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AN AND DETECTION TECHNIQUE FOR HYBRID SUBCARRIER MULTIPLEXED SPECTRAL-AMPLITUDE-CODING OPTICAL CDMA TECHNIQUE

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Abstract. A new detection technique named AND subtraction which is based on subtraction technique is proposed for a hybrid system of subcarrier multiplexed (SCM) spectral-amplitude-coding optical code division multiple access (SAC-OCDMA) of a point-to-point link. Spectral-amplitude-coding OCDMA is used because of its ability to cancel the multiple access interference (MAI) when code sequences with fixed in-phase cross correlation are used. On the other hand, the SCM scheme is able to enhance the channel data rate of OCDMA systems. This hybrid system is proposed for the purpose of combining the advantages of both techniques. As a result, the hybrid system is robust against interference and is much more spectrally efficient. A new code structure for spectral-amplitude-coding OCDMA system based on double weight (DW) code family is employed. The experimental simulation results of the hybrid system using the new proposed AND subtraction detection technique are compared to the hybrid system using complementary subtraction detection technique. The results show that the hybrid system using the proposed new AND subtraction detection technique improve the system performance significantly.

Keywords: SCM, SAC-OCDMA, hybrid SCM SAC-OCDMA, detection scheme, subtraction technique

Abstrak. Satu teknik pengesanan baru yang dinamakan teknik penolakan AND yang berasaskan teknik penolakan dikemukakan untuk sistem hibrid pemultipleks subpembawa kod amplitud spektra akses pelbagai pembahagian kod optik bagi penyambungan titik-ke-titik. Kod amplitud spektra akses pelbagai pembahagian kod optik telah digunakan kerana kebolehannya untuk membatalkan gangguan pelbagai akses apabila jujukan kod sekaitan silang tetap dalam fasa digunakan. Skema pemultipleks subpembawa pula berkebolehan untuk meningkatkan kadar data saluran bagi sistem akses pelbagai pembahagian kod optik. Sistem hibrid ini telah dikemukakan bagi tujuan menggabungkan kelebihan kedua-dua teknik tersebut. Hasil keputusannya, sistem hibrid ini berketahanan terhadap gangguan dan lebih baik dari segi spektranya. Satu struktur kod baru untuk sistem kod amplitud spektra akses pelbagai pembahagian kod optik berasaskan keluarga kod berat kembar telah digunakan. Keputusan yang diperoleh dari ujikaji simulasi untuk sistem hibrid yang menggunakan teknik pengesan penolakan AND dibandingkan dengan sistem hibrid yang menggunakan teknik penolakan pelengkap. Keputusan yang diperoleh menunjukkan sistem hibrid yang menggunakan teknik pengesanan baru yang dinamakan teknik pengesan penolakan AND yang telah dikemukakan dapat memperbaiki prestasi sistem ini.

Kata kunci: SCM, SAC-OCDMA, hibrid SCM SAC-OCDMA, skema pengesanan, teknik penolakan

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1.0 INTRODUCTION

Fiber optic code division multiple access (CDMA) techniques provide flexible solution for asynchronous high-capacity communication in the field of digital local area networks. The early incoherent optical CDMA (OCDMA) systems used pseudo-orthogonal sequences to encode signals in the time domain, but the codes were long and multiple access interference (MAI) limited the number of simultaneous users. Thus, spectral-amplitude-coding (SAC) of OCDMA systems was proposed because of its ability to eliminate the influence of MAI and to preserve the quasi-orthogonality between network users [1, 2]. MAI exists in the OCDMA systems when multiple users accessing the same medium using the same time and frequencies for transmitting concurrent data streams.

In SAC-OCDMA systems, each user is assigned with a sequence code that serves as its address. An OCDMA user modulates its code (address) with each data bit and asynchronously initiates transmission. Thus, this modifies its spectrum appearance, in a way recognizable only by the intended receiver. Otherwise only noise like bursts is observed [3]. Several code families have been developed for SAC-OCDMA such as modified quadratic congruence (MQC) codes [4], M-sequence codes [5], double weight (DW) codes [6], etc. Let $\lambda = \sum_{i=1}^{N} x_i y_i$ as the in-phase cross correlation of two different sequences $X = (x_1, x_2, ..., x)$ and $Y = (y_1, y_2,..., y_N)$. A code with length N, weight w and in-phase cross correlation λ can be denoted by (N, w, λ). Code sequences with fixed in-phase cross correlation λ can be described as when any two of users' sequences are aligned chip by chip, pulses are hit in exactly λ times [7]. When $\lambda = 1$, it is considered the code possesses ideal in-phase cross correlation. The ability to totally suppress the MAI is due to the use of complementary subtraction detection techniques for codes with a fixed in-phase cross correlation [8, 9].

The SCM technique is attractive because it encompasses the multiplexing of both multichannel of analog and/or digital signals. These signals can carry either voice, data, video, digital audio, high-definition video or any other analog or digital information. In SCM system, the input signals are modulated with different electrical carriers at microwave frequencies and then they are combined by using a combiner. The combined signal is then modulated by intensity modulation or external modulation techniques. The modulated lightwave signal is transmitted through an optical fiber. At the receiver end, the optical signal is converted back to an electrical current by a photodetector. The particular signals can then be demultiplexed and demodulated, using conventional detection methods. The attractive feature of SCM is the independence of the different channels. This allows for great flexibility in the choice of modulation schemes. In addition to being flexible, the current SCM technology is also cost effective as it provides a way to take advantage of the multi-gigahertz bandwidth of the fiber optics, using well-established microwave techniques for which components are commercially available. Furthermore, it is less expensive than the corresponding WDM technology [10].

In this paper, a new and simple detection scheme named as AND subtraction is proposed. The studies were made using a DW code of SAC-OCDMA system. The DW code has a fixed weight of two. The modified double weight (MDW) code is a DW code family variation that has weight of an even number greater than two. The SCM is employed to improve the channel data rate of the OCDMA [11, 12]. A large number of channels can be achieved with many code sequences and few subcarriers per code sequences, or with the converse. It is shown in this paper that the hybrid of SCM SAC-OCDMA system using the proposed AND subtraction detection technique provides a significantly better performance than the hybrid system using complementary subtraction technique. The transmission distance of the hybrid SCM SAC-OCDMA system can be extended using this new technique compared to the complementary subtraction technique. The signal-to-noise ratio (SNR) is improved by 7dB when the transmitted power is fixed at 0dBm. This detection technique can be used for codes that are suitable for SAC-OCDMA and fulfill the condition Z in Equation 5. The hybrid system is explained in the following sections.

2.0 THE CONFIGURATION OF SCM OCDMA FOR A POINT-TO-POINT LINK

This section describes the hybrid system of SCM OCDMA for a point-to-point link. The simplest kind of lightwave system is a point-to-point link. The signals are transported from one place to another. The transmission distance can vary from less than a kilometer to thousands of kilometers.

Figure 1 illustrates the block diagram of the hybrid SCM OCDMA system. The transmitter consists of microwave mixers and combiner, optical external modulator (OEM) and code sequence. The receiver consists of optical decoder, photodetector, splitter, bandpass filters (BPF), microwave mixers and low-pass filters (LPF).

At the transmitter, data with independent unipolar digital signal is mixed by a different microwave carrier. The subcarriers are combined and optically modulated onto the code sequence using an OEM. Then m modulated code sequences are multiplexed together and transmitted through the optical fiber.

At the receiver, an optical demultiplexer is used to separate different modulated code sequences. Via the decoder, the received signal can be decoded by using a matched code sequence and the unmatched components will be filtered out. Then, the decoded signal is detected by the photodetector. A splitter and an electrical BPF are used to split the subcarrier multiplexed signals and reject unwanted signals, respectively. In order to recover the original transmitted data, the incoming signal is electrically mixed with a microwave frequency f_i and filtered using LPF.

In this hybrid system, each user is assigned a particular code sequence c_i, and subcarrier frequency f_i, where the pair (c_i, f_i) is unique with respect to every other user.

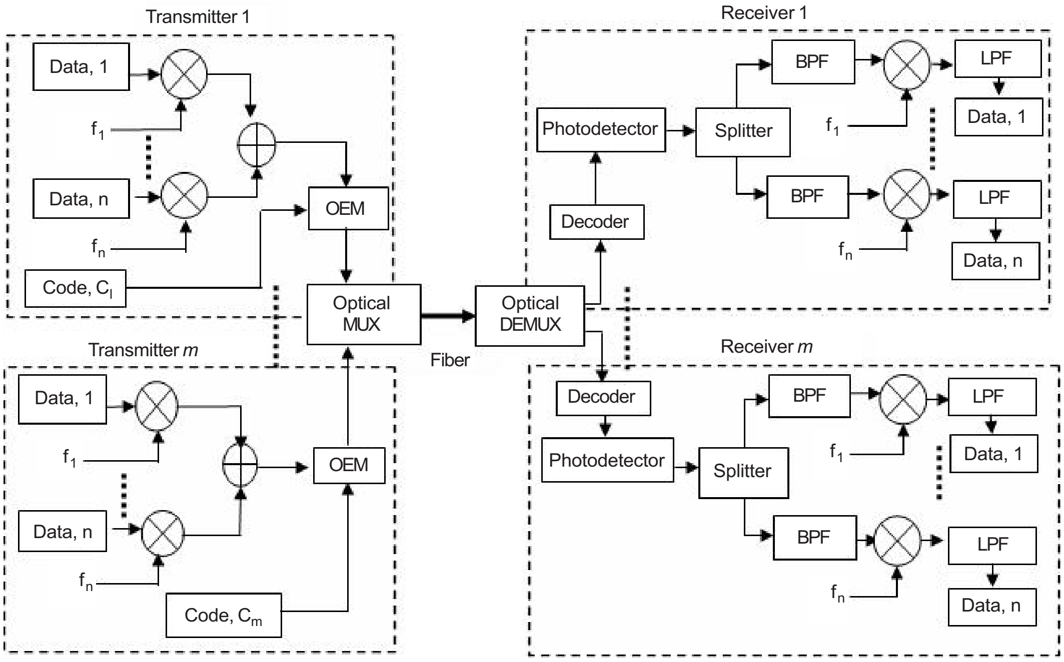

Figure 1 Block diagram of SCM OCDMA system

Only the intended receiver is able to correctly demodulate the detected signal. Every receiver is matched to a pair (c_i, f_i). The transmitter must generate the correct code sequence and the subcarrier frequency of the receiver to ensure that the data will reach its destination. Each receiver must tune to the correct frequency and code sequence to receive the desired data. Other signals are rejected. Therefore the hybrid scheme is able to support high transmission rate with high level of security.

3.0 OCDMA RECEIVER DETECTION TECHNIQUES

In general, OCDMA system can be classified based on the working principle. When coding is done on an optical power basis, OCDMA can be classified into incoherent OCDMA and when the coding is done on a field amplitude basis, it is classified into coherent OCDMA [13]. The coding operation in incoherent OCDMA is performed in a unipolar manner whereas the coding operation in coherent OCDMA is performed in a bipolar manner. In incoherent OCDMA system, the detection at the receiver does not require some degree of matching or controlling of the light phase and polarization [14]. Therefore the hardware complexity of the system is reduced. This is the reason why the incoherent detection using subtraction techniques is chosen in this study. MAI can be reduced by using subtraction technique [15, 16]. The complementary and AND subtraction detection techniques will be discussed in the following sections.

3.1 Complementary Subtraction Detection Technique

The complementary subtraction detection technique is also known as balance detection technique [8, 9] and the implementation for two code sequences is shown in Figure 2. Filters are used as encoders and decoders. The optical pulses are encoded according to the DW code sequence and then the code is optically modulated with the SCM signal. The outputs of the two OEMs are combined and transmitted through the optical fiber. Referring to Receiver 1 in Figure 2, the signals are demultiplexed and decoded separately by two complementary decoders. The outputs from the complementary filters are detected by the two photodetectors connected to a subtractor. The MAI can be completely eliminated using this technique because the in-phase cross-correlation between any two DW code sequences is always equal to 1.

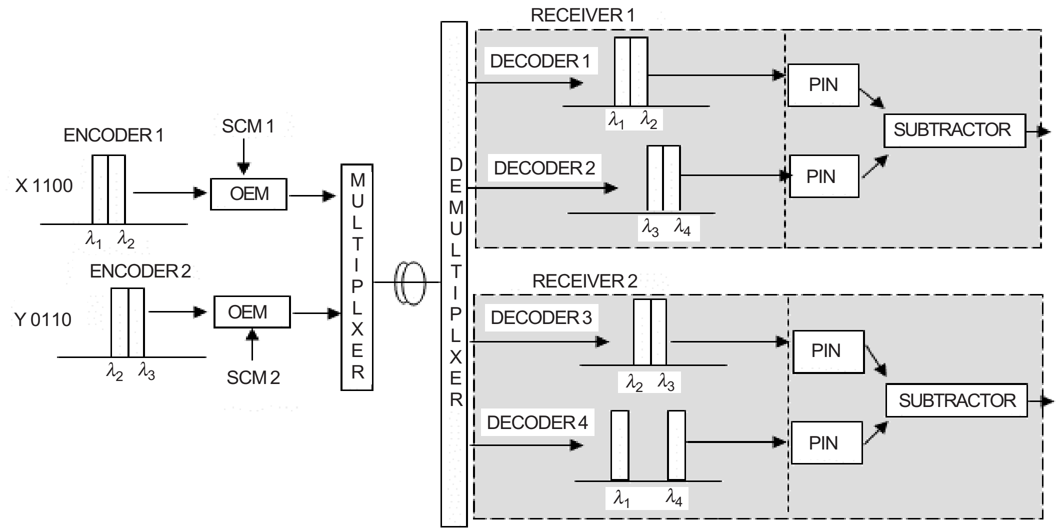

Figure 2 Implementation of the complementary subtraction technique

Complementary subtraction technique was first proposed by Kavehrad [17]. The cross-correlation is defined as:

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

for any integer k, $0 < k < N-1$. 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 = 1100 and Y = 0110 and therefore $\bar{X}$ = 0011. The periodic cross-correlation sequence between $(\bar{X})$ and (Y) is similar to Equation (1) and is expressed as:

$$\theta_{\overline{X}Y}(k) = \sum_{i=0}^{N-1} x_i y_{i+k} \tag{2}$$

The cross-correlation sequences required are as:

$$\theta_{XY}(k) = \theta_{\overline{X}Y}(k) \tag{3}$$

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:

$$Z_{Comp} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k) = \mathbf{0} \tag{4}$$

If the photodetectors are assumed to have an ideal characteristic, the output of the subtractor $Z_{Comp} = \mathbf{0}$ will reject the interference coming from other user, otherwise $Z \neq \mathbf{0}$ or incomplete interference rejection.

3.2 AND Subtraction Detection Technique

In AND subtraction detection technique, the cross-correlation $\theta_{\overline{X}Y}(k)$ is substituted by $\theta_{(X\&Y)Y}$, where $\theta_{(X\&Y)}$ represents the AND operation between sequences X and Y. For example, let X = 1100 and Y = 0110 and therefore (X AND Y) = 0100. Figure 3 depicts the proposed AND subtraction technique.

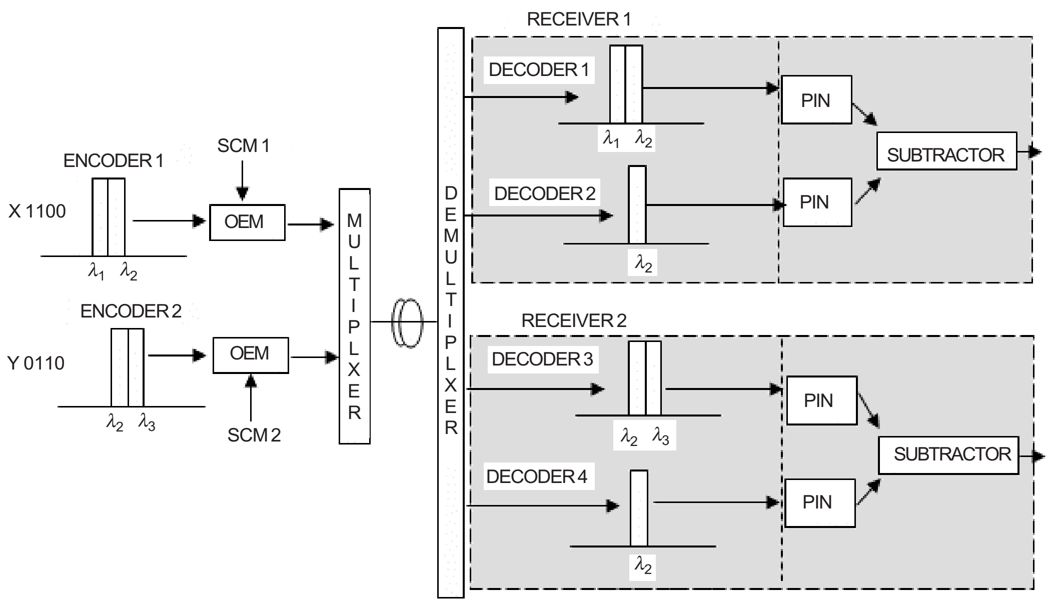

Figure 3 Implementation of the AND subtraction technique

At the receiver,

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

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

Table 1 Comparison of complementary and AND subtraction techniques

	Complementary Technique				**AND Technique**			
	λ_1	λ_2	λ_3	λ_4	λ_1	λ_2	λ_3	λ_4
X	1	1	0	0	1	1	0	0
Y	0	1	1	0	0	1	1	0
	$\theta_{XY} = 1$				$\theta_{XY} = 1$			
	$\overline{X} = 0011$				$X \& Y = 0100$			
	$\theta_{\overline{X}Y} = 1$				$\theta_{(X\&Y)Y} = 1$			
Z	$Z = \theta_{XY} - \theta_{\overline{X}Y} = 0$				$Z = \theta_{XY} - \theta_{(X\&Y)Y} = 0$			

Note that λ_i where i is 1, 2, ... N, is the column number of the codes which also represents the spectral position of the chips. Therefore as discussed in the Sub-section 3.1 and 3.2, MAI can be cancelled out by using both techniques. However in term of the architecture, AND subtraction detection technique needs less number of filters in the decoder. For example, complementary subtraction detection technique as shown in Figure 2, five filters are required for decoders of the receivers. Three filters with the bandwidth twice the chip width for λ_1 and λ_2, λ_3 and λ_4, λ_2 and λ_3 and two separate filters for λ_1 and λ_4. Whereas for AND subtraction technique as shown in Figure 3, only four filters are needed for decoders of the receivers. Two filters with bandwidth twice the chip width for λ_1 and λ_2, and λ_2 and λ_3, and two filters at the position of the overlapping spectra occurring in the code sequences, that is λ_2.

The performance of the SAC-OCDMA system is improved significantly because with less number of filters in the AND subtraction detection technique, 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.

4.0 EXPERIMENTAL SIMULATION SETUP

The system was designed and simulated using OptiSystem Ver. 4, which is widely used for optical fiber simulations. The simulations were carried out for DW and MDW (weight, W=4) with two SCM channels. The bit rate of each channel is 155 Mbps (STM-1). The DW code family has been proven to provide a better performance compared to the system encoded with Hadamard and MFH codes. The detailed of DW code families' construction and performances compared to other codes have been presented in [6]. The ITU-T G.652 standard single mode optical fiber without any amplifier was employed for a point-to-point optical transmission. Each chip has a spectral width of 0.8 nm. The attenuation and dispersion were set at 0.25 dB/km and 18ps/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 hybrid SCM SAC-OCDMA system were characterized by referring to the bit error rate (BER) and SNR for the complementary and AND types of detection techniques.

5.0 RESULTS AND DISCUSSION

Figure 4 shows the BER performance carried out against the transmission distance taken at the subcarrier frequency of 0.61GHz. It can be seen that BER increases with the transmission distance. A longer fiber provides a larger dispersion and attenuation thus increasing the error rate. The results for the SCM SAC-OCDMA system using AND subtraction shows better BER compared to the complementary subtraction technique. This is because the AND subtraction technique has significantly compensate the dispersion effect of the system and therefore the performances are limited mainly by the fiber losses. It was found that the system using complementary subtraction technique could perform sufficiently well up to 20 km only and AND subtraction for DW and MDW up to 40 km and 50 km, respectively. The results also show that the

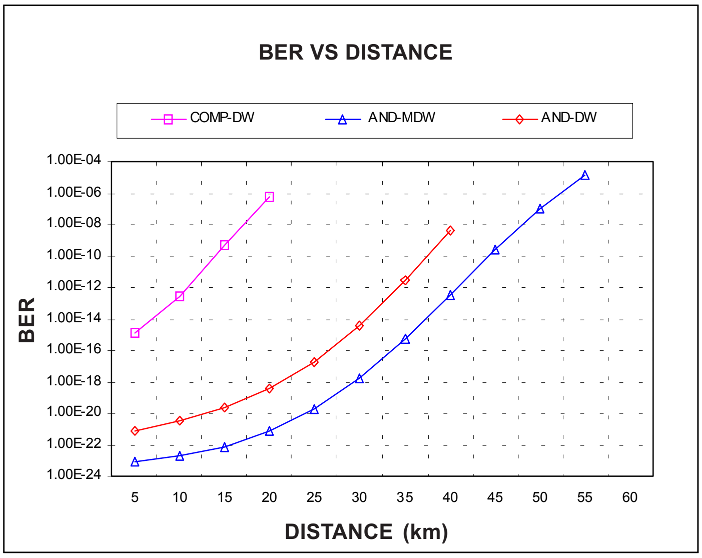

Figure 4 BER vs distance for SCM SAC-OCDMA systems using complementary and AND detection techniques for DW and MDW

performance becomes better with the increase of code weight, *W* while the in-phase cross-correlation is always equal to 1.

Figure 5 shows the effect of transmitted input power on the hybrid system performance SNR taken at subcarrier frequency of 0.61GHz. The distance of the optical fiber was set at 25 km. The SNR of the hybrid system increases when the transmitted input power is increased. However the SNR of the hybrid system using AND subtraction detection technique is significantly higher than the system using complementary subtraction technique. It is shown that the SNR are greatly improved by 7 dB when the transmitted power is 0 dBm. Taking the SNR threshold of 20 dB, the system with AND subtraction could perform sufficiently well when the transmitted power is at 0 dBm whereas for the complementary subtraction the transmitted power should set be at 3.5 dBm or higher. AND subtraction technique requires less number of filters in the system, thus less overall power loss compared to complementary subtraction technique.

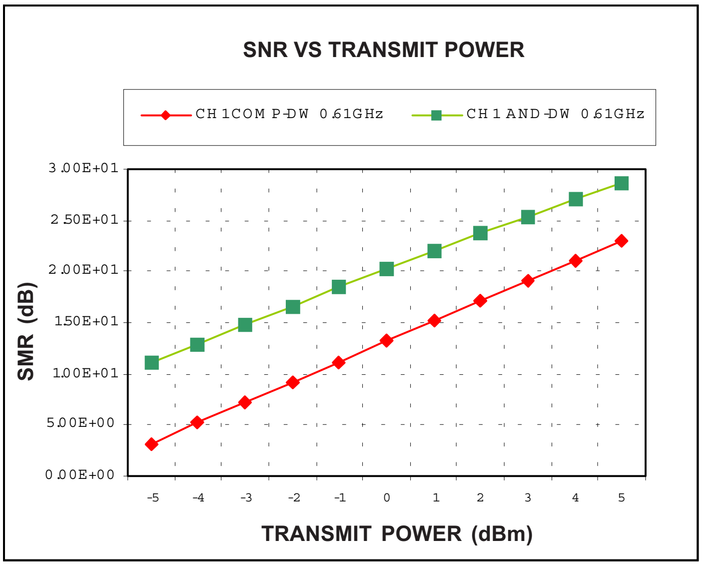

Figure 5 SNR *vs* transmit power for SCM SAC-OCDMA systems using complementary and AND detection techniques for DW

Figure 6 shows noise power decreases when the distance is increased. This is because the longer the fiber, the larger the attenuation. Hence, the overall total power in the hybrid system is reduced. However by using the proposed AND subtraction technique, it is slightly higher than the complementary subtraction technique. The results for complementary subtraction technique were measured up to 20 km only because the system cannot support longer distance at acceptable BER performance. The figure also shows that there is nearly linear reduction of output power with distance for the hybrid system using AND and complementary subtraction techniques. For example

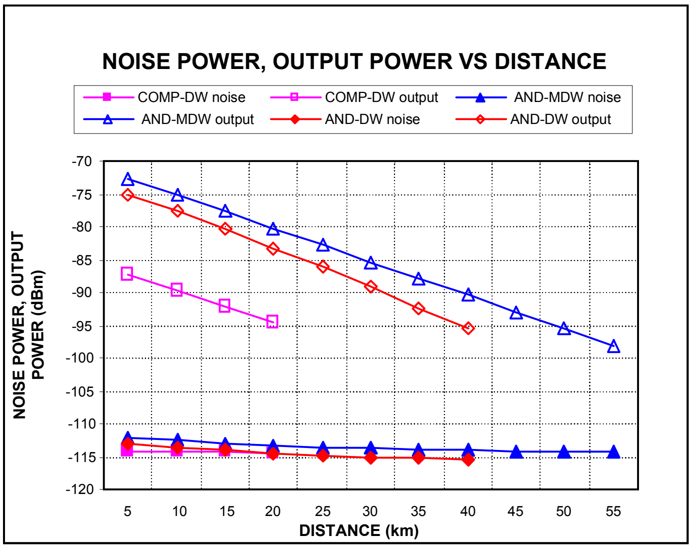

Figure 6 Noise power and output power vs distance for SCM SAC-OCDMA systems using complementary and AND detection techniques for DW and MDW

at the distance of 10 km, the output power for the system using AND subtraction and complementary subtraction techniques are about –78 dBm and –90 dBm, respectively. As a result, the output power of the system using AND subtraction is increased by 12 dB.

Therefore the effectiveness of the newly proposed AND subtraction detection technique for the SCM SAC-OCDMA system is confirmed and the validity is proven through experimental simulation.

6.0 CONCLUSION

In this paper, 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.

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