Accelerated Brillouin Frequency Shift Estimation Algorithm

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Abstract: We propose an efficient Brillouin frequency shift (BFS) estimation algorithm assisted by ternary search (TS), experimentally demonstrating a 4.39-fold estimation accuracy improvement over TS-BOTDA and 70% scanned frequency number reduction over conventional BOTDA.

1. Introduction

Brillouin optical time domain analyzer (BOTDA) is one of the most widely researched optical fiber sensors [1]. However, in conventional BOTDA, a frequency-sweeping (FS) process is a time-consuming process to precisely determine the Brillouin frequency shift (BFS), which requires hundreds of frequency scanning trials. Several fast BOTDA scheme have been proposed to alleviate this problem [2–4], while the inherent shortages of these schemes such as limited sensing range and frequency/spatial resolution trade-off restrain their sensing performance. In [5], we proposed a TS-BOTDA achieving over 80% reduction in the scanned frequency number with a 3-m spatial resolution. However, the unimodality requirement for the Brillouin gain spectrum (BGS) restricts the BFS searching accuracy, especially when the signal-to-noise-ratio (SNR) is insufficient.

In this paper, we propose a novel BFS estimation algorithm utilizing TS as a BFS fast-locating tool. After obtaining the approximate BFS location, a small-range frequency sweeping is conducted for the BFS precise estimation. Experimental results show that the proposed algorithm can achieve an average of 0.75-MHz BFS estimation accuracy and 70% reduction in the scanned frequency number.

2. Principle

Following the TS-accelerated fast searching in [5], the proposed scheme performs the FS operation and Lorentzian curve fitting (LCF) over the BFS vicinity spectrum. The details are shown as follows:

1. Initialize f_{start}, f_{end}, TS frequency step f_t, sweeping frequency step f_s and switching interval f_i, dynamic range $D = f_{end} - f_{start}$;
2. According to f_t, calculate and scan two trisection frequencies f_{left} and f_{right} where $f_{right} > f_{left}$;
3. Compare the measured Brillouin gain G_{left} and G_{right}: if $G_{left} < G_{right}$, $f_{start} = f_{left}$; Else if $G_{left} > G_{right}$, $f_{end} = f_{right}$; Else, $f_{start} = f_{left}$ and $f_{end} = f_{right}$.
4. Check whether $D > f_i$; if yes, repeat procedure 2-4; If no, frequency-sweeping operation activates from current f_{start} to f_{end} with frequency step f_s;
5. Apply LCF on the measured partial Brillouin gain spectrum obtained in procedure 4 to get BFS estimation.

Figure 1a reveals the working principle with a 10.910-GHz BFS searching. The frequency-searching process is switched to the frequency-sweeping process once the dynamic range D is smaller than the default 30-MHz switching interval. The inlet depicts the LCF operation near BFS over normalized Brillouin gains.

3. Experimental Validation

We have conducted experiments under different temperatures to validate the proposed scheme. Figure 1b shows the experimental setup, composing of the conventional setup and a PC-controlled feedback loop. The sensing range is set from 10.8391 GHz to 10.9390 GHz with f_s equal to 0.1 MHz. To speed up the searching process while guaranteeing the estimation accuracy, f_t is selected larger than f_s as 1 MHz. The switching interval is 30 MHz. A 3-m polarization maintaining fiber serving as the fiber under test, is heated by a water bath from 30°C to 50°C with

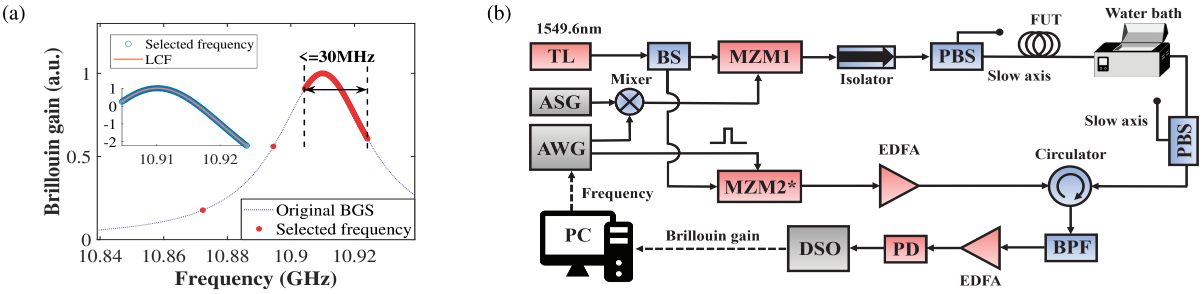

Fig. 1: (a) Working principle of the proposed scheme; (b) Experimental setup. TL: tunable laser, AWG: arbitrary waveform generator, ASG: analog signal generator, BS: beam splitter, MZM: Mach-Zehnder modulator (*: high extinction ratio), EDFA: Erbium-doped fiber amplifier, PBS: polarization beam splitter, FUT: fiber under test, BPF: bandpass filter, PD: photodetector, DSO: digital storage oscilloscope, PC: personal computer.

an increment of 5°C. Figure 2a shows the measured BFS-temperature curve and the average number of scanned frequencies. The BFS-temperature curve accords with the theoretical curve meanwhile a high linearity is observed with a temperature sensitivity of 1 MHz/°C. The number of scanned frequencies is averaged with 50 measurements for each temperature. The average scanned frequency number in five temperatures is 301.4, demonstrating a 70% reduction over FS-BOTDA. Figure 2b shows the measured BFS estimation accuracy comparison between our scheme and the TS-BOTDA. The root mean square error (RMSE) is calculated with 50 measurements, each with only 10-time averaging. An overall mean BFS estimation RMSE of 0.75 MHz is observed for the proposed scheme compared with that of 3.3 MHz for TS scheme, showing a 4.39-fold improvement.

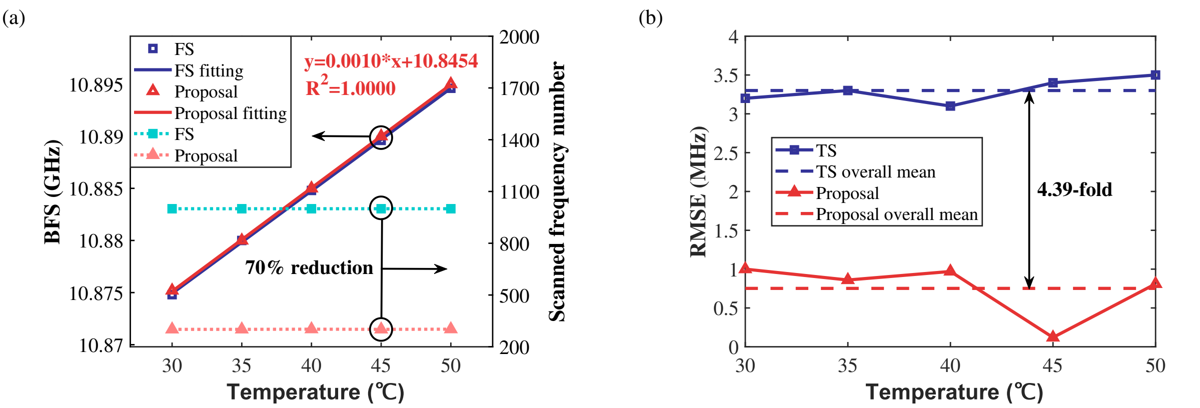

Fig. 2: (a) BFS-temperature curve and average scanned frequency number under different temperatures; (b) BFS estimation RMSE over TS scheme under different temperatures.

4. Conclusion

We have proposed a TS-accelerated fast BFS estimation algorithm. Experimental demonstration reveals that the proposed scheme shows a 4.39-fold improvement in BFS estimation accuracy over TS-BOTDA under insufficient SNR condition and 70% reduction in the number of scanned frequencies over FS-BOTDA.

References

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