Proposal of Integrated-Optical Circuit for Recognition of 8PSK-Coded label for Photonic Label Router

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ABSTRACT

This paper discusses optical label recognition which is one of the key functions for photonic label routing. Previously, we have proposed a basic waveguide-type circuit for recognition of optical label encoded in quadrature-phase-shift-keying (QPSK) format. To increase the number of labels represented with the same symbol number, we have studied 8-ary PSK (8PSK) recognition circuit based on the QPSK recognition circuit. The recognition of the proposed method is theoretically discussed and noise tolerance is also investigated.

Keywords: label recognition, optical 8PSK coded label, optical QPSK code, optical waveguide circuit, noise tolerance

1 INTRODUCTION

A conventional optical network system, electrical signal processing is applied to the routing node together with an optical-to-electrical and electrical-to-optical conversion. This conversion takes time for processing and requires power consumption which makes transmission system more complex. The optical signal processing without conversion to electrical signals is expected to be applied to routing nodes to overcome those disadvantages [1], [2], [3].

Our team has been working on several pieces of researches including waveguide-type devices for recognition of 16 quadrature-amplitude-modulation (16QAM) labels [4] and 8QAM labels [5]. These QAM modulated pulses have multiple amplitudes, which results in efficient bandwidth and high bit rate for transmission. Although the distance between codes in the signal constellation can be large compared with a single amplitude codes such as multiple PSK codes, optical recognition scheme for such M-ary PSK labels can be much simpler. Therefore, we propose an optical recognition circuit for 8PSK labels. The proposed circuit is based on the optical QPSK recognition circuit (QPRC) which consists of an asymmetric X-junction coupler, Y-branches, and a 3-dB directional coupler. The electric power consumption of the proposed circuit is considered to be low because of the passive integrated-optical devices and thresholds. The recognition is performed during optical wave propagation through the proposed passive devices and thresholds. Therefore, the processing speed is expected to be fast.

The proposed waveguide-type 8PSK recognition circuit employs two decision schemes, i.e., recognition from the maximum output port or from the minimum output port. First, the input-output relation of the recognition circuit is theoretically analyzed. Then, the bit-error-rate (BER) characteristics against optical signal-to-noise ratio (OSNR) are evaluated by numerical simulations using OptiSystem software (Optiwave Systems Inc.) in order to clarify the label recognition performance since noise tolerance is considered as one of the important factors in the telecommunication system. For the purpose of comparison, we also build a back-to-back (B2B) model which uses a digital coherent receiver to recognize 8PSK codes.

In the optical label network system, a large number of routing labels are required. Thus, we propose scaled two-symbol length 8PSK label recognition circuits for the two recognition schemes. We evaluate and compare the BER characteristics of the two recognition schemes.

2 TWO-SYMBOL LENGTH 8PSK-CODED LABEL RECOGNITION CIRCUIT

The constellation diagram of 8PSK is illustrated in Fig.1(a). The previously our proposed basic optical waveguide circuit for recognition of QPSK labels is shown in (b), which is named QPSK-phase recognition circuit (QPRC). Our proposed one-symbol 8PSK recognition circuit (8PRC) consists of two QPRCs and a "$-\pi/4$"-phase shifter as shown in (c). From the theoretical calculation, it is found that there is one maximum output port and one minimum (null) output port for each 8PSK code. The circuit structures of the maximum-output and the minimum-output detection schemes are different.

2.1 Maximum output detection scheme

Fig.2(a) shows a two-symbol RC by the maximum output detection scheme. The circuit has a two-stage connection of the 8PRCs. We use phase adjustment in order to make a complete interference between the reference signal and the second symbol signal.

Fig.2(b) shows the relative output intensities $|E^{(i)}_{\rm out2}/E_0|^2, (i = 1, \ldots, 64)$ from the theoretical calculation for the case $n = 0$.The maximum intensity is found to be 0.250 at the output port, port number of 10, 14, 12,

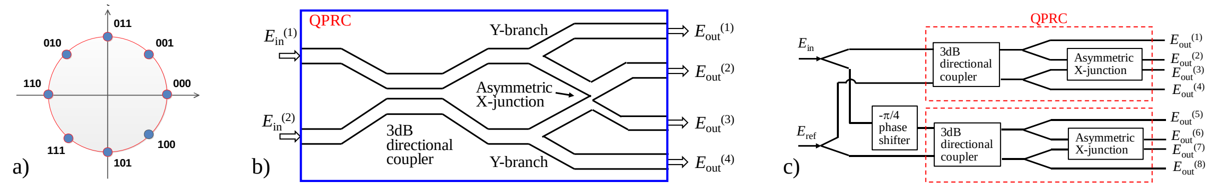

Figure 1. (a) Constellation of 8PSK coded signals, (b) a basic module for recognition of QPSK coded labels, and (c) a proposed circuit for recognition of 8PSK coded labels

16, 11, 15, 9, 13, out of 64 ports for each input of $m = 0, 1, 2, 3, 4, 5, 6, 7$, respectively. The second maximum intensity is 0.2225 (89.0 % of the maximum intensity). Similarly, for all the combination of m and n, only one maximum output is obtained at a different port. Thus, the two-symbol 8PSK labels can be recognized by the maximum-output scheme with our proposed recognition circuit using thresholding between 0.250 and 0.2225.

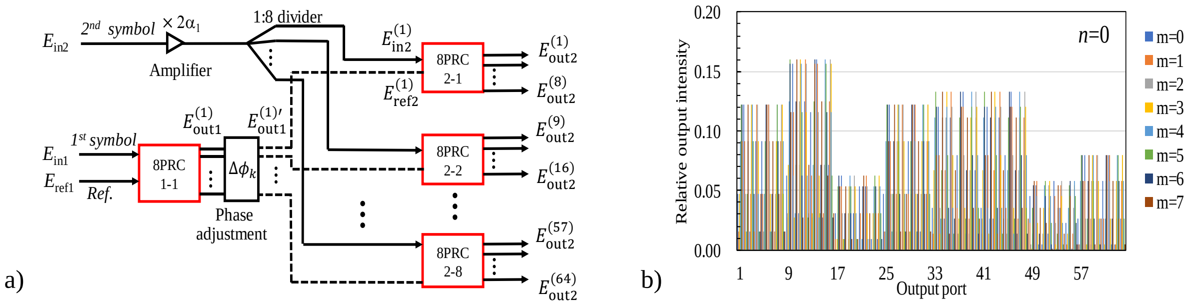

Figure 2. (a)Optical circuit for 2-symbol 8PSK label recognition by Maximum-output detection scheme and (b) Theoretical output intensities for two-symbol 8PSK codes

3 MINIMUM OUTPUT DETECTION SCHEME

Fig.3 shows a two-symbol recognition circuit by the minimum-output detection scheme. The circuit also has a two-stage connection of the 8PRCs. It is noted that the phase adjustment circuit is not employed after 8PSK 1-1 since the null output from 8PSK 1-1 is used for part of the reference signal to the second-stage 8PRCs. From the calculation, for the case n = 0, the maximum output intensity is 0.160. Null outputs are obtained at ports from 17 to 24. The second minimum outputs appear at ports from 49 to 56 and the intensity is 0.000785 (0.49 % of the maximum intensity). The two-symbol 8PSK labels can be recognized by thresholding the outputs between 0.000785 and 0.

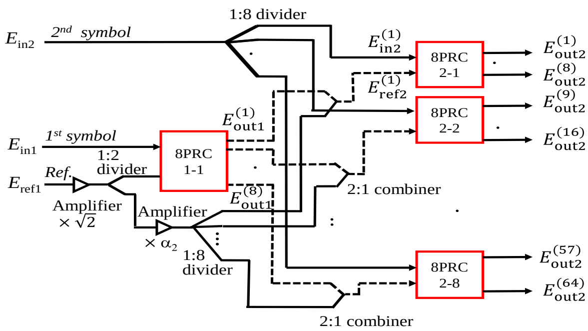

Figure 3. Optical circuit for 2-symbol 8PSK label recognition by Minimum-output detection scheme

4 EVALUTION OF NOISE TOLERANCE

To investigate the noise tolerance for the proposed two-symbol waveguide-type 8PRC, we built a simulation model using OptiSytem software (Optiwave Systems Inc.). The simulation setup for one-symbol label recognition is illustrated in Fig. 4.

A pseudo-random-bit sequence (PRBS) with the length of 214-1 is used for generating a non-return-to-zero (NRZ) sequence at half of the bit rate R0 for 8PSK signals. The sequence signal is connected to a serial-to-parallel (S/P) converter to make a sequence of 3-bit parallel signals. At the same time, a reference signal is generated by a user defined bit sequence generator with the same bit rate as that of the data signal and is connected to another S/P converter. A parallel-to-serial (P/S) converter is used to combine a data signal and a reference signal. The combined sequence is connected to a pulse-amplitude-modulator (PAM) to generate a modulation electric signal. To generate the optical 8PSK coded signal, we use a continuous wave (CW) laser at a frequency of 193.1 THz as a light source, a phase modulator (PM), and an intensity modulator (IM1) to carve the NRZ to the return-to-zero (RZ) pulse train. The component, named as Set OSNR, is used to add noise

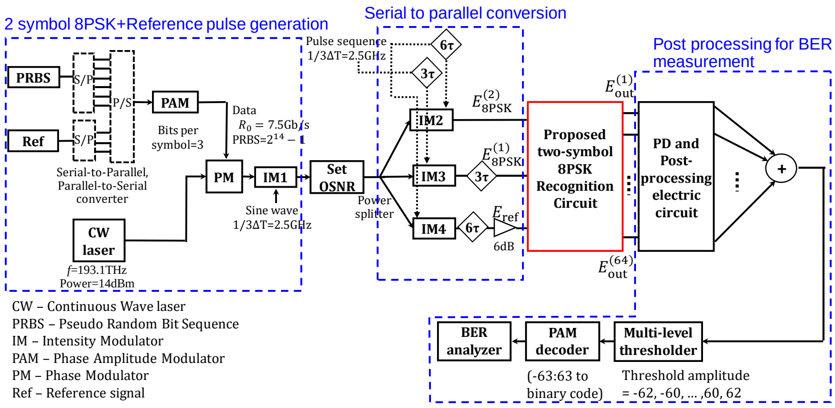

Figure 4. A simulation setup for two-symbol 8PSK recognition circuit.

to the sequential train of the 8PSK pulse and the reference pulse. The noise added signals are sent to a serial to parallel conversion circuit which consists of two intensity modulators and delays elements. The converted parallel 8PSK pulse train and the reference pulse train are incidents to the proposed label recognition circuit.

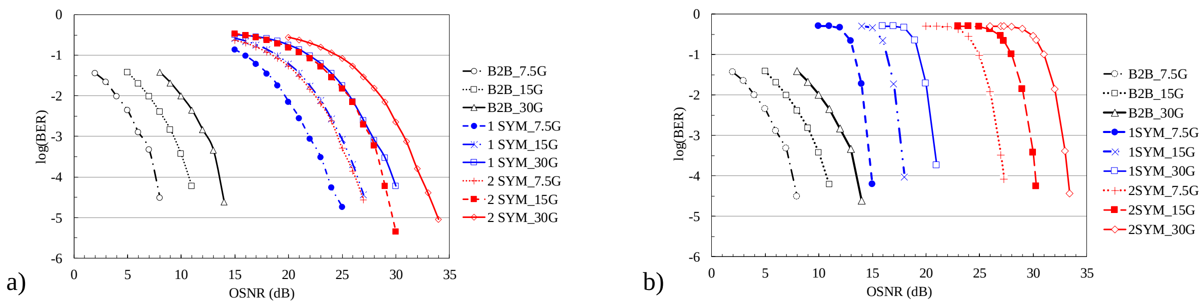

Figure 5. BER performance for one and two-symbol 8PSK labels by (a) maximum output detection scheme, (b) minimum output detection scheme.

The simulated BER performance as a function of OSNR at the receiver is shown in Fig.5. As a comparison, a BER measured by back-to-back (B2B) configuration is plotted by using a digital coherent receiver with adaptive equalization, frequency offset estimation, and carrier phase. recovery. The BER performances at the bit rate R_0 of 7.5, 15 and 30 Gb/s are plotted. For the maximum output detection scheme, the required OSNR, for example, at BER of 1.0×10^{-3} at R_0 = 7.5 Gb/s is around 22 dB and 24.5 dB for 1- symbol and 2-symbol length signals, respectively, is shown in Fig. 4(a). For the minimum output detection scheme, The required OSNR at BER of the same point is around 14.5 dB and 26.8 dB for 1-symbol and 2-symbol length signals, respectively.

5 CONCLUSIONS

We have proposed the optical waveguide-type device for recognition of optical 8PSK coded labels. The proposed device is based on the previously proposed waveguide-type circuit for recognition of QPSK coded labels. The recognition method was theoretically discussed and the noise tolerance was also investigated. The proposed circuit could recognize from either maximum or minimum output port. These two recognition schemes were compared from the viewpoint of noise tolerance. We also discussed the scalability for the proposed recognition circuits. The maximum-output detection scheme was found to be superior to the minimum-output one because the phase adjustment cannot be employed between the first-stage 8PRC and the second-stage 8PRCs for the minimum-output detection circuit.

REFERENCES

[1] I. Glesk, K. I. Kang, and P. R. Prucnal: Ultrafast photonic packet switching with optical control, Optics Express, vol. 1, no. 5, pp. 126-132, 1997.

[2] A.E. Willner, S.Khaleghi, M.R. Chitgarhi, and O. F. Yilmaz: All-Optical signal processing, J. Lightwave Technol., vol. 32. no. 4, pp. 660-680, 2013.

[3] K. Kitayama, N. Wada, and H. Sotobayashi: Architectural considerations for photonic IP router based upon opticalcode correlation, J. Lightwave Technol., vol. 18. no. 18, pp. 1834-1844, 2000.

[4] K. Inoshit, Y. Hama, H. Kishikawa, and N. Goto: "Noise tolerance in optical waveguide circuits for recognition of optical 16 quadrature amplitude modulation codes, Optical Engineering, vol. 55, no. 12, 126105, 2016.

[5] T. Surenkhorol, H. Kishikawa, N.Goto, and K. Gonchigsumlaa: Waveguide-type optical circuits for recognition of optical 8QAM-coded label, Optical Engineering, vol. 56, no. 10, 107101, 2017.