Photonics lab report:
Electro-optic comb

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(Dated: December 20, 2021)

I. OBJECTIVES

In this lab we use typical devices used in photonics experiements to study optical-frequency-comb generation, pulse shaping, phase-noise characterization and phase-sensitive amplification. We start with the generation of an optical frequency comb using electro-optic modulation of a continuous-wave laser. Then we generate very short picosecond pulses from the comb by pulse compression using a pulse shaper. A characterization of the phase noise is performed for different scenarios, e.g., measuring the phase noise for different length fibers. Lastly we perform a phase-sensitive amplification of filtered signals from the comb.

II. METHODS

In Fig 1, we show the basic setup diagram for different experiments performed in this lab. The initial stage is the

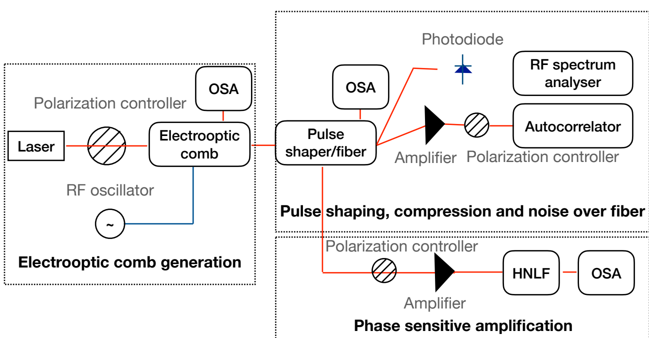

FIG. 1: The basic setups for different experiments. We use the electro-optic comb to generate the pulse trains from a continuous wave laser after adjusting the polarization. Then, use use a pulse shaper to manipulate the amplitude and frequency of different frequency components. Optical spectrum analyzers (OSAs) are used to obtain the data for the spectrum after different stages. A second polarization controller with an amplification is used to measure the autocorrelations. In phase sensitive amplification, we use a highly nonlinear fiber for wave mixing before analyzing the output with an OSA.

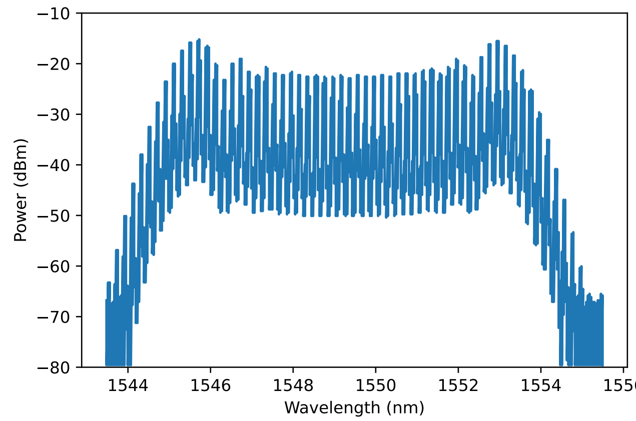

FIG. 2: The generated frequency comb had wavelengths between 1545 nm an 1553 nm, with a spacing of 0.2 nm which gives $f_r = 25$ GHz. (Data file: 2_OSA_Spectrum_Comb.csv)

electro-optic comb generation, followed by pulse shaping, pulse compression and analyzing the noise spectrum over a fiber. Finally, we perform phase sensitive amplification using a higly nonlinear fiber for wave mixing and analyze the results of different parts using optical spectrum analyzers.

Electro-optic comb generation

A continuous wave laser was connected to a polarization controller, which was connected to an electrooptic comb and measured by an optical spectrum analyzer. The comb genarator is mixing a microwave signal with the optical signal to generate pulse trains with a repetition rate of f_r. The frequency comb repetition rate, f_r which is the inverse of the pulse-to-pulse timing, T_r. The spacing between each peak in the comb then becomes f_r in frequency domain. The optical signal is a carrier for the electrical signal, which becomes the envelop, in other words the detectable signal by the photo detector. The carrier and envelop will have a phase offset which is represented by the offset frequency f_o.

Pulse shaping

The electric comb was connected to a pulse shaper which could filter and control the attenuation and/or group delay added to the pulse. We use a pulse shaper

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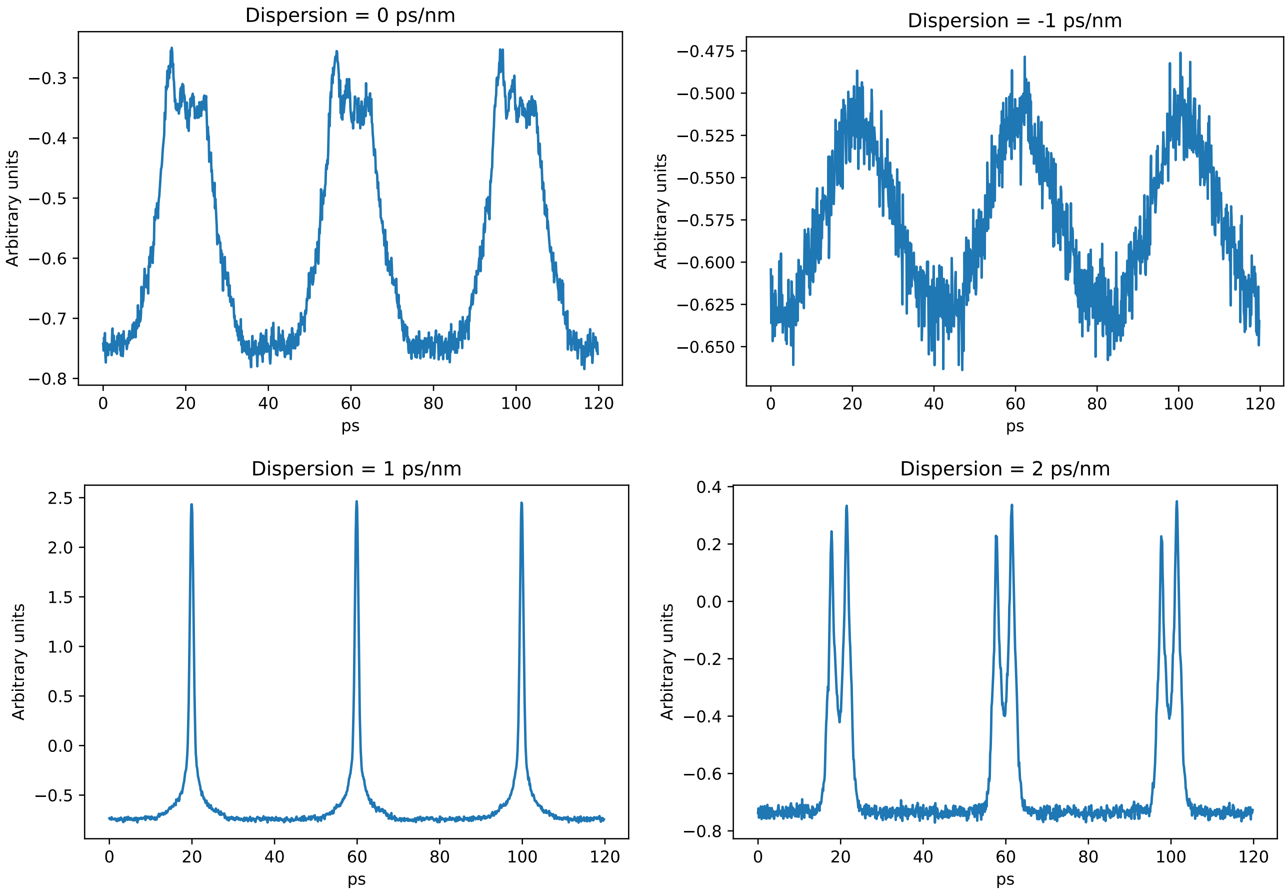

FIG. 3: Pulse shaping for different values of added dispersion (the y-axis is in arbitrary units). When the dispersion is 0, the pulse is only affected by the dispersion from the connectors. We compare the effects of adding dispersions of -1, 1, 2 ps/nm. The sharpest pulses are obtained with a dispersion of 1 ps/nm. (Data files: 3_displacement_[0, -1, 1, 2].csv)

based on using a reflective Fourier pulse shaper. It uses a diffraction grating to split the input light based on its frequency components by angular dispersion. A spatial light modulator can then change the amplitude and phase of each frequency component. We obtained the sharpest pulses with around 1 ps/nm added dispersion.

Noise performance over a fiber

The effects on the noise performance from adding a fiber was evaluated by measuring the phase noise using a spectrum analyzer. We consider fibers of effective lengths 1 and 2 km.

Phase sensitive amplification

: Three peaks were filter out using a digital filter. The center peak was attenuated 20 dB. A highly nonlinear fiber (HNLF) was used to mix the three signals. The phase of the pulse was varied between 0 and 3 radians, and the power of the middle peak was measured.

III. RESULTS

In Fig. 2, we plot the generated frequency comb. If the waveform is transform limited it has an instantaneous frequency of 0, which means that the signal is not chirped. We obtain a repetition rate of 25 GHz set by the RF clock and a fairly flat comb between 1547 to 1552 nm.

In Fig. 3, we show the results of pulse shaping by adding various dispersions. We find that the sharpest pulses are obtained with a dispersion of 1 ps/nm. The pulse durations have a FWHM of around 1 ps. By assuming Gaussian pulses, we can compute the transform-limited duration of the pulses as $\Delta t = 0.441/\Delta f$ where Δf is the spectral width. We consider $\Delta f = 5nm$ and obtain $\Delta t = 0.8$ ps. Therefore we are close to the transform-limited duration of the pulses with a dispersion of 1 ps/nm.

We compare the phase noise characteristics for differ-

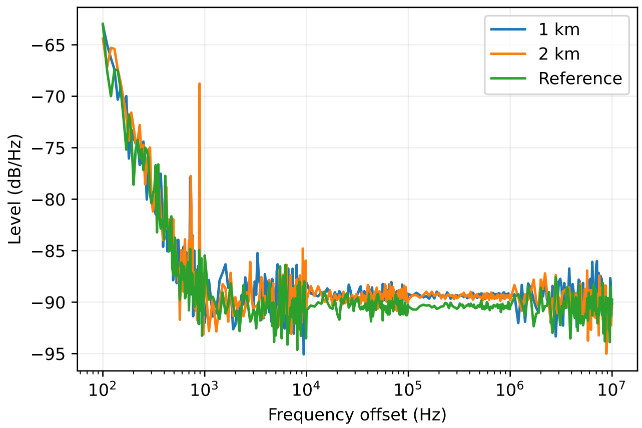

FIG. 4: Phase noise performance compared between the reference (no fiber connected), 1 km fiber connected and 2 km fiber connected. (Data files: 4_phase_noise_1km.csv, 4_phase_noise_2km.csv, 4_phase_noise_refkm.csv)

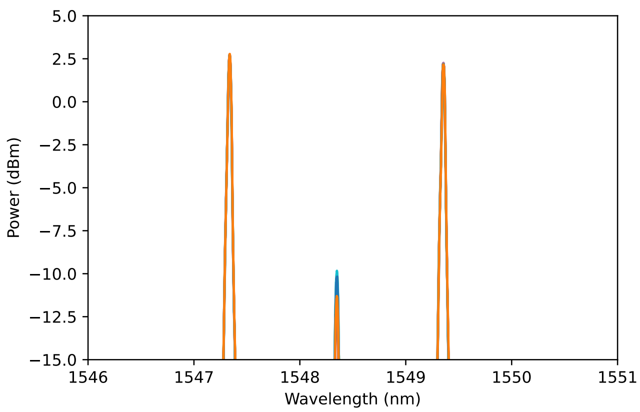

FIG. 5: Power of the three peaks for different phase angles. We sweep the phase between 0 and 3. (Data files: phase-sensitive-amp-phase-x.mat, where x is the phase)

ent length fibers in Fig 4. The phase noise after adding the fiber is higher than the reference and adding a fiber cannot improve the phase noise.

We select lines from the comb using the pulse shaper and show the results of phase-sensitive amplification in Fig 5. The power from the side peaks are transferred to the center using the highly nonlinear fiber that mixes the three waves.

In order to find the phase which leads to the most power of the center line, we sweep the phase between 0 to 3 and plot the gain of the middle peak in Fig 6. The highest gain in power is obtained for the phase 2 (-10 dB).

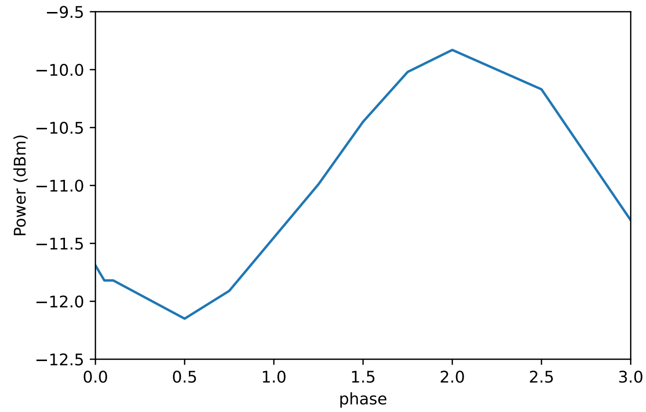

FIG. 6: Change in amplitude of the middle peak for different phases. The highest value is obtained at phase 2 which corresponds to the largest transfer of power from the side peaks to the middle. (Data files: phase-sensitive-amp-phase-x.mat, where x is the phase)

IV. DATA AVAILABILITY

The data and code to reproduce the results of the experiment are available in the repository: https://github.com/quantshah/photonics-lab/