DUAL PIN PHOTODIODE FOR PHASE SHIFT KEYING OPTICAL TELECOMMUNICATION SYSTEMS

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We have developed 40-Gbps dual PIN photodiode modules for Differential Phase Shift Keying (DPSK) or Differential Quadrature Phase Shift Keying (DQPSK) telecommunication systems using proprietary compound semiconductor devices. The modules are composed of a surface illuminated dual PIN device, unifying a post amplifier with a twin pigtail fiber. The modules offer high responsivity of 40 Gbps, good frequency response, high common mode reduction ratio, and low bit error rate. This dual PIN photodiode is used in Yokogawa's RZ-DQPSK transponder (PNTR404), the world's first to enable 40-Gbps long-haul transmission.

INTRODUCTION

Communication traffic has continued to increase owing to rapid growth in broadband access in recent years. As a result, backbone long-haul optical communication networks require higher speed and larger capacity. One solution is to raise the transmission rate from 10 Gbps to 40 Gbps per wavelength. However, On-Off Keying as represented by the Non-Return-to-Zero (NRZ) format has a limitation on transmission reach. To resolve this problem, transmission formats which use phase shift keying, such as Return-to-Zero Differential Quadrature Phase Shift Keying (RZ-DQPSK), are being studied.

To achieve long-haul transmission systems using Differential Phase Shift Keying (DPSK) or DQPSK technologies, we have developed a dual PIN photodiode module which can be used in the front-end circuit in such phase shift keying formats. This module has been incorporated in Yokogawa's PNTR404, the world's first RZ-DQPSK transponder[(1)].

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DESIGN OF DUAL PIN PHOTODIODE

Development examples and discussions

Some research institutes and laboratories have developed 40-Gbps dual PIN photodiode modules. Sinsky et al. made a module in which two waveguide-type InP-PDs, a SiGe differential amplifier, and surrounding matching circuits are integrated (Figure 1-(A))[(2)]. They optically coupled the PDs in the module to the amplifier via optical fibers independently and

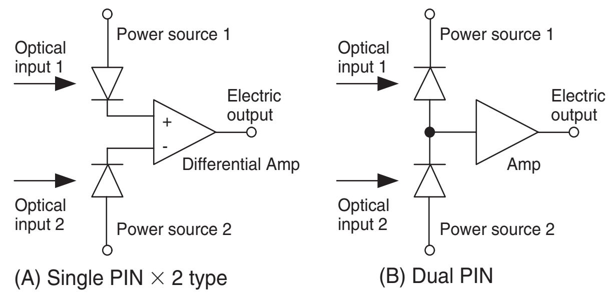

Figure 1 Configuration Example of Dual PIN Photodiode Module

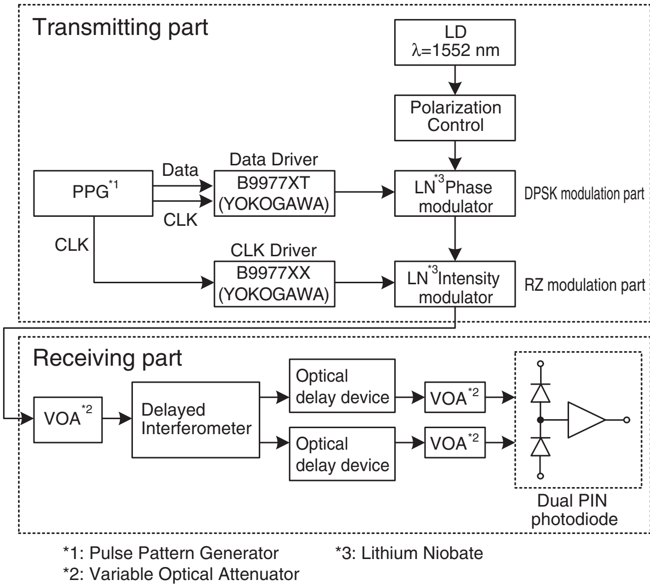

Figure 2 RZ-DPSK Evaluation System

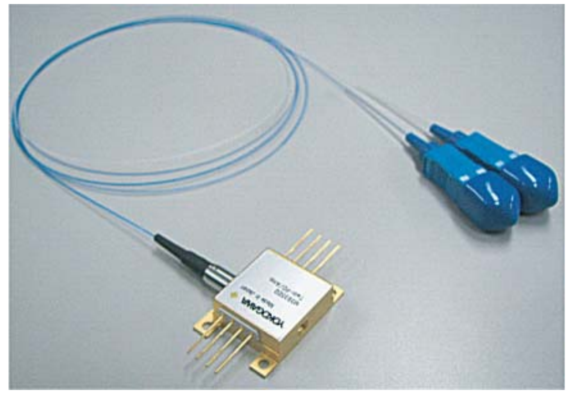

Figure 3 Dual PIN Photodiode for 40-Gbps DPSK

evaluated various characteristics of RZ-DPSK signals. Bach et al. developed a waveguide-type dual PIN photodiode(3). The waveguide-type PD has an optical receiving area of 5 µm × 25 µm. To raise the coupling efficiency of the PD and optical fiber, they integrated an InGaAsP spot-size converter before the waveguide-type PD. Different from Sinsky et al., Bach et al. devised a twin configuration by setting the common mode between the two PDs to improve the common mode rejection ratio (CMRR) (Figure 1-(B)). The CMRR value of a dual PD is important for the DPSK system and this twin configuration is expected to be preferable for the integrated module.

There have been other reports on waveguide-type PDs. A module containing dual PIN photodiodes and a post-amplifier was developed(4), which is characterized by using a waveguide type for optical coupling between two optical fibers and PDs, and also using a differential amplifier for the post-amplifier. Waveguide-type PDs are susceptible to polarized waves compared with surface illuminated-type PDs. A differential amplifier is generally designed to have a certain level of saturated output with a constant-current source inside. On the other hand, the linearity of output signals against optical input into a PD is important to control the free spectral range (FSR) of the delayed interferometer in DQPSK or DPSK systems. To control the delayed interferometer, a linear amplifier or a trans impedance amplifier (TIA) with high linearity should be used rather than a differential amplifier.

Design of our module

Figure 1-(B) shows the configuration of the dual PIN photodiode module we developed. We adopted the surface illuminated-type twin configuration, considering high-speed response, high responsivity, CMRR, low PDL (polarization dependent loss), and implementation.

Different from inputting optical signal to a single PD, it is important to keep the sensitivity balance of the two PDs to respective light sources in order to maintain symmetrical output waveforms, as described later. As for responsivity, this module can handle wavelength division multiplexing (WDM) from the O band to U band, which is achieved by enriching the indium composition of the InGaAs optical absorbing layer compared with the stoichiometric composition. The responsivity at the end of the L band is improved to 30% better than that of the conventional PIN configuration, and more than 60% better in the U band(5).

As for high-speed response, to decrease the junction capacitance, it is advantageous to increase the thickness of the intrinsic InGaAs optical absorbing layer. On the other hand, as for electron transmission time, optically excited electrons/holes in the depletion layer need to be transmitted to the P layer or N layer in a short time, the layer must be thin. To address this trade-off relation, we selected an optimum thickness of the InGaAs layer to develop a dual PIN photodiode module with high-speed response.

A surface illuminated-type PD is not affected by transmission modes, transverse electric (TE) or transverse magnetic (TM), and so it is superior in terms of low PDL (polarization dependent loss).

As for CMRR, considering the core pitch of duplex optical fibers, we optimized the distance between the PDs and maintained the sensitivity balance of the two PDs to respective light sources.

There are two optical inputs to the dual PIN photodiode and the lengths of fibers need to be kept equal. Considering the difference in length between two optical fibers, a difference of 1 mm is equivalent to a time difference of about 5 ps. In 40-Gbps transmission, the distance for 1 bit corresponds to 25 ps on the time axis, so a variation in optical fiber length of 1 mm results in a skew as much as 20% of 1 bit at the dual PIN. This distorts the output waveform in the direction of the time axis. To address this skew reduction, we optimized the length of fibers to keep the difference below 2 ps.

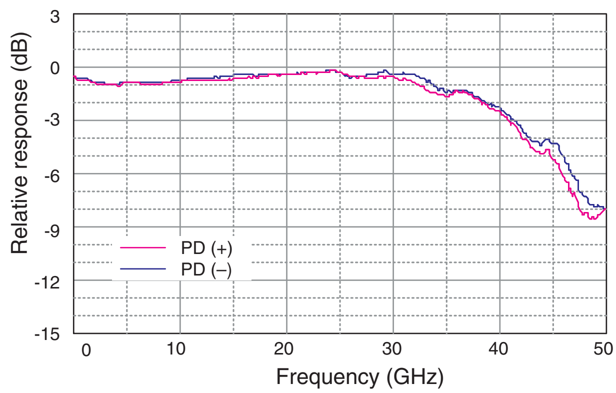

Figure 4 Frequency Characteristics of 40-Gbps Dual PIN Photodiode

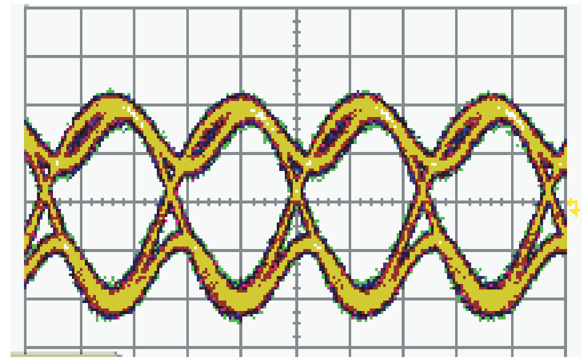

Figure 5 Output Waveform of 40-Gbps Dual PIN Photodiode

SYSTEM FOR EVALUATING THE MODULE

Figure 2 shows the DPSK evaluation system for the module. The transmitting part consists of a phase modulator in the first stage and an intensity modulator called an RZ carver in the next stage. A generally-available lithium niobate (LN) intensity modulator is used for phase modulation with double half-wavelength voltage (2 $V\pi$) and an appropriate DC bias point selected. In the RZ carver in the next stage, intensity modulation with sine wave is carried out on the phase modulated signals in the first stage to improve the S/N ratio of the transmission system. The main components in the receiving part are a delayed interferometer and a dual PIN photodiode. The RZ-DPSK modulated signals are inputted into the receiving part, where the delayed interferometer converts phase-modulated signals to intensity-modulated signals, and they are inputted into the dual PIN module.

PERFORMANCE OF THE PRODUCT

We have developed 40-Gbps and 10-Gbps dual PIN photodiodes for DPSK transmission this time. We also have developed a dual PIN photodiode for 40-Gbps RZ-DQPSK. They both consist of a dual PIN photodiode and a post-amplifier (Figure 1-(B)).

Dual PIN photodiode module for 40-Gbps DPSK

Figure 3 shows a photograph of a dual PIN photodiode module for 40-Gbps DPSK. A dual PIN photodiode and an amplifier are contained in the metal casing of 27 mm × 17.5 mm × 8 mm. An SMPM connecter is provided for a radio frequency output terminal. The length of duplex optical fibers is kept equal to minimize skew. Two SC connectors are used for the optical connection interface with the next stage.

Figure 4 shows the frequency characteristics of the dual PIN device. The -3 dB cut-off frequency is over 40 GHz and the relative response is flat up to that point. There is no difference in frequency characteristics between the two optical inputs, which improves the CMRR. We made a module by connecting a broadband amplifier of over 40 GHz with the dual PIN photodiode. The frequency characteristics of two optical inputs are equal and a good waveform is obtained. Figure 5 shows the output waveform of the 40-Gbps dual PIN amplifier in combination with the delayed interferometer. When 0 dBm is inputted in one side of the fiber, amplitude of about 600 mV is obtained.

Dual PIN photodiode module for 10-Gbps DPSK

Figure 6 shows a photograph of the dual PIN photodiode module for 10-Gbps DPSK. In conventional 10-Gbps long-haul transmission, the On-Off Keying format as represented by NRZ or carrier-suppressed return-to-zero (CSRZ) format is widely used. In recent years, however, some fields including submarine communication have been switching formats to DPSK. Our module is the surface-mount type compliant with the Multi-Source Agreement (MSA). The module made of ceramic, with dimensions of 10 mm × 6 mm × 4.5 mm, is small and inexpensive. Other characteristics include: equal length of duplex optical fibers, an MU connecter for optical connection interface, and differential RF output of the feed type.

Like the 40 Gbps photodiode, there is no difference in

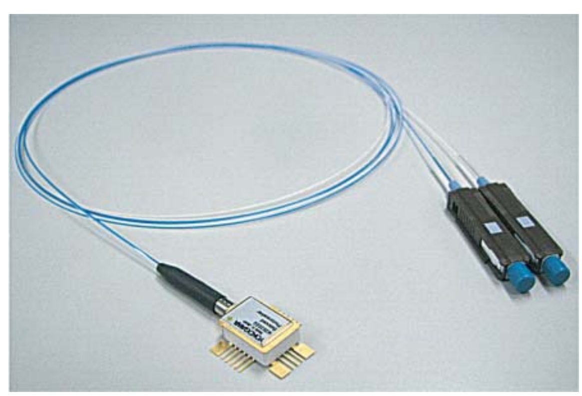

Figure 6 Dual PIN Photodiode for 10-Gbps DPSK

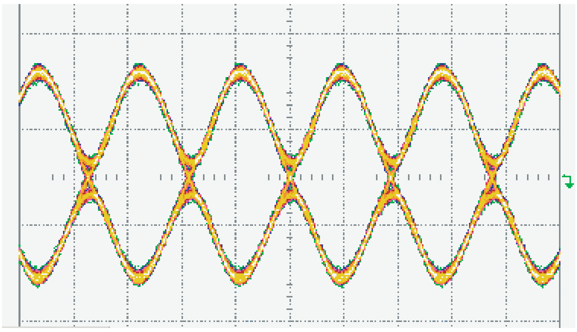

Figure 7 Output Waveform of 10-Gbps Dual PIN Photodiode

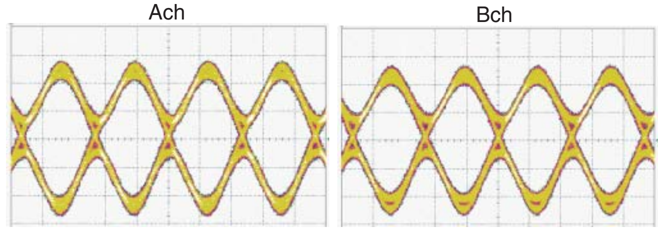

Figure 8 Output Waveform of DQPSK 20-Gbps Dual PIN Photodiode

frequency characteristics between the two optical inputs, which improves the CMRR. The -3 dB cut-off frequency is about 8 GHz. Even after that point, roll-off of relative response is small. Figure 7 shows the output waveform. The excellent electric output balance of the dual PIN including optical fiber coupling and roll-off factor of frequency characteristics result in superior symmetry of wavelength. Regarding the bit error rate (BER) characteristics, the minimum receiving sensitivity is about -20 dBm, which confirms sufficient immunity to noise.

Dual PIN photodiode module for 40-Gbps DQPSK

The DQPSK receiving part has two sets of delayed interferometers having a phase difference of $\pi/2$. These carry out optical-electric conversion of four optical outputs by using two dual PIN photodiode modules. Each dual PIN module operates at 20 Gbps and is connected to a post de-serializer. The dual PIN photodiode used is the same type as that for DPSK. The built-in amplifier for DQPSK has a narrower band and several dB larger gain than that for DPSK though both have high linearity of output waveform amplitude against optical input. The output waveform and BER characteristics of the two modules are also equal, and the optical signal-to-noise ratio (OSNR) achieved 16 dB at BER of 1×10^{-12}.

Figure 8 shows the output waveform of two dual PIN photodiodes in combination with the DQPSK delayed interferometers. An output amplitude of about 500 mV is obtained as the waveform output for an delayed interferometer input of +4 dBm. Amplitude, waveform quality, and BER characteristics between A-channel and B-channel are almost the same. This DQPSK dual PIN photodiode has been incorporated in Yokogawa's PNTR404, the world's first RZ-DQPSK transponder.

CONCLUSION

This paper described the dual PIN photodiode module for the receiving part using new optical transmission formats such as DQPSK or DPSK. The optical communications market is now shifting from 10 Gbps to 40 Gbps. Yokogawa continues to optimize the design, improve the performance, and raise the reliability. We are determined to improve the performance and production of the developed photodiode module, research the performance upgrade of next-generation communication modules, and provide high value-added products. ◆

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