1 pm, bandwidth β = 50 pm)

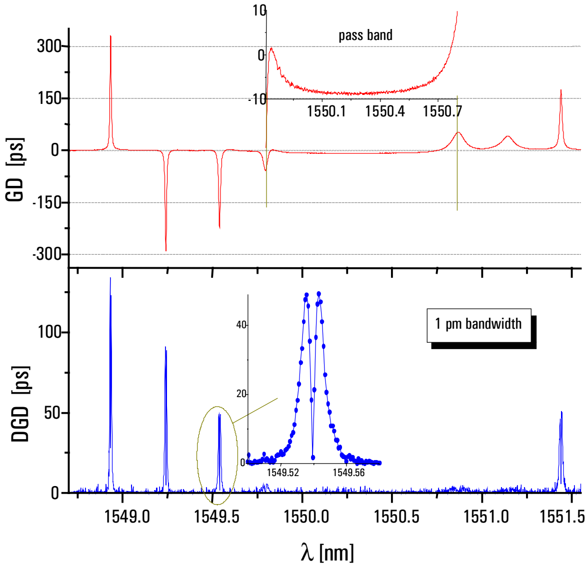

Figure 13: Group delay and DGD of the FBG in reflection (resolution 1 pm, bandwidth β = 1 pm)

Manufacturing-proof interface

The 81910A Photonic All-parameter Analyzer comes with a full-featured, easy-to-operate and ready-to-start application software featuring a graphical user interface, designed to meet the needs of the manufacturing floor. If required, the solution allows control of all kind of measurements by simple start and stop buttons provided by the application software. Based on the Photonic Foundation Library, the solution is also fully remote controllable, and can easily be integrated into common manufacturing software environments.

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Related Agilent literature:

[1] "State of the Art characterization of optical components for DWDM applications", *p/n 5980-1454E*

[2] "Polarization dependent loss measurement of passive optical components", *p/n 5988-1232EN*

[3] D. Derickson (ed): "Fiber Optic Test and Measurement", *Prentice Hall 1998*

[4] Thomas Jensen, Eckart Witzel, Alexandre Paduch, Patrick Ziegler, E.U. Wagemann, and Oliver Funke: "A new method to determine Loss, PDL, GD and DGD of passive optical components", *paper submitted for publication, NFOEC 2002*

[5] Emmerich Müller, Clemens Rück, Torsten Born, E.U. Wagemann and Edgar Leckel: "Fast and accurate determination of a tunable laser wavelength and its application to DWDM components", *paper WB 2, Optical Fiber Conference, Baltimore, March 2000*

[6] Edgar Leckel, Jürgen Sang, E.U. Wagemann and Emmerich Müller: "Impact of source spontaneous emission (SSE) on the measurement of DWDM components", *paper WB 4, Optical Fiber Conference, Baltimore, March 2000*

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