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Bit-Error-Rate Performance in Optical 16QAM Recognition with Integrated-Optic Circuit

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Abstract: Optical processing of optical labels is expected in broadband photonic label routers. We have proposed integrated-optic circuits to recognize optical 16QAM codes. The recognition function is theoretically analyzed. We also discuss noise tolerance in the circuit, and perform numerical simulation to evaluate bit-error-rate characteristics against incident optical signal-to-noise ratio.

Introduction

In photonic networks, optical label routing will be a practically promising solution because of its simplicity and flexibility. Optical label recognition is one of key functions in label routers. Various methods to recognize optical labels in on-off-keying (OOK) and multi-level phase-shift-keying (PSK) modulation formats have been investigated.[1,2] The authors have proposed waveguide circuits for recognizing optical quadrature amplitude modulation (QAM) codes. We reported two kinds of schemes depending on whether the detecting output port is exiting minimum or maximum output.[3,4]

In this report, we discuss noise tolerance in label recognition processing by detecting minimum-output port using computer simulation, where the proposed integrated-optic circuit is modeled by parallel connection of optical discrete devices. We obtain the bit-error-rate (BER) performance.

Recognition of 16QAM Codes

The optical electric field $E_{16\mathrm{QAM}}$ can be written as $E_{16QAM} = E_0 e^{j\pi/4}\left(2e^{jn\pi/2} + e^{jm\pi/2}\right)$, where n, m=0,1,2,3. We consider recognition of the 16QAM code by cascaded connection of two circuits for QPSK code recognition.

Fig.1 shows a waveguide circuit for QPSK phase recognition circuit (QPRC) followed by phase adjustment waveguides.[5] This circuit consists of a 3-dB directional coupler, two Y-branches, and an asymmetric X-junction coupler. The output fields are related to the input fields by

$$\begin{pmatrix} E_{out}^{(1)} \\ E_{out}^{(2)} \\ E_{out}^{(3)} \\ E_{out}^{(4)} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & -j \\ 1 & 1 \\ 1 & -1 \\ 1 & j \end{pmatrix}\begin{pmatrix} E_{in}^{(1)} \\ E_{in}^{(2)} \end{pmatrix}. \qquad (1)$$

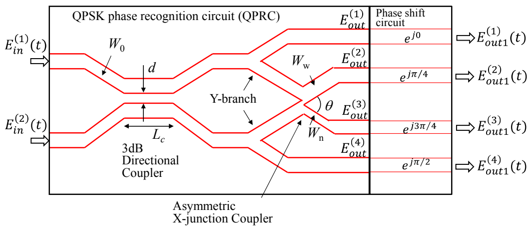


Fig.1 Optical waveguide circuit (QPRC) for recognition of QPSK code and phase shift circuit.

Using two-stage connection of this QPRC, a proposed

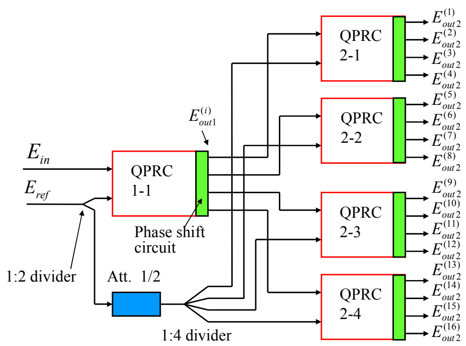


Fig.2 A recognition circuit for 16QAM codes consisting of QPRCs.

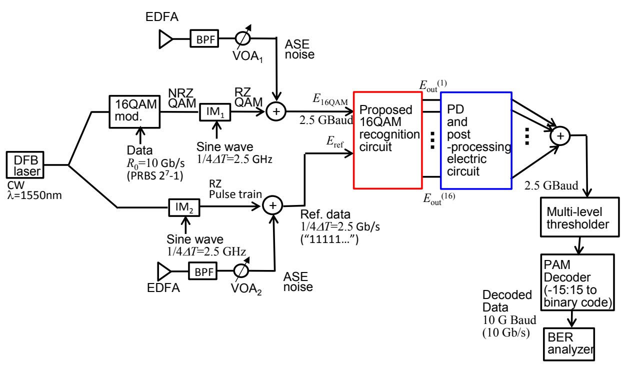


Fig.3 System diagram to evaluate noise tolerance.

circuit for recognition of 16QAM codes is formed as shown in Fig.2. The input-to-output relation is given by

$$\begin{pmatrix} E_{out2}^{(1)} \\ E_{out2}^{(2)} \\ E_{out2}^{(3)} \\ E_{out2}^{(4)} \\ E_{out2}^{(5)} \\ E_{out2}^{(6)} \\ E_{out2}^{(7)} \\ E_{out2}^{(8)} \\ E_{out2}^{(9)} \\ E_{out2}^{(10)} \\ E_{out2}^{(11)} \\ E_{out2}^{(12)} \\ E_{out2}^{(13)} \\ E_{out2}^{(14)} \\ E_{out2}^{(15)} \\ E_{out2}^{(16)} \end{pmatrix} = \frac{1}{4} \begin{pmatrix} 1 & -j3/2 \\ 1 & 1/2-j \\ 1 & -1/2-j \\ 1 & -j/2 \\ 1 & 1-j/2 \\ 1 & 3/2 \\ 1 & 1/2 \\ 1 & 1+j/2 \\ 1 & -1-j/2 \\ 1 & -1/2 \\ 1 & -3/2 \\ 1 & -1+j/2 \\ 1 & j/2 \\ 1 & 1/2+j \\ 1 & -1/2+j \\ 1 & j3/2 \end{pmatrix} \begin{pmatrix} E_{in} \\ E_{ref} \end{pmatrix}. \quad (2)$$

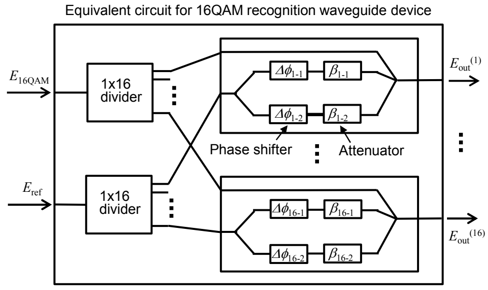
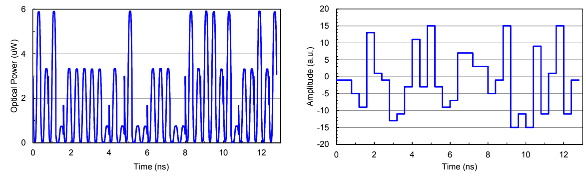


Fig.4 Equivalent circuit model for 16QAM recognition waveguide device.



(a) (b)

Fig.5 Simulated signals; (a) RZ 16QAM pulse train and (b) Output from multi-level thresholder.

E_{16QAM} enters as E_{in}, and the reference signal $E_{ref} = 2\sqrt{2}E_0 e^{j\pi/4}$ enters as E_{ref}. We find that only one null output port exists for each (*n*,*m*). Although the maximum intensity of the outputs for each code depends on (*n*,*m*), the second minimum intensity is constant 0.125 E_0^2. By using inverters at each output port whose threshold is below 0.125 E_0^2, the output port having null output can be distinguished.

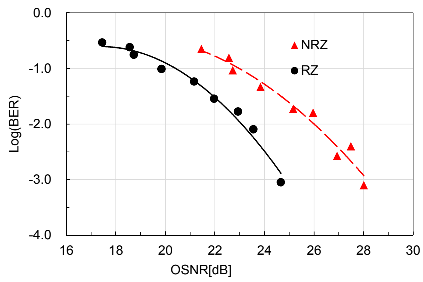


Fig.6 BER performance as a function of OSNR.

Noise Tolerance

The code recognition was numerically simulated using OptiSystem (Optiwave Systems Inc.). An optical system is shown in Fig.3. The optical waveguide circuit of Fig.2 was modeled with discrete optical devices as shown in Fig.4. A post-processing electric circuit and followed circuits of a combiner, multi-level thresholder, and a pulse amplitude demodulator can retrieve the incident 16QAM code. As optical 16QAM signal, RZ and NRZ pulse trains were considered. Fig.5 shows an example of simulated signals at input to the recognition circuit and at the output of multi-level thresholder. Simulated BER performance is shown in Fig.6 as a function of the OSNR at the input of the recognition circuit, where ASE noise was added only at the 16QAM signal as a preliminary study.

Conclusion

The optical waveguide circuit for recognition of 16QAM codes was discussed from the viewpoint of noise tolerance. We will further investigate to improve the circuit having larger noise tolerance.

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