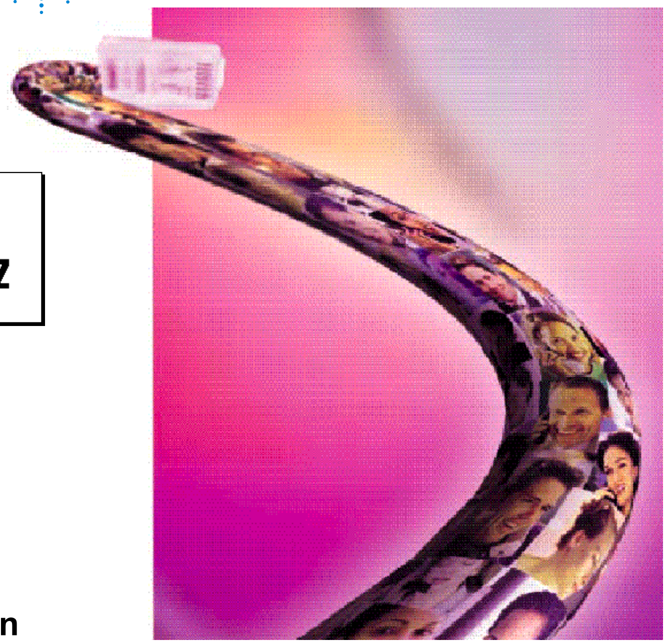
•Slides 1-9: Industry Buzz

•Slides 10-66: eSeminar - Optical Components

Agilent Technologies



THE 40G INDUSTRY BUZZ

May 7, 2002

presented by:

Larry DesJardin

THE 40G Industry Buzz

- Industry Update & Commentary
- "Late Breaking News" from Agilent
- Viewer Poll & Feedback

THE 40G Industry Buzz

- ***Industry Update & Commentary***
- **“Late Breaking News” from Agilent**
- **Viewer Poll & Feedback**

Industry Update and Commentary

SFI-5 Specification Status

- OIF Specification
- Status of Balloting
- Next Steps

Agilent Technologies

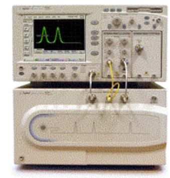
THE 40G Industry Buzz

- **Industry Update & Commentary**
- ***"Late Breaking News" from Agilent***
- **Viewer Poll & Feedback**

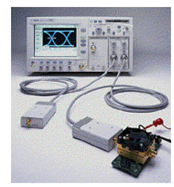
Late Breaking Agilent News

New Communication Analyzer Products:

- **Agilent 86119A Optical Sampler>500Ghz BW,**
  - **Pure optical sampling for breakthrough performance**
  - **>500Ghz BW, <200fs jitter**
  - **For 40Gb/s and 160Gb/s systems**



- **Agilent 86118A Dual 60+ Ghz Remote Head**
  - **>60Ghz Electrical BW**
  - **Small, lightweight housing**
  - **High fidelity time-domain response**



Agilent Technologies

THE 40G Industry Buzz

- **Industry Update & Commentary**
- **“Late Breaking News” from Agilent**
- ***Viewer Poll & Feedback***

Agilent Technologies

Viewer Poll and Feedback

In 40Gb/s systems, CD and PMD issues are...

a) **Easily solvable using today's methods.**

b) Solvable but require next generation components and measurement techniques.

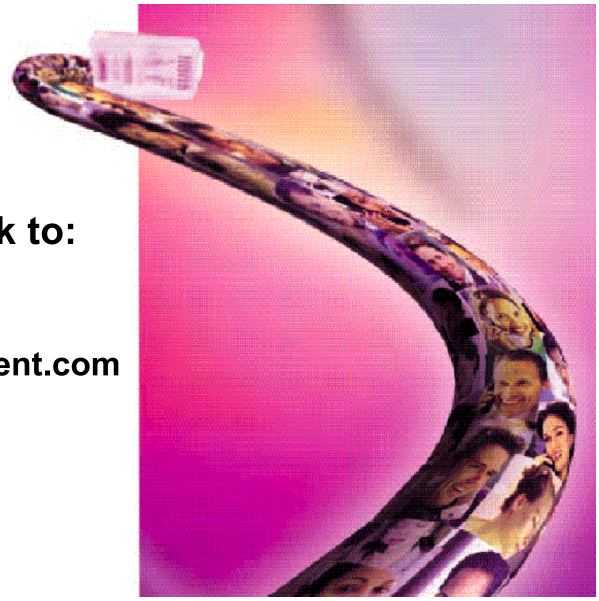
c) Very difficult, requiring a breakthrough.

Agilent Technologies

THE 40G
INDUSTRY BUZZ

Send any feedback to:

larry_desjardin@agilent.com



Agilent Technologies

Leading-edge Techniques for Testing Advanced Optical Components

May 7th, 2002

presented by:

Ulrich Wagemann
Gunnar Stolze

Welcome to the presentation "Leading Edge Technologies for testing Advanced Optical Components" My Name is Gunnar Stolze, and with me is Ulrich Wagemann who will present the second part of this presentation.

Outline

- Network Evolution- The Need for Breakthroughs in Testing Components
- Review of Loss and Dispersion Parameters
- Measuring Loss and PDL
- Today’s Challenges for Loss and Dispersion Test
- A New Method: Swept Homodyne Dispersion Measurements
- All Parameter Test: Swept Loss and Dispersion Test

Agilent Technologies

The presentation gives an overview on the Network Evolution, and the consequences for component test solutions. We are reviewing the different parameters that a component is characterized for, namely loss and dispersion parameters. Then, we will discuss loss and PDL measurement principles to test optical components.

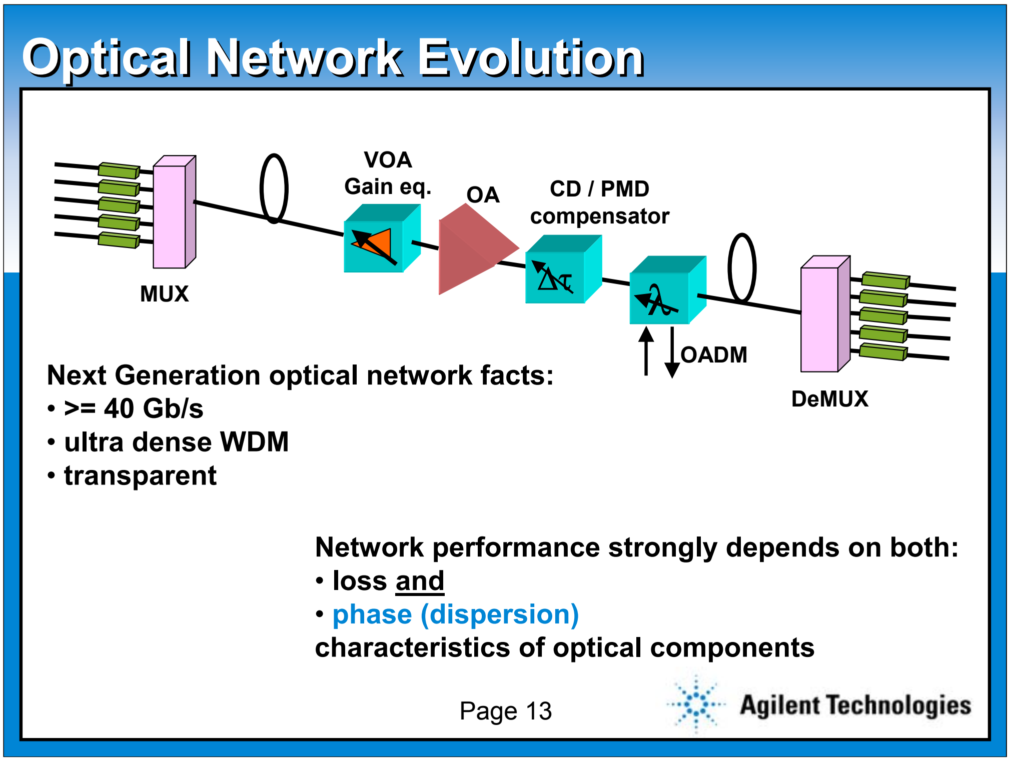
Recently, measuring loss and dispersion properties of most advanced optical components has become more and more important. The challenges associated with loss and dispersion measuremens are discussed. Afterwards, a new method for measuring dispersion of optical components, called swept homodyne method is introduced. Last but not least, we will talk about testing all parameters, meaning loss and dispersion parameters, of optical components.

Evolution of optical network industry

- This section describes
  - Parameter evolution of optical networks
  - Implications of network evolution
  - Test System Evolution (Test Content, Cost of Test)

Agilent Technologies

Let’s start with having a look at the network evolution. This section describes the parameter evolution of optical networks and the implications for optical components, and finally, for test solutions.



On slide 4, we see a typical scheme of a point to point optical network, including some of the most advanced components that recently emerged.

Despite, or because of the current economic situation, optical networks evolve in several directions:

- higher bit rates (40GBit and beyond)

- tighter channel spacings (25GHz and below)

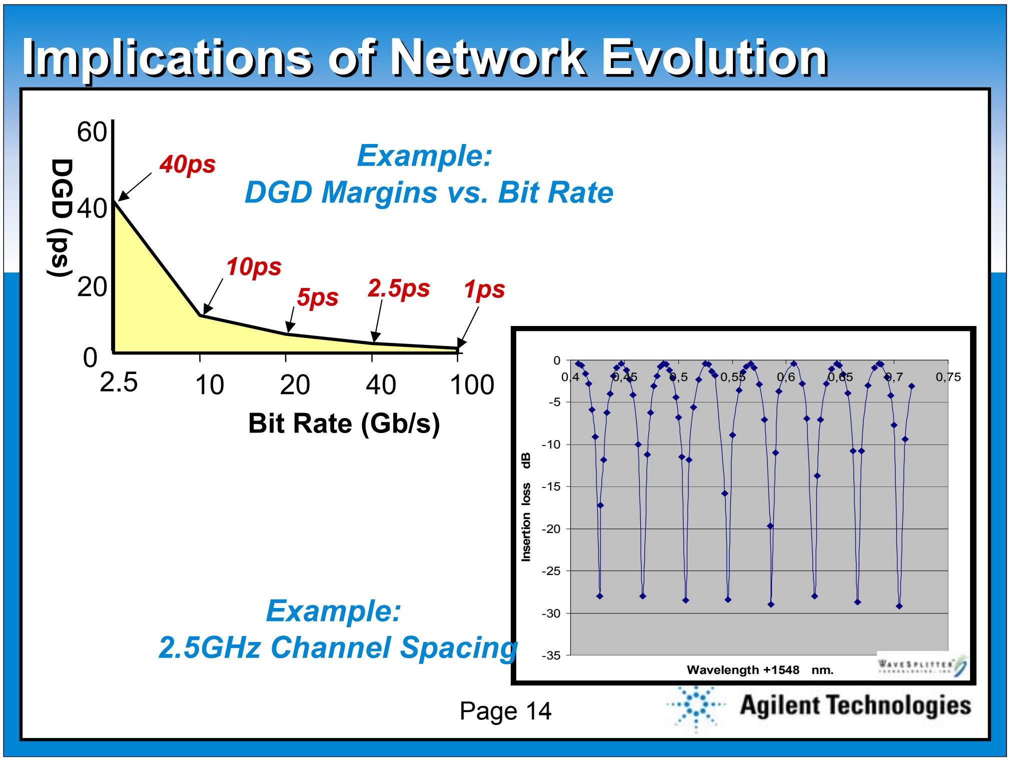
- different wavelength bands (S, E, O bands)

- longer reaches with less optical amplifiers or regenerators.

The main motivation behind these developments is to reduce cost per bit.

These developments, especially the move to higher bit rates or closer channel spacings, imply that network performance depends not only on loss anymore, but on loss *AND* dispersion throughout the network link.

It should be mentioned at this point, that one must chose as with higher modulation frequencies the optical signals become wider in wavelength.

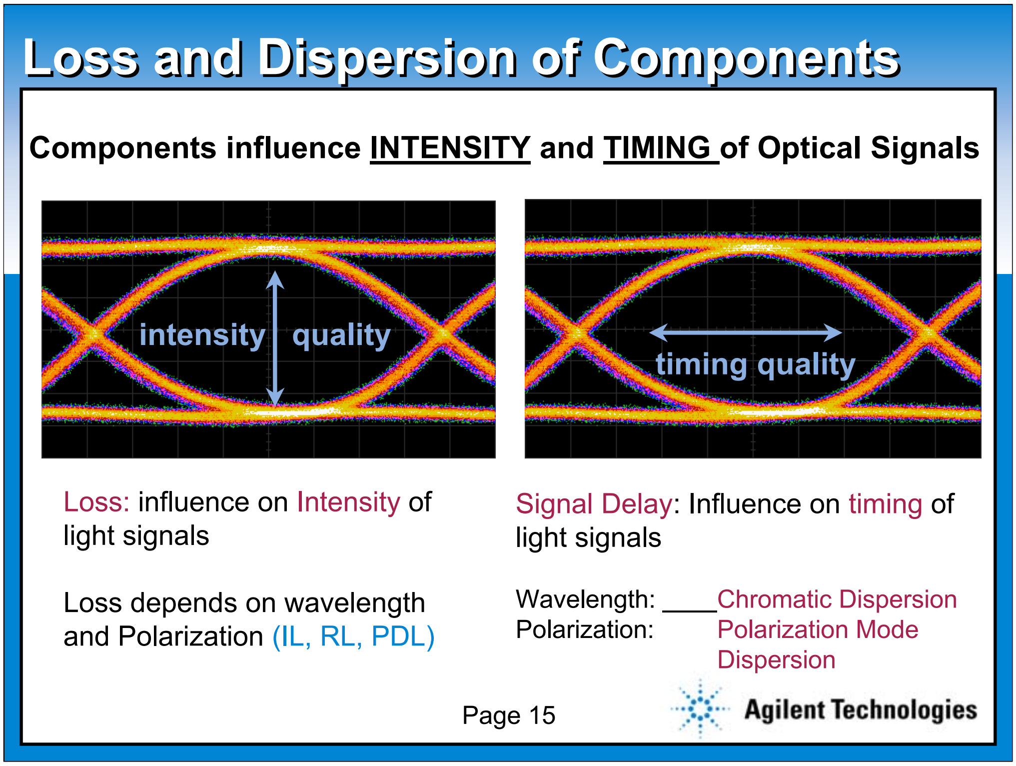


On slide 5, the implications of the network evolution are demonstrated on two examples.

The graph on the left hand side denotes the allowable differential group delay, or PMD, of optical signals, depending on the bit rate. As can be seen, as the bit rate increases, the allowable differential group delay drastically reduces. As PMD has been of little concern for 2.5GBit transmission systems, it has become a major concern for system designers for 10G, 40G and higher bit rates. Therefore, optical components must be tested for their contribution to dispersion, namely chromatic dispersion and PMD.

The picture of the right hand side shows a channel grid with a spacing of 2.5GHz. Even though being far from implementation, this example demonstrates what is possible, and what is currently done in R&D labs.

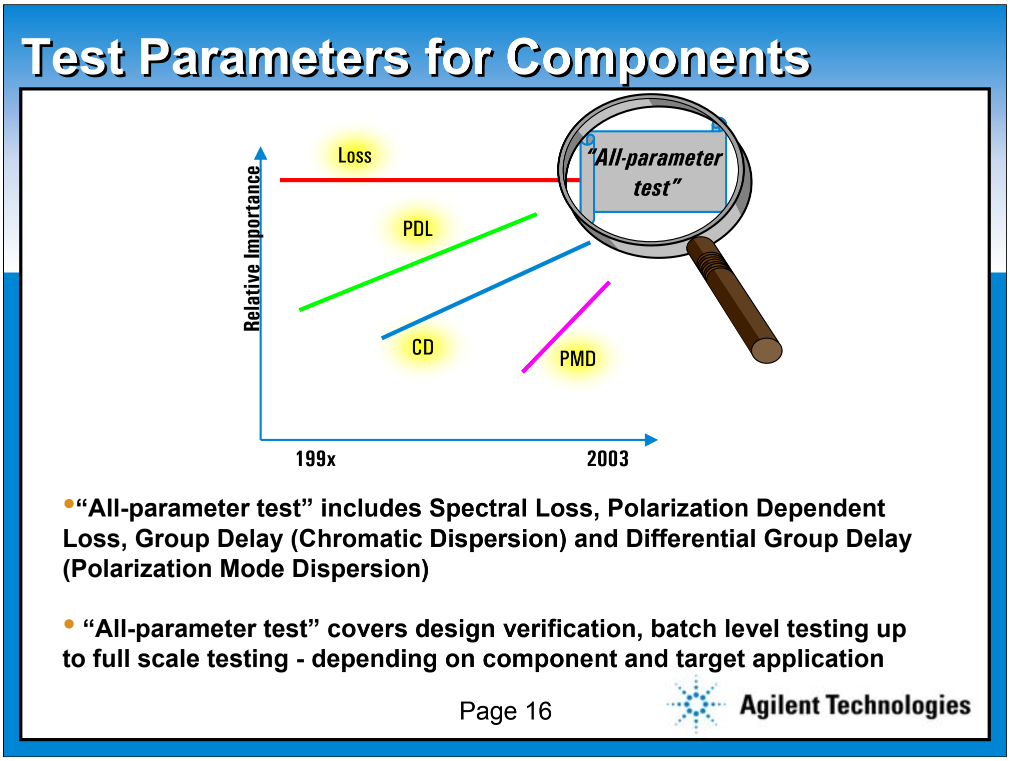
These developments have direct implications for testing optical components. Test solutions for components and system are at the very end of the optical network food chain. Hence, the requirements set by the optical networks on components are directly converted into tough challenges for optical test solutions. On the other hand side, meeting these challenges enables the next generation optical networks, as components can be tested as required. One example of this is the need to test for loss and dispersion, in a cost effective, fast and accurate manner.



On slide 6, the effects of optical components on signal intensity and timing are demonstrated by means of an eye diagram. The intensity quality is determined by the height of the eye diagram, their timing quality by the width of the eye. If one or the other have been severely impacted by optical components, the tranmission quality degrades dramatically, resulting in a higher bit error rate.

Both loss and dispersion properties of optical components are wavelength and polarization dependent. The polarization dependence of the loss is called PDL, of dispersion it is called differential group delay, or Polarization Mode Dispersion. The wavelength dependence of the dispersion is called Relative Group Delay, or Chromatic Dispersion.

We will discuss all of these parameters in greater details later on.

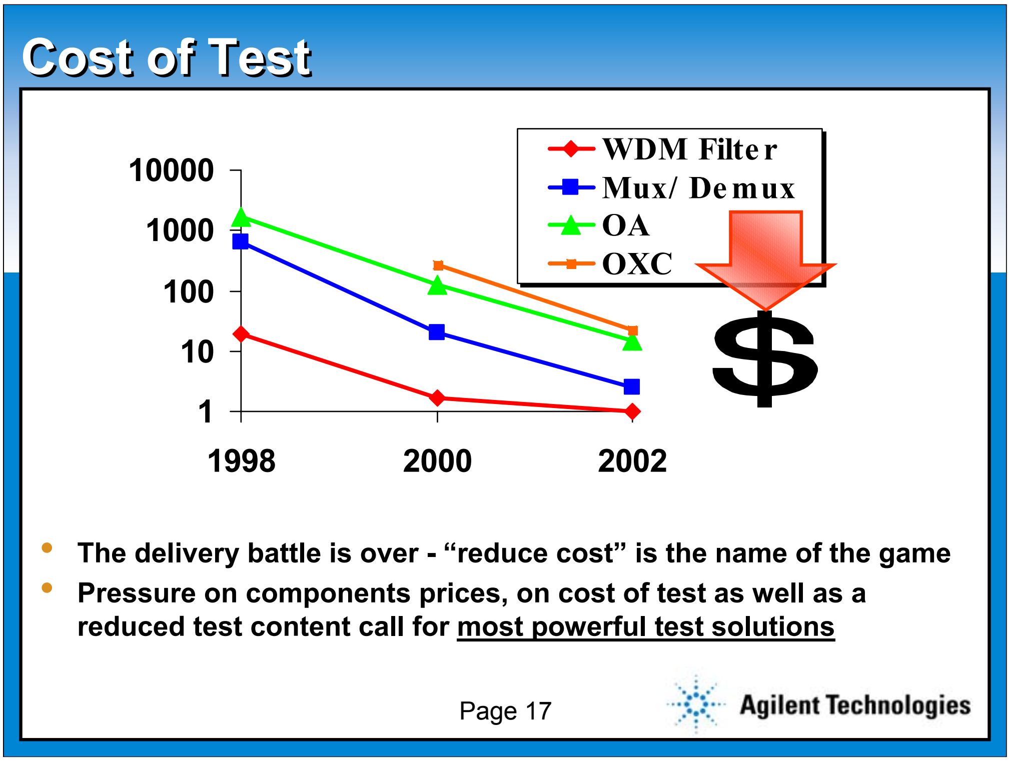


On slide 7, the need to test more parameters than just insertion loss is shematically shown.

Optical components are always tested for their loss. For wavelength dependent components, such as optical filters, multiplexers etc., spectral loss measurements determine higher order parameters that evaluate the quality of the optical filter, such as filter shape, bandwidth, crosstalk or passband ripple. Measuring loss is still the most important parameter to measure.

Because Polarization is not constrained in optical networks, polarization dependent loss or PDL has become more and more important. The PDL represents the influence of Polarization on the loss properties of optical signals. Higher order parameters of optical filters such as bandwidth, passband ripple or crosstalk are also Polarization dependent. For a throrough analysis of these, the Polarization influence must be included.

With the evolution to higher bit rates and narrower channel spacings, the determination of the dispersion properties, namely chromatic and Polarization mode disperion, is more and more important. This does not mean that loss and PDL are not evaluated anymore. It rather means that optical components must be characterized for their loss AND dispersion properties in the future. Such a test is called the all-parameter test.



Slide 8.

At the same time as test content increases, and more complex optical components emerge, component prices drop. Reducing the cost of everything is the name of the game throughout the entire industry. In the context of optical component test, reducing the cost of test is key. In the past, the test cost has been as much as 40% or more of the overall component price. With the increased complexity of components, the higher test content required for most advanced optical components, and the need to reduce test cost, new test methods and solutions are required.

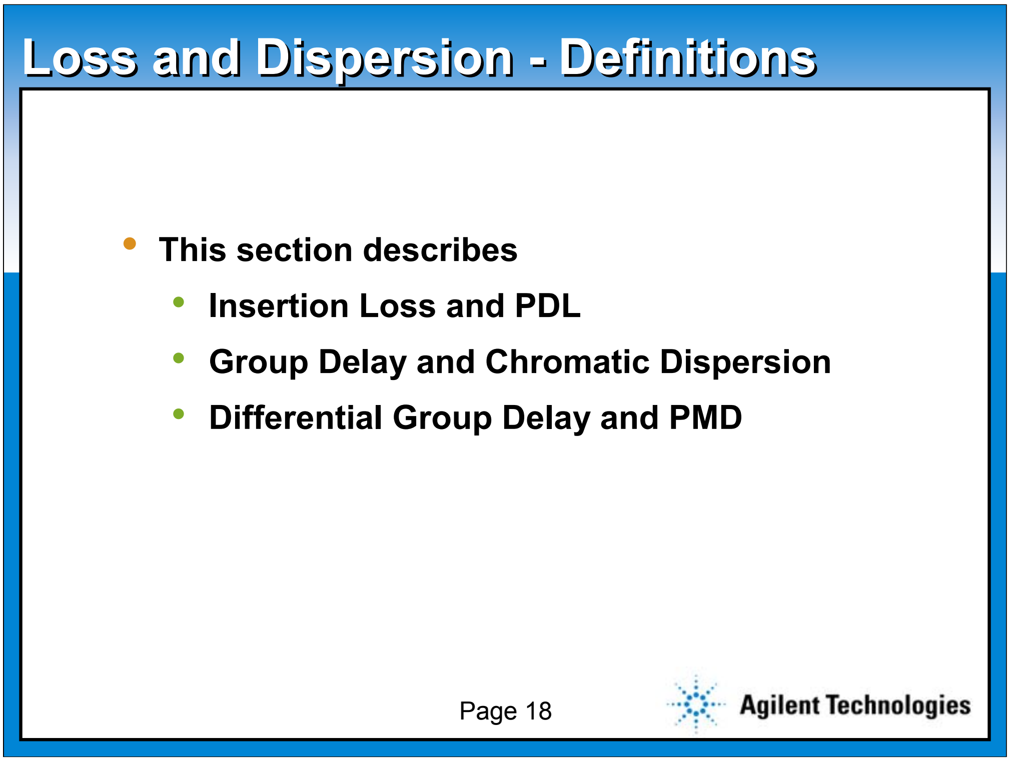
In summary, the motivation for new, leading edge test methods can be summarized as:

- Network evolution (higher bit rates, tighter channel spacings)

- Implication of the Network evolution to optical component test (loss and dispersion measurements over wavelength and Polarization)

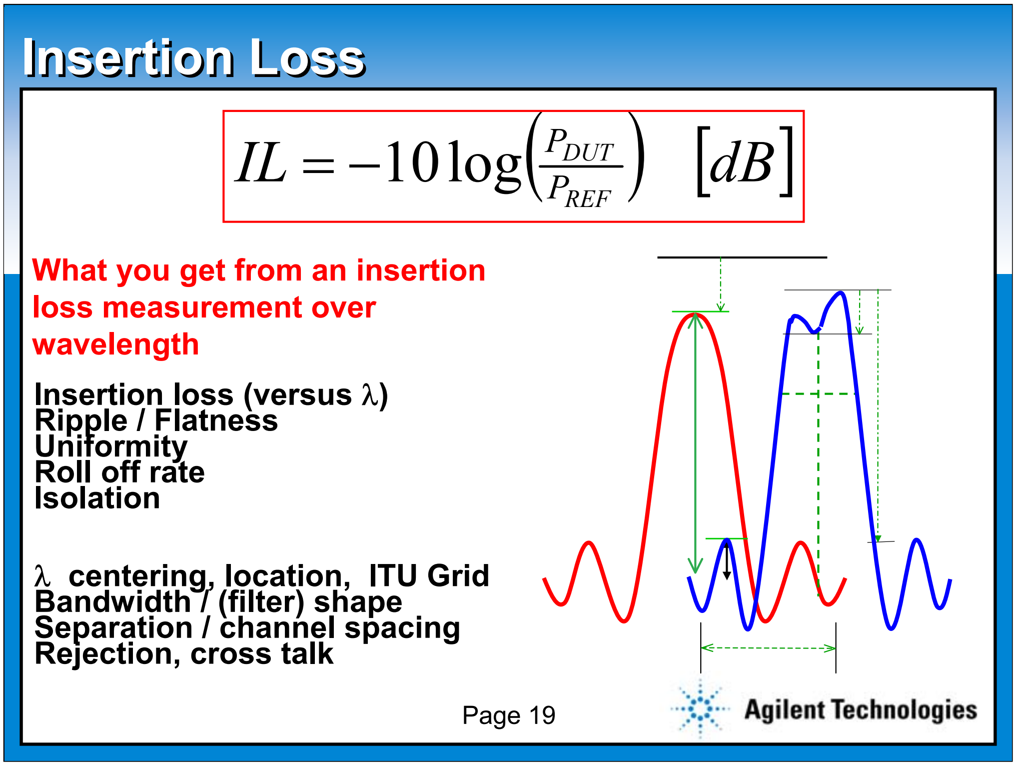
- More complex components require new test plans and principles

- Reduce cost of test (initial and operational investment)



Slide 9.

Before going into a discussion about leading edge test methods, the parameters to be measured are reviewed in the next section. The section describes loss and PDL, and dispersion parameters such as group delay and chromatic dispersion, as well as differential group delay and Polarization mode dispersion, and their relation to each other.



On slide 10, we discuss insertion loss.
Insertion Loss denotes the decrease in optical power when a light signal is travelling through a component. Sometimes, optical components act as filters, transmitting only a small number of wavelengths while blocking all others. For such components, typically wavelength division multiplexing components, the insertion loss is measured over wavelength.
From such a spectral insertion loss measurement, filter characteristics can be deduced.
Among the most important parameters are

•Center wavelength

•Bandwidth

•Ripple

• Isolation

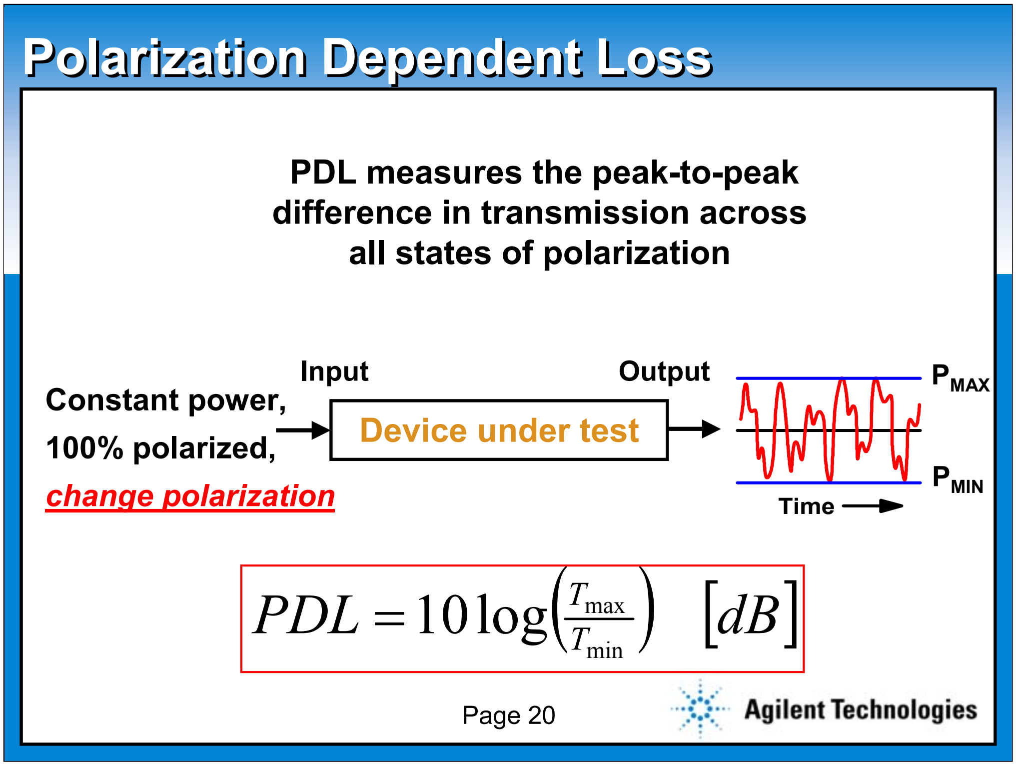
If the device consists of more than one filter, the interaction among the corresponding channles becomes of interest:

• Crosstalk

• Channel Spacing

• Flatness

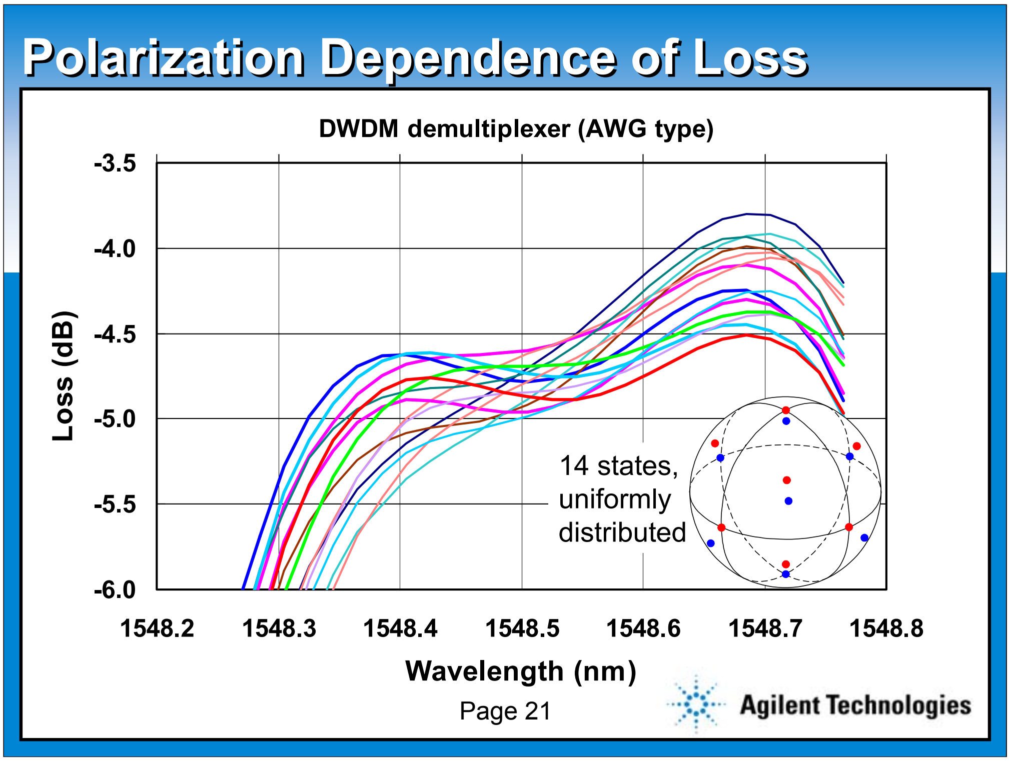
Therefore, the spectral insertion loss contains the most information about the components filter behavior, and is still the measurement task performed most.



On slide 11, we have a look at Polarization dependent loss.

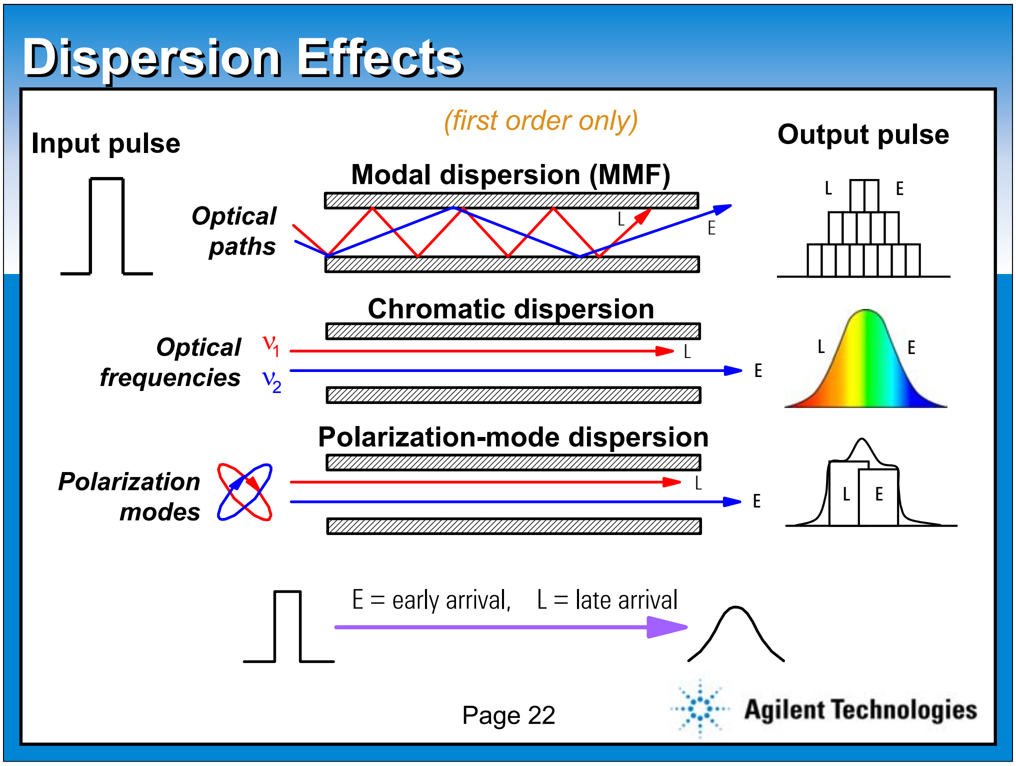
The insertion loss of optical components, and hence higher order filter parameters, depend on the Polarization of the incident light signal. As Polarization is not defined in optical networks, ie may change randomly, the loss of a component changes. The Polarization influence to the component's loss is defined as the polarization dependent loss. This value represents a margin around an average insertion loss value, denoting the maximum variation of the loss depending on Polarization.

As shown above, if the Polarization is changed, the transmission of the device under test changes, and hence the optical signal power.



On slide 12, we see an example of how the insertion loss of a component is influenced by the Polarization of the incident lightwave signal. The device under test is a typical WDM filter component exhibiting passband characteristics.

As can be seen, different states of polarization result in different spectral losses, and hence in different passband shapes. Higher order parameters such as ripple, bandwidth, peak or center wavelength change for different states of Polarization. Therefore, for an accurate analysis of the loss and associated filter characteristics, the Polarization dependence must be included.



Let's now go on and discuss some dispersion effects, starting at slide 13.

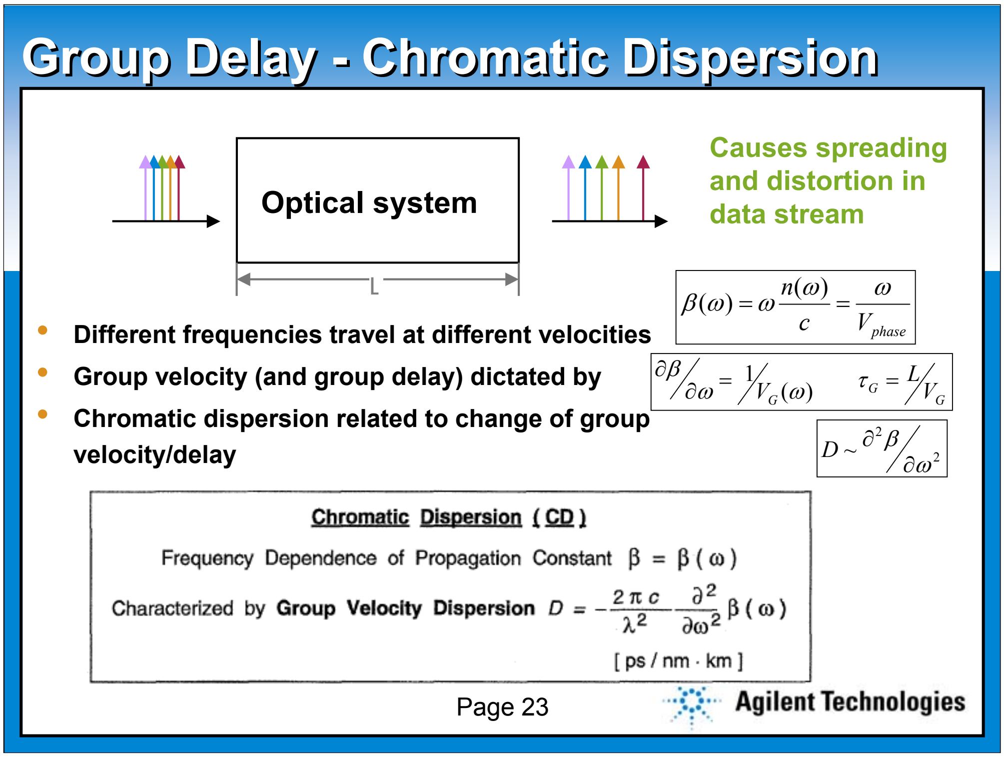
All forms of dispersion degrade the modulation-phase relationships of lightwave signals, reducing information-carrying capacity through pulse broadening in digital networks.

Three dispersive phenomena are known to degrade fiber optic system performance by broadening the digital pulses. In each dispersion phenomena, the trouble is caused by a difference in arrival time of various components of the signal - spatial modes, colors, or polarization modes.

***Modal dispersion* occurs because light splits into many spatial paths, each having a different length and thus a different arrival time. This causes a pulse to spread. This affects multimode systems only. As most networks use single mode fibers, except for short haul, this dispersion effect is of little concern.**

***Chromatic dispersion* arises from the waveguide and material properties of single-mode fiber. A variation of group delay with wavelength delays different frequency components of the signal by different amounts, distorting the pulse.**

***Polarization-mode dispersion* (PMD) becomes a performance limitation in high speed systems when chromatic dispersion is compensated by special fibers or devices. Pulse spreading is caused by the difference in propagation velocity between orthogonal polarization states.**



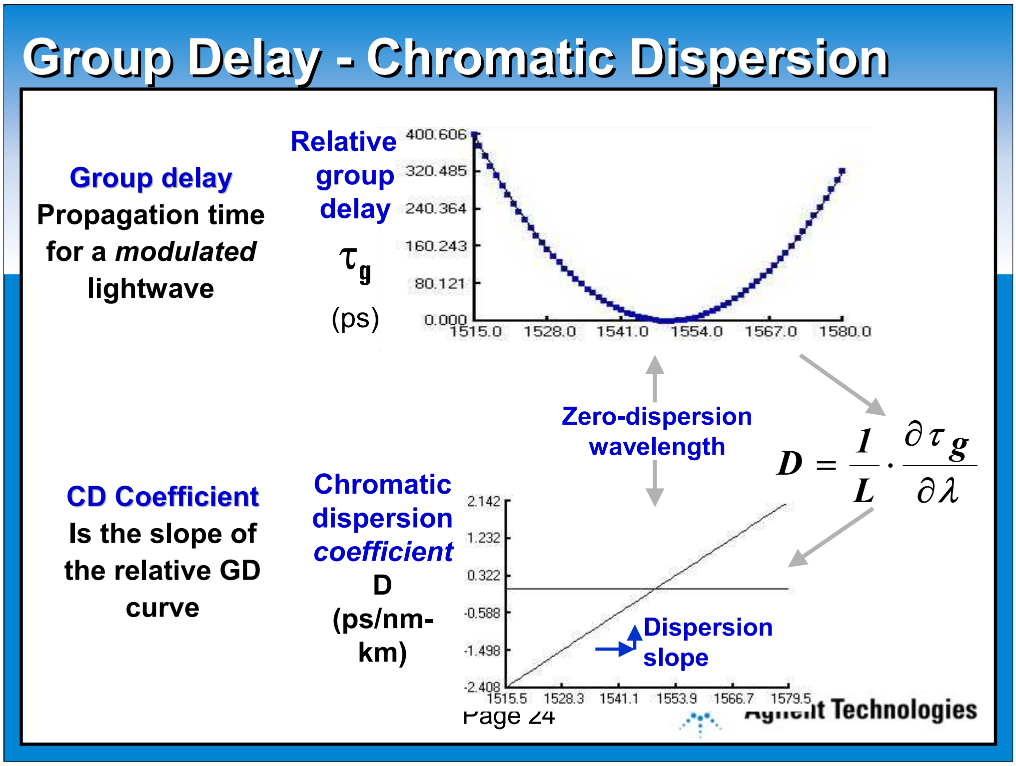
Let's consider chromatic dispersion and group delay, and their relation to each other´, slide 14.

Chromatic Dispersion is simply the variation in the speed of propagation of a lightwave signal with wavelength. As a transmitter laser is modulated, the line width of the optical signal emitted by the laser is broadened. Each wavelength component of the of the signal travels at slightly different speed, resulting in pulse broadening as shown in the picture.

***Group delay* is the propagation time for a modulated lightwave, such as an optical pulse. If we were able to put a 'dot' on the corner of a pulse (or any modulation 'envelope'), the group delay would be the time for that 'dot' to travel through the test device.**

The delay is determined by path length and propagation velocity, which can both vary with wavelength and polarization.

Chromatic dispersion is the rate of change of group delay (GD) with wavelength with units of ps/nm.



Slide 15 demonstrates the relation between group delay and chromatic dispersion on the example of optical fiber dispersion. As mentioned before, group delay denotes the propagation time of a pulse.

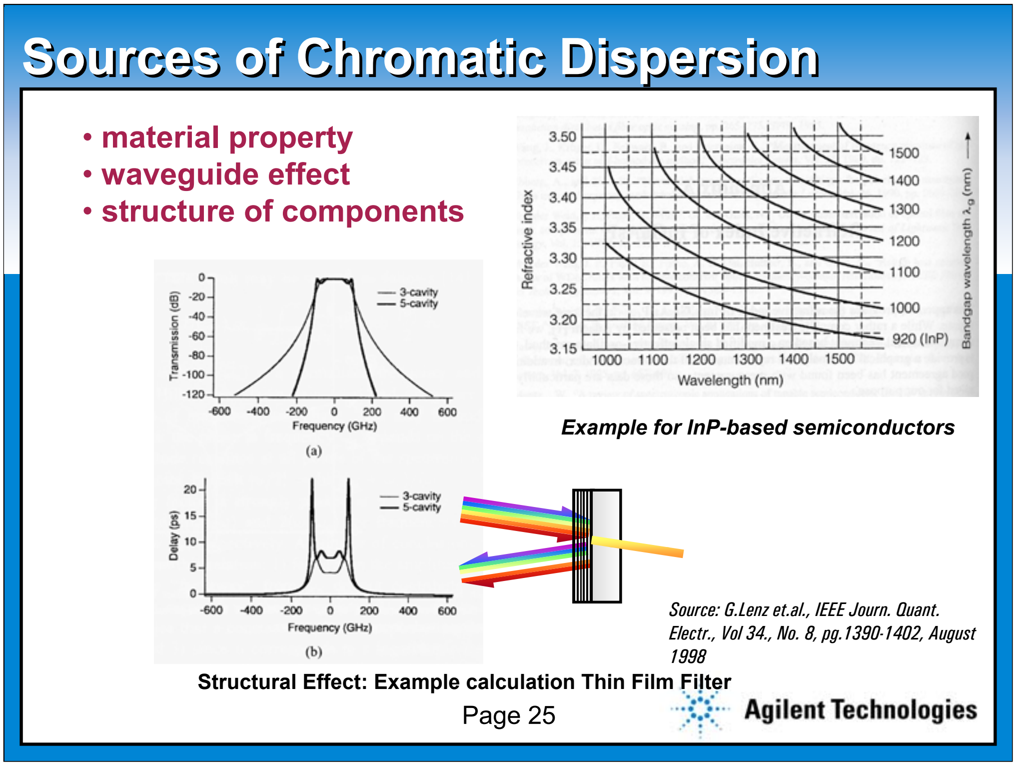
Relative group delay is the *change* in group delay from wavelength to wavelength. In narrowband device testing, this is the major parameter to determine. Relative group delay is not an absolut number. It denotes the change in absolute group delay over wavelength, from a chosen reference point, which is typically the point of lowest group delay in the band of interest.

The *chromatic dispersion* is the rate of change, or the slope of the relative group delay curve. The graph allows us to calculate the time spreading for a signal of a given spectral width.

At the *zero-dispersion wavelength*, two closely-spaced frequency components travel at approximately the same speed. The *dispersion slope* tells us how the dispersion changes between channels of a DWDM system.

The *chromatic dispersion coefficient* of a material, like an optical fiber is the amount of Chromatic Dispersion per unit length. For a fiber it is expressed in units of ps/nm-km.

This is meaningful because CD is generally “deterministic”, meaning it is well defined and reasonably constant for a particular component or length of fiber so that the total CD is just a simple summation of the individual components.

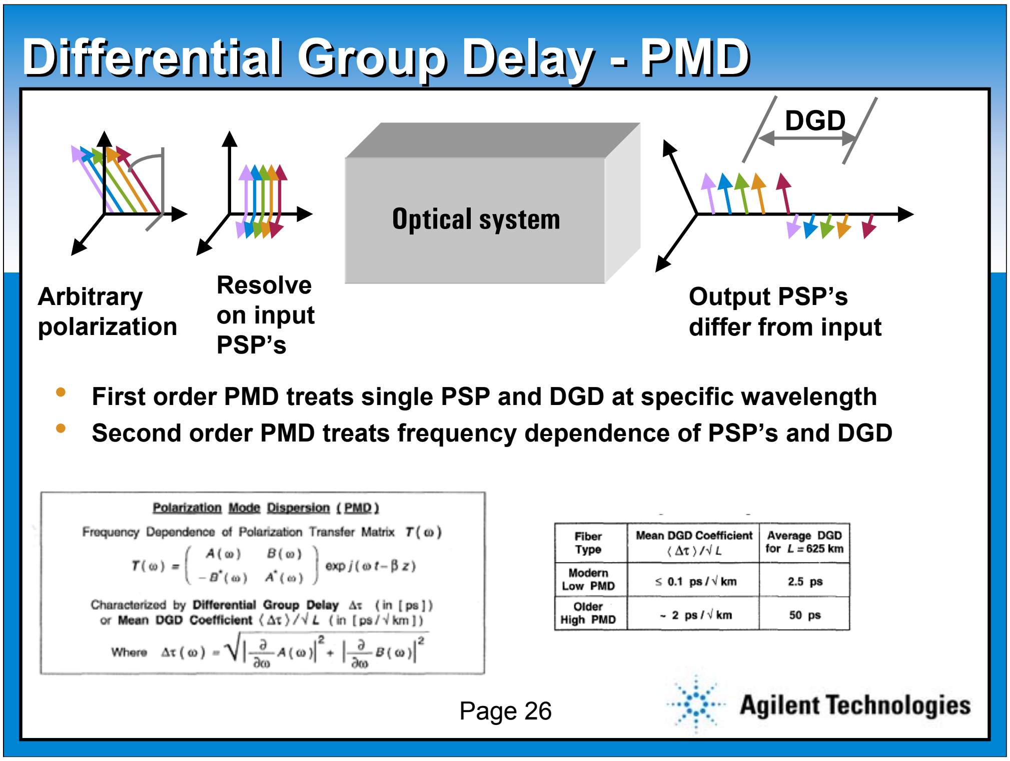


On slide 16, the main sources of chromatic Dispersion are shown.

•CD is caused by material properties **-The index of refraction generally varies wavelength causing changes in the group velocity. This material dispersion is generally strongest at wavelengths near absorption peaks in the material, like vibrations (Kramers-Kronig). The dispersion as a function of wavelength and refractive index is shown for Indium Phosphide as an example.**

•CD can also be generated by a waveguide effect. **-In narrow paths surrounded by material of different *n*, like fiber cores and planar waveguides, the amount of overlap of the light with the surrounding cladding is wavelength-dependent, yielding a λ-dependent effective refractive index.**

•Last, but not least, the structure of components **can cause different propagation speeds for different wavelengths, and hence induce dispersion. -In complex device structures, like multilayer films or AWGs where multiple paths are possible, the addition of the various paths depends on the phase of the interference so that the combined "effective path length" can be λ-dependent. This is shown on the example of a thin film filter. The graphs represent the typical dispersive characteristics of a three and five cavity thin film filter.**

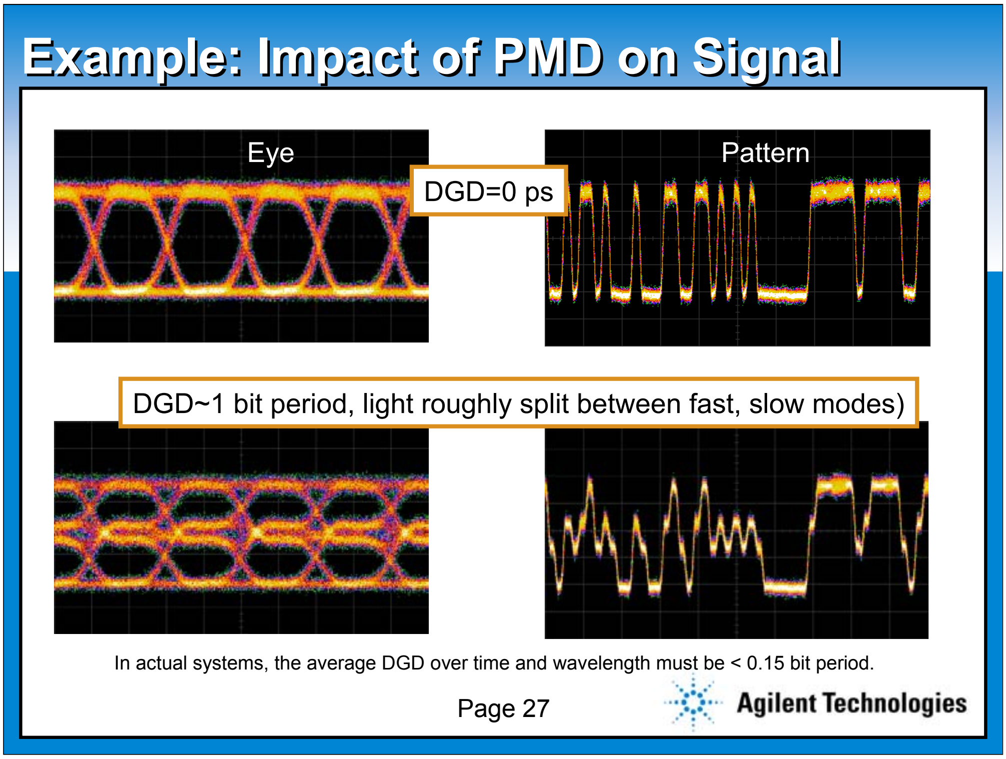


The Polarization dependence of dispersion is demonstrated on slide 17.

Polarization mode dispersion, or PMD, is a fundamental property of singlemode optical fiber and components in which signal energy at a given wavelength is resolved into two orthogonal Polarization modes of slightly different porpagation velocity. The resulting difference in propagation time between Polarization modes is called the differential group delay.

Differential Group delay may vary rapidly in time or as a function of wavelength, especially if the axes of different parts of the device are not aligned with each other (mode coupling).

Polarization mode dispersion (PMD) gives the effective (average) DGD and is a more convenient specification parameter, especially for fibers.



As an example of the impact of DGD on transmission quality, a transmission signal with DGD and without DGD are shown on Slide 18.

These measurements show the impact of severe PMD on a 10 Gb/s non-return to zero (NRZ) signal. In the upper pictures, where the DGD value was set to zero, the eye diagram shows a wide opening, and in the pattern the different bits can be recognized.

The lower two pictures show the effect of DGD on the transmission quality. A PMD emulator is set to approximately 100 ps of differential group delay (DGD), roughly one bit period, with the modes carrying approximately equal optical power. Note the well-defined bars across the center of the eye. We are observing “inter-symbol interference” (ISI).

Polarization causes a number of serious capacity impairments, including pulse broadening. Compared to chromatic dispersion, Polarization mode dispersion, at any given signal wavelength, is not very stable, making passive compensation impossible.

Let’s now discuss test methods for measuring loss, and later on for measuring dispersion.

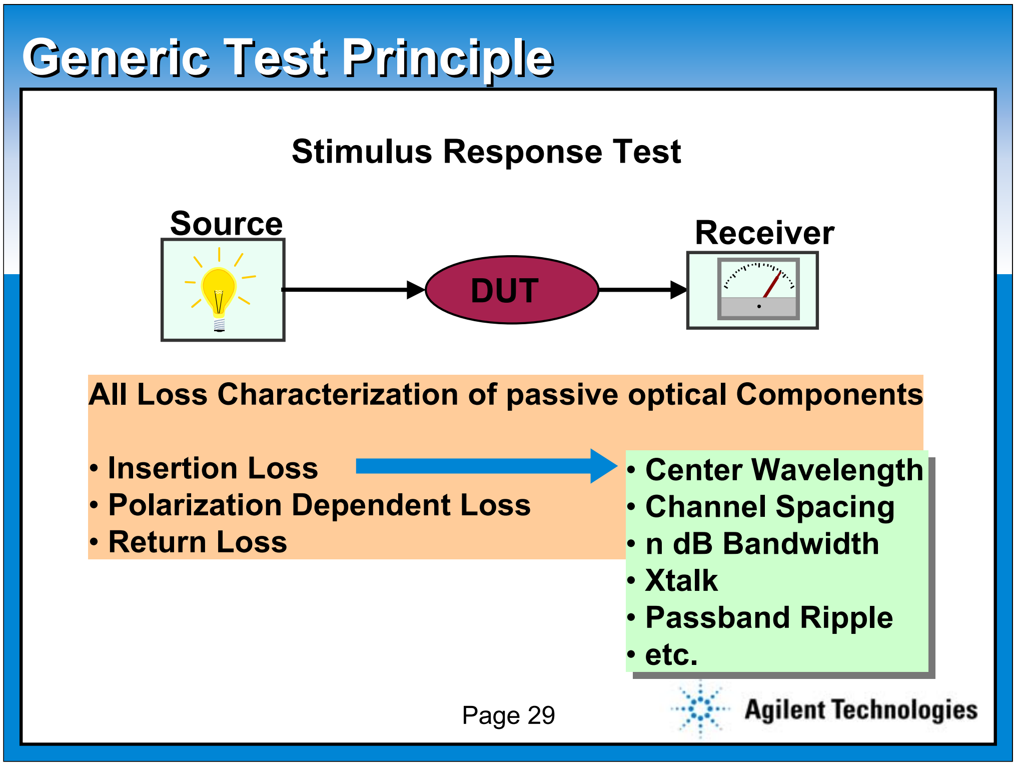
Measuring Loss Parameters

- This section describes
  - Stimulus Response Test
  - Loss and PDL Measurement Principles
  - How to measure loss precisely

Agilent Technologies

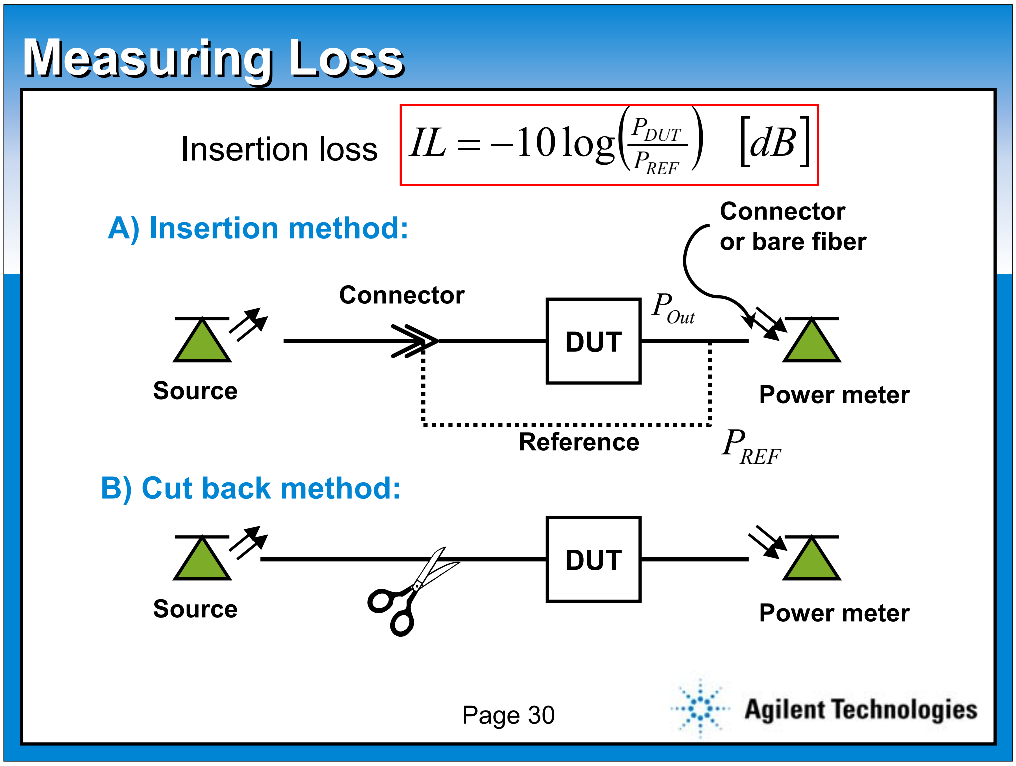
Slide 19.

In the following section, we discuss how loss and PDL can be measured, and what needs to be done to perform accurate measurements.



On slide 20, the most basic principle of passive optical component test, the so-called "stimulus-response test", is shown.

The device is stimulated with an optical source and the response depending on variable input parameters, like power, wavelength or state of polarization (SOP), is recorded. The response may be captured in the transmission or reflection path of the device under test (DUT). This way, loss parameters such as insertion loss, polarization dependent loss (PDL) or return loss can be determined.



On slide 21, two basic principles for measuring loss are depicted.

A loss measurement is a ratio type measurement. This means the ratio of two power levels has to be determined. Insertion loss gives a measure, how much light passes the device compared to the amount of light that was send into the device.

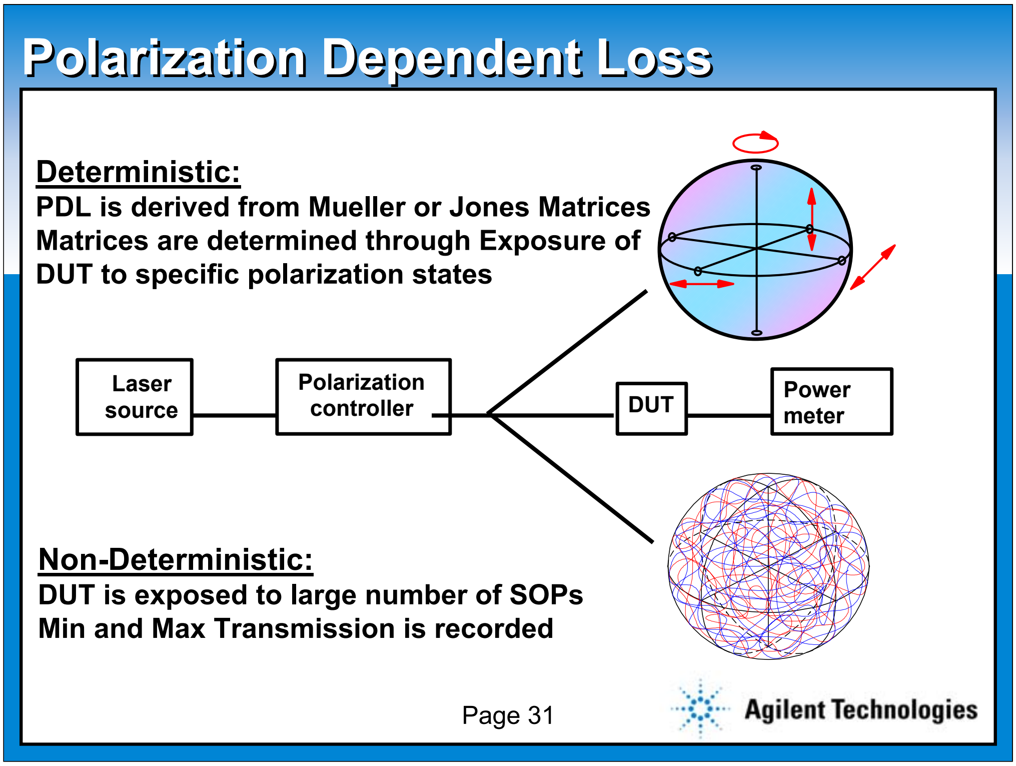
For a WDM filters as the device under test, insertion loss must be measured as a function of wavelength.

Consequently, there are two measurement steps to be carried out: In the insertion method, the reference power without the device under test (DUT) in the setup has to be recorded. This is indicated by the dashed line. Then the DUT is inserted and the output power P_{Out} after the DUT is measured.

The insertion loss is then given by the ratio of output power to reference power.

However, the measured DUT insertion loss includes the loss of one connector pair, which contributes to the overall measurement uncertainty in the order of 0.1 dB.

To reduce uncertainty it is possible to splice the DUT into the signal path. Then, the output power after the DUT is measured first. Afterwards, the fiber before the DUT is cut and its bare end connected to the power meter for reference reading. This method is called cut-back method.



Slide 22.

PDL has become a standard measurement when characterizing components.

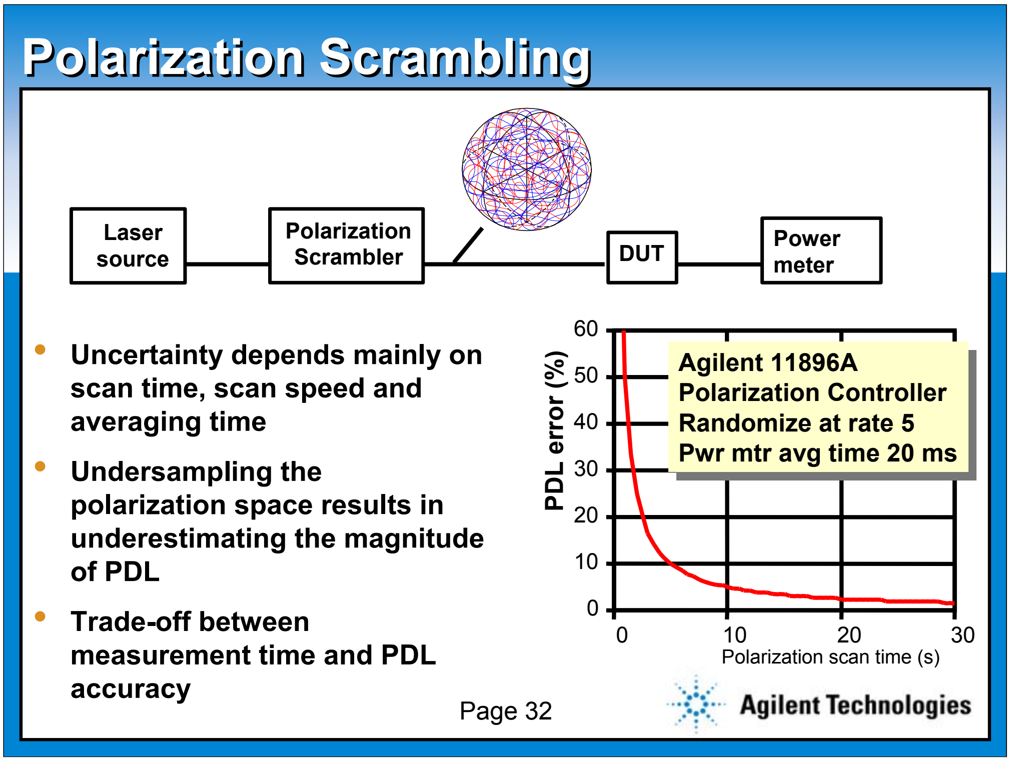
There exist two different classes of PDL measurement principles, deterministic and non-deterministic. The deterministic techniques derive the DUT's PDL from its Mueller or Jones matrices, which are obtained by measuring the transmission properties of the DUT over a set of *defined* input polarization states, like for example in the Mueller method.

In contrast, the nondeterministic techniques measure the minimum and maximum transmission through the DUT over a large number of input polarization states.

The principle difference between the two classes of measurement methods lies in the number of applied polarization states: The deterministic methods rely on exposure of the DUT to only a few but well-known states of polarization, whereas nondeterministic methods apply a large number, but unknown states of polarization to the DUT.

No matter what type of test method is used, a typical PDL setup utilizes the same components: a source (a tunable laser source if PDL is to be measured over wavelength, a polarization controller, the device under test and an optical power meter. The state of polarization is changed and a series of measurements are performed to evaluate the polarization dependency of the device.

The only difference between deterministic and nondeterministic setups is the kind of polarization controller that is used.

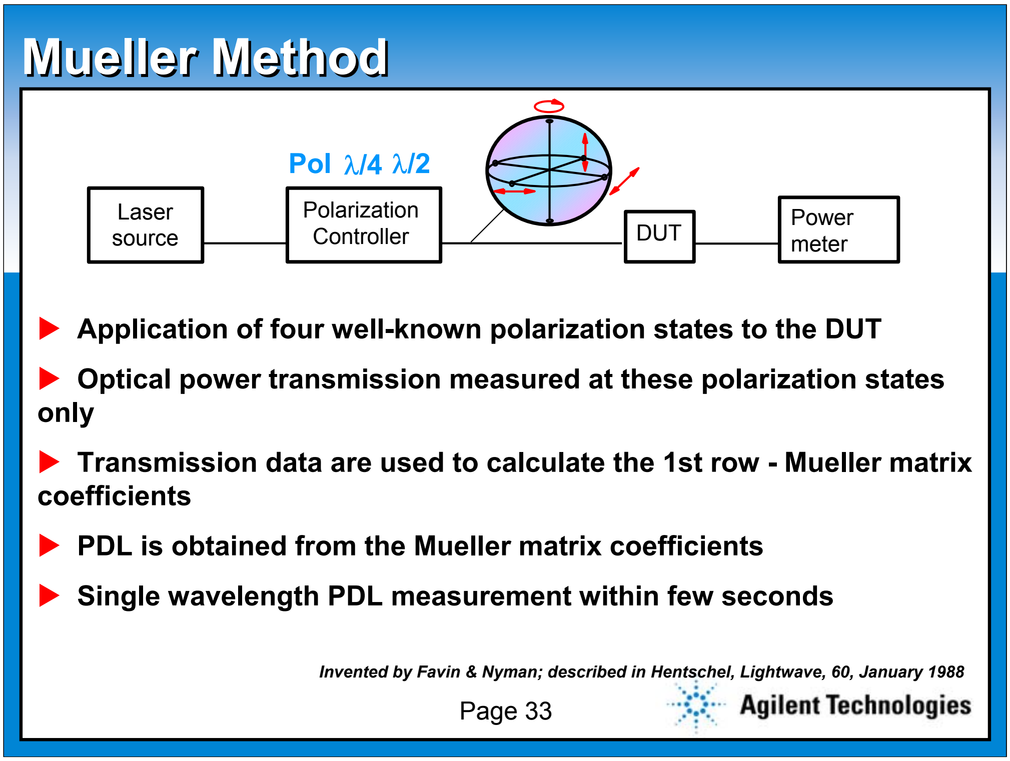


Slide 23 shows the fundamental method of measuring PDL, the Polarization scanning technique.

The device under test (DUT) is exposed to all states of polarization and the transmission is measured with a power meter. The maximum and minimum transmission through the DUT can directly be measured. The polarization dependent loss is then the ratio of minimum and maximum transmission.

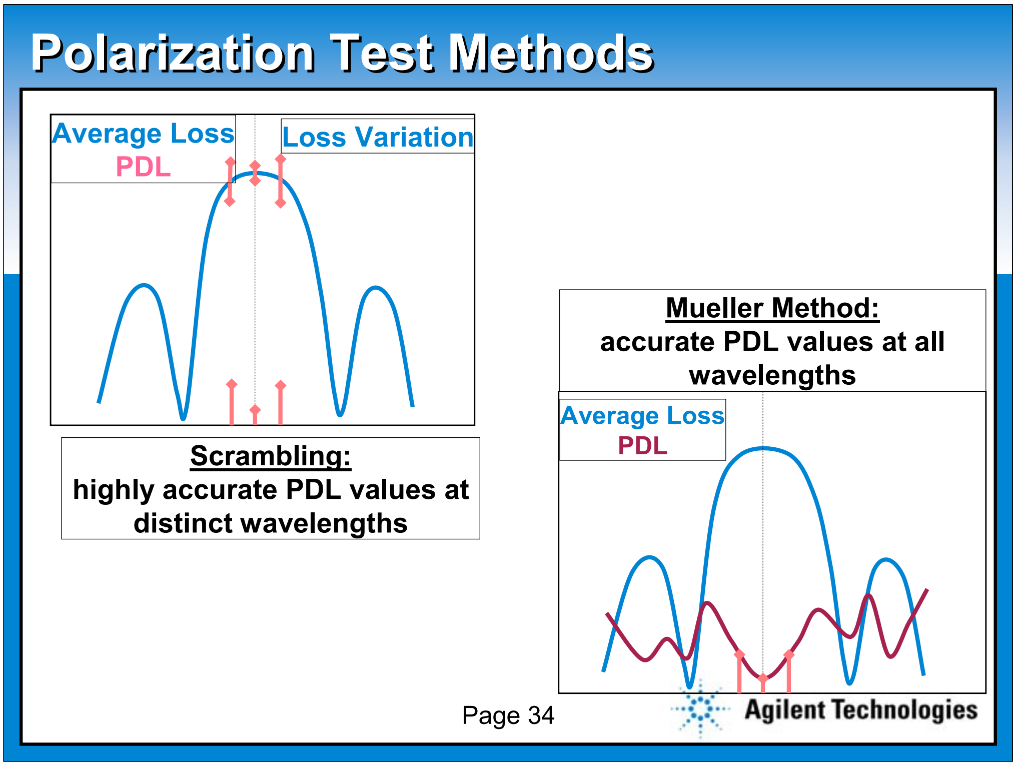
Exposing the DUT to all states of Polarization is fairly impossible. In practice, a large number of Polarization states is generated at a scan rate that is suitable for the power meter averaging time. The longer a Polarization scan takes, which means the transmission through the DUT is obtained at more Polarization states, the smaller the uncertainty of the PDL measurement. This is demonstrated in the graph. However, at some point an increase of the measurement time does not yield a significant improvement of the measurement accuracy. The PDL measurement uncertainty has always to be considered in the context of measurement time, scan rate and power meter averaging time.

The Polarization Scanning technique is suitable for PDL measurements at few wavelengths, because the scanning is performed place at each wavelength individually.



Slide 24.

The Mueller method, which belongs to the class of deterministic PDL measurement methods, determines the PDL by exposing the DUT to only four but well-known states of polarization. The four polarization states are typically LHP (linear horizontal polarized), LVP (linear vertical polarized), L+45 (Linear +45 degree), RHC (right hand circular). The first row coefficients from the Mueller matrix are then calculated from the transmission results. Finally, the matrix coefficients yield the average insertion loss, the minimum and maximum transmission, and hence, the PDL.

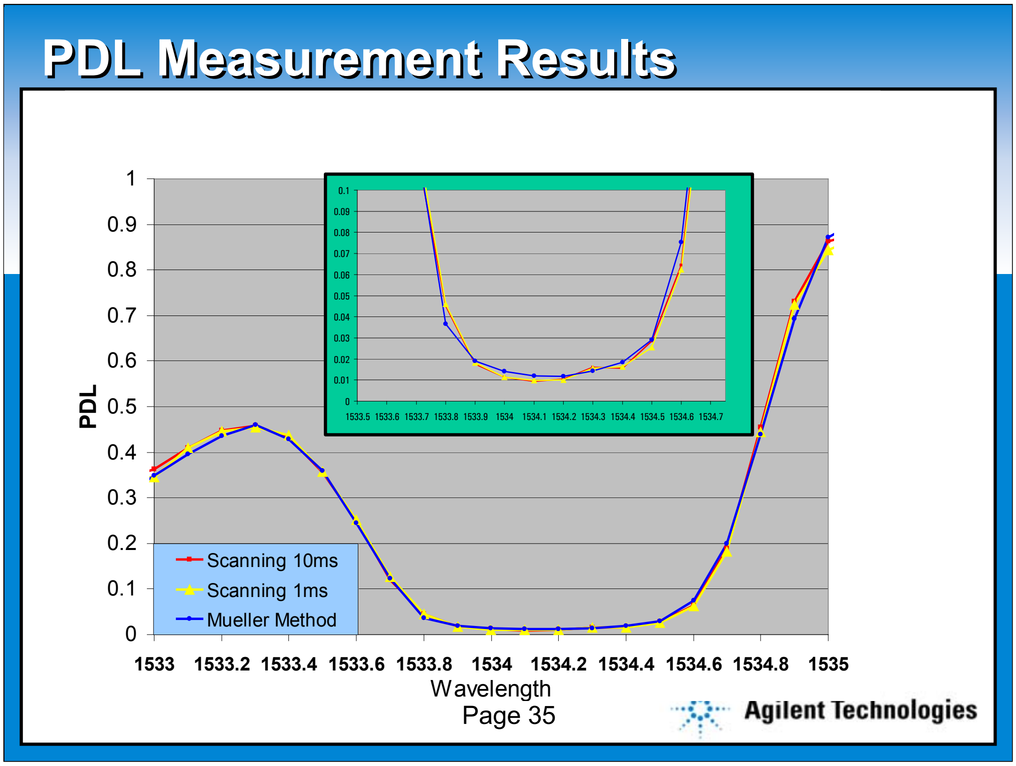


Slide 25.

The Polarization scanning method and the Mueller method determine the PDL, but their use in measurement applications is different.

If the PDL is only required at certain points of a filter passband, such as the center or 3dB bandwidth wavelengths, the Polarization Scanning technique is sufficiently fast. A tunable laser is required to set the appropriate wavelengths. The PDL is then determined by scanning the Polarization and recording the minimum and maximum transmission at the given wavelength. However, spectrally resolved PDL measurements, meaning measuring PDL over an entire passband and even outside the passbands with fine wavelength resolution, the scanning method becomes time consuming.

The “Mueller method” uses another approach: The DUT is exposed to four well defined states of polarization. This is especially advantageous if the PDL needs to be measured over wavelength, with high resolution. The Mueller method can be incorporated with transmission measurements over wavelength, where, at each of the four Polarization states, the transmission over wavelength is recorded. Consequently, for a large number of wavelength points the Mueller method obtains accurate measurement results in a short time.

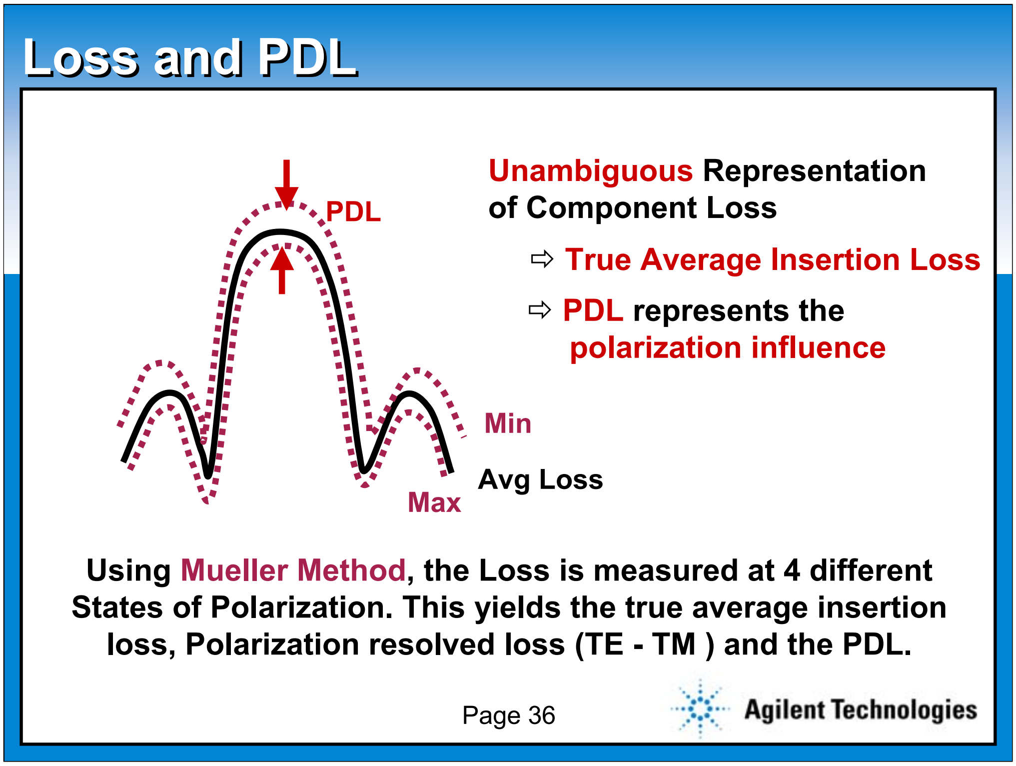


Slide 26 shows a PDL measurement of a WDM filter, measured with Polarization scanning and Mueller method.

Even though based on different approaches, both methods should ideally yield the same measurement results.

As there have been many concerns about the accuracy of the Mueller method, especially in measurements over wavelength, a comparison of results obtained by the Polarization Scanning technique can help to validate the Mueller method approach.

In the passband of the filter, around 1534.2 nm, the PDL of the device is very small, around 10mdB. Both methods demonstrate that they are capable of measuring low PDL values, and the results over wavelength are in very good agreement. The measurement cycle time becomes the dominating criterion for choosing the appropriate method.



Slide 27.

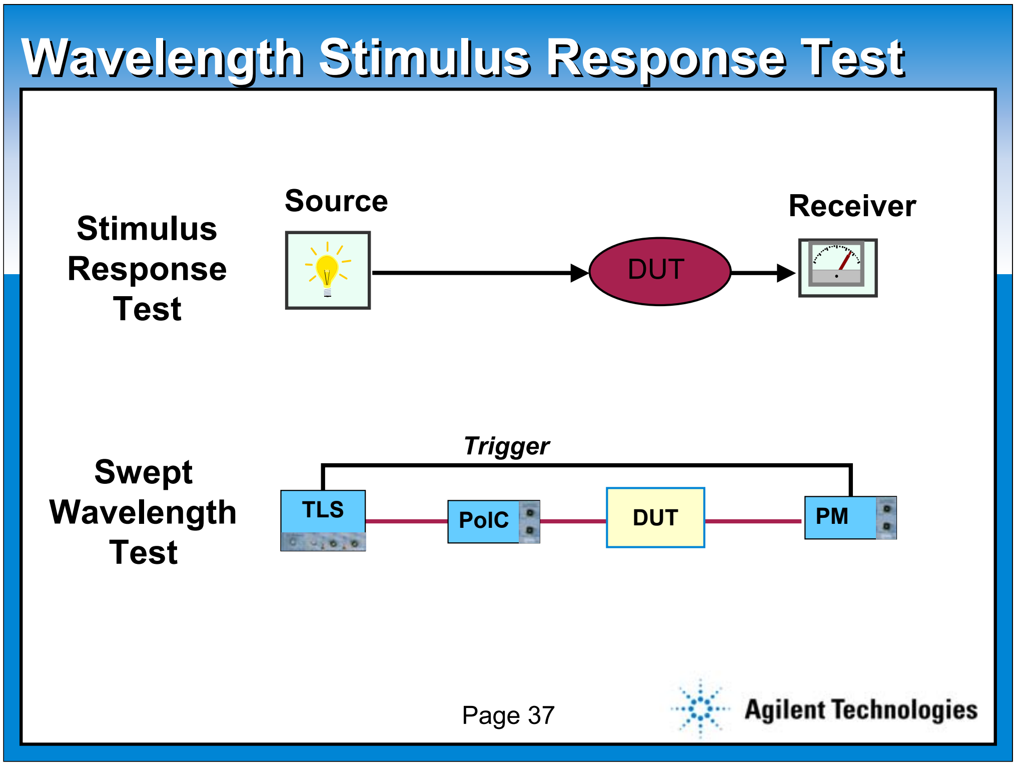
The Mueller method has some more advantages over the Polarization scrambling method, resulting from the deterministic nature of the method.

First, the determined insertion loss is the true average insertion loss, excluded any Polarization effects. This corresponds to as if the device under test was measured using an unpolarized source.

Second, the obtained PDL is the true Polarization dependence. The value of the PDL spans the area of what min and max losses around the average insertion loss that can be expected when of different Polarization is incident.

Third, Polarization resolved measurements can be performed. In integrated optical components, such as arrayed waveguide gratings, there exist two fundamental modes of propagation. These are typically denoted as TE and TM modes. These modes correspond to two orthogonal states of Polarization. Lightwave signals with other states of polarization can be resolved into these fundamental modes.

The results from a PDL measurement using Mueller method can be analyzed to yield the spectral loss at the two fundamental modes. This is possible because the Mueller method uses known states of polarization, and hence the loss and Polarization transformation can be described in Matrix form.

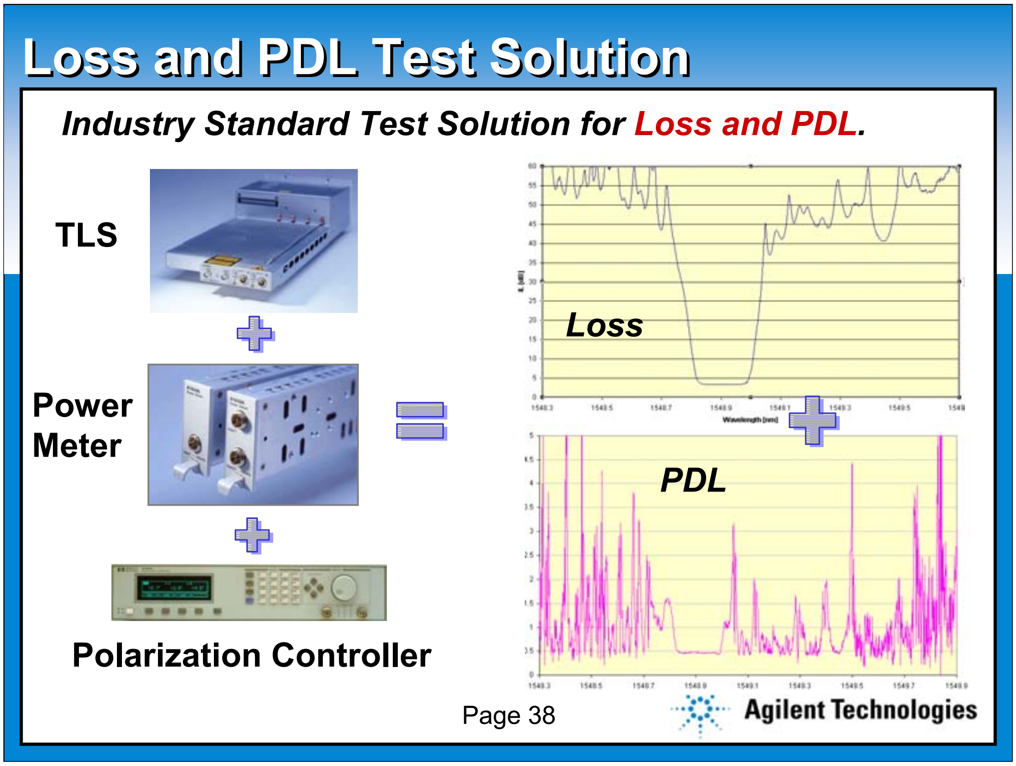


Slide 28.

It has already been mentioned that often it is required to characterize the device under test over wavelength, i.e. performing a "spectrally resolved stimulus - response test ". For that matter, one could either use a broadband source and a wavelength selective receiver, such as an optical spectrum analyzer (OSA), or a tunable laser source in combination with a broadband receiver, as shown above. Tunable laser sources usually overcome the wavelength resolution limitations of OSAs.

The State-of-the-art approach of wavelength resolved stimulus response measuruements uses tunable lasers which are capable of continuously tuning across the wavelength range. Such a measurement of power as a function of wavelength is called "sweep" or a "swept measurement". The power meters are triggered to take power readings at specific wavelengths.

A Polarization controller is used in order to change or set the state of Polarization of the probing lightwave signal. This way, the Mueller method can be combined with swept wavelength measurements, enabling wavelength resolved PDL measurements over broad spectral ranges in a short amount of time.



Slide 29.

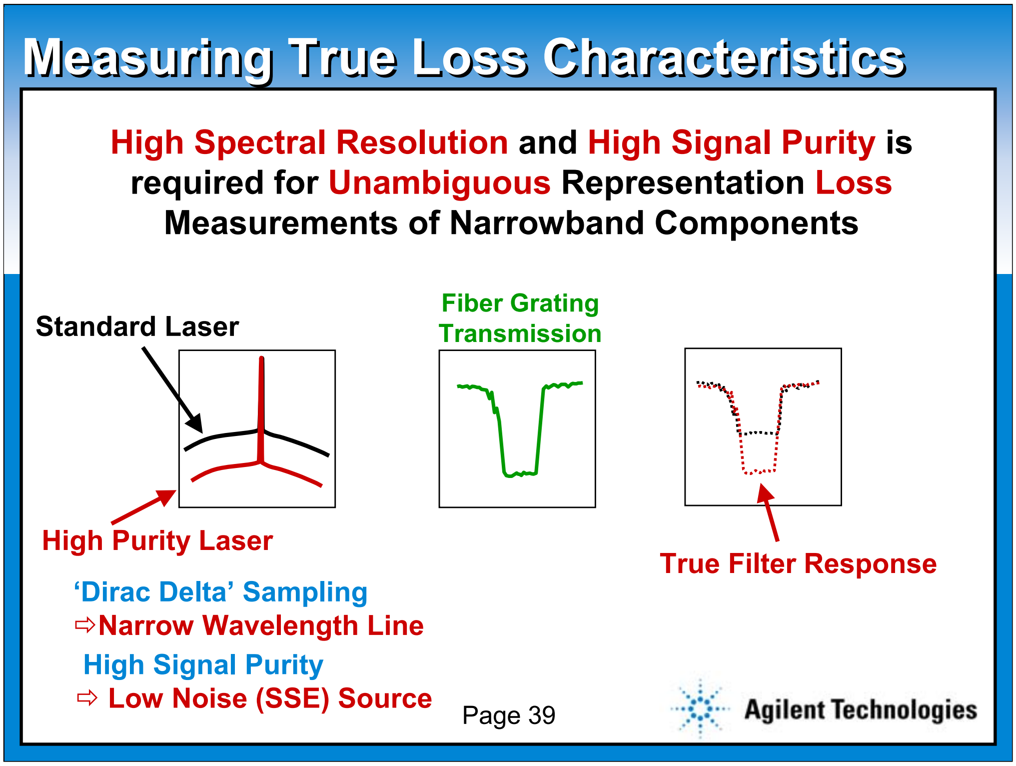
A real life test solution uses a tunable laser source, power meters and a Polarization synthesizer to measure loss and PDL. This sounds very simple, but there is some more in order to measure loss and PDL accurately, namely:

wavelength accuracy

wavelength resolution

dynamic range

all of these are especially important when measuring narrowband components, and will therefore be discussed in more detail in the next few slides.

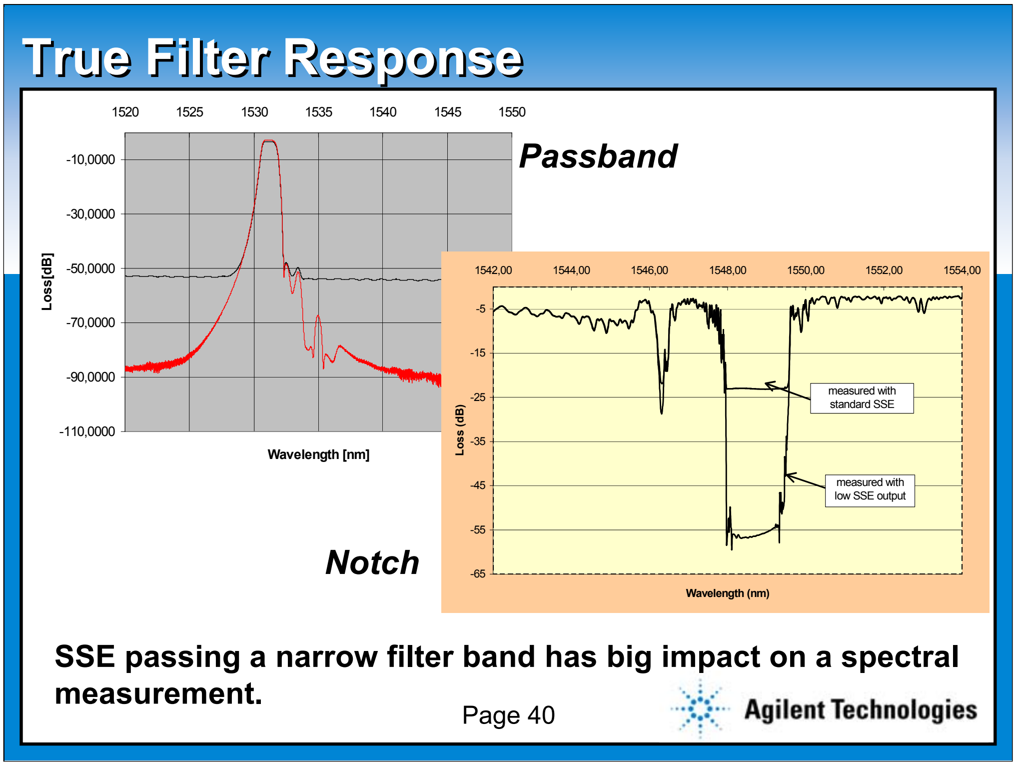


Slide 30 considers resolution and dynamic range. Optical components can easily exceed dynamic ranges of 50 or 60dB. So how can this be measured?

Typically, most of the optical power of tunable lasers is at the signal wavelength. However, tunable lasers also produce some broadband background noise called source spontaneous emission. When measuring optical filters, this source sponatenous emission can limit the dynamic range.

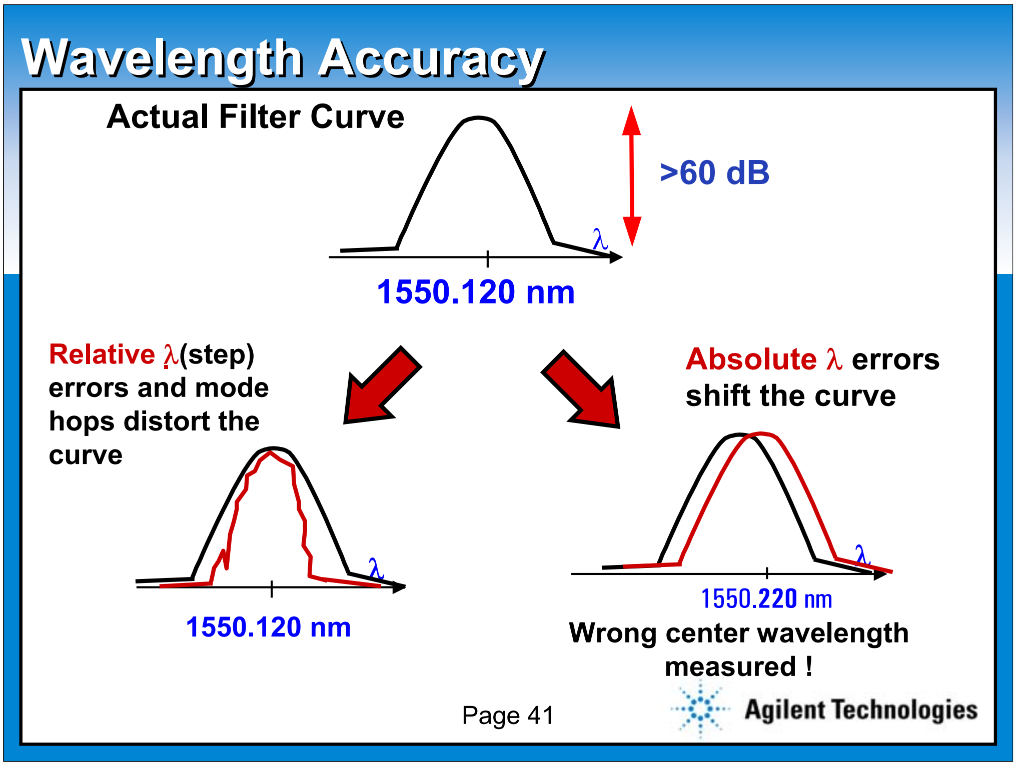
Consider a standard tunable laser signal, as shown in black color in the left picture. When measuring a notch filter, the signal wavelength is attenuated by the notch when sweeping across the filter. However, the background noise is passing the filter, leading to detected optical power that does not represent the true filter response. Therefore, a laser with low source spontaneous emission is a must for measuring optical filters, either notch or passband filters. Such a high purity laser is shown in red color.

The other important factor is the linewidth of the probing signal. Small details in the filter shape can only be resolved if the probing signal is much narrower that the features to be resolved. With the advances of optical networks as discussed earlier, passbands and features become much narrower, and hence the requirements on resolution become tougher.



Slide 31 shows measurement examples using standard and low SSE tunable lasers. Regardless whether considering notch or bandpass filters, the arguments about noise effects are valid for both. Clearly, the dynamic range of the measurement setup is limited by the noise passing the filter. Higher order filter parameters such as isolation or crosstalk can not be derived accurately anymore, and hence, the component may not be recognized as good, and fail the test.

With the low noise laser, the true filte response can be measured up to high losses. This means, that crosstalk or isolation of the filter meet the specifications, and the filter passes the test.



On slide 32, we discuss another parameter which is important for loss measurements. It is obvious, that the most important parameter to be controlled in wavelength resolved measurements is just wavelength.

When talking about wavelength accuracy, one must distinguish between relative and absolute wavelength errors. Their influence on a filter measurement is depicted as an example. A third one could be added, that is wavelength repeatability.

Absolute Wavelength accuracy denotes a shift of the entire wavelength axis by a constant. The consequence of this error is, that measured filter responses are shifted, and the determined center wavelength is not correct.

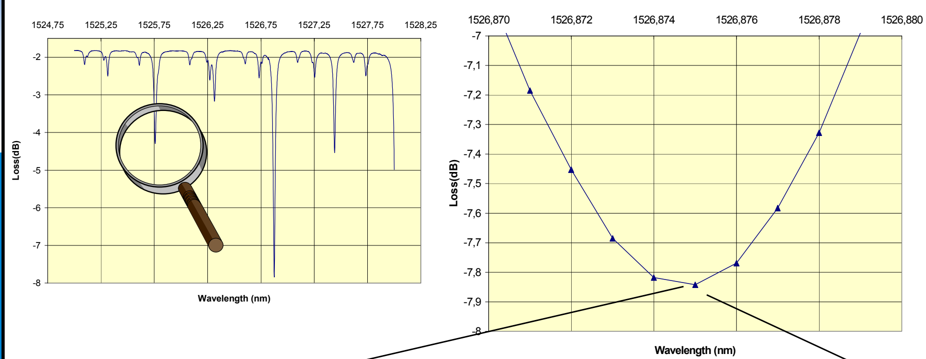
Relative Wavelength accuracy is the shift in wavelength between individual wavelength points. This error leads to distortions in the measured filter response.

Each of these errors can lead to misinterpretation of test results and therefore will lead to lost time, lost component yield or lost revenues.

The required accuracy moves down to the picometer regime and the challenge today is not only to minimize these errors but to do it at high speed in swept wavelength measurements.

In Agilent tunable laser sources, a built-in real time wavelength meter measures the wavelength during a swept measurement, over the entire tuning range. A commonly used gas cell is not required to ensure wavelength accuracy. Gas cells have the disadvantage that they can only be used in a limited wavelength range, which is usually much smaller than the tuning range of the source.

Wavelength Accuracy



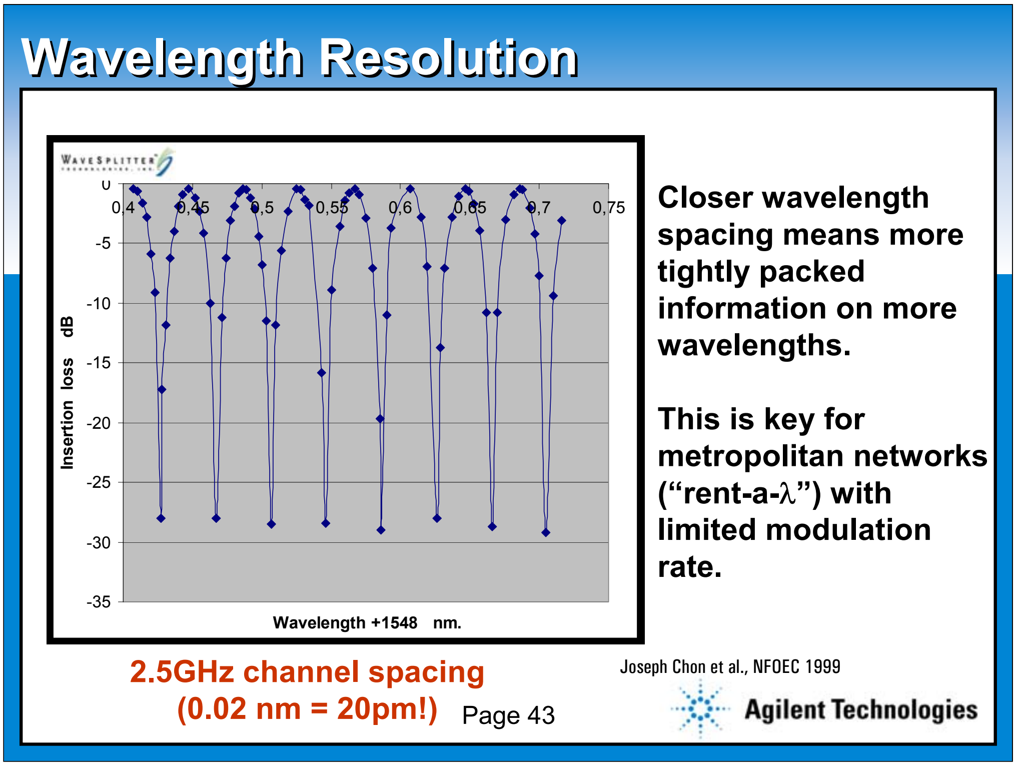
P-Branch	NIST	Agilent
1	1525.7607 [nm]	1525.759
2	1526.3147	1526.314
3	1526.8751	1526.875
4	1527.4419	1527.442

Slide 33.

Despite the limitation of a gas cell for ensuring wavelength accuracy, verification of the wavelength accuracy of the source can be done using a gas cell, over the specified range of the gas cell.

Due to its sharp and calibrated peaks, a gas cell is a brilliant test object to validate the performance of a tunable laser source.

This slide compares typical measured data to published calibrated data from NIST and shows an excellent agreement.



Slide 34.

Wavelength resolution is another important feature. As channel spacing decreases, more spectral information is contained over wavelength. At the same time, spectral features narrow down.

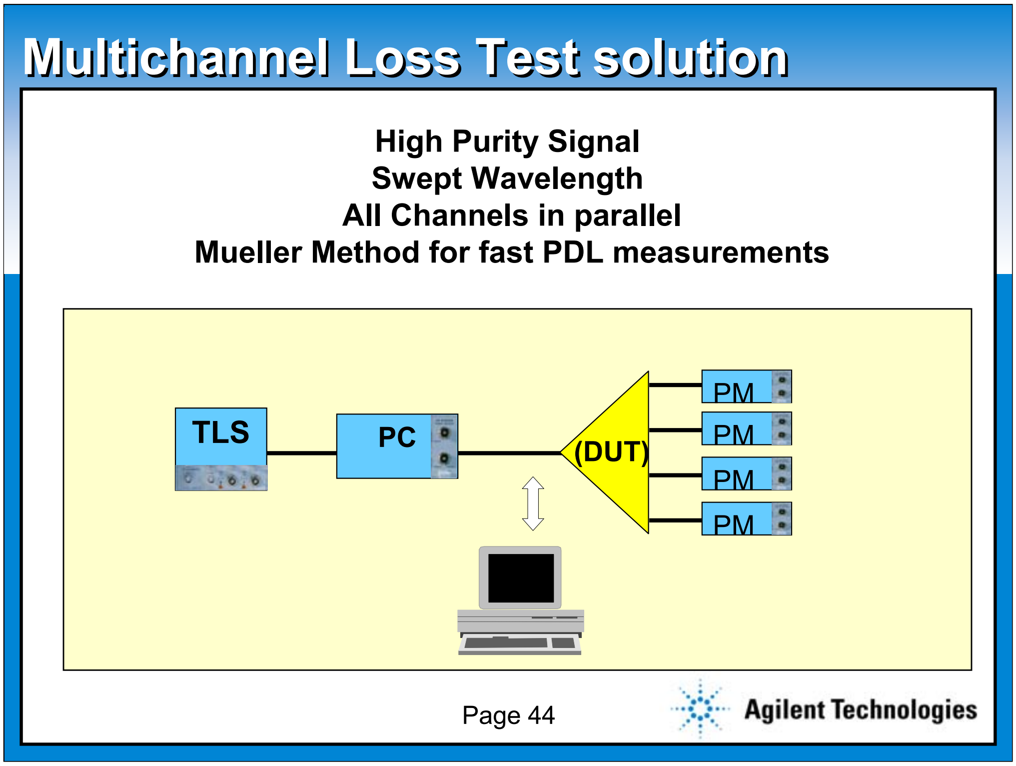
The above trace shows the wavelength dependency of some special demultiplexer configuration. In this case, the individual channels are separated by no more than 20pm!

Any test method, which is limited in wavelength resolution, in wavelength linearity or in wavelength accuracy will have a hard time to characterize these components in a sufficient way.

It is obvious, that a tunable laser with its highest resolution (limited only by the laser line width) is best used here as the probing signal. At the same time, the actual wavelength must be known very precisely during tuning. This goes back to the wavelength accuracy which was mentioned before.

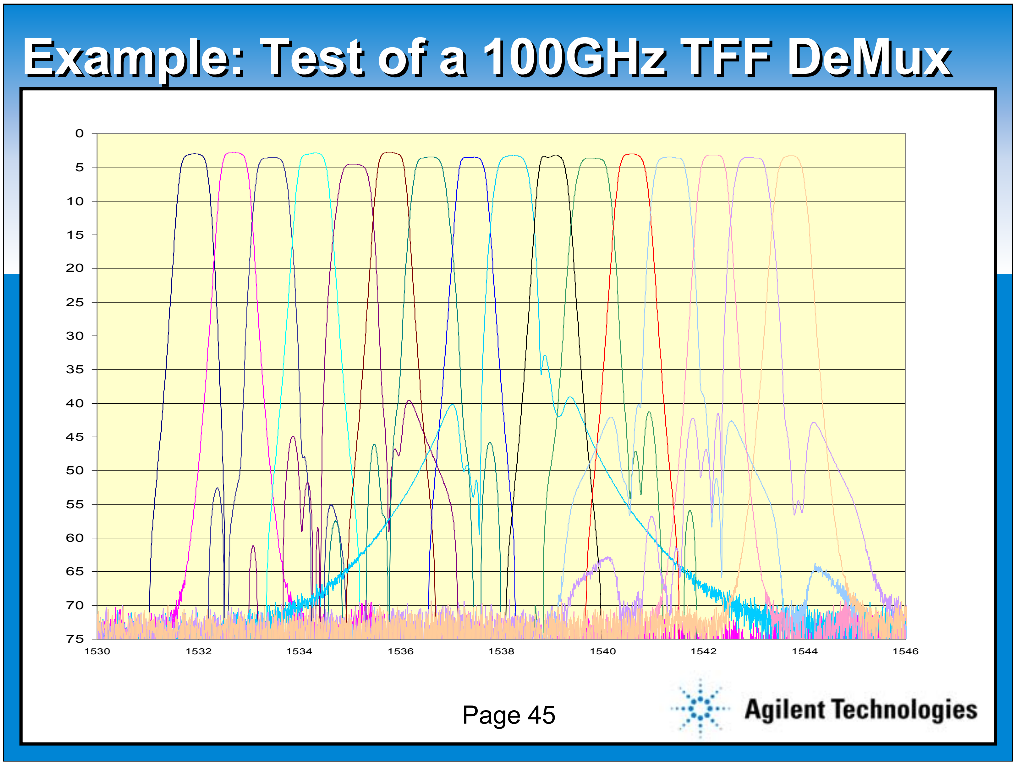
Another issue that is related to the wavelength resolution is dynamic range. In the graph, an isolation between the channels of about 30dB can be seen, but is this really the actual depth? Or is the isolation even higher, but we can not resolve the full dynamic?

This gives us a hint, that wavelength accuracy alone is not sufficient to characterize all components. It is also wavelength resolution.



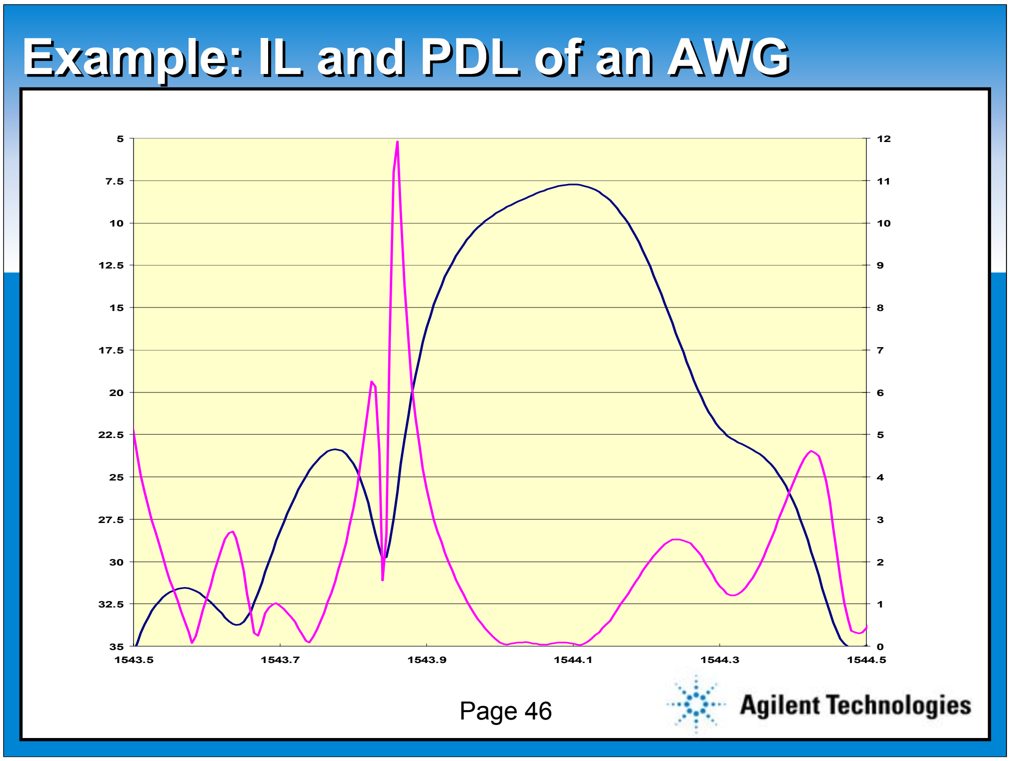
On Slide 35, a typical Loss and PDL measurement setup is shown for measuring multi-channel devices with the swept wavelength method, using tunable laser source, Polarization controller, and multiple power meters. The major advantage of the system can be easily seen: Measurements over wavelength take only seconds to minutes instead of hours, enabled by the continuous tuning and parallel power measruements.

From a technological standpoint, this is a major advance in optical test and measurement: synchronous wavelength and power readings of multiple channels. The power meters are triggered to take a reading whenever a defined wavelength point has been reached during a sweep. The triggering is initiated by the tunable laser source, and the indication for a trigger is taken from the integrated real-time wavelength meter.



On slide 36, a measurement of a 100GHz demultiplexer based on thin film filters is shown. The measurement was taken with a test solution as shown on the previous slide.

This measurement shows 16 Channels, which have been measured all in parallel. Note the high dynamic range of more than 70dB in loss.

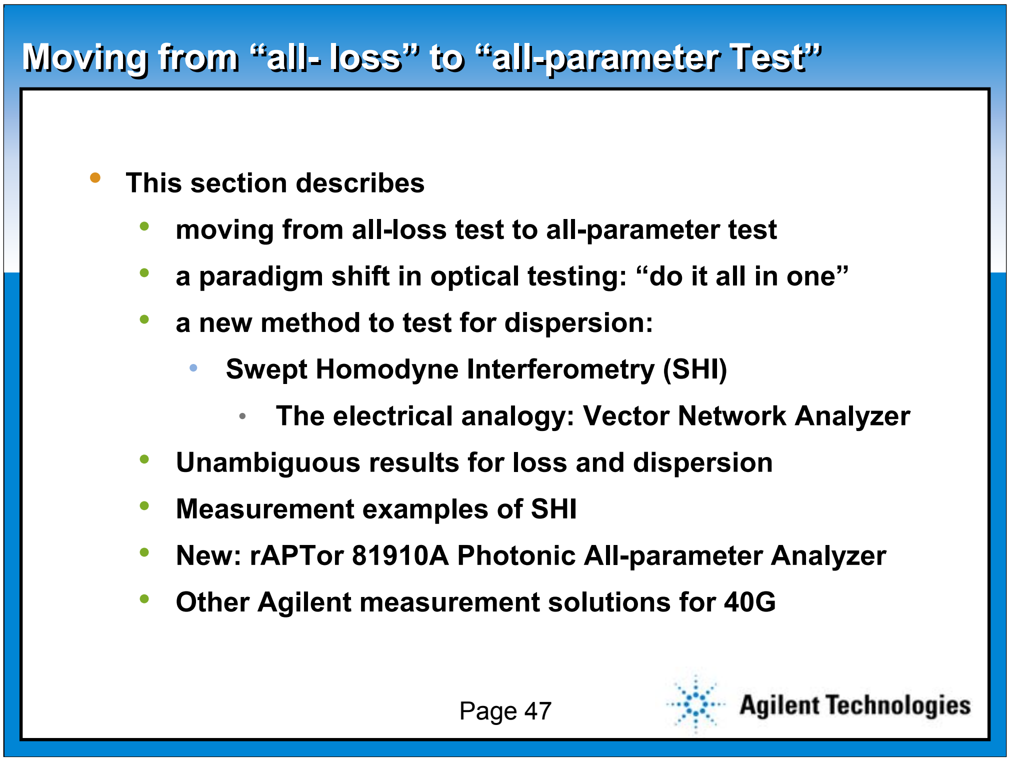


On slide 37, an insertion loss and PDL measurement of one channel of an AWG multiplexer. Again, all other channels of this 40 Channel multiplexers were measured in parallel. For better visibility, only one channel is shown.

The Loss and PDL measurements are again done in swept manner, for PDL the Mueller method was used.

To summarize:

Now I would like to hand over to Ulrich Wagemann, who will talk in the second part of this presentation about combined loss and dispersion measurements.



Up to know we talked about spectral loss only, and its polarization dependency, PDL.

In this part we will discuss

- why we believe that “all-parameter test” is moving into manufacturing;

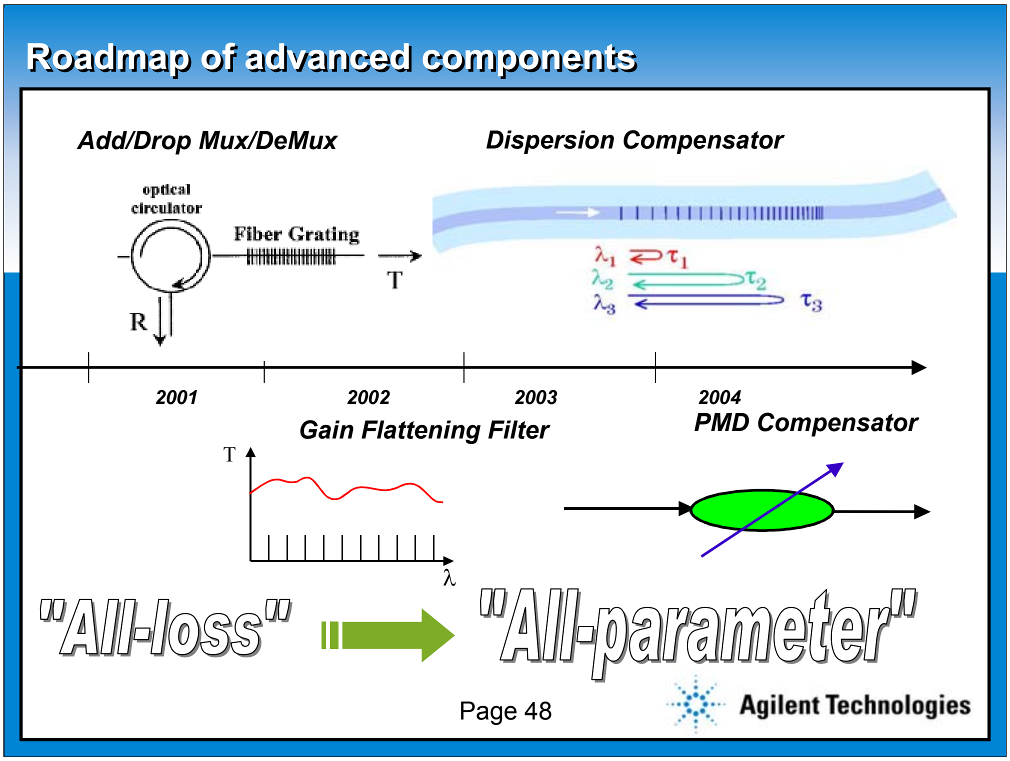
- we will describe what is behind all-parameter test and

- that moving from “all-loss” to “all-parameter test” is a natural way to go.

In this context we will describe a new method to test for dispersion, “Swept Homodyne Interferometry”, and show how it can be combined with the well-known measurement techniques for loss and PDL to achieve unambiguous measurement results for all measurement parameters.

A new instrument that can achieve this is the 81910A Photonic All-parmeter Analyzer” and we will briefly discuss this approach.

The presentation closes with a brief sketch of other Agilent solutions for 40G networks.



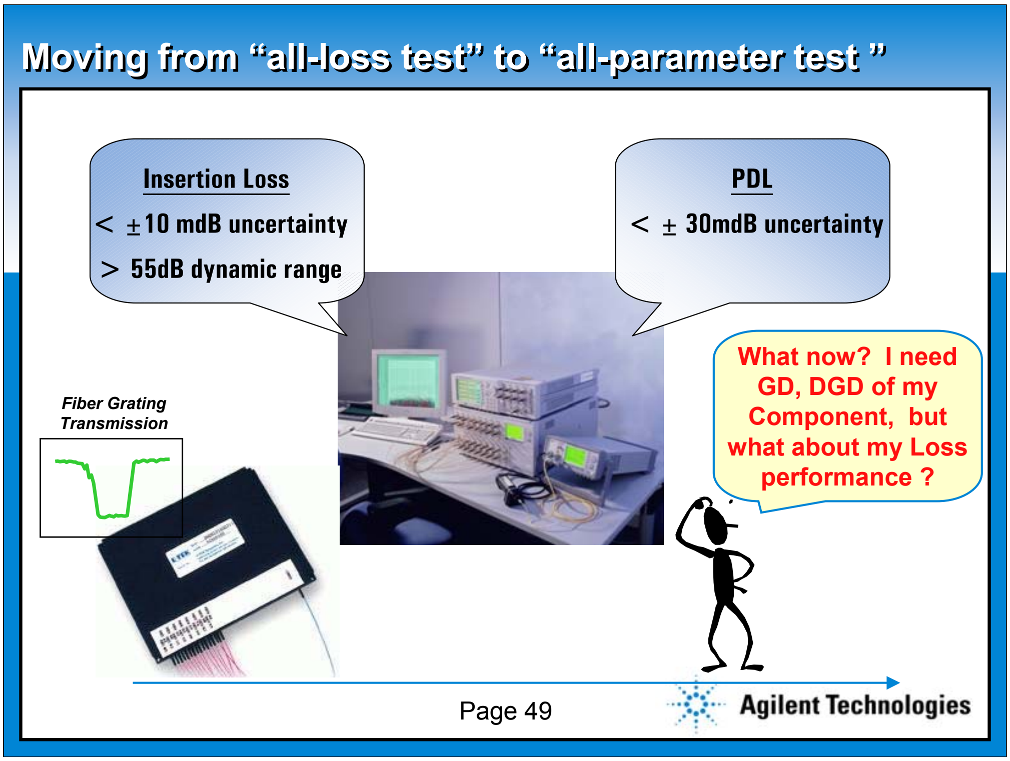
Let us start with the motivation of “all-parameter test”.

On the parametric scale, higher bandwidth can be achieved by higher data rates, more channels, or channels put more densely together. But this is just half of the game, and a view on future components gives some hints here.

Parametric evolution, especially moving to higher bitrates, calls for new components. In the past, components like an add-drop had to be tested for loss only, in the future we have to talk about dispersion as well.

This indicates that in future we have to face more parameters to be controlled and to be specified.

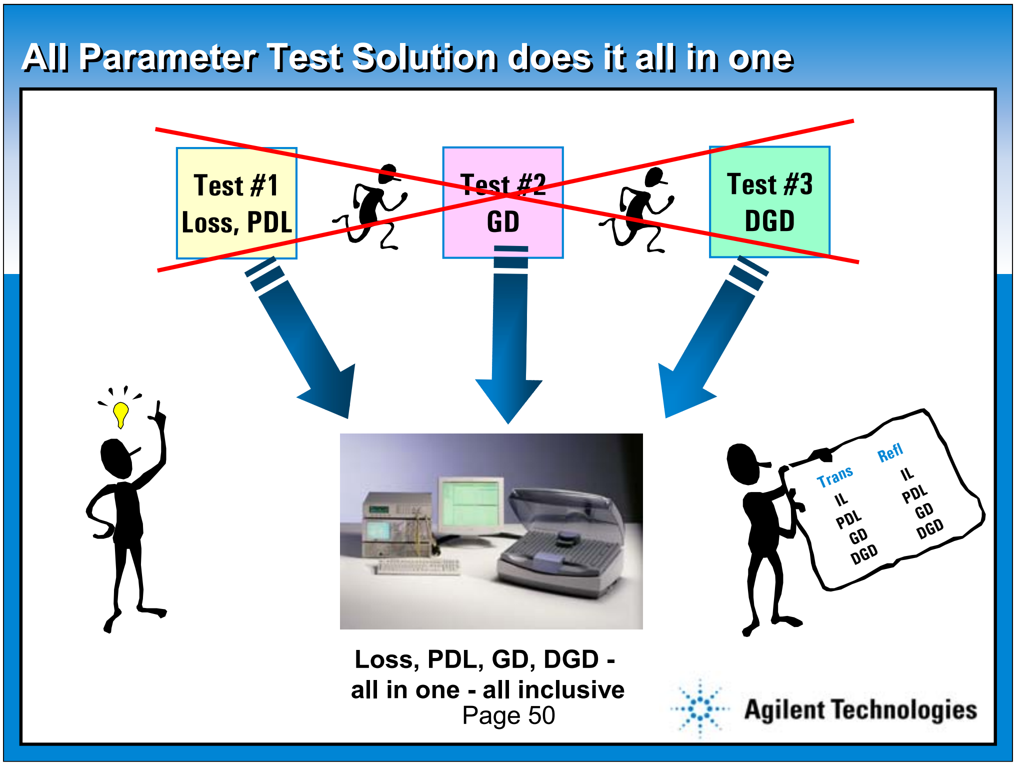
If we talk about all-parameter test, this includes “spectral loss”, “PDL”, Group Delay and Differential Group Delay.



To underline the idea behind All-Parameter Test, consider a typical component manufacturer, a manufacturer of AWGs or FBGs.

He is used to test precisely for loss and PDL up to know - but, driven by his customers, he has to specify his components for dispersion (GD, DGD) now as well.

What is he going to do? Buy an additional solution? Or compromise on some parameters?

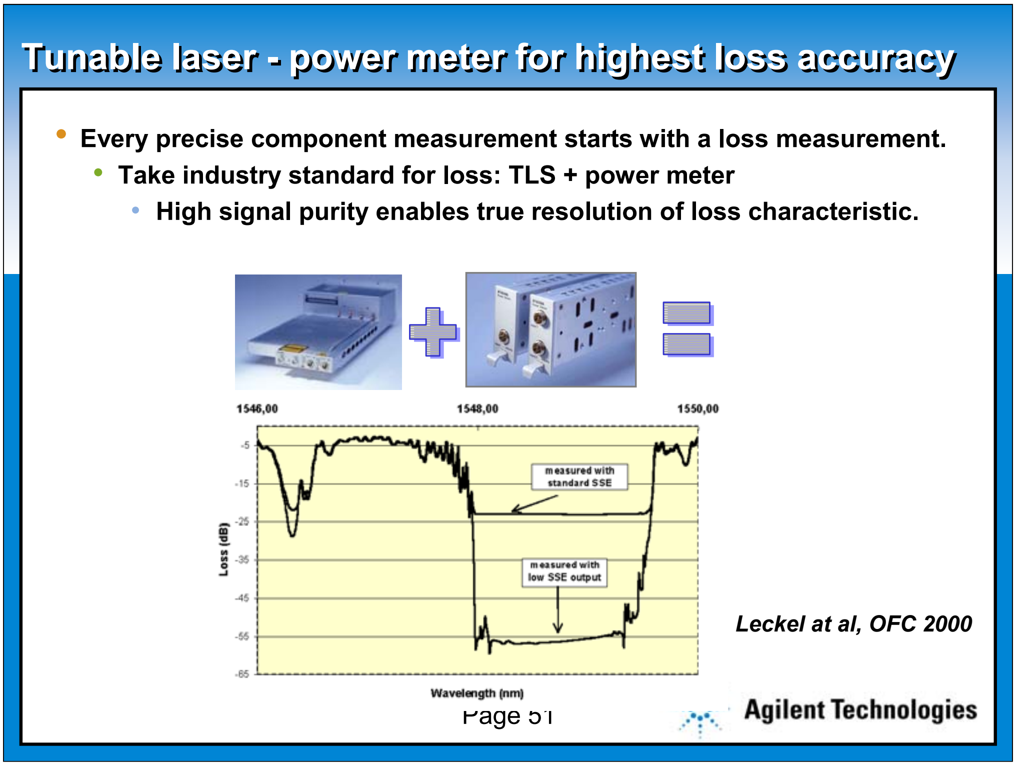


This is where the idea of all-parameter test comes into play.

To enable a smooth extension of loss measurement to "loss and dispersion" test, an ideal fully equipped component test solution should be able to replace two or three individual and individually specialized test stations by a single one.

This would bring benefits in terms of test time, test uncertainty and needed investment.

"All Parameter Test" should include a single device connection as well as test in transmission and reflection simultaneously to fully characterize a component.



So let us think about "all-loss" as a part of an "all-parameter" test solution.

This graph shows how a laser with high signal purity together with a high performance power meter enables the precise characterization of critical passive components like a Fiber Bragg Grating down to the limits. We have learned more about it in previous slides.

If we are moving from all-loss to all-parameter, one way to look at it is to rely on the same building blocks for loss measurements - a Tunable Laser as stimulus and a Power Meter as response for loss and PDL measurements.

Looking for an adequate dispersion test method

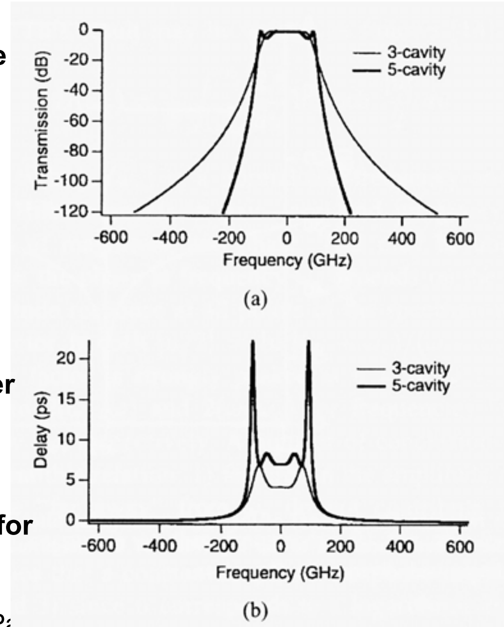
- Advanced components require high resolution and high accuracy for both loss and dispersion test

⇨ Take the industry leading solution for loss:

  ⇨ use swept TLS + power meter.

⇨ Do for dispersion what a laser with high signal purity did for loss

  ⇨ use Swept Homodyne Interferometry (SHI) to test for dispersion

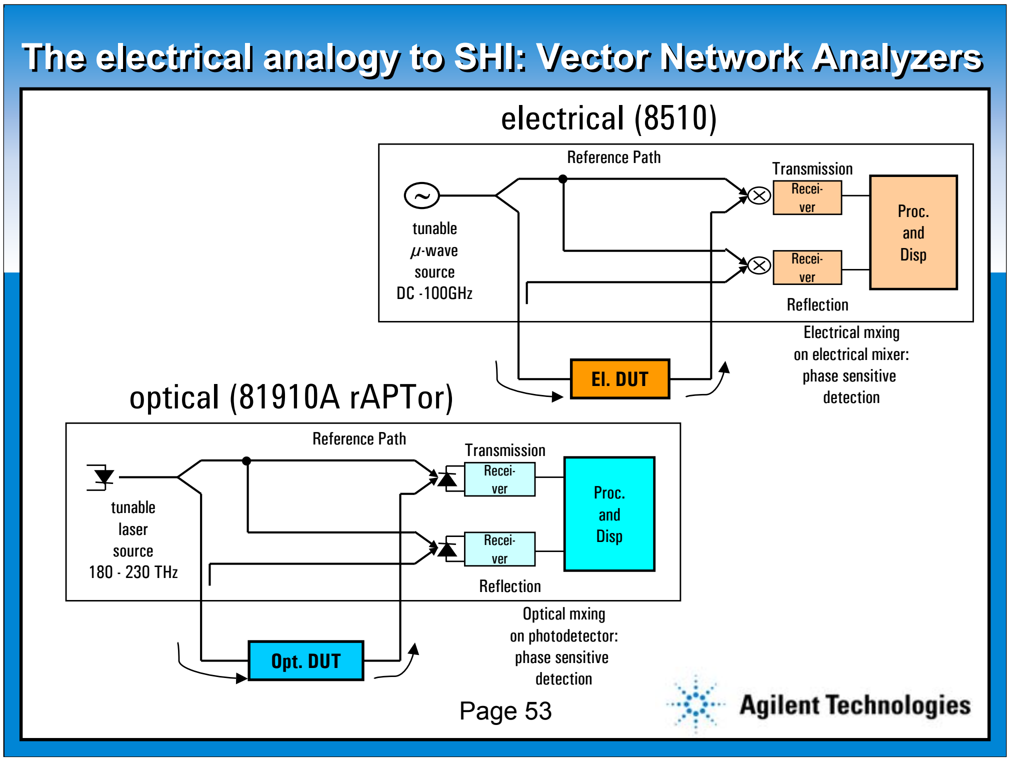


Now how to measure dispersion?

For loss, we have a an accurate test method with high accuracy, high resolution and a high dynamic.

In advanced components loss and dispersion may be related - this is an example of a TFF design - and both loss and dispersion show up with high dynamic traces, sharp edges, steep characteristics. The more steep the loss traces, the more steep the filters dispersion response.

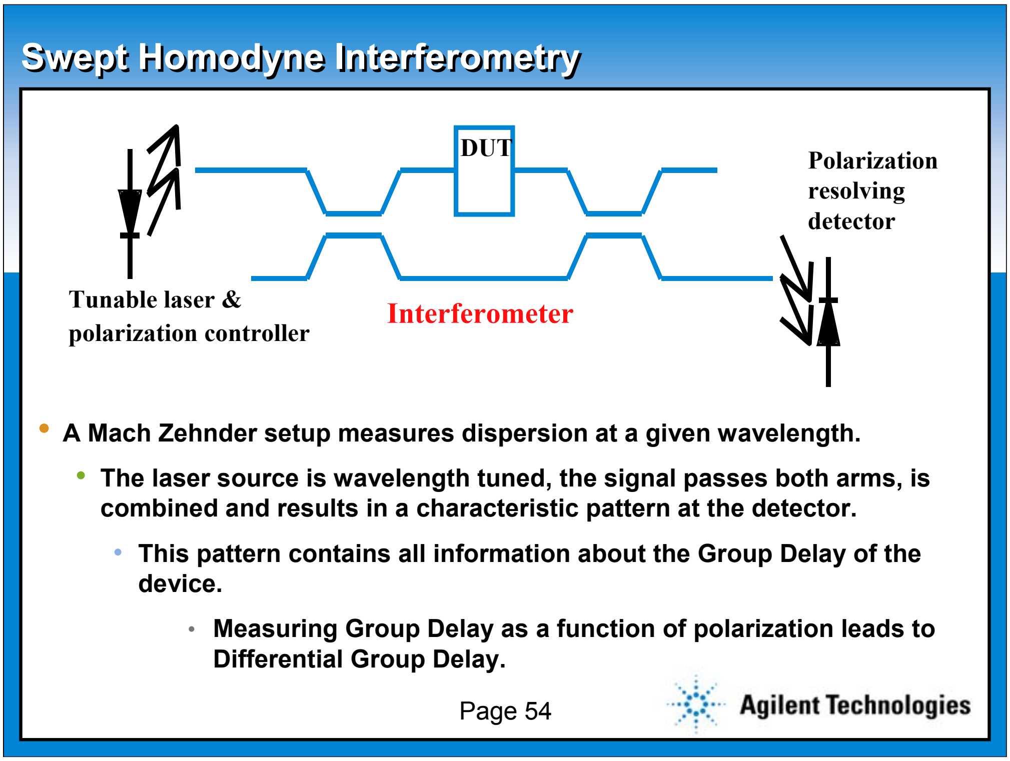
To have a method that is comparable to a swept loss measurement in terms of accuracy, resolution and dynamic it might make sense to think about a new method for dispersion test, also based on a swept wavelength approach, a method called “swept homodyne interferometry”.



Maybe a good way to look at SHI it is the analogy to electrical network analyzers. The architecture fit of an electrical Network Analyzer and Swept Homodyne Interferometry is almost 1:1.

Electrical Network Analyzers are sensitive to phase, and so is the optical setup of Swept Homodyne Interferometry as well.

This is what Swept Homodyne Interferometry does: detect for phase of the DUT - dispersion properties can be easily calculated from this phase information.



So the basic setup for swept homodyne interferometry is very simple (in fact it's a Mach Zehnder Interferometer) - no moving parts are needed.

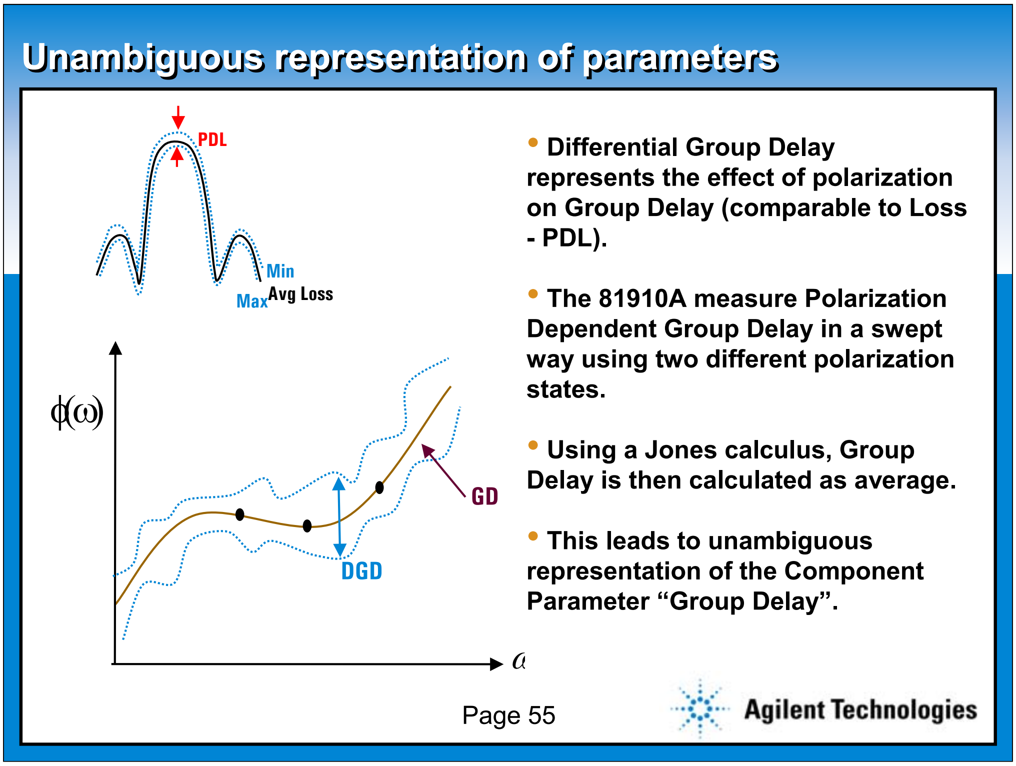
The laser is tuned over wavelength, the light is split and recombined after the DUT, and so called "interference pattern" containing the phase information of the Device Under Test is received by the detector.

From the phase information Group Delay information can be extracted.

Inserting a polarization controller and having a polarization resolving detector allows to check for the dependency of Group Delay over polarization; and the maximum deviation is, by definition, Differential Group Delay.

Swept homodyne interferometry is a swept method, and gives continuous information on both GD and DGD.

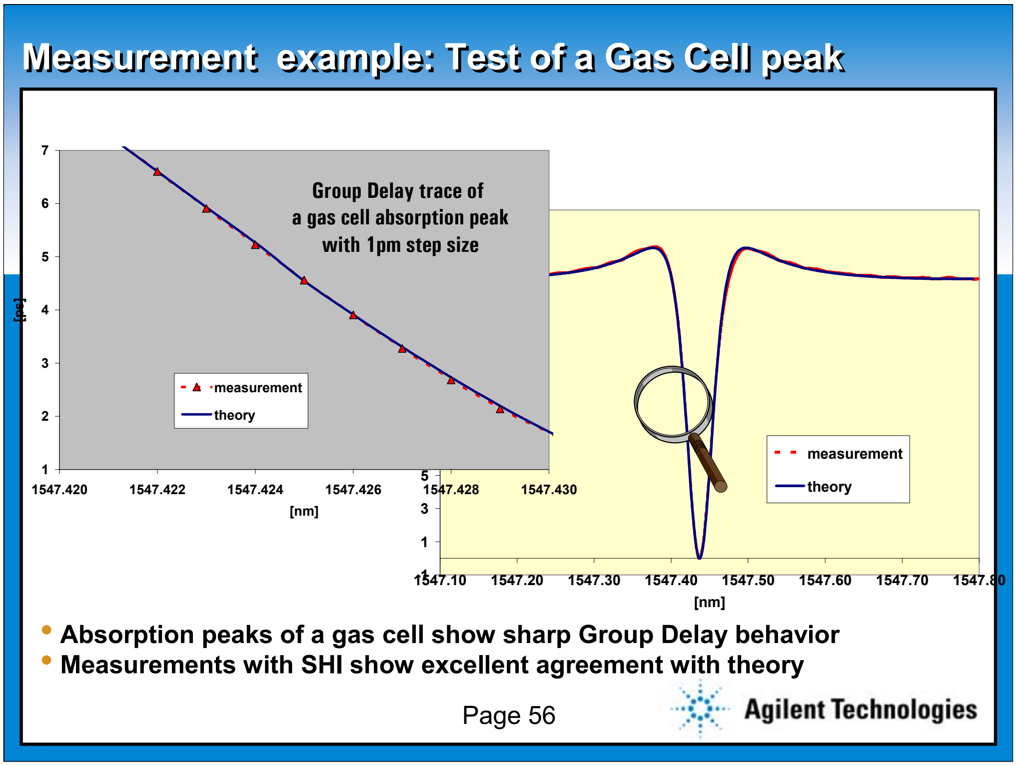
Dispersion information is extracted from a single wavelength signal - basis for high resolution.



When measuring loss most precisely, it should measured and displayed as average over its polarization dependency. To include both average and variance of loss, it makes sense to specify both loss and PDL.

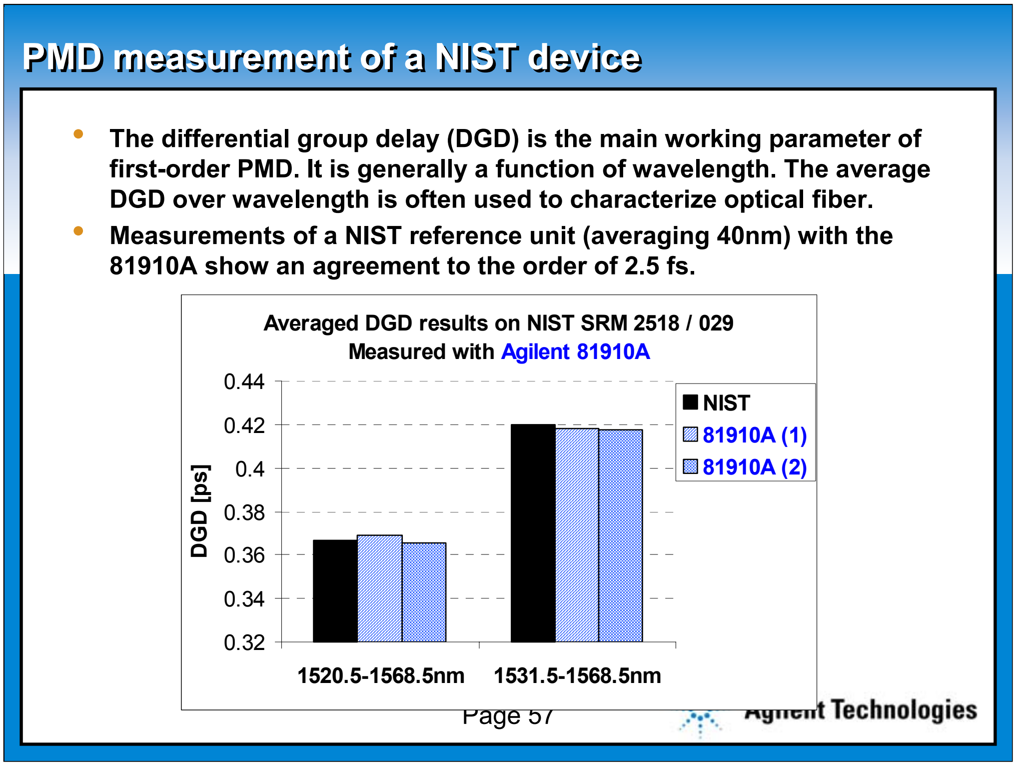
It is very similar between GD and DGD: DGD shows the influence of polarization on GD. So to be accurate, DGD should always be calculated as average over its polarization dependency.

One way to achieve this is to use a polarization resolved SHI method as described above.



To give an example about the resolution and accuracy capability of SHI, let's consider the Group Delay response of an Gas Cell absorption peak.

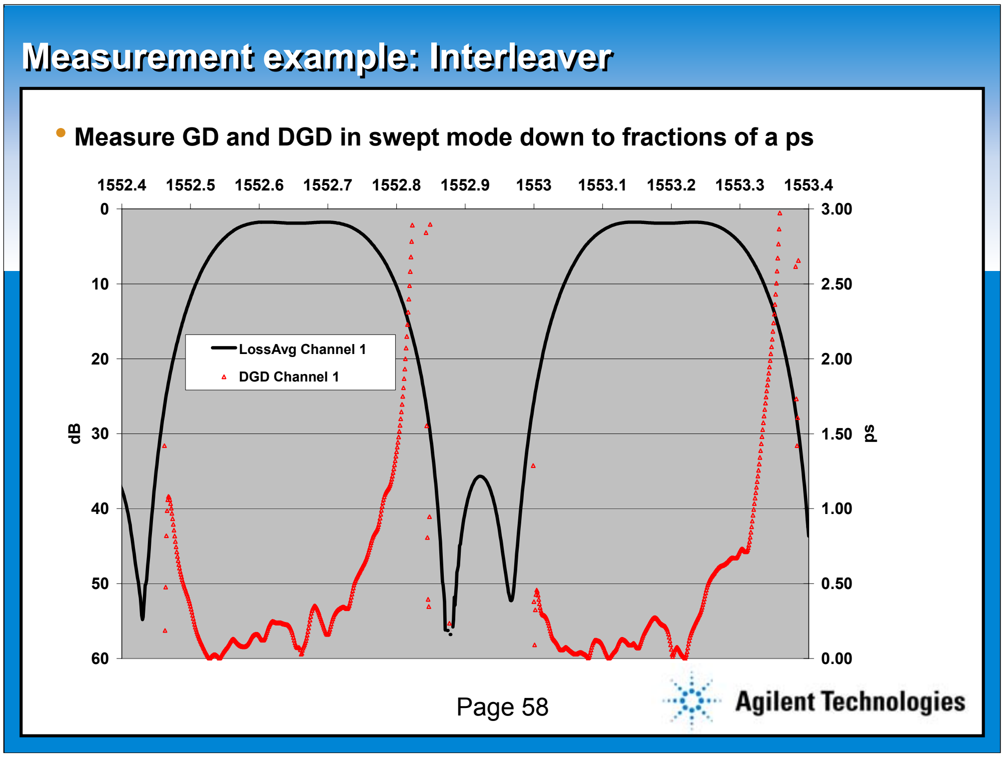
A comparison between theoretical data and measured data shows excellent agreement and gives good confidence in Swept Homodyne Interferomatry as test method for passive components.



Another extreme is test for Polarization Mode Dispersion.

PMD is of same origin than DGD, but more related to fibers and therefore of statistical nature. PMD is mostly averaged over a wavelength range.

A comparison of the performance of SHI against a NIST reference device has been performed within 2.5 fs, which are fairly good data.

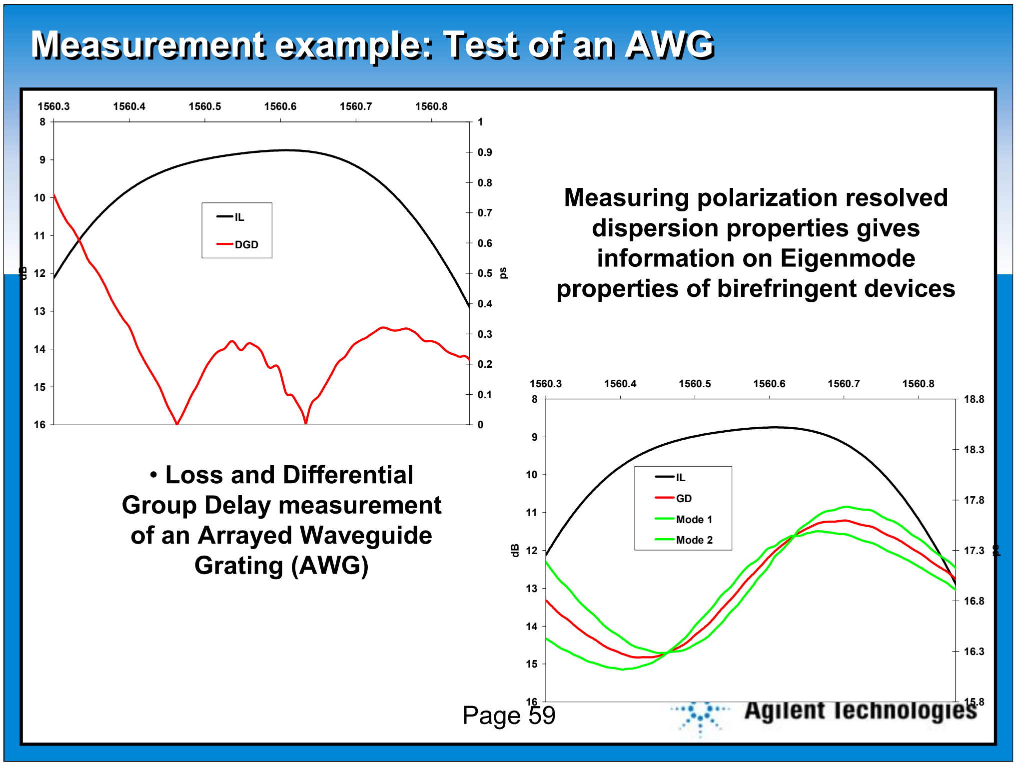


Somewhere in between Gas Cell and PMD measurements we have to consider passive component test.

Coming to typical measurement examples for all-parameter test, these include all wavelength selective components that route, redirect, or block light - like Fiber Gratings, Thin Film Filters or AWGs.

In our discussion we saw that the test requirements -high accuracy, -high resolution, and -high dynamic are valid for both loss and dispersion

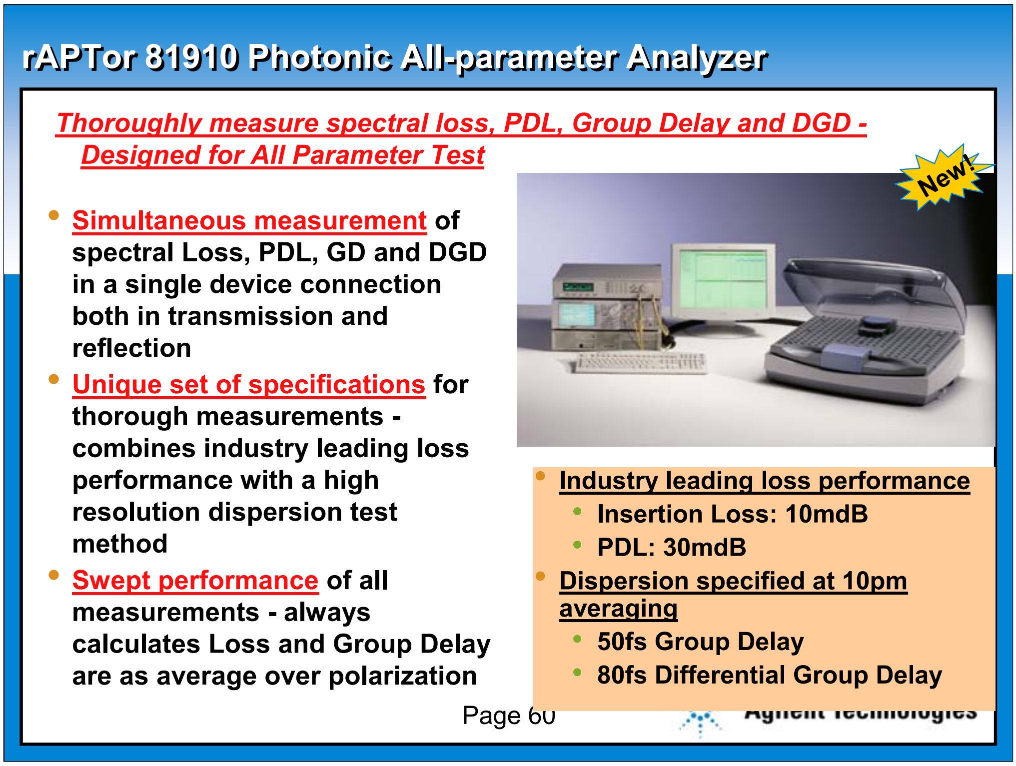
A good example is test of an Interleaver showing high loss dynamics and the continuous DGD data down to fractions of a picosecond.



Doing polarization resolved dispersion measurements and mathematical approaches like Jones algorithms can be used to resolve more inner life of birefringent devices as modes in an AWG.

In this example, DGD shows up with two wavelengths with Zero DGD, and this is exactly where two modes are crossing in wavelength.

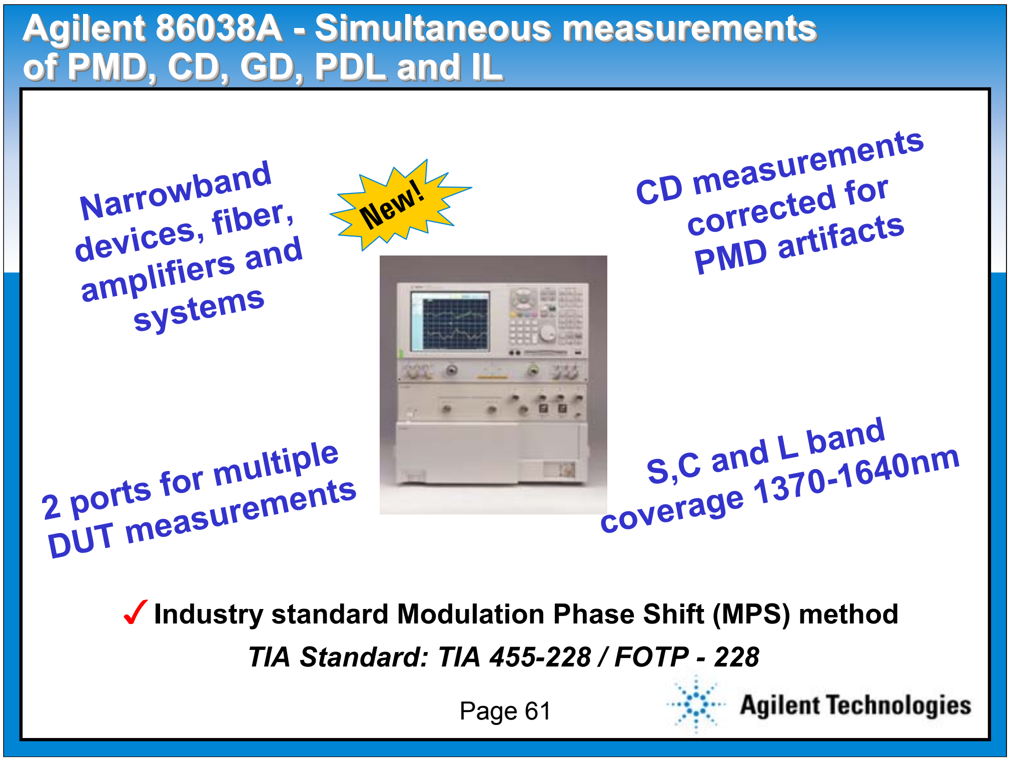
Information like this is of high value for all people involved in design of birefringent devices.



So to summarize here, there is a new Agilent instrument available that comes closest to the challenges of all-parameter test.

It relies on the building blocks for most precise loss and PDL measurements (tunable laser - power meter - polarization controller) and combines SHI as a high resolution, high accuracy, polarization resolving dispersion test method into a single instrument.

That's why we call the 81910A a "All Parameter Test Solution" or All-Parameter Analyzer". All Parameter means that the 81910A measures spectral loss, PDL, GD and DGD with equal importance in a single device connection both in transmission and reflection.



Beside the 81910A Agilent has recently introduced the 86038A Optical Dispersion Analyzer for test of 40G applications. Both solutions are capable to test for loss and dispersion, but with different focus and using different techniques.

The 86038A is the next generation of the CD test system using the modulation phase shift method. The 86038A uses a tunable laser and a high performance network analyzer as receiver and a polarization scrambler for polarization dependent measurements.

Agilent 86038A

Preliminary Specifications

Group delay accuracy (CD) (100MHz to 2GHz)	<± 0.05 ps (50 fs) *
Group delay resolution	1fs
Differential group delay accuracy (PMD) (100MHz to 2GHz)	<± 0.05 ps (50 fs)*
Insertion loss accuracy	< ± 50 mdB
Polarization Dependent Loss accuracy (PDL)	< 100 mdB
Dynamic range	> 50 dB
Measurement Speed for CD / IL	< 3 ms/point
Wavelength accuracy (with integrated 86122A wavemeter)	±0.3 pm*

* Industry leading accuracy

Agilent Technologies

Taking a look at specifications, we see 50fs for both Group Delay and DGD, 50mdB for Insertion loss and 100mdB for PDL.

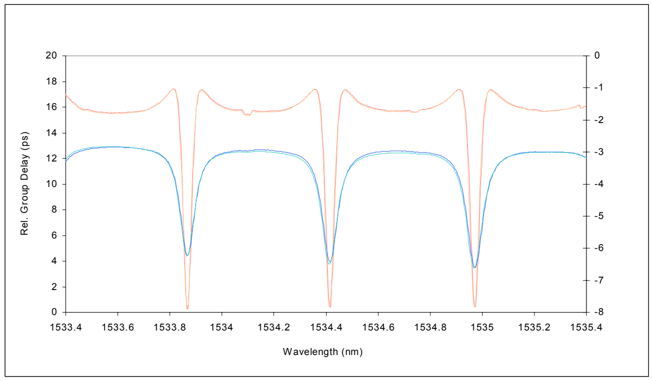
An optional wavelength meter can be used to increase the accuracy down to 0.3pm.

A big step forward especially in speed was realized for Group Delay and Insertion Loss in the order of just a few ms per data point.

Agilent 86038A: Testing of a NIST Gas Cell Response

Excellent resolution and accuracy

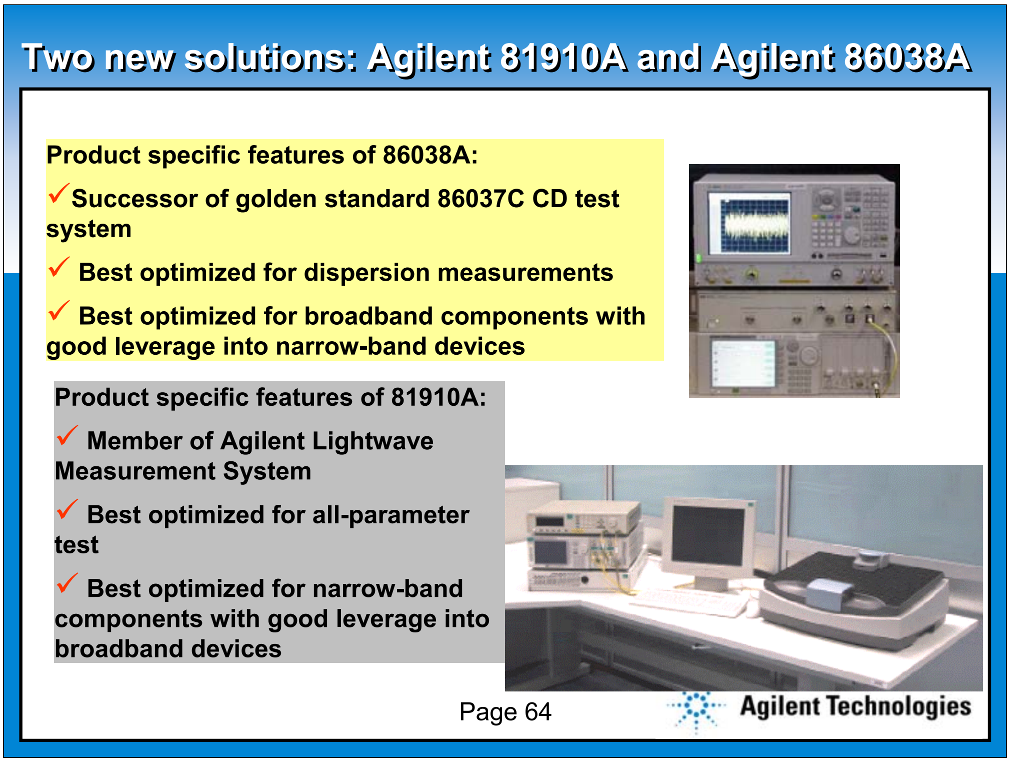
High speed Swept measurement of Group delay and Insertion loss
1pm step size with modulation frequency set to 100 MHz



The ability to cleanly resolve the absorption peaks of a Gas Cell points out the very high resolution measurement capability of the 86038A.

Agilent Technologies

Using a high performance network analyzer, the system allows to set modualtion frequencies as low as 100MHz and has performance capability to clearly resolve finest GD traces - as for example of an Absorption Gas Cell.

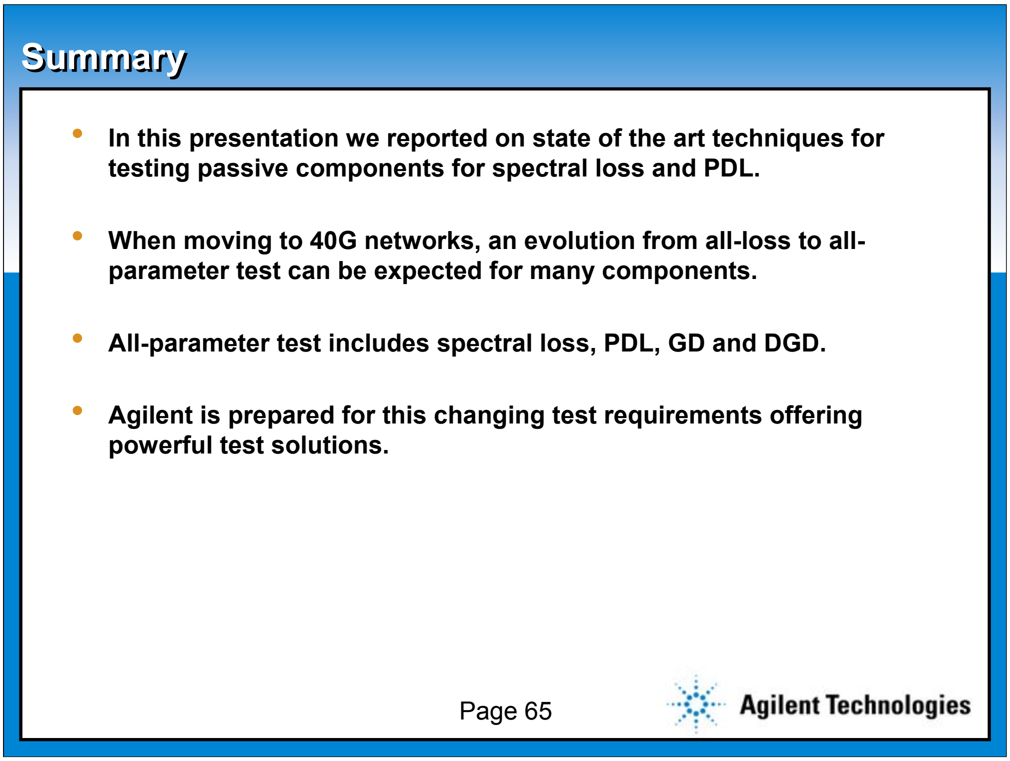


Having these two strong solutions, Agilent is prepared to address all applications from system test down to thorough component test optimally, covering all user preferences, user needs and use models, and all devices under test.

For easy notification, we noted three bullets describing the core of the products. One describes the history, one what it does and one for what. These bullets make most sense if seen as whole.

For the 81910A this would read: “A member of the LM system, an all parameter test solution for narrow-band components”

To learn more about both products, please check our web sites and webcasts from earlier this year.



To summarize here, in this presentation we reported on state of the art techniques for testing passive components for spectral loss and PDL.

We saw, that moving to 40G networks might require an evolution from all-loss to all-parameter test for many components.

All-parameter test will then include spectral loss, PDL, GD and DGD.

Agilent is prepared for this changing test requirements offering powerful test solutions.

Further information

- www.agilent.com
- www.photonic-all-parameter.com
- www.netseminar.com

•Special Thanks to Paul Hernday

Agilent Technologies