Pulse Detector [Temporal]

Digital Twin Specification

Twin Code:	DF-PDTE01
Twin Name:	Pulse Detector [Temporal]
Category:	Detector
Type:	Function-Based
Version:	1.0
Package:	Platform
Last Updated:	2026-03-20

Description

This detector converts a pulsed electromagnetic field from the frequency domain (native to VirtualLab Fusion's field tracing engine) into the time domain, allowing you to analyze its temporal characteristics. You can select a specific evaluation region—a point, a line, or a rectangle—and choose whether to output the slow-varying temporal envelope or the full pulse, including the fast carrier oscillations. This twin is essential for designing and verifying systems involving ultrafast lasers, pulse shaping, and time-resolved optics.

Simulation Model

The detector samples the incident field in the frequency domain at a set of discrete frequency points covering the pulse spectrum. It then performs an inverse Fourier transform to reconstruct the time-domain field $V(t)$ at the specified spatial location(s).

For a scalar field component $V(\boldsymbol{\rho}, \omega)$, the time-domain field at a fixed lateral position $\boldsymbol{\rho}_0$ is given by:

$$V(\boldsymbol{\rho}_0, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{V}(\boldsymbol{\rho}_0, \omega)\, \mathrm{e}^{-\mathrm{i}\omega t}\, \mathrm{d}\omega, \tag{1}$$

where $\tilde{V}(\boldsymbol{\rho}_0, \omega)$ is the complex spectral amplitude at that point. The detected intensity is proportional to $|V(\boldsymbol{\rho}_0, t)|^2$.

Key Physical Principle: Envelope vs. Full Pulse

The parameter **Show Pulse With Carrier Frequency** controls the level of detail in the output:

- **Envelope only**: The detector outputs the intensity envelope $I_{\mathrm{env}}(t)$, which follows the slowly varying amplitude of the pulse, suppressing the rapid $\exp(-\mathrm{i}\omega_0 t)$ oscillations of the central carrier frequency ω_0. This is ideal for visualizing the pulse duration and shape.
- **Full pulse**: The detector outputs the complete field $V(t)$, including the carrier frequency. This reveals the electric field oscillations within the pulse envelope and is necessary for studying phenomena sensitive to the exact field waveform, such as coherent control or nonlinear interactions.

The transition between these two outputs is handled mathematically by either filtering the carrier frequency component or retaining it during the Fourier synthesis.

Model Parameters

- **Show Pulse With Carrier Frequency**: Boolean switch (default: `false`).
  - `false`: Output only the temporal intensity envelope.
  - `true`: Output the full field, including the high-frequency carrier oscillations.
- **Oversampling Factor**: Numeric value ≥ 1 (default: 1). An oversampling factor > 1 interpolates the frequency-domain data onto a finer grid before the Fourier transform, resulting in a smoother time-domain signal and a longer time window without aliasing.
- **Evaluation Region**: Selection of spatial evaluation mode.
  - **Point**: Specify a single (x, y) coordinate.
  - **Line**: Specify start and end points; output is a 2D dataset $(t, \text{position})$.
  - **Rectangle**: Specify corners; output is a 3D dataset (t, x, y).

Typical Application Scenarios

1. **Ultrafast Laser Characterization**: Measure the temporal profile of femtosecond or picosecond pulses after propagation through lenses, gratings, or dispersive media to verify pulse duration and peak power.
2. **Pulse Shaping Verification**: Use after a pulse shaper (e.g., a 4-f line with a spatial light modulator) to confirm that the synthesized temporal waveform matches the target intensity envelope or field.

Software Usage

After adding the Pulse Detector (Temporal) to your system:

1. **Activate the detector add-ons**: Double-click the detector icon to open its properties. Navigate to the `Add-ons` tab. You will find three available add-ons: *Pulse Evaluation (Point)*, *Pulse Evaluation (Line)*, and *Pulse Evaluation (Rectangle)*. Activate the desired one by clicking the eye symbol next to it.
2. **Configure the evaluation region**:
   - For a *Point*, enter the (x, y) coordinates in the detector's local coordinate system.
   - For a *Line*, define the start and end points and the number of sampling points along the line.
   - For a *Rectangle*, set the corner coordinates and the number of sampling points in x and y.
3. **Set time-domain parameters**: In the same add-on dialog, specify the **Oversampling Factor** and toggle **Show Pulse With Carrier Frequency** as needed.
4. **Run the simulation**: Execute the field tracing. After the simulation completes, right-click the detector and select *Show Add-On Results*. A new window will display the time-domain data. Use the visualization tools (e.g., 1D graph for points, 2D color map for lines/rectangles) to inspect the pulse.
5. **Export data**: If needed, right-click the result view and select *Export* to save the temporal data as a text file for external analysis.

Important notes:

- The input to this detector must be a pulsed source (e.g., a Pulsed Gaussian Waveguide or a custom pulse defined in the frequency domain). Continuous-wave sources will produce a trivial time-domain result.
- The temporal resolution is determined by the spectral bandwidth of the pulse and the frequency sampling in the simulation. The **Oversampling Factor** only interpolates existing data; it cannot recover frequencies outside the simulated spectrum.

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Keywords: pulse, temporal, time-domain, ultrafast, femtosecond, carrier envelope, Fourier transform, dispersion, detector, envelope, carrier frequency, oversampling
Related Twins: DF-PDFR01, DF-PDUR01, DF-PENG01, DF-IFLX01, DF-IIRR01