

# Measurement of Localized Heating in Fiber Optic Components with Millimeter Spatial Resolution

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**Abstract:** We present a novel technique for ultra-high resolution distributed fiber-optic temperature sensing based on measuring spectral shifts in the Rayleigh backscatter signature along an optical fiber. We demonstrate that a temperature measurement with  $\pm 0.1$  °C resolution can be achieved with spatial resolution of 10 mm, and a resolution of  $\pm 1$  °C can be achieved with a spatial resolution of 2 mm. We demonstrate how this technique can be applied to in-situ temperature monitoring for high power amplifier module applications.

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## 1. Introduction

Optical fiber, by the nature of its material properties, is an ideal distributed temperature sensor. There are several methods available for extracting distributed temperature information from optical fiber. These include techniques based on Raman, Brillouin, and Rayleigh scattering as well as those involving multiplexed fiber Bragg gratings (FBGs) [1-3]. Techniques based on Raman and Brillouin scatter measurement employ optical time domain reflectometry (OTDR) and thus are not well suited for applications that require high resolution. Methods that employ FBGs can achieve higher resolution but are often limited by the number of gratings that can be multiplexed in a single fiber. Both FBG-based and scatter-based techniques also usually require specialty optical fiber.

In this talk, we present measurements of local temperature changes on a millimeter scale in a high power fiber amplifier. We use swept wavelength interferometry (SWI) to measure the Rayleigh backscatter as a function of length along the assembly with high spatial resolution [4]. A sensor is formed by measuring the temperature-induced shift in the reflected spectrum of the Rayleigh backscatter in the location of the heating [5]. A tapered fiber bundle (TFB) within the amplifier is used as a specific example as a component that undergoes local heating, but the technique applies to nearly any temperature sensitive optical component.

For many applications, it can be advantageous to measure local heating conditions in-situ, but identification of the precise location of the heating during operation can be difficult or impossible in packaged devices. This is especially true for high power applications, because small defects within a component can scatter light from the guiding core and induce local heating in the fiber and surrounding coating or packaging. Raman or Brillouin scatter systems cannot provide spatial resolution on the order of the component length itself, let alone individual features of the component. The temperature sensing method described here is advantageous not only because of its high resolution, but because it can monitor in-situ temperature changes in an optical component. That is, the local temperature profile within a component, to a very high degree of accuracy and resolution, can be extracted while the component is being subject to its normal operating condition. Swept wavelength measurement of the Rayleigh scatter can provide temperature measurements as precise as 1°C over spatial regions as small as 3 mm, providing the necessary spatial resolution and temperature sensitivity for component evaluation.

## 2. Experiment

Rayleigh backscatter in optical fiber is caused by random fluctuations in the index profile along the fiber length. For a given fiber, the scatter amplitude as a function of distance is a random but static property of

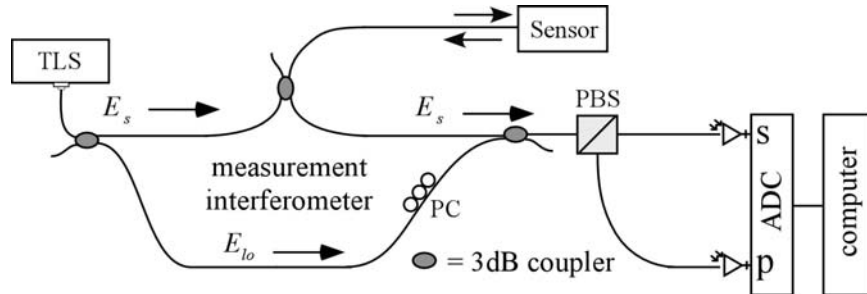


Fig. 1. Optical network used for polarization-diverse measurement of Rayleigh backscatter for distributed fiber sensing.  $E_s$  and  $E_{lo}$  from the tunable laser source (TLS) combine and interference fringes are detected at the “s” and “p” and digitized at the ADC ‘A’ to ‘D’ converter (ADC).

that fiber. Changes in the local period of the Rayleigh scatter caused by an external stimulus (like temperature) in turn cause changes in the locally reflected spectrum. This spectral shift can then be calibrated to form a distributed temperature sensor.

In this work, polarization-diverse SWI is used to measure both the amplitude and phase of the Rayleigh backscatter signal. The measurement network used is shown in Fig. 1. Light from an external-cavity tuneable laser source (TLS) is split between the reference and measurement arms of an interferometer. In the measurement path, a 50/50 coupler further splits the light to interrogate a length of fiber under test (FUT, labelled “Sensor” in the figure) and return the reflected light. Another 50/50 coupler then recombines the measurement and reference fields. A polarization beam splitter and a polarization controller are used to split the reference light evenly between two orthogonal polarization states. The interference between the measurement field and these two polarization states is then recorded at detectors labelled S and P.

SWI is used to measure the complex reflection coefficient of a FUT as a function of wavelength. The Rayleigh scatter as a function of length is obtained via the Fourier transform (see reference 4 for details). In this work, the scatter profile is measured over lengths up to 20 meters with ~20 micrometer resolution, with the laser operating in the 1550 nm wavelength band.

Figure 2 shows the results of distributed temperature sensing using the SWI technique and SMF28 as the sensing fiber. Using the relationship between spectral shift and temperature change quoted in ref. [6], 10 pm/°C, the peak spectral shift at a distance of 15.9 m represents a temperature change of 38.8°C. With a  $\Delta x$  of 5 mm the estimated spectral error was  $\pm 3$  pm corresponding to  $\pm 0.3$  °C. A  $\Delta x$  of 2 mm increased this error to  $\pm 20$  pm or  $\pm 2$  °C. Increasing  $\Delta x$  to 10 mm reduced the error to  $\pm 1$  pm or  $\pm 0.1$  °C

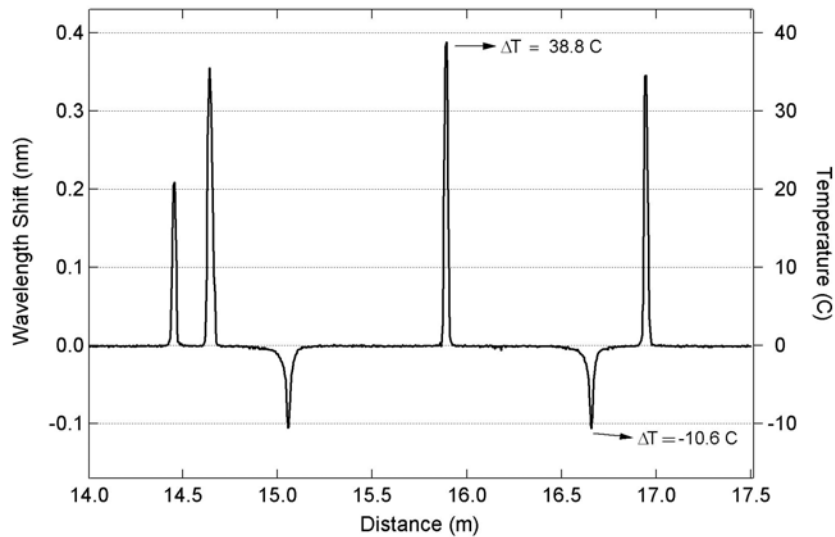


Fig. 2. Distributed temperature measurements using SMF28 with four “hot” spots and two “cold” spots

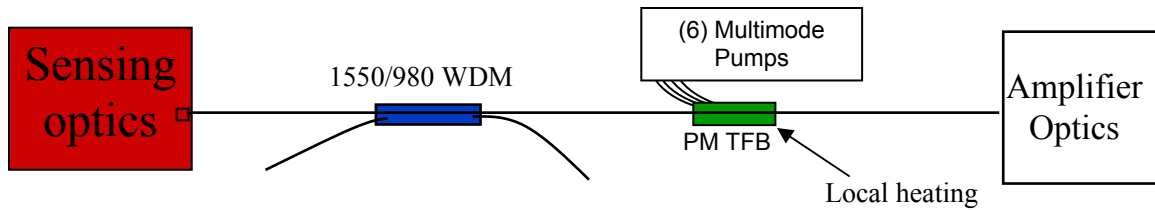


Fig. 3. Setup for measurements of tapered fiber bundle (TFB).

### 3. Localized Heating Results

The setup for local heating measurement in a polarization maintaining tapered fiber bundle (PM TFB) is shown above in Fig. 3. Six multimode optical pumps operating at 980 nm are injected into the single mode amplifier module using the TFB. This type of arrangement is used for high power amplifier systems that require multiple pump lasers. The quality of both the taper region in the TFB and the splice to the SMF can drastically impact the performance of the component and the system.

Heating in the TFB was measured for a series of different input pump powers ranging from 2 Watts to 26 Watts. The results for the local heating profile are shown below in Fig. 4. The two “bumps” represent heating at the splice locations on either side of the TFB and the area in between the splices is heating in the taper region. The spatial width of the first large peak is about 2 mm.

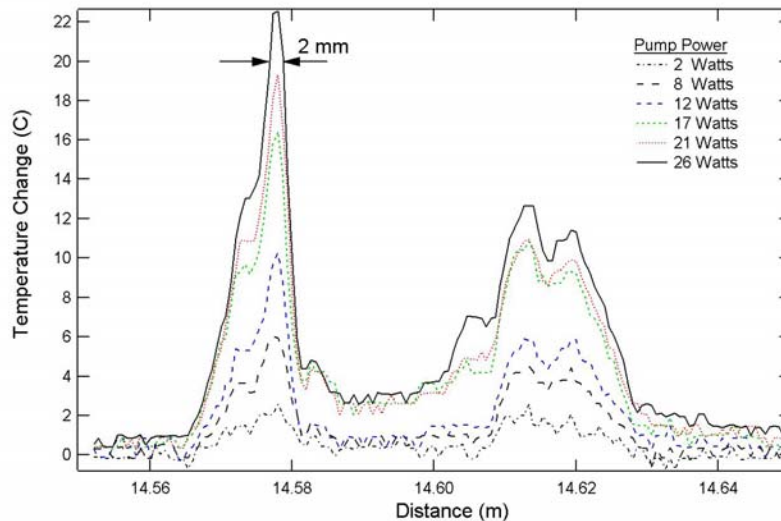


Fig. 3. Distributed temperature measurements of localized heating in TFB

### 4. Conclusions

Coherent reflectometry, or swept wavelength interferometry, has significant advantages in distributed sensing. First, it is capable of very high spatial-resolution temperature measurements, enabling temperature monitoring at the component and subcomponent level. Second, it does not require specialty fiber or nonlinear techniques, making it suitable for in-situ monitoring of local heating effects. This in turn enables robust component monitoring and screening for a variety of temperature sensitive applications.

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