

## OPTIMIZATION OF POWER IN OPTICAL OFDM SYSTEM

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### ABSTRACT

The application of the optical sensors and the optical devices make it possible to realize the configuration of an all optical OFDM system. The use of optical OFDM is proposed for achieving high bit rate data transmission. It is also utilized for reducing the inter symbol interference. The infrared radiation, as a medium for the high speed and short range wireless digital communication has been applied in optical wireless communications. This proposed system will show the promising results for a high speed optical wireless channel. In this paper, the history of research and development on OFDM and COFDM is reviewed. Then, the basic principles, performance and implementation of OFDM and COFDM are examined. Analysis is given to enable the selection of key elements for meeting the constraints of the required applications. Based on the ATV channel model, performance expectation of COFDM under imperfect channel conditions and implementation issues are examined in details.

**Keywords:** Cyclic Prefix, DFB Lasers, Orthogonal Frequency Division Multiplexing, Inter symbol Interference (ISI) Inter channel Interference (ICI).

### 1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is used in many broadband wired and wireless communication systems but until recently has not been used in optical communications. Recent research has shown that OFDM can be applied to many optical communication systems, including both single mode and multimode optical fiber applications and optical wireless systems. At this year's OFC conference two experimental demonstrations were presented of transmission at 20 Gb/s over hundreds or thousands of kilometers of single mode fiber using one optical carrier. One of the main benefits of these fiber-optic OFDM systems is that these transmission systems are realized without any kind of optical chromatic dispersion compensation. In both cases compensation was achieved digitally in the receiver using the properties of OFDM. Although both papers used OFDM, two fundamentally different approaches were used, namely direct-detection optical OFDM (DD-OOFDM) and coherent optical OFDM (CO-OFDM). The main advantages of DD-OOFDM is that it is a more cost-effective solution and very tolerant to laser phase noise, whereas CO-OFDM is a more spectrally efficient solution and theoretically provides higher ASE-sensitivity. In this talk, Sander Jansen will discuss CO-OFDM as a modulation technique for long-haul transmission systems. Several design and implementation aspects of a CO-OFDM system are reviewed and in particular phase noise compensation is discussed.

Orthogonal frequency division multiplexing (OFDM) has been widely employed into numerous digital standards for broad-range of applications such

as digital audio/video broadcasting and wire line/wireless communication systems. Recently it has been shown that OFDM can be applied in optical long haul transmission systems and had many advantages over conventional single-carrier modulation format [1]. Many key merits of the OFDM techniques have been studied and proven in the communications industry. Firstly, the frequency spectra of OFDM sub carriers are partially overlapped, resulting in high spectral efficiency. Secondly, the channel dispersion of the transmission system is easily estimated and removed, and thirdly, the signal processing in the OFDM transceiver can take advantage of the efficient algorithm of FFT/IFFT with low computation complexity.

Due to the recent advances of digital signal processing (DSP) and very large scale integrated circuit technologies, the initial obstacles of OFDM implementation, such as massive complex computation, and high speed memory do not exist anymore. Another reason for the growing popularity of OFDM is that only very recently its optimal performance has been proven theoretically [4].

Recently, the proposed 8-VSB modulation subsystem has been tested in Charlotte, NC by PBS, MSTV, and Cable labs. It is expected that the test results will provide valuable information on the performance of the 8-VSB system. In this paper, an overview of OFDMCOFDM research and development is presented. The motivations of using OFDMCOFDM and their applications are discussed. The principles of the technology are examined in details. Analysis is given on how to select key system elements. In addition, the performance expectations of

COFDM under imperfect channel conditions and implementation issues are examined.

## 2. POWER EFFICIENT OPTICAL OFDM

The discussions are given below.

### 2.1 OFDM Signals

In OFDM, signals are transmitted in parallel on a number of subcarriers at different frequencies. Usually quadrature amplitude modulation (QAM) modulates each sub carrier. The transmitter uses an inverse fast Fourier transform (IFFT) to generate a sampled waveform. Let  $X(m)$  be the complex number representing the constellation point on the  $m$ th subcarrier of a given symbol [7]. Then the baseband time domain samples for that symbol are given by  $x(k)$  where

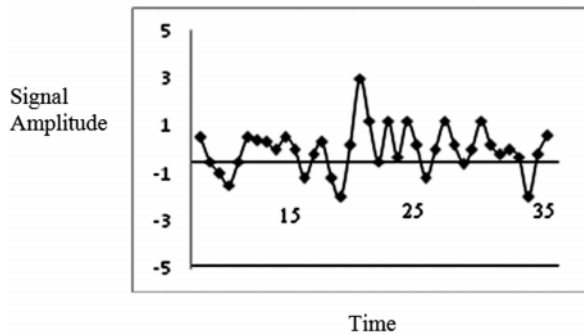


Figure 1(a): All Subcarrier Modulated

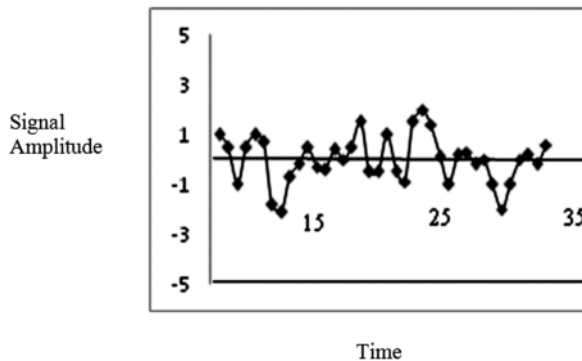


Figure 1(b): Only Odd Subcarriers Modulated

$N$  is the size of the IFFT. In general,  $x(k)$  and  $X(m)$  are complex. For baseband systems the frequency domain vector  $X$  is constrained to have Hermitian symmetry, so that  $x(k)$  is real. Figure 1a shows samples of a typical OFDM baseband symbol and the waveform  $x(t)$  which could be generated from them. Figure 1b shows a symbol where only odd subcarriers are used. In this case, for clarity,  $N/4 = 32$ , although typical values range from 64 to 8192. OFDM signals have a high peak-to-average power ratio. For  $N=64$  the central limit theorem applies and the distributions of  $x(k)$  and  $x(t)$  are approximately Gaussian.

### 2.2 Optical OFDM

Optical OFDM systems [8] a unipolar signal  $x_{dc}(t)$  is derived from  $x(t)$  by adding a DC bias. In Figure 2a the bias is twice the standard deviation of  $x(t)$ . For a fixed bias, there will be occasional OFDM symbols with large negative peaks which will be clipped, adding noise to the signal. Because  $x_{dc}(t)$  gives the intensity of the optical signal, the average transmitted optical power is approximately equal to the DC bias, which in this example is 2, for an RMS electrical power of unity. Thus this system is very inefficient in terms of optical power. We propose using no bias. In the new scheme the signal  $x_{dc}(t)$  shown in Figure 2b would be transmitted. All negative values are forced to zero. We will show that if the subcarrier frequencies used for data transmission are correctly chosen, the data can be retrieved from a signal of this form with little, or for some configurations, no in-band clipping noise. Optical OFDM Signal consisting of the DC Biased OFDM signals and clipped OFDM signals. The difference between these two are given in the figure 2(a) and 2(b) between these two are given in the figure 2a and 2b, showing that the values of the signal amplitude is always positive for the DC biased OFDM where as the values of signal amplitude are almost Linear in nature. Spectral efficiency is an important aspect of WDM systems. Optical OFDM's spectral efficiency is up to 1 bit/s/Hz, in principle. This method utilizes the orthogonality between the spectral profiles of each channel [9].

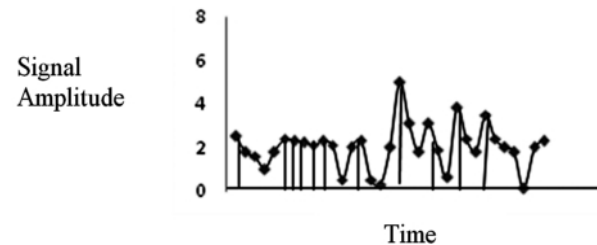


Figure 2(a): Optical OFDM Signal DC Biased OFDM

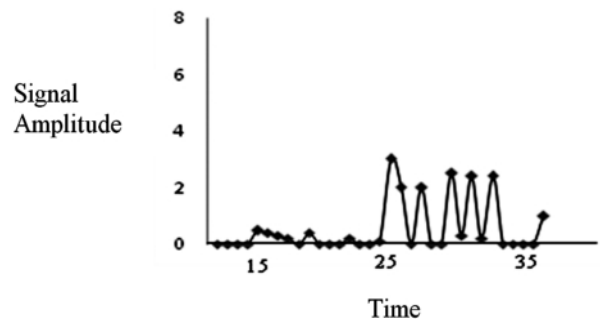


Figure 2(b): Clipped Optical OFDM Signal

The  $N$  multiplexed signals, whose frequency spacing is  $f$ , can be represented as

$$S(k\Delta t) = \sum_{n=0}^{N-1} d_n(k\Delta t) \cdot e^{j2\pi(f_0 + n\Delta f)k\Delta t} \quad (1)$$

where  $d_n(t)$  is the data sequence of the  $n$ th channel,  $T$  is the symbol interval and  $t = T/N$  is the sampling interval. The multiplexed data sequence can be separated using a discrete Fourier transform (DFT),

$$d_n = \sum_{K=0}^{N-1} S(k\Delta t) \cdot e^{-j2\pi(f_0 + n\Delta f)k\Delta t}$$

We can implement the optical DFT as shown in Figure 1. In this Eq., the terms  $S(k t)$  and  $e - j2 k f t$  physically represent an optical delay line with delay time  $k t$ , and a phase shifter, respectively. The summation means an optical coupler. Furthermore, we require bit synchronization at the input and an optical gate at the output, because the optical DFT is effective for the duration of unchanged  $dn(t)$ . This scheme was demonstrated as shown in Figure 2. We used a Mach-Zehnder (MZ) filter for the separation and an EA modulator for the gate. In the multiplexed signals, the spectra overlapped considerably and no eye opening was observed [10].

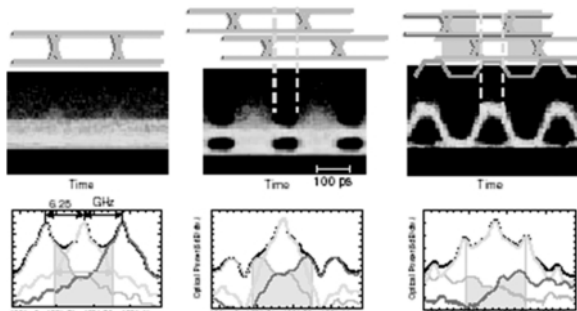


Figure 3(a): Multiplexed (b) After MZ Filter (c) After (EA) Signal gate

After the MZ filter, the eye opening was observed only when the same bit overlapped itself. After the EA modulator, only a clearly opened eye pattern was observed, and error-free operation was obtained. This scheme can completely separate one modulated spectrum from other signals that have a substantial overlap with 0.8 bit/s/Hz of spectral efficiency.

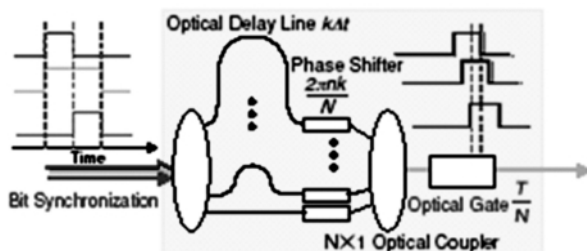


Figure 4: Optical Circuit for Discrete Fourier Transform

### 2.3 Simulated Results

Simulations using the introduced OFDM setups have been conducted in order to show the impact of differential

group delay on the transmission performance. Throughout this work we set the bit-rate to 10 Gb/s and use a sub-carrier spacing of approximately 39 MHz which corresponds to an OFDM symbol duration of 25.6 ns. 3.2 ns thereof is the duration of the cyclic prefix, i.e.  $r_{CP} = 1/8$  of the original OFDM symbol is added for avoiding inter-symbol interference [11].

At first the following results show the bit error ratio (BER) versus OSNR (noise bandwidth 12.5 GHz) for the OFDM setup using coherent detection. The number of sub-carriers was set to 256; BPSK modulation was used, channel estimation is based on 3 preamble symbols known to the receiver.

A further aspect which leads to implementation losses shall be neglected here: non-zero laser line width. The authors of [12] assume a line width of 100 kHz. It is well-known that an OFDM system is distinctly more sensitive to non-zero carrier line width than single carrier systems. For a given oscillator line width  $LW$  there is an approximate SNR degradation  $\Delta SNR$  (in dB) of [5] is

$$\Delta SNR \cong \frac{10}{\ln 10} \frac{1}{60} \left(4\pi \frac{Lw}{\Delta f}\right) \frac{Es}{No} \quad (3)$$

The crucial measure is the ratio of the linewidth and the sub-carrier spacing  $f$ . Note that the degradation is proportional with  $ES/NO$ , which denotes the (linear) SNR within the considered sub-carrier. Given  $LW$  equaling 100 kHz and  $f = 39$  MHz the approximate SNR degradation is 0.26 dB for a sub-carrier SNR of 10 dB. In this case a laser linewidth of 2 MHz leads to 5.1 dB penalty.

#### 2.3.1 Simulation Through I/Q Modulation and Coherent Detection

Figure 3 shows the BER performance for various DGD values up to 70 ps (for worst case launch). We observe distinct performance degradation for rising DGD measures.

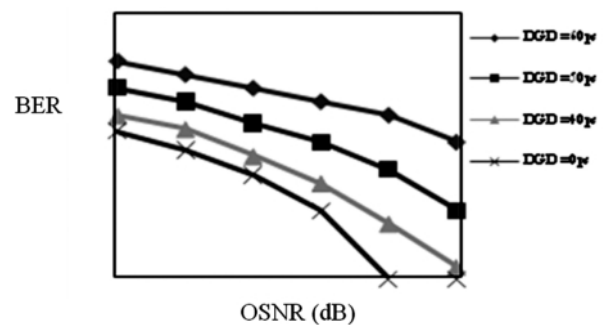


Figure 5: BER Performance (Coherent System, 256 Subcarriers, BPSK Modulation)

This is because DGD depolarizes the optical signal. The coherent detector down-converts the signal fraction which is 45°-linearly polarized; the signal fraction of the orthogonal state of polarization is lost. In terms of

transfer functions this effect causes fading as depicted in Figure 4. The SNR of the outer sub-carriers is reduced which leads to an increasing bit error ratio.

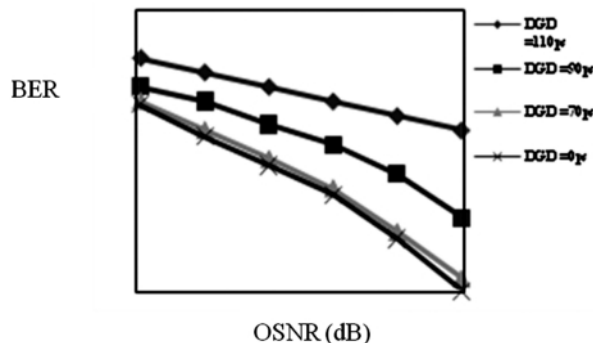


Figure 6: BER Performance (Coherent System, 128 Subcarriers, 4QAM)

### 2.3.2 SSB Transmission and Direct Detection

Next the SSB direct detection system was investigated. 128 sub-carriers have been modulated using a 4QAM constellation. As depicted in Figure 2, after SSB filtering the modulated sub-carriers are located in the upper half of the upper side-band. It should be mentioned that this architecture requires half of the optical signal power reserved for the carrier in order to achieve good RX sensitivity. However, this fraction of the signal does not contain information.

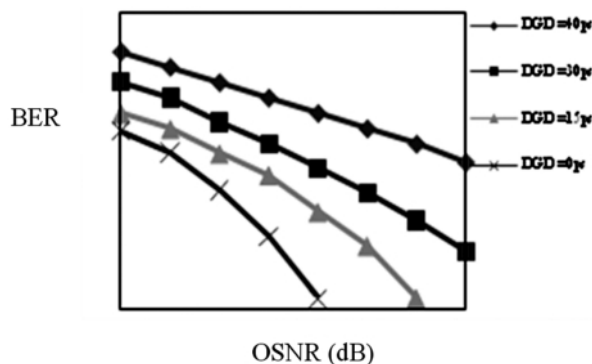


Figure 7: BER Performance (SSB System, 128 Subcarriers, 4 QAM)

## 3. CONCLUSIONS

This paper describes the utility of optical devices and optical sensors in the realization of an all optical OFDM System. The analysis of the OFDM Signal and Optical OFDM signal has a great importance in the utilization of these systems in optical wireless networks. The proposed power estimated optical OFDM system is very useful for all the industrial and telecommunication purposes.

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