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A High-Speed Visible Light Indoor Network Employing a Short Pulse Modulation and a QPM-LN Module

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Abstract: We propose the concept of over-gigabit visible light indoor networks using λ-conversion achieved by combining a short pulse modulator with a QPM-LN module. Error free operation at 1.25 Gb/s is confirmed in a free space.

OCIS codes: (060.4510) Optical communications; (230.7405) Wavelength conversion devices; (230.4320) Nonlinear optical devices

1. Introduction

In recent years, high-speed indoor networks have been studied with the advancement of broadband optical access networks [1]. For future indoor networks such as offices and homes, optical wireless communications are attractive in terms of both their transmission capacity and flexibility. In particular, the utilization of visible light brings several advantages: high security, less impact to the human body, and easy handling due to visibility. The major approach to implementing visible light communications is to use light-emitting diodes (LEDs) [2]. The key technical issue to enhancing transmission performance is raising the modulation speed; 1 Gb/s transmission was recently reported by using On-Off binary amplitude modulation [3]. As for the transmission speed, the alternative is using the wavelength conversion. Although a 10 Gb/s visible light transmission experiment was conducted, the wavelength conversion efficiency was low and high power pump lasers were required [4]. As a solution, we have indicated that the combination of short pulse modulation and a highly efficient quasi-phase-matching lithium niobate (QPM-LN) module enable us to drastically increase the conversion efficiency and form a visible in-line signal monitoring for easy maintenance in optical fiber access networks [5].

In this paper, we propose a concept of over-gigabit visible light indoor networks based on λ-converter comprising a short pulse modulator with a QPM-LN module. The applicability to over-gigabit visible light indoor networks is investigated by free space transmission experiment. Bit error rate (BERs) are measured and the effect of short pulse modulation is quantitatively clarified.

2. Proposed high-speed visible light indoor networks using λ-converters

Figure 1 is a schematic representation of our proposal. In this network, communication band wavelength division multiplexing (WDM) signals, which are passed through an optical fiber, are converted into visible light signals by a wavelength converter (λ-converter). Generated visible light signals are used to feed electronic devices such as personal computers (PCs) and televisions (TVs) in offices and homes. By using visible light, indoor networks that feature high security, less impact on the human body, and ease of handling, can be constructed. In addition, by

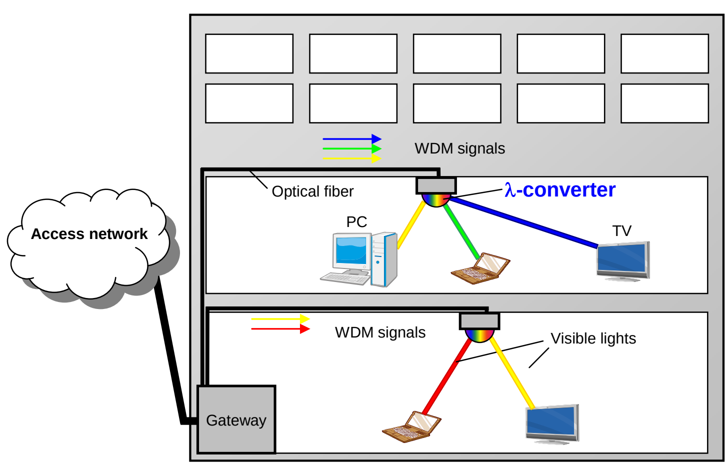

Fig.1 Schematic representation of proposed high-speed visible light indoor networks

applying WDM, superior scalability can be achieved to satisfy various user demands for the increase in the number of users' instruments and the transmission speed to over-gigabits.

Figure 2 (a) shows that the highly-efficient λ-converter consists of a short pulse modulator and a QPM-LN module. The latter uses a nonlinear process, called second harmonic generation (SHG), to create visible light signals at λ/2 (e.g. 650 nm) from input signals with wavelength of λ (e.g. 1300 nm). In order to obtain a high power visible light signal from the QPM-LN module, a short pulse modulation technique is applied.

Figure 2 (b) shows the principle of the short pulse modulation technique. The second harmonic (SH) mean power obtained from a conventional non-return-to-zero (NRZ) pulse (width T, intensity $P(t)$) can be written by using proportionality coefficient α as follows,

$$\left\langle P_{\mathrm{SH}} \right\rangle_t = \alpha \{P(t)\}^2 \cdot T. \tag{1}$$

This process makes output power proportional to the square of the intensity of the input signal. On the other hand, the SH mean power obtained from a short pulse (width T/η, intensity $\eta \cdot P(t)$) can be written as follows,

$$\left\langle P_{\mathrm{SH\ pulse}} \right\rangle_t = \alpha \cdot \{\eta \cdot P(t)\}^2 \cdot \frac{T}{\eta} = \eta \cdot \left\langle P_{\mathrm{SH}} \right\rangle_t . \tag{2}$$

η is a peak factor (PF). PF indicates the ratio between the maximum and mean powers at unit symbol time. Equation (2) indicates that the SH mean power obtained from a short pulse is η times larger than that obtained from a conventional NRZ pulse under the same total input power. Thus the power of a visible light signal can be drastically enhanced by increasing the PF.

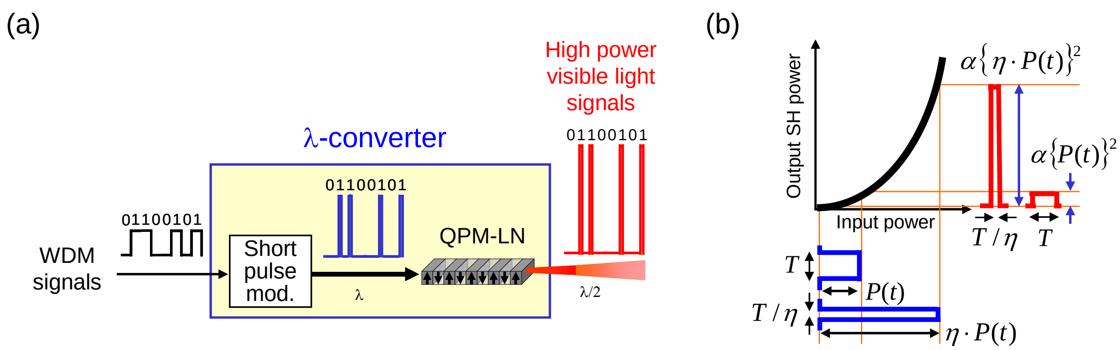

Fig.2 (a) Configuration of the highly-efficient λ-converter and (b) principle of short pulse modulation

3. Experimental setup and results

Figure 3 shows the experimental setup used to test the proposed network. A 1300 nm continuous wave (CW) light was generated by a tunable laser source (TLS) and modulated with a 1.25 Gb/s 2^{31}-1 pseudo random bit sequence (PRBS) in a LN-Mach-Zehnder modulator (LN-MZM1). To generate short pulses with different PF values, optical signals were modulated by 1.25 Gb/s repetition pulses with widths ranging from 200 to 800 psec; these were synchronized to the PRBS. A praseodymium-doped fiber amplifier (PDFA) and an attenuator (ATT) were used to adjust the 1300 nm-band signals' power. The QPM-LN module converted the 1300 nm-band signals to 650 nm SH

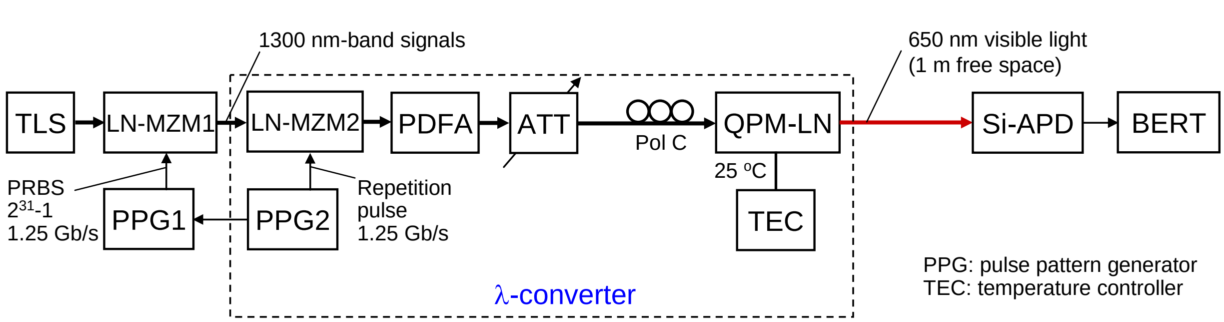

Fig.3 Experimental setup

visible signals. The 650 nm SH visible light was transmitted via free space over a distance of 1 m and received. A silicon avalanche photo diode (Si-APD) was used as a receiver and the BER of its output was measured to evaluate transmission performance. In λ-conversion, the polarization state of the 1300 nm-band signals was adjusted by a polarization controller (Pol C) before the QPM-LN module.

Figure 4(a) shows the structure of the QPM-LN module used in this experiment. For this experiment, we fabricated a 48 mm long QPM-LN waveguide coupled to the input optical fiber by a lens. The waveguide converted 1300 nm-band signals to 650 nm SH visible signals. The 650 nm SH visible signal was extracted by a λ filter. Figure 4(b) shows the 650 nm SH power versus the input power to the QPM-LN module at 1300 nm. The fitted curve is quadratic and the correlation coefficient is 0.9988. This shows that the measured data agree well with the theoretical values.

Figure 5 shows the relationship between input 1300 nm-band signals and BER measured at the bit error rate tester (BERT) with two PF values (1.9, 4.2) at the bit rate of 1.25 Gb/s. The BER was better than 10^{-10} for both peak factors. In addition, BER was improved by approximately several dB when the PF was increased from 1.9 to 4.2. Adding WDM technologies to the proposal will yield over 1 Gb/s visible light indoor networks with spans of meters.

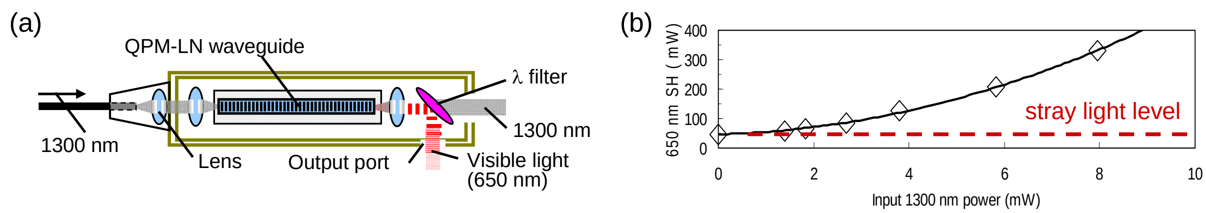

Fig.4 (a) Structure of QPM-LN module. (b) 650 nm SH power vs. 1300 nm input power

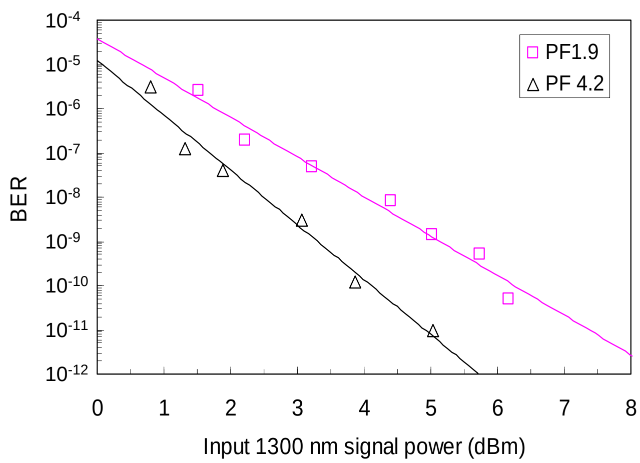

Fig.5 BER at PF(1.9, 4.2).

4. Conclusions

We proposed the concept of high-speed visible light indoor networks based on a highly-efficient λ-converter combining short pulse modulation with a QPM-LN module. Error free operation (10^{-10}) was confirmed over a 1 m free space span at the speed of 1.25 Gb/s. Raising the peak factor from 1.9 to 4.2 improved the BER by approximately several dB. This experiment confirmed the feasibility of over-gigabit visible light indoor networks with spans of the order of meters.

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