# Pulsed Lasers: How to Choose the Right Fast Photodetector

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Ophir's line of fast photodetectors expands your measurement capability to high speed temporal characterizations of laser pulses. Let us explain how.

**Figure 1. The new Ophir Fast Photodiode Detectors series.**

The vast majority of lasers used today in industrial applications are pulsed ones. Except for the very high power (multi kilowatt-level) CW lasers used for cutting, welding and cladding of metals, all other industrial uses of lasers need short and energetic pulses. Micromachining, drilling, scribing, marking or repairing of precision electronic components are only a few examples of the large variety of processes enabled by short pulsed lasers. In the bio-medical field, pulsed lasers are found in almost all applications: from laser surgery and medical implant fabrication to non-linear imaging of tissues and aesthetics. What these applications have in common is the requirement to deliver the pulse energy to the target in a precise timing. The temporal characteristics of the pulses such as pulse duration, pulse shape and profile, pulse timing jitter and repetition frequency are key parameters which need to be measured and monitored if one wants to guarantee the success of the application.

Short pulses lasers can be grouped into three different classes, depending on their temporal regime of operation. Nanosecond pulses are typically emitted from Q switched lasers, but picosecond and femtosecond pulse duration are a feature of mode-locked lasers.

To address the need for short pulse characterization, Ophir introduced the FPD series of fast photodetectors. In combination with a suitable oscilloscope or RF spectrum analyzer, the temporal performance of short pulsed lasers can be quantified. For pulse durations of nanoseconds down to a few tens of picoseconds, Ophir's fast photodiodes output signal can be directly sampled by an oscilloscope and the temporal characteristics can be obtained. For pulse duration shorter than a few tens of picoseconds, the fast photodiodes can be used to monitor the pulse train repetition rate and amplitude jitter.

For a complete characterization of the pulse duration, an Autocorrelator should be used. Spectra Physics' new PulseScout2 Autocorrelator is a great solution for ultrafast pulse measurements from 35 picoseconds down to 20 femtoseconds.


**Figure 2. Left: PulseScout2 Autocorrelator from Newport. Right: Autocorrelation trace of a 198 femtosecond pulse.**

Since the temporal behavior of pulsed lasers can span several orders of magnitude, from nanoseconds to femtoseconds, care has to be taken when choosing the right fast photodiode for the intended measurement. It is then important to correctly understand photodiode specifications to properly select the suitable model for the application.

In the following we discuss how to select the proper photodiode for commonly used laser types.

## *Responsivity*

First we need to consider the Responsivity [A/W] of the photodiodes. Responsivity is defined as the produced photocurrent (in Amperes) per Watt of incident radiation. It is a function of wavelength. Hence, the spectral response of the photodiode should be as high as possible at the wavelength of the laser to be measured. The spectral responsivities of the FPD series are shown in the figure below.

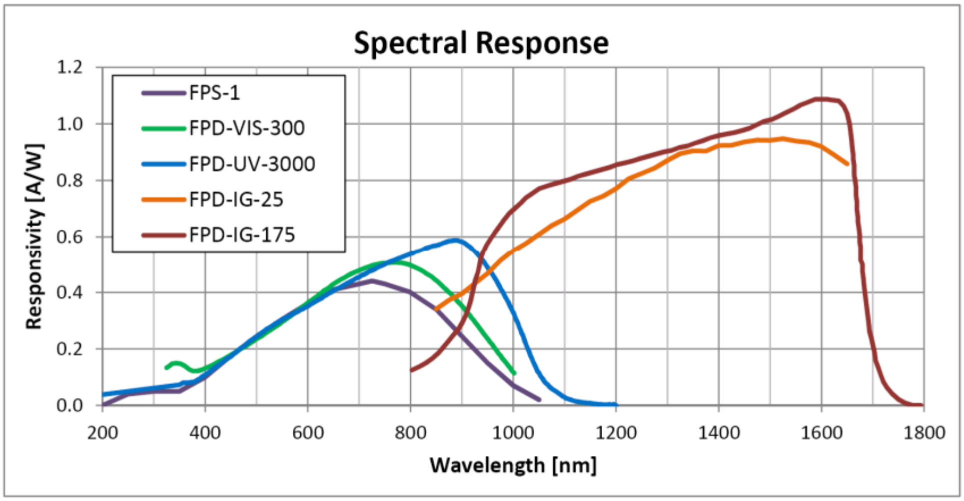


**Figure 3. Responsivity of the Ophir's FPD series.**

Ophir offers several fast photodiodes models with Silicon photodiodes having spectral response from 320 nm to 1100 nm, UV enhanced Silicon with extended response from 193 nm to 1100 nm, and InGaAs photodiodes which are sensitive from 900 nm to 1700 nm.

## *Bandwidth*

When the suitable type of photodiode has been selected based on the laser wavelength, we need to consider next the photodiode bandwidth and rise time. The rise time is equivalent to the response speed of the device. It is defined as the time required for the photodetector output signal to change from 10% to 90% of the peak level. A good rule of thumb is to choose a photodiode with a rise time that is one fifth of the laser pulse width to be measured. This ensures the pulse shape will be reliably measured without distortion.

The bandwidth is related to the rise time according to the following:

$$BW_{det} \sim \frac{K}{T_r}$$

Where $BW_{det}$ is the Bandwidth [Hz] and $T_r$ the rise time [seconds] of the photodetector. $K$ is a constant which depends on the pulse shape and the frequency response of the device. It will typically fall between 0.35 and 0.45. For Gaussian shaped pulses, taking K = 0.35 is generally quite accurate, and the expected error is only 2%. Photodetectors with larger bandwidth have faster temporal response and can be used for measuring shorter pulses.

## *Visualization*

Another very important consideration is how to properly match the photodetector to the oscilloscope used to visualize and measure the signal.

The FPD series photodetectors are designed to be used with a 50 Ω termination resistance for impedance matching. Simply select the internal 50 Ω impedance of your oscilloscope channel to adapt the output of your photodiode to the input of the scope. If the scope does not have a 50 Ω option, use a termination resistance of 50 Ω at the cable when connecting it to the scope.

The bandwidth of the scope should also be matched to the photodetector bandwidth. Using a 1 GHz bandwidth oscilloscope with a 15 GHz photodetector like the Ophir FPD-IG-25 won't take advantage of the fast response time offered by the photodetector. The same considerations apply to the connecting cable. A BNC cable designed for 50 Ω impedance has a typical bandwidth of 4 GHz. For higher speeds, SMA cables must be used, since they have a typical bandwidth of 18 GHz. Following our rule of thumb, **all components in the measuring chain should have a combined rise time which is one fifth of the laser pulse width expected to be measured.** Given the scope and cable bandwidths, the rise times of each component can be calculated with the same relation given above.

Once the rise times of all the components are determined, the expected rise time of the complete measuring chain is obtained by RMS summing:

$$T_{r,measured} = \sqrt{T_{r,scope}^2 + T_{r,det}^2 + T_{r,cable}^2}\,,$$

Where $T_{r,measured}$ is the total rise time of the full system, and it is the one which will be measured and displayed on the oscilloscope screen.

Let's now consider some examples to see how to apply what we learned.

### *Example 1*

**Problem**: A PCB manufacturer is tasked to characterize the pulse shape and pulse duration of a Spectra Physics Quasar industrial UV laser at 355 nm for via hole drilling in ceramic and glass materials. The Quasar UV laser features 'TimeShift' Technology allowing programmable control of the pulse width, shape and repetition rate to optimize the drilling process. The pulse widths can be adjusted from 2ns to 100 ns.

https://www.spectra-physics.com/products/fiber-lasers/quasar?subcat=pulsed-green

**Solution**: From the minimum pulse width of 2 ns, we apply our rule of thumb and specify a total system rise time of one fifth of the pulse duration in order to obtain less than 2% measurement error. We hence need a detection system with 0.4 ns rise time sensitive at 355 nm. The [Ophir FPD-VIS-300] is a Silicon photodetector sensitive from 320 to 1100 nm with a 0.3 ns rise time, corresponding to a bandwidth of 1.2 GHz. Using a 2 GHz oscilloscope and a 50 Ω , 4 GHz BNC cable, we calculate our total system response time to be:

$$T_{r,measured} = \sqrt{0.3^2 + (\frac{0.35}{4})^2 + (\frac{0.35}{2})^2} = \sqrt{0.3^2 + 0.0875^2 + 0.175^2} = 0.358\ ns\ ,$$

which is faster than our requirement of 0.4 ns rise time. Note that if we had chosen a 1 GHz scope, we would have expected a 0.469 ns total system rise time, introducing an error greater than 2% in the pulse measurement.

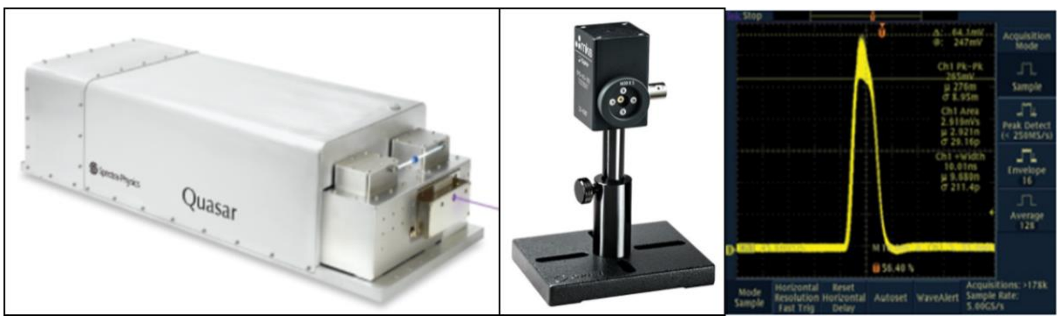


**Figure 4. Spectra Physics Quasar Laser, Ophir FPD-VIS-300 and a typical 10 ns pulse profile.**

### *Example 2*

**Problem**: An automotive LiDAR manufacturer is seeking to characterize the precision of his transceiver module used for time of flight distance measurements.  A 940 nm diode laser is emitting 1 nanosecond pulses at a 1 MHz repetition rate. Knowing the pulse duration and timing jitter of the emitted laser pulses is critical for assessing the resolution uncertainty of the distance measurement and evaluating the performance of the synchronization electronics.

**Solution**: To accurately measure a 1 ns pulse width we need a detection system with at most 0.2 ns rise time. The Ophir FPD-IG-175 is a InGaAs photodiode with a responsivity of  ~ 0.6 A/W at 940 nm and a rise time of 175 ps, corresponding to a bandwidth of 2 GHz.

When using this photodiode with a 6 GHz oscilloscope and a 50 Ω , 4 GHz BNC cable, we calculate our total system response time to be:

$$T_{r,measured} = \sqrt{0.175^2 + (\frac{0.35}{6})^2 + (\frac{0.35}{4})^2} = \sqrt{0.175^2 + 0.0583^2 + 0.0875^2} = 0.204\,ns\ ,$$

which meets our requirement of 0.2 ns system rise time.

Note that a 6 GHz oscilloscope can be prohibitively expensive so an alternative solution could be to use the Ophir FPD-IG-25 with its 15 GHz bandwidth instead, in combination with a 2 GHz scope and a SMA cable with a typical 18 GHz bandwidth. The total response time could be:

$$T_{r,measured} = \sqrt{0.025^2 + (\frac{0.35}{2})^2 + (\frac{0.35}{18})^2} = \sqrt{0.025^2 + 0.175^2 + 0.0194^2} = 0.178\,ns,$$

which also meets our requirements at a far lower system cost. A drawback of this solution is the lower responsivity of 0.5 A/W for the FPD-IG-25 at our 940 nm wavelength.

## *Conclusion*

Understanding how to apply photodetector specifications at the system level is critical to ensure the accuracy of temporal measurements. The photodetector is only a part of a detection system and the success of a precise measurement depends on the interplay of many factors. As applications continue to move toward shorter pulses and higher repetition rates, temporal characterization is becoming mandatory. But here at Ophir, we will continue to address these needs with market leading solutions. Stay tuned!