

Application Note

Photonic Doppler Velocimetry

The velocity measurement of fast-moving materials is essential to several areas of scientific and technical investigations, including shock physics and the study of the behaviour of materials at high pressure and at high strain rates. Laser based velocimetry is an important diagnostic tool in many experiments. Recent advances in telecommunications have enabled laboratories to develop and perform state-of-the-art compact, inexpensive and robust laser based velocimetry.



Coherent Solutions DopplerPXIe-1001 module

In its simplest form, an optical velocimeter is a coherent wave travelling out to a surface and back. Over the years several experiments were carried out to measure the velocity of fast moving objects, amongst them a few popular ones were:

1. Fabry- Perot interferometer. [1]
2. Velocity Interferometer System for Any reflector (VISAR). [2]

Both of them have the following disadvantages;

- Expensive to build.
- Susceptible to the variation of the intensity of the reflected light from the shocked surface and abrupt changes in velocity.

The latest advancement in optical telecommunications led to the availability of a new measurement method. In 2004, Ted Strand introduced the Photon Doppler velocimetry (PDV) [3, 4]. It is similar in concept to the laser doppler velocimeter introduced in 1965 [5]. However Strand refined this design using optical fibres instead of free space. The fibre-coupled optics significantly improved the robustness to experimental variation as well as simplifying its implementation. Although several variations on this architecture exist, the basic principle of heterodyning a reference laser with a target laser remains the same. When the two lasers are combined and converted to a voltage signal through a photodetector, they yield a beat frequency, which is based on their phase difference (or optical path length difference).

PRINCIPLE OF OPERATION

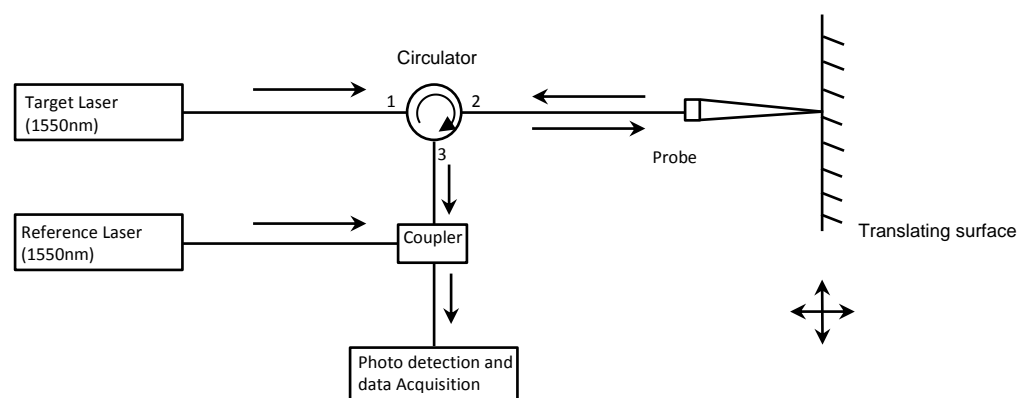


FIGURE 1: Simplified diagram of fibre-coupled PDV

The circulator functions as an optical directional coupler for the incoming target laser on port 1. A circulator is a three port device that allows light to travel in only one direction. The incoming light exits port 2 and is transported to an optical probe. The incident light is then reflected from the moving surface and collected by the same optical probe. This light then re-enters the same fibre and moves back into port 2, where it is redirected inside the circulator to port 3. An external reference laser source provides the unshifted or reference light.

In our case, reference light at frequency f_{ref} interferes with the Doppler shifted light at frequency $f_{doppler}$ producing beat frequency at the detector which can then be seen on a high speed oscilloscope.

The beat frequency B,

$$B = |f_{doppler} + f_{Target} - f_{ref}|$$

where $f_{doppler}$ is the doppler shift, f_{Target} is the optical frequency of target laser and f_{ref} is the optical frequency of the reference laser.

For an object that is moving at a fixed velocity of v , the relationship between the doppler frequency and the velocity is given by

$$v = \left(\frac{\lambda_{Target}}{2} \right) f_{doppler}$$

where λ_{Target} , is the wavelength of the target laser. The beat frequency that is produced is slow enough that it can be monitored on a high speed oscilloscope. By recording the beat frequency over time, a complete velocity history of the moving object can be obtained.

As an example, let's set the target laser to $f_{Target} = 193.000$ THz (1553.329nm) it is possible to detect a velocity of

$$\lambda_{Target}/2 * 10^9 = 0.776 \text{ km/s per GHz}$$

Studies have shown PDV systems with up to 20 GHz are available, corresponding to velocity measurements over 15 km/s.

ADVANTAGES OF FIBER-BASED PDV

The advantages of using PDV as a favoured approach in optical velocimetry over VISAR and Fabry-Perot:

- The use of a single 9/125um (core/cladding) optical fibre for both transmit and receive paths of the measurement lends itself to using small optical probes, enabling high channel density for multi-probe systems.
- The system uses 1550 nm CW fibre lasers which are eye-safe under normal use like class 1. Class 3b and higher are utilized for certain test cases.
- Since the velocity measurement is embedded as a frequency in a time domain signal, digital signal processing methods can be used to extract weak signals with high precision. This means that under difficult experimental conditions one can obtain reliable measurements when other approaches would likely fail.

EXAMPLE PDV SETUP

Figure 2 shows an example configuration of a Doppler setup. It consists of two laser sources (Target and Reference), a Doppler module that incorporates many of the key fiber optical modules required to accurately condition the target and the reference laser and to mix the probe with the reference. The output of the Doppler module is sent to a high gain and high bandwidth optical detector where the probe and reference laser beat. The electrical beat signal is then digitized with an oscilloscope.

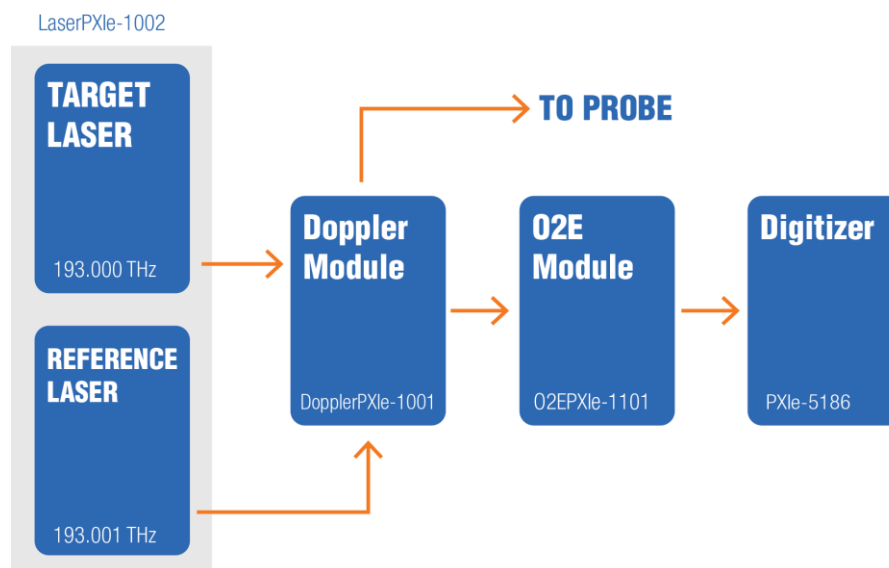


Figure 2: Photonic Doppler velocimetry test setup

All of this functionality is incorporated into the open standard PXI platform. This provides the user with all the flexibility required to create large multiplexed systems. It also lets the user upgrade the system over time by changing to higher bandwidth detectors and digitizers.

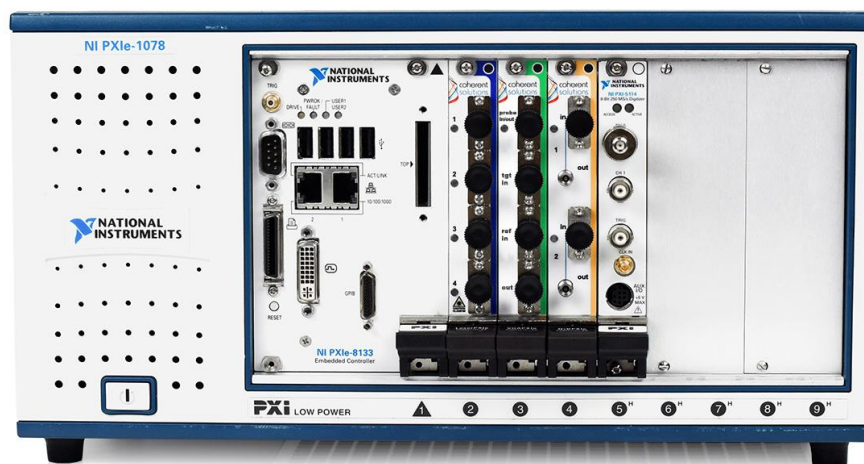


Figure 3: PXIe modular configuration of PDV

Figure 4 represents the configuration of the Doppler module (Doppler-PXIe-1001-1-FA), which incorporates some of the key components of Photon Doppler velocimetry.

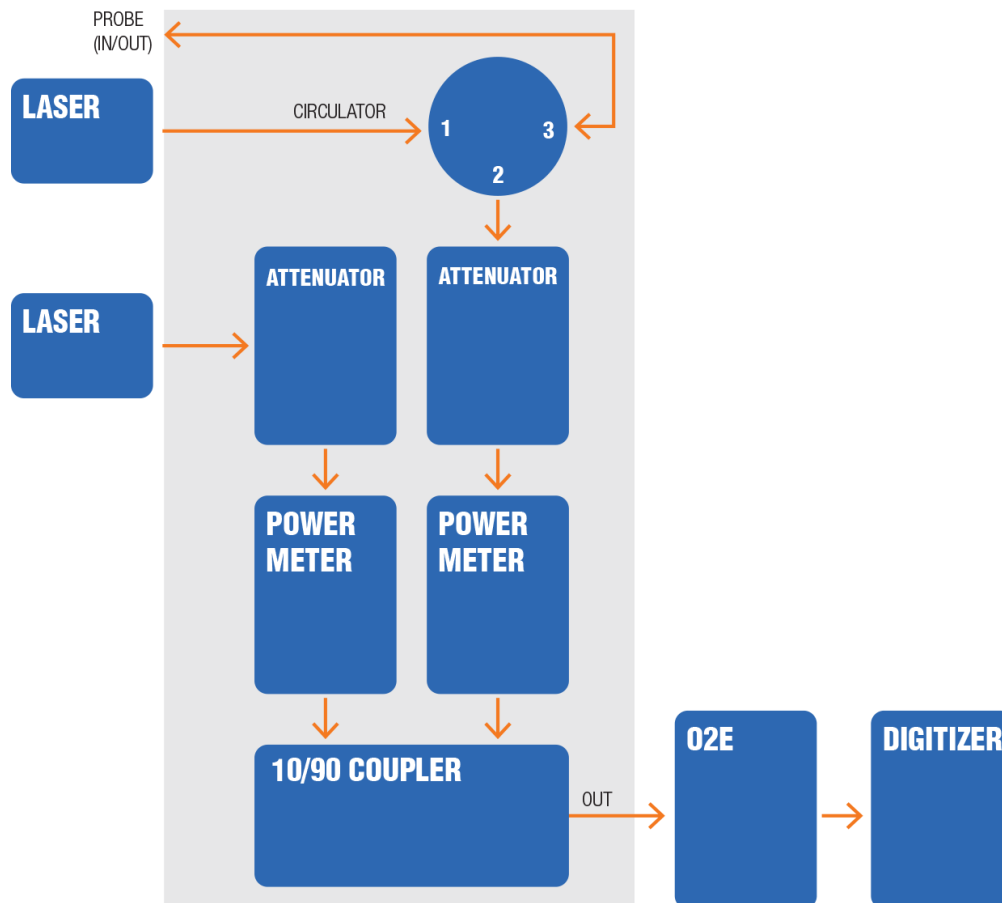


Figure 4: Doppler module (DopplerPXIe-1001) schematic

This is a single slot PXIe module, with the following functions:

- Target input
- Reference input
- Probe port (input/output)
- Output port

It is compatible with PXIe chassis. Some of the key benefits of the Doppler module are the following:

- Accurate control of target, probe and reference power
- Accurate measurement of probe power and reference power
- Compact and reliable
- Easily scalable for multiplexed systems

LATEST DEVELOPMENTS

Some of the developments done in this field are:

a. Multiplexed Photon Doppler velocimetry (MPDV) [6,7,8,9]

This was developed by National Security Technologies, which is a four-channel digitizer capable of measuring 32 distinct velocity histories measured by 32 separate optical probes. MPDV enables multiple probes to be used with the same digitizer, resulting in a denser spatial sampling of the target surface.

b. Leapfrogged Photon Doppler velocimetry [10]

Developed by Dan Dolan and his team at Sandia National Laboratories, this particular system was designed to read higher velocities as shown in **figure 5**.

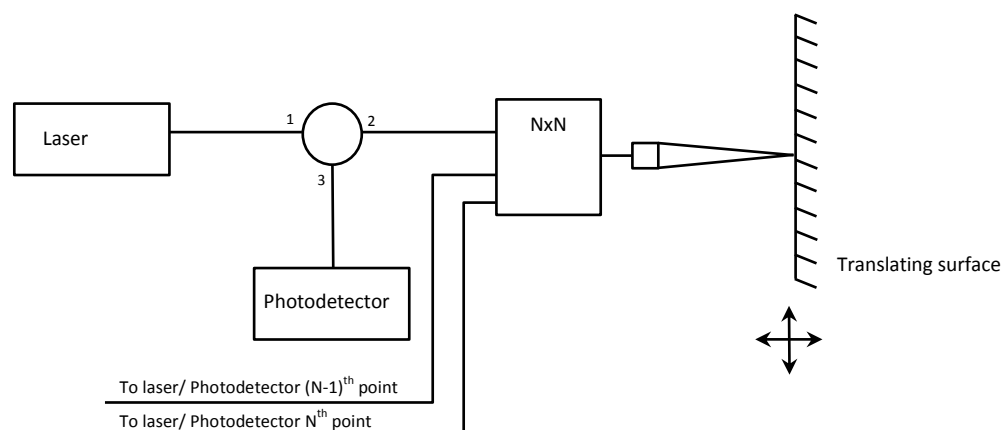


Figure 5: Leapfrogged Photon Doppler velocimetry

Several laser/photodetector pairs are used in parallel to increase the range of the PDV's velocity. The reference laser of each laser/photodetector pair is tuned such that it measures a specific velocity range. For example a three channel leapfrogged photon doppler velocimeter was designed to measure speeds of up to 97km/s.

CONCLUSION

Due to its robust and high-performance measurement capabilities, PDV's will have continued applications in the measurement of high velocity measurements. Coherent Solutions provides all of the necessary equipment to perform reliable, repeatable measurements for the most complex of multiplexed PDV experiments.

Please visit www.coherent-solutions.com/pxi/ for more information on the PDV modules presented.

LaserPXIe-1002 2 channel tunable laser, 191.5- 196.25 THz, +15dBm output power

DopplerPXIe-1001 Doppler module that incorporates 2 variable optical attenuators, 2 inline power meters, a circulator and a 10/90 optical coupler

O2EPXIe-1101 25GHz optical to electrical converter with 900V/W of conversion gain

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REFERENCES

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