Proposal of Optical Waveguide Circuits for Recognition of Optical QAM Codes

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Abstract— **Optical processing of optical labels is expected in broadband photonic label routers. We propose optical circuits to recognize optical QAM codes. The circuits are multi-stage connection of previously proposed circuit for QPSK code recognition. The recognition characteristics for 16 and 64 QAM codes are theoretically analyzed.**

Keywords-component; optical QAM code; code recognition; optical waveguide circuit; optical QPSK code

I. INTRODUCTION

Optical processing is expected to be applied in routing nodes for fast processing and reducing power consumption. In broadband networks, optical label routing will be a practical solution because of its simplicity and flexibility. Optical label recognition is one of key functions in label routers. Various label architectures have been investigated, including wavelength multiplexed and multi-level coded pulse trains. The authors have proposed waveguide circuits for recognizing on-off-keying (OOK), binary phase-shift-keying (BPSK), and quadrature PSK (QPSK) labels.[1-3]

In recent high-bit rate fiber transmission, optical quadrature amplitude modulation (QAM) has been employed. A 2^M QAM symbol effectively represents 2^M codes. A transmission experiment with 512QAM codes at 64Gbps having bandwidth of 5.4GHz was reported.[4]

In this report, we propose waveguide circuits for recognition of optical QAM codes, by regarding a QAM code as a combination of two QPSK codes whose amplitudes are different. The circuits are based on the previously proposed QPSK recognition circuit. The proposed circuit for 16QAM recognition is theoretically analyzed. A circuit for recognition of 64QAM code is also discussed.

II. RECOGNITION OF 16QAM CODE

A constellation of a 16QAM code set is illustrated in Fig.1. We regard these codes as a combination of two QPSK codes. The optical electric field $E_{16\mathrm{QAM}}$ can be written as

$$E_{16QAM} = E_1 + E_2 , \qquad (1)$$

and

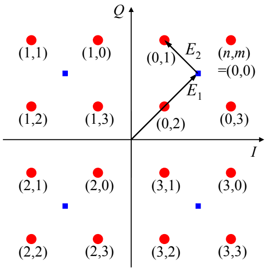

Fig.1 Constellation of 16QAM codes.

$$E_1 = 2E_0 e^{j\pi/4} e^{jn\pi/2}, \quad E_2 = E_0 e^{j\pi/4} e^{jm\pi/2}, \qquad (2)$$

where n, m=0,1,2,3. In Fig.1, sixteen codes corresponding to (n,m) are shown. The fields E_1 and E_2 are regarded as those of QPSK codes of amplitude $2E_0$ and E_0, respectively. Therefore, we consider recognition of the 16QAM code by cascaded connection of two circuits for QPSK code recognition.

Fig.2 shows a waveguide circuit for recognition of a QPSK code, named as QPSK phase recognition circuit (QPRC).[2] This circuit consists of a 3dB directional coupler, two Y-branches, and an asymmetric X-junction coupler. The output fields are related to the input fields as

$$\begin{pmatrix} E_{out}^{(1)} \\ E_{out}^{(2)} \\ E_{out}^{(3)} \\ E_{out}^{(4)} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & e^{j3\pi/4} \\ e^{j7\pi/4} & e^{j7\pi/4} \\ e^{j5\pi/4} & e^{j\pi/4} \\ e^{j3\pi/4} & 1 \end{pmatrix} \begin{pmatrix} E_{in}^{(1)} \\ E_{in}^{(2)} \end{pmatrix}. \qquad (3)$$

Using two-stage connection of this QPRC, a proposed circuit for recognition of 16QAM codes is formed as shown in Fig.3. In addition to one QPRC and four QPRCs in the first and second stages, respectively, an amplifier having amplitude amplification coefficient of $2^{1/2}$, a 1:2 divider, an attenuator having amplitude attenuation coefficient of 1/2, a 1:4 divider, and a phase shift circuit after the

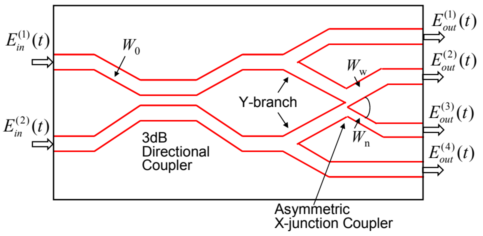

Fig.2 Basic circuit for QPSK code recognition (QPRC).

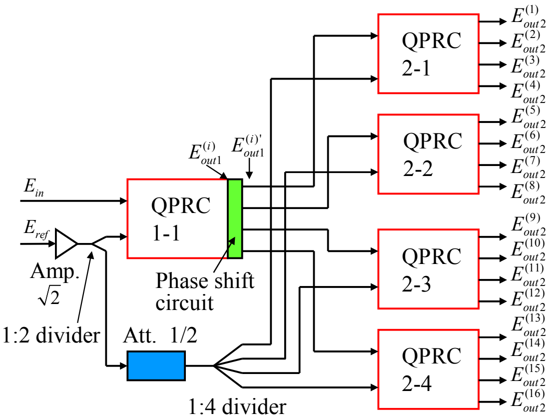

Fig.3 A circuit for recognition of 16QAM codes.

first QPRC. As the inputs E_{in} and E_{ref}, we consider E_{16QAM} and the following reference signal:

$$E_{ref} = 2E_0 e^{j\pi/4}. \qquad (4)$$

The phase shift circuit after the first QPRC is employed to adjust the phases among four outputs. The outputs $E^{(i)}{}'_{\text{out1}}$ are related to the inputs $E^{(i)}_{\text{out1}}$ as

$$\begin{pmatrix} E^{(1)}_{out1}{}' \\ E^{(2)}_{out1}{}' \\ E^{(3)}_{out1}{}' \\ E^{(4)}_{out1}{}' \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j\pi/4} & 0 & 0 \\ 0 & 0 & e^{j3\pi/4} & 0 \\ 0 & 0 & 0 & e^{j\pi/2} \end{pmatrix} \begin{pmatrix} E^{(1)}_{out1} \\ E^{(2)}_{out1} \\ E^{(3)}_{out1} \\ E^{(4)}_{out1} \end{pmatrix}. \qquad (5)$$

When the input given by (1) and (4) are incident, the outputs of the phase shift circuit is given by

$$\begin{pmatrix} E^{(1)}_{out1}{}' \\ E^{(2)}_{out1}{}' \\ E^{(3)}_{out1}{}' \\ E^{(4)}_{out1}{}' \end{pmatrix} = \frac{E_0 e^{j\pi/4}}{2} \begin{pmatrix} 2e^{jn\pi/2} + e^{jm\pi/2} + 2e^{j3\pi/2} \\ 2e^{jn\pi/2} + e^{jm\pi/2} + 2 \\ 2e^{jn\pi/2} + e^{jm\pi/2} - 2 \\ 2e^{jn\pi/2} + e^{jm\pi/2} + 2e^{j\pi/2} \end{pmatrix}. \qquad (6)$$

Therefore, the outputs of QPRC2-*k*, (*k*=1,…4) are given by

$$\begin{pmatrix} E^{(1+4(k-1))}_{out2} \\ E^{(2+4(k-1))}_{out2} \\ E^{(3+4(k-1))}_{out2} \\ E^{(4+4(k-1))}_{out2} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & e^{j3\pi/4} \\ e^{j7\pi/4} & e^{j7\pi/4} \\ e^{j5\pi/4} & e^{j\pi/4} \\ e^{j3\pi/4} & 1 \end{pmatrix} \begin{pmatrix} E^{(k)}_{out1}{}' \\ E_{ref}/4 \end{pmatrix}. \qquad (7)$$

By combining (6) and (7), we find that only one output whose electric field is canceled out for each (*n*,*m*) in the electric complex plane. Although the maximum intensity of the outputs for each code depends on the combination of *n* and *m*, with the largest value $2.25E_0^2$ for (*n*,*m*)=(0,0), (1,1), (2,2), and (3,3), 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.4 shows the output intensities for all codes, where a constant value of 0.01 E_0^2 is added for all outputs as a crosstalk which may occur through the waveguide circuit.

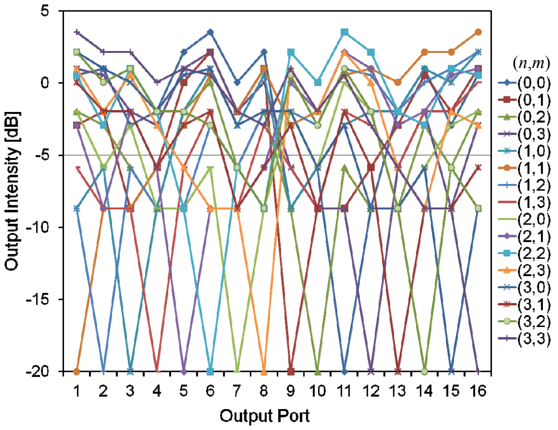

Fig.4 Normalized output intensities from sixteen output ports for all 16QAM codes.

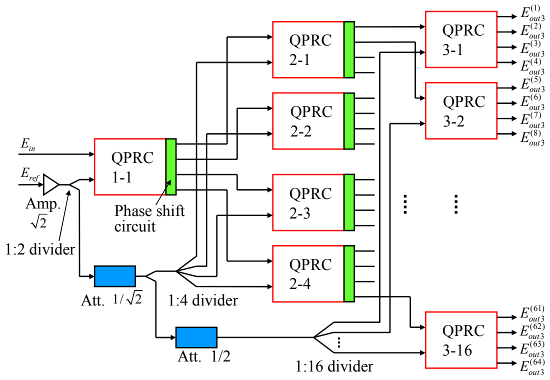

Fig.5 A circuit for recognition of 64QAM codes.

III. RECOGNITION OF 64QAM CODE

We consider a scaled circuit for recognition of 64QAM codes. Electric fields of 64QAM can be composed of three QPSK codes. The circuit can be formed by three-stage QPRCs as shown in Fig.5. The maximum and the second smallest output intensities are $3.0625E_0^2$ and $0.03125E_0^2$, respectively. By using inverters whose threshold is below $0.03125E_0^2$, the output port having null output can be distinguished.

IV. CONCLUSION

Optical waveguide circuits for recognition of 16 and 64QAM codes were proposed. Since the maximum output intensity for each code differs, the code is recognized at the output port whose output is minimum by using inverters. We will further investigate for circuits to recognize multiple symbols.

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