Rejection of crosstalk and noise by a quasi balanced CFPI for remote ultrasound detection

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Abstract. In this paper we show the benefits of a quasi balanced fringe hopping CFPI (confocal Fabry-Pérot interferometer) with broadband CMRR (common mode rejection ratio) for remote ultrasound detection. Ultrasonic information in general lies in the phase modulation of laser light which in this case is demodulated by using the CFPI at a certain working point on a fringe. By hopping from the positive to the negative slope on the same fringe the detected ultrasonic signals are inverted. In contrary interference signals like crosstalk from the generation, ghosts, or noise correlated to pulse laser excitation are not influenced and hence get rejected by subtracting the signals from both slopes. Hence, a minimum of two measurements is needed for common mode rejection. The fringe hopping from the positive to the negative slope is done by changing the distance of the CFPI mirrors with a precise piezoelectric-stack and a fast high resolution digital controller. As only one photo-detector with a transimpedance-amplifier is needed a high CMRR can be accomplished which is not affected by the symmetry of the fringe but only by pulse to pulse energy fluctuations of the generation laser. We show that with fringe hopping and averaging the signal to noise ratio increases much faster than with averaging without fringe hopping. This is due to the correlation of the quasi-noise with the generation cycle.

1. Introduction

The CFPI (confocal Fabry-Pérot interferometer) is the workhorse for the contactless detection of laser ultrasound in many industrial applications. In laser ultrasound an ultrasonic wave is generated by a short laser pulse and further contactless detected with an interferometer setup. Unfortunately the sensitivity of contactless interferometer setups is much smaller compared to contacting ultrasonic detectors like piezo transducers. Therefore improvements to the signal to noise ratio are very important. In this paper we present a simple method to improve SNR (signal to noise ratio) by rejecting common mode noise like generation crosstalk and high frequency amplitude fluctuations with a fringe hopping technique. With the proposed technique no additional costs compared to a standard CFPI setup are incurred, but it needs a minimum of two measurements to achieve common noise rejection. Dubois et al [1] demonstrated a more cost intensive way to improve SNR with two CFPI but with the advantage of common mode rejection with only one measurement.

2. Principle of common mode rejection by differential signals and balance lines

In electronics often very small signals have to be detected, amplified or transmitted. The signal to noise ratio of these signals suffers from their small amplitude and often also from the high input impedance of the amplification circuit. Both lead to a poor SNR ratio. To enhance the signal to noise ratio...
ratio of signals the balanced circuit principle with differential source was implemented (figure 1a). In principle the signal is separated into two differential signals (lines) which are symmetrical in respect to a defined amplitude level. At a balanced detector the signals are subtracted and the noise (figure 1b) which is common on both signals is rejected (figure 1c and 1d).

![Figure 1](image1.png)

**Figure 1.** Principle of ambient noise cancellation by differential signals and balanced lines.

This principle can be found on many devices in daily life, for example in audio (differential signal from microphone capsule), balanced photo-detectors (two photo-detectors in complimentary), computer data transmission (twisted pair lines) et cetera.

3. **The confocal Fabry Perot detector and implementation of quasi balanced principle**

The proposed setup is based on the well known CFPI detector setup [2, 3, 4] for remote laser ultrasound. An ultrasonic wave is generated by a short laser pulse. The generation process can be either in thermoelastic or ablative regime which affects both the amplitudes and directions of the ultrasonic waves [5, 6]. Detection is done with a continuous wave (or long pulse [7] laser) which is back reflected from the surface and gets phase modulated by the surface vibrations caused by the ultrasonic waves. Subsequently the phase modulation is demodulated by the CFPI to an amplitude modulation which is measured by a fast optical detector. To achieve high bandwidth detection a Si-detector was utilized to measure ultrasonic signals in reflection scheme of the CFPI.

![Figure 2](image2.png)

**Figure 2.** Principle of differential detection with fringe hopping technique
Demodulation is done at a certain working point (WP). The working point can be set by controlling the distance of the CFPIs mirrors. The WP which regularly is used is at half the height of the fringe and on the positive slope (figure 2 WP1).

The principle of differential and balanced detection can be applied to the CFPI detector by using quasi differential signals and signal averaging. By measuring first at the positive slope (figure 2 WP1), hopping to the negative slope, and following another measurement at the negative slope (figure 2 WP2) quasi-differential signals are acquired. By subsequently subtracting both signals common mode noise is rejected.

Stabilization of the working points and jumps between the slopes to the desired WPs were realized by a 12 bit A/D, ARM7 digital control and a precise piezoelectric stack. Before the laser ultrasound measurement is started FSR (free spectral range) and finesse of the CFPI are analyzed on. These variables are used to calculate a trajectory to hop from one WP to the other. The hopping including settling time was achieved within 3 ms.

4. Measurements

Measurements were carried out on a 1 mm thick steel sample. Ultrasonic waves were generated on one side of the sample by short laser pulses with a pulse duration of 20 ps and energy of 2 mJ. The generation laser was focused to a spot with a diameter of around 100 µm. Detection was done on the opposite side of the sample (measurement in transmission) with the proposed CFPI detector.

![Figure 3](image1.png)

**Figure 3.** Single shot measurement on 1mm a thick steel sheet. The red trace shows the balanced detection. A direct signal is eliminated at about 0.5 µs.

![Figure 4](image2.png)

**Figure 4.** LUS measurement on 1 mm thick steel sheet. Signals were averaged 180 times. The traces show zoom-in of first echo. Red trace shows elimination of quasi-noise.

Figure 3 shows a typical measurement. Several echoes can be identified. The blue trace shows the detected signal on the positive slope, the black on the negative slope, and the red curve shows the subtraction of both signals. As can be easily seen the first direct signal (figure 3 at 0.5 µs) from the generation laser is rejected. Figure 4 shows the averaging results over 180 signals. A zoom on the first echo is depicted to show the rejection of ripples on the subtracted signal. The ripple is apparent on both negative and positive slopes and cannot be eliminated by averaging, even by a multitude of measurements.

By looking at the frequency spectra (see figure 5) of 180 averaged signals (see figure 4 for time traces) the frequency bands of the ripples are apparent. These frequency bands get almost rejected by subtraction of the differential signals in the time domain. As this noise is not eliminated by averaging it must be time correlated to the cycle of the generation laser pulse and is further called quasi noise.

Most prominent quasi noises which apply to that symptom are:
• Generation crosstalk – electric field: The first eliminated signal (figure 3 at 0.5 µs) is attributed to stray pickup of the high electric field of the flashlamps of the ps-generation laser.
• Generation crosstalk – ablative generation: At the same time as the stray pickup of electric field takes place a small amount of plasma radiation generated by the focused generation laser reaches the detector. The polarity of this crosstalk is not affected of the chosen slope.
• Amplitude ghosts [1]: Amplitude ghosts are high frequency amplitude fluctuations which travel inside the cavity and therefore have a period time of the cavity length. Also these amplitude fluctuations are not affected by the chosen WP.

5. Conclusion
The benefits of a quasi balanced fringe hopping CFPI for ultrasound detection was shown. It is evident that only with a differential type CFPI quasi noise can be rejected. Dubois et al [1] demonstrated a more cost intensive way of implementing differential signals with CFPI: a detector with two CFPIs and working points on different sides of the fringes was used. Therefore, with a single shot measurement quasi noise signals can be rejected. The setup shown in this work needs two measurements to achieve common noise rejection. However, as measurements are usually averaged to achieve a good SNR this is no disadvantage for most applications. The proposed technique offers a method to reject quasi noise at lower material cost and low complexity. The work also shows that SNR is enhanced significantly compared to standard measurements without fringe hopping.

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