# AN ALL-OPTICAL CODE CONVERTER SCHEME FOR OCDM ROUTING NETWORKS

**Yonggang Wen, Lian Kuan Chen, Keang-Po Ho, Frank Tong**

Lightwave Communications Lab., Department of Information Engineering,
The Chinese University of Hong Kong, Shatin, N. T., Hong Kong;
Phone: +852-2609 8479; Fax: +852-2603 5032; Email:ygwen9@ie.cuhk.edu.hk

*Abstract: A novel all-optical code converter scheme using a TOAD-based architecture is proposed for OCDM routing networks. Theoretical analysis of BER and power penalty is given and shows less than 0.22 dB extinction-ratio-induced power penalty.*

## Introduction

Recently, much attention has been paid to the research of combining optical code division multiplexing (OCDM) with WDM in photonics routing networks /1-3,8/. While less attractive in long haul transmission, OCDM can perform better for switching or routing in local-area network (LAN) environment. In OCDM routing networks, the concept of a virtual optical code path (VOCP) was introduced for the end-to-end connection within the transport layer of the network /1/. As each VOCP connection consists of several concatenated spans, denoted as virtual optical code channels (VOCC) here, ways to allocate the finite Optical Orthogonal Codes (OOC) and route the data along a particular VOCP have to be investigated. Analogous to the role of wavelength conversion, one of the solutions is code conversion. So far, two types of code converters have been suggested, the first scheme /1/ uses OE-EO method for coherent OCDM networks, the other /3/ includes the look-up table and also requires OE-EO processing. Both methods suffer from the bandwidth bottleneck of OE-EO. Thus all optical processing for code-conversion is necessary for future high-speed networks.

In this paper, we report the scheme of an all-optical code converter based on an all-optical logic XOR gate for OCDM routing networks. The power penalty due to the code conversion is analysed.

## Scheme and basic principle

Figure 1 shows the schematic diagram of our proposed all-optical code converter. To have a large system capacity, the sequence inversion keyed (SIK) direct spread (DS) code division multiple-access (CDMA) scheme is considered /7/. In an optical SIK system, the data bits are modulated either by a unipolar signature sequence $C_i$ or its complement $\overline{C_i}$, depending on whether the transmitting bit is ZERO or ONE, respectively. It was shown that an optical SIK DS-CDMA LAN using unipolar-bipolar transceiver pair has the same capacity performance as that of a bipolar-bipolar system /7/.

In our proposed routing scheme, the main code-conversion function is implemented by an all-optical XOR gate. In the routing node, the input signal is a SIK DS-CDMA signal modulated by the code $C_i$, corresponding to the VOCC of *VOCC*(*i*). An optical code converter is used to convert the code $C_i$ to code $C_j$, corresponding to the routing from *VOCC*(*i*) to *VOCC*(*j*). Here the concept of conversion code $Q_{ij}$ is introduced. By processing the input signal with $Q_{ij}$, the information carried in the *VOCC*(*i*) can be coupled to the *VOCC*(*j*). Thus our proposed code converter realizes the all-optical CDMA switching function.

For our scheme, the conversion code $Q_{ij}$ must have two properties of $C_i \oplus Q_{ij} = C_j$ and $\overline{C_i} \oplus Q_{ij} = \overline{C_j}$. We found that with $Q_{ij} = C_i \oplus C_j$, we can obtain

$$C_i \oplus Q_{ij} = C_i \oplus (C_i \oplus C_j) = C_i \oplus C_i \oplus C_j = 0 \oplus C_j = C_j$$

$$\overline{C_i} \oplus Q_{ij} = \overline{C_i} \oplus (C_i \oplus C_j) = \overline{C_i} \oplus C_i \oplus C_j = 1 \oplus C_j = \overline{C_j}$$

Thus the unique conversion code $Q_{ij} = C_i \oplus C_j$ can facilitate the routing function from *VOCC*(*i*) to *VOCC*(*j*). For example, for the 4-chip Walsh codes having $C_1$=[1 0 1 0] and $C_2$=[1 1 0 0], the code conversion function from $C_1$ to $C_2$ is verified by

$$Q_{12} = C_1 \oplus C_2 = [0 \quad 1 \quad 1 \quad 0]$$

$$C_1 \oplus Q_{12} = [1 \quad 0 \quad 1 \quad 0] \oplus [0 \quad 1 \quad 1 \quad 0] = [1 \quad 1 \quad 0 \quad 0] = C_2$$

$$\overline{C_1} \oplus Q_{12} = [0 \quad 1 \quad 0 \quad 1] \oplus [0 \quad 1 \quad 1 \quad 0] = [0 \quad 0 \quad 1 \quad 1] = \overline{C_2}$$

## Code Converter Architecture

The core element of our code converter is an all-optical XOR logic gate. In SIK DS-CDMA system, very fast processing rate is essential. Among various XOR implementations, the TOAD-based /4/ all-optical XOR logic gate /5,6/ is chosen for its fast processing speed.

A proposed code converter is shown in Fig. 2. The code converter is a modified TOAD that has two arms of control pulse input. One is the routing node's input channel code $C_i$, and the other is the conversion code $Q_{ij}$. These two signals are of the same wavelength, whereas the XOR clock is on a different wavelength, such that they can be separated by an optical filter at the output port. After the clock enters the loop through the main coupler, it splits into two pulses, a clockwise (CW) and a counter-clockwise (CCW) pulse. Each of these two pulses passes through the SOA once, and returns to the main coupler at the same time. When the two control arms have the same signal level, 1 or 0, the CW and CCW pulses will experience the same transmission properties of the SOA. The clock train is then totally reflected into the input port and no pulse appears in the output port. On the other hand, if one of the two control arms has a 1 level and the other has a 0 level, the CW and CCW pulses will experience different transmission properties of the SOA. The clock pulse train will come out from the output port of the TOAD when the phase difference between the CW and CCW pulses is π. Thus, the output channel code $C_j = C_i \oplus Q_{ij}$ is obtained at the output port of the code converter.

## Analysis and Discussion

For the SIK DS-CDMA optical network, the BER bound was derived with an optical unipolar-bipolar transceiver pair /8/,

$$SNR = \frac{(RP_t)^2}{\frac{2(K-1)}{3N}(RP_t)^2 + 4eKBP_t + 16BN_{th}} \quad (1)$$

and

$$Pe = Q\left(\sqrt{SNR}\right) \quad (2)$$

where $R$ is the PIN diode responsivity, $P_t$ is the received chip power, $K$ is the number of simultaneous users, $N$ is the code length, $B$ is the data rate, $N_{th}$ is the thermal noise and Q(*) is the Q-function.

For the conventional SIK DS-CDMA optical network without a code converter, power penalty mainly results from the extinction ratio of the OCDM encoder. If the extinction ratio of OCDM encoder is $r_{ex0} = P_0/P_1$, the chip power after a balance decoder /7/ is decreased to $(1-r_{ex0})P_t$. So the power penalty for the network without code conversion is

$$\delta(r_{ex0}) = 10\log_{10}\left(\frac{1}{1-r_{ex0}}\right) \quad (3)$$

When code converter is employed, power penalty arises from the code converter's nonzero extinction ratio, which is originated from the encoder's nonideal extinction ratio. After some derivation, the extinction ratio of the code converter is $r_{ex1} = [1-\cos(r_{ex0}\pi)]/2$. Therefore power penalty for the network with code conversion is

$$\delta(r_{ex0}) = 10\log_{10}\left(\frac{2}{1+\cos(r_{ex0}\pi)}\right) \quad (4)$$

Figure 3 shows the power penalty of networks without and with code conversion as a function of $r_{ex0}$. Due to the regeneration effect, the network with conversion suffers less power penalty than the network without conversion when $r_{ex0}$ is below 0.5. Using a reported experimental data for an optical XOR gate demonstration with an on/off ratio of 13 dB /6/, the extinction ratio, $r_{ex1}$, of the code-converter is lower than 0.05. Thus from Equation (4), the proposed code converter can work well in OCDM routing network by inducing less than 0.22 dB power penalty.

## Conclusion

A novel ultrafast all-optical code converter for OCDM routing networks is proposed. By introducing a unique conversion code $Q_{ij}$, all-optical code-division routing can be implemented by XOR processing in the optical layer. The proposed code converter eliminates the OE/EO bottleneck that limits the speed of OCDM routing. Theoretically, with a reported extinction ratio $r_{ex1}$ of 13 dB, extinction-ratio-induced power penalty is reduced from 0.675-dB to 0.22-dB.

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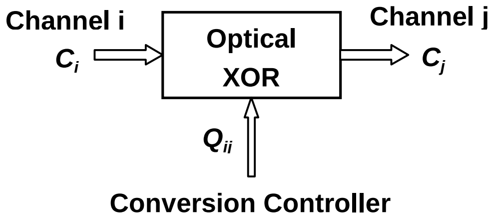


**Figure 1. The basic schematic diagram of the novel all-optical code converter.**

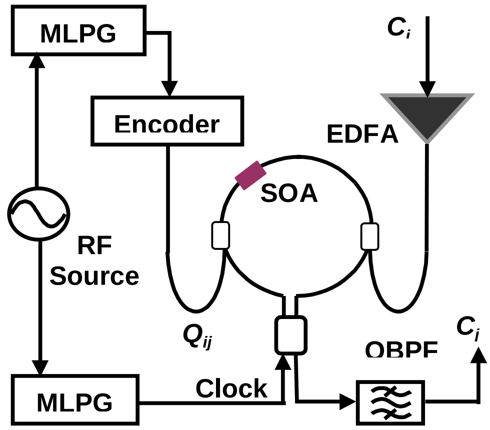


**Figure 2. The proposed code converter architecture. MLPG: Mode-locked Pulse Generator. OBPF: optical bandpass filter. SOA: Semiconductor optical amplifier.**

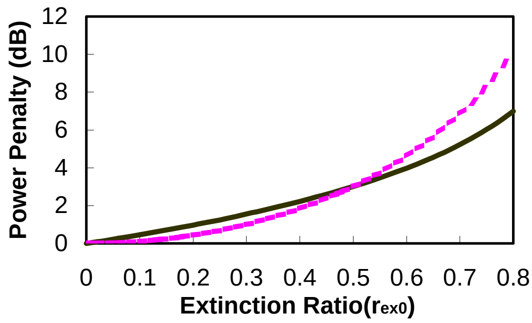


**Figure 3. Power Penalty of SIK OCDM routing networks versus $r_{ex0}$. Solid line is for the network without code converter; dash line is for the network with code converter.**