Abstract—OFDM is a multi-carrier-modulation (MCM) which is deliberated as a special case of FDM technology. Single polarization fibers means that the fundamental mode propagate in only one polarization state. Single polarization Optical OFDM system is simulated with Opti-system V14.0 program. "Coherent optical orthogonal frequency division multiplexing (CO-OFDM)" system with different effective area and cyclic prefix length was investigated to reach high data rates with long distance by using single mode fiber (SMF). The performance of the system has been deliberated by calculating signal to noise ratio (SNR), bit error rate (BER) and optical signal to noise ratio (OSNR), it was found that as the effective area increase, the BER decreases. The optimal value is at a BER of 75*10^-6 where the cyclic prefix is at 1/16 (6.25%) and the used effective area is 150 µm².

Index Terms—BER, Cyclic prefix, Effective Area, Launch power, O-OFDM, Optisystem, Single Polarization.

I. INTRODUCTION

High speed digital communications has broadly used Orthogonal Frequency Division Multiplexing all through last three decades. There are many obstacles of the OFDM implementation are such as Digital Signal Processing (DSP), massive complex computation and high speed memory due to the Very Large Scale Integrated circuit (VLSI) that marked as an nominal technologies [1]. For high capacity transmission systems Optical Orthogonal Frequency Division Multiplexing (O-OFDM) is considered as a combination of modulation and multiplexing arrangement. [2]

The revolutionary work of Robert W. Chang was published on the formation of band-limited orthogonal signals and it's deliberated as the first OFDM system [3]. A genuine increment of consideration in optical OFDM from the optical communication has lately perceived. Optical OFDM was recommended as a remarkable modulation scheme for high data systems either in Direct Detection (DD) [4, 5] or coherent detection [6].

The "Coherent optical orthogonal frequency-division multiplexing (CO-OFDM)" has been broadly examined due to its favorable circumstances such as flexible bandwidth scalability and allocation, low required sampling rates and high spectral efficiencies [7].

II. THEORY

The propagation of the fundamental mode in single one polarization state is called the single polarization. The aim of this paper is to discuss the main two subjects which are the cyclic prefix and the effective area; these two parameters are presented below.

A. CYCLIC PREFIX (CP)

In media transmission, duplicating the finish of the symbol and sending it toward the start is called Cyclic Prefix [8]. This additional part will be removed at the receiver; the main objective of using cyclic prefix is to decrease the effect of Inter-symbol-interference and to offer strength to the OFDM signal, the cyclic prefix length (T cp) must be picked more noteworthy than the delay spread (Δt) to decreases the Inter-Carrier-Interference and Inter-Symbol-Interference properties as displayed in equation (1):

$$T_{cp} > DL \frac{c}{f} \frac{R}{m} (1+r_{cp})$$

Where $T_{cp}$ refer to the interval of the cyclic prefix, $D$ is the chromatic dispersion, $L$ is the length of the fiber, $f$ is frequency of optical carrier, $R$ is the data rate, $m$ is the number of bits, $r_{cp}$ is denoting as the ratio of cyclic prefix length [9]. Adding the cyclic prefix to the signal has a weak point which is the data loss by means of the decrease of Signal to Noise Ratio (SNR) as appeared in equation below.

$$SNR_{loss} = -10\log(1 - \frac{T_{cp}}{T})$$

Where $T$ is the data symbol length and $T_{cp}$ is the cyclic prefix length, to minimize the SNR loss, the cyclic prefix ought not be larger than required. The reduced Guard Interval in Coherent-OFDM systems accomplished less ICI because shorter symbol intervals are employed [10, 11], if the cyclic prefix length is high, this takes higher vitality for transmission and it won't convey any information and this lead up to a ruin in the system performance, on the other hand the cyclic prefix can't compensate dispersion effects if the cyclic prefix length is undersized [9].

B. EFFECTIVE AREA

The nonlinear effects of the fiber are an effective parameter on the power of the electromagnetic field in the medium. The effective area (A eff) of the fiber is deliberated as a standout amongst the most vital optical property which shows the

Rend N. Alrays, is currently a MSc. Student in the University of Technology. E.mail: rne.ghaeel@yahoo.com
Sinan M. Abdul Satar, is currently a MSc. Student in the University of Technology. E.mail: sinansma@yahoo.com Razi J. Al-Azawi is currently an assistant prof. in the University of Technology. E.mail: 140009@uotechnology.edu.iq
The effective area of the fiber is computed by using the next equation [12].

\[
A_{\text{eff}} = \frac{2\pi}{\int_0^\infty |\psi(r)|^2 r dr} \cdot \frac{\int_0^\infty |\psi(r)|^4 r dr}{2}
\]  

(3)

Where \( r \) is the radius of the fiber and \( r \) is calculated from the central longitudinal axis of the fiber and \( \psi(r) \) refers to the modal field distribution.

The ultra-extensive effective area of the fiber (150 µm²) is used to decrease the effects of the nonlinearities, as it allow the higher launch of signal power into the fiber and it requires a low attenuation to decrease the loss of the optical signal [13], effective area of the fiber is shown in figure (1).

![Figure (1): The effective area of the optical fiber.](image)

### III. SINGLE POLARIZATION OFDM SYSTEM DESCRIPTION

Optical-OFDM system design is performed by using Optisystem 14.0 [14]. The optisystem software is used to produce the fiber channel and its influence on the communications. The suggested single Polarization Optical OFDM (SP-O-OFDM) system block diagram is shown in figure (2) which comprises of the Optical-OFDM transmitter, which embraces the BER test set which contain the pseudo-random bit sequence generator to generate the data bits with bit rate of 40 Gb/s and sequence length of 20480 bits, a 16 Quadrature amplitude modulation (16QAM) which encode a binary signal to an electrical as it carries 4 bits per symbol, an OFDM modulation block is used to generate an OFDM signal with 128 maximum number of subcarriers, 15 points of prefix points, 6 is the number of pilot symbols and the average OFDM power is 15 dBm.

Low pass filter with depth of 100 dB and cutoff frequency of 75*symbol rate is used to lower the radiation of the band. The RF signal of the ofdm is converted to an optical signal over the RF to optical converter which comprises of a CW laser source and two mach-zehender modulators, with laser power of 10 dBm and 1 dB insertion loss of the modulator. The optical fiber is of 1000 Km length, single mode fiber, an optical amplifier is located after every 50Km of gain 10dB, 16.75 ps/nm.km is the dispersion parameter and 0.2 dB/km is the attenuation constant. The optical-OFDM receiver contain a detection as the optical signal is identified and transformed into an electrical signal with 1 A/W responsivity and photo detector type of PIN, the OFDM demodulation component where the signal is demodulated by using the fast fourier transform (FFT), a 16QAM is used to decode and convert the signals into bits. The proposed system with single polarization Optical-OFDM scheme was used, the used optical fiber is a standard-Single-Mode-Fiber consists of 20 loops of 50Km, and the system with variable value of effective area is used to explore the best value to use in the future communication applications which is varied from 60-150 µm² in steps of 10. The cyclic prefix length is also changed from (1/4 to 1/256).

![Figure (2): proposed Single Polarization Optical OFDM (SP-O-OFDM) system block diagram.](image)
IV. RESULTS AND DISCUSSION

For a Single polarization optical-OFDM signal is transmitted over an extended length of 1000Km of single mode fiber with a 40 Gbps coherent detection 16-QAM Optical-OFDM. The optimal value of effective area is 150 µm² at the cyclic prefix length of 1/16 (6.25%), where it has a BER of 75*10⁻⁶. The in-phase component of the RF spectrum after the OFDM modulation and demodulation are presented in Figure (3, 4). The OSNR and SNR are measured at 24.79 and 22.81 Sequentially.

![Figure 3: The in-phase component of RF spectrum for 1/32 CP after OFDM modulation.](image3)

The constellation diagram of the received signal at the OFDM demodulation receiver after carrier phase estimation is presented in Figure (5). The power of the RF is measured at -10 dBm after the OFDM modulation and at -37dBm after the OFDM demodulation For the effective area of 150 µm² the launch power is changed from -2 to 10 dBm, increasing power lead to decrease bit error rate value, Figure (6) shows the BER as a function of the fiber launch power per channel after 1000 km transmission for single polarization system.

![Figure 4: The in-phase component of the RF spectrum for 1/32 CP after OFDM demodulation.](image4)

The lengths of cyclic prefix (rₑ) are varied from 1/4, 1/8, 1/16, 1/32, 1/64, 1/128 and 1/256. Estimated pulse broadening using analytical expression equation (1) is tabulated in table (1).

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>DELAY SPREAD FOR VARYING LENGTHS OF CP FOR SINGLE POLARIZATION O-OFDM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclic Prefix length(rₑ)</td>
<td>Delay spread (ns)</td>
</tr>
<tr>
<td>1/4 (25%)</td>
<td>1.609</td>
</tr>
<tr>
<td>1/8 (12.5%)</td>
<td>1.448</td>
</tr>
<tr>
<td>1/16 (6.25%)</td>
<td>1.367</td>
</tr>
<tr>
<td>1/32 (3.1%)</td>
<td>1.327</td>
</tr>
<tr>
<td>1/64 (1.56%)</td>
<td>1.307</td>
</tr>
<tr>
<td>1/128 (0.78%)</td>
<td>1.297</td>
</tr>
<tr>
<td>1/256 (0.39%)</td>
<td>1.292</td>
</tr>
</tbody>
</table>

V. CONCLUSION

In this paper, we have suggested and established the enhancement of the Single Polarization Optical Orthogonal Frequency Division Multiplexing system and performed the optimal effective area and cyclic prefix length to use in terms of BER. The optimal value of the cyclic prefix is at 1/16 (6.25%), where the used effective
area is 150 µm², as it has a BER of 75×10⁻⁶, as the effective area increase the system achieves the lower bit error rate. The OSNR and SNR are measured at 24.79 and 22.81 respectively and the measured the peak to average power ratio at this CP is 8.2 dB.

REFERENCES


