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TECHNICAL REPORT

colour inside

Dynamic modules –
Part 6-3: Round robin measurement results for group delay ripple of tunable dispersion compensators

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DYNAMIC MODULES –

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FOREWORD

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IEC 62343-6-3, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/917/DTR	86C/952/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of IEC 62343 series, published under the general title *Dynamic modules,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The most important means of enhancing the technology for communication systems are networking, faster speed, and longer distance. In long-distance, high-speed communication systems operating at 40 Gbps or more, dispersion is known to limit transmission distance. Various tunable dispersion compensators (TDCs) have been commercialized in order to minimize the degradation of signals caused by chromatic dispersion. However, the group delay (GD) in TDCs is known to have ripples dependent on the principles of TDC operation, and such GD affects signal degradation.

IEC TC86 (*Fibre optics*) describes several methods of measuring chromatic dispersion (CD). One example is IEC 61300-3-38, but it does not specify a measurement method for group delay ripple (GDR). The representative passive component for compensating for chromatic dispersion is dispersion compensation fibre (DCF), but given its principles, the GD has no ripples. Conversely, many TDCs use the interference effect, which explains why there are ripples.

Under these circumstances, round robin testing has been conducted by using various TDCs and diverse GD measurement methods. This technical report, based on the findings from round robin testing, examines the direction of standardization for GDR measurement methods.

This technical report is based on and translated from OITDA document- TP06/SP DM-2008 (Group Delay Ripple Measurement Method for Tunable Dispersion Compensators－Technical Paper).

DYNAMIC MODULES –

Part 6-3: Round robin measurement results for group delay ripple of tunable dispersion compensators

1 Scope

This technical report describes the round robin measurement results for the group delay ripple (GDR) of tunable dispersion compensators (TDCs). It briefly explains the four typical TDCs measured and four typical methods of measuring group delay (GD), as well as the GDR round robin measurement results of TDCs, and an analysis of repeatability and differences among these measurement methods. This technical report also proposes suitable measurement parameters and a new parameter of phase ripple instead of GDR.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/PAS 61300-3-38, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-38: Group delay and chromatic dispersion*

IEC 62343-1-2, *Dynamic modules – Part 1-2: Performance standards – Dynamic chromatic dispersion compensator with pigtails for use in controlled environments (Category C)*

3 Abbreviated terms

For the purposes of this document, the abbreviated terms apply.

CD	chromatic dispersion
DGD	differential group delay
DUT	device under test
EOP	eye opening penalty
FBG	fibre Bragg grating
FSR	free spectral range
GD	group delay
GDR	group delay ripple
MPS	modulation phase shift
MZ	Mach-Zender
PLC	planar lightwave circuit
PPS	polarization phase shift
RBW	resolution bandwidth
SWI	swept wavelength interferometry
TDC	tunable dispersion compensator
VIPA	virtually imaged phased array

4 Types of tunable dispersion compensators (TDCs)

Various TDCs have been announced and commercialized in the market. The following briefly describes typical TDCs.

4.1 Virtual imaged phased array (VIPA)

Figure 1 shows the structure of a virtually imaged phased array (VIPA). The input light from a single-mode fibre is line-focused onto a glass plate. The glass plate is coated on both sides and collimated light is emitted from the reverse side of the glass after multiple reflections on the glass plate. The light from the glass plate is focused onto a curved mirror. The reflected light travels back to the glass plate and is finally coupled to the fibre. The 3-dimensional mirror is moved to vary the optical distance for each wavelength, thereby changing the CD.

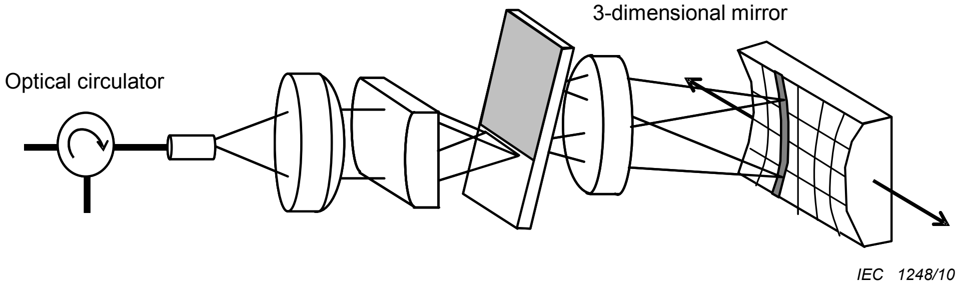


Figure 1 – Structure of the VIPA

4.2 Fibre Bragg grating (FBG)

An FBG periodically changes the refraction index of the optical fibre core, thereby forming a grating to generate Bragg diffraction, which functions as a reflection filter. Gradually changing the pitch of Bragg diffraction varies the reflection return time according to wavelength, thereby generating CD. The temperature of the fibre formed in the FBG can be varied or given tension to change the FBG pitch. This principle is used to change the CD.

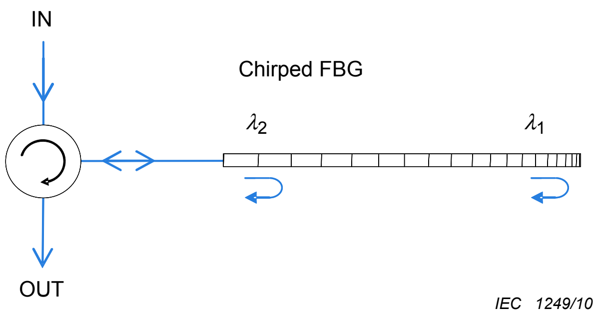
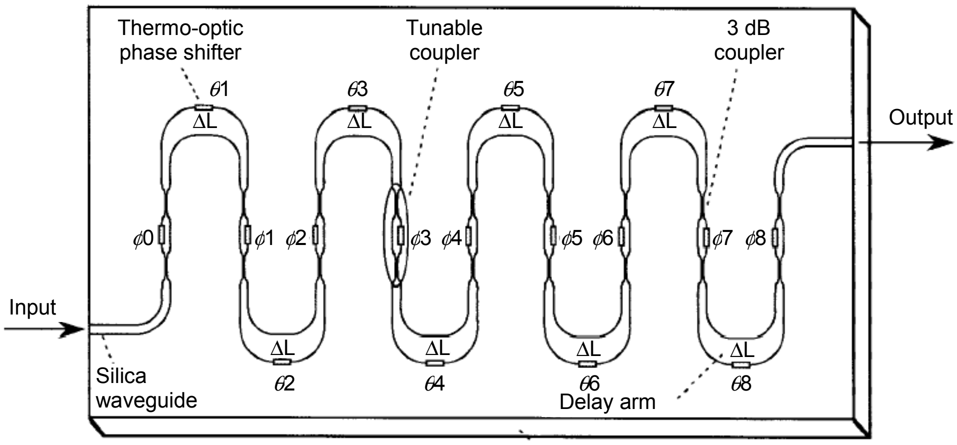


Figure 2 – Chirped fibre grating

4.3 Planar lightwave circuit (PLC)

A ring resonator can be formed on a quartz lightwave circuit. The resulting interference effect can then be used to produce periodic loss and GD characteristics over the wavelength. Moreover, the ring resonator can be replaced with MZ interference circuits in multiple stages to produce similar effects. The temperatures of some of these interference circuits can be varied to change the CD.



IEC 1250/10

Figure 3 – PLC (MZ interference circuit)

4.4 Etalon

Etalon is an optical cavity housing a pair of parallel reflective mirrors. Multiple reflection interference between two filters yields a cyclic spectrum and dispersion characteristics. The period of the cyclic spectrum is called free spectral range (FSR). The operating wavelength and FSR can be adjusted by changing the optical distance between both mirrors. A Gires-Tournois interferometer (shown in Figure 4 below) is suitable for dispersion compensation.

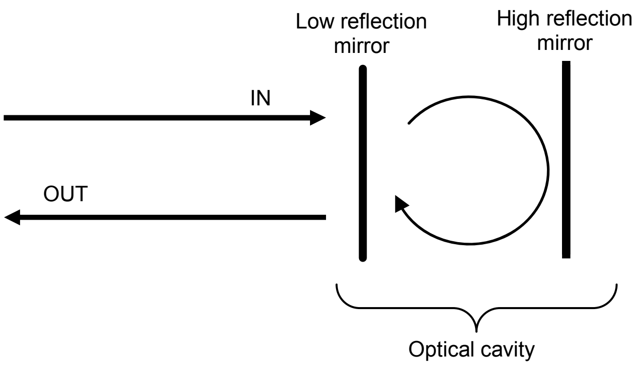


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Figure 4 – Etalon (Gires-Tournois interferometer)

5 Measurement methods

The following describes the representative methods of measuring GD. Refer to IEC/PAS 61300-3-38 for details.

5.1 Modulation phase shift (MPS) method

The MPS method is used to calculate GD and CD by adding amplitude modulation to output light from a wavelength-variable light source, receiving it with a receiver through a device under test (DUT), and then analyzing the wavelength dependence of the phase of the demodulated signal received. The wavelength resolution depends on the signal's modulation frequency. Because there is a trade-off between wavelength resolution and measurement accuracy, modulation frequency is an important measurement parameter.

5.2 Modulation phase shift-Mueller matrix (MPS-Mueller) method

The MPS-Mueller method combines the MPS method with a process to produce four polarization states of modulated light entering the DUT, and then solving the Mueller matrix for each phase calculated, thereby calculating GD and CD in an average polarization state. Similarly to the MPS method, modulation frequency becomes an important measurement parameter.

5.3 Polarization phase shift (PPS) method

The PPS method expands on the MPS method by adding hardware to divide the light beam transmitted through the DUT into two orthogonal polarized beams. The two polarization states are analyzed and GD and CD are calculated for an average polarization state. Similar to the MPS method, modulation frequency becomes an important measurement parameter.

5.4 Swept wavelength interferometry (SWI) method

Unlike the method above, the SWI method does not modulate the light beams measured. The wavelength of the wavelength-varied light source is swept before entering the receiver via the Mach-Zehnder (MZ) interferometer. With two paths through the MZ interferometer, one as the reference path and one through the interfered signal into the receiver are analyzed to determine the phase of light. The resultant findings are then used to calculate GD and CD. That is how this method works. Since the setting of wavelength resolution and measurement accuracy can be changed to oppose each other, wavelength resolution becomes an important measurement parameter.

6 DUTs and test parameters

Table 1 lists the DUTs measured and the measurement methods used. For the MPS and SWI methods, products from two different manufacturers identified as (A) and (B), respectively, were used depending on the test date. The PPS and MPS (A) methods used the same measuring equipment, with only the measurement method being switched over. The same is true of the MPS-Mueller and MPS (B) methods. Moreover, the SWI (A) method is based on a homodyne-type interferometer, while the SWI (B) method is based on a heterodyne-based interferometer.

Table 1 – DUTs and measurement methods used in round robin testing

DUTs	Measurement methods
VIPA	PPS, MPS (A), SWI (A)
FBG (1) FBG (2) FBG (3)	PPS, MPS (A), SWI (A) MPS-Mueller, PPS, MPS (A) MPS-Mueller, PPS, MPS (A)
PLC	MPS-Mueller, MPS (B), SWI (B)
Etalon	MPS-Mueller, MPS (B), SWI (B)

MPS (A) MPS mode of PPS test equipment

MPS (B) MPS mode of MPS-Mueller test equipment

SWI (A) Homodyne type

SWI (B) Heterodyne type

In comparing measurement results obtained using the measurement methods above, the measurement conditions concerning wavelength resolution, wavelength steps for the data obtained, average frequency, and measurement conditions for smoothing operation are set as shown below. The wavelength resolution was specified directly with resolution bandwidth (RBW) for the SWI method. For the MPS method, MPS-Mueller method and PPS method, modulation frequency is used to make this setting. Table 2 lists the relation between RBW and modulation frequency in the wavelength resolution used in this test. In the test results given below, wavelength resolution is specified as RBW in all measurement methods.

– Wavelength resolution: 2 pm, 4 pm, 8 pm, 16 pm, 32 pm
– Wavelength increment: 1 pm
– Averaging: 1 (MPS, MPS-Mueller, PPS), 10 (SWI)
– Smoothing: no

Table 2 – RBW and modulation frequency

RBW pm	**Modulation frequency** MHz
2	125
4	250
8	500
16	1 000
32	2 000

Linear fitting was conducted on the GD measurement results for the bandwidth specified in the TDC specifications (i.e., 3 dB band of IL, unless otherwise specified), and after the deviation from the linear curve was calculated, the peak to peak amplitude of GDR was extracted from typical ripple.

To consider repeatability, three measurements were taken (or two with some TDCs) under the same conditions.

7 Measurement results

The following describes the results of round robin testing on each TDC.

7.1 VIPA

The wavelength range of GDR analysis was specified as 1 549,16 nm to 1 549,44 nm, with the CD value set to 2 points: 0 ps/nm and 1 000 ps/nm. The PPS, MPS (A) and SWI (A) measurement methods were used. The PPS and MPS (A) methods used the same measuring equipment. Figure 5 shows the measurement results of GD and IL (insertion loss) obtained with the CD value set to 0 ps/nm. In this example, the SWI (A) method was used with RBW set to 8 pm.

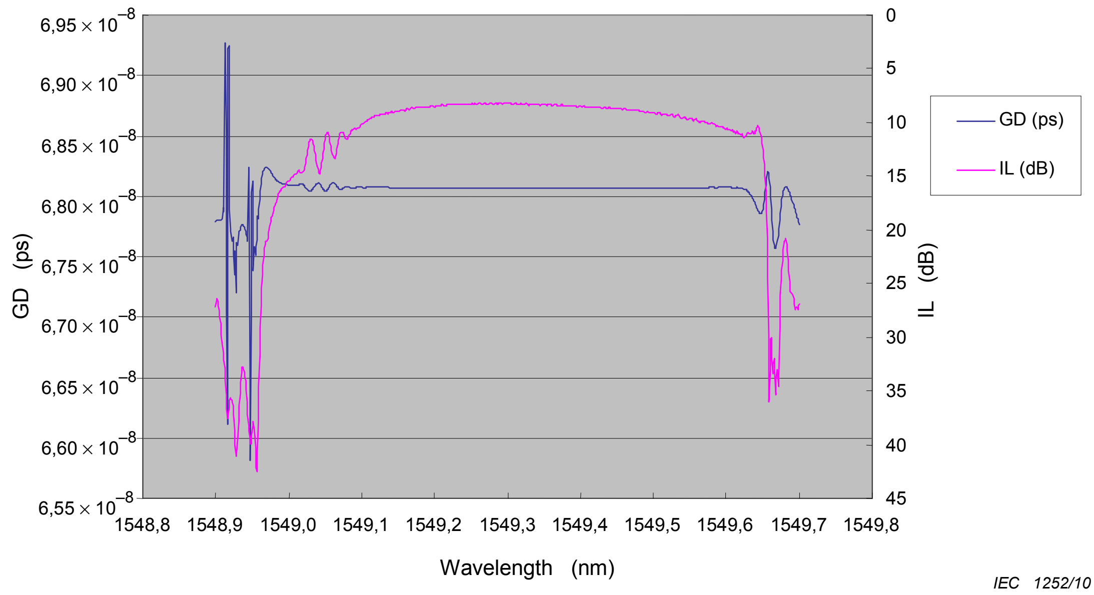

Figure 5 – GD and IL of the VIPA

Figure 6 shows GD deviation from linear fitting with the CD value set to 0 ps/nm, and RBW set to 8 pm.

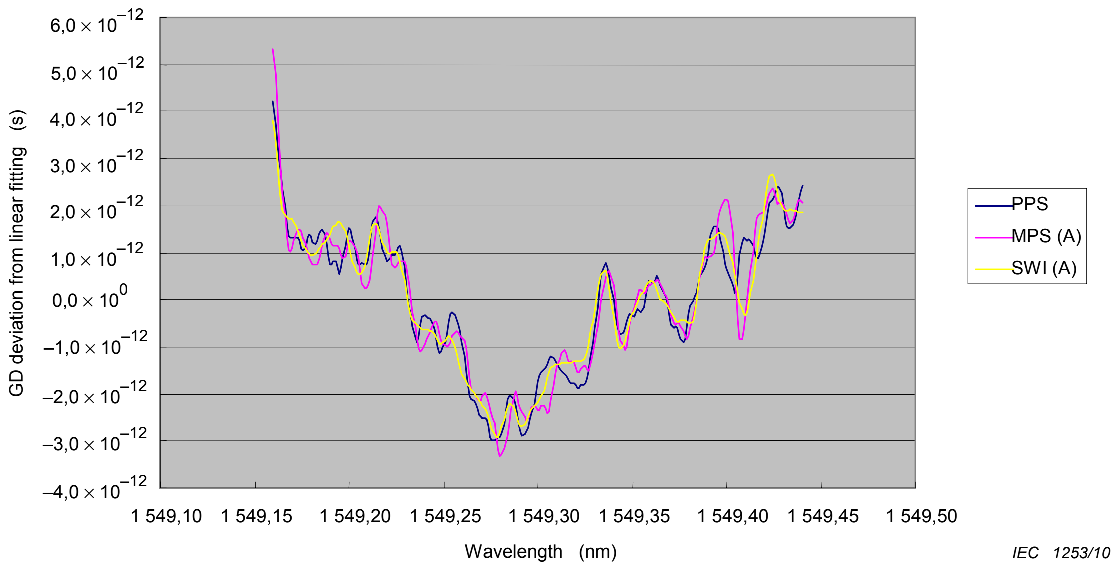

Figure 6 – GD deviation with each measurement method of the VIPA

Figure 7 shows the measurement results obtained with the CD value set to 0 ps/nm. The MPS (A) method was used to take measurements, with RBW being set to 2 pm, 4 pm, 8 pm, 16 pm and 32 pm. When RBW was set to 2 pm and 4 pm, the period of GDR was 8 pm.

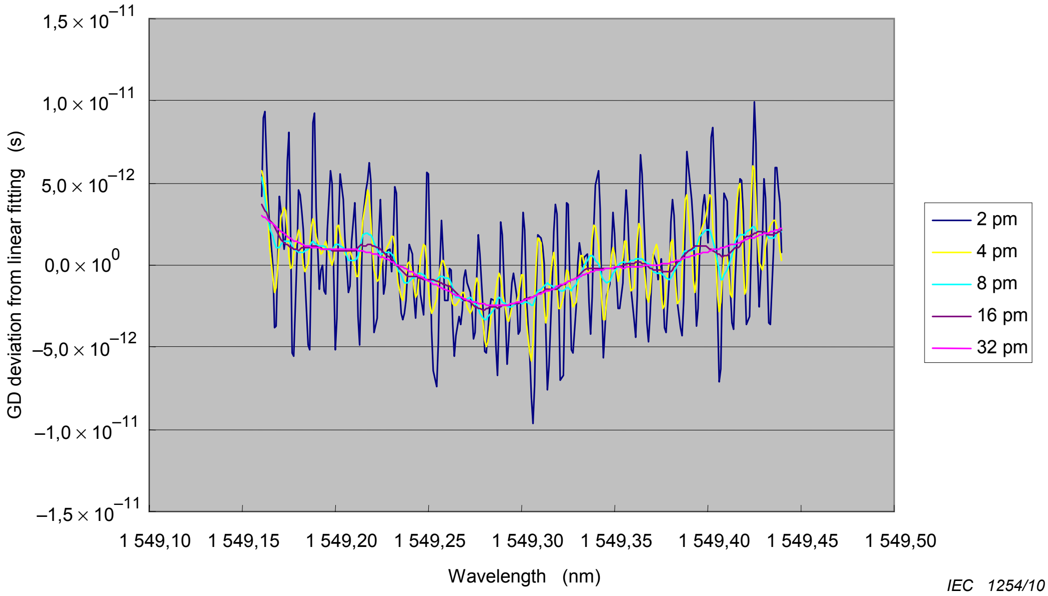

Figure 7 – GD deviation at different RBWs of the VIPA

Figure 8 summarizes the measurement results. When RBW is 8 pm or more, changing the CD setting will not change the GDR value much. The smaller the RBW, the larger GDR tends to be. When RBW is 2 pm and 4 pm, GDR tends to be larger in the PPS and MPS (A) methods than in the SWI (A) method. The PPS and MPS (A) methods have somewhat different values though using the same measuring equipment. This is because the PPS method is considered to cancel the artifact of differential group delay (DGD).

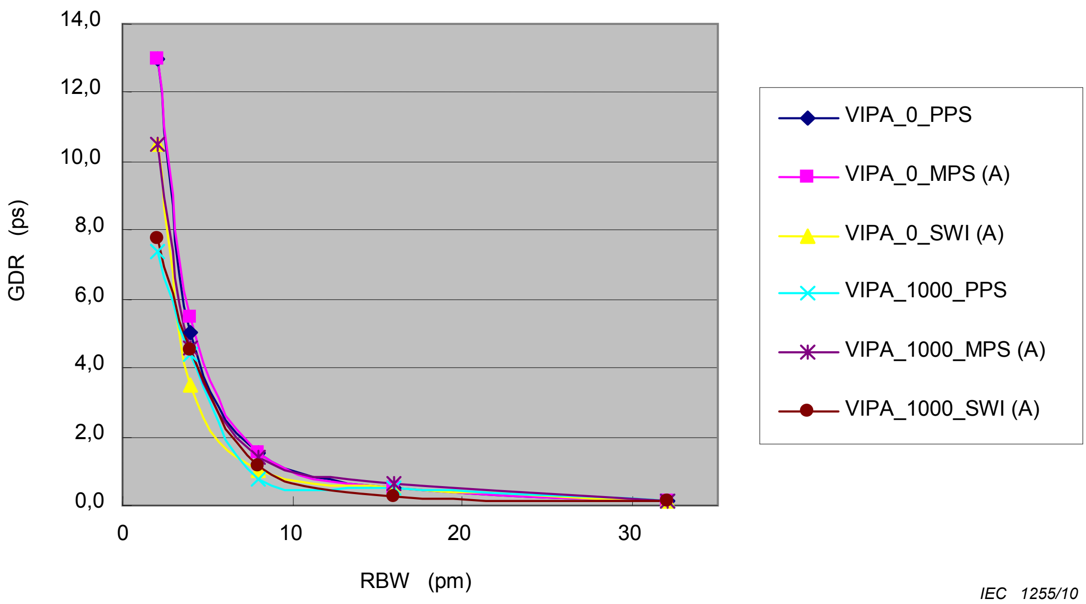

Figure 8 – Summary of GDR measurement results of the VIPA

Two measurements were taken. Figure 9 shows the differences in measurement results under the same conditions. Setting RBW to 8 pm or more produces repeatability of about 0,5 ps.

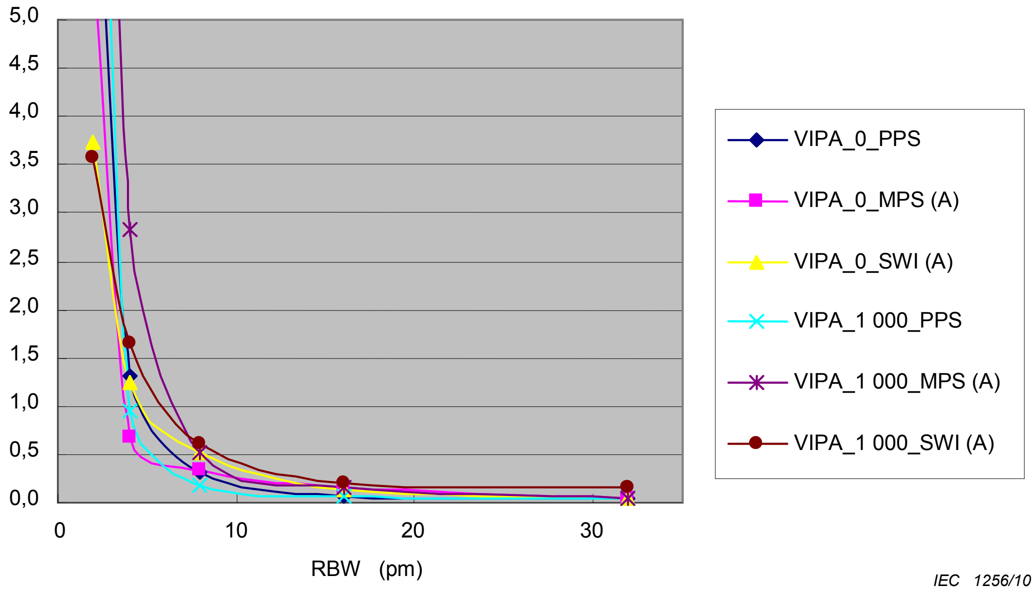

Figure 9 – Summary of GDR repeatability of the VIPA

7.2 FBG

For the FBG, three DUTs having different characteristics were measured. The CD values were set as follows: -193 ps/nm, -251 ps/nm and -371 ps/nm for FBG1; -196 ps/nm and -380 ps/nm for FBG2; -240 ps/nm and -390 ps/nm for FBG3. Since the wavelength range of GDR analysis is set within the 3 dB bandwidth of IL, it varies with the DUT and CD settings. FBG1 is a standard product, but FBG2 and FBG3, are intentionally provided DUTs having larger GDR and GDR periods than the standard product. The PPS, MPS (A) and SWI (A) measurement methods were used for FBG1; the MPS-Mueller, PPS and MPS (A) methods were used for FBG2 and FBG3. The PPS and MPS (A) methods used the same measuring equipment. Figure 10 shows the GD and IL characteristics of FBG1 with the CD value set to -251 ps/nm. In this example, the SWI (A) method was used to set RBW to 8 pm. For an unspecified reason, RBW was set to 2 pm, 8 pm, 16 pm and 32 pm for measurement only for FBG1.

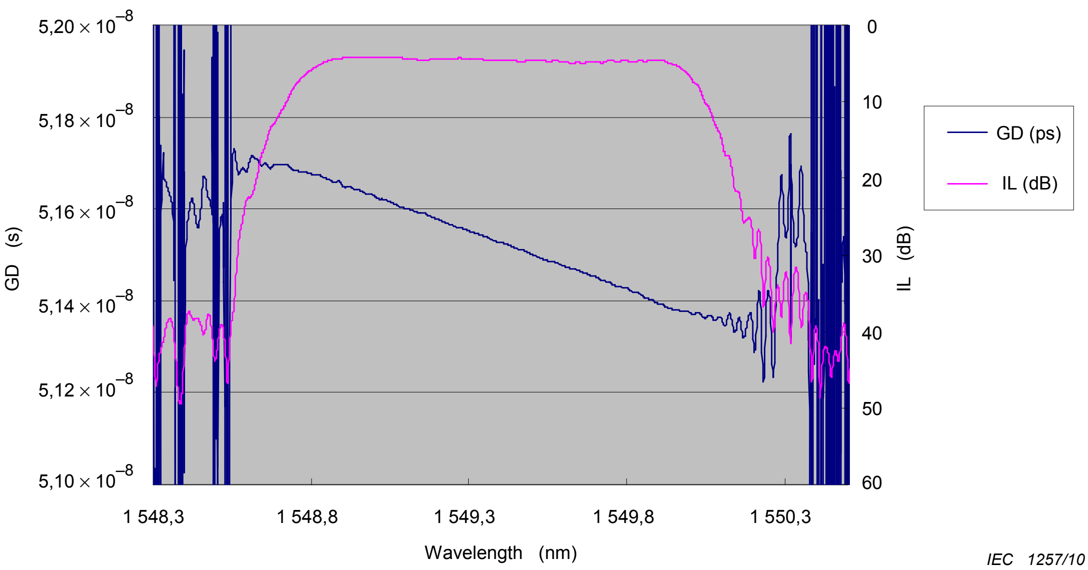

Figure 10 – GD and IL of FBG1

Figure 11 shows the GD deviation from linear fitting with the CD value set to -251 ps/nm for FBG1and RBW set to 8 pm.

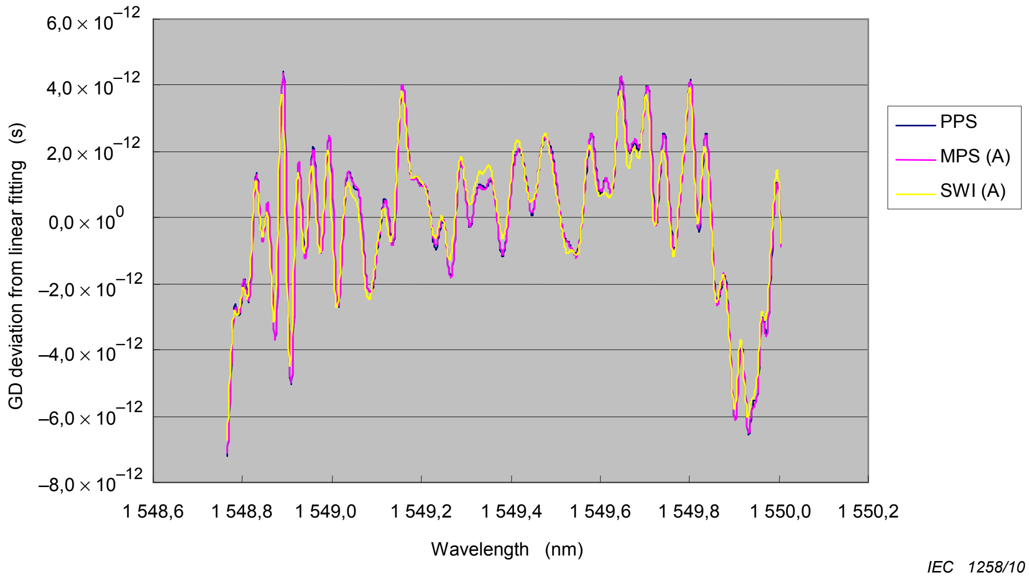

Figure 11 – GD deviation with each measurement method of FBG1

Figure 12 shows the measurement results obtained with the CD value set to -251 ps/nm. The SWI (A) method was used with RBW being set to 2 pm, 8 pm, 16 pm and 32 pm. The GDR periods were as follows: 30 pm for FBG1, 40 pm for FBG2, and 40 pm for FBG3.

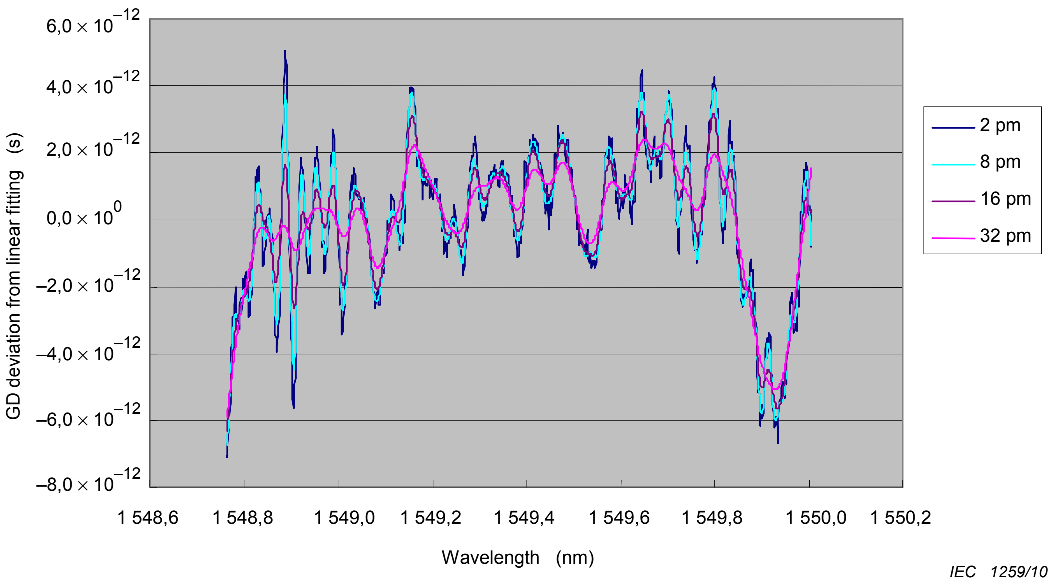

Figure 12 – GD deviation at different RBWs of FBG1

Figure 13 summarizes the measurement results. Measurements were taken with different CD values set for each DUT. However, GDR did not vary much. Therefore, only the results obtained at the typical CD settings are indicated for each DUT. The smaller the RBW, the larger GDR tends to be. For FBG1, the PPS and MPS (A) methods tend to show larger GDR than the SWI (A) method. Moreover, the PPS and MPS (A) methods also tend to show larger GDR than the MPS-Mueller method for FBG2 and FBG3.

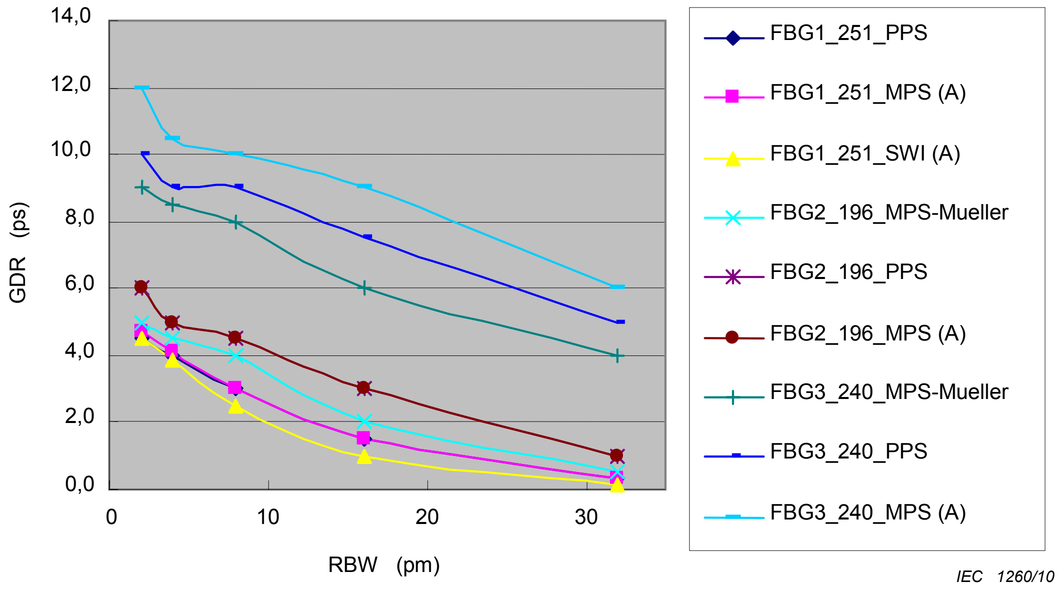

Figure 13 – Summary of GDR measurement results of the FBGs

FBG1 was measured twice, and FBG2 and FBG3 were measured three times to examine their repeatability. Figure 14 shows the results. Setting RBW to 8 pm or more produces repeatability of up to 0,6 ps.

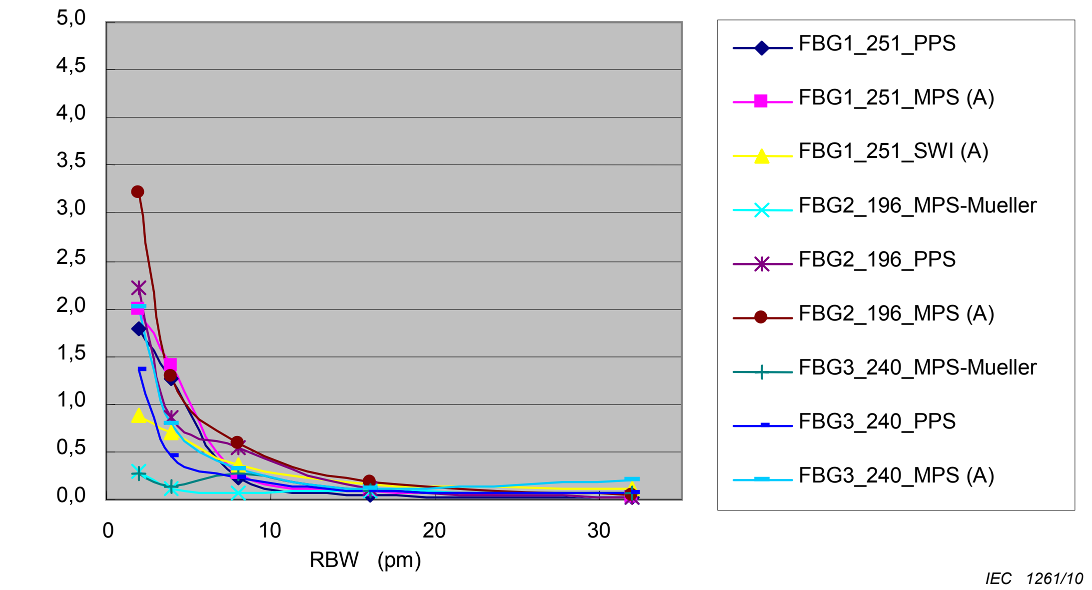

Figure 14 – Summary of GDR repeatability of the FBGs

7.3 PLC

Measurements were taken with the wavelength range of GDR analysis set from 1 545,119 to 1 545,525 nm, and with the CD values set to 0 ps/nm and -200 ps/nm. The MPS-Mueller, MPS (B) and SWI (B) measurement methods were used. The MPS-Mueller and MPS (B) methods used the same measuring equipment. Figure 15 shows the measurement results of GD and IL obtained with the CD value set to -200 ps/nm. In this example, the MPS-Mueller method was used, with RBW set to 8 pm.

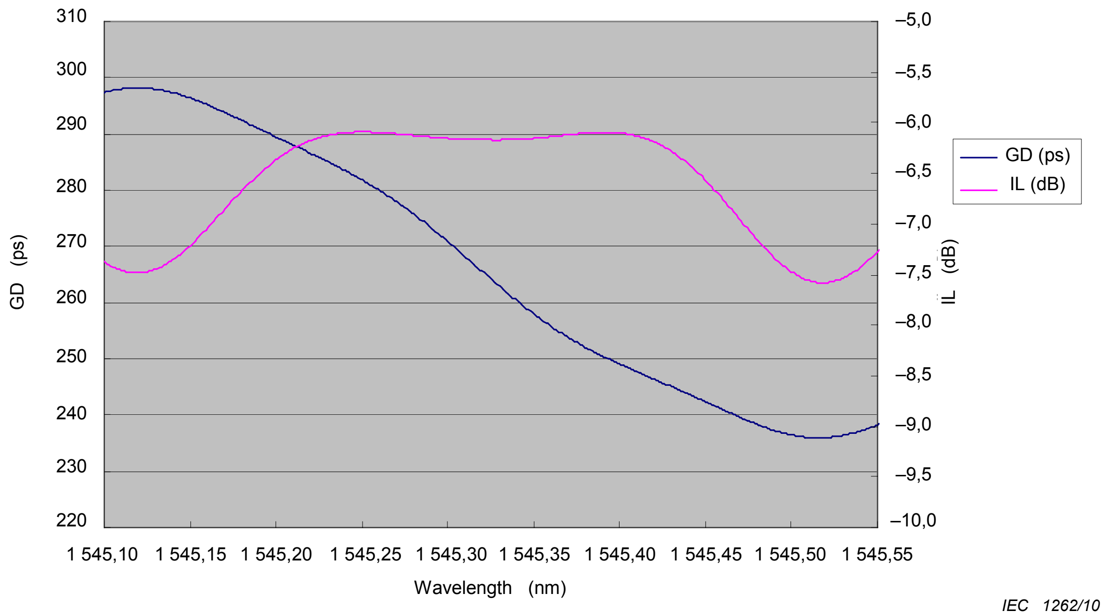

Figure 15 – GD and IL of the PLC

Figure 16 shows the GD deviation from linear fitting at a CD value of -200 ps/nm. RBW was set to 8 pm.

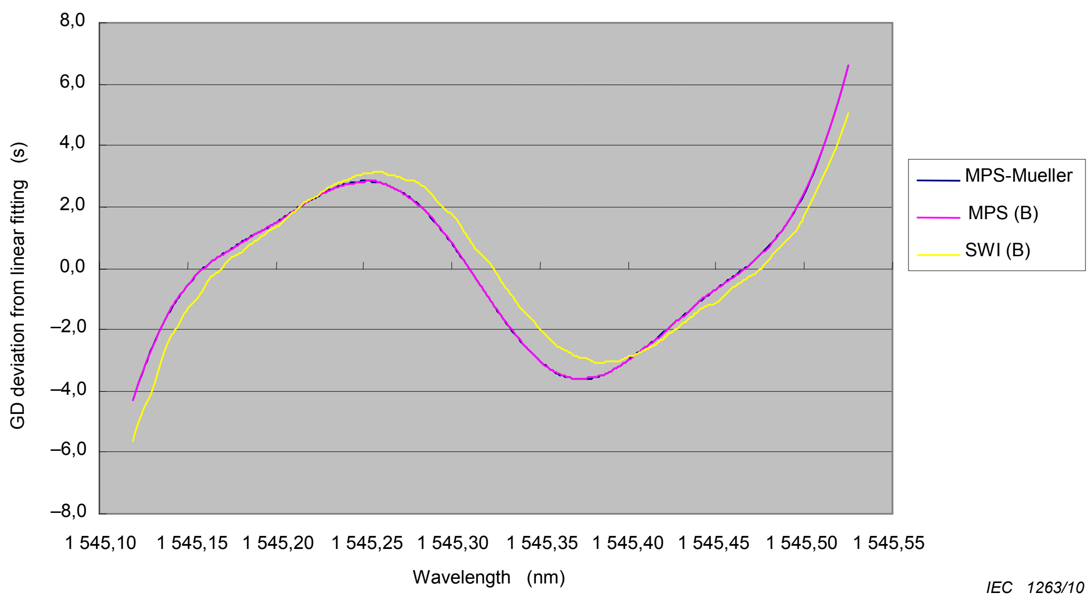

Figure 16 – GD deviation of the PLC with different measurement methods

Figure 17 shows the measurements taken with the MPS-Mueller method at a CD value of -200 ps/nm, and RBW of 2 pm, 4 pm, 8 pm, 16 pm and 32 pm. The GDR period was 300 pm.

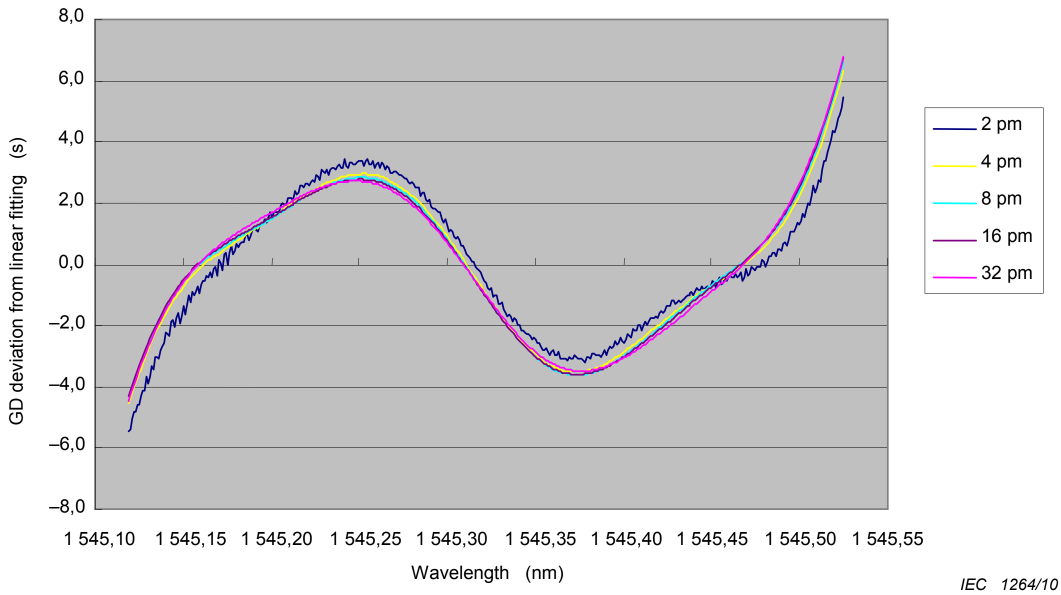

Figure 17 – GD deviation of the PLC at different RBWs

Figure 18 summarizes the measurement results. Changing the CD value setting significantly varies the GDR value. Moreover, regardless of the RBW setting, the GDR value remains almost unchanged. Only when RBW is set to 2 pm does the GDR value tend to rise a little. The difference in the GDR value as measured by different measurement methods is also relatively small.

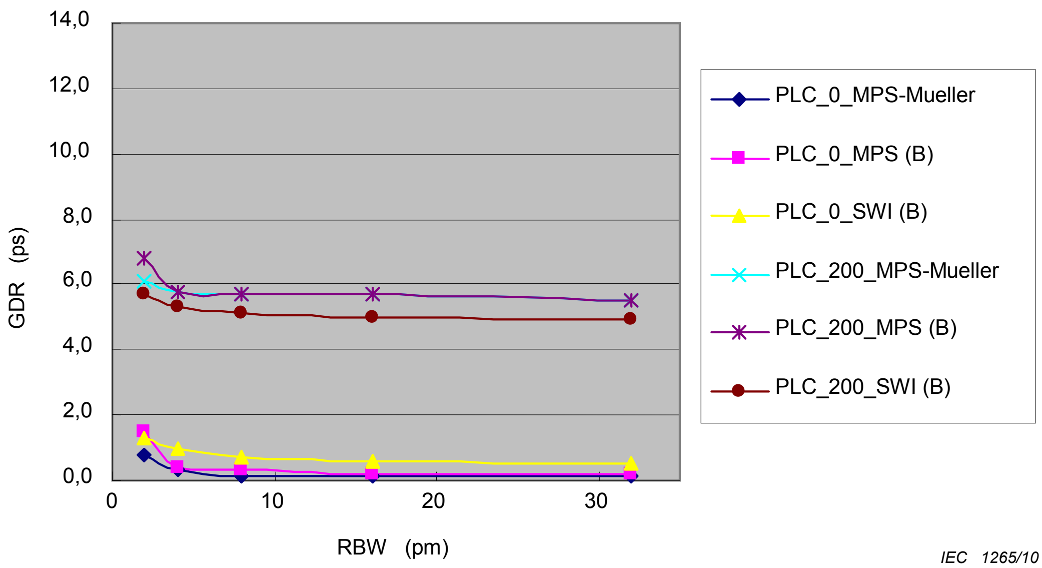

Figure 18 – Summary of GDR measurement results of the PLC

Three measurements were taken under the same conditions to examine their repeatability. Figure 19 shows the results. Setting RBW to 8 pm or more produces repeatability of 0,4 ps in all the measurement methods.

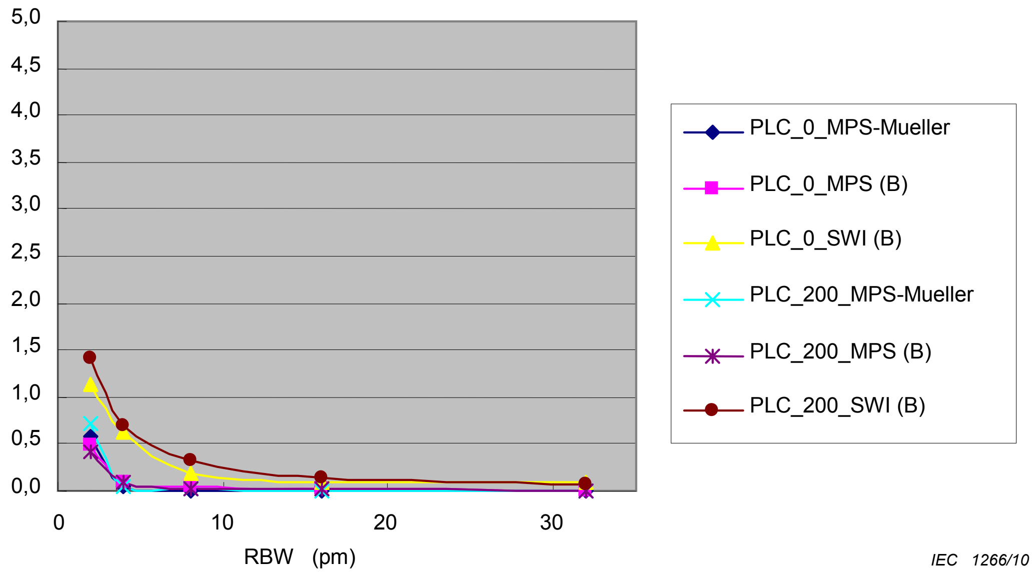

Figure 19 – Summary of GDR repeatability of the PLC

7.4 Etalon

Measurements were taken with a wavelength range of GDR analysis from 1 545,258 to 1 545,386 nm, and with the CD values set to 0 ps/nm and -500 ps/nm. The MPS-Mueller, MPS (B) and SWI (B) measurement methods were used. The MPS-Mueller and MPS (B) methods used the same measuring equipment. Figure 20 shows the measurement results of GD and IL at -500 ps/nm. In this example, the MPS-Mueller method was used, with RBW set to 8 pm.

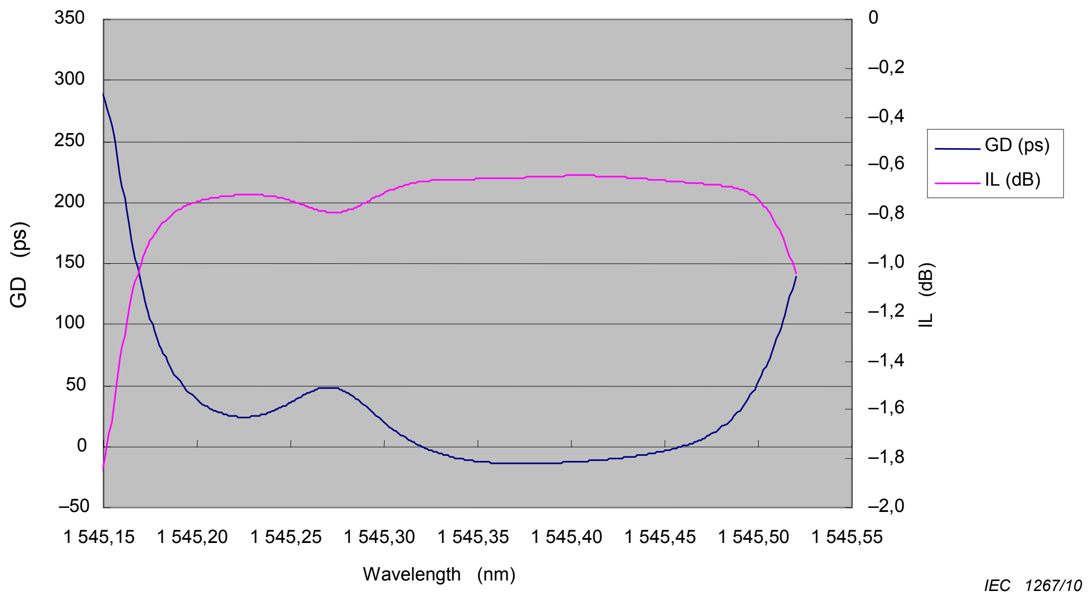

Figure 20 – GD and IL of the etalon

Figure 21 shows the GD deviation from linear fitting at -500 ps/nm. RBW was set to 8 pm.

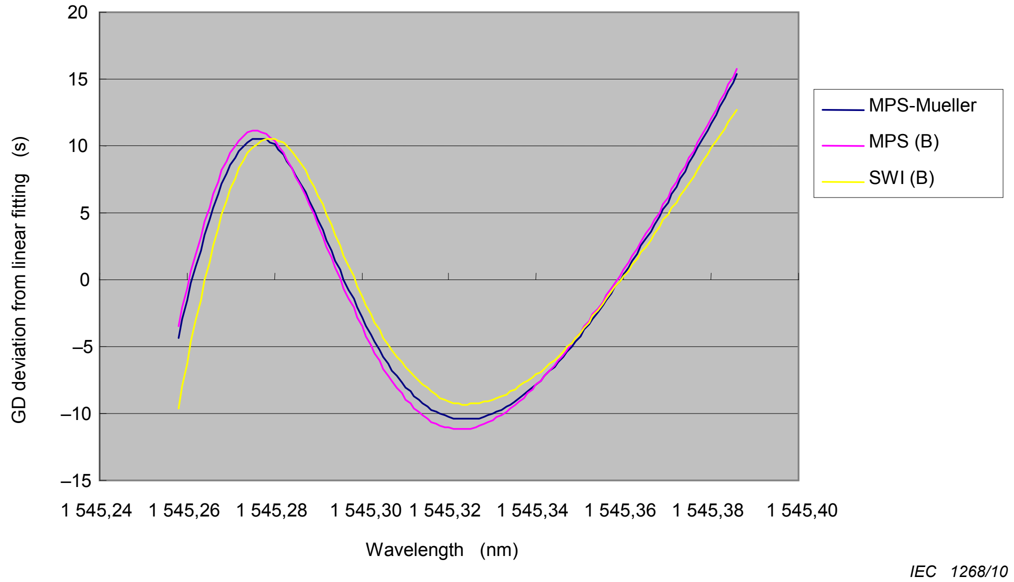

Figure 21 – GD deviation of the etalon with different measurement methods

Figure 22 shows the results of measurements taken using the MPS-Mueller method with the CD value set to -500 ps/nm, and RBW being set to 2 pm, 4 pm, 8 pm, 16 pm and 32 pm. The GDR period was 100 pm.

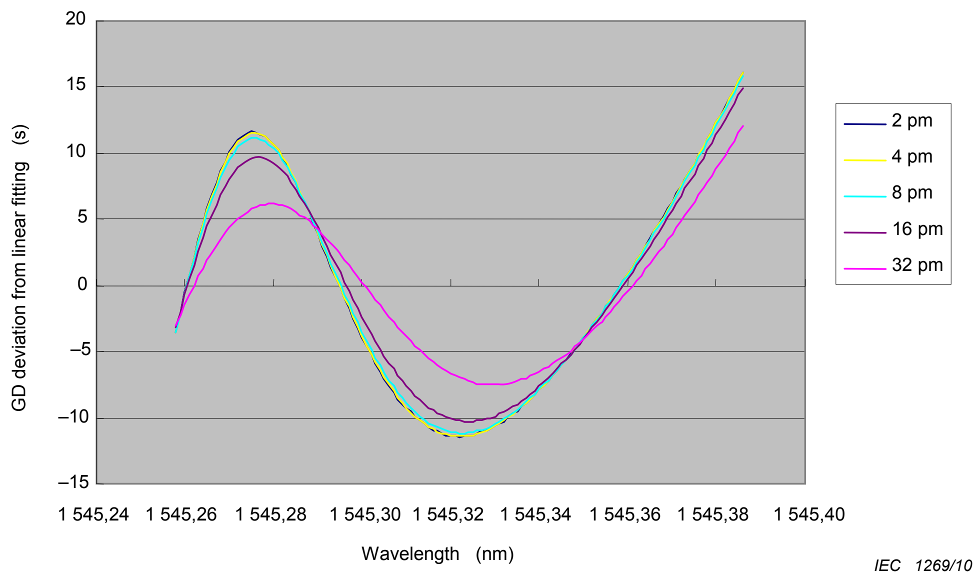

Figure 22 – GD deviation of the etalon at different RBWs

Figure 23 summarizes the measurement results. Changing the CD value setting significantly varies the GDR value. Setting the CD value to 0 ps/nm does not vary the GDR value, however, despite the RBW being changed. However, setting the CD value to -500 ps/nm will vary the GDR value with RBW. In that case, the GDR value remains almost constant at RBW of 8 pm or less. At 0 ps/nm, the GDR value tends to be small only with the SWI (B) method, but the difference is small among all measurement methods at -500 ps/nm.

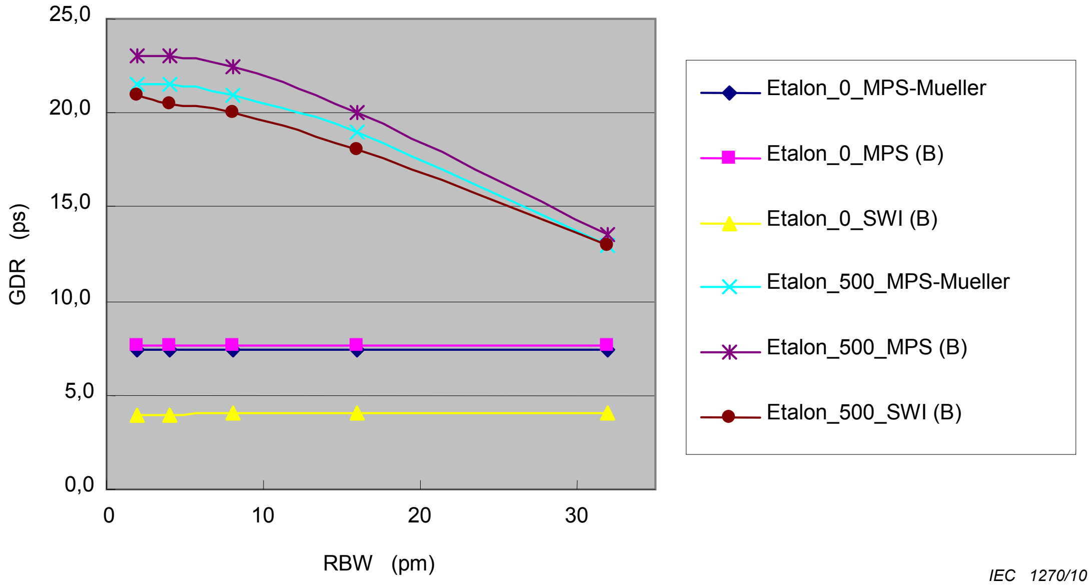

Figure 23 – Summary of GDR measurement results of the etalon

Three measurements were taken under the same conditions to examine their repeatability. Figure 24 shows the results. Setting RBW to 8 pm or more produces repeatability of 0,5 ps or less in all the measurement methods.

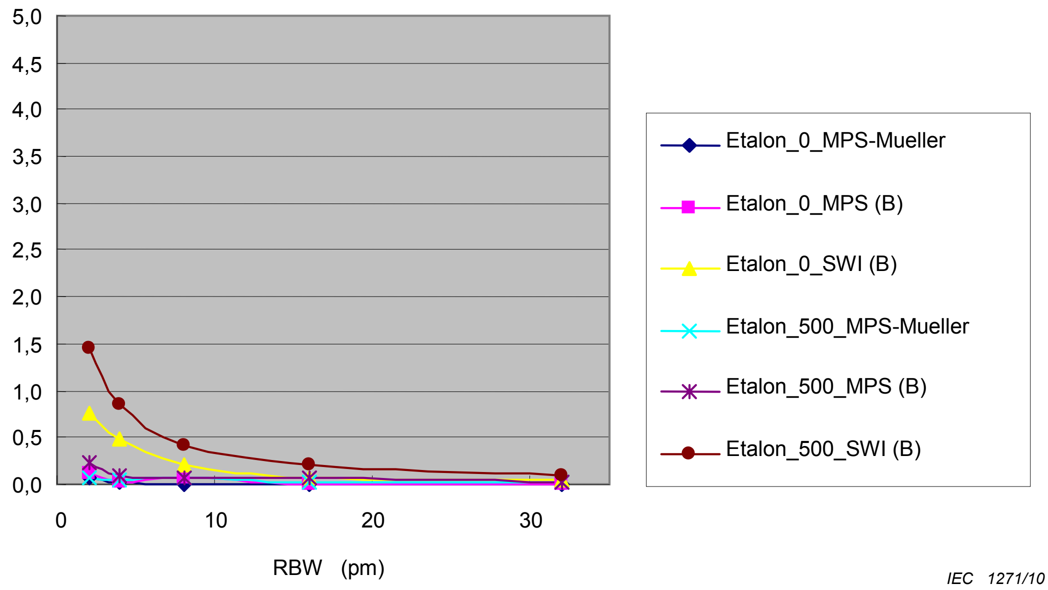

Figure 24 – Summary of GDR repeatability of the etalon

8 Data analysis

8.1 Repeatability

From the measurement results, it is clear that GDR repeatability depends largely on the RBW. When RBW goes below 16 pm, repeatability generally tends to decline in reverse proportion to the RBW. Moreover, the technology used in each TDC produces a ripple period peculiar to it, thereby affecting the repeatability and RBW dependence of the GDR.

Setting a larger RBW averages, the ripple amplitude over wavelength, however, and thus reduces the GDR value measured. It is therefore necessary to minimize the RBW setting for accurately measuring the ripple amplitude.

The TDC performance standard requires a GDR value of up to 6 ps for operation at 10 Gbps. Obtaining sufficient measurement accuracy probably requires repeatability of 0,6 ps or less. This means that, to achieve an even more accurate ripple amplitude while satisfying those requirements, measurements should be taken with RBW set to 8 pm (that is, at a modulation frequency of 500 MHz).

Figure 25 compares the results of GDR repeatability taken with all the measurement methods, and with RBW being varied. The results with RBW of 2 pm show very large variations and are therefore not included in the figure. Here, it is known that significant variations remain at RBW of 4 pm, and that measurement repeatability of up to 0,6 ps can be achieved at 8 pm or more, thus satisfying the requirement indicated above.

A comparison among the measurement methods reveals that the MPS-Mueller and MPS (B) methods show better repeatability than the other methods. Both methods used the same measuring equipment. One presumable factor of such variations is the possible great effect of differences due to measuring equipment performance, rather than differences between the measurement methods.

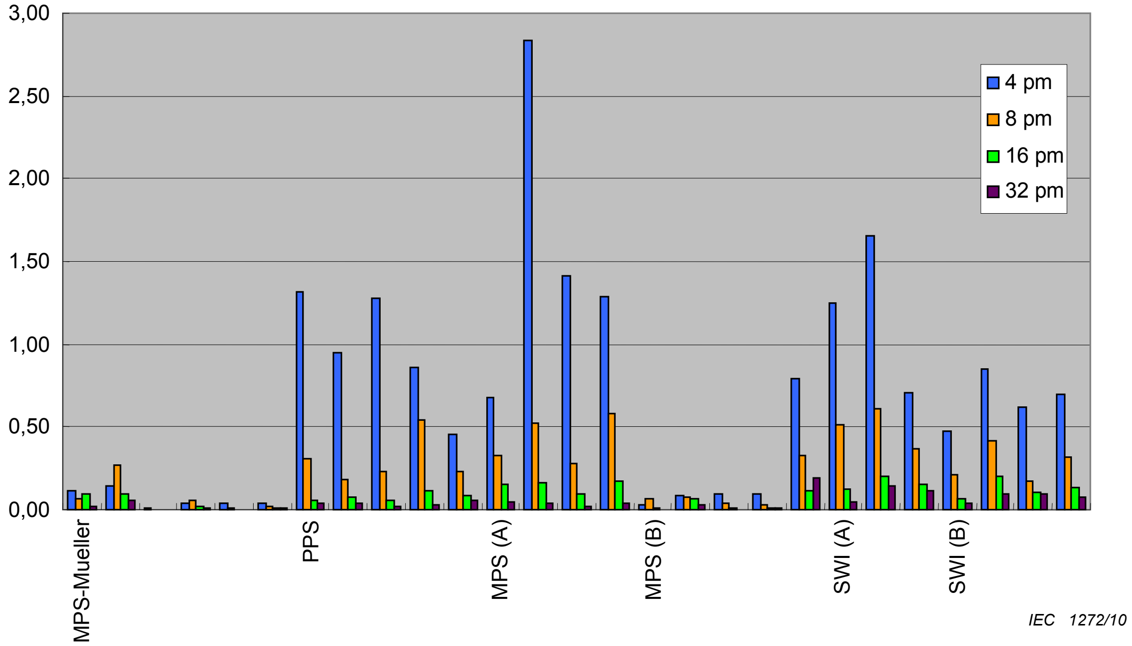

Figure 25 – RBW, measurement methods and GDR repeatability

8.2 Measurement method differences

In round robin testing, the GDR of the same TDC is measured using more than one method. Figure 26 shows the greatest differences between the GDR measurement results obtained. The degree of difference varies among the TDCs, as explained by three reasons: (1) different types of measuring equipment are used for each TDC; (2) different TDCs have significantly different GDR values, so that the greater the GDR, the greater the difference; and (3) variations are also large when RBW is small.

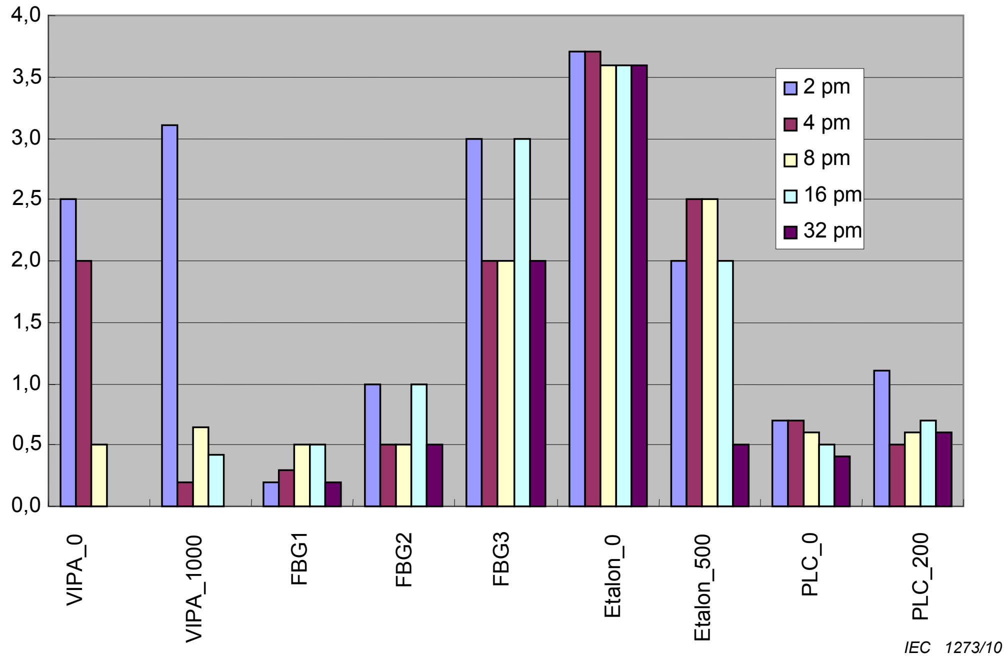

Figure 26 – Differences in GDR measurement results between measurement methods

Should one wish to limit the scope of consideration to TDCs having GDR of up to 6 ps (as used in actual practice), and take measurements at RBW of 8 pm, then the results will be as shown in Figure 27 below. This sets the differences between the measurement methods to about 0,6 ps or less, a magnitude within a problem-free range in assessing a GDR value of 6 ps (at 10 Gbps), which is required as a TDC performance standard.

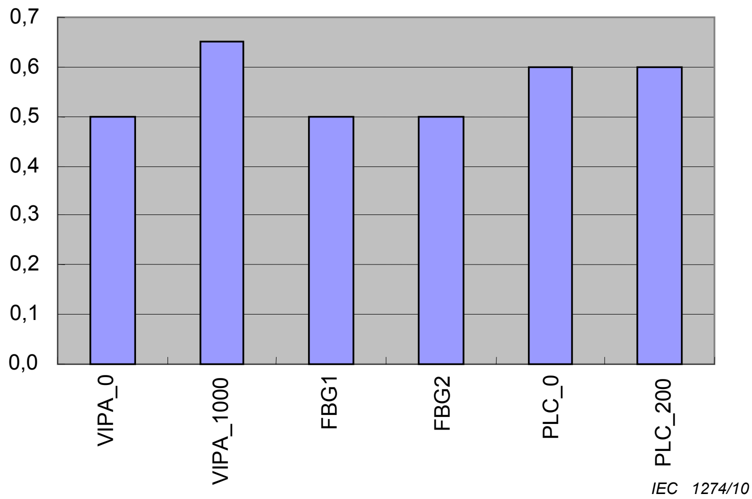

Figure 27 – GDR differences produced when measuring a TDC with GDR of less than 6 ps at RBW of 8 pm

The GDR period, on the other hand, showed hardly any difference between the measurement methods. The wavelength resolution is almost standardized by specifying the RBW or modulation frequency.

9 Consideration of phase ripple

In recent years, the importance of considering the GDR period in addition to the GDR amplitude when determining the effect of GDR on transmission quality has been clarified. It is also necessary to use the phase ripple instead of GDR in evaluating the TDC. The phase ripple is defined below.

Peak-to-peak phase ripple ($\Delta\theta$);

$\Delta\theta = f_{\text{period}} * A_{\text{rip}}$ (unit: radian),

where

A_{rip} is the peak-to-peak-GD ripple (unit: s);

f_{period} is the period of the GD ripple (unit: Hz).

Here, if $\Delta\theta << 1$, the worst eye opening penalty (EOP) generated by phase ripple can be estimated with the following equation.

$$\text{Worst EOP (dB)} = - 10 \log (1 - \Delta\theta/2)$$

Figure 28 shows the typical measurement result of GDR concerning FBG2. Figure 29 shows the phase ripple calculated from GDR.

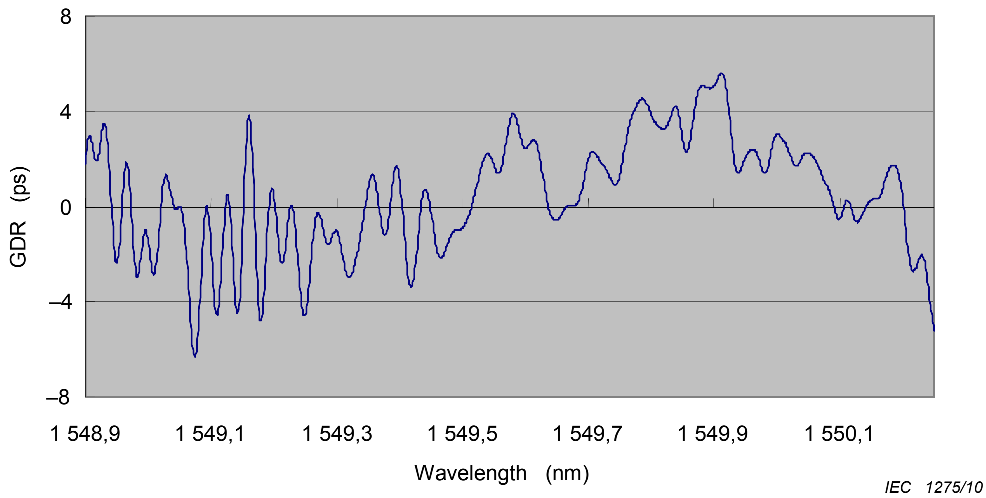

Figure 28 – Typical measurement result of GDR

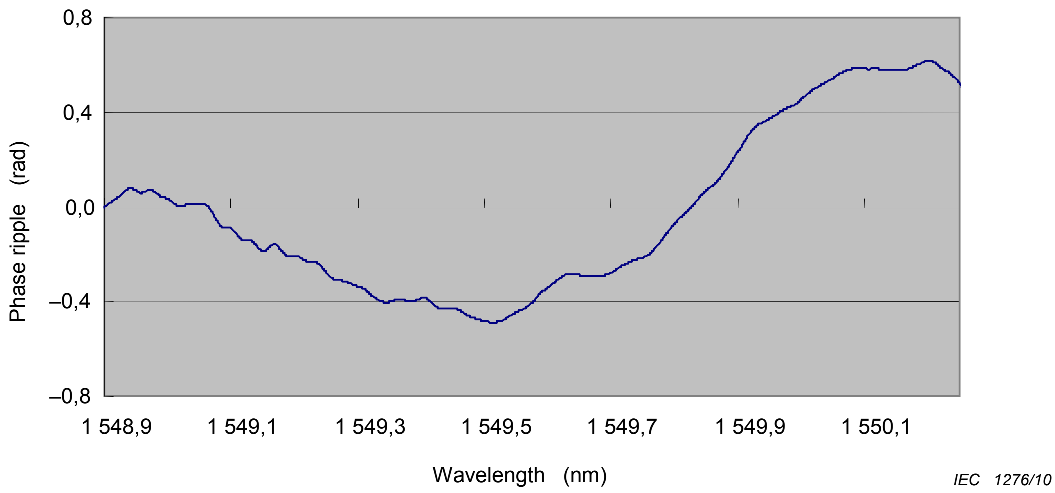

Figure 29 – Phase ripple calculated from GDR

Figure 30 shows the relation between the amplitude and period of GDR, and the phase ripple converted to the worst EOP. The trace at an EOP of 0,1 dB shows phase ripple of 0,046 rad. When the EOP should be 0,1 dB or less, the amplitude and period of GDR must be defined below that trace. The plots in the figure show the results with the VIPA in round robin testing and the greatest GDR of FBG1/2/3. This indicates that, even with large GDR amplitude, a small GDR period results in only a small effect on the EOP.

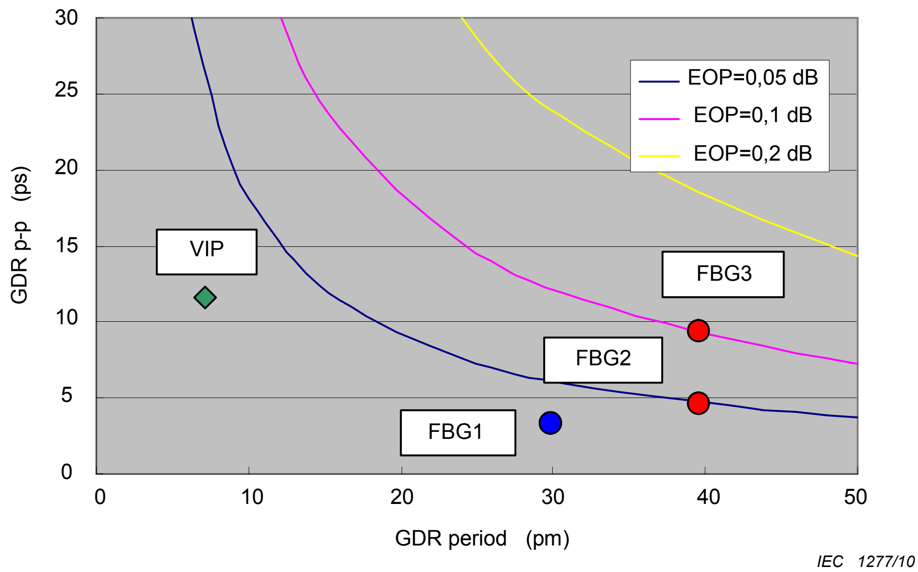

Figure 30 – Amplitude, period, and EOP of GDR

Figure 31 shows the measurement results of the VIPA and FGB1/2/3 in round robin testing as represented in phase ripple calculated based on the amplitude and period of GDR. The phase ripple (p-p) corresponding to an EOP of 0,1 dB is 0,046 rad.

The VIPA and FBG1 used as standard products show an EOP of 0,05 dB or less, but it is known that FBG3 provided intentionally as a DUT with large GDR amplitude and period has an EOP of more than 0,1 dB.

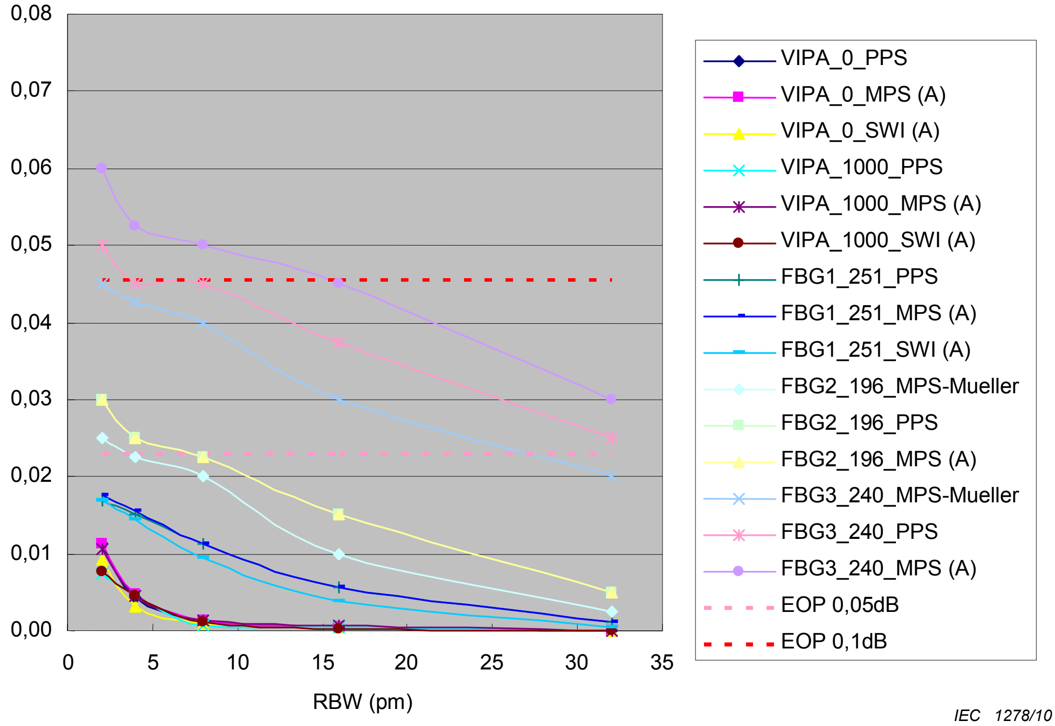

Figure 31 – Phase ripple of the VIPA and FBGs

Figure 32 shows the repeatability results of the VIPA and FBGs as represented in phase ripple. It is known that setting RBW to 8 pm or more will produce repeatability sufficiently lower than an EOP of 0,01 dB (0,0046 rad).

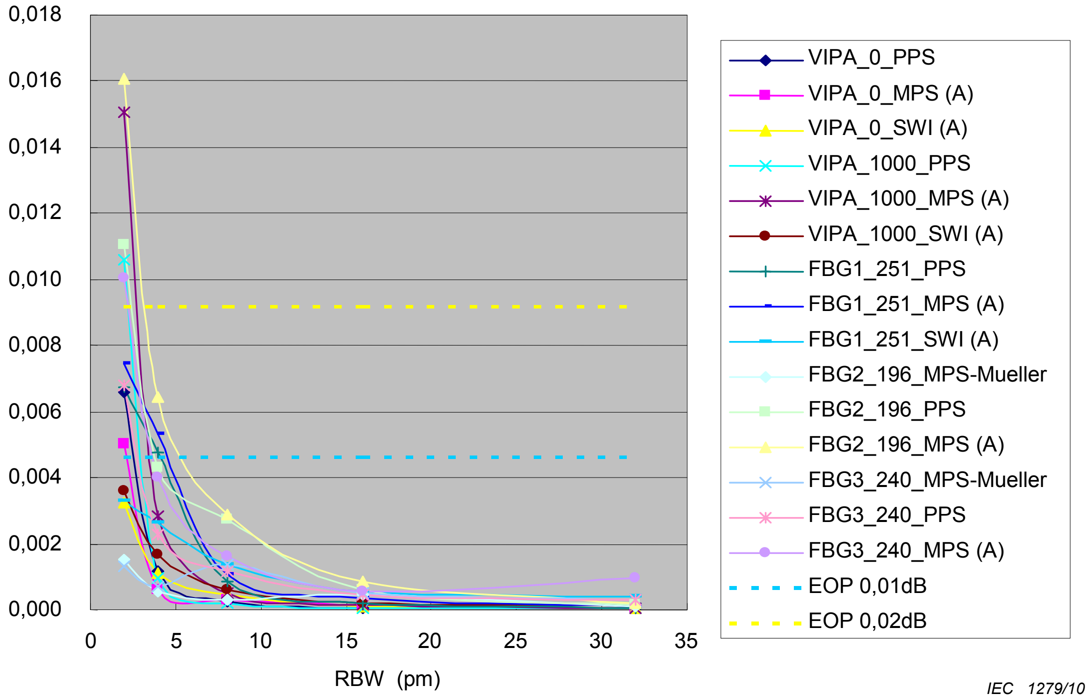

Figure 32 – Phase ripple repeatability of the VIPA and FBGs

Figure 33 shows the results of differences in the VIPA and FBGs using different measurement methods as represented by phase ripple. It is known that, except for FBG3 provided intentionally as a DUT with large ripple, setting RBW to 8 pm or more will almost control the difference with an EOP of 0,01 dB (0,0046 rad) or less.

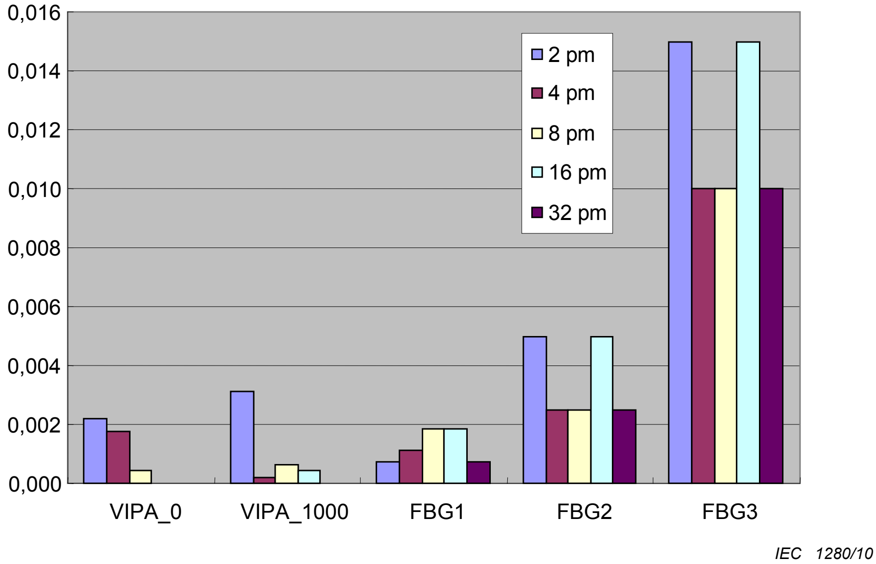

Figure 33 – Differences in phase ripple between measurement methods

10 Conclusion

Various TDCs were subjected to round robin testing by using different GD measurement methods. It was found that each TDC has a GDR amplitude and period peculiar to itself. In conclusion, the wavelength resolution recommended for GDR measurement should desirably be set to 8 pm (at a modulation frequency of 500 MHz). This condition enables even more accurate measurement of GDR, while controlling the differences between repeatability and measurements using the various measurement methods in a range that does not affect actual transmission quality.

The use of phase ripple instead of GDR was proposed to evaluate the TDCs. Phase ripple calculated from the GDR amplitude and period can be converted into an eye opening penalty. This means that the effect on transmission quality by a TDC can be estimated directly by using phase ripple.

In the future, the methods of measuring phase ripple should be standardized based on the results of this technical report.

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