EUROPHOTONICS/POESII MASTER 2015-2016

EXPERIMENTAL PROJECT ON

OPTICAL AUTOCORRELATION: HOW TO ESTIMATE THE MONOCHROMATICITY OF LASER LIGHT?

BY

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1 Introduction

The project aims to understand Optical Autocorrelation including building the setup from different optical components and to measure the laser linewidth in optical spectrum analyser (OSA) based on the optical beat signal of two laser paths where one is frequency-shifted by acousto-optic modulator and other propagated in a long optical fiber. Measurement is taken for two fibers of length 150m and 10km.

2 Theory

The basic principle of an optical autocorrelator is to split an incoming pulse into two beams and to superimpose those with a variable temporal delay. A nonlinear interaction is used for obtaining a signal thatdepends on the pulse overlap, and the pulse duration canbe retrieved from that signal.

Assuming two incident plane wave of the following form,

$$E_1 = A_1 e^{i((\omega+\omega_A)t-kz-\phi(t))}$$

$$E_2 = A_2 e^{i(\omega t-k(z+L)-\phi(t+L/c))}$$

Where $E_1$is coming through an acousto-optic modulator being shifted by the modulating frequency $\omega_A$and $E_2$is coming through an optical fiber of length ***L***inducing a phase delay. When these two beams interfere into the crystal, we can calculate the detected intensity of the resultant beam as follows:

$$I(t) = |A_1 e^{i((\omega+\omega_A)t-kz-\phi(t))} + A_2 e^{i(\omega t-k(z+L)-\phi(t+L/c))}|^2 \tag{1}$$

$$I(t) = |A_1|^2 + |A_2|^2 + 2Re[A_1 A_2^* e^{i(\omega_A t+KL+(\phi(t)-\phi(t+L/c)))}] \tag{2}$$

$$I(t) = |A_1|^2 + |A_2|^2 + 2A_1 A_2^* \cos(\omega_A t + KL + \theta(t)) \tag{3}$$

Here $\theta(t) = \Phi(t) - \Phi(t+L/c)$. We can compute the frequency of the resultant beam as--

$$\frac{d}{dt}(\omega_A t + KL + \theta(t)) = \omega_A + \frac{d}{dt}\theta(t)$$

Which consists of frequency from the acousto-optic modulator and phase dependent frequency resulting from the path delay between two incoming beams. At the frequency ω_A, we expect to see a beat node and **dθ/dt** is responsible for frequency modulation.

In the proposed method, a part of the laser output itself is used the local oscillator power. The principal is shown in **Figure (a).** Laser output is divided into two paths. The light through a branch is delayed by time τ_d through a single-mode fibre, and is regarded as local oscillator power. The frequency of the other branch is shifted by a frequency ω_A which is much higher than the spectral spread to be measured. The outputs of the two branches are mixed by an avalanche photodiode (APD). For spectral width of $\Delta\vartheta$:

$$\tau_d = \frac{1}{\pi\Delta\vartheta}$$

When τ_d is much longer than the coherence time of the laser output, the two throughputs are not correlated. Therefore, if we measure the noise spectrum of the mixer output by a radio frequency spectrum analyzer, the obtained spectrum will exhibit a FWHM spectral spread somewhat wider than the original spectrum.Because the signal and the local oscillator light outputs are equally noisy. More specifically, if the spectral spread stems from FM-type noise as is actually the case, the FWHM spectral spread is twice the original value when the spectrum is Lorentzian.

3. Experimental Setup

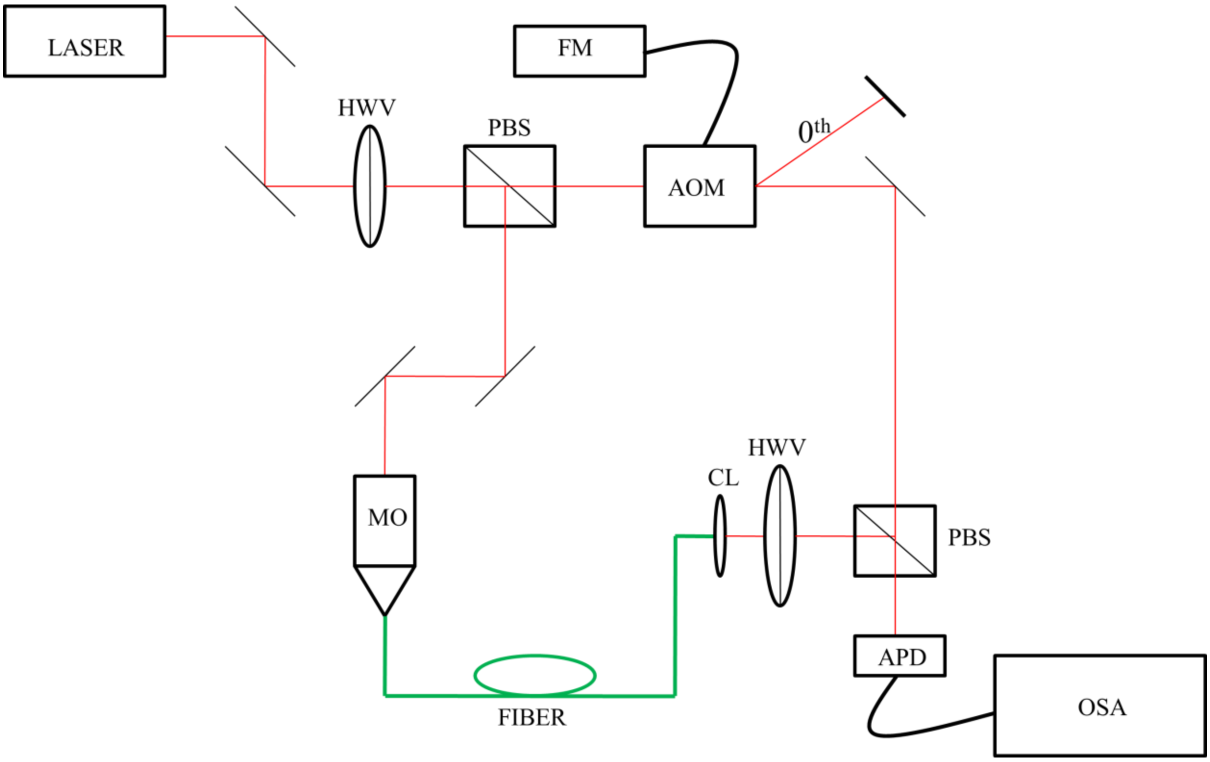


Figure (a) Schematic diagram of the experimental setup

Note: HWV-Half wave plate, PBS-Polarised Beam splitter, FM-Frequency modulator, AOM-Acousto-optic modulator, MO- Microscope Objective, CL-Collective Lens, APD-Avalanche Photodiode and OSA-Optical Spectrum Analyser

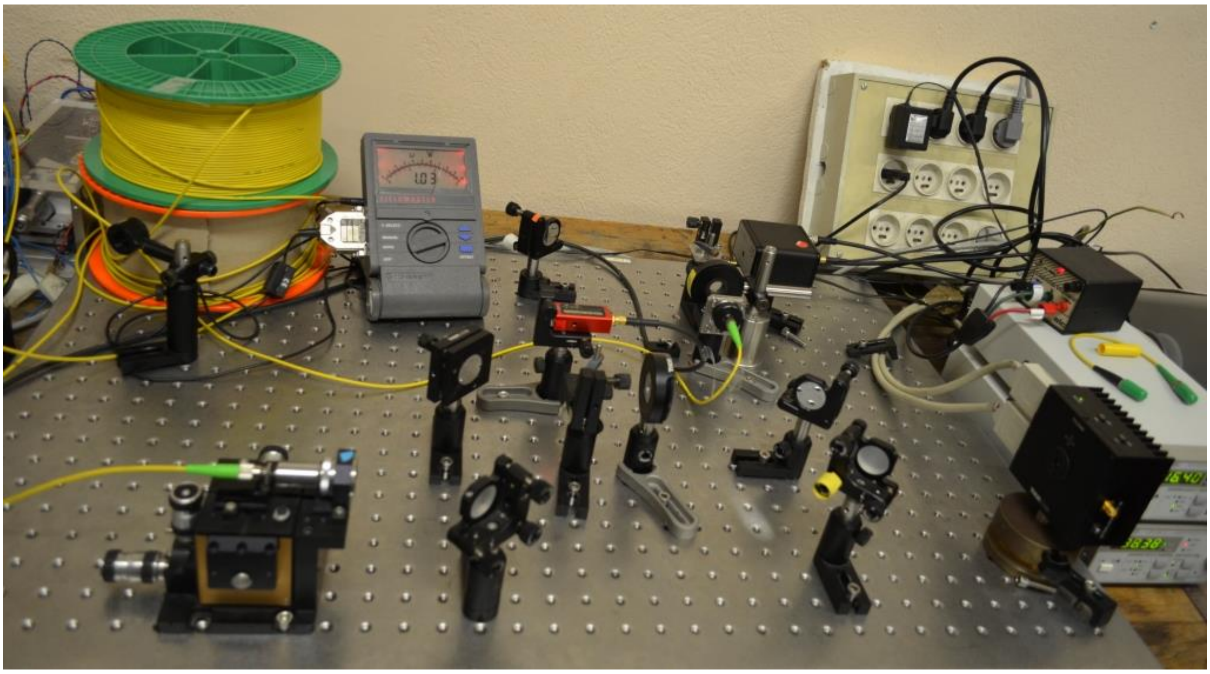


Figure (b) Experimental setup in the lab

Laser Diode

In this experiment a diode laser is used which is being controlled by the temperature controlled and it is operated by the laser-current source. Temperature of 16.40 degree centigrade is kept constant throughout the entire experiment and a current source of 38.02mA drives the laser diode. Laser is emitting at a wavelength of 780nm.

Plane mirrors and alignment

In order to adjust 2 directions and 2 translations of the laser beam, 4 degrees of freedom are required. Because mirror once fixed can only be fine adjust for 2 tilt angles, 2 mirrors are requiredand sufficient to have 4 degree of freedom. Therefore, the total number of mirrors is 4 to align the laser beam and the 5^{th} one is used to let the beam interfere in the second polarised beam splitter.

Microscopic Objective

It is the most essential part in the setup and it allows to focus the laser beam into the fiber for propagation through it.

Collective Lens

After propagating through the fiber the beam is collected by the collective lens and it focuses into the half-wave plate and finally to the polarised beam splitter.

Polarised Beam Splitter

The main function of a polarised beam splitter is to polarise the beam after passing through it. First beam splitter is used to divide the laser beam into two paths, one through the fiber and other through the Acousto-optic modulator. The second beam splitter is used to combine the beam after propagating through the fiber and the Acousto-optic modulator and focus it to the avalanche photodiode. It splits the incoming beam according to polarization means after emerging from PBS we get two beams of light which are perpendicular of each other. Generally it reflects the s-polarization and transmit p-polarization beam.

Half Wave Plate

A half wave plate basically rotates the polarisation of the light beam by an angle of 90 degrees.

Fiber

Fiber basically guides the light and it creates a temporal delay. Two fibers are used of length 150m and 10km in order to create a delay.

Acousto-optic modulator

It is a device in which frequency or the spatial direction of a laser beam can be controlled by electrical drive signal. The refractive index of the material is being changed by acousto-optic effect in which sound wave of frequency 100 MHz is generated.

Avalanche Photodiode

Avalanche Photodiode is the basic detector in any optical setup and it is the most sensitive, high speed semiconductor device which can multiply electrons by the application of external reverse voltage and the resultant gain in the output signal means that low light levels can be measured at high speed.

Optical Spectrum Analyser

Similar to oscilloscope, spectrum analyser can be used to measure the spectral components of an optical pulse and all the relevant information about the pulse can be estimated very smoothly.

Frequency Modulator

In order to generate acousto-optic wave a frequency generator is used to produce sound waves which will transduce the crystal in the acousto-optic modulator to about 100MHz and this will lead to a refractive index change in the crystal allowing the modulator to shift the frequency of the incoming laser beam.

4. Results

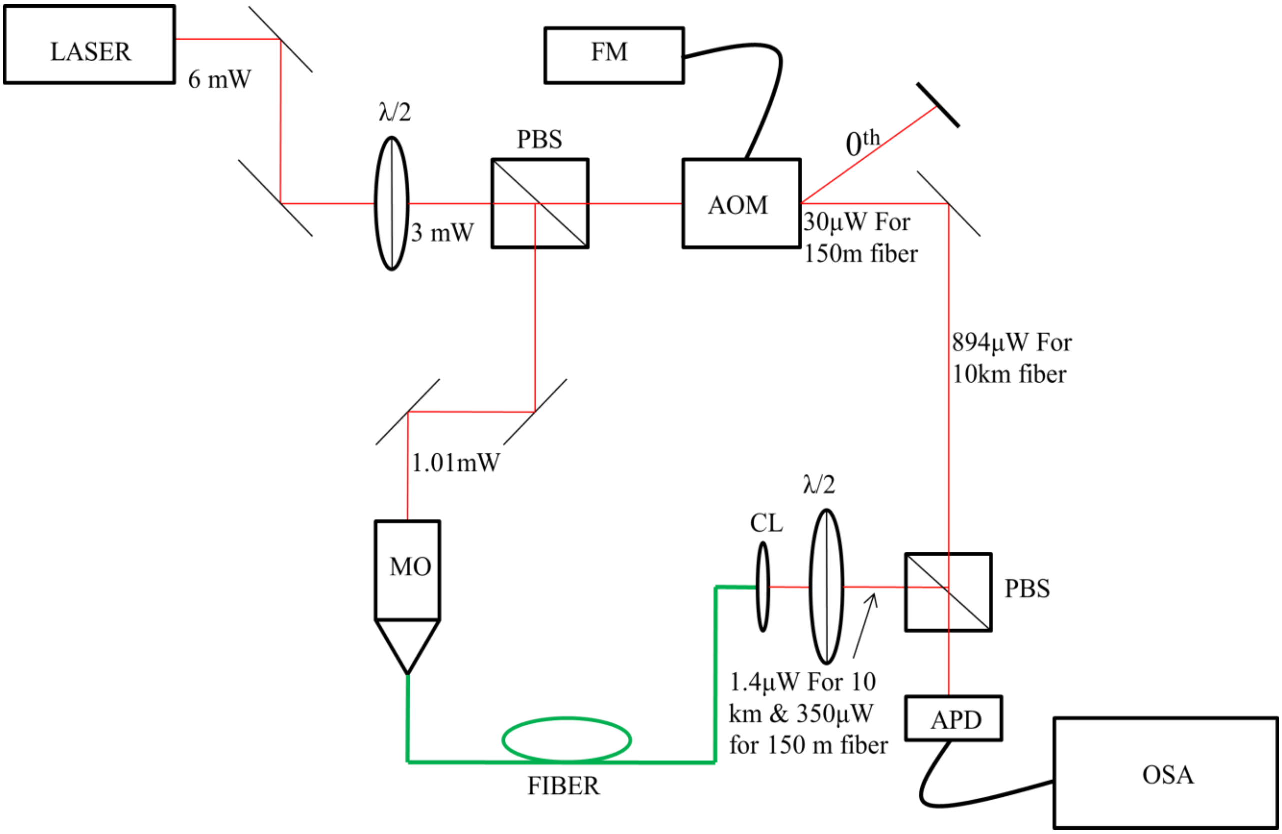
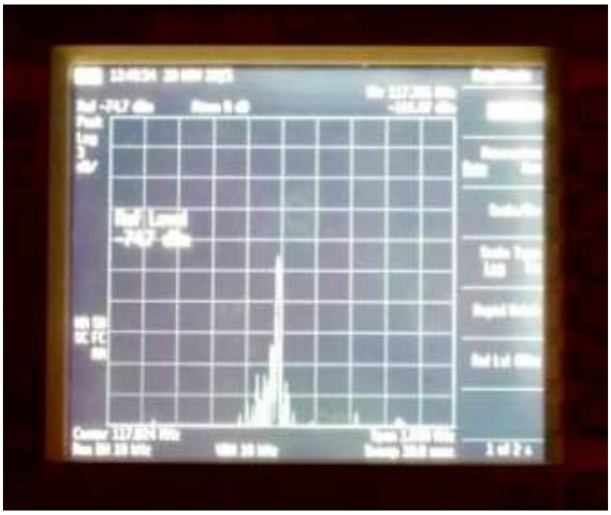


Figure (c) Schematic Diagram with power obtained at different points in the path.

The power is being measured with power-meter at different position of the path of light beam.

At output of laser, after 1st half waveplate and after the first polarized beam splitter (in the both direction before next optical element) the power remains same for both the fibres 10 km and 150 m.

The spectrums got for 150 m and 10 km fibres are given below:



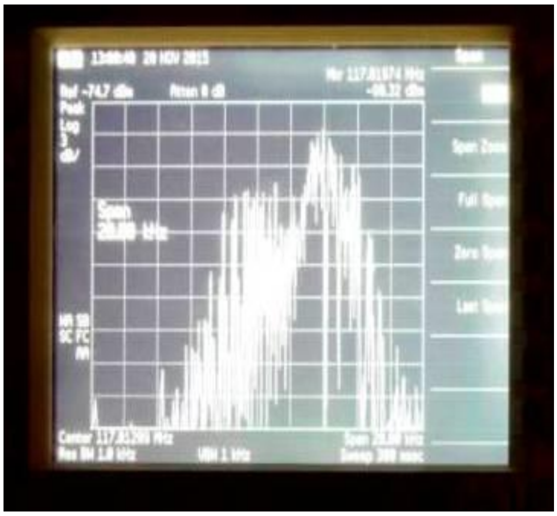
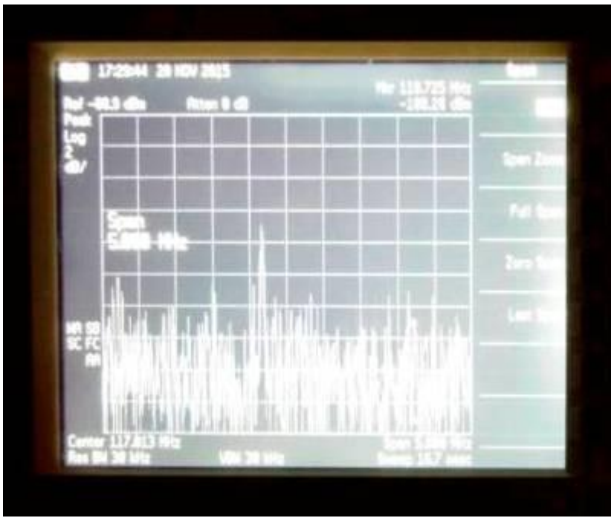


Figure (d) Beat Knot got with 150 m fibre

Figure (e) Magnified peak for 150 m fibre



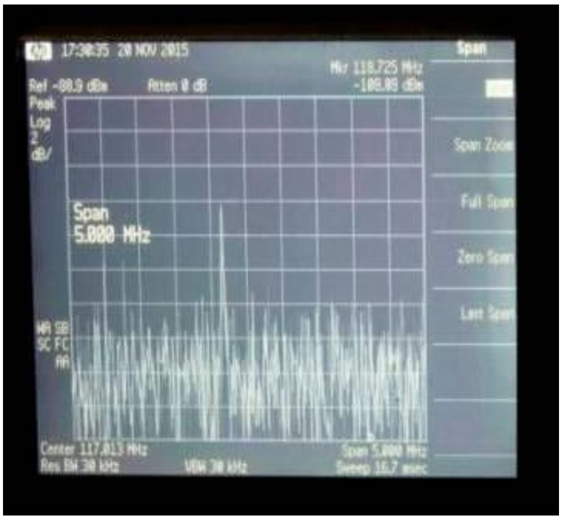
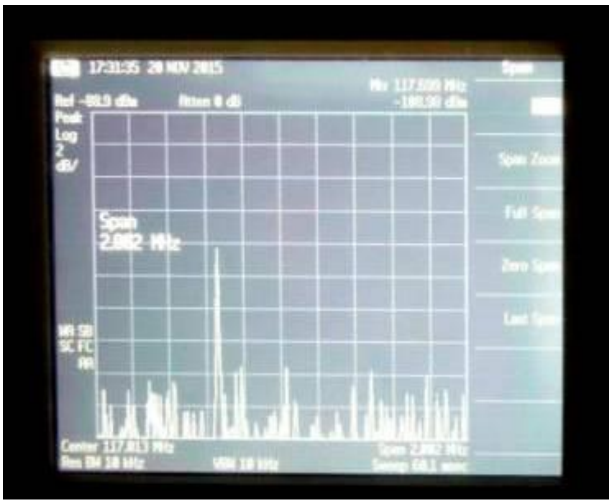


Figure (f) Spectrum for the 10 km fibre

Figure (g) Spectrum is moving (1st snap)



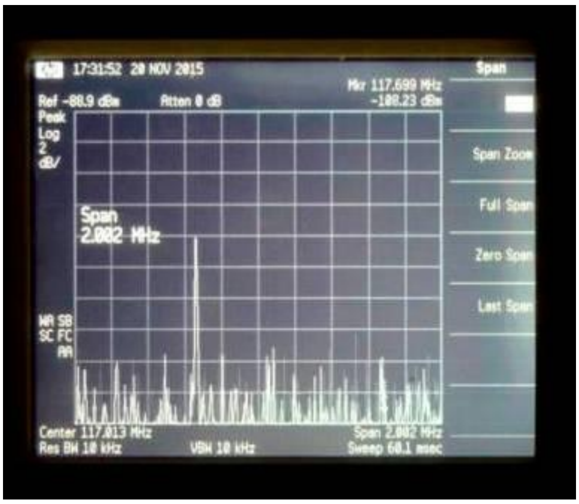


Figure (h) Spectrum is moving (2nd snap)

Figure (i) Spectrum is moving (3rd snap)

5. Result analysis

The beat knot is got for the 150 m fibre which is shown in the figure (d) and figure (e). From the figure (e) it is obtained the 3dB frequency spread (FWHM) which is 4KHz. The spectrum is Lorentzian type. So, the actual FWHM will be 2KHz. From this information the coherence τ_d length can be calculated.

$$\tau_d = \frac{1}{\pi\Delta\vartheta}$$

We got, $\Delta\vartheta = 2KHz$

$$\tau_d = \frac{1}{\pi 2KHz} = 159\mu s$$

It is checked that the peak is real beat knot or not by suppressing one of the two beam. When it is the real one we loss the beat knot when one of the two beams is suppressed.

Figure (f) is the spectrum of the 10km fiber but it is not the real beat knot. It is tried a lot to get the real beat knot but it was not come.
Figure (g), (h), (i) are the real beat knot for the 150 m fiber. By looking at these three figures it is seen that the beat knot is moving as the frequency of the frequency modulator is changing.