

Pulse Detector [Frequency]

Digital Twin Specification

Twin Code:	DF-PDFR01
Twin Name:	Pulse Detector [Frequency]
Category:	Detector
Type:	Function-Based
Version:	1.0
Package:	Platform
Last Updated:	2026-03-20

Description

This detector evaluates the electromagnetic field of an optical pulse in the frequency domain. It samples the field at user-defined locations (point, line, or rectangle) and returns the spectral distribution. The detector can output the spectrum as a function of either optical frequency or wavelength.

VirtualLab Fusion uses a dedicated algorithm to find a smooth phase of the result by optical path length analysis. This is essential to keep the sampling effort for propagation towards the detector manageable—without this algorithm, the pulse would be completely undersampled or the required sampling would be prohibitively high. The results of this analysis can optionally be output.

Model Parameters

- **Output Evaluated Phase By Optical Path Length:** Toggle to output the results of the phase analysis based on optical path lengths.
- **Show Spectrum over Frequency instead of Wavelength:** Toggle to use optical frequency (Hz) as the coordinate instead of wavelength (m).
- **Point/Line/Rectangle of Evaluation:** Defines the spatial region where the field is sampled:
 - **Point:** Specify (x, y) coordinates.
 - **Line:** Specify start point, end point, and number of sampling points.
 - **Rectangle:** Specify bottom left corner (x_1, y_1) and top right corner (x_2, y_2) , with number of sampling points in each direction.

Simulation Model

The detector operates on the electromagnetic field incident at its evaluation plane, which is already represented in the frequency domain. For each spatial sampling point $\mathbf{r} = (x, y)$, the detector provides access to the complex field components:

$$\mathbf{E}(\mathbf{r}, \omega) = \begin{bmatrix} E_x(\mathbf{r}, \omega) \\ E_y(\mathbf{r}, \omega) \\ E_z(\mathbf{r}, \omega) \end{bmatrix} \quad (1)$$

Phase Evaluation via Optical Path Length

When analyzing pulses propagating through complex systems, the phase can become highly oscillatory, making it difficult to sample and interpret. The detector applies an optical path length analysis to decompose the phase into components with clear physical meaning. This decomposition is performed internally to enable efficient propagation; what is optional is the output of the resulting components.

For each spatial point \mathbf{r} , the total phase is first separated into a spatially-independent part and a spatially-dependent part:

$$\phi_{\text{total}}(\mathbf{r}, \omega) = \phi_{\text{OPL}}(\omega) + \phi_{\text{angular}}(\mathbf{r}, \omega) \quad (2)$$

where:

- $\phi_{\text{OPL}}(\omega)$ is the phase contribution from the optical path length, which is independent of the lateral position \mathbf{r}
- $\phi_{\text{angular}}(\mathbf{r}, \omega)$ contains the spatially varying phase information (e.g., wavefront curvature, aberrations)

The OPL term $\phi_{\text{OPL}}(\omega)$ is further decomposed into a linear term and a residual:

$$\phi_{\text{OPL}}(\omega) = \tau \cdot \omega + \phi_{\text{residual}}(\omega) \quad (3)$$

where:

- τ is the time shift (group delay) corresponding to the optical path length: $\tau = \text{OPL}/c$
- $\phi_{\text{residual}}(\omega)$ contains the remaining frequency-dependent phase (e.g., material dispersion)

Combining equations (2) and (3), the total phase is expressed as:

$$\phi_{\text{total}}(\mathbf{r}, \omega) = \underbrace{\tau \cdot \omega}_{\text{linear OPL term}} + \underbrace{\phi_{\text{residual}}(\omega)}_{\text{dispersion}} + \underbrace{\phi_{\text{angular}}(\mathbf{r}, \omega)}_{\text{spatial variation}} \quad (4)$$

The detector determines the best-fit time shift τ and provides access to the residual phase components when output is enabled.

Typical Application Scenarios

1. **Ultrafast Pulse Analysis:** Characterize the spectral content of femtosecond or picosecond laser pulses after propagation through dispersive elements (gratings, prisms, fiber).
2. **Dispersion Measurement:** Quantify group delay dispersion (GDD) and higher-order dispersion introduced by optical components by analyzing $\phi_{\text{residual}}(\omega)$.
3. **Pulse Shaping Verification:** Validate the output of pulse shapers (e.g., spatial light modulator-based systems) by comparing the measured spectrum against the target spectral phase and amplitude.
4. **Chromatic Aberration Analysis:** Evaluate how different wavelength components of a pulsed beam focus at different axial positions in a lens system by placing the detector at various z -planes and examining $\phi_{\text{angular}}(\mathbf{r}, \omega)$.
5. **Coherence and Interference Studies:** Analyze the spectral interference pattern of two or more pulses to determine relative delays or coherence properties.

Software Usage

After adding the detector to your system, configure it as follows:

1. **Double-click** the detector to open its properties. Navigate to the **Add-ons** tab.
2. You will find three add-ons: **Spectrum Evaluation (Point)**, **Spectrum Evaluation (Line)**, and **Spectrum Evaluation (Rectangle)**. Activate the desired one by clicking the eye icon.
3. In the add-on settings, adjust:
 - The evaluation geometry (coordinates, size, sampling points)
 - Toggle **Output Evaluated Phase By Optical Path Length** if the decomposed phase components should be included in the results
 - Toggle **Show Spectrum over Frequency instead of Wavelength** to select the coordinate for the x-axis
4. Run the simulation. Results can be viewed in the detector's result tab, displaying the electromagnetic field components as functions of the chosen coordinate.

Important notes:

- The optical path length analysis is always performed internally to enable efficient propagation. The toggle only controls whether the decomposed phase components (τ , $\phi_{\text{residual}}(\omega)$, $\phi_{\text{angular}}(\mathbf{r}, \omega)$) are output for user inspection.
- The computed time shift τ (group delay) is available in the detector's result list when output is enabled and can be used for system alignment verification or dispersion analysis.

Author:	LightTrans International GmbH
Contact:	support@lighttrans.com
Keywords:	pulse, ultrafast, spectrum, frequency domain, dispersion, OPL, phase, group delay, time shift, angular phase, wavelength, optical path length, residual phase, sampling efficiency
Related Twins:	DF-PDTE01, DF-PDUR01, DF-PENG01, DF-IFLX01, DF-IIRR01