Multipoint Temperature Measurement Technology using Optical Fiber

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Energy consumption in data centers is increasing dramatically as the information technology (IT) infrastructure provides higher speeds and capacities and the deployment of IT equipment expands. In a data center, the percentage of energy consumed by air conditioning is high at about 40%, and reducing this energy use has become a major issue against the background of global warming. To make detailed temperature measurements with the aim of achieving energy-efficient data centers, we have developed multipoint measuring technology to increase the spatial resolution by more than twice that of existing technology. This uses a new algorithm for correcting signal processing output from temperature-distribution measuring equipment that utilizes Raman-scattering light in an optical fiber. We have also developed technology for fast and reliable laying of optical fiber on server racks. These technologies enable accurate and detailed measurement of temperature distributions in data centers, which should in turn lead to optimal air conditioning and an energy-saving effect.

1. Introduction

Information technology (IT) systems, which support the IT society, have been expanding noticeably in recent years due to the spread of the Internet infrastructure and the deployment of high-performance servers and other computers. This trend has been accompanied by a dramatic jump in the floor space of data centers and the number of servers that they accommodate, resulting in a significant increase in the power that data centers consume. In 2006, the amount of power consumed by data centers amounted to about 1% of the total amount of power consumed in the world, but if current trends continue, this figure is expected to increase markedly by 5 to 9 times by 2025.[1),2)] For this reason, making data centers more energy efficient has become a very important environmental issue against the backdrop of global warming and the need to preserve energy resources.

A data center contains many servers, generally from a few tens to several thousand, and the working servers generate a considerable amount of heat. As a result, air conditioning systems using large-scale air conditioning equipment have become essential for cooling these servers and keeping the room temperature below the specified value. The power required for air conditioning, however, has risen to about 40% of the total power consumed by data centers (**Figure 1**). Consequently, reducing the energy used by air conditioning in data centers has become essential in order to achieve energy-efficient data centers. In response to this need, Fujitsu is working to improve the energy-saving performance of air conditioning systems and other facilities by applying Green Infrastructure Solutions (GIS) that support the construction of environmentally friendly data centers. This paper describes optical-fiber-based temperature

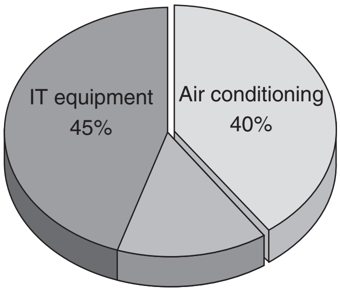

Figure 1
Breakdown of energy consumption in data centers.

measurement as a next-generation temperature measurement technology in GIS.

Achieving energy-efficient air conditioning requires not only the deployment of high-efficiency air conditioning equipment, but also the appropriate use of cooling at the target site. The temperature settings in server rooms are often rather low to prevent the servers overheating despite the fact that excessive cooling can generate an energy loss.[1] There is also concern that cooling efficiency can drop due to a rise in the temperature of chilled air as air warmed by exhaust heat gets sucked back in for various reasons at points (server intake panels) designed to be supplied with chilled air.

Thus, to achieve energy savings by optimizing the air conditioning system, an accurate and detailed temperature distribution in the vicinity of servers must be obtained. Temperature measurements have traditionally been performed using discrete temperature sensors like thermocouples, thermistors, and platinum resistance thermometer bulbs. More recently, integrated-circuit-type temperature sensors, which integrate a temperature sensor with communication functions in a one-chip configuration, have become practical and have been applied to temperature measurement in various situations. However, conventional temperature sensors such as these cannot easily handle a few hundred to several thousand servers considering the work involved in laying signal-lines, the need to shorten measurement time, the cost involved, and other factors. Accordingly, to achieve a temperature measurement technique that can handle such a large array of servers, we have been developing optical-fiber-based temperature measurement technology.

2. Optical-fiber-based temperature measurement

2.1 Overview

Optical fiber is indispensable for achieving the high-speed, large-capacity communication systems of today. When laser light with wavelengths in the near-infrared region is launched into optical fiber, various types of scattered light are generated as a result of the physical state of the fiber's silica glass. Three main types of scattering are known to occur here: Rayleigh scattering at the original wavelength, Brillouin scattering at a wavelength shifted by about 20 nm, and Raman scattering at a wavelength shifted by about 50 nm. Of these, Raman scattering consists of anti-Stokes light (50 nm shorter than the injected light wavelength), which is sensitive to changes in the optical fiber's temperature, and Stokes light (50 nm longer than the injected light wavelength), which has low temperature dependence. By measuring the ratio of these two types of light, we can determine the temperature distribution along the length of an optical fiber.[3)-8)]

In more detail, laser light in the form of short pulses having a duration of several nanoseconds is injected into an optical fiber. Then, while the light propagates through the optical fiber, the backscatter intensity of Raman-scattering light generated at various locations in the optical fiber is measured together with the delay propagation time. The principle is shown in **Figure 2**. The change in intensity with time (Figure 2 upper right) corresponds to the temperature at different locations in the fiber (Figure 2 lower right), and

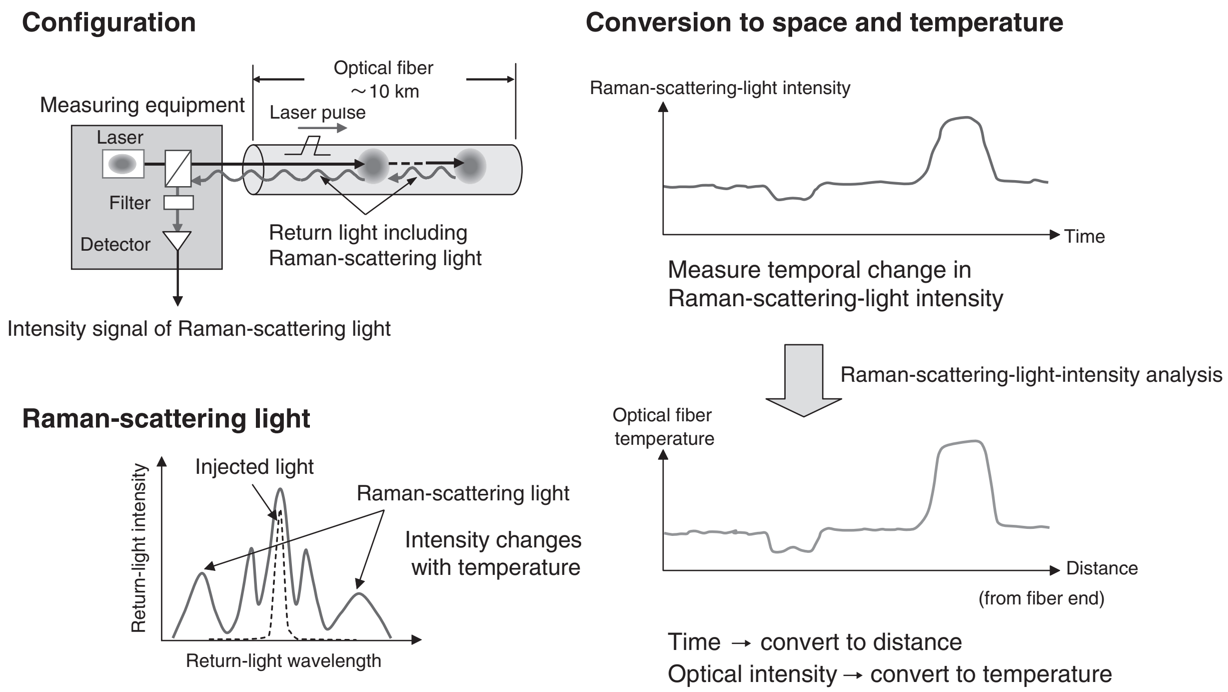

Figure 2
Principle of optical-fiber-based temperature measurement.

the distance of a location is computed by multiplying the delay propagation time of the Raman light by the speed of the light propagation in the optical fiber (about 2×10^8 m/s). In a 10-km-long optical fiber, for example, it takes excitation light about 50 µs to arrive at the other end, which means that temperature information along the entire 10 km of the optical fiber can be obtained within about 100 µs. In addition, typical silica-based optical fiber used for communications purposes exhibits excellent heat-resistance, which usually makes it possible to measure even high temperatures above 200°C, though this depends somewhat on the type of protective sheath used for the optical fiber. Furthermore, since this technique works adequately with the widely used 1-Gb/s-class multimode optical fiber, it is reasonably cost effective.

This system can be used to detect fires in automobiles or subway tunnels, check for abnormal temperatures in power lines or chemical plants, and measure temperature distributions within boreholes in oil-well drilling or geological surveys, etc.[9)-14)] The spatial resolution along the length of the optical fiber (a few meters) is adequate for these applications, but it is not really suitable for making efficient measurements of the temperature distribution in a data center, which is extremely complicated. For this reason, we conducted a comprehensive development program to improve the system's spatial resolution to enable optical-fiber-based temperature sensing to be applied to data centers.

2.2 Application to data centers

2.2.1 Increased resolution

Since the pulse length of excitation light traveling through an optical fiber is about 2 m, it is generally difficult to determine temperature information over shorter distances. We tried to increase the spatial resolution by giving the optical fiber various temperature profiles and investigating the corresponding output temperature responses.

1) Spatial correction technique

The measuring system feeds Raman-scattering light from pulses of excitation light into an optical detector inside the measuring equipment and calculates the fiber temperature by integrating that signal. As a consequence, if heat is not being applied uniformly along the length corresponding to the excitation light pulse width, accurate temperature measurement cannot be performed. The length of optical fiber needed to make accurate temperature measurements is called the "minimum heating length".

When part of the optical fiber is heated in a step-like manner, that is, when a certain length of optical fiber is heated uniformly, the temperature distribution measured in the lengthwise direction is a curve having a smooth convex shape like a normal distribution. If the heated section is shorter than the minimum heating length, the peak of the temperature distribution data is lower than the actual temperature, which produces a measurement error. However, by giving an optical fiber various step-shape temperatures over lengths shorter than the minimum heating length and making accurate measurements of the responses obtained under those conditions, we can derive a transfer function for the optical fiber's temperature distribution. This transfer function differs slightly according to the type of optical fiber, but once the transfer function for the optical fiber to be used in measurements has been determined, the original temperature profile can be reproduced by using it to deconvolute the obtained temperature-distribution data.

2) Temperature reference point

Many data centers use a forced-air system of cooling in which chilled air is blown upwards from the space underneath a raised floor (free-access floor). With this in mind, we installed a section of optical fiber at a location similar to the bottom section of a server rack that had a stable low temperature reading. The temperature measured here can therefore be used as a reference temperature enabling the complex temperature distribution within the server rack to be measured. For this purpose, we developed an algorithm that can reproduce temperature-variation data with high accuracy. In this algorithm, we set up a high-order polynomial that corresponds to the temperature change envisioned within the server rack and approximately solve multidimensional partial differential equations using the temperature transfer function and temperature information from the reference-temperature point. A schematic diagram of signal correction for increasing accuracy in conjunction with the spatial correction technique described in section 2.2.1 1) is shown in **Figure 3**. This signal-correction algorithm can follow changes in temperature for optical fiber lengths shorter than 1 m, thereby enabling optical fiber to be used at more than twice the efficiency of existing technology. Although there is a tradeoff between temperature accuracy and the number of integrations, accuracy of ±0.5°C after 30 s of integration can currently be achieved. This level of response and accuracy is sufficient for monitoring and controlling an air conditioning system.

2.2.2 Optimization of optical fiber

As mentioned earlier, relatively cheap

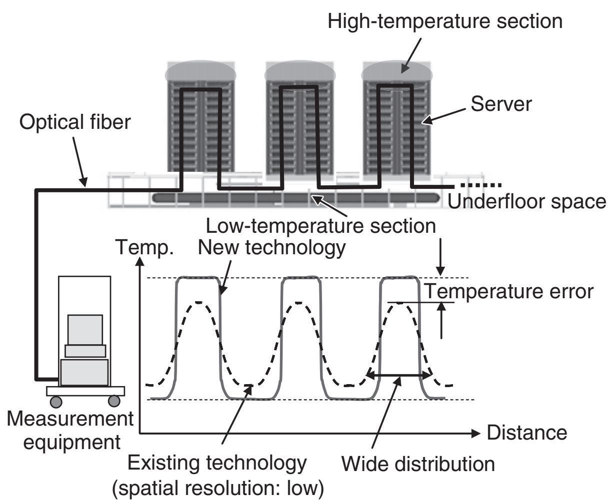

Figure 3
Schematic diagram of signal correction.

graded-index multimode optical fiber can be used for this measurement technology. However, there are slight limitations on the type of outer covering. The data-communications optical fiber often seen in typical data centers and offices, called optical fiber cord or optical fiber cable, is covered with reinforcing material made of aramid fiber or with a thick sheath to provide greater mechanical strength. This covering, however, increases the time taken for heat to propagate to the core of the optical fiber and hence lengthens the temporal response. In short, the speed of heat transmission in optical fiber depends greatly on the thickness of the optical fiber. We performed thermofluid simulations to determine the optimal optical fiber thickness. We found that an optical fiber with a diameter of less than 1 mm would be needed to achieve a 10-s temporal response for a 10°C step response. Here, an optical fiber core (0.9 mmϕ) or an optical fiber strand (0.25 mmϕ) would be suitable. For this optical fiber, materials like nylon, ultraviolet-curable resin, or polyester elastomer could be used for the outer covering. These all have different dynamic properties such as elasticity and flexibility, so the choice depends on the size and shape of the installation target.

2.2.3 Optical fiber laying technology

To lay optical fiber in an efficient and reliable manner, we developed various installation tools. In particular, an optical fiber retainer, which can be used in a versatile manner in conjunction with the mesh on the door of the server rack, enables optical fiber to be fixed firmly, quickly, and easily. Since laying optical fiber from a large reel at the installation site is not very efficient in the case of multiple servers, we prepared pre-rolled cassettes of optical fiber of a prescribed length at a plant so that as much optical fiber as needed can be pulled from these cassettes at the installation site. This approach makes the laying of optical fiber much more efficient. A photograph of optical fiber laying in a server rack is shown in **Figure 4**.

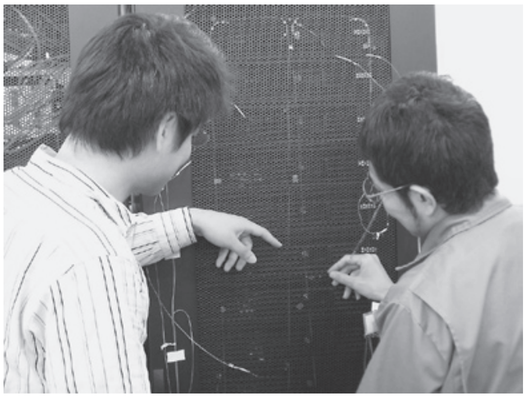

Figure 4
Installation of optical fibers in a server rack.

3. Conclusion

With the aim of reducing the energy used by air conditioning systems in data centers, we have developed a multipoint temperature measurement technology using optical fiber that enables accurate and detailed temperature visualization. Looking forward, we plan to use this temperature measurement technique as a basis for developing a dynamic air conditioning control technique that can automatically optimize the operation of an air conditioning system.

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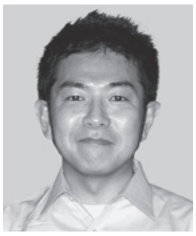

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