# CD MEASUREMENT METHODS: PHASE SHIFT VS. DIFFERENTIAL PHASE SHIFT

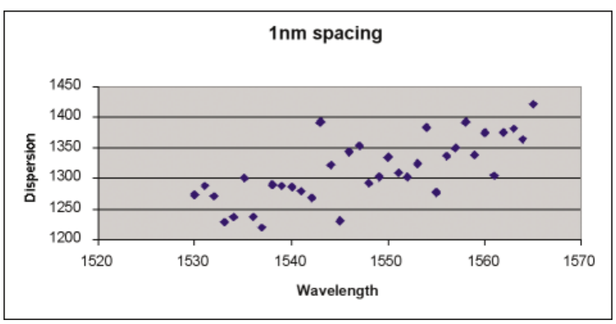
123 APPLICATION NOTE

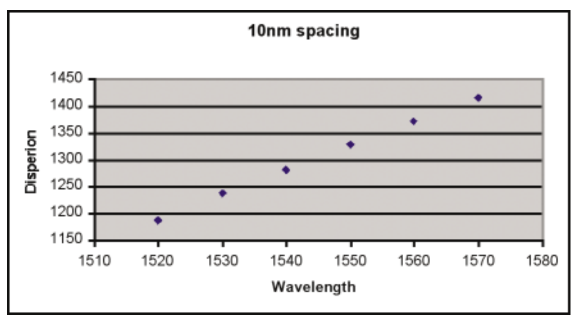
*Francis Audet, Eng., Senior Product Manager, EXFO Headquarters*

Phase-shift approaches are now accepted as the most accurate and reliable techniques for measuring chromatic dispersion (CD). These methods basically involve using a modulated light source to launch a signal into the DUT and verifying the change in phase. For example, once a signal such as Asin ($\omega\tau+\phi$) (where $\omega$ represents the modulation frequency and $\phi$ represents the phase) is launched into the DUT, the phase at the output of the DUT will have changed as a function of wavelength. Measuring the phase shift determines the delay, which in turn helps determine the amount of chromatic dispersion.

## Differential Phase-Shift (DPS) Method, as per FOTP-175

The differential phase-shift method measures CD directly instead of measuring delay and then applying a fit to calculate the CD. The source power is modulated, but the wavelength also toggles between adjacent wavelengths. This generates a local delay with a local wavelength step, with which a local CD value is calculated ($t_2$-$t_1$/$\lambda_2$-$\lambda_1$). The process is then repeated with several wavelength pairs in the test range, producing a CD curve. As distinguishing two closely spaced signals is relatively difficult, this method requires large wavelength steps in order ensure accuracy and prevent error. While the main advantage of the differential phase-shift method is that it gives CD directly, its main disadvantage is that it cannot measure with small wavelength steps, which limits the resolution of the instrument. As the steps get smaller, the error grows larger. Since it measures fewer points, it is a less accurate and flexible method:




As the test points used in this method are far from each other, the technique is forced to use a trendline or linear fit to evaluate the CD between the test points, but this means large areas of interpolation. In a spectral region where CD accuracy is extremely important (since it is the DWDM long-haul band) and where acute compensation is often applied, this is a major shortcoming.

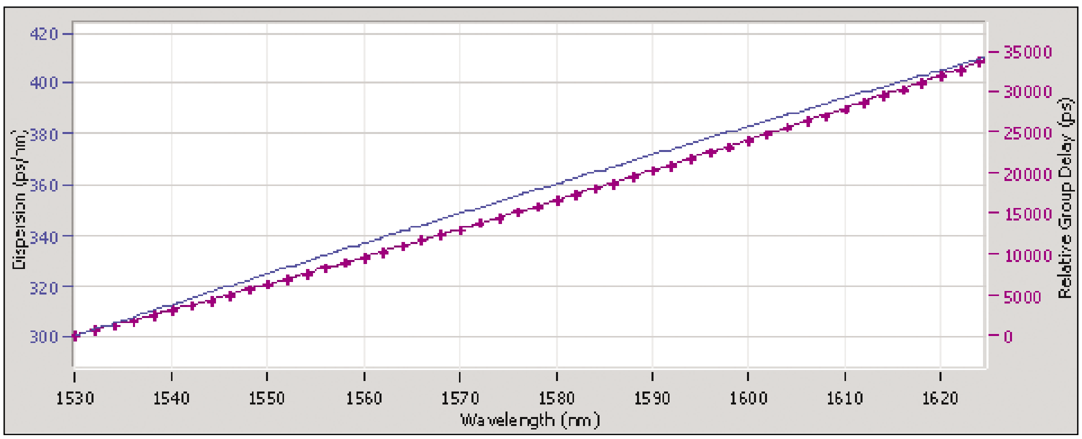
Another significant drawback of this method is that it cannot extrapolate results outside of the tested band since there aren't any fitting equations.

## Phase-Shift (PS) Method, as per FOTP-169:

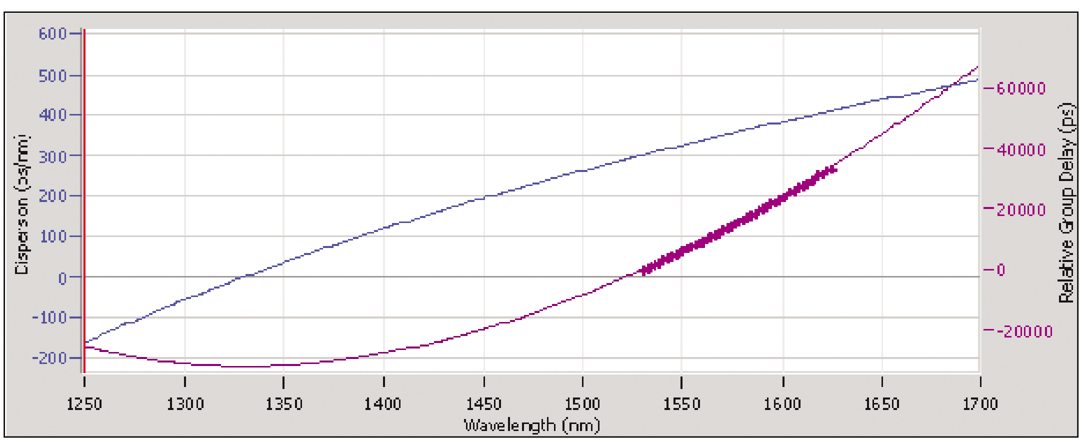
In this method, a fixed reference wavelength is used to compare the difference in delays ($t_n$-$t_{ref}$/$\lambda_n$-$\lambda_{ref}$). Delay points are acquired to represent the delay in transmission between the test wavelength and a reference wavelength. Then, a fitting equation is applied to connect all the acquired points, and a global derivative is applied to the fit. These fitted equations are defined in the different ITU-T G.65x standards defining fiber type, as well as in the TIA-FOTP-224 standard entitled *Calibration of CD test equipment*[1].

The phase-shift method offers several advantages. As the reference is fixed, wavelength step can be made as small as needed because the delay is not compared to an adjacent wavelength, but to a distant one. Of course, when testing wavelengths in the area close to the fixed reference wavelength, these points become somewhat inaccurate, just like all the test points in the differential phase-shift method. On high-quality systems, points can be acquired down to 0.1 nm spacing with excellent accuracy, making the phase-shift method much more flexible and precise.

Since the fits are well-defined and accurate, the phase-shift method presents another important advantage: data extrapolation. For example, measuring delay in the C-band can also be used to calculate accurate CD in the L-band and in the O-band.




*Delay can be measured at very small steps (2 nm in this example; purple line)*




*Well-defined and reliable fits also allow for result extrapolations for bands other than the test bands.*

[1] *There is obviously a close correlation between how well the fit represents the fiber under test and the accuracy of the method.*

When doubts arise regarding the fitting accuracy for a particular system, such as a complex links, including EDFAs, flattening filters, and possibly OADMs, it is because the fit does not properly match the points. If the fit crosses most of the points, then it is usable, but if the fit looks very different from the figure traced by the points, it means one of three things:

1. Points are too noisy, in which case a longer acquisition is required.
2. Improper fit has been selected.
3. The system produces too many variations for any fit to mimic, in which case a local derivative technique should be used (see below).

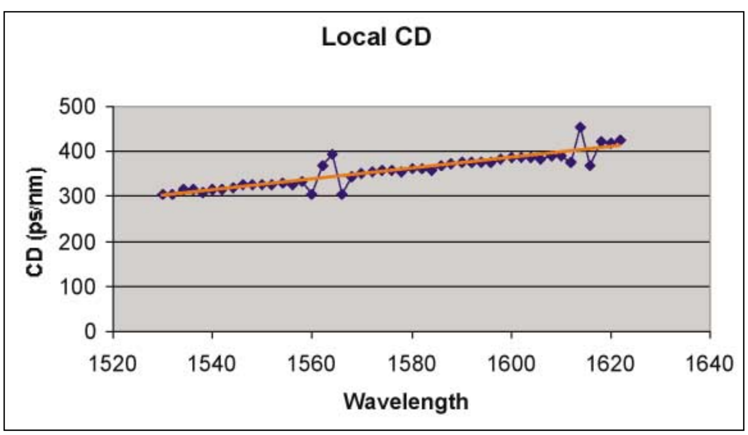
## Local Derivative Using the Phase-Shift Approach

Finally, to add flexibility to the general method, since all the delay points already exist and are already saved, differential phase-shift mathematics can be applied to a phase-shift-based instrument.

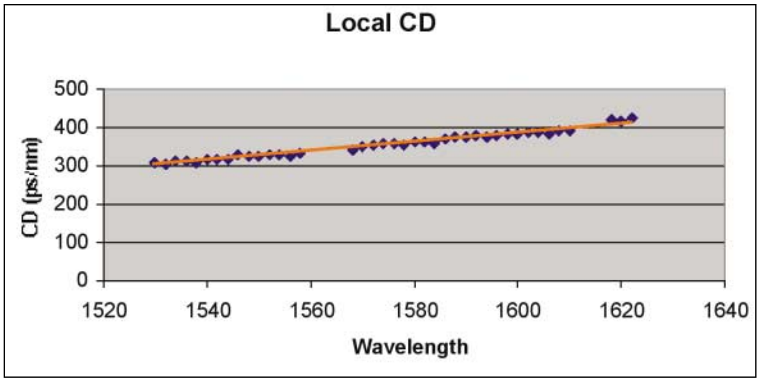
For example, the following spread sheet was created using the points on the above trace and applying this equation (Delay 2 – Delay 1)/(Wavelength 2 – Wavelength 1) to every point pair.

| Wavelength (nm) | RGD (ps) | | Derivative (= (RGD2-RGD1)/(λ2-λ1)) | | |
|---|---|---|---|---|---|
| 1530 | 0 | | 306.695 | | |
| 1532 | 613.39 | | 305.455 | | |
| 1534 | 1224.3 | | 313.93 | | |
| 1536 | 1852.16 | | 314.13 | | |
| 1538 | 2480.42 | | 309.285 | | |
| 1540 | 3098.99 | | 315.355 | | |

This gives the following graph:

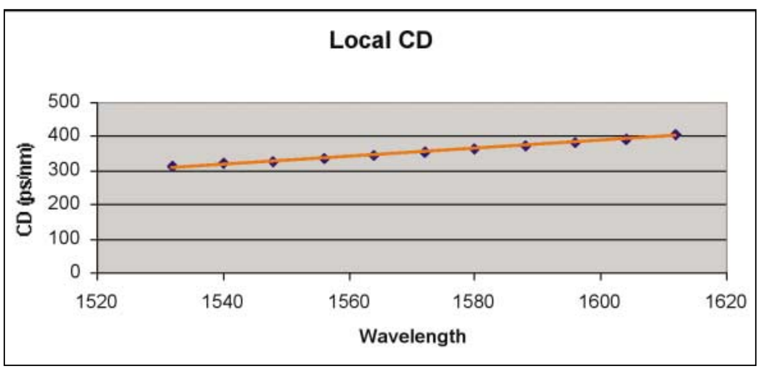



The two fluctuating areas represent the reference filters. As they are, by definition, inaccurate, they can be removed:




Of course, just like in the true DPS method, a small step size means added uncertainty. Taking the same set of data and averaging every point over a larger band instead of only two bands results in the following:

| Wavelength (nm) | RGD (ps) | Average wavelength | Average RGD | | Derivative (= (RGD2-RGD1)/(λ2-λ1)) |
|---|---|---|---|---|---|
| 1530 | 0 | | | | |
| 1532 | 613.39 | 1533 | 922.4625 | | 311.9366 |
| 1534 | 1224.3 | | | | |
| 1536 | 1852.16 | | | | |
| 1538 | 2480.42 | | | | |
| 1540 | 3098.99 | 1541 | 3417.955 | | 320.1622 |
| 1542 | 3729.7 | | | | |




In conclusion, the differential phase-shift method provides direct CD results, but has low resolution, less flexibility and does not allow for extrapolation. The phase-shift method, on the other hand, is more flexible, especially if there is local CD, such as when testing through filters and OADMs; it is also more accurate, it allows for extrapolation, and also allows for differential phase-shift analysis.

Corporate Headquarters > 400 Godin Avenue, Vanier (Quebec) G1M 2K2 CANADA | Tel.: 1 418 683-0211 | Fax: 1 418 683-2170 | info@exfo.com

Toll-free: 1 800 663-3936 (USA and Canada) | www.exfo.com

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|---|---|---|---|---|
| EXFO America | 4275 Kellway Circle, Suite 122 | Addison, TX 75001 USA | Tel.: 1 800 663-3936 | Fax: 1 972 836-0164 |
| EXFO Europe | Le Dynasteur, 10/12 rue Andras Beck | 92366 Meudon la Forêt Cedex FRANCE | Tel.: +33.1.40.83.85.85 | Fax: +33.1.40.83.04.42 |
| EXFO Asia-Pacific | 151 Chin Swee Road, #03-29 Manhattan House | SINGAPORE 169876 | Tel.: +65 6333 8241 | Fax: +65 6333 8242 |
| EXFO China | Beijing New Century Hotel Office Tower Room 1754-1755 No. 6 Southern Capital Gym Road | Beijing 100044 P. R. CHINA | Tel.: +86 (10) 6849 2738 | Fax: +86 (10) 6849 2662 |

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