Estimating spatial resolution in BOCDR using Rayleigh scattering

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Background and Purpose

BOCDR

(**B**rillouin **o**ptical **c**orrelation-**d**omain **r**eflectometry)

Y. Mizuno et al, *Opt. Express* **16**, 12148 (2008).

- Capability to measure **temperature** and **strain distributions**
- **Operated by light incident from only one end of sensing fiber**
- **Random accessibility** to measurement points
- **High spatial resolution** ⇒ millimeter order (maximum)

➡ **Applications to structural health monitoring**

Spatial resolution of BOCDR

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

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

Need to measure modulation amplitude Δf to determine spatial resolution

- Conventional methods for measuring modulation amplitude

➢ Using optical spectrum analyzer (OSA)

The Δf value is typically 100 MHz – 5 GHz.

However, the frequency resolution of an OSA is insufficient.

➢ Using heterodyne detection system

The freq. resolution of an electrical spectrum analyzer (ESA) is sufficient.

However, alteration to the BOCDR setup is required.

K. Noda et al, *Appl. Phys. Express* **12**, 022005 (2019).

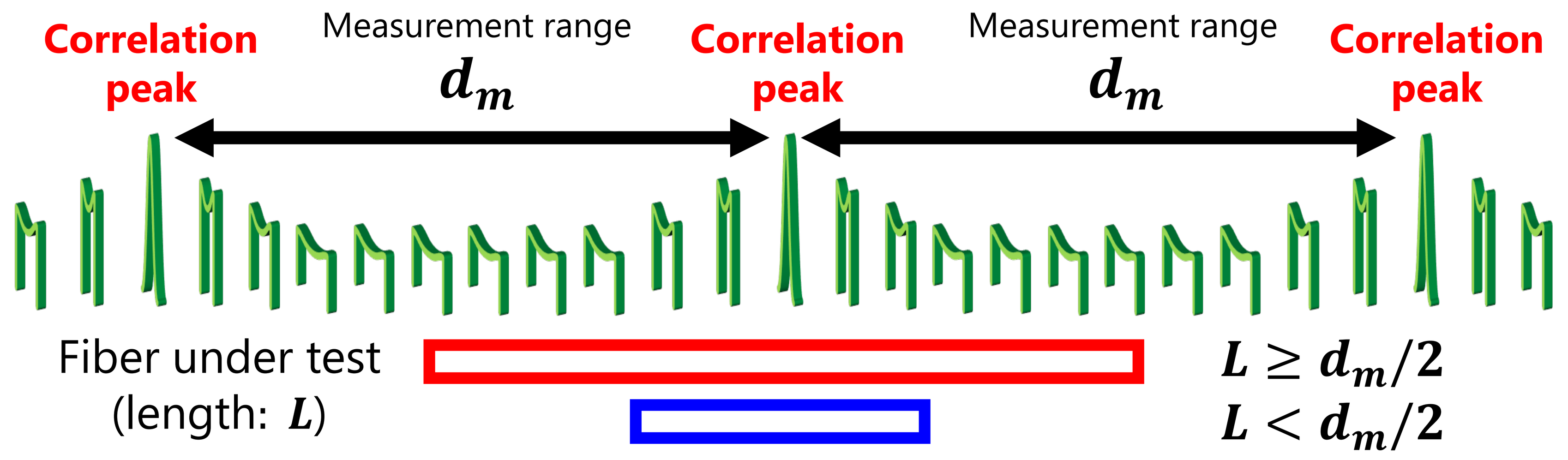
Purpose

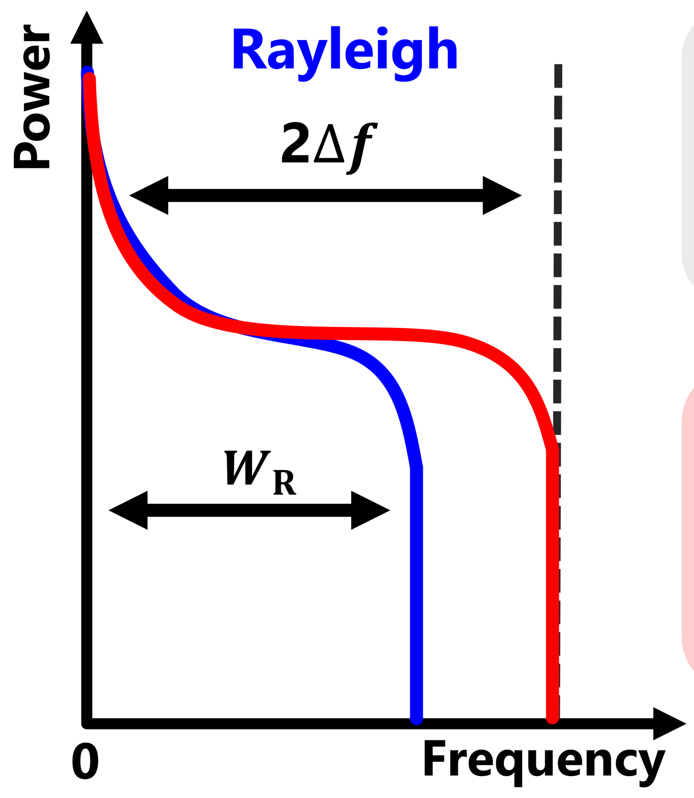
We propose a new method to measure the modulation amplitude with high accuracy without alteration to the BOCDR setup, using the noise spectral width of Rayleigh scattering.

Method

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

- **Noise spectral width of Rayleigh scattering**



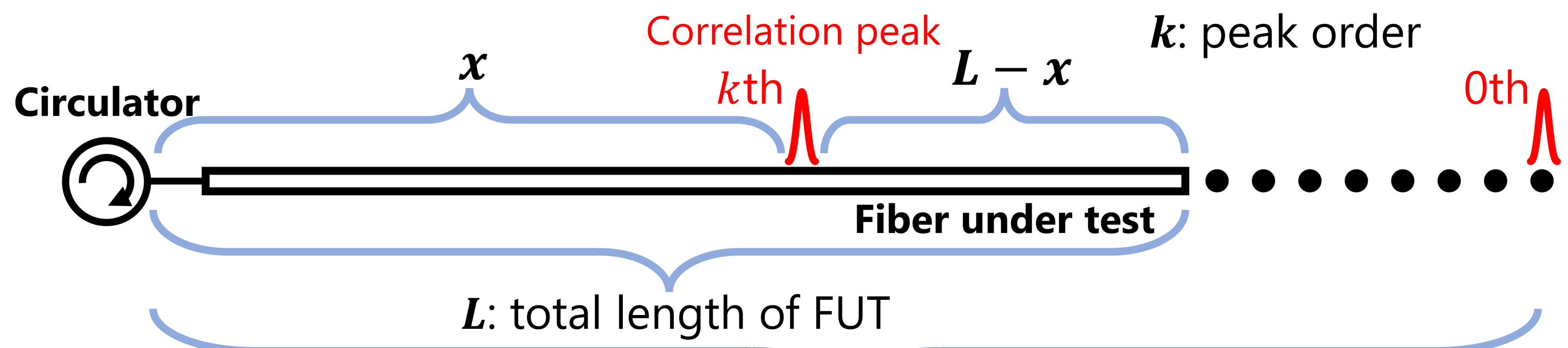


Stokes light also includes Rayleigh scattering. The spectral width due to Rayleigh scattering is **$2\Delta f$, which makes it possible to measure the modulation amplitude**.

If the measurement fiber length is **shorter than half of the measurement range d_m**, the spectral width due to Rayleigh scattering is **smaller than $2\Delta f$**. Therefore, it is necessary to **estimate Δf** from **the spectral width W_R**.

W_R: Rayleigh noise width observed in ESA

- **Estimation of modulation amplitude Δf_R using W_R**



D: distance from 0th correlation peak and proximal end of FUT

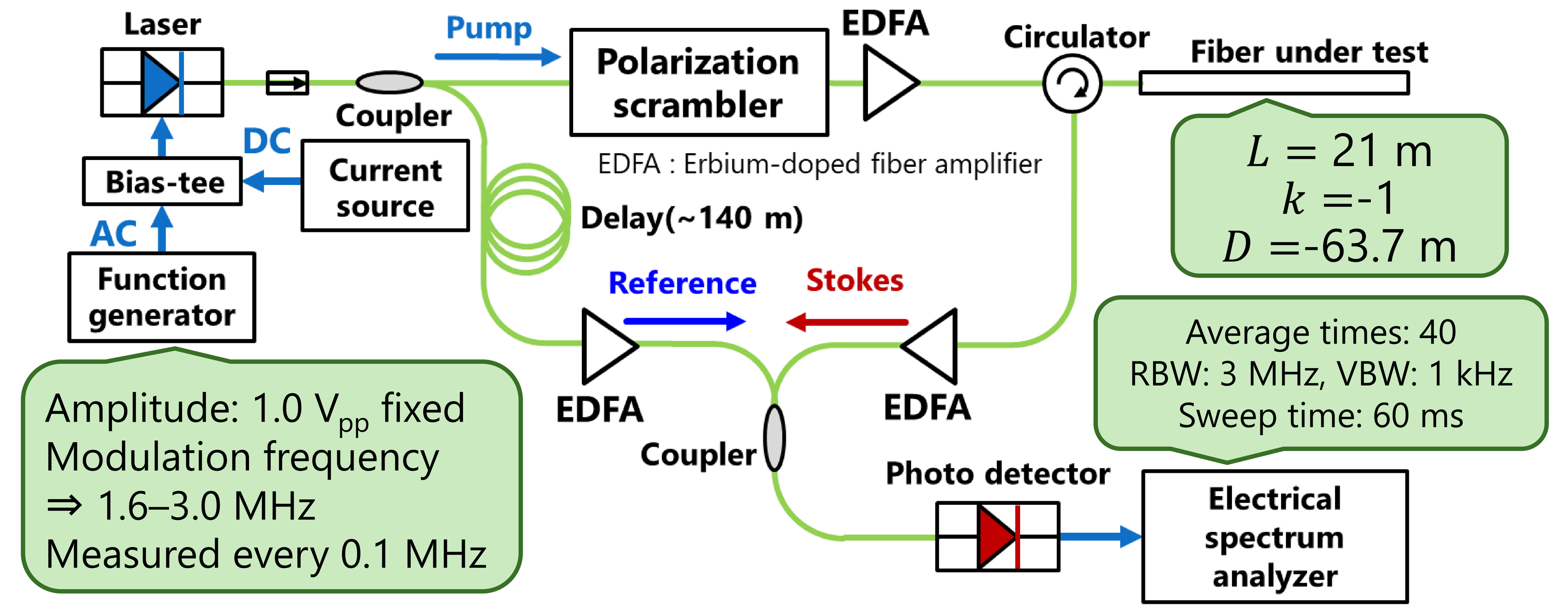
Measurement (correlation peak) position: $x = k \cdot d_m - D$

The Δf_R value can be determined by:

$$\Delta f_R = \frac{W_R}{2} \cdot \mathrm{cosec}\left\{\frac{\pi}{d_m}\max(L - k\cdot d_m + D, k\cdot d_m - D)\right\}$$

Experiments

① Measurement of Rayleigh noise width W_R using BOCDR

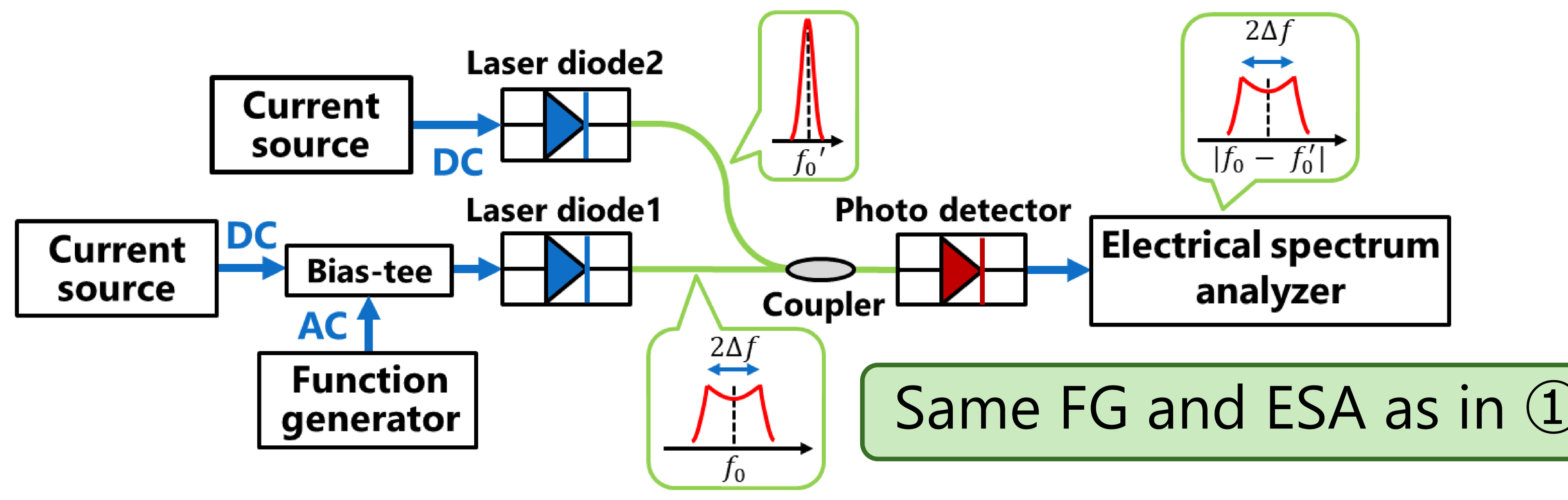


Relationship between d_m and L

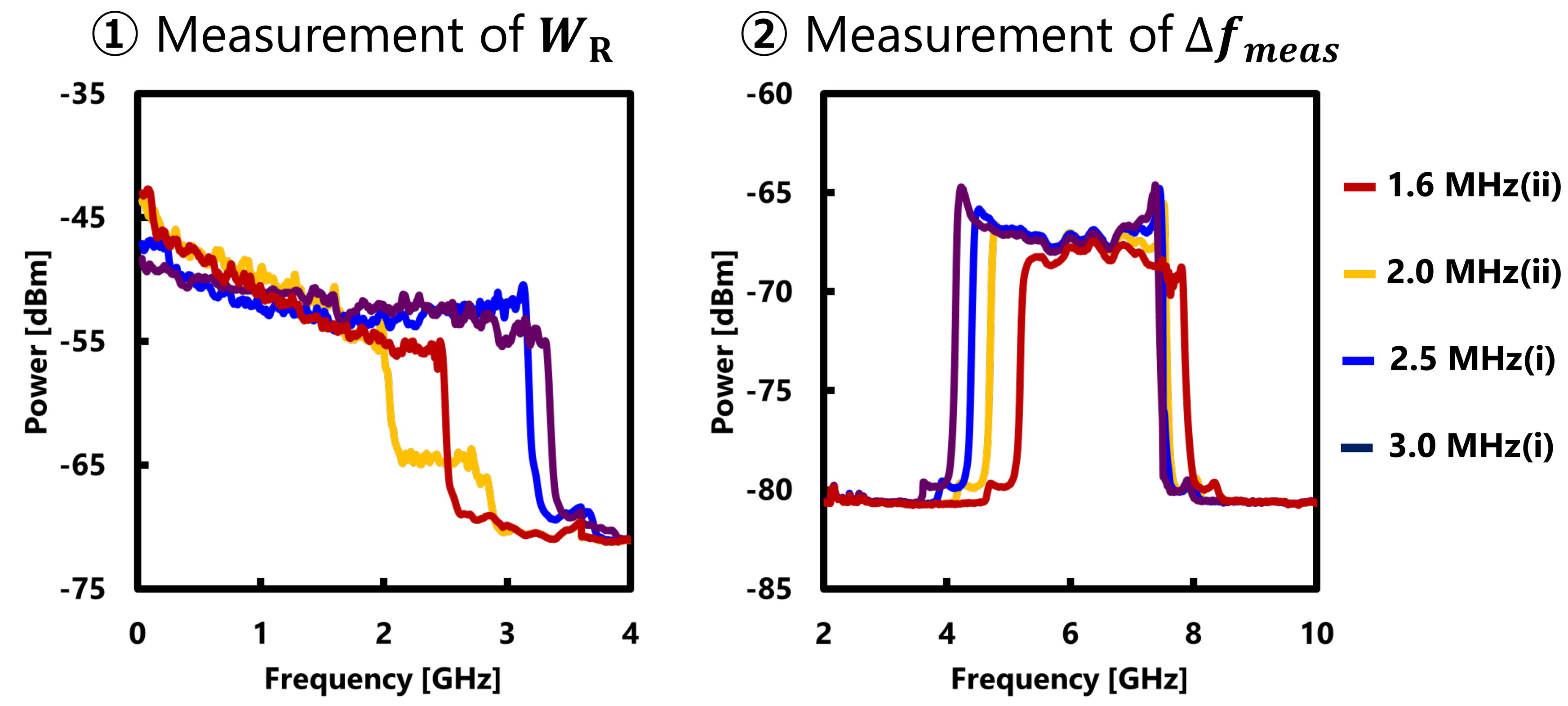
(i) when f_m is higher than ~2.42 MHz, $L \geq d_m/2$

(ii) when f_m is between ~1.60 and ~2.42 MHz, $L < d_m/2$

② Measurement of modulation amplitude Δf_{meas} using heterodyne detection system

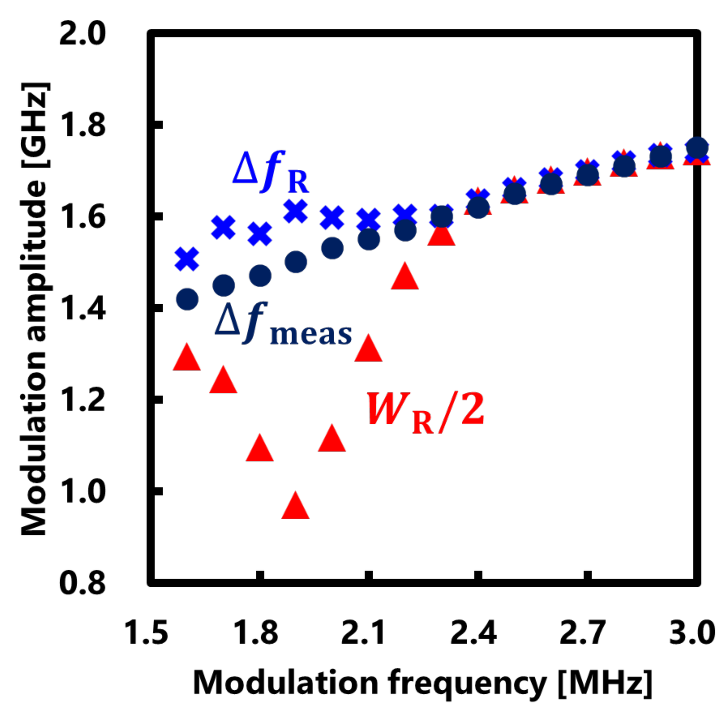


- **Observed spectral waveforms**



W_R decreased toward ~2.0 MHz and then increased, while Δf_{meas} monotonically increased.

- **f_m dependence of Δf**



$W_R/2$ differed from Δf_{meas} at 1.9 MHz when $L < d_m/2$. (**Max. error**: **~35%** at **1.9** MHz)

The error between Δf_R and Δf_{meas} **was drastically reduced.** (**Max. error**: **~9%** at **1.7** MHz)

Conclusions

- We proposed a method for **estimating the modulation amplitude** in BOCDR based on **the spectral width of Rayleigh noise**.
- **Utilizing an ESA** instead of an OSA, our approach offers **high measurement accuracy** and **convenience** as **it does not require changes to the experimental setup**.
- Our method enables accurate measurement of the modulation amplitude **while overcoming length restrictions on the FUT.**
- In the future, we expect **widespread use** of this method for accurately assessing **spatial resolution** in BOCDR research.