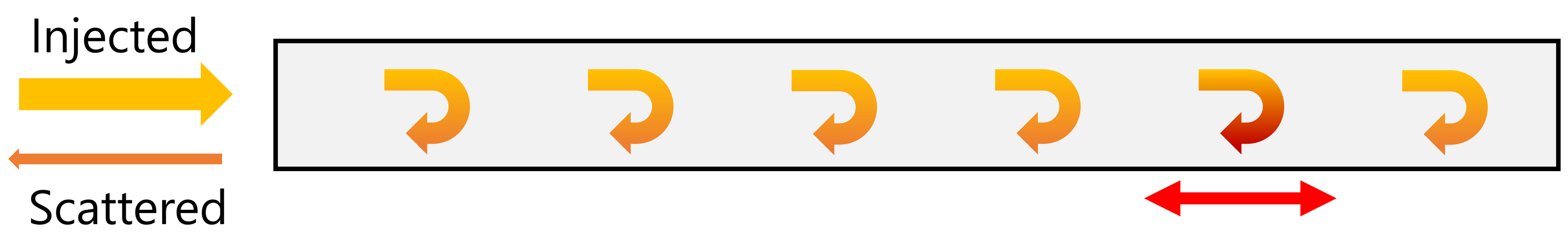
Brillouin optical correlation-domain reflectometry with differential spectrum scheme for distributed strain sensing at a distance

Haruki Sasage[1], Ryo Inoue[1] , Yusei Shirai[1], Yosuke Mizuno[2], and Heeyoung Lee[1]

[1]Shibaura Institute of Technology, [2]Yokohama National University

Background

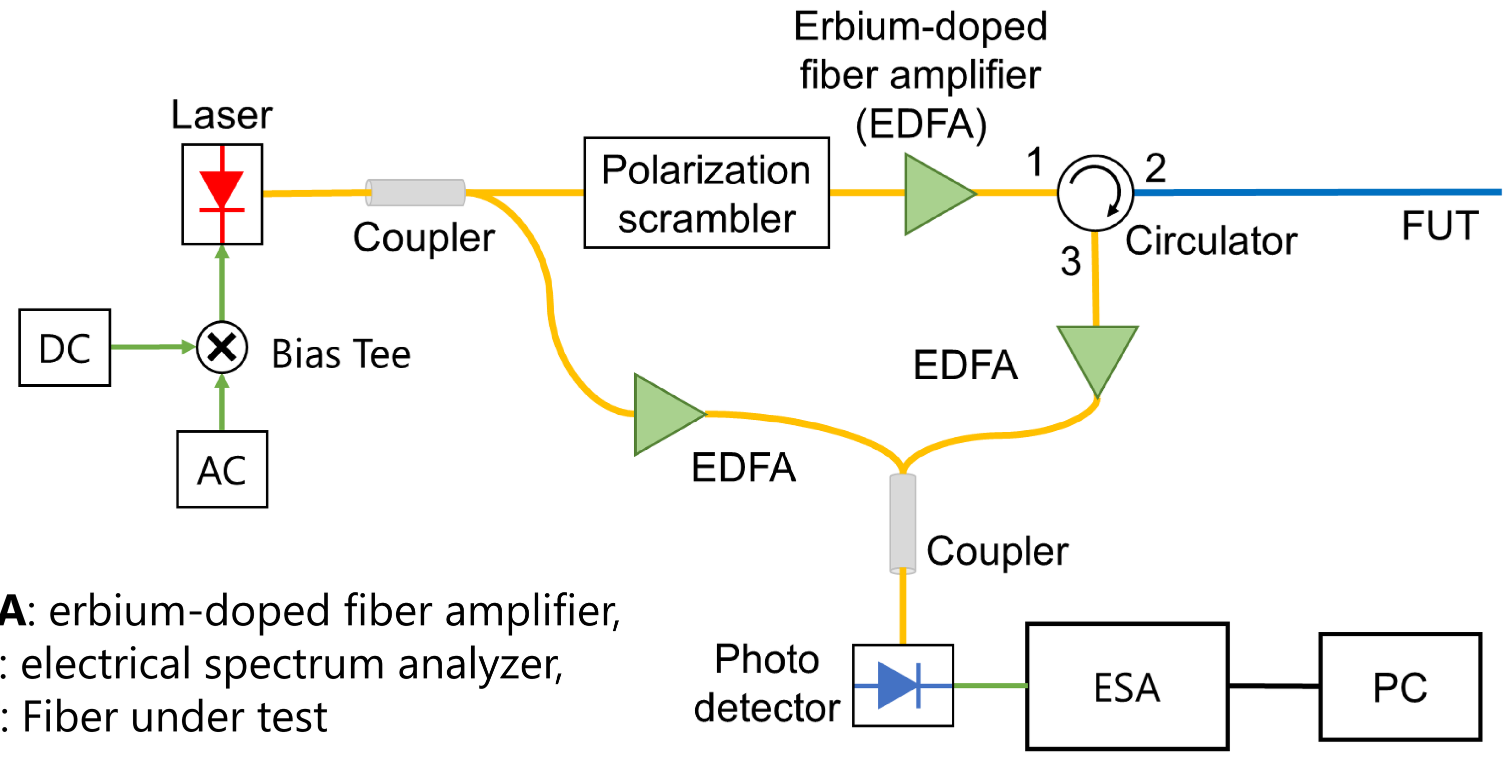
Distributed sensing using Brillouin scattering



Frequency shift of scattered light linearly depends on applied strain and temperature change along fiber

BOCDR

Promising technique for measuring strain and temperature distributions with advantages, such as high spatial resolution, one-end accessibility, high sampling rate, and cost efficiency



EDFA: erbium-doped fiber amplifier,
ESA: electrical spectrum analyzer,
FUT: Fiber under test

Trade-off relation in BOCDR

Measurement range $d_m = \dfrac{c}{2n\,f_m}$

Spatial resolution $\Delta z = \dfrac{c\,\nu_B}{2n\pi\,\Delta f\,f_m}$

c: velocity of light in vacuum
n: core refractive index
f_m: modulation frequency
$\Delta\nu_B$: Brillouin bandwidth
Δf: modulation amplitude

Difficult to extend measurement range while maintaining spatial resolution

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The double modulation method and time gate method can alleviate the problem, but the high cost of the measurement system is unavoidable.

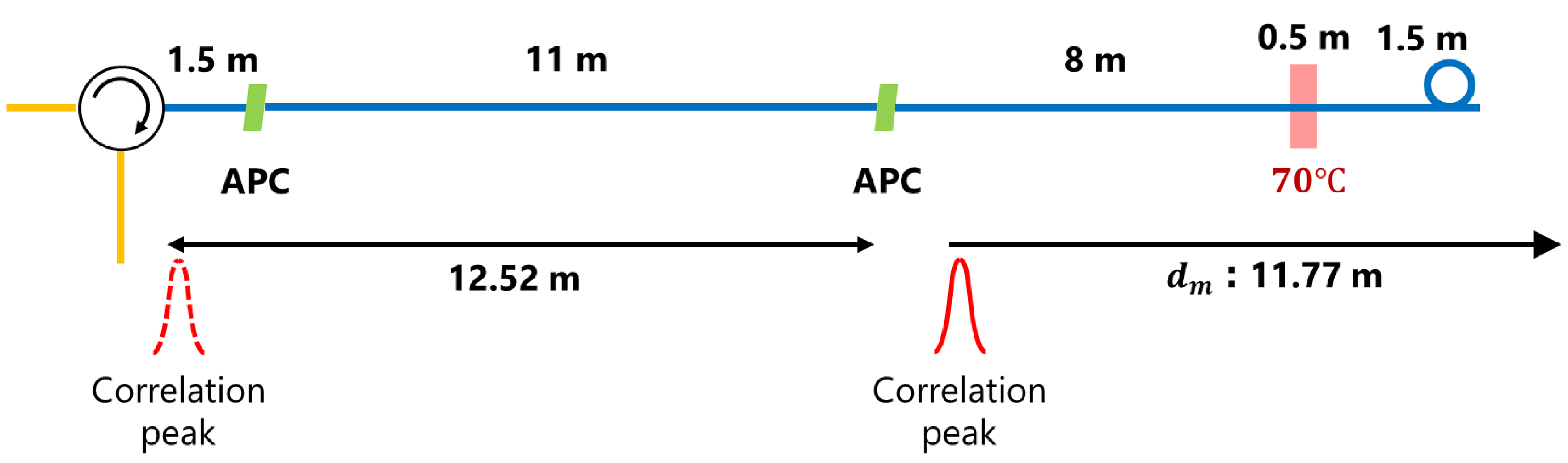
Y. Mizuno et al., Opt. Express **17**, 9040 (2009).
Y. Mizuno et al., Opt. Express **18**, 5926 (2010).

Purpose

Development of "**differential spectrum method**" for measuring strain distribution near open end of sensing fiber, beyond theoretical measurement range

Method

In standard BOCDR, only one correlation peak present with sensing fiber, limiting measurement range



- Generate multiple correlation peaks in sensing fiber
- Acquire Brillouin signal from all correlation peaks
- Eliminate scattering effects from correlation peaks other than measurement point

Experimental conditions

Setup: Same as conventional BOCDR (except for signal processing)

- Modulation Amplitude: ~1.27 GHz
- Modulation frequency: 7.7 – 8.15 MHz
  - ➢ Theoretical spatial resolution : ~10 cm

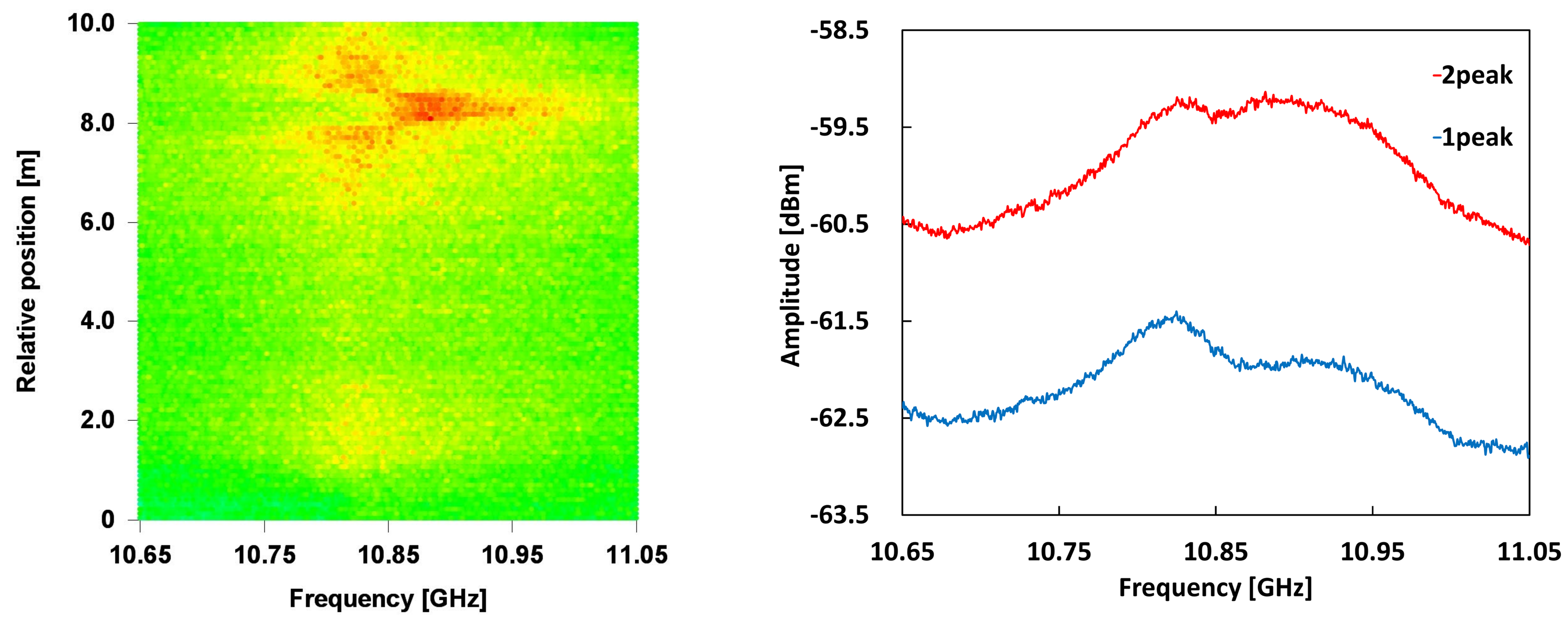
- Two correlation peaks
  - ➢ Fiber length: ~22.5 m
  - ➢ Measurement range: ~11.8 m
- Three correlation peaks
  - ➢ Fiber length: ~35.5 m
  - ➢ Measurement range: ~11.02 m

- 1.5-2.0 m section away from open end of sensing fiber heated to 70°C

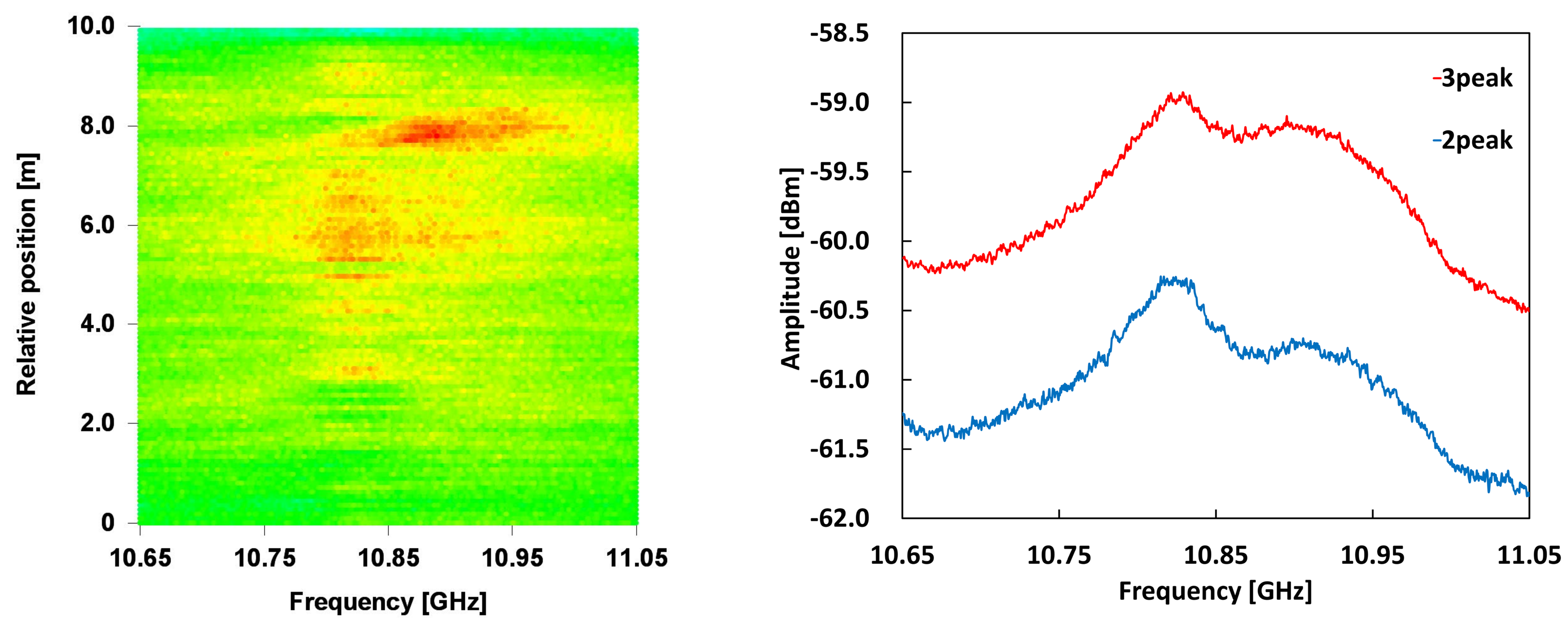
Result

BGS power distribution along measurement point (left) and observed BGS at heated section (right)

When using two correlation peaks



When using three correlation peaks



In both experiments, BFS at heated section (~8 m) shifted to higher frequency

Conclusion

To overcome a trade-off relation in BOCDR, we developed the "differential spectrum method" for long-distance strain distributed measurement in BOCDR and demonstrated its basic operation.

This cost-effective and straightforward approach is expected to enable strain/temperature distributed measurement in remote locations.