3D Photonic integration platform based on multilayer PolyBoard and TriPleX technology for optical switching and remote sensing and ranging applications

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Updated set of system level specifications and simulation results

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Executive Summary

According to the Document of Work, the present deliverable entitled "Updated set of system level specifications and simulation results".

This document is devoted to the fiber based experimental set up developed by ICCS/NTUA for the LDV, for the performance evaluation of Module-4 and the Optical Phased Array activity (as part of Module-6). In the first section of Part 1 of this document the whole topology of the developed test bed is presented. The second section is devoted to the off-line LDV signal processing code developed in MATLAB for the spectral filtering of the LDV signal and the demodulation technique required in order to vibration measurements are acquired. In section 3, the performance of the developed test bed is verified with exceptionally good results. Finally, in Part 2 the updates on the OPAs activity are presented.

Keywords: Laser Doppler vibrometer, Optical Phased Array, TriPleX, PolyBoard

List of Acronyms

AOM	acousto-optic modulator
BPF	band pass filter
DAC	digital to analog converter
DC	direct current
DUT	device under test
EC	European Commission
FFT	fast Fourier transform
ICT	Information and Communications Technology
IFFT	inverse fast Fourier transform
IQ	in-phase / quadrature
IR	infrared
LDV	Laser Doppler Vibrometer
LP	Low pass filter
PD	photodiode
OPA	Optical Phased Array

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Introduction

3PEAT is an ambitious project that aims to combine the TriPleX platform with the PolyBoard platform, and use this hybrid integration technology for the development of a new generation of optical switching and Laser Doppler Vibrometer (LDV) modules in a compact form.

The present document describes the fiber based experimental setup/testbed developed for the evaluation performance of Module 4 for the LDV modules. Since, Module 4 is not incorporated yet, in this stage for the modulation of the reference signal an acousto-optic modulator is used, in order the performance of the developed experimental set up is verified. Additionally, the post-processed MATLAB code developed for the off line digital processing of the LDV signal needed for the estimation/measurement of the vibration of a target based on I-Q demodulation is exhibited. Finally, some first experimental results are presented.

The second part of this document contains the description of the development of a Fourier imaging system and the Far-field characterization of OPA test structures.

Part 1: LDV experimental setup verification

1.1 LDV fiber based experimental setup/testbed configuration

In this section the experimental setup/testbed developed for the evaluation of Module-4 is presented. As described in previous deliverables Module-4 integrates the modulation, polarization handling and detection part, but it uses an external laser source and an external vibrometer scan-head for the scanning of the target object. Three different schemes will be used (the serrodyne shifter, the 4-branch shifter, the sophisticated shifter) for the phase modulation of the and their performance in LDV applications will be evaluated using the developed test bed. Since in this stage Module-4 has not been incorporated in this system for the modulation of the reference signal an acousto-optic modulator (AOM) is employed.

In Figure 1 a draw of the developed experimental test bed is presented. The module 4 will be placed in the reference signal line instead of AOM

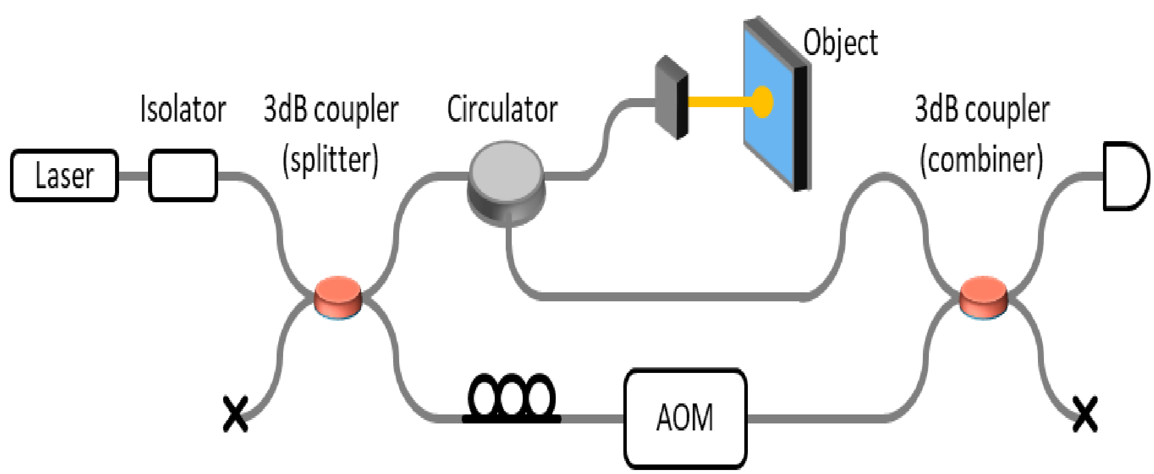


Figure 1 LDV experimental set up draw

As it is exhibited in Figure 1 the test bed consists of:

- A laser source: In our case an LXI laser source (see Figure 2) operating in infrared (IR) at 1550nm with low linewidth (around 100Hz). As it has been thoroughly analysed in deliverable D.2.2 the use of a laser source with low linewidth is important for keeping phase noise low. If linewidth is high then the phase noise becomes strong and deteriorates heavily the performance of the Vibrometer.

- An isolator is used, in order to the light is transmitted only to one direction and to be prevented unwanted feedback to the laser cavity (see Figure 3).
- A 3 dB splitter is used in order to the laser beam is divided into a measurement (upper/measurement branch) beam and a reference beam (lower/reference branch) (see Figure 3).
- An acousto-optic modulator is employed for up shifting the reference beam by 80MHz.
- An optical circulator is employed for separating the laser beam propagating towards the target and the reflected beam from the target which has to be guided to the photo detector (see Figure 3).
- Collimated beam via lensed fiber.
- As a target an acoustic cone armed with a fine mirror is used. The acoustic cone can be driven from to 1 – 20 kHz with different altitude and different waveforms.
- 3 dB coupler is used for combining the reference beam and the reflected beam and guide them to the photo detector (see Figure 3).
- 50 GHz BW photodiode (PD) is employed (see Figure 4).

It must be noted here that in the developed set up to now only one photo diode is used. Therefore balanced detection is not applied. One of the advantages of employing balanced detection is that the DC component is removed. Therefore, in order to the signal is demodulated and the results are not biased the DC component is removed digitally in the off line processing of the data (more information will be added to the following sections).

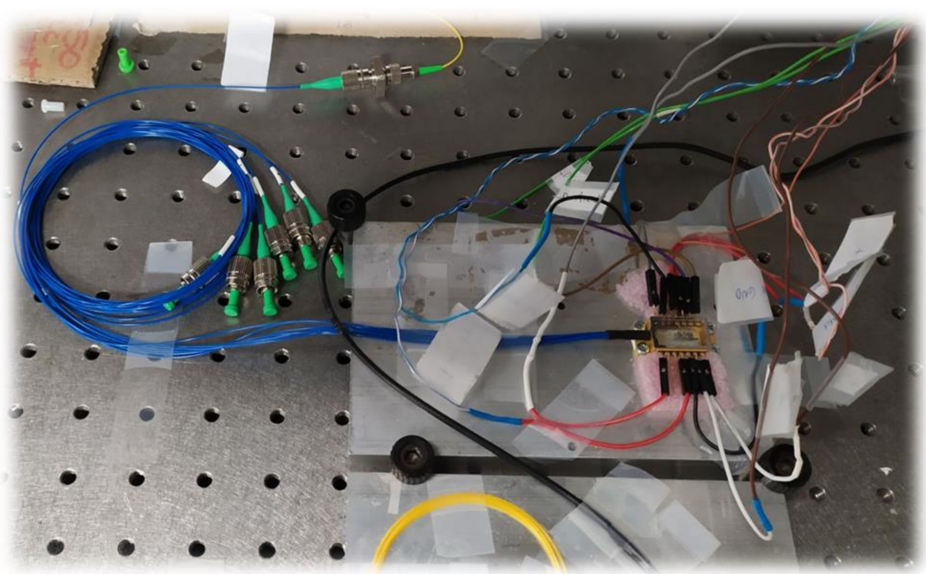


Figure 2 LXI laser source

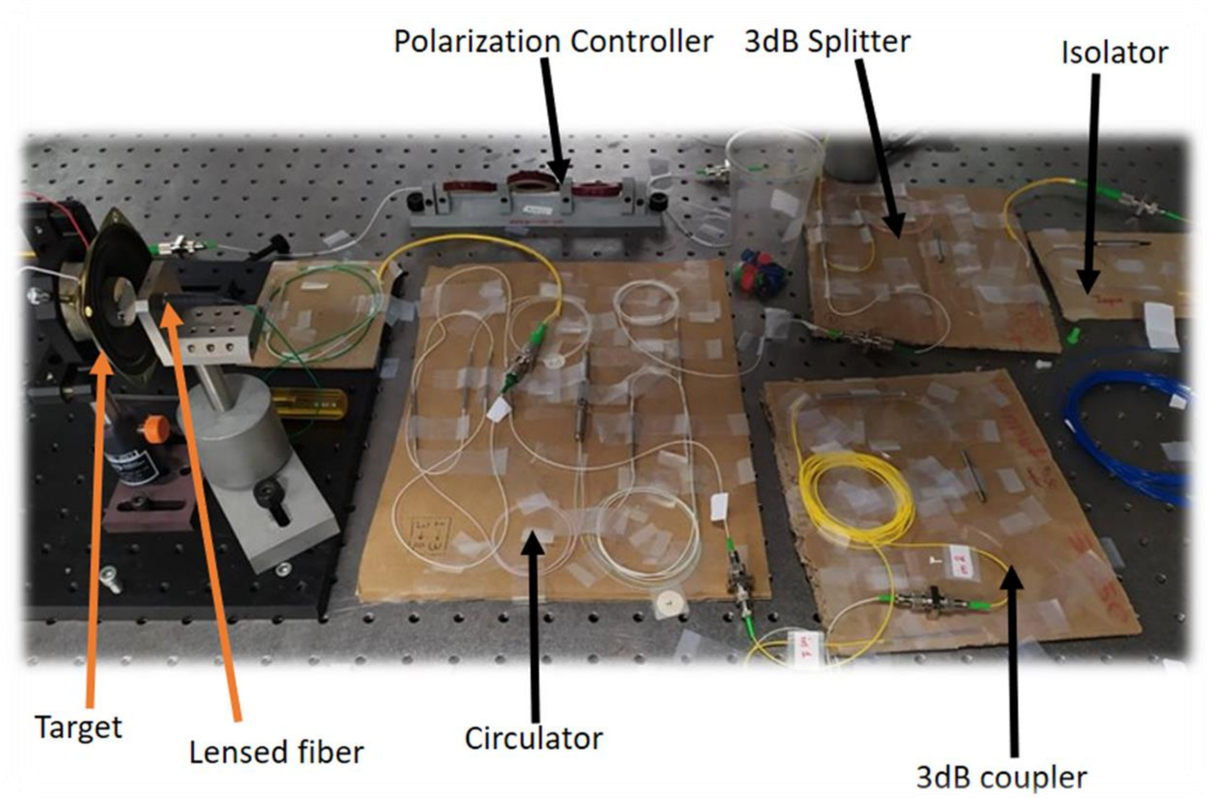


Figure 3 Modules of the experimental set up

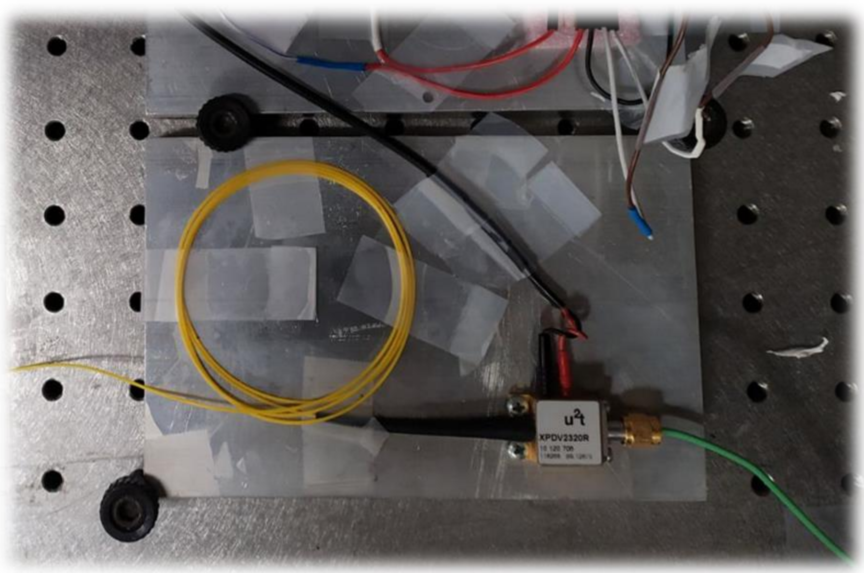


Figure 4 Photodiode

Additionally polarization controllers are added to the system where it is required.

Finally, for retrieving the data and continuing with the off line processing a real time oscilloscope is used (see Figure 5).

Figure 5 Real time osciloscope

1.2 Digital signal processing-Demodulation

In this section the off line code developed for the digital processing of the LDV signal for the estimation/measurement of the vibration of a target is presented. In this section information about the digital filtering is executed is exhibited. Additionally, detailed information about the I-Q demodulation process is performed is presented.

1.2.1 Digital Filtering

To begin with, an oscilloscope is used for the digitization of the LDV signal and therefore voltage time series/measurements are fed to the off line developed MATLAB processor.

Firstly, a fast Fourier transform (FFT) is performed in the LDV signal in order to be processed in the frequency domain. As mentioned from the previous section, in this stage of the experimental set up development balanced detection is not performed. Therefore a band pass filter (BPF) around the 80MHZ (AOM upshift) with 80MHz full bandwidth is applied in order to on one hand the DC component of the LDV signal is removed and on the other hand unwanted noise spikes are as well rejected.

Since the signal is filtered, inverse fast Fourier transform (IFFT)is performed in order to take the signal into the time domain and to continue with the demodulation process in the following subsection.

1.2.2 I-Q Demodulation

After the digital filtering and the transformation of the signal in the time domain I-Q demodulation is performed.

To begin with, the displacement of the target corresponds to the change in phase of the optical signal according to the following expression:

$$\varphi(t) = \frac{4\pi \cdot s(t)}{\lambda} \tag{1}$$

where $\varphi(t)$ is the phase of the signal λ is the wavelength and is the displacement of the target.

Additionally, doppler frequency (f_d)is expressed as:

$$f_d(t) = \frac{2 \cdot n \cdot v(t)}{\lambda} \tag{1}$$

where v is the velocity.

To extract the phase information and as a result according to expression (1) the displacement of the target an I-Q based demodulation is performed. The prerequisite for this technique is the computation of quadrature I & Q signal pair derived from the LDV signal as presented in Figure 6.

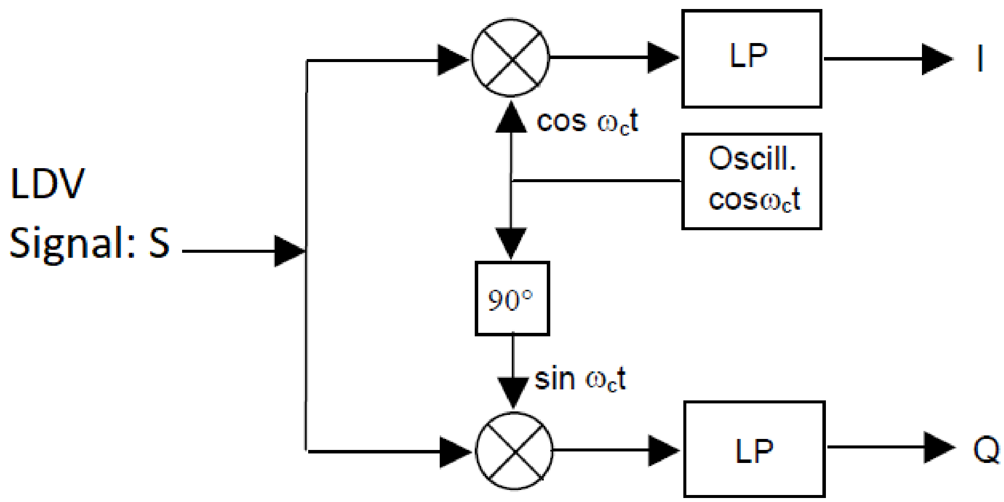


Figure 6 IQ demodulation blocks

The following procedure is followed:

- For the generation of the in phase signal I:
  - The LDV filtered signal is multiplied with a cosine with frequency 80MHz i.e. the known frequency of the AOM ($\omega_c = 2 * \pi * f_{AOM}$).
  - FFT is performed in order to a low pass filter (LP) with bandwidth of 80MHz is applied.
  - IFFT is performed and the I signal is derived

  For the generation of the quadrature signal Q:
  - The LDV filtered signal is multiplied with a sine with frequency 80MHz i.e. the known frequency of the AOM ($\omega_c = 2 * \pi * f_{AOM}$).
  - FFT is performed in order to a low pass filter with bandwidth of 80MHz is applied.
  - IFFT is performed and the Q signal is derived

The pair of quadrature signals can by considered as the real part and the imaginary part of a complex rotate phasor where the rotation describes the time dependence of the phase angle as depicted in Figure 7.

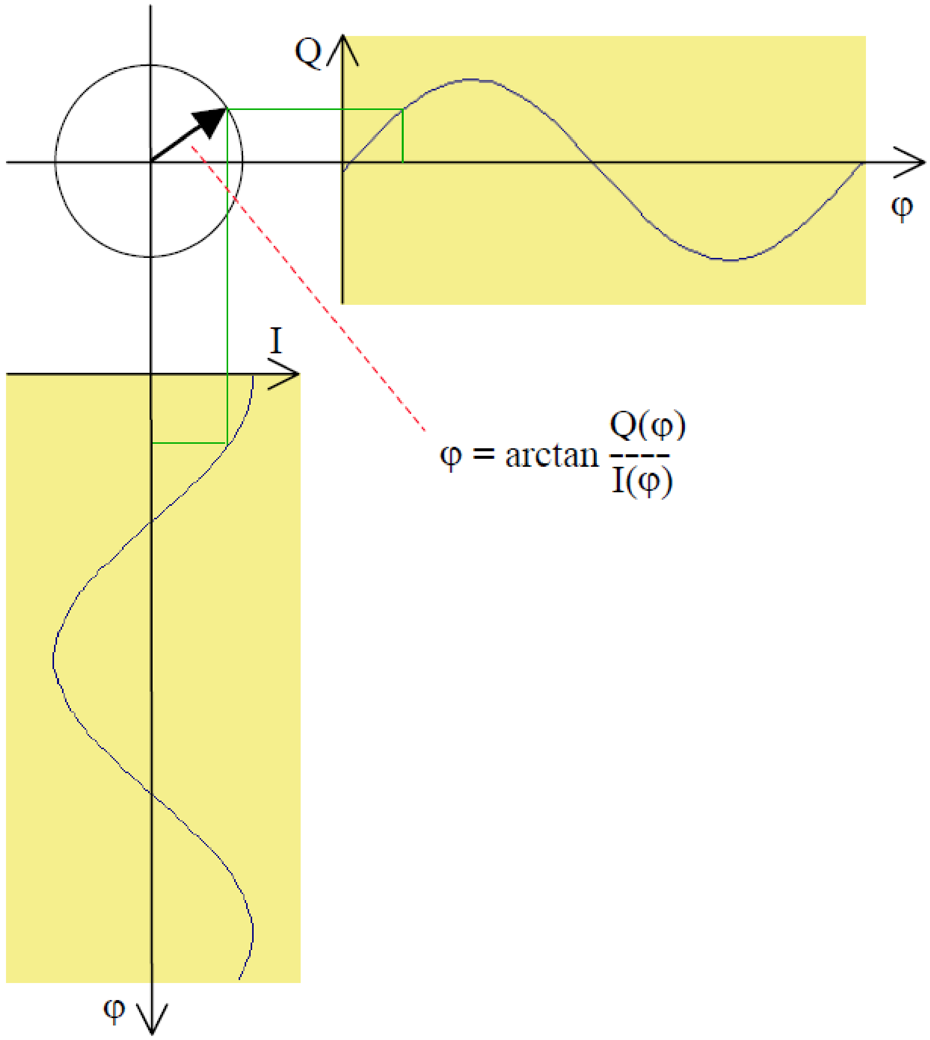


Figure 7 I and Q signals described as a rotating vector in a vector diagram.

Finally, the phase of the signal can be estimated according to the following expression

$$\varphi(t) = \arctan\left(\frac{Q(t)}{I(t)}\right) \tag{3}$$

and the displacement of the target by inverting expression (1). It must be noted that A complete period or 2π phase increment is equivalent to a displacement of λ/2.

1.3 Experimental Set up Verification/Experimental Results

In this section the performance of the experimental test bed is verified and experimental results are presented.

To begin with, the target is driven by a pulse generator applying sine waveforms in different frequencies and different amplitudes. It must be noted here that Doppler frequency changes also with the change of amplitude as can be observed from expression (2).

Firstly, the test bed is tested without a applying any vibration to the target. In Figure 8 a snapshot of the spectrum derived using the real time oscilloscope is exhibited.

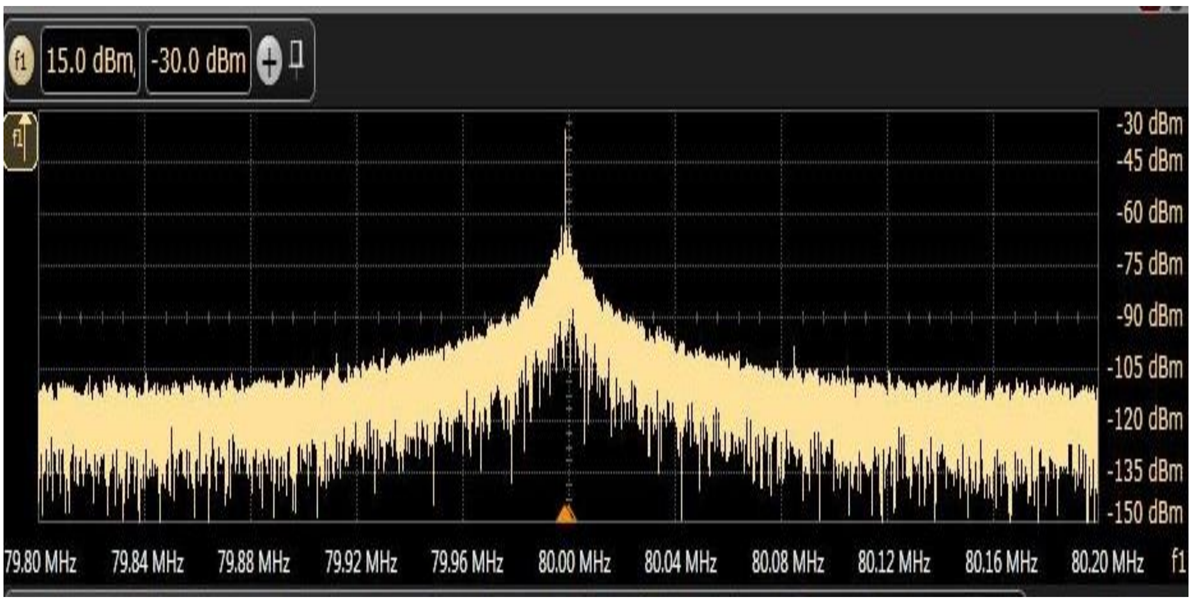


Figure 8 Spectrum derived from Oscilloscope-No vibration

Now in Figure 9, the spectrum derived from the oscilloscope is computed applying to the acoustic cone (target) vibration. The acoustic cone is driven with a 5Vpp sine waveform with 60Hz frequency. The differences in the spectrum because of the Doppler frequencies can be easily observed.

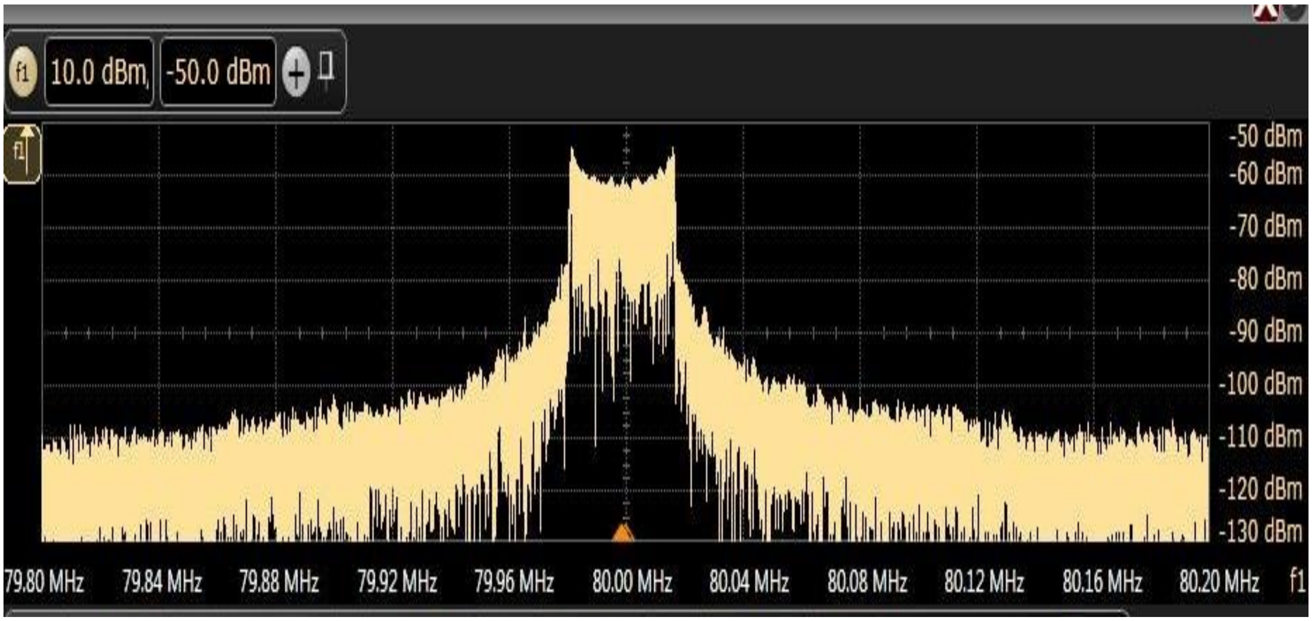


Figure 9 Spectrum derived from Oscilloscope-60Hz vibration

Then, the real time oscilloscope measurements derived for this case i.e. the acoustic cone is driven by a 60Hz sine waveform, are fed to the developed off line MATLAB code in order to the displacement is estimated. It can be observed in Figure 10 that the displacement computed has sinusoidal form and the frequency computed is 60Hz,i.e. as the one the cone was driven.

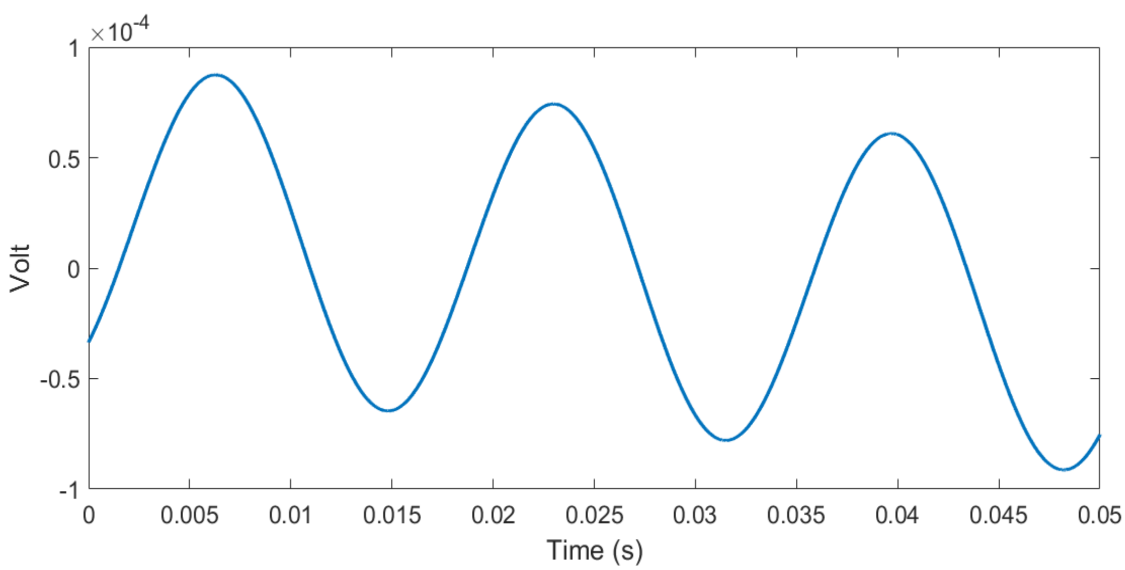


Figure 10 Displacement-60Hz

Now the cone is driven with 100Hz frequency sine form and in Figure 11 the displacement as computed is presented. The computed displacement has sunisodal form and the frequency computed is 100Hz, i.e. as the one the cone was driven.

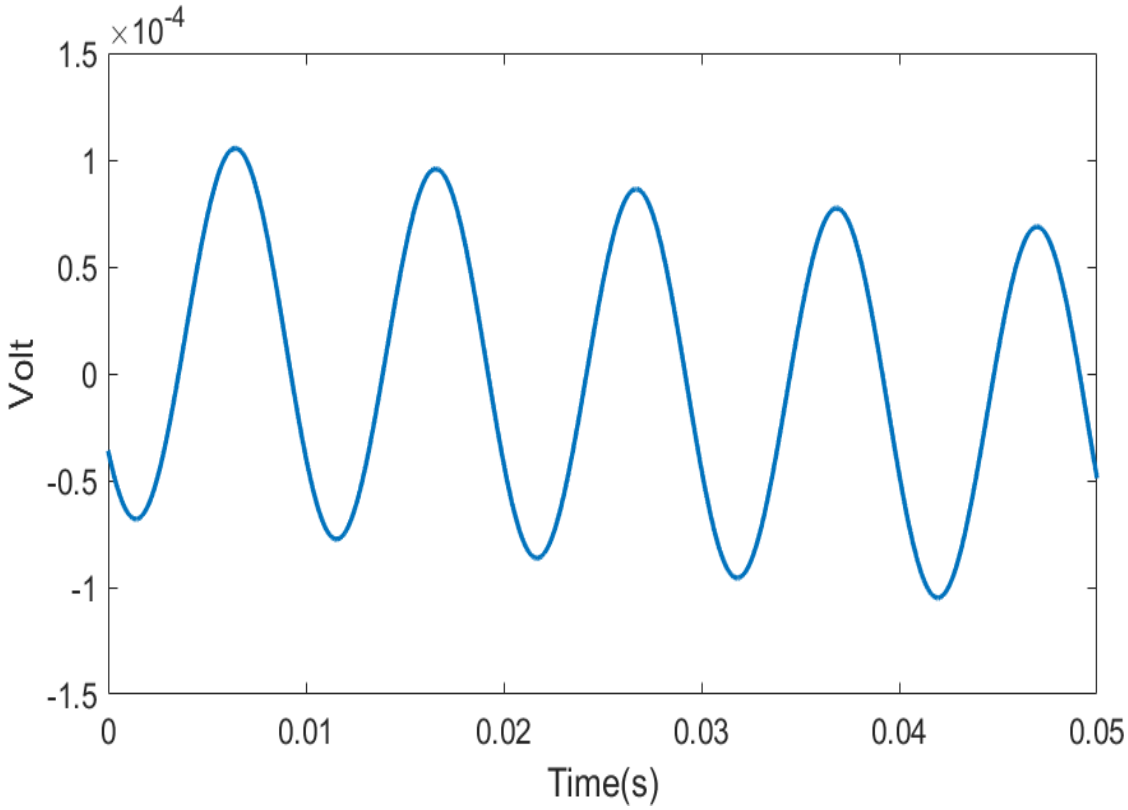


Figure 11 Displacement-100Hz

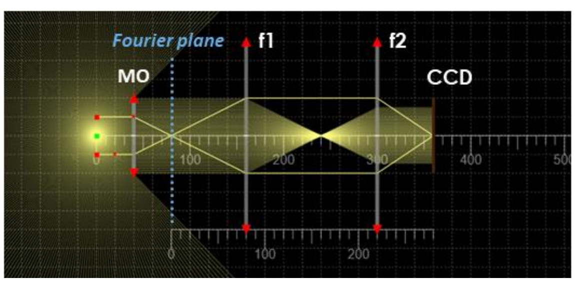
Both in Figure 10 and Figure 11 it can be seen that there is a small drop in the amplitude of the sine. It is probably because the mirror was not perfectly stuck on the cone and with the time passing the alignment of the lensed fiber and the mirror was not perfect. Further development of the setup will follow during the validation experiments of the upcoming period.

Part 2: OPAs setup

A testbed has been prepared at Optagon in collaboration with ICCS/NTUA for the investigation of the radiation characteristics of the OPA test structures and for the evaluation of the associated modules that will be later realized within the project, alongside with a specialized image processing algorithm to support the above tasks. Further improvements have been made to expand the capabilities of the setup: a dedicated lens imaging system has been developed to enable the accurate characterization of the far-field radiation pattern of the emitting structures and distortion calibration functionalities have been added to the image processing algorithm. Initial results have been obtained using test structures provided from the partner HHI.

Development of a Fourier imaging system

A Fourier imaging system has been developed to replace the fixed focal length that has been initially used with the NIR CCD sensor in the setup. Fourier imaging is widely used for studying the Far-field characteristics of propagating light emitting from integrated structures. In this type of imaging system the far-field is imaged on the back-focal plane (Fourier plane) of a high numerical aperture microscope objective (NA = 0.4) that is placed at a small distance from the device under test. Every point in the Fourier plane corresponds to a specific direction of emission and thus represents the far-field. The back-focal plane of the objective is reproduced onto a NIR CCD with a well-defined ratio image, determined by the focal lengths of two plano-convex lenses (e.g. f1=80mm, f2=60mm), as it can be seen in the following figure.



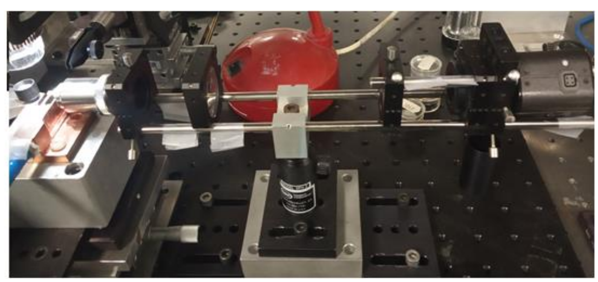


Figure 12: (Left) Ray diagram of the Fourier imaging system and (Right) the realized system

The calibration of the imaging system (creating pixel to physical dimensions correspondence) is an essential and challenging task. An image processing algorithm has been developed that can extract the intrinsic and extrinsic parameters of a camera system (focal length, principal point, skew coefficient, radial distortion, tangential distortion) by using a 25x25mm distortion calibration target with a dot grid of 250um pitch and it can be used for characterizing the two plano-convex lenses installed in the setup. An auxiliary setup is also being developed for the characterization of the microscope objective based on rotating optical emitter as it can be seen in figure 13. As a next step NIR-coated lenses will be used in the final set-up to increase the transmittance of the imaging system.

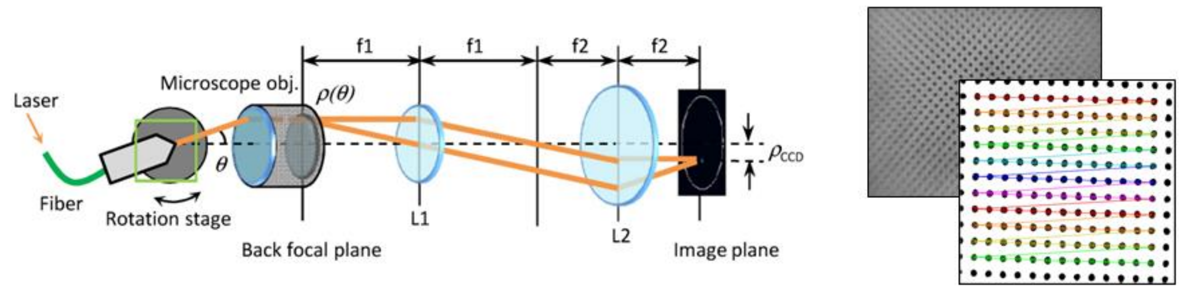


Figure 13: (Left) Auxiliary setup for lens-system calibration (*P. Stepanov, A. Delga, N. Gregersen, E. Peinke, M. Munsch, J. Teissier, J. Mork, M. Richard, J. Bleuse, J.M. Gerard and J. Claudon, App. Phys. Lett. 107, 2015*) and (Right) the distortion calibration target

Far-field characterization of three test OPA structures

Using the imaging system described above we have evaluated the far-field radiation pattern of three OPA test structures provided be the partner HHI:

- ✓ Single optical emitter
- ✓ Linear array of 4x1 optical emitters
- ✓ Planar array of 4x2 optical emitters

The radiation patterns are presented in the following figure. The validation of the experimental results through simulations is an ongoing activity in parallel with system calibration to create a pixel-to-angle correspondence.

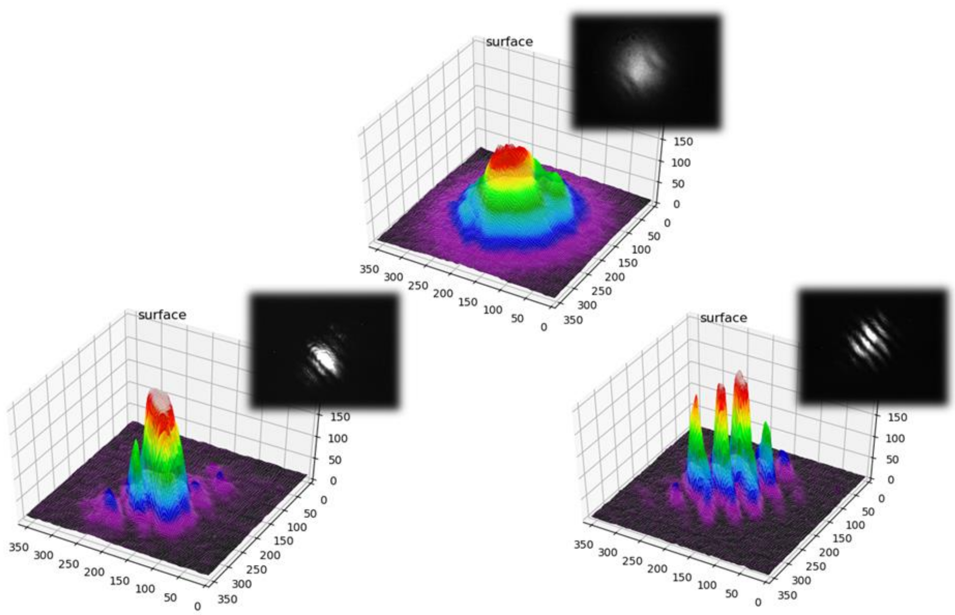


Figure 14: 3D plots of the radiation pattern of (Top) the single optical emitter, (Left) the 4x1 linear array and (Right) the 4x2 planar array OPA structure.

Conclusions

The present document has summarized the activities regarding the development of the experimental fiber based LDV set up/test bed for the performance evaluation of

Module 4-LDV. The whole set up is extensively described and the off line procedure for the LDV signal processing and demodulation developed in MATLAB is exhibited. Additionally, some first experimental results for the verification of the performance of the developed test bed are presented.

For the phase shifting an AOM is employed. The next step is the incorporation of Module-4 instead of the AOM and its performance is tested. Module-4 with the simple serrodyne phase shifter has been delivered and its performance is going to be tested.

Finally, the testbed for the characterization of the OPA structures has been built-up and the algorithms for the image processing have been developed.

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