Demonstration of a 4-Sensor Folded Sangac Sensor Array with Active Phase Biasing Scheme

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Abstract—A 4-sensor folded Sagnac sensor array with an active phase biasing scheme is presented. The overlapping of the signal and noise pulse is avoided through a time division multiplexing scheme and the noise pulses is eliminated almost completely. The scheme can address 16 sensors when the repeat frequency of input pulse is at 68.3 kHz. The alternative phase bias technique is demonstrated, which can provide sensors with stable phase bias. The future benefit of this technique is that the 1/f noise in the circuit can be suppressed.

Index Terms—Fiber optic sensor, sensor array, Sagnac interferometer, time division multiplexing.

1. Introduction

The fiber-optic hydrophone array based on Sagnac interferometers presents several advantages over the acoustic sensor array based on Mach-Zehnder (MZ) interferometers\cite{1,2}. The former is insensitive to signal fading and source phase noise and can be easily desensitized to polarization fading just by inserting a Lyot depolarizer in the interferometer. In addition, broadband luminescent sources can be used instead of more expensive narrow-line-width lasers. Now Sagnac interferometers based acoustic sensor array is being actively researched and should soon be developed on a large scale for field evaluation\cite{3,4}. A 16-sensor time-division-multiplexed Sagnac-based acoustic sensor array with a polarization-based biasing scheme was demonstrated\cite{5,6}. To desensitize the delay coil to phase modulations, a folded configuration of the Sagnac sensor array was proposed. The full-scale prototype array aimed to solve some important difficulties in the basic SSA, but its structure was too complex.

Here, we describe an experimental demonstration of folded Sagnac-based acoustic sensor array with an active phase bias scheme. The overlapping of the signal and noise pulse in the folded Sagnac sensor array is avoided through a time division multiplexing scheme, and the quarter phase bias is produced by an integrated optical chip. The structure is much simpler and has the ability to suppress the low-frequency noise in the detector circuit.

2. Experimental Setup

The front end of the experiment setup is shown in Fig. 1. The source is an amplified spontaneous emission (ASE) source with a central wavelength of 1539 nm and optical power of 5 mW. A fiber polarizer, whose rejection is about 30dB, is placed before the LiNbO3 intensity modulator (IM) that can operate correctly in only one state of polarization. Polarization preserving fiber is used between the polarizer and the intensity modulator (IM), and the main light is aligned with the operating axis of the IM. The input light pulses are generated after it travels through the IM. The width and repetition rate are controlled by a drive signal produced by a field-programmable gate array (FPGA). Because the IM is a MZ structure, another bias signal is needed for generating a high extinction ratio light pulse. In this paper, the extinction ratio of the light pulse is about 25 dB.

Since we have a polarizing phase modulator (PM) in the Sagnac loop, a polarization preserving optical circulator and a 2×2 directional coupler are used in this structure to guarantee fringe visibility and eliminate additional intensity loss. The PM is located at one end of the Sagnac loop, and its half-wave voltage in this experiment is 3.05 V. A depolarizer is placed at another end to suppress polarization-induced signal fading. The PM operates in pulsed mode, and the drive signal pulse is synchronized with the IM. It provides arbitrary, phase difference between the interfering clockwise (CW) and counterclockwise (CCW) pulses.

The array telemetry is illustrated in Fig. 2. The Sagnac loop is a folded structure. The length of the delay coil is about 6.3 km. The effective loop length is doubled to 12.6 km corresponding to a loop proper frequency of 7.94 kHz. The array is a ladder structure with four rungs. A piezoelectric (PZT) cylinder placed in each rung with a two meter fiber wrapped around simulates an acoustic sensor. As mentioned in \cite{7}, the folded Sagnac loop may cause noise pulses in time division multiplexing (TDM) system.
To avoid the overlap of the signal pulses and the noise pulses, two pieces of delay fiber B1, 25 meters long, corresponding to about 125 ns optical transit time, is inserted before the first rung. Signal pulses and noise pulses will experience different time delay because the former travels through the Sagnac loop and the latter is reflected back to the output port of the circulator. If the width of the input pulse is less than 250 ns, the returned pulses will be separated in time without overlap. More details are described in [8].

Usually, the intensity of the noise pulses, especially the first one reflected back directly without traveling through any rung, are more powerful than the signal pulses. It will cause the detector to go out of range before the amplitude of the signal pulse is high enough. It will be more serious with the increase of the number of sensors. We used a Faraday rotator mirror (FRM) at the end of the delay coil, which causes the light to orthogonally polarized to its input state for any arbitrary coil birefringence. As mentioned above, the optical circulator was designed to be \( x(y) \) polarized. So the noise pulses, \( y(x) \) polarized at the port 2, can not pass the optical circulator to the detector. In this structure, signal pulses and noise pulses have been separated in time, so there is no special requirement on the optical circulator and the FRM\(^9\).

The return pulses are sent to a detector. The detector has no less than 10 MHz bandwidth and its voltage is acquired by a 2.5 MHz/14-bit data acquisition NI 6132. For each input pulse, 4 pulses are returned at the output. In order to separate these 4 pulses in time and be able to de-multiplex hydrophone signals, an additional 50 meters length of fiber was placed between adjacent couplers, so that the pulses were separated by a delay time around 500 ns. That is long enough for the data acquisition (DAQ) system to sample every returned pulse. The DAQ operated in continuous mode with an external sample clock produced by FPGA. The sample clock was adjusted to ensure that the DAQ can sample every returned pulse correctly. All the data of the four sensors was sent to a computer in a queue, and then we were able to choose the data of anyone of the sensors for further processing.

3. Results

Fig. 3 shows the relationship between the returned pulse train (top) and the input pulse (bottom) at the detector. The input pulse is 250 nano-seconds wide with a 68.3 kHz repetition rate. We could only see 4 signal pulses from the oscillatory traces, and the noise pulses were almost completely eliminated. We could also see that there was nearly a 15 micro-seconds time gap between any two input pulses. That was wide enough to address at least 16 sensors for this array.
The ability to set the bias point of each sensor was checked. Fig. 4 shows the output waveform of sensor 1 when the phase modulation voltage was changed from \(-10\) V to 10 V at the frequency of 1 Hz. It was observed that arbitrary bias points could be achieved through adjusting the voltage of the phase modulation signal.

If the phase bias kept constant at \(\pi/2\), the envelope of the pulse train from each sensor directly represented the acoustic signal. But in this paper, we alternated the bias point between \(\pi/2\) and \(-\pi/2\). When a harmonic signal at 2.5 kHz with the phase modulation amplitude of about 100 mrad was applied to sensor 1, the output of sensor 1 is shown in Fig. 5. The original signal is modulated by a square-wave at the frequency of half of the input pulse repetition frequency. For every other data in the series we multiplied by \(-1\), and then the acoustic signal was recovered after passing through a low-pass filter. Because this kind of noise had nothing to do with the phase modulation, the modulation and demodulation process suppressed the low-frequency circuit noise.

This signal processing scheme has another advantage. The phase drift in the interferometer can be measured through the difference between the average amplitude of the output signal at difference phase bias point and his phase drift can be compensated to zero with a proportion-integration (PI) method. Fig. 6 shows the phase drift and the compensation result.

4. Conclusions

We have constructed a 4-sensor folded Sagnac acoustic array with active phase biasing scheme. The signal pulses and noise pulses were separated in time and the noise pulses was suppressed almost completely. An integrated optic chip in the SSA alternated the phase bias point between \(\pi/2\) and \(-\pi/2\). The phase drift induced by non-reciprocity was measured by the difference between the two phase bias points and can be compensated with a PI method. The low-frequency noise of the detector circuit could be suppressed effectively.

References


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