3-8 OCDM Transmission Experiments on JGNⅡ Test bed Optical Link

KAMIO Yukiyoshi, WADA Naoya, KUBOTA Fumito, KUTSUZAWA Satoko, MINATO Naoki, SASAKI Kensuke, KOBAYASHI Shuko, NISHIKI Akihiko, USHIKUBO Takashi, and KAMIJOH Takeshi

Optical code division multiplexing (OCDM) is a promising technology for photonic packet switching and the optical metro- and local-area-networks (MAN/LAN) system applications, due to its all-optical signal processing, flexible capacity, and highly secured transmission. We have proposed and developed, time-spread/wavelength-hopping systems utilizing fiber-Bragg-grating (FBG) filters. We report field trial of 200 km transmission on time-spread/wavelength-hopping OCDM was achieved using FBG en/decoders with 10 Gbps×2-ch signals on the JGNⅡ network.

Keywords
OCDM, Optical communications, Field trial, Optical network

1 Introduction

The rapid development of the Internet has led to pressing communication demands on optical networks, and the urgent need to construct a flexible networks. In particular, optical metro- and local-area-networks (MAN/LAN) for inter-city and intra-city communications require a high-speed, flexible networks.

Optical Code Division Multiplexing (OCDM) is one of the multiplexing methods that may be used to construct such a network. The Communications Research Laboratory (CRL), the predecessor of the National Institute of Information and Communications Technology (NICT), took note for usefulness of OCDM and has been researching on the techniques. OCDM has also gained further attention through its inclusion in a project begun by the US Defense Advanced Research Projects Agency (DARPA).

Many studies on OCDM have been conducted to date, including experiments on the basic principles at work. However, most of these studies have been theoretical and laboratory-based; aimed, for example, at increasing the number of multiplexing channels. Meanwhile, few studies have addressed performance in installed transmission lines.

Given these circumstances, we performed an OCDM transmission experiment using the JGNⅡ installed optical fiber testbed[1][2] in July, 2004, achieving stable transmission as a result[3].

This article describes the OCDM method and presents an overview of a recent field trial in a practical environment with installed optical fiber cable, with the discussion here focusing on the experimental equipment used. The field trial involved the OCDM/wavelength-hopping method, based on the use of a Fiber Bragg Grating (FBG).

2 What is OCDM?

Effective multiplexing of bands leads to more efficient network use. Many methods of multiplexing are currently under study, including Wavelength Division Multiplexing (WDM), which assigns multiple channels by dividing the given wavelength band by a fixed wavelength interval. Optical Time Division Multiplexing (OTDM), on the other hand, assigns multiple channels by dividing a optical signal in time. Optical Code Division Multiplexing (OCDM) identifies multiplexed signals simultaneously given frequency band based on codes that are the sequence of signal waveforms.

Among these methods, OCDM provides a number of distinct characteristics, as follows: (a) an advanced network based on variable transmission rate, (b) highly flexible routing, (c) high security by spread encoding, and (d) guaranteed bandwidths. OCDM is thus an effective method of constructing a flexible and secure optical networks.

2.1 Principles of OCDM

OCDM is a multiplexing method that uses codes to ensure orthogonality in the same frequency and spatial domain. This method is grounded on the same concept as the Code Division Multiple Access (CDMA) method, which has been commercialized for use in mobile phones. Modulation signals in multiple channels are optically coded by an encoder and transmitted through a single fiber. While standard methods express bit data (1 or 0) through the presence or absence of light, OCDM sends an attributed code (constructed based on the unit of a "chip", determined as the bit duration divided by code length) instead of a single bit in the presence of light. When the receiver inputs the received optical signal into the optical correlator, the signal is output if the code of the correlator matches the received code, and no signal is output otherwise (i.e., when the correlator code is for another user or another channel). This function is implemented based on the principle that the correlating operation accumulates matching codes, and generates a random value when the codes are different.

Based on this principle and designing the system such that the codes are independent, these codes can be separated as indicated above even when codes for many channels are multiplexed within a wavelength band at the same time. This method thus allows for the flexible establishment of independent channels.

It is also possible to multiplex signals without synchronization between users. Thus, OCDM is also highly expected to find useful applications in access networks.

2.2 Present state of OCDM studies

The CRL began studying the possibilities of OCDM in the early stages and conducted a range of research on the topic, including investigations on increasing the extent of multiplexing, improving transmission efficiency, developing the frequency hopping method, and a transmission experiment using a PLC circuit for the encoder[4].

The CRL also conducted research on the application of OCDM to address recognition within an optical network[5].

Among possible dispersion methods, many researchers are studying the so-called "time spread method". Some are also investigating the time/wavelength spread method, which uses a two-dimensional code distributed along the time and wavelength domain[6]-[10].

3 Time-spread/wavelength-hopping OCDM based on FBG

An encoder based on an FBG has attracted attention in terms of promising practical applications in that such an encoder can in theory allow for low loss, a high signal-to-noise ratio, small size, and low cost based on a simple implementation.

3.1 Time-spread/wavelength-hopping method

Although most OCDM studies concern methods in which the OCDM codes are spread along the time domain, some studies are investigating the time-spread/wavelength-hopping method, which spreads codes two-dimensionally along the wavelength domain as well.

In this case, we used prime-hop coding, which applies a sequence of prime codes to the time-spread and wavelength-hopping schemes. A code corresponding to the prime number p=5 has a code length of p^2, and optical pulses with five wavelengths are spread in time and wavelength as shown in Fig. 1. A FBG, described in the next section, is suitable for this type of coding and decoding.

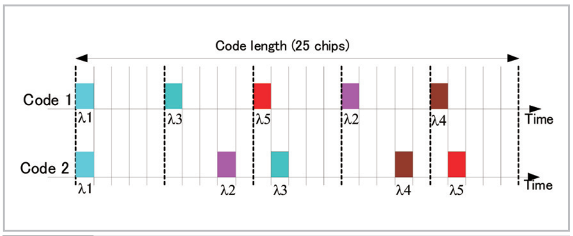

Fig.1 Example code in time-spread/wavelength hopping

3.2 Principle of FBG

Figure 2 shows the structure of an FBG. An FBG is an optical fiber with a Bragg grating built into the core; the optical signal passes through this grating. The FBG functions as a reflective optical filter that reflects light at a particular wavelength (i.e., the Bragg wavelength: λ_B) and transmits light of other wavelengths. The Bragg grating is formed by increasing the refractive index of the core at a constant interval. The Bragg wavelength λ_B—the light reflected by this Bragg grating—is expressed as in the following equation.

$$\lambda_B = 2n\Lambda.$$

Here, n is the refractive index of the core and Λ is the grating period.

Figure 3 shows the principles behind encoding and decoding in this case. With this sort of structure, the position of reflection varies according to the wavelength of light, such that the light arrives at different moments depending on the wavelength. When wavelength-multiplexed pulses are input into the encoder, time delays arise within this component between the optical pulses generated by different light sources at different wavelengths. These delays are a function of the propagation delays arising according to the position of each FBG corresponding to the wavelength of each of the light sources. This process generates a series of optical pulses. In short, this means that the signal can be spread two-dimensionally in both wavelength and time domain.

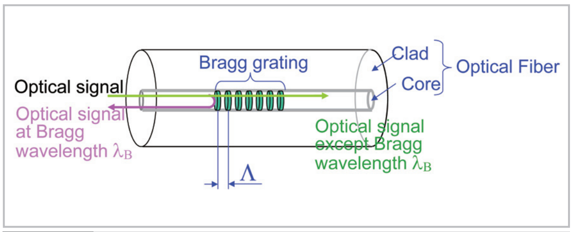

Fig.2 Structure of FBG

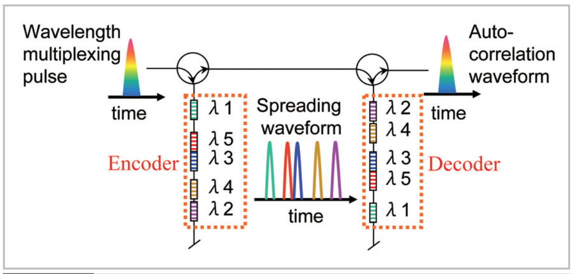

Fig.3 Operation of FBG-based OCDM encoder

The sequence of optical pulses (generated in the encoder based on the difference in wavelengths) and the time interval between the optical pulses together constitute the code. The signal is thus transmitted in this state.

A decoder featuring the same code as the encoder corrects the time differences between the optical pulses generated in the encoder, and the original optical multiplexed pulses are obtained as an auto-correlated waveform. This decoding can be implemented by inputting the received light into an FBG identical to the corresponding one within the encoder, this time in the opposite direction. When the codes of the encoder and decoder do not match, the signal is further spread in time and does not produce an auto-correlated waveform.

3.3 Characteristics of FBG-based OCDM encoder

An FBG is a passive device, so it does not require electrical processes for encoding and decoding. Thus, no optical-electrical conversion is required, which leads to a number of advantages, as follows:

- Simple configuration with fewer parts
- Reduced power consumption
- High-speed processing without processing speed limit for electrical process

As an FBG is a fiber-type device, it also has the following advantages:

- Low loss (due to fiber coupling)
- Small polarization dependence

3.4 Enhanced data rate method

In an FBG encoder, device configuration influences the signal transmission rate, so an advanced technique is required when constructing the encoder. Reference[9] describes the use of the enhanced data rate method, resulting in a transmission rate four times faster with the same encoder. Specifically, the spread time of the encoder is 400 ps and the data transmission rate is 2.5 Gbps. However, by superposing the coded optical signals spread in time using time shifts, the method can be applied to arrive at a data transmission rate of 10 Gbps. The transmission rate can be changed by adjusting the input pulse interval.

Figure 4 (b) shows the output pulses when the 2.5 Gbps data signal indicated in (a) is input into an encoder with a maximum spread time of 400 ps. As shown in the figure, a single data pulse is spread in time and wavelength (i.e., in color).

Figure 5 shows the output pulse when a 10 Gps data pulse is input into the same encoder as above. The figure shows that pulses at the same wavelength do not overlap, even when the timing is the same.

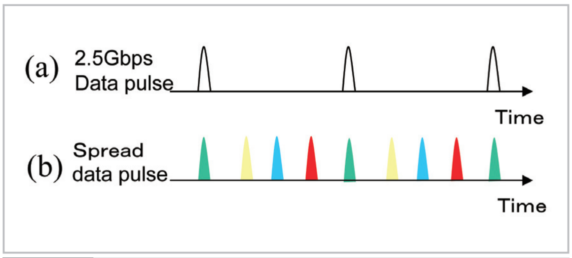

Fig.4 Relationship between input pulse and output

(a) Basic data pulse, (b) Spread pulse

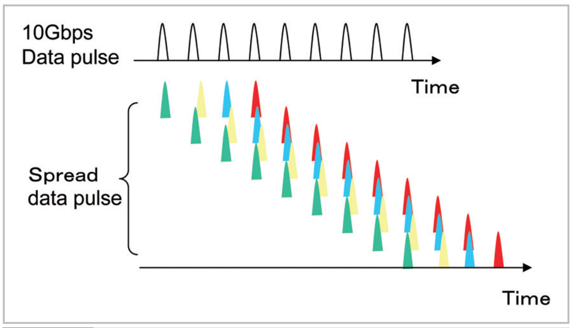

Fig.5 Results when 10 Gbps data pulses were input into the encoder

4 Setup for field trial

To demonstrate the implementation of the OCDM transmission method described above in an installed transmission line, we performed a field trial using the JGNII installed optical fiber cable. In this case, we added signals from different encoders and performed experiments for multiplexing of up to 10 Gbps, two-channel multiplexing.

This section presents an overview of the transmission line and the experimental equipment.

4.1 Field trial environment

We used the JGNII optical testbed line in the Kanto area[1][2][11]. As shown in Fig. 6, we performed loopback experiments on the approximately 100 km line connecting Otemachi Station, Kashiwa Station, and Tsukuba Station. Thus, the transmission distance was approximately 200 km, a distance corresponding to inter-city transmission.

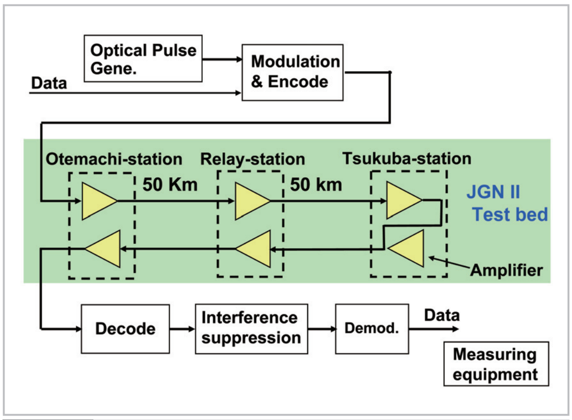

Fig.6 System diagram of field trial

4.2 Experimental equipment

The accumulated dispersion of the transmission line is adjusted to within 1 ps by the dispersion-compensating fiber.

Figure 7 shows the experimental system.

The transmitter combines the outputs from five DFB lasers at different wavelengths and generates 10 GHz pulsed light with an EA modulator. The wavelengths used are from 1556.8 nm to 1560.1 nm, with wavelength intervals of 0.8 nm. The pulsed light is modulated and delayed to generate two channels of modulated signals. These two signals are encoded in different encoders and sent out to the transmission line.

The receiver decodes the desired channel using an FBG decoder and suppresses interference from the undesired multiplexing channel using a time-gate based on an EA modulator. A 3R optical receiver then demodulates the received data. Clock recovery is performed using the demodulated signal.

Figure 8 shows the external appearance of the experimental system placed in Otemachi Station. Here, we did not mount the components to respond quickly to events in the field trial, such as parameter modifications. Nevertheless, the mounting configuration is as shown in Fig. 9.

4.3 Design and prototype construction of FBG

The key device in the proposed system is the Fiber Bragg Grating (FBG) for the encoder and decoder. Figure 10 shows the external appearance of the encoder and decoder used in this experiment. Table 1 shows its specifications. An FBG is a passive device; it does not feature a moving and control unit. Thus, the device is relatively easy to handle. The apodization technique[12] is adopted to reduce distortion of the pulses reflected by the FBG. Further, passive temperature compensation[13] is adopted, allowing for simple system configuration without requiring control by a Peltiert device or a temperature controller.

Further, we have this encoder to take into consideration the effects of wavelength fluctuation and polarization rotation of the light in the field.

4.4 Experimental results

Figure 11 shows the pulse signals before spreading. Figure 12 shows the transmitted waveform after two-channel multiplexing. The spread coding complicates the signals in the transmission line, rendering them impossible to identify.

Figure 13 shows the decoded waveform after 200-km transmission of the two-channel multiplexed signals. The decoding recovers only the necessary signals, though interference components are also included in addition to the desired signals. Figure 14 shows the waveform after the time gate.

The results show that although noise caus-

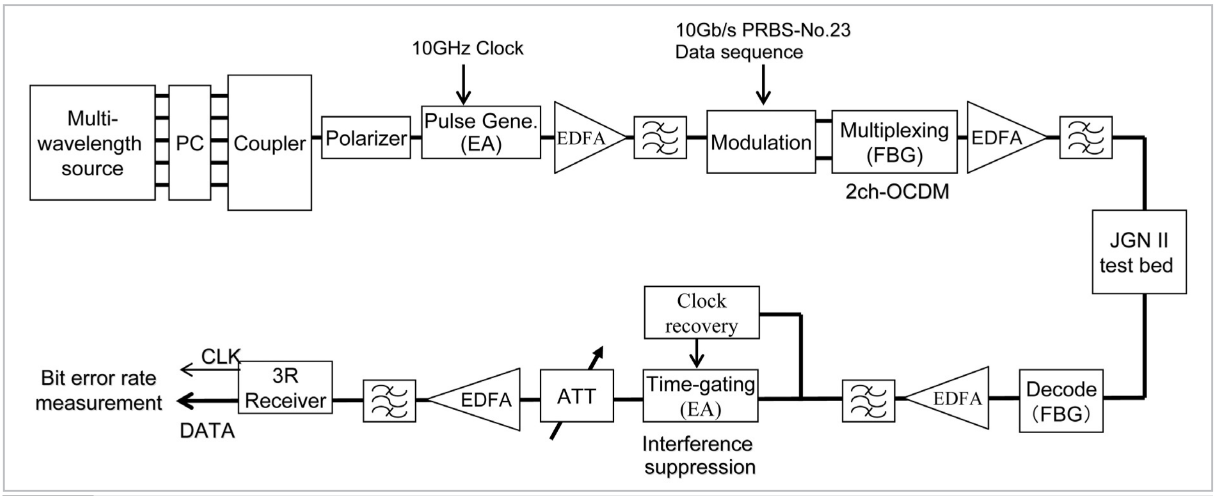

Fig.7 *Configuration diagram of experimental system*

es distortion, this distortion is not large after transmission over 200 km.

Figure 15 shows the signal-to-noise performance. The figure shows that the system offers good transmission performance.

This field trial thus demonstrated that OCDM transmission can be applied to existing installed optical fiber cables.

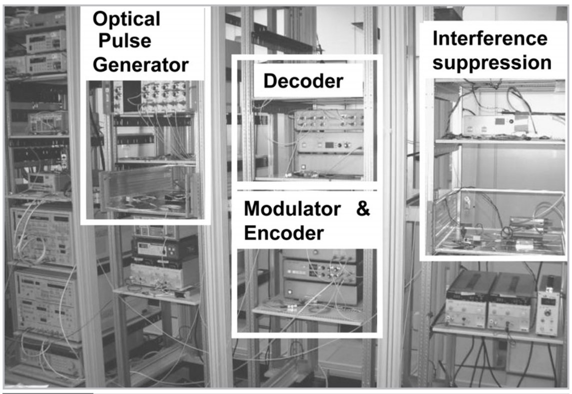

Fig.8 External appearance of transmitter and receiver used in experiments

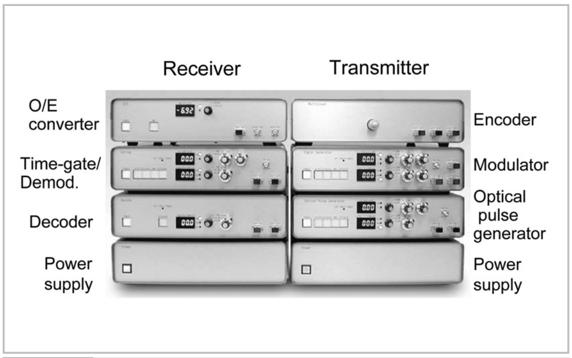

Fig.9 External appearance of mounted transmitter and receiver

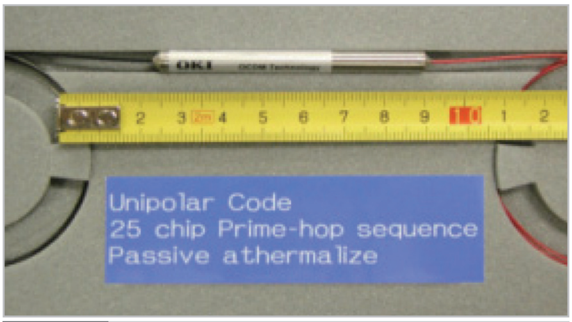

Fig.10 External appearance of FBG encoder/decoder

Table 1 Specifications of encoder used in experiment

Type of code	Time-spread/wavelength-hopping method
Code length	25 chips
Chip time	16 ps
Spread time	400 ps
Number of wavelengths	5 (100-GHz intervals)
Applied data rate	2.5 Gbps (can be expanded to 10 Gbps by data rate enhancement)
Temperature compensation	Passive

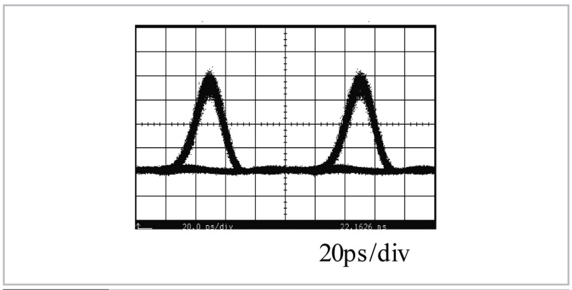

Fig.11 Modulated waveform

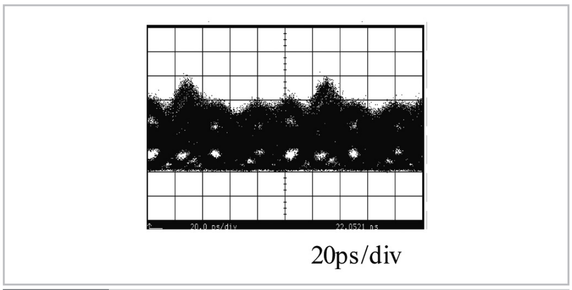

Fig.12 Waveform after spread coding (two-channel multiplexing)

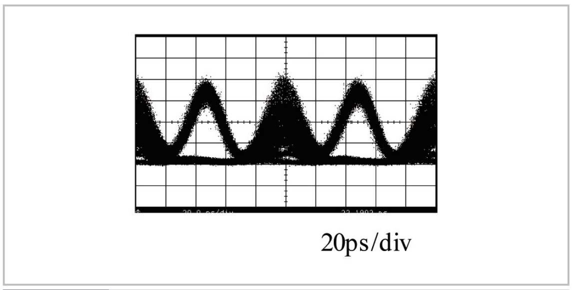

Fig.13 Decoded waveform after 200-km transmission

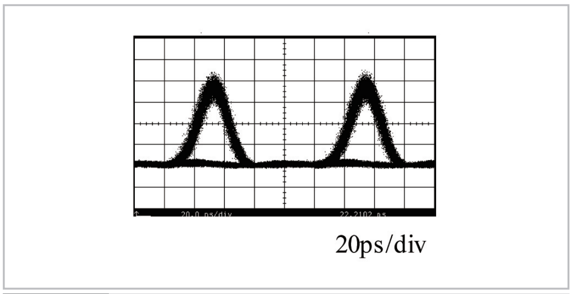

Fig.14 Waveform after decoding and interference removal

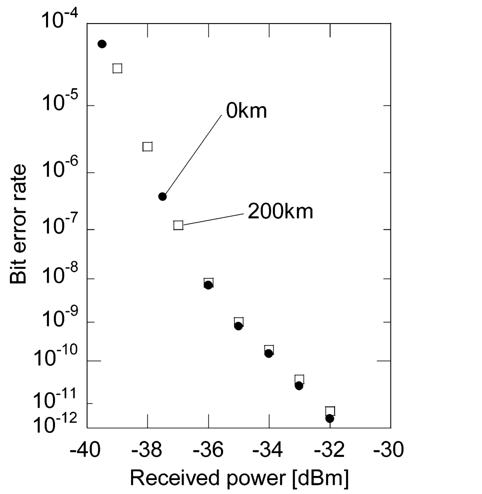

Fig. 15 Error-rate characteristics

5 Conclusions

We performed multi-user, multiple-access transmission based on the Optical Code Division Multiplexing (OCDM) method and demonstrated with an existing optical fiber cable that the OCDM method can be applied to 200 km transmission, as will be required in any inter-city metro-area network.

In the future, we need to pursue further research, development, and commercialization, aimed at increasing the number of multiplexed channels. In particular, we need to conduct research and development in view of specific application to next-generation metro-area optical networks.

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KAMIO Yukiyoshi

Senior Researcher, Ultrafast Photonic Network Group, New Generation Network Research Center (former: Senior Researcher, Ultrafast Photonic Network Group, Information and Network Systems Department)

Optical Communications Technology

***WADA Naoya**, Ph.D.*

Reseaerch Manager, Ultrafast Photonic Network Group, New Generation Network Research Center (former: Senior Researcher, Ultrafast Photonic Network Group, Information and Network Systems Department)

Photonic Network

***KUBOTA Fumito**, Dr. Eng. of Computer Science*

Executive Director of New Generation Network Research Center (former: Research Supervisor, Information and Network Systems Department)

Network Architecture

KUTSUZAWA Satoko

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Fiber-Optic Communication System

MINATO Naoki

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Fiber-Optic Communication System

SASAKI Kensuke

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Optoelectronics Device

KOBAYASHI Shuko

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Optoelectronics Device

NISHIKI Akihiko

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Fiber Bragg Grating

USHIKUBO Takashi

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Fiber-Optic Communication System

***KAMIJOH Takeshi**, Ph.D.*

Corporate Research & Development Center, Oki Electric Industry Co., Ltd

Optoelectronics