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A method of implementation of frequency encoded all optical encryption decryption using four wave mixing

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ABSTRACT

All optical encryption decryption method using frequency encoding is proposed based on semiconductor optical amplifiers. The plain text and key are encoded in frequency encoding format i.e. the states of information '0' and '1' are represented by two different frequencies in the c-band. The ultra fast speed of operation of the devices used for the implementation of this system makes it very attractive for future all optical secure communication network. A simple method of conversion of frequency encoded data stream and intensity encoded data stream is also described, which enables us to use same technology of production and detection of intensity encoded data signals until new techniques based on frequency encoding comes out.

1. Introduction

With the increase applications of all optical communication, the security is becoming an important issue for the researchers in the field of all optical communication. To ensure secure high speed optical communication networks, the all optical encryption decryption is of prime importance for developing all optical packet switching [1–3], identity verification and security clearance. An X-OR gate is very suitable for encryption decryption and its fully developed implementation attracted interest of many people in this field after the advent of image encryption based on X-OR gate [4]. After that a lots of proposal and implementation based on X-OR based encryption decryption are given using liquid crystal displays [5–7], using SOA [8,9] and by other method such as using chaotic dynamics [10]. All the implementations have some advantages and disadvantages. They are first of all complex in hardware and require precise synchronization of every bit and amplified spontaneous emission noise sensitiveness puts a limit to the practical implementation [9]. The polarization sensitivity and intensity loss dependent problems of the previous proposals are the two major disadvantages of the schemes. The polarization states of the signals changes during transmission of the signal and require polarization controllers to be used making the hardware complex. But this becomes difficult for long distance communication. In intensity encoded system, the main problem is the loss of intensity during reflection or transmission and thus a constant intensity should be maintained at each stage. Above all the intensity loss can cause problem in channel selection, because a non-linear material sends light of different intensities in different directions. Recently frequency encoding technique [11,12] and hybrid encoding technique [13] free from polarization and intensity loss dependent problems are proposed. In this communication the author proposes the frequency encoded all optical encryption decryption schemes using SOA non-linearity.

The basic principle of operation of the encryption and decryption scheme is based on the X-OR gate. Here the property of the X-OR operation (A X-OR B) X-OR B = A will be used for encryption and decryption. If **P** represents the plain text or message encoded in binary form and **K** represents the key, then the cipher text (**C**) i.e. the encrypted message will be given by **C** = **P** X-OR **K**, and in the decryption part, the plaintext **P** is recovered by the operation **C** X-OR **K** = (**P** X-OR **K**) X-OR **K** = **P**, so the plain text is found back. The proper operation of the system requires that the key **K** should be shared by the Alice and Bob. This type of cryptography is called symmetric key cryptography. In this technique the length of the key and the plain text should be equal. But this technique is some how very secured because more is the length of the key less is the probability of Eavesdropping. For example using eight bit, one can generate $2^8 - 1$ i.e. 255 different keys and for 16 bits the number of keys become 65,535, so for a standard size message it is impossible for Eave to guess a key to encode the message. In this communication the plaintext, key, are in frequency encoded format and the cipher is also frequency encoded which has due advantages over other encoding systems in terms of information security also. For frequency encoding in this case we only need two frequencies from the broad range of frequencies in the **C** band of optical communication.

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2. Operation principle

The basic operation of the encryption decryption scheme is based on frequency encoding, four wave mixing in SOA, frequency routing by add drop multiplexer and frequency conversion by reflective SOA (RSOA).

2.1. Frequency encoding

In this encoding system the logical states '0' and '1' are represented by signals of two different frequencies υ_1 and υ_2 respectively. Thus any binary bit stream of the form 0101010. . .. will be represented by υ_1 υ_2 υ_1 υ_2 υ_1 υ_2 υ_1. . .. The encoding technique is new and no devices for such encoded bit generation is fully available, but the present devices for intensity modulation with some modification can be suitably used to implement the frequency encoding technique. Such bit pattern generation in the form of frequency encoding will be also discussed in this communication.

In this communication the states of information are encoded by frequencies υ_1 and υ_2 corresponding to the wavelengths λ_1 = 1545 nm and λ_2 = 1550 nm respectively. So when in any stage if the detected signal corresponds to wavelength 1545 nm, the state is zero or low or if the detected signal is of wavelength 1550 nm, the state is high.

2.2. Four wave mixing

Four-wave mixing is a coherent non-linear process and can occur in SOA between two signals, a strong pump and a weaker probe signal. There are different mechanisms behind the generation of four wave mixing:

(i) Modulation of the carrier density, in which the carrier–hole recombination between the conduction and valence band.
(ii) Spectral hole burning (SHB), is caused due to the creation of hole in the inter band carrier distribution.
(iii) Carrier heating which is caused by the stimulated emission and free carrier absorption.

For efficient FWM, the polarization state of the pump and the probe signals must be the same. So some polarization control mechanism of either probe or pump will be necessary. But in co-polarized and orthogonal polarized dual pump schemes, the FWM is polarization insensitive. In the implementation of all optical X-OR logic in this communication, orthogonal polarized pumps scheme to generate FWM will be used. In this scheme the orthogonal polarized pumps interact with the input data signal to generate a new conjugate signal, the power of which is also polarization independent. For these two orthogonally polarized pumps of frequencies υ_A and υ_B are combined by a 50:50 coupler and the combined pump signal is combined again with a low power probe signal of frequency υ_s by a 90:10 coupler and injected into the SOA for FWM in all the SOAs used in this communication. The FWM converted frequency is $\upsilon_A + \upsilon_B - \upsilon_s$. In this communication the states of information are encoded by frequencies υ_1 and υ_2 corresponding to the wavelengths λ_1 = 1545 nm and λ_2 = 1550 nm respectively. The frequency of the probe signal is υ_s and the corresponding wavelengths is λ_s = 1535 nm as used in this communication. The scheme is shown in Fig. 1.

2.3. Frequency routing by ADM

The frequency routing is achieved using ADM by suitably adjusting the driving current. The function of ADM is to separate a particular frequency channel without interference from adjacent channels. This is achieved by a frequency demultiplexer by integrated tunable SOA filter as in Fig. 2.

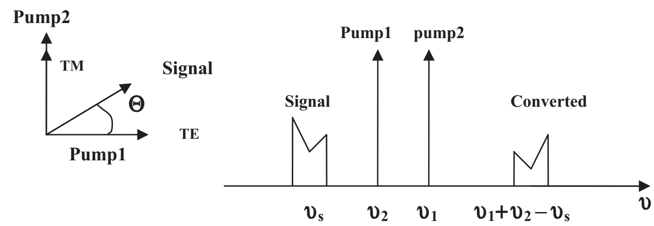

Fig. 1. Four wave mixing in orthogonal polarization scheme.

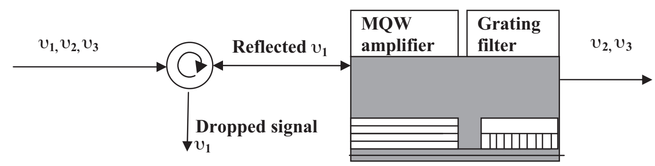

Fig. 2. Add/drop multiplexer.

The filter can be tuned by changing injection current. The frequency channel selected is reflected by the filter, amplified second time by the MQW section and extracted to drop port using circulator. The remaining frequency channels pass through the filter section.

2.4. Frequency conversion by RSOA

It utilizes a high reflecting coating on one facet and ultra low reflecting coating (or anti reflecting coating) on the other facet to produce a highly versatile reflective gain medium. The basic structure is shown in Fig. 3 as used in this communication. A weak signal of frequency υ_1 can be converted to a high power signal of a different frequency υ_2 using a signal of frequency υ_2 from outside. Inside the RSOA multiple reflections occurs and the power of the weak signal is converted to the high power signal. The basic phenomenon behind this type of operation is the well known cross gain modulation (XGM) of converting information at one frequency to another frequency. The converted signal is of high power due to amplification caused by the RSOA [14].

3. Working of the X-OR gate and the encryption/decryption systems

For implementation of the X-OR gate one has to use FWM in an SOA, three ADMs, and two RSOAs. The implementation of the X-OR gate is shown in Fig. 4.

When both the inputs are υ_1, the converted signal of frequency $2\upsilon_1-\upsilon_s$ is blocked and reflected back by the ADM1 and is dropped

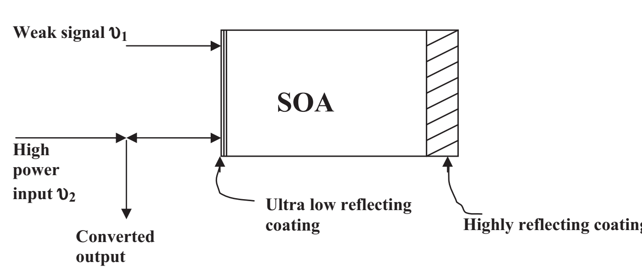

Fig. 3. Reflective semiconductor optical amplifier.