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Pulse Interferometry for Ultrasound Detection

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***Abstract*—This work demonstrates an optical approach for ultrasound detection via pulse interferometry technique, enabling shot-noise limited detection and multi-channel simultaneous detection.**

Keywords—ultrasound, interferometry, shot-noise.

I. Introduction

The detection of ultrasound via optical resonators is most commonly performed with a simple interrogation setup in which a continuous wave (CW) laser is tuned close to the resonance wavelength and a photodetector measures the reflection (or transmission) of the light from (through) the resonator[1]–[3]. In such a scheme, ultrasound-induced wavelength shifts of the resonance lead to variations in the detected intensity, ideally proportional to the magnitude of the ultrasound signal.

While simple, CW interrogation methods suffer from two major drawbacks: vulnerability to external disturbances and the lack of a scalable scheme for detector arrays. These drawbacks will limit the use of this technique to single sensor systems, prohibiting imaging application due to extensive scanning time required for imaging resolution.

Pulse interferometry represents an alternative to CW interrogation, in which a wideband, pulsed source is used and the detection is performed by frequency demodulation[4]–[7]. The use of a wideband source can potentially enable the interrogation of numerous wavelength-encoded resonators with a single laser and offer high stability against external disturbances, along with low noise interrogation system for high sensitivity measurements.

II. Methods and Results

Pulse interferometry was implemented in a fiber-optics setup shown in Fig. 1(a) including a pulse laser and a demodulation scheme that is robust to external disturbances. To reduce the noise level, a free space Fabry-Perot was included, which rejected the incoherent spontaneous emission and enabled shot-noise limited detection[7]. Figure 1(b) shows the noise spectrum with and without the Fabry-Perot demonstrating 35 dB noise reduction due to the Fabry-Perot spontaneous emission rejection. The systems in Fig. 1(a) was scaled up for four ultrasound sensors used to simultaneously detect an ultrasound burst with a central frequency of 1 MHz. The four detected signals are shown in Fig. 1(c), demonstrating the parallel detection capability of pule interferometry. The sensitivity of the measurement presented in Fig. 1(c) is .

III. Discussion

Pulse interferometry is a technique capable of interrogating multiple ultrasound sensors with high sensitivity and dynamic range. Pule interferometry overcomes the two major drawbacks of CW interrogation: robustness and scalability – the two properties required for the development of a detector array. Detector arrays simultaneously interrogated via pule interferometry will reduce dramatically the scan duration required for optoacoustic imaging. Pulse interferometry provides ultrasound detection with high spatial resolution, high dynamic range, and sensitivity, beyond what is currently possible with piezoelectric transducers or CW interrogation.

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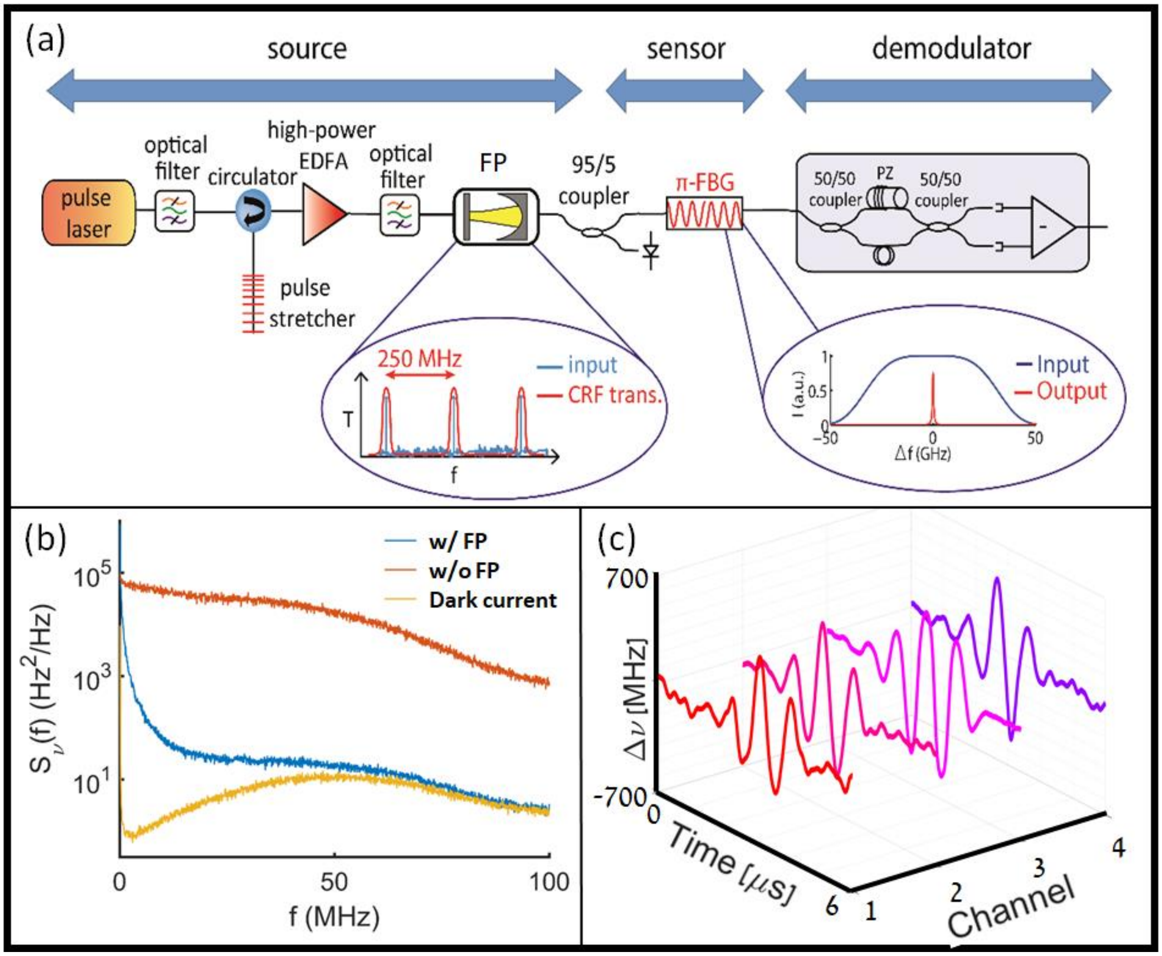

Fig. 1. (a) A schema of PI with FP noise reduction filter. (b) Noise spectra with and without FP and dark current noise. (c) 4 signals simultaneously measured with PI.