

Basics of Digital Vibrometry



FOR BEGINNERS AND EXPERIENCED USERS

New digital signal processing (DSP) hardware combined with affordable advanced PC platforms enables a new generation of digital laser-Doppler vibrometers (LDV). Based a heterodyne interferometer, high-speed A/D conversion and numerical demodulation algorithms, digital LDVs provide outstanding measurement accuracy and resolution. They are characterized by the following features:

- *Calibration accuracy that has minimal drift with time*
- *Amplitude resolution limited by shot noise (received laser power)*
- *Sub-nanometer displacement resolution within the full velocity and frequency range*
- *Flat frequency response from DC to 2 MHz*
- *Simple data acquisition and evaluation*

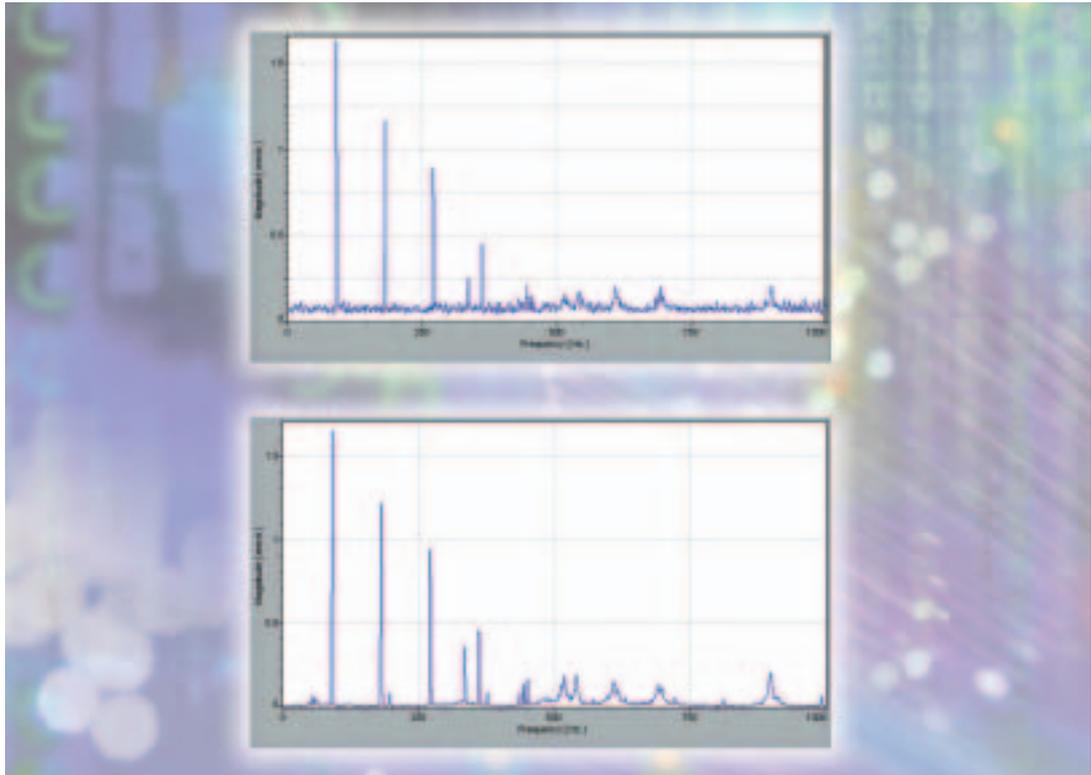
These outstanding properties enable numerous cutting edge applications where high accuracy, very low noise floor or numerical post-processing of the measurement information are important, ranging from next generation MEMS device and hard disk drive (HDD) technology test and characterization to higher precision general metrology.

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Figure 1:
A comparison of analog and digital decoders shows a reduction in the noise floor for digital decoding. Vibration velocity measured out-of-plane on spinning HDD media.

Top: OFV-5000 Vibrometer Controller with analog VD-02 Velocity Decoder and VibSoft.

Bottom: VDD Digital Vibrometer with digital DD-600 Displacement Decoder (signal differentiated)



Introduction

Laser Doppler vibrometry is a proven technology for accurate, non-contact measurement of vibration or small displacements in industrial, engineering and scientific applications. Current analog velocity decoders acquire velocity peak amplitudes of 30 m/s in a frequency range from DC to >20 MHz. Due to the wide bandwidth of laser Doppler signals, the phase linearity of amplifiers and filters are a challenge for the designer. Accuracy strongly depends on each component in the analog signal processing chain, with particular emphasis on the quality of phase and frequency demodulators.

To overcome some of the drawbacks of analog signal processing, the Doppler signal is digitized and demodulated using numerical methods. High-speed hardware in combination with advanced numerical signal-processing algorithms can perform Doppler signal decoding in real-time. In Figure 1 we show the noise floor decrease as we examine the VD-02 Analog Velocity Decoder (top) compared to the DD-600 Digital Displacement Decoder (bottom). Depending on the particular application, the preferred solution can be either a PC-based system or a plug-in DSP decoder module.

Digital Demodulation Techniques

Displacement Decoding by Fringe Counting

The classical digital method to recover displacement information from a phase-modulated Doppler signal is a technique called fringe counting. At the photo detector, a complete interference fringe cycle corresponds to one complete period or a 2π -increment of the interferometric phase angle. This corresponds to a displacement of $\lambda/2$. More sophisticated methods utilize pulse interpolation techniques in order to increase resolution. Systems based on this method achieve a 2 nm per count resolution, but further improvements are not expected.

The Arctangent Phase Demodulation Method

In order to extract the maximum information from large bandwidth Doppler signals, high-speed A/D converters and powerful processors are absolutely necessary for high performance DSP-based vibrometer systems. Polytec's development team has successfully combined both standard PC platforms and tailored DSP chips to perform the required numerical high-speed processing. Signal decoding is based on the well known arctangent phase demodulation method. On the basis of an output signal in quadrature format, this method calculates the phase angle

by simple trigonometric relationships. Since this demodulation method is very accurate and stable, it is one of the preferred methods for Doppler signal decoding according to ISO 16063-11 (Methods for the calibration of vibration and shock transducers - Part 11: Primary vibration calibration by laser interferometry).

The key prerequisite of the arctangent method is a signal pair comprised of I (in-phase) and Q (quadrature) components. Their voltage amplitudes depend on the interferometric phase angle $\varphi_m(t)$:

$$u_i(t) = U_i \cos \varphi_m(t)$$

$$u_q(t) = U_q \sin \varphi_m(t)$$

Such a signal combination is called an I & Q base band signal (Figure 2), as there is no frequency offset present. In the base band, a signal pair is needed to carry the complete Doppler information. While the absolute value of displacement is represented by each component, its sign can only be recovered from both signals in combination.

With increasing phase angle $\varphi_m(t) \sim s(t)$ the visualizing vector describes a perfect circle, centered on the coordinate origin. A quadrature signal pair can also be considered as real and imaginary parts of a complex phasor.

The I & Q format is an ideal starting point for numeric Doppler signal decoding. Recovering the object displacement $s(t)$ simply requires the calculation of the phase angle $\varphi_m(t)$ from the sampled instantaneous voltage values of the I&Q signals based on the trigonometric relationship $\tan \alpha = \sin \alpha / \cos \alpha$. The inverse function provides the value of the phase angle at time t_n

$$\varphi(t_n) = \arctan \frac{u_q(t_n)}{u_i(t_n)} + 2m\pi$$

$$m = 0, 1, 2, \dots$$

The ambiguity of the arctangent function can be removed by a phase unwrapping algorithm, which provides the integer number m , representing multiples of $\lambda/2$. The quotient $u_q(t)/u_i(t)$ eliminates the actual value of the signal amplitude U . This is crucial for the accuracy of this method. Finally, the discrete displacement function $s(t_n)$ is obtained.

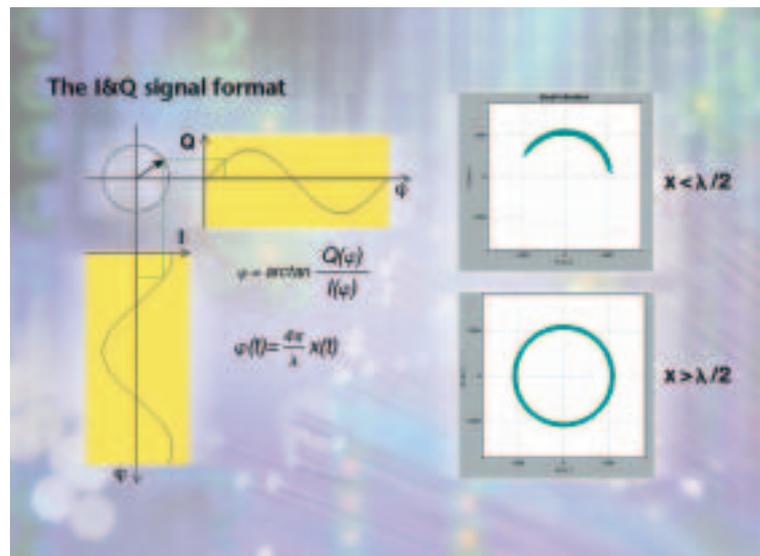
$$s(t_n) = \frac{\lambda}{4\pi} \varphi(t_n)$$

Digital Interfacing

Digital velocity decoders are equipped with both a serial data interface and an analog output. This allows the user to pick the most appropriate output for their application. Polytec implemented the S/P-DIF standard (Sony/Philips Digital Audio Interface) for data transmission of digitized vibration signals in the audio frequency range. S/P-DIF uses single-line transmission either via coaxial cable or optical fiber and enables data acquisition and recording with standard commercial equipment such as PC sound boards or digital audio recorders.

Current implementations support 24-bit amplitude resolution at a sample rate of 48 kSa/s or 96 kSa/s, resp. (OFV-5000), in the frequency range 0 - 22 kHz or 0 - 42 kHz, resp.

Figure 2: Representation of the I & Q signal in a vector diagram (left) and the resulting real display for different vibration amplitudes (right)



Polytec's Range of Digital Vibrometers



PDV-100 Portable Digital Vibrometer

The first single-box, portable and lightweight digital laser Doppler Vibrometer for field applications like predictive maintenance of machinery. In addition to the conventional analog output, a S/P-DIF standard digital output connects easily to sound cards, bypassing expensive data acquisition electronics.



IVS-300 Digital Industrial Vibration Sensor

A digital single-box vibrometer specifically developed for non-contact vibration measurement up to 22 kHz in production test applications. The robust and compact design is sealed to the IP-64 standard to meet the challenges of harsh industrial areas.



CLV Compact Laser Vibrometer

The CLV combines a robust, compact optical head with a modular controller optionally equipped with a digital signal decoder. Designed for vibration measurements up to 350 kHz, its small size makes it perfect for difficult-to-reach places or for production lines where space is limited.



OFV-5000/-50X/-55X Modular Vibrometer System

This state-of-the-art laser vibrometer system with modular design can be tailored to specific or multiple applications. It is available with OFV-505/503 standard sensors or OFV-551/552 fiber-optic sensor heads and powerful digital and analog velocity and/or displacement decoders covering frequencies up to 20 MHz.



VDD Digital Vibrometers

Combines the highest performance data acquisition, comprehensive "VibSoft" software package and either a compact front-end shown or a DD-600 decoder to be installed in an OFV-5000 Controller. Ultra-precise vibration measurements for data storage, MEMS, hearing dynamics or calibration applications can be accomplished.



PSV-400 Scanning Vibrometer

This measurement technology has been designed for the full-field analysis of structural vibrations. It can scan entire surfaces resolving noise and vibration issues for the automotive, aerospace, commercial manufacturing and R&D markets. It is available with a combination of analog and digital decoders for highly sophisticated and precise measurements.

More info: www.polytec.com/usa/Lm-digital

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