Calculating Group Delay and Chromatic Dispersion from OVA Optical Phase

Introduction

In the OVA, the group delay (GD) and chromatic dispersion (CD) are optical frequency/wavelength domain derivatives calculated from the measurement of the Jones Matrix phase responses of the device under test (DUT). The time domain resolution bandwidth (TDRBW) may be used to filter the impulse response of the DUT and is used to set the derivative step size for the polarization mode dispersion (PMD) calculation; however the TDRBW is not used to set the derivative step size for calculating GD or CD. This derivative step size is set to the highest resolution afforded by the OVA, approximately 1.2pm or 0.16 GHz.

In the following note, the OVA calculations for GD and CD are presented, along with a straightforward way for the user to calculate these parameters, starting from the OVA optical phase measurement, with a user-defined optical frequency derivative step size. Example measurements are included that illustrate these calculations and practical considerations. It is shown that increasing the optical frequency derivative step size improves noise characteristics; however care must be taken to avoid suppression of actual device characteristics. Insight into the ideal derivative step size for a particular device is provided by inspecting the time domain impulse response. In general, the time domain window width should be set as tightly as possible about the impulse response, being careful to include the *entire* response. The resultant TDRBW is the *maximum* derivative step size appropriate for the device.

OVA Calculations of Group Delay and Chromatic Dispersion: Maximum Spectral Resolution, Minimum Derivative Step Size

The group delay and chromatic dispersion, by definition, are given by

$$GD = \frac{d\varphi(\omega)}{d\omega}; \quad CD = \frac{dGD}{d\lambda}; \ \omega = 2\pi\text{v}$$

Where GD is the group delay, CD is the chromatic dispersion, φ is the optical phase, ω is optical angular frequency, v is optical frequency, and λ is optical wavelength. Explicitly, the discrete variable versions of these definitions as implemented by the OVA follow, where group delay in picoseconds is calculated as

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$$GD[i] = \frac{\boldsymbol{arg}\{JM_A[i] \cdot JM_A^*[i+1] + JM_B[i] \cdot JM_B^*[i+1] + JM_C[i] \cdot JM_C^*[i+1] + JM_D[i] \cdot JM_D^*[i+1]\}}{2\pi(0.001)(d\nu)}$$

such that dν is the optical frequency increment in GHz (~0.16 GHz), *i* is an array index over angular frequency space, and JM_X are the complex Jones Matrix elements. The value 0.001 converts the GD from units of nanoseconds to units of picoseconds. Chromatic dispersion in picoseconds per nanometer is then calculated as the wavelength derivative of the group delay.

$$CD[i] = \frac{\mathrm{GD_{i+1}} - \mathrm{GD_i}}{\lambda_{i+1} - \lambda_i}$$

Calculating Group Delay and Chromatic Dispersion from Optical Phase: User-defined Derivative Step Size

If desired, the user may calculate GD and CD using the derivative step size of their choice. This simple algorithm is outlined below, assuming an OVA measurement of the DUT has been taken (see user guide if more detail is required).

1. Set the time domain window to fully encompass the impulse response of the device, and eliminate system noise.

2. Save a text file that contains the raw phase response. This is accomplished by saving the linear phase deviation (LPD) where the vertical cursors and calculate button were not activated, and thus a line was not subtracted from the optical phase. In the OVA software, the save options can be set to select specific curves (e.g. LPD) and ensure the smoothing filter (front panel Filter Resolution BW) is not applied.

3. Open the saved text file from step 1 in the processing software of your choice (e.g. MatLAB, LabVIEW, Mathematica, Excel, etc.)

4. From the Frequency column of the data, extract the frequency step size, $d\nu$. For example, from the first and second points in the frequency array calculate $d\nu$ as follows

$$\nu_0 - \nu_1 = d\nu$$

5. Calculate Group Delay in ps from the optical phase (LPD) using the following

$$GD[i] = \frac{\varphi_{i+n} - \varphi_i}{2\pi * 0.001 * n * d\nu};\ n = nint\left(\frac{desired\ step\ size\ [GHz]}{d\nu\ [GHz]}\right)$$

where φ is the optical phase (LPD), *n* is the index shift associated with the desired derivative step size, dν is the optical frequency increment calculated in step 2 in GHz (~0.16 GHz), and *i* is an array index over angular frequency space. *nint()* is a function that returns the closest integer to its argument.

6. Calculate chromatic dispersion in ps/nm from the derivative of the GD with respect to wavelength.

$$CD[i] = \frac{GD_{i+n} - GD_i}{\lambda_{i+n} - \lambda_i};\ n = nint\left(\frac{desired\ step\ size\ [GHz]}{d\nu\ [GHz]}\right)$$

7. Rotate the GD and CD arrays to account for the shift of the derivative operation. GD is shifted by *n/2* indices, CD is shifted by *n* indices.

Measurement Example: GD and CD of a Thin Film Filter

The algorithms outlined above were used to calculate the GD and CD of a thin-film filter from an OVA measurement of optical phase (LPD). The results are presented below and compared with OVA calculations.

First, a thin film filter was connected to the OVA 5000 and 64 measurement scans were averaged. As illustrated in Figures 1 and 2, the TDRBW was set to 20 pm centered about the device impulse response.

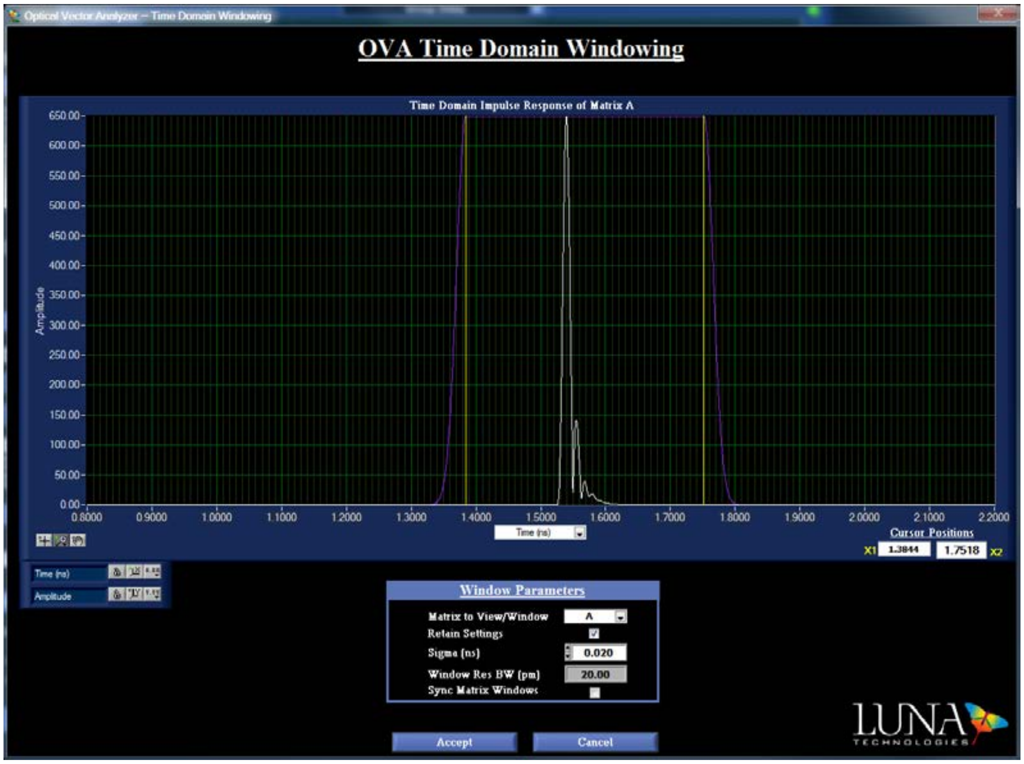

Figure 1. The time domain window and impulse response of a thin film filter.

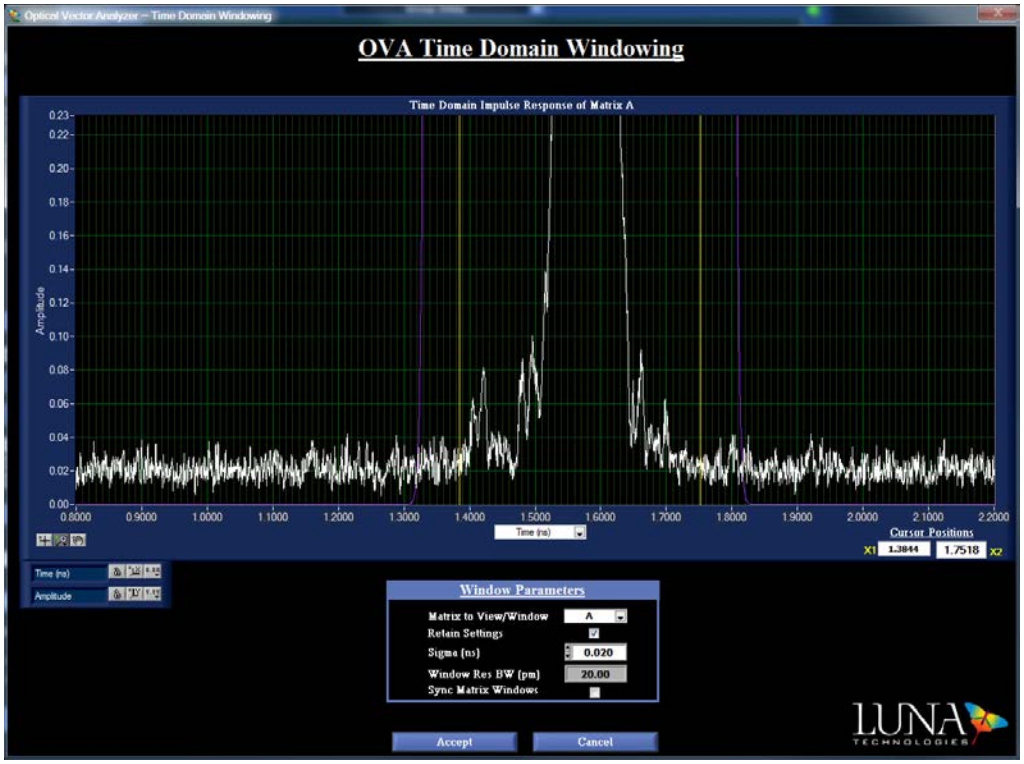

Figure 2. Vertically expanded view of Figure 1, which illustrates the impulse response is fully encompassed by a 20 pm TDRBW.

Next, a text file was saved containing the IL, GD, CD and LPD data. The resultant IL data is shown below in Figure 3. Starting from the OVA measurement of optical phase (LPD), the GD and CD were calculated according to steps 1-6 above and compared with the OVA calculations. The GD data are plotted in Figure 2. Note the reduced noise in the black curve, corresponding to a 60 pm derivative step size, as compared with the red curve, corresponding to the OVA measurement. Also note however, the peak GD value near 1559.4 nm has been reduced by approximately 0.5 ps.

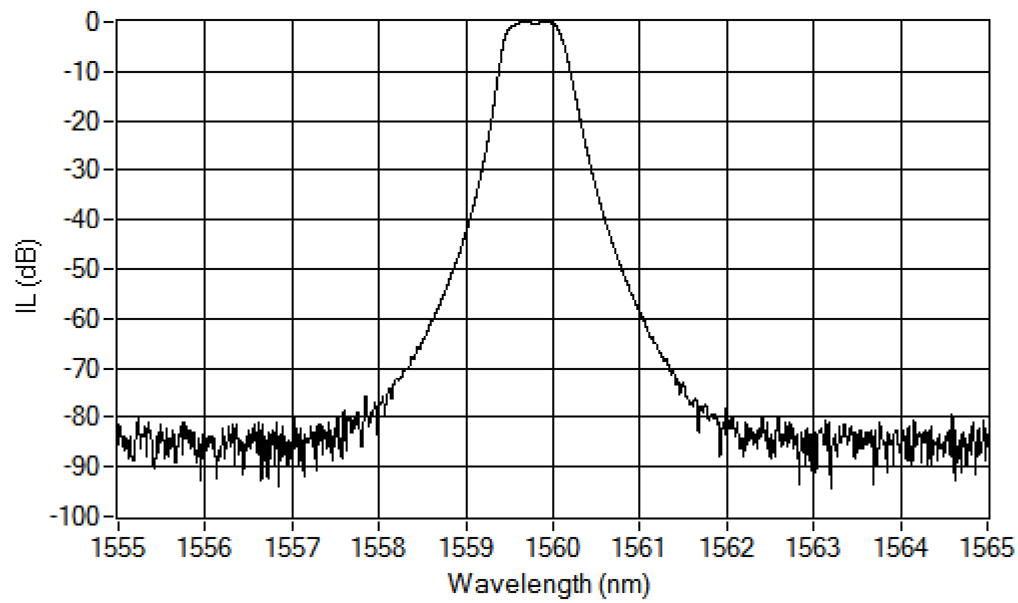

Figure 3. Insertion loss of a thin film filter measured using an OVA 5000. The TDRBW was set to 20 pm.

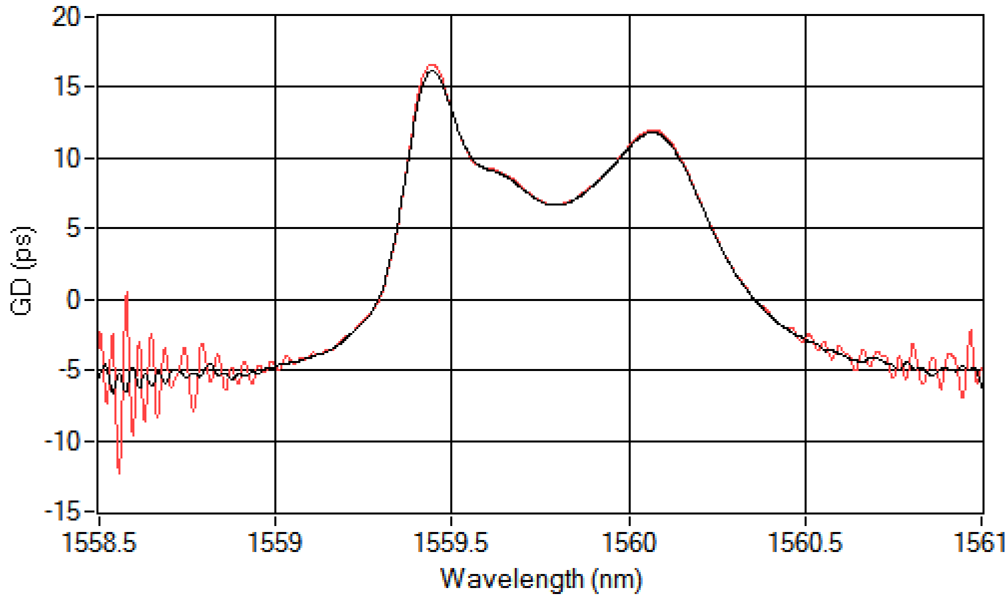

Figure 4. Group Delay of a thin film filter measured over the -60 dB passband using an OVA 5000 with 20 pm TDRBW. (Black) GD calculated from optical phase using a 60 pm derivative step size. (Red) OVA GD calculation.

The CD data are plotted below in Figure 5. Note the reduced noise in the black curve, corresponding to a 60 pm derivative step size, as compared with the red curve, corresponding to the OVA measurement. Also note however, the peak CD value near 1559.4 nm has been reduced by nearly 30 ps/nm. For this device, a smaller filter step size is recommended, since using a 60 pm derivative step size results in the suppression of real spectral features. The time domain impulse response in Figures 1-2 suggests that the maximum derivative step size appropriate for this device is 20 pm.

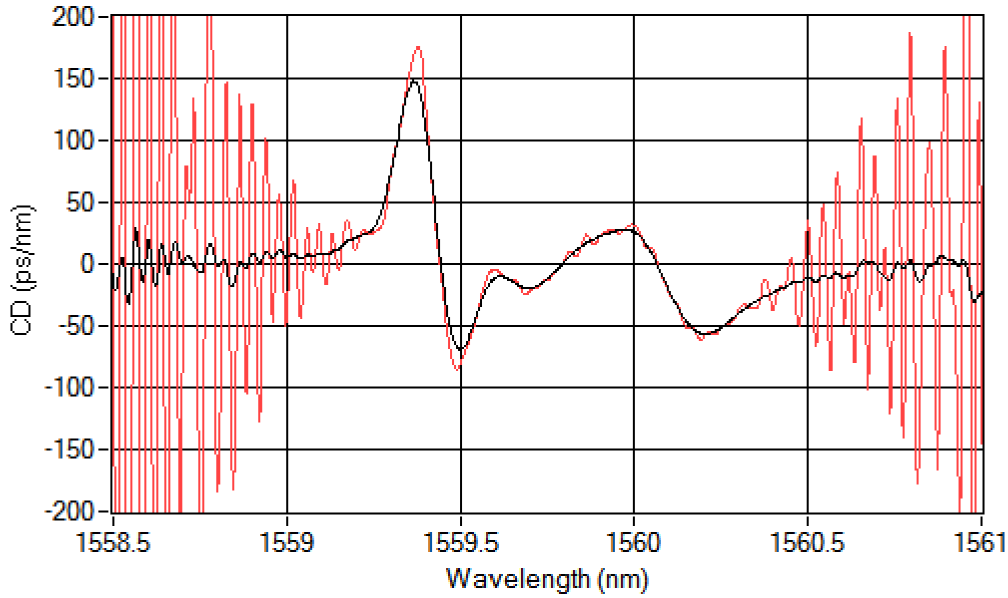

Figure 5. Chromatic Dispersion of a thin film filter measured over the -60 dB passpand using an OVA 5000 with 20 pm TDRBW. (Black) CD calculated from optical phase using a 60 pm derivative step size for both the GD and CD calculations. (Red) OVA CD calculation.

Therefore, the GD and CD data were re-processed with a 20pm derivative step size and the results are plotted below in Figures 6 and 7, respectively. Note that the GD and CD ripple in the low transmission regions (plot edges) has been reduced as compared with the OVA calculation, without affecting actual device features.

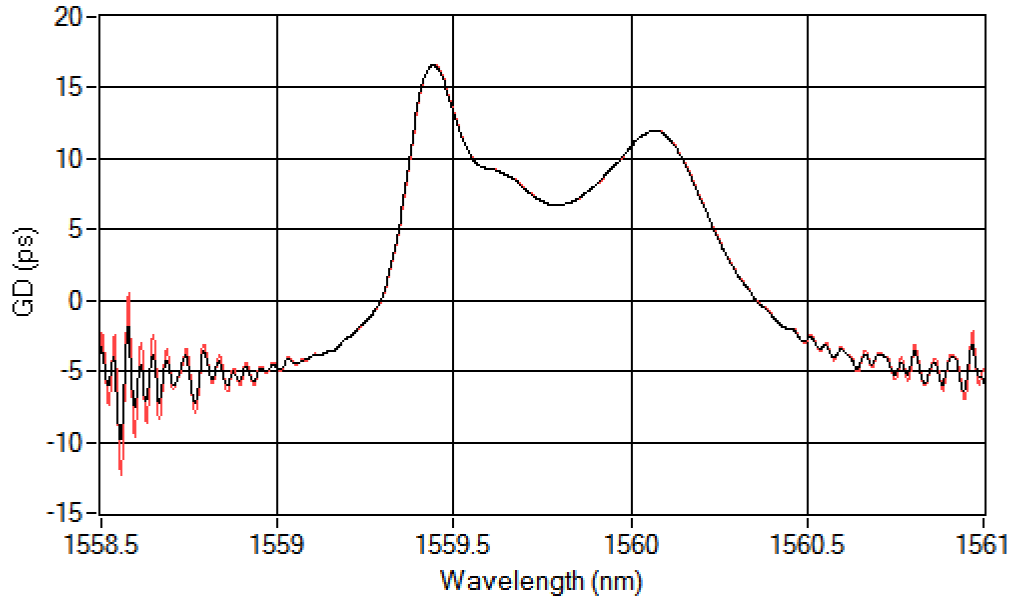

Figure 6. Group Delay of a thin film filter measured over the -60 dB passband using an OVA 5000 with 20 pm TDRBW. (Black) GD calculated from optical phase using a 20 pm derivative step size. (Red) OVA GD calculation.

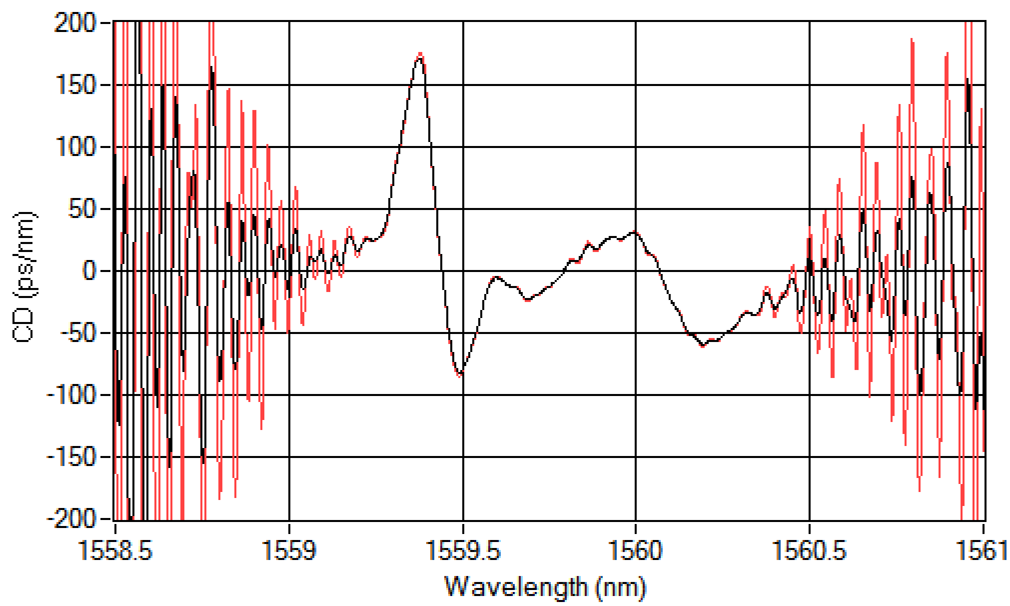

Figure 7. Chromatic Dispersion of a thin film filter measured over the -60 dB passpand using an OVA 5000 with 20 pm TDRBW. (Black) CD calculated from optical phase using a 20 pm derivative step size for both the GD and CD calculations. (Red) OVA CD calculation.

Conclusion

Starting from the OVA optical phase measurement, an algorithm was presented for calculating GD and CD utilizing a user-defined frequency derivative step size. Measurement examples were presented that demonstrate this method and illustrate that increasing the frequency derivative step size improves noise characteristics especially at low signal levels; however care must be taken to avoid suppression of actual device characteristics. In general, the derivative step size should be set below the scale upon which spectral features are present. In practice, this value is determined by minimizing the OVA's time domain window width about the device's impulse response, while being careful to include the *entire* response. The resultant TDRBW is the maximum appropriate derivative step size for GD and CD calculations.

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