

# Comparative Performance of Hybrid SCM SAC-OCDMA System Using Complementary and AND Subtraction Detection Techniques

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**Abstract:** *This paper presents the comparative performance of two detection schemes based on subtraction detection technique for a hybrid scheme of subcarrier multiplexed spectral-amplitude-coding optical code division multiple access (SCM SAC-OCDMA) system. SAC-OCDMA systems are receiving more attention because of their ability to completely eliminate multi access interference by using code sequences with fixed in-phase cross correlation. On the other hand, the SCM scheme is capable of improving the channel data rate of OCDMA systems. This hybrid scheme is proposed for the benefit of combining the advantages of both schemes. Consequently, the hybrid system is robust against interference and is much more spectrally efficient. Double weight code family is a new code structure used for SAC-OCDMA system. The experimental simulation results show that the proposed new AND subtraction detection technique improve the system performance significantly.*

**Keywords:** *Hybrid SCM SAC-OCDMA, subtraction detection technique, multi access interference, optical communication system.*

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## 1. Introduction

Optical Code Division Multiple Access (CDMA) systems have received more attention because CDMA allows many users to simultaneously access the channel with a high level of transmission security [1]. However, Multi Access Interference (MAI) is the main reason for performance degradation in optical CDMA especially when large numbers of users are involved. The SAC-OCDMA systems employing code sequences fixed in-phase cross correlation can eliminate MAI by using balanced detection or also known as complementary subtraction detection technique [3, 5, 9].

Several code families have been developed for SAC-OCDMA such as modified quadratic congruence codes [4], M-sequence codes [5], double weight codes [6], etc. Therefore it is desirable to develop a detection technique that provides the MAI elimination capability. In this paper, a new and simple detection technique named AND subtraction is proposed. It is shown in this paper that the technique provides a significantly better performance than the complementary subtraction technique, which in turns allows for longer transmission distance or higher data rate or a larger number of users. The studies were carried out using a hybrid SCM SAC-OCDMA

system. A better spectral efficiency can be achieved by using the SCM technique [2].

## 2. SCM SAC-OCDMA for Point-to-Point System

Figure 1 illustrates the block diagram of the system. The data signals multiply with the assigned subcarrier signals, and then modulated the signals with a distinct codeword using the Optical External Modulator (OEM). The received optical signals are decoded and converted to electrical signals, which then are filtered and demodulated accordingly to recover the original data.

The data are protected by the difference in either the codes or the subcarrier frequencies. Each filter only corresponds to the desired data tuned to its center frequency and with a matching code. Other signals are rejected. Therefore the hybrid scheme is robust against interference and is more spectrally efficient.

## 3. OCDMA Detection Techniques

In general, there are two basic detection techniques, namely coherent and incoherent [8].

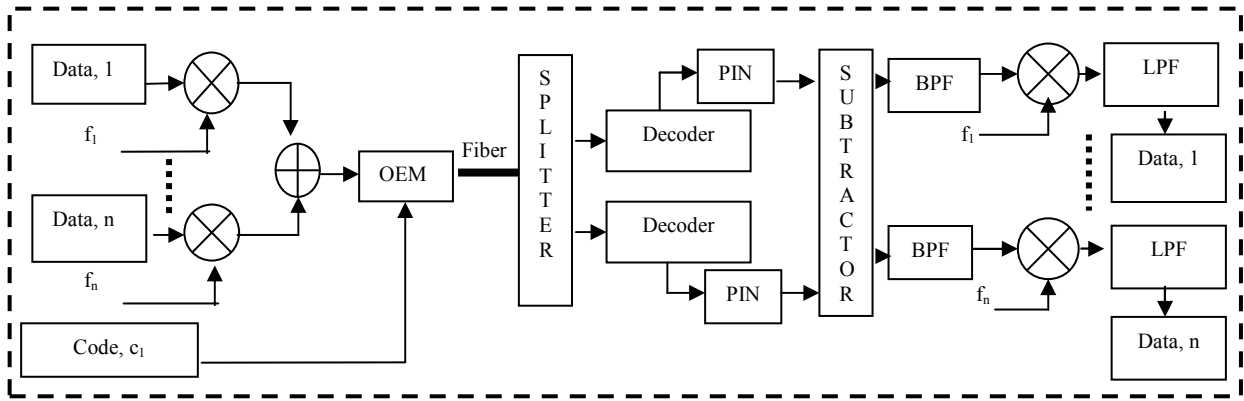


Figure 1. A block diagram for one code of hybrid SCM SAC-OCDMA.

Coherent system uses bipolar codewords whereas incoherent system consists of unipolar sequences in the signature code. Incoherent detection has a less hardware complexity compared to coherent detection because it does not need phase synchronization. In this study, the incoherent detection using subtraction techniques is used. The complementary and AND subtraction detection techniques will be discussed in the following sub-sections.

### 3.1 Complementary Subtraction Detection Technique

The implementation of complementary subtraction detection technique is shown in Figure 2. The figure shows two different sequences X= (0110) and Y= (1100) are modulated with data and sent to multiplexer. The received signal in Receiver is divided into two complementary branches of spectral chips. These two branches of spectral signals are sent to a subtractor that computes the correlation difference.

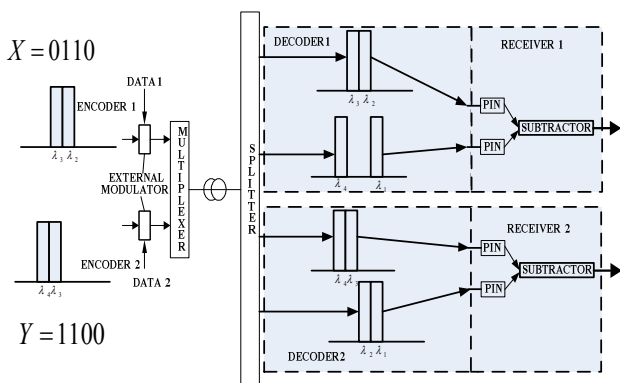


Figure 2. Implementation of the complementary subtraction technique.

The complementary subtraction technique was first proposed by Zaccarin [7]. The cross-correlation is defined as:

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x_i y_{i+k} \quad (1)$$

where X and Y are the two OCDMA code sequences. The complementary of sequence (X) is given by  $(\bar{X})$  whose elements are obtained from (X) by  $\bar{x}_i = 1 - x_i$ . Let X= 0011 and Y= 0110 and therefore  $\bar{X} = 1100$ . The periodic cross-correlation sequence between  $(\bar{X})$  and (Y) is similar to Equation 1 and is expressed as:

$$\theta_{\bar{X}Y}(k) = \sum_{i=0}^{N-1} \bar{x}_i y_{i+k} \quad (2)$$

The sequences required are as:

$$\theta_{XY}(k) = \theta_{\bar{X}Y}(k) \quad (3)$$

At the receiver, the photodetectors will detect the two complementary inputs which will be fed to the subtractor whose cross-correlation output, Z can be expressed as:

$$Z_{\text{Complementary}} = \theta_{XY}(k) - \theta_{\bar{X}Y}(k) = 0 \quad (4)$$

There is no more signal from other users in the intended channel when  $Z_{\text{Complementary}} = 0$ .

### 3.2 AND Subtraction Detection Technique

In AND subtraction technique, the cross-correlation  $\theta_{\bar{X}Y}(k)$  is substituted by  $\theta_{(X \& Y)Y}$ , where  $\theta_{(X \& Y)}$  represents the AND operation between sequences X and Y. For code sequences of X= (0011) and Y= (0110),  $(X \text{ AND } Y) = 0010$ . Figure 3 depicts the proposed AND subtraction detection technique.

At the Receiver

$$Z_{\text{AND}} = \theta_{XY}(k) - \theta_{(X \& Y)Y}(k) = 0 \quad (5)$$

Equation 5 shows that with AND subtraction technique, MAI or the interference from other channels also can be cancelled out. Comparison between complementary and AND subtraction technique using DW codes is shown in Table 1.

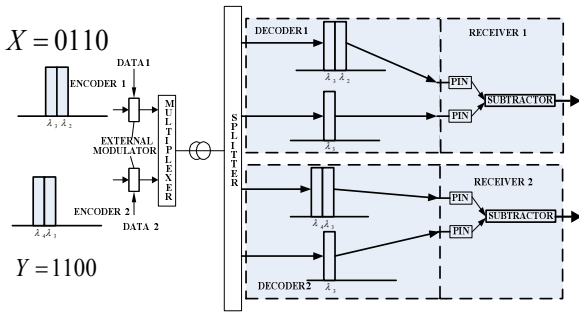


Figure 3. Implementation of the AND subtraction technique.

Table 1. Example of complementary and AND subtraction techniques.

	Complementary Technique				AND Technique			
	$\lambda_4$	$\lambda_3$	$\lambda_2$	$\lambda_1$	$\lambda_4$	$\lambda_3$	$\lambda_2$	$\lambda_1$
$X$	0	0	1	1	0	0	1	1
$Y$	0	1	1	0	0	1	1	0
	$\theta_{XY} = 1$				$\theta_{XY} = 1$			
	$\bar{X} = 1100$				$X \& Y = 0010$			
	$\theta_{\bar{X}Y} = 1$				$\theta_{(X \& Y)Y} = 1$			
$Z$	$Z = \theta_{XY} - \theta_{\bar{X}Y} = 0$				$Z = \theta_{XY} - \theta_{(X \& Y)Y} = 0$			

Therefore, as discussed in the sections 3.1 and 3.2, MAI can be cancelled out by using both techniques. However in term of the architecture, AND subtraction needs less number of filters in the decoder. For example, complementary subtraction detection technique as shown in Figure 2, three filters are required for decoder 1. A filter with the bandwidth twice the chip width for  $\lambda_2$  and  $\lambda_3$ , and two separate filters for  $\lambda_1$  and  $\lambda_4$ . Whereas for AND subtraction technique as shown in Figure 3, only two filters are needed for decoder 1. A filter with bandwidth twice the chip width for  $\lambda_2$  and  $\lambda_3$ , and a filter at the position of the overlapping spectra occurring in the code sequences, that is  $\lambda_3$ .

#### 4. Experimental Simulation Results and Discussion for SCM SAC-OCDMA System

The performance of the system was evaluated using OptiSystem Ver. 4.1, which is widely used for optical fiber simulations. The simulation was carried out for Double Weight (DW) code family with weight equal to 2 for four SCM channels. The bit rate of each channel is 155 Mbps (STM-1). Table 2 shows the DW code with weight equal to 2. The advantages of DW code are easy and efficient code construction, simple encoder-decoder design, existence for every natural number  $n$ , ideal cross correlation and high SNR. The detailed of DW code families' construction and performances are explained in [6].

Table 2. DW code with weight= 2 and 4 users.

$K_{th}$	$C_6$	$C_5$	$C_4$	$C_3$	$C_2$	$C_1$
1	0	0	0	0	1	1
2	0	0	0	1	1	0
3	0	1	1	0	0	0
4	1	1	0	0	0	0

The ITU-T G.652 standard single mode optical fiber without any amplifier is employed for a point-to-point optical transmission. The spectral width of each chip was 0.8 nm. The attenuation and dispersion were set at 0.25 dB /km and 18 ps /nm-km, respectively. The nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible. The performances of the system are characterized by referring to the Signal-to-Noise Ratio (SNR) and eye pattern for the complementary and AND types of detection schemes.

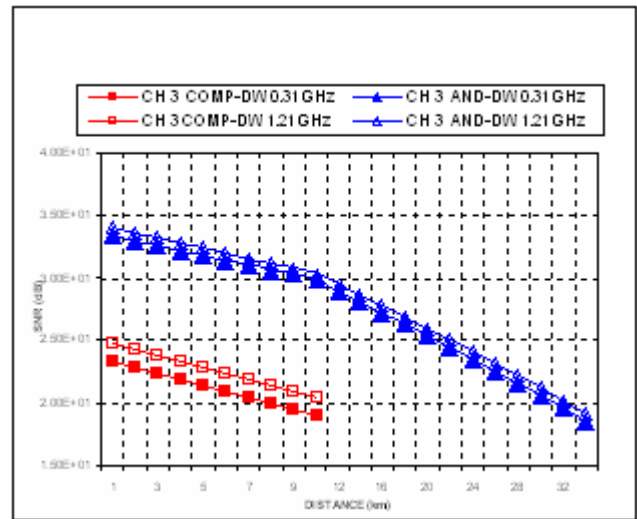


Figure 4. SNR vs. distance for SCM SAC-OCDMA systems using complementary and AND detection technique.

Figure 4 shows the SNR performance carried out against the transmission distance taken at the lowest and highest sub carrier frequencies, 0.31 and 1.21GHz, respectively. It can be seen that SNR decreases with the transmission distance. A longer optical fiber provides a larger dispersion and attenuation thus decreasing the SNR. The results for the SCM SAC-OCDMA system using AND subtraction shows better SNR compared to the complementary subtraction technique. It is found that the system using complementary subtraction technique could perform sufficiently well only up to about 10 km and AND subtraction up to 32 km.

Figure 5 shows the effect of transmitted input power on the system performance taken at the lowest and highest subcarrier frequencies, 0.31 and 1.21 GHz, respectively. The distance of the optical fiber is set at 10 km. Taking the SNR threshold of 20, the system with AND subtraction could perform sufficiently well even when the transmitted power is at -5 dBm whereas

for the complementary subtraction the transmitted power should set at 0 dBm or higher.

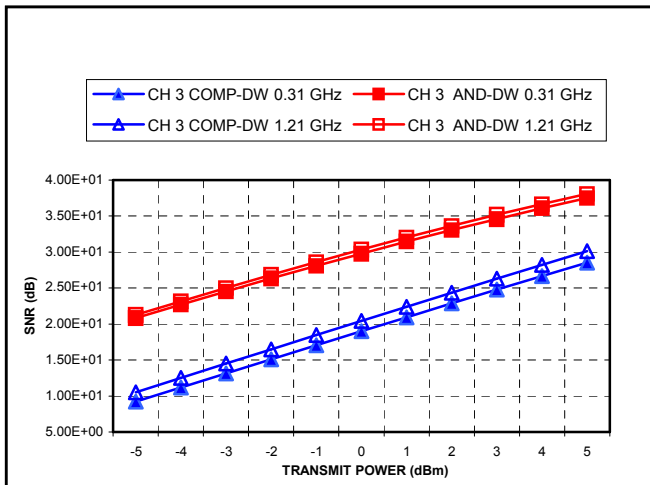


Figure 5. SNR vs. transmit power for SCM SAC-OCDMA systems using complementary and AND detection technique for DW.

Figures 6 and 7 show the results for the SCM SAC-OCDMA with optical fiber length of 15 km using complementary and AND subtraction detection techniques, respectively. The eye patterns show that the AND subtraction detection technique gave a better performance. The BER for complementary and AND subtraction technique were  $10^{-7}$  and  $10^{-22}$ , respectively.

The performance of the SAC-OCDMA system is improved significantly because with less number of filters in the AND subtraction, the total power loss can be reduced. Hence, the overall hybrid SCM SAC-OCDMA system cost and complexity is reduced with less number of filters.

### 5. Conclusion

A new AND detection technique based on subtraction technique has been proposed. The performance of the hybrid SCM SAC-OCDMA system with the new AND subtraction technique using DW code family has been presented. The results of the experimental simulation have proved that the new AND subtraction technique provides a better performance than the complementary subtraction technique. The performance of the system improved significantly because the total power loss is reduced as AND subtraction technique requires less number of filters in the decoder.

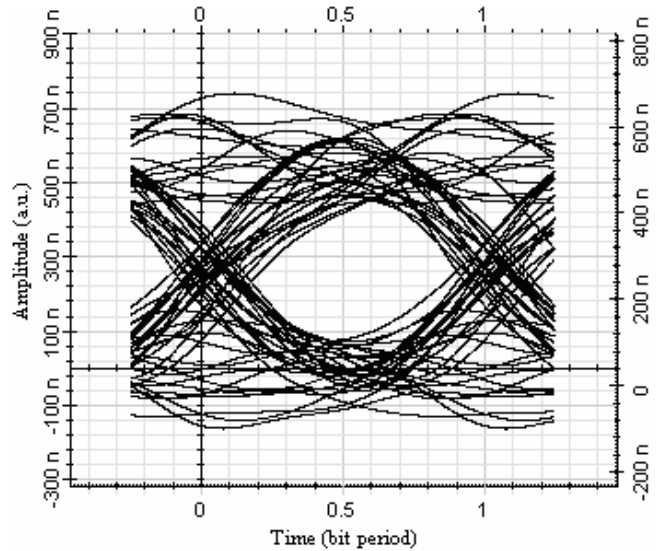


Figure 6. Eye diagram taken at channel 1 with complementary subtraction detection technique, subcarrier frequency of 0.61GHz.

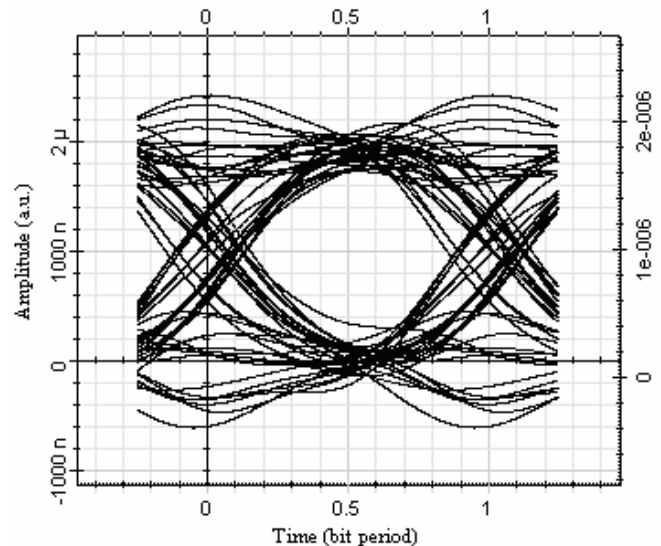


Figure 7. Eye diagram taken at channel 1 with AND subtraction detection technique, subcarrier frequency of 0.61GHz.

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