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Recognition of Optical Layered BPSK Labels Using Acoustooptic Processor for Hierarchical Photonic Routing
階層型光ルーティングのための音響光学プロセッサによる階層構造光BPSKラベル識別

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1. Introduction

Optical processing for packet routing can overcome bottleneck in large-capacity photonic networks. We have studied on collinear acoustooptic (AO) switches[1)] and applications to optical label recognition in label routing networks. We proposed recognition of hierarchical routing labels encoded in on-off-keying (OOK) format with an AO processor consisting of optical delay waveguides, parallel AO switches, and electrical multipliers[2-5)]. We also considered label recognition for binary-phase-shift-keying (BPSK) labels[6)]. In this paper, we propose an AO processor for recognition of layer-structure BPSK labels for hierarchical routing control.

2. Layered BPSK labels and AO label processor

We consider an optical label $\boldsymbol{C}^m_{label}$ with a layered structure which is used in a hierarchical label network as shown in Fig.1. The label structure is shown in Fig.2. Label *m* consists of a WDM pulse train in BPSK format and is represented by

$$\boldsymbol{C}^m_{label} = [\boldsymbol{c}^m_1, \boldsymbol{c}^m_2, ..., \boldsymbol{c}^m_{N_t}],\ \boldsymbol{c}^m_i = [c^m_{1,i}, c^m_{2,i}, ..., c^m_{M,i}]^t \qquad (1)$$

where $c^m_{2,i} = 1$ or -1. The optical electric field of this label is written as

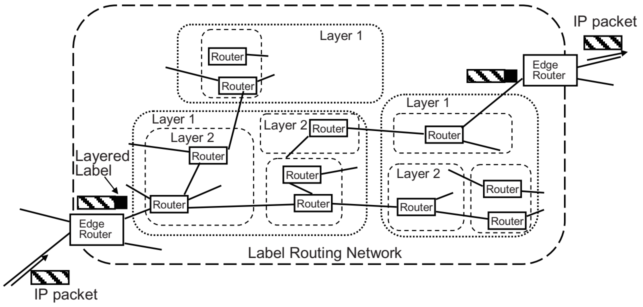

Fig.1 Label routing network using hierarchical routing labels.

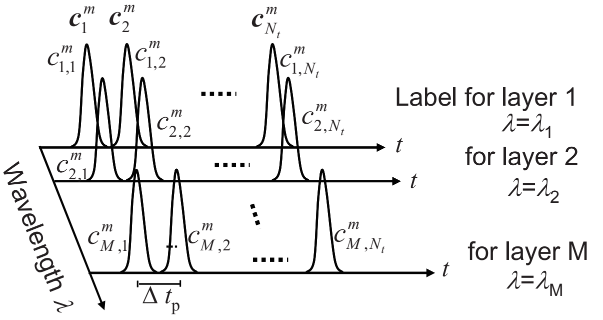

Fig.2 WDM pulse trains for layered labels.

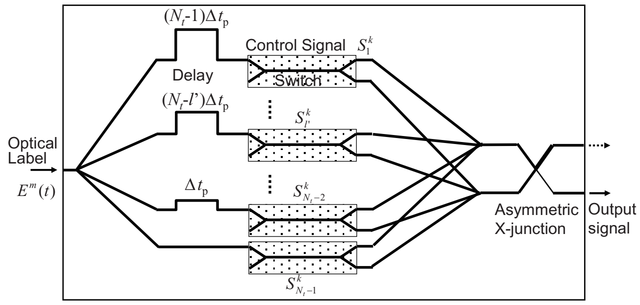

Fig.3 The label processor consisting of parallel double-stage AO switches and an asymmetric X-junction coupler.

$$E^m(t) = E_0 \sum_{i=1}^{M}\sum_{l=1}^{N_t} c^m_{i,l}\, g_{in,0}(t-t_0) e^{j\omega_i(t-t_0)},\ t_0 = (l-1)\Delta t_p \qquad (2)$$

Fig.3 shows an integrated-optic label processor consisting of collinear AO switches. Each of the AO switches is double-stage AO switch which enables compensation of frequency shifting. The incident label is divided into N_t pulse trains. WDM layered label *k* to be matched in this device is represented by frequency-multiplexed SAWs. The SAWs at the *l*'th AO switch for *p* layer of label *k* is written by

$$S^{k,p}_{l'}(t,z) = \tilde{c}^k_{p,l'}\, s_0 \cos(\Omega_p t - K_p z), \quad \tilde{c}^k_{p,l'} = 0 \text{ or } 1 \qquad (3)$$

The label pulse trains are wavelength-selectively switched and the outputs from all the switched and the unswitched ports are separately added. The added

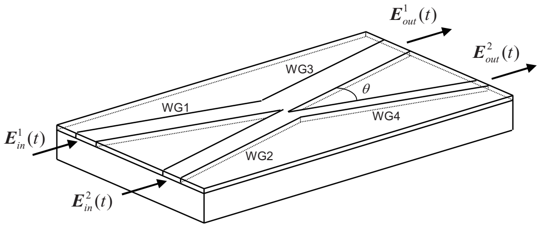

Fig.4 Asymmetric X-junction coupler.

optical signals are input to an asymmetric X-junction coupler as shown in Fig.4[7]. The subtraction of the two input signals is obtained at the lower output port which corresponds to the narrower waveguide. The output optical intensity at wavelength λ_p is ideally written as

$$I^{m,k,p}(t) = \frac{I_0}{N_t}\left\{\left|\sum_{l'=1}^{N_t}\sum_{l=1}^{N_t}[c_{p,l}^{m}\tilde{c}_{p,l'}^{k} - c_{p,l}^{m}\tilde{\tilde{c}}_{p,l'}^{k}]g_{in,0}(t-t_3)\right|^2 + \left|\sum_{i=1(i\neq p)}^{M}\sum_{l'=1}^{N_t}\sum_{l=1}^{N_t}c_{i,l}^{m}g_{in,0}(t-t_3)\right|^2\right\} \tag{4}$$

where

$$t_3 = (N_t - 1)\Delta t_p + (l - l')\Delta t_p + 2l_{SW}/v_p \tag{5}$$

l_{sw} denotes the interaction length of the AO switch and v_p is the velocity of optical guided wave at λ_p. From eq.(4), we obtain the following correlation signal at time $t=t_4=t_3-(l-l')\Delta t_p$:

$$I^{m,k,p}(t=t_4) = \frac{I_0 g_{in,0}^2(t_4)}{N_t}\left\{\left|\sum_{l'=1}^{N_t}[c_{p,l'}^{m}\tilde{c}_{p,l'}^{k} - c_{p,l'}^{m}\tilde{\tilde{c}}_{p,l'}^{k}]\right|^2 + \left|\sum_{i=1(i\neq p)}^{M}\sum_{l'=1}^{N_t}c_{i,l'}^{m}\right|^2\right\} \tag{6}$$

Each component of WDM signals corresponds to the correlation signal for each layer.

3. Recognition characteristics

Since the second term in eq.(6) is caused from the other wavelength components corresponding to the other layers, we employ orthogonal code sets to reduce the contribution from this second term. We consider Hadamard orthogonal codes. The number of 1 and 0 in an orthogonal code is denoted by n_1 and n_0, respectively. Normalized output intensity for the auto-correlated and cross-correlated codes is found from eq.(6) to be N_t^2+M-1 and M, respectively, as shown in Table 1. Examples of the contrast ratio of the auto-correlation to the cross-correlation are calculated as shown in Fig.5.

Table 1 Output intensity

Label bit number	N_t
Number of 1	n_1
Number of 0	$n_0=N_t-n_1$
Output intensity	
Auto-correlation	N_t^2+M-1
Cross-correlation	M

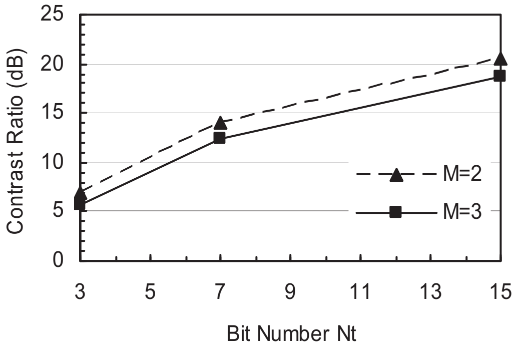

Fig.5 Contrast ratio of auto-correlation to cross-correlation as a function of the bit number.

4. Conclusions

We discussed optical label recognition of layer-structured labels using an integrated-optic device. By using different wavelength for each of the layered labels, label matching of individual layer is performed. We will further investigate the detail characteristics for the recognition characteristics.

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