Demonstration of Correlation Peak Profiling in Frequency Correlated Brillouin Optical Time Domain Analysis

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Abstract: We propose a combination of frequency correlation and temporal gating techniques to map the correlation peaks, investigate their tunability through simulations and experiments. Correlation peaks in 1 km fiber are tracked with 100 ns pulses.

OCIS codes: 060.2370, 290.5900, 060.4080.

1. Introduction

Structural Health Monitoring (SHM) has recently become an essential part in civil structures such as bridges, dams and aircrafts in order to detect any damages; thereby extending their lifetime [1]. Since vibration is one of the key parameters, its continuous monitoring requires a reliable, high resolution multi-point dynamic strain sensor. A promising candidate for such dynamic sensing is the Frequency Correlated Brillouin Optical Time Domain Analysis technique (FC-BOTDA), where the pump/probe correlation occurs within a localized region in the sensing fiber [2].

An important milestone in achieving the multi-point dynamic strain sensing using FC-BOTDA is to physically map the correlation peak. In this paper, we have attempted to map the correlation peak (although with a coarse resolution as a proof-of-principle experiment) by appropriately gating the pump, and also demonstrate its tunability across the sensing fiber. Simulations performed to fine-tune the mapping technique has been validated by controlled experiments.

2. Frequency Correlated BOTDA Simulations

In the Frequency Correlated BOTDA, the pump and the probe are derived from a single laser, which is frequency modulated at frequency $f_m$ [2]. Depending on the $f_m$ and the maximum frequency deviation $\Delta f$, the pump and the Brillouin frequency-shifted probe interact only at specified locations in the fiber. These locations are separated by a distance $d$ given as [3]

$$d = \frac{c}{2nf_m}$$

and the interaction length $\Delta z$ is given by

$$\Delta z = \frac{c}{2\pi f_m} \Delta f$$

where $c$ is the velocity of light, $n$ is the effective index of fiber and $\Delta v_B$ is the Brillouin linewidth. For a fiber of length 1 km, the $f_m$ required to obtain a single correlation peak within the length of the fiber can be calculated as 100 kHz from eq. 1. For this $f_m$, the width of the correlation peak is estimated to be 42 m for a $\Delta f$ of 225 MHz. Such a result is confirmed through simulations performed to map the spatial distribution of the correlation peak for a 1 km long fiber as shown in Fig. 1.

![Fig. 1. (a-c) Correlation peak profiles for different modulation frequencies; $\Delta f = 225$ MHz for all cases](image-url)
In Fig. 1 (a), the correlation peak profile is observed at around 500 m for a modulation frequency corresponding to 100 kHz. As expected, increase in $f_m$ results in a decrease in the width of the correlation peak as well as the spacing between adjacent peaks. Thus with a careful choice of $f_m$ and $\Delta f$, the Brillouin gain be engineered to occur at specific locations across the length of the fiber. It is also found that the location of these peaks can be tuned by tuning the $f_m$. The location of these peaks can be extracted in an experiment by using pulsed pump with pulse widths smaller compared to $\Delta z$. Such results are validated experimentally, as described in the next section.

3. Experimental Results and Discussion

The schematic of the experimental setup is shown in Fig. 2. A narrowband laser (Eblana Photonics) is frequency modulated by modulating its current with the same modulation parameters as discussed previously. The modulated light is split into the pump and probe arms. Light in the pump arm is gated using an electro-optic modulator (EOM), amplified and allowed to propagate through the fiber. The probe is frequency shifted through carrier suppressed modulation at 10.807 GHz and counter propagated. Fig. 3 shows the backscattered traces for different modulation frequencies.

Prominent correlation peaks observed in the experiment are located at the positions as predicted in the simulations. The reduction in the width of correlation peak as well as spacing between adjacent peaks is observed with increase
in $f_m$. In order to verify the tunability of correlation peaks, a buffer fiber of length 2 km (delay corresponding to second order correlation in the sensing fiber) is added on the probe arm. The backscattered traces are observed for different $f_m$ as in Fig. 4.

![Fig. 4. Traces showing the tunability of correlation peak location](image)

The location of correlation peak has been changed with $f_m$. The uneven amplitude of correlation peaks are due to internal stresses and a consequent shift in Brillouin frequency along the length of the fiber spool used. This is independently verified using a BOTDA experiment. For frequencies 140 kHz and 150 kHz, we can clearly observe that the 2nd order correlation peaks have come within FUT of 1 km. Fig. 5 shows correlation peaks for different $\Delta f$.

![Fig. 5. Trace showing the correlation peak widths for different $\Delta f$; $f_m = 100$ kHz for all cases](image)

As predicted, the size of the correlation peak has reduced with increase in $\Delta f$. This reduction is limited by the width of the pump pulse. For $\Delta z$ smaller than the spatial extent of the pump pulse, the decrease is not observable experimentally. In general through this technique, the correlation peaks can be mapped with a spatial resolution of 1 m – corresponding to that decided by the phonon lifetime.

4. Conclusions

In this paper, we have demonstrated a novel scheme based on temporal gating to map the correlation peak profile in frequency correlated BOTDA as well as to demonstrate its tunability across the sensing fiber. The results obtained from detailed simulations are validated by controlled experiments. Efforts are underway to extend the scheme to advanced modulation formats to achieve simultaneous multi-point sensing.

5. Acknowledgement

The authors would like to acknowledge the financial support from the Ministry of Human Resource Development (MHRD) and Department of Electronics and Information Technology (DeitY), Government of India and thank Prof. Liam Barry of DCU, Ireland for providing the narrowband laser source.

6. References

