Abstract - Orthogonal Frequency Division Multiplexing is an FDM modulation technique for transmitting large amounts of digital data over a radio wave. In this work a design of OFDM (Optical Frequency Division Multiplexing) system fully in optical domain using M-QAM(Quadrature Amplitude Modulation) modulation technique with different M values (16,64) and send through fibre. The conversion of electrical to optical is done by using MZIM (Mach-Zehnder Interferometric Modulator). In terms of Bit Error Rate (BER) of the two modulation schemes and varying the length of fibre, the performance are analysed by MATLAB, using Simulink tool.

Keywords: QAM; OFDM; BER; MZIM

I. INTRODUCTION

Recently, a worldwide convergence has occurred for the use of Orthogonal Frequency Division Multiplexing (OFDM) as an emerging technology for high data rates. In particular, many wireless standards (Wi-Max, IEEE802.11a, LTE, DVB) have adopted the OFDM technology as a mean to increase dramatically future wireless communications. OFDM is a particular form of Multi-carrier transmission and is suited for frequency selective channels and high data rates. This technique transforms a frequency-selective wide-band channel into a group of non-selective narrowband channels, which makes it robust against large delay spreads by preserving orthogonality in the frequency domain. Moreover, the ingenious introduction of cyclic redundancy at the transmitter reduces the complexity to only FFT processing and one tap scalar equalization at the receiver.

i) OFDM

OFDM works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequencies to the receiver. The sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other as shown in Fig1.[Orthogonality -The maximum of one signal will coincide with the zero of another signal]

Orthogonality -The principle of orthogonality helps to ensure that cross talk does not occur between the carrier frequencies. Also it is possible, from a receiver’s point of view, to extract data from one specific carrier simply by knowing its frequency. The orthogonality also allows high spectral efficiency. The orthogonality requires that the sub-carrier spacing is

$$\Delta f = \frac{K}{T_U} \text{ Hertz} \quad (1)$$

where $T_U \text{ seconds is the useful symbol duration }$ and $k$ is a positive integer, typically equal to 1.

II. OFDM SYSTEM MODEL

The schematic model for OFDM system used in the paper is shown in Fig 2. The basic and main building blocks of model shown in Fig 2 are transmitter, channel and receiver.

Fig 2. OFDM System

a) Transmitter and receiver section.
This segment consists of following blocks.
1) S/P converter and P/S converter: This block is used at both, transmitter and receiver. These blocks convert random generated data with high rate into low data rate and vice versa.
2) Data to symbol mapper and De-mapper: This block provides modulation. The input data bits are grouped decrease data rate. When input stream is of low rate, a simple BPSK modulation works well; otherwise, QPSK or 16/64-QAM is used. The selection of modulation scheme applied to each sub channel depends solely on the compromise between the data rate requirement and transmission robustness.
3) IFFT/FFT: Before IFFT, numbers of zeros are inserted in the input to make its length equal to IFFT bin size (say L, L is 64 in this paper). This addition of zeros is called zero padding, and is used only when the subcarriers are less than bin size. Generally, in OFDM system, we select the number of data symbols equal to 52 giving 12 zero symbols. Zero padding removal does the reverse at receiver.
4) Add Cyclic Prefix and remove cyclic prefix: The cyclic prefix shown in FIGURE 3. is used to mitigate ISI effect in original OFDM symbol. This is achieved by adding partial symbol information of each cycle to the beginning of the symbol. Higher is the delay spread, higher is the length of cyclic prefix, and in this paper, the CP length is chosen 1/4 of the symbol period. After CP insertion, the symbols from
parallel paths are combined to make a serial data. In OFDM, one frame length is
\[ T = TS + TCP \]  
(2)
where \( TS = NT \), \( N \) is number of carriers, and \( TCP \) is cyclic prefix duration.

![Effective channel impulse response](image)

**Fig 3. Cyclic Prefix**

This is to ensure that the orthogonal nature of the structure is maintained.

For all optical OFDM system we use the Mach Zehnder interferometric modulator to convert electrical to optical.

b) Mach-Zehnder interferometer:

A Mach-Zehnder interferometer optical modulator utilizes a mechanism such that when light propagated through a waveguide is branched in two directions and a modulation signal current is flowed through the center of each branch, there occur magnetic fields of opposite phases with respect to grounds provided on opposite sides in a sandwiching relation to the waveguides, so that the phases of light signals propagated through the respective routes become opposite to each other and the phase lead and lag are offset each other when both lights are later combined together. A Mach-Zehnder interferometric modulator is a dual waveguide device. In operation, an electromagnetic signal, such as a RF or microwave signal, interacts with an optical signal in one of the waveguides over a predetermined distance that is known as the interaction distance. The RF signal propagates in a coplanar waveguide (CPW) mode. A Mach-Zehnder optical modulator is normally constructed such that the phase difference between the two optical waveguides that propagate the split beams is 0 when voltage is not being applied. A typical Mach-Zehnder modulator includes an interferometer having an input waveguide, two arms that branch from the input waveguide, and an output waveguide at the junction of the two arms. The Mach-Zehnder optical modulator includes an optical waveguide formed on an electro-optic substrate, which for exemplary purposes is lithium niobate. The optical waveguide includes a first Y-branch, a first interferometer arm, a second interferometer arm, and a second Y-branch. An optical signal is directed into and propagates in the input waveguide, and is split between the two arms so that approximately one-half of the input optical signal propagates in each of the interferometer arms. A drive voltage is applied to one arm of the interferometer which changes the effective refractive index of that arm and introduces a phase shift in an optical signal propagating in that arm. In a Mach-Zehnder optical modulator, input light is split into two beams which each undergoes phase modulation and then are combined. In this way, modulation of light intensity is effected by mutual interference. The Mach-Zehnder interferometric optical modulator is widely used as an external modulator particularly for ultra-high-rate optical communication systems because it can provide modulation characteristics which are stable against disturbance and have a good S/N ratio by canceling out in-phase noise components with the push-pull application of a drive voltage. MZ modulators are important because they can be integrated with other optical devices, such as semiconductor lasers, optical amplifiers, or other electronic circuits. Integrated electro-optical devices, such as Mach-Zehnder interferometric optical modulators, are fabricated on substrates of electro-optic material. Among all the known substrate materials, lithium niobate is probably the most widely used because of the enhanced electro-optic properties thereof and the possibility of making low loss optical waveguides.

c) QAM

QAM (Quadrature amplitude modulation) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. In a QAM signal, there are two carriers, each having the same frequency but differing in phase by 90 degrees. One signal is called the I signal, and the other is called the Q signal. Mathematically, one of the signals can be represented by a sine wave, and the other by a cosine wave.

The two modulated carriers are combined at the source for transmission. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information. A variety of forms of QAM are available and some of the more common forms include 16 QAM, 32 QAM, 64 QAM, 128 QAM, and 256 QAM.

**Advantage of QAM**:

1) The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol.
2) By selecting a higher order format of QAM, the data rate of a link can be increased.
3) QAM achieves a greater distance between adjacent points in the I-Q plane by distributing the points more evenly. And in this way the points on the constellation are more distinct and data errors are reduced.
4) Spectral efficiency for the radio communications system.

III. FIBRE MODEL

The mostly used fiber is single mode fibers (SMF). Single-mode optical fiber is an optical fiber in which only the lowest order bound mode can propagate at the wavelength of interest typically 1300 to 1320nm. They are designed so as to maintain optical signal integrity for as long as possible. This gives single mode fibers incredible data capacity at very low losses, lending them too many various applications. As a result, the standard SMF (ITU G.652) have become the primary means through which data is transmitted. Further advanced optical fibers can also be used such as NRZ-DSF, Corning LEAF etc. with large effective index area to maximize the channel input optical power. The dispersion of the transmission medium can also be compensated using various dispersion compensating or management schemes.

The optical input signal to the fiber link can be a single pulse or a sequence of pulses. The fiber is modeled as a concatenation of randomly oriented birefringent segments, which results in a frequency dependent Jones matrix.

Each segment is represented by
\[
A_k(\omega) = \begin{bmatrix}
e^{i\delta_k/2} & 0 \\
0 & e^{-i\delta_k/2}
\end{bmatrix} \begin{bmatrix}
\cos \theta_k & \sin \theta_k \\
-sin \theta_k & \cos \theta_k
\end{bmatrix}
\] 

(3)

where \(\theta_k\) is the relative rotation angle, \(\delta_k\) is the delay of each segment and \(\omega\) is the angular frequency.

In the above Simulink model, the constant parameters are called by using the MATLAB m-file.

**Calculation of relative rotation angle & angular frequency:**

The value of relative rotation angle \(\theta_k\) is calculated using the formula

\[
\theta_k = (nL - nR) \pi / \lambda
\]

(4)

Where \(n\) is the refractive index of the fiber, \(L\) is the length of the fiber, \(R\) is the core radius and \(\lambda\) is the wavelength of the incident light. Here, for the calculation of relative rotation angle, all these parameters are taken from the SMFC-28 data sheet, as

Table I Data sheet of SMFC-28

<table>
<thead>
<tr>
<th>Single Mode Fiber, Coming SMF-28</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coating Diameter</strong></td>
</tr>
<tr>
<td><strong>Numerical Aperture</strong></td>
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<tr>
<td><strong>Cladding Diameter</strong></td>
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<tr>
<td><strong>Effective Group Index of Refraction</strong></td>
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<tr>
<td><strong>Core Diameter</strong></td>
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<tr>
<td><strong>Effective Group Index of Refraction</strong></td>
</tr>
<tr>
<td><strong>Cladding-Cladding Confinement</strong></td>
</tr>
<tr>
<td><strong>Cladding Non-Circularity</strong></td>
</tr>
<tr>
<td><strong>Mode Field Diameter @1310nm</strong></td>
</tr>
<tr>
<td><strong>Zero Dispersion Wavelength</strong></td>
</tr>
<tr>
<td><strong>Height of First Mode</strong></td>
</tr>
</tbody>
</table>

The angular frequency \(\omega\) is calculated from the carrier frequency using the formula

\[
\omega = 2\pi f
\]

(5)

where \(f\) is the carrier frequency. Here, the value of carrier frequency is taken as 7 THz. So, the value of angular frequency is calculated as 4.398*10^13 Hz.

**IV. SIMULATION**

It is assumed that the simulator will be run within the MATLAB program. Simulink is integrated with MATLAB, providing immediate access to an extensive range of tools that let you develop algorithms, analyze and visualize simulations, create batch processing scripts, customize the modeling environment, and define signal, parameter, and test data. More importantly it is assumed that the relevant blockset libraries have been initialized upon the user’s platform. This simulator was designed using Matlab 7.10(R2010a). The specific blocksets needed to ensure operation are:

(i) Simulink DSP blockset
(ii) Simulink Communications Blockset

**Data sampling:**

In accordance with the sampling theorem all data was sampled at or above the Nyquist frequency. That is all sampling was performed at twice the highest frequency within the simulator. The use of discrete sampling periods helped to ensure synchronization of the various system components as the data signal was propagated, an important consideration in optical systems. Considerations of optical transmission system parameters show the highest frequency to be that of the carrier waveform. For the purpose of this project the carrier frequency was defined as 7 THz. Thus sampling within the system needed to occur at twice this rate, approximately 16 THz in order to ensure signal aliasing issues did not arise. All block sets requiring a discrete sampling time were given this sampling rate at which to generate data.

The carrier:

The carrier waveform shown in the Fig 6 is one of the most important factors within any data transmission system. For the simulator a sinusoidal carrier was assumed as

\[
C(t) = A \cos(\omega_0 t + \Phi)
\]

(6)

Where the carrier frequency was defined as 7 thz and the phase was set to zero. Normalized amplitude is used for simplicity. High frequency, small line-width lasers generate an oscillating signal modeled in information transmission theory as a sinusoidal carrier. This simplifies simulations, as non-ideal waveforms can be difficult to model on existing software. As an expansion one could consider more exact carrier approximations based upon experimental data. Waveform generators could be used to model an exact practical carrier.

Data pulses:

For externally modulated signals the light wave pulses are modulated with the carrier (FIGURE 7.) as light waves generated by the CW laser sources. Data transmission forms another critical component of the optical system simulator. Two data pulses are considered: (i) for simplicity a standard return to zero (RZ) binary pulse and (ii) a RZ Gaussian binary pulse sequence. Eventually Gaussian waveform would be incorporated as it more accurately models the data waveforms generated in practical systems. The gradual rise and fall of the Gaussian pulse reflects the non-instantaneous rise/fall
of modern electrical/optical equipment.

Converting all optical using MZIM:

The signal so far generated are in electrical domain. This need to be converted to optical domain as this project mainly deals with all optical system. Hence by modeling Mach-Zehnder Interferometric Modulator (MZIM) in Simulink in MATLAB the electrical signal is converted to optical. The scope output after converting to optical is shown in Fig8.

![Fig 8. Scope after converting electrical to optical](image)

Then after conversion to optical domain, Inverse Fourier transform is taken for conversion from frequency domain to time domain as shown in FIGURE 9. Then cyclic prefix is done.

![Fig 9. After taking IFFT](image) ![Fig 10. After adding guard time](image)

Guard time or cyclic prefix (Fig 10.) is inserted between consecutive OFDM symbols to reduce ISI problem and multipath distortion and also multipath fading is reduced which provide bandwidth efficient system.

V. CONCLUSIONS

The OFDM signal is generated and converted into optical signal by designing MZIM modulator block using Simulink tool in MATLAB. Then the optical signal is taken IFFT and cyclic prefix is added and the output is shown in the simulation section. The behaviour OFDM with different modulation formats are to be simulated and analysed. Then send through the fibre channel and the receiver block is to be designed and the OFDM signal obtained from the fibre is passed through the receiver section and the performance is analysed by comparing the input and output signal. Thus the BER is studied for both the modulations. The investigations are based on the assumption that the optical and electronic devices are all 12 Gbit/s equipment irrespective of the modulation level. Thus we automatically increase the bit rate up to a factor of three without requesting more bandwidth or higher speed component.

VI. REFERENCES