A Novel Security Enhanced Decoder Based on XOR Detection for Optical Code Division Multiple Access System Using Multi-Diagonal Code

Shivani Rana and Amit Gupta

Department of Electronics and Communication Engineering, Chandigarh University, Mohali, 140301, India; shivy.299@gmail.com, amitguptacgc@gmail.com

Abstract

Objective: The main aim of this research paper is to design a security enhanced decoder based on the XOR logic gate detection technique. Methods/Statistical Analysis: An all optical XOR gate has been designed by using Semiconductor Optical Amplifier (SOA) for the secure transmission in Optical code division multiple access system. Multi Diagonal (MD) code is implemented with all optical logical gate detection using non-linear effects in semiconductor optical amplifiers. To realize the XOR gate, two identical SOAs in MZI structure have been used. Finding: The Non-Return-to-Zero (NRZ) and RZ bit format have been compared and results show that using NRZ bit format the performance is better than RZ bit format and its optimum power comes out to be 0.6mW. A new design of Multi-diagonal code has been proposed by using all optical logical gate detection considering nonlinear effects in SOA. The design has successfully worked at Bit Error Rate (BER) 8.77×10⁻⁹. Application/Improvements: This design having decoder based on XOR logic gate utilizing the Multi-diagonal code will have wide applications in military for the secure transmission of data.

Keywords: Cross Gain Modulation, Cross Phase Modulation

1. Introduction

Optical Code-Division Multiple-Access (CDMA) can be termed as the multiple access technique and main benefit of using Optical Code-Division Multiple-Access (OCDMA) is the capability of providing high bandwidth with asynchronous transmission. For security purpose use of OCDMA with logical gates will be beneficial in today’s communication era. However, due to huge requirement of bandwidth, signal processing with respect to optical domain has attracted the considerable attention. In order to achieve the desired optical signal processing, all optical signal processing is the most important necessity¹. In OCDMA, it can be smoothly achieve by sending the signals on the different wavelength by taking specific OCDMA code³. In this work, the code used is Multi-Diagonal (MD) code for two users having zero cross correlation property.

In the semiconductor devices or in waveguides all optical logical gates can be achieved by considering the non-linear effects. In order to achieve this, optical amplifiers especially, has been found very attractive for the realization of different logical functions. So far research work has been done to achieve the all optical logic operations using non-linear optics. Various operations have been demonstrated by using SOA non-linear processes like SOA in Mach-Zehnder Interferometer configuration, Sagnac Interferometer or Non-Linear Loop Mirror.
(NOLM) etc. If we compare SOA based logical gates with other non-linear mediums such as optical non-linear fibre, the former will offer good result than the latter because it possesses several properties like high power efficiency, fast switching and capability of providing photonic integration. Mainly the benefits of using SOA are its smaller size, cost effective implementation and their capability to be modulated at GHz speed. The SOA can be further used for amplification and conversion process especially for the wavelength. Many research work has been done till date to improve the performance of optical networks. In proposed an all optical novel ultra compact XOR and 'AND' logic gates without considering non-linear effects.

In this paper, a zero cross correlation code i.e., multi diagonal code is implemented with all optical logical gates detection using non-linear effects in semi conductor optical amplifiers. The SOA based MZI and travelling wave SOA schemes are proposed in this paper. To realize the XOR gate, two identical SOAs in MZI structure have been used. The design has been successfully demonstrated at 10 Gb/s with no clock signal. This paper is organised into two fold, the first fold describes the working principle of proposed model and the construction of MD code has been described in second fold.

### 2. Working Principle

#### 2.1 Multi Diagonal Codes

To improve security in the network, the system should be designed in such a way that amount of energy received by an eavesdropper by tapping fibre signals should be minimized. This needs that each transmitter transmits the minimum power into the network. This minimization affects the Bit Error Rate (BER) performance of the system. BER performance of an authorized receiver is the function of the received Signal to Noise Ratio (SNR) which is given by:

\[
\frac{e_u}{n_{ou}} = \frac{e_u}{n_{OM} + n_{OR}}
\]  

(1)

Here, \(n_{OM}\) is noise spectral density due to multiple access interference and \(n_{OR}\) is the spectral density of the receiver noise. \(n_{OM}\) is proportional to both the number of active transmitters and to the transmitted power of each user while \(n_{OR}\) is fixed for a given receiver imple-

mentation. If \(n_{OR}\) is negligible compared to \(n_{OM}\), the SNR of an authorized user’s receiver will maintain the specified BER. If each transmitter reduces its transmitting power level sufficiently to increase confidentiality, though \(n_{OM}\) will also be reduced and \(n_{OR}\) will become significant compared to \(n_{OM}\). The ratio \(e_u/n_{ou}\) determines BER, and this will be reduced by reducing the power level of each user and hence, increases the BER. If the transmitted power is reduced arbitrarily, then to keep the BER from exceeding a specified value is to reduce the \(n_{OM}\) term as well. So there is need have zero cross correlation in order to increase confidentiality. The MD code provides no cross correlation between the transmitting users as per their construction.

The MD code consists of following parameters:
- \(L\) represents the code length
- \(W\) represents the code weight
- \(\lambda\) represents phase cross correlation.

Steps for the construction of MD codes:

1. Step 1: Initially decide the number of subscribers (K) and fix any value of the weight (W).

2. Step 2: From K and W, the i, j is defined where i=1, 2, 3…….., and j=1, 2, 3… W

3. Step 3: The position matrix is defined as:

\[
Z_{ij} = \begin{cases} \frac{1}{2} & \text{when } j \text{ is even number} \\ \frac{3}{2} & \text{when } j \text{ is odd number} \end{cases}
\]

(2)

\[
Z_{1,1} = \begin{bmatrix} 1 \end{bmatrix}, Z_{1,2} = \begin{bmatrix} 3 \\ 1 \end{bmatrix}, Z_{1,3} = \begin{bmatrix} 3 \\ 1 \end{bmatrix}, Z_{1,w} = \begin{bmatrix} 3 \\ 1 \end{bmatrix}
\]

(3)

Each element in \(Z_{ij}\) denotes the value of 1 in \(Q_{ij}\) matrices with K × K dimensions.

4. Step 4: \(Q_{ij}\) matrices with K × K dimensions are represented as:

\[
Q_{i1} = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix}, \quad Q_{i2} = \begin{bmatrix} 0 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{bmatrix}.
\]

(4)

\[
Q_{iw} = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix}.
\]

Step 5: The combination of diagonal matrices (given in equation 4) gives the matrix for Multi-diagonal code of order K × L:
\[ MD = [Q_{i,1} \quad Q_{i,2} \quad \ldots \quad Q_{i,W}]_{K \times L} \]  

i.e;
\[ MD = \begin{bmatrix} \alpha_{1,1} & \cdots & \alpha_{1,L} \\ \vdots & \ddots & \vdots \\ \alpha_{n,1} & \cdots & \alpha_{n,L} \end{bmatrix} \]  

For MD code weight value should be assigned more than 1 (W > 1). For example, to design the MD code, let us consider K=2 and W=2.

The position matrix is defined as:
\[ \mathbf{z}_{l1} = \begin{bmatrix} 1 \\ 2 \end{bmatrix}; \quad \mathbf{z}_{l2} = \begin{bmatrix} 2 \\ 1 \end{bmatrix}; \]  

and,
\[ Q_{l1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}; \quad Q_{l2} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \]

So, the MD code matrix will be of order 3 x 6 and is given as:
\[ MD = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix} \]

Hence the codeword for each user will be:
Codeword for user 1 = \( \lambda_{1,1}, \lambda_{1,2} \),
Codeword for user 2 = \( \lambda_{2,1}, \lambda_{2,2} \).

It is clear that the MD code design possesses the property of zero cross-correlation which results in cancellation of MAI.

2.2 Principle of SOA Based Logic Gate

2.2.1 Cross-Gain Modulation (XGM)

XGM in SOA modulate the gain in the SOA via gain saturation effect. This non-linear effect takes into account when the signal with high power i.e pump signal and with probe signal (low power) is fed into the SOA medium simultaneously. The available carrier density is changed for further amplification that is mainly caused by the pump signal with high power. The optical gain is shared between pump signal and probe signal depending upon the photo-densities with the stronger pump signal. It has an opposite effect on the gain that is available to the low power signal due to which data occurs and optical gate is realized. The gain coefficient is proportional to imaginary part of susceptibility (N) as shown in\(^{17}\):

\[ g(N) = -\frac{\omega g}{c \eta} X_{im}(N) \]

Some other applications regarding optical signal processing such as wavelength conversion, logical operations etc can be realized using XGM in SOAs.

2.2.2 Cross-Phase Modulation (XPM)

SOA can be utilized in XPM mode. The methodology of XPM totally depends on the refractive index of the carrier density\(^{17}\). The carrier density will get diminished by the incoming signal and further modulate the refractive index and hence results in phase modulation of signals.

2.2.3 Four-Wave Mixing (FWM)

FWM is one of the non-linearity that is generated in the optical fibre. It is a method by which optical signal interact or get mixed at different wavelength resulting in a new signal at other wavelength. When the signals of different frequency are fed into SOA, combination of the optical power varies the gain and carrier density. The input signal gets interacted with the modulated parameters including gain and carrier density that will result in a new frequency component as \( 2\omega_1 - \omega_2 \) and \( 2\omega_2 - \omega_1 \). Now if the pump signal carrying high power at a wavelength \( \omega_1 \) is higher than that of probe signal carrying low power, then the FWM signal at a wavelength \( 2\omega_1 - \omega_2 \) it has extensive power\(^{18}\).

3. System Architecture

The proposed model consists of MD-OCDMA codes and detection using optical logical gate. At the transmitter side MD-OCDMA coding technique is used and at the receiver side detection is using XOR logical gate. The XOR gate is formed by non-linear effects i.e. XGM, XPM and FWM in SOA based MZI configuration. Nonlinear operation travelling wave SOA is used in the simulation. Biasing of SOA is done at 300mA. SOA acts as non-linear element and all the data combined together is given into the SOA. In XOR detection technique along with the input signals one of the input to SOA in Mach-Zehnder configuration is the CW array laser signal that is also called pump signal. Inside SOA, non-linear effects occur depending upon system design.

Further, parameters of optical filter like wavelength and bandwidth are defined to get the required gate opera-
tion. For optical XOR logical gate detection, the optical filter is required to have bandwidth of 60GHz at a wavelength which is generated due to FWM. So, the optical filter should select proper wavelength and bandwidth to achieve detection of different optical logic gates. To implement logical XOR, design of SOA in Mach Zehnder configuration is used. A pump signal using CW laser array is coupled with the coded wavelengths using 3db coupler as shown in Figure 1.

![Diagram](image.png)

**Figure 1.** Design structure of MD codes using logical XOR detection technique.

The truth Table of XOR logic gate is shown in Table 1.

| Case | Signal 1 | Signal 2 | XOR |
|------|----------|----------|-----|
| Case 1 | 0        | 0        | 0   |
| Case 2 | 0        | 1        | 1   |
| Case 3 | 1        | 0        | 1   |
| Case 4 | 1        | 1        | 0   |

The parameters of SOA used in all optical XOR logical gate design are shown in Table 2.
4. Results and Discussion

The realization of optical XOR gate is done by using two identical SOAs in each arm of MZI in the SOA-MZI configuration. The XOR gate depends upon one of the non-linear effect i.e. XPM. The two data signals whose wavelength may or may not be same are passed through two arms of MZI i.e. upper arm and lower arm respectively. The probe signal having low power is fed to the upper arm and the lower arm of the interferometer. When data signals coupled with the signal having low power are set in motion into the SOAs, then the modulated param-

| Sl. No. | Parameter                      | Value      |
|--------|--------------------------------|------------|
| 1.     | Bias current                   | 0.3 A      |
| 2.     | Length of active region        | 0.0005 M   |
| 3.     | Width of active region         | 3×10^-6 M  |
| 4.     | Thickness of active region     | 8×10^-8 M  |
| 5.     | Confinement factor             | 0.3        |
| 6.     | Line width enhancement factor  | 5          |
| 7.     | Carrier density at transparency| 1.4×10^24 m^-3 |
| 8.     | Initial carrier density        | 3×10^24 m^-3 |
| 9.     | Pump current                   | 0.8 A      |

Table 2. SOA used in the design
eters like carrier density and the refractive index are modulated. This results in the phase shift over the probe pulse counter propagating through the SOAs according to the change in the intensity of the input pulses. For XOR operation the optical filter with 20GHz bandwidth is used. In order to assess the performance of the XOR gate used for the reception of MD codes at 10 Gb/s, a continuous wave with peak power 0.2 W is modulated with chirp factor 0.5. Similar MD code construction is used at the transmitter side. At the receiver side SOA-MZI configuration for performing logical XOR operation is used. CW laser array signal of 0.25mW is used along with the coded wavelengths as pump signal at 1538nm and 1548 nm. 0.5db coupler is used to couple this pump signal with

Figure 2. Spectrum of data signals at the (a) transmitting end. (b) Receiver side of user 1 (c) receiver side of user 2.

Figure 3. Shows the graph plot comparing RZ and NRZ bit format (a) Quality factor v/s optimum power (b) Quality factor v/s distance (Km).
the coded wavelengths and input to the travelling wave SOA in Mach Zehnder configuration. Bessel optical filter at 1538nm and 1548nm of 20 GHz bandwidth is used at the receiver end to suppress the sideband signals. Figure 2 shows the spectrum of data signals at the transmitting and the receiving end. The spectrum of the data signals can be seen in Figure 2.

The quality factor for the RZ and NRZ bit formats with respect to power and distance can be seen in Figure 3. For NRZ and RZ the optimum power is 0.6 but NRZ provide better quality factor than RZ and also if the distance is increased, the quality factor degrade more for RZ than NRZ.

Figure 4. Eye diagrams of (a) user 1 in case of RZ with Q factor 4.11 (b) user 2 in case of RZ with Q factor 3.82.
Figure 5. Eye diagram of (a) user 1 in case of NRZ with Q factor 6.0175 (b) user 2 in case of NRZ with Q factor 6.2242 (c) user (case 1 and case 4) with Q factor 2.2 in case of NRZ.

Figure 4 and 5 represents the eye diagram in case of RZ and NRZ that clearly elaborate the performance comparison of NRZ and RZ bit formats and also the security concern respectively.

5. Conclusion

In this paper, we presented MD code with logical gate reception using XOR gate. This code design shows excellent performance with logical gate reception. Due to logical gate reception the data transmitted is highly secureable using this code design. The NRZ bit format provides better performance than RZ for the OCDMA system. It is also proved that the MD code design has no overlapping of spectra and hence zero cross correlation due to its construction. All optical logical transmission and reception at 10 Gb/s have been designed and simulated with acceptable BER.

6. References

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