doi: 10.4302/plp.2014.4.07 PHOTONICS LETTERS OF POLAND, VOL. 6 (4), 133-135 (2014)

Multichannel WDM vibrometry at 1550 nm

A. T. Wąż, G. Dudzik, P. R. Kaczmarek and K. M. Abramski

Faculty of Electronics, Wroclaw University of Technology, Wyb.Wyspianskiego27, 50-370Wroclaw

Received November 27, 2014; accepted December 30, 2014; published December 31, 2014

Abstract—We present a multichannel laser-fiber vibrometer concept, realization and obtained results. The vibrometer is based on the WDM (*Wavelength Division Multiplexing*) telecommunication technique and operates at the 1550 nm region. Four independent fiber-coupled laser diodes form a system of sources for multipoint vibration measurement according to the rule "one wavelength–one point". Such a solution minimizes crosstalk between channels and allows to arrange measuring points freely. Our system measures vibrations at four points simultaneously. It allows phase-relation measurements between vibrating points. Additionally, it is an all fiber design thus it gives the possibility to measure vibrations in hard-to-reach places.

Laser vibrometry techniques have been developed during the last two decades [1-7]. Well-developed vibrometry is based mainly on direct analysis of laser beams which are scattered from an object (bulk vibrometry) [8-9]. This technique has one main disadvantage – it is not sufficiently flexible. Hence, vibration analysis is difficult or impossible in hard-to-access places, like car engines, planes, household appliances, etc. The one possibility to improve its flexibility is applying optical fiber. Except for flexibility, the proposed 1550nm fiber solution has other important advantages – it is "eye safe" radiation (the higher optical powers can be applied, and as a result, signal processing is simpler) and the WDM technique applied to a fiber network can lead to multichannel fiber vibrometry. The proposed multi-channel system gives the possibility of choosing any point of a vibrating object. It works as four independent vibrometers, but the proposed 4-channel fiber vibrometer requires only one acousto-optic Bragg modulator, one EDFA (erbium doped fiber amplifier) and all signals are transmitted via a common fiber.

The laser-fiber vibrometer has been evaluated during our investigations [10-11]. Figure 1 presents the idea of a four-channel laser-fiber vibrometer. As a light source for the vibrometer, four continuous wave DFB (*Distributed Feedback*) laser diodes were used. Each laser diode output power is split by *couplers 1* into *reference* and measure beams (*transmitter*). The main optical power passes through the *transmitter* and illuminates the vibrating object via collimators. The transmitter channel consists of two multiplexers, isolator, fiber-coupled acousto-optic Bragg (*AO*) frequency shifter (Gooch &Housego, M040-8J-F2S) operating at 40MHz. The AO shifter is necessary for heterodyne detection, which is more efficient than homodyne [12]. The presented

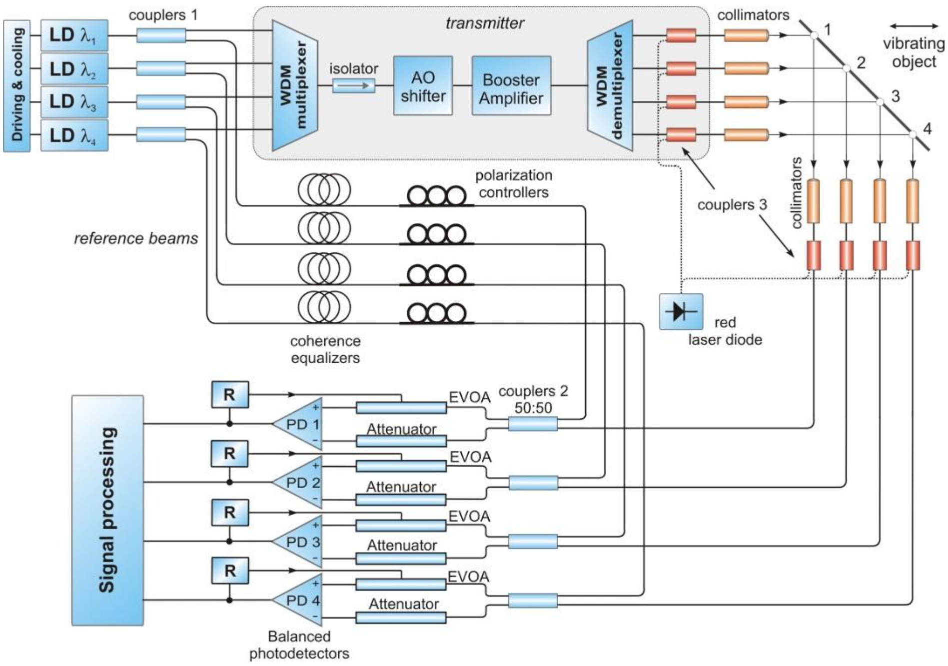

Fig. 1. The idea of 4 – channel laser-fiber vibrometer.

transmitter setup allows to shift frequency and amplify all wavelengths simultaneously. It is a very convenient and economical solution. Due to 1550nm invisible radiation, additional red laser diodes have been coupled into the transmitting and receiving path to observe the precise location of an analyzing point. The booster amplifier is based on a double-clad erbium-ytterbium fiber (Fig. 2). It allows to amplify all four signals to a level of 20dBm and is enough to obtain a reasonable level of scattered light. The amplifier gain is adjustable and it depends on a pump laser diode current.

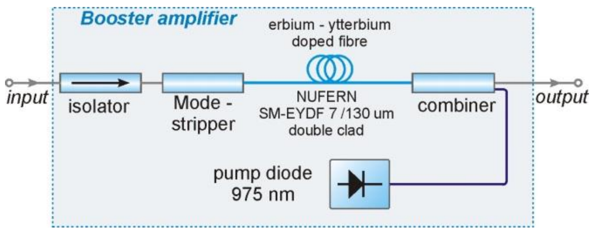

Fig. 2. The block diagram of booster amplifier.

The scattered light from the vibrating object is collected by collimators and goes to *couplers 2*. The 50:50 couplers were used to mix input signals, being required for balanced photodetection. The main advantages of using balanced photodetectors are: doubling the output heterodyne signal and reducing the DC level and laser noise. Since a balanced photodetector requires almost equal input optical power (for the presented model, the differences should be less than 30μW) an automatic controller is used. It consists of *R* (Regulator), *EVOA* (Electrical Variable Optical Attenuator), and an *Attenuator*. In real time the DC voltage level on the photodetector output is monitored and minimalized by appropriate EVOA controlling [13].

In the laser Doppler vibrometry, interferences between scattered and reference light are observed. Heterodyne detection is used in proposed setup, therefore on the photodetectors output we obtain a frequency-modulated signal with a frequency carrier f_B=40MHz. The Doppler frequency deviation $\Delta f(t)$ depends on the object velocity $V(t)$ according to the equation [11]:

$$\Delta f(t) = \frac{2 \cdot V(t)}{\lambda}, \tag{1}$$

where λ is the wavelength of laser radiation. The heterodyne signal is FM demodulated and after calibration provides a measure of velocity of the vibrating object. For the wavelength which we use, λ=1550nm, the velocity of the object $V(t)$=1m/s causes deviation Δf=1.29MHz. Another parameter of the detected beat signal is phase shift φ(t), which corresponds to the displacement $s(t)$ of the vibrating object. The phase-modulated signal φ(t) is in linear relation between the displacement $s(t)$ according to the equation:

$$\varphi(t) = \frac{4\pi}{\lambda} \cdot s(t). \tag{2}$$

Electrical heterodyne signals from photodetectors are conditioned and demodulated in a *Signal processing* module (Fig. 3) controlled by a microcontroller. Firstly, the RF input signal is amplified by an amplifier with AGC (*Automatic Gain Control*). It minimizes speckles influence on heterodyne signal quality and adapts the signal level for demodulators. A suitable demodulator type can be chosen using the electronic RF switch.

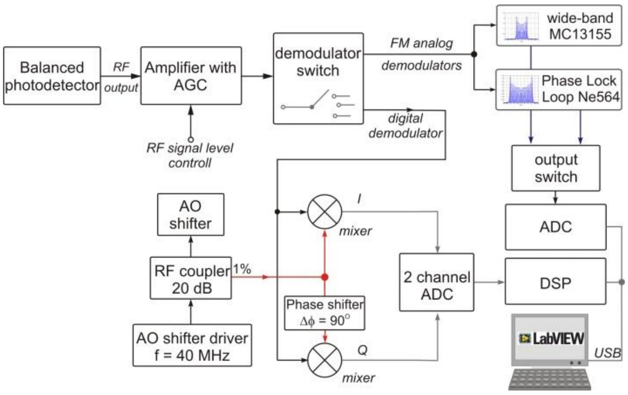

Fig. 3. The laser-fiber vibrometer signal processing scheme (only one channel is presented).

The first one is an IQ demodulator, which is the most sensitive one. As reference, we use 1% signal power from an acousto-optical (AO) shifter driver. The signal proportional to the displacement (after computing) is a product of IQ demodulation. All IQ channels are sampled simultaneously by an analog-to-digital converter (*ADC*) integrated with a digital signal processor (*DSP*). All demodulators were self-made, and their parameters are presented in Tab.1.

Table 1. The most important parameters of adapted demodulators.

Demodulator / Parameter	IQ	FM - wideband	FM - PLL
Input power [dBm]	-40÷10	-30÷20	-35÷13
Velocity range [m/s]	0÷0.07	0.05÷0.755	0.5÷5
Uncertainty displacement/ velocity measure	50nm	200μm/s	2mm/s
Vibration frequency range [kHz]	0÷20	0÷20	0÷10

After measurements, signals from all three demodulators are sent to the computer. Further signal processing (e.g. vibration frequency spectra) and presentation of results are carried out by a PC via a USB interface. The photo of a complete device is shown in Fig. 4.

For the transmission of a laser beam and collection of scattered light, a setup using two single mode fiber collimators were chosen. The measuring range for the described head is 0.1÷2m. The Receiving collimator can

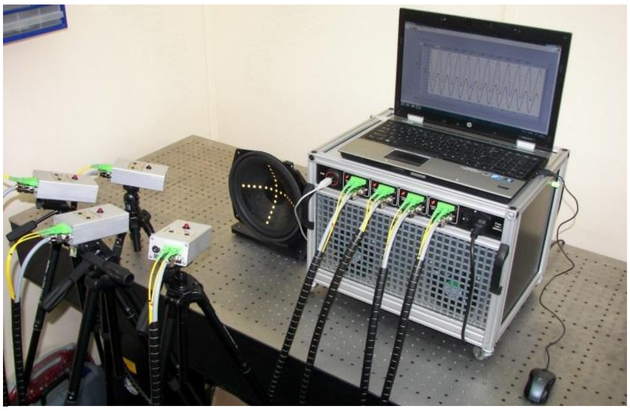

Fig. 4. Four channel laser-fiber vibrometer.

be moved by step motors to obtain the maximum power of scattered light. Automatic scattered signal search is done using a special algorithm implemented in LabView.

A setup wa arranged to measure a piezoelectric speaker (typical speaker using in electronic equipment) vibrations (Fig. 5) .

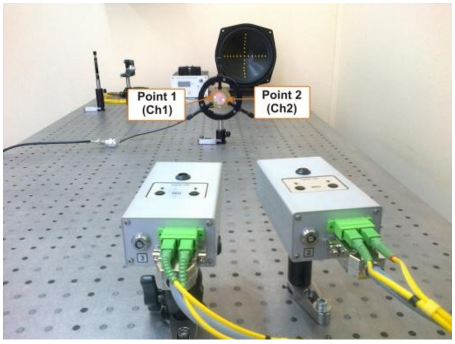

Fig. 5. The experimental setup with piezoelectric element.

At the beginning, vibrations amplitude was measured versus frequency at the speaker centre (Fig. 6). A special LabView application was written for an automatic speaker driving signal frequency f_{DR} sweep and acquisition signal from the vibrometer. The amplitude of the driving signal was 1Vpp. The object under investigation has several resonances in the measured range. For further analyzes of two channels, the frequency f_{DR} of about 1kHz was chosen.

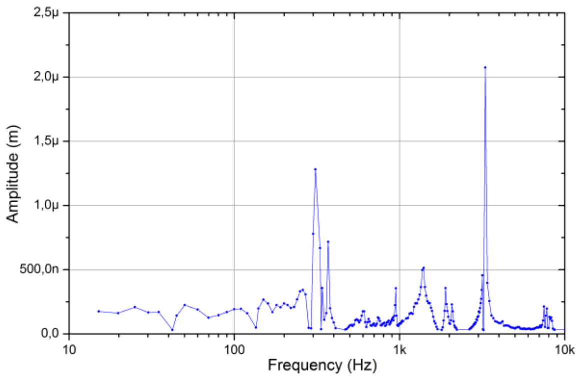

Fig. 6. Piezoelectric element frequency response.

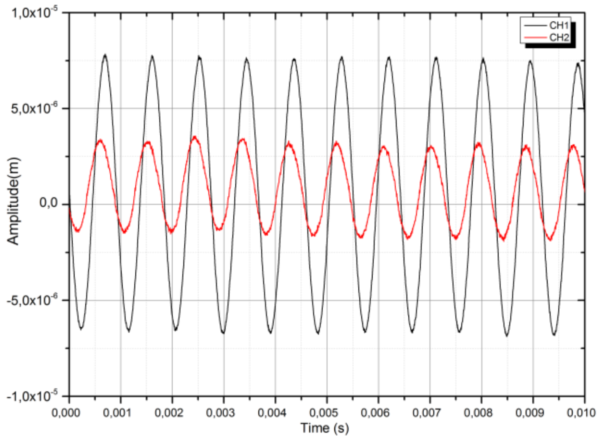

Fig. 7. Vibrations of piezoelectric element at two measurement points for f_{DR}=1.14 kHz.

The results for f_{DR}=1.14 kHz are presented in Fig. 7. The differences in amplitude and phase between the vibrating points can be observed.

In this paper we presented a four channel WDM vibrometer at 1550nm. Special emphasis was put on the optical and electronic parts of vibrometer. We showed the idea of a vibrometer, same parameters of our device and gave an example of experimental results. Our current research is focused on the development of a signal processing system.

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