A Matlab/Simulink Design of an Orthogonal Frequency Division Multiplexing System Model

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ABSTRACT: *The design of an orthogonal frequency division multiplexing system model is shown in this paper using the discrete multitone modulation and in-phase/quadrature modulation technique. The Matlab/Simulink software is used for the design and while the complete system models were presented, a detailed description and explanation of each block in the model is shown. Results obtained show models where no errors bits were detected.*

KEYWORDS: *orthogonal frequency division multiplexing, discrete multitone, in-phase/quadrature.*

I. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) scheme has been proved to be an effective solution to frequency selective channel response in an indoor wireless network (i.e. a multipath environment). In single carrier modulation, a single carrier having a symbol rate R (i.e. symbol period, $T_s = \frac{1}{R}$) symbols per second is used in the transmission of data serially over the channel. In a multipath fading channel, this leads to inter symbol interference (ISI) because the symbol period can be significantly less than the time dispersion thus requiring a complex equaliser to compensate for the channel distortion. OFDM offers high data rates, high bandwidth efficiency, immunity to ISI introduced by a multipath channel and avoidance of complex equalisers [1, 2]. A block diagram showing a communication system based on the OFDM modulation is shown in figure 1 below;
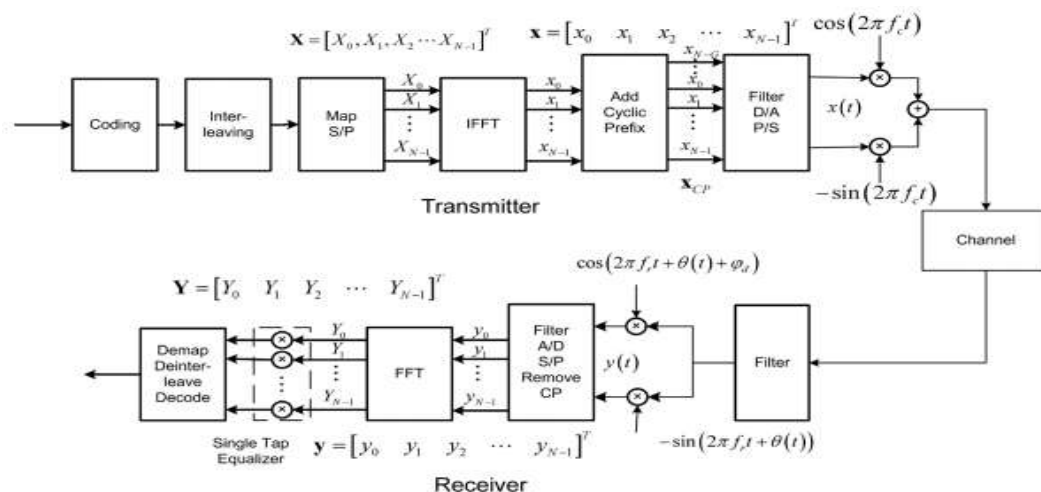

Figure 1: A block diagram showing a communication system based on the OFDM modulation [3]

In an OFDM transmission, multiple carriers N are used to transmit data symbols in a parallel manner by equally sharing the available bandwidth W. Each subcarrier is modulated at a lower symbol rate $\Delta f = \frac{W}{N}$ with the total number of subcarriers having an overall data rate equal to a single carrier modulation having the same channel bandwidth. Note that when frequency division multiplexing (FDM) and wavelength division multiplexing are used in conventional wireless systems and optical systems respectively, transmission of information is carried out on different frequencies as well but what differentiates them from OFDM is that the OFDM subcarriers frequencies are mathematically orthogonal. The Inverse Fast Fourier Transform (IFFT)

operation is performed on the subcarriers resulting in a group of overlapping sinc functions. The frequency spectrum of OFDM subcarrier signals is shown in figure 2 below;
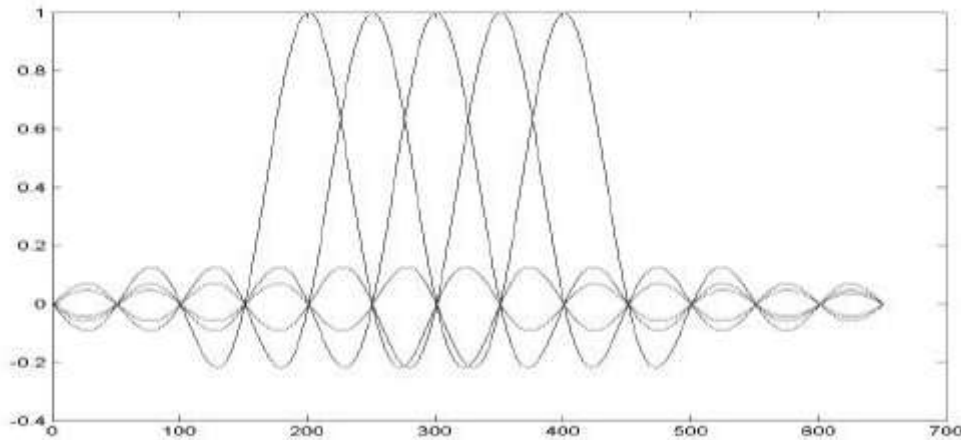

Figure 2: OFDM subcarrier signals (frequency spectrum) [4]

As observed in figure 2.3 above, though this signals overlap significantly, their orthogonal state remains the same because at the sampling instant of one of the subcarriers, the other subcarriers are zero [5, 6].In practical systems, a guard slot is added to the OFDM symbol to prevent channel distortions from disrupting the orthogonality of the subchannels. By adding a guard slot -which is shorter than the channel multi-path time spreading and longer than the symbol duration- to the OFDM symbol, it is possible to avoid inter symbol interference because the symbol period T_s of each subcarrier is longer than the channel multi-path time spreading (i.e. $T_s \gg \tau_{max}$ where $T_s = \frac{N}{R}$ and τ_{max} = maximum delay). In radio frequency (RF) transmissions, a major disadvantage of an OFDM transmission is that the peak to average ratio (PAR) is quite high. Nevertheless, the high PAR (i.e. the time signal experiencing high variations) in OFDM can be used for intensity modulation of the optical source in visible light communication systems as the human eyes cannot observe these variations [2, 5, 7].

II. THE OFDM SYSTEM MODEL DESIGN

The OFDM system model design is presented in this section of the report. The design format is related to the model in figure 2.2. The Matlab/Simulink software was used in modelling the system.

2.1 Discrete Multitone (DMT) Modulation Technique Design

In contrast to the conventional In-phase/Quadrature (I/Q) modulation OFDM technique that makes use of RF signals, the DMT modulation techniques does not require modulation with a carrier frequency. The DMT modulation technique applies Hermitian Symmetry in its operation. The Hermitian Symmetry permits the transmission of just the real part of the OFDM signal by setting the lower half subcarriers to the complex conjugate of the upper half conjugate. The transmitted real component of the OFDM signal is directly IM modulated over the optical carrier and connected to the decoder's real input after photo-detection takes place [1]. A DMT current signal x(t) can be described as [8];

$$x(t) = X_{DC} + Re(\sum_{m=1}^{M-1} s_m e^{-jw_m t}) \qquad (1)$$

where X_{DC} = LED bias current, M= Number of subcarriers, s_m = Transmitted QAM symbol in the mth subcarrier channel [8],

$$w_m = 2\pi f_m \qquad (2)$$

and [8];

$$f_m = m/T \qquad (3)$$

where T= Duration of the DMT symbol [8].

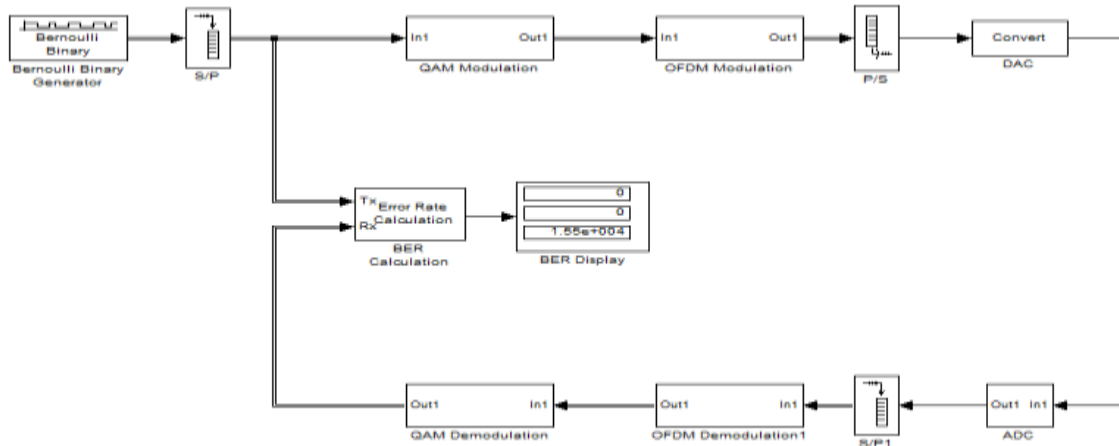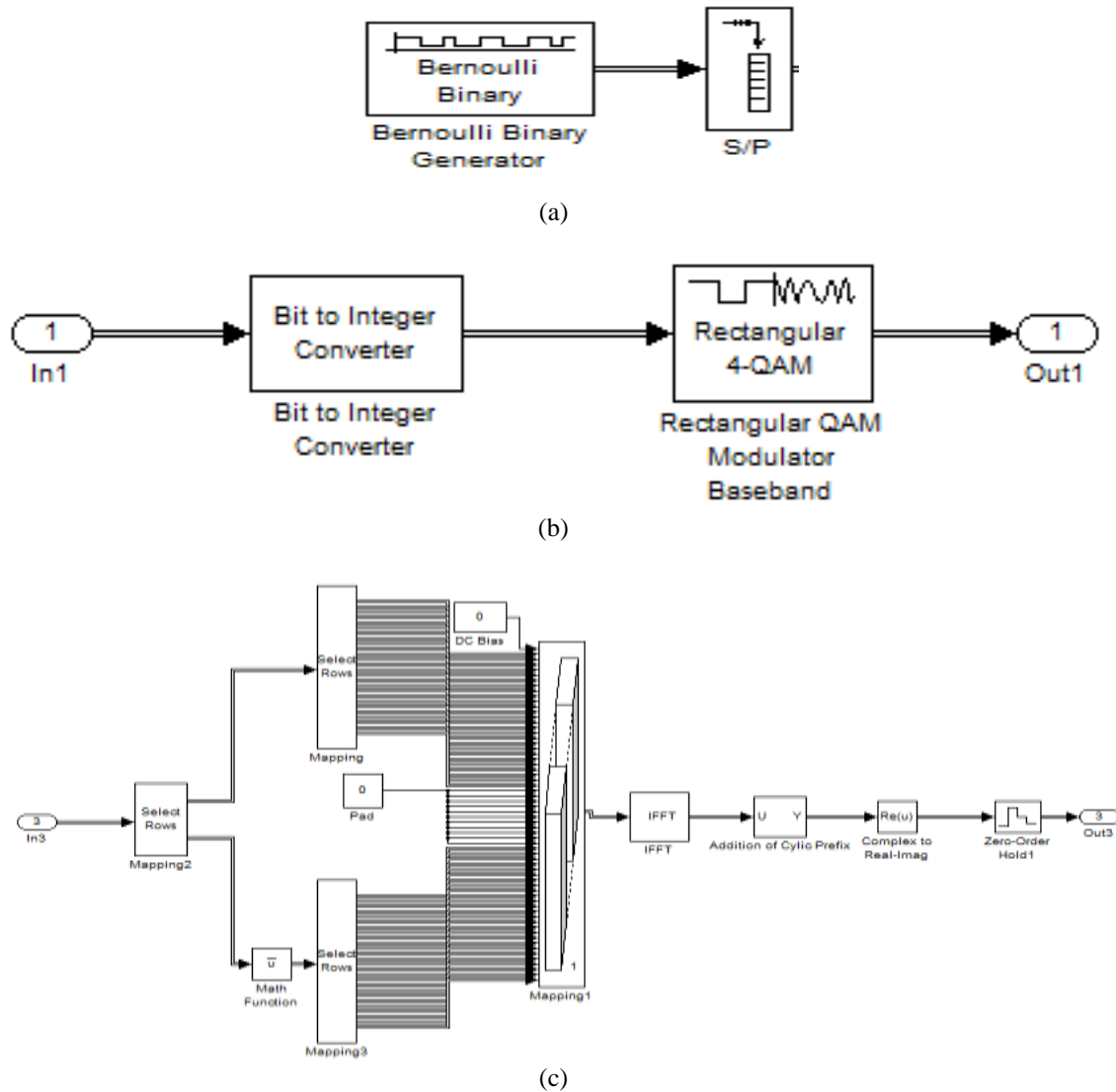A DMT OFDM system model developed with the Matlab/Simulink software is shown in figure 3 below;

Figure 3: A DMT OFDM system model

Figure 3 above shows a DMT system model designed with the Matlab/Simulink software. A detailed description and explanation of some of the blocks used in figure 3 is given in figure 4 below;
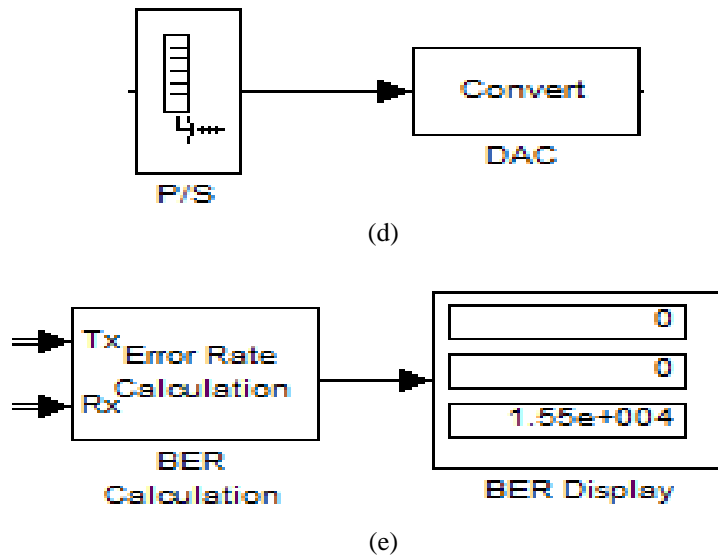

(a)

(b)

(c)

(d)

(e)

Figure 4: (a) Signal Generation and serial to parallel (S/P) conversion (b) Symbol Modulation in the QAM Modulation block in figure 4.1 (c) DMT Symbol Mapping, Inverse Fast Fourier Transform (IFFT) Operation and the addition of Cyclic Prefix in the OFDM Modulation block in figure 3(d) Digital to Analogue (D/A) Conversion (e) Signal detection and error rate calculation

The serial binary data representing the transmitted signal is generated by the binary generator block shown in figure 4(a) above. The generated serial data is then transferred to a serial-to-parallel (S/P) converter. Since the OFDM modulation format basically involves parallel transmissions, the S/P converter converts the data into the required parallel. In Figure 4(b), the parallel binary data is then converted into integers which represent the symbols to be modulated. Modulation of the symbol takes place in the modulator block (i.e. in the model shown above, the 4-Quadrature Amplitude Modulation (4-QAM) format is utilized). DMT Symbol Mapping, Inverse Fast Fourier Transform (IFFT) Operation and the addition of Cyclic Prefix is shown in figure 4(c). The modulated symbols are mapped into the DMT format which involves executing the Hermitian Symmetry. The IFFT operation which is the major significance of the DMT OFDM modulation format is then carried out before the addition of cyclic prefix [1, 9]. The cyclic prefix addition helps to avoid intersymbol interference provided the multipath channel length is less or at most equal to the cyclic prefix length [2]. Figure 4(d) shows the digital to analogue converter (DAC) operation after a parallel-to-serial (P/S) converter converts the parallel data into a serial format. The received signal is detected and an error rate calculation takes place at the receiver section where a reverse operation takes place. As shown in figure 4(e), there was no error in the model because a no-noise/channel scenario was assumed in order to ascertain the basic working of the model.

2.2 In-phase/Quadrature (I/Q) Modulation OFDM Technique Design

This technique is similar to the DMT technique except that for the In-phase/Quadrature (I/Q) modulation and demodulation technique, Hermitian symmetry is not required and a carrier signal is required since information is transmitted over an analogue channel. The transmitted signal is modulated by the carrier signal frequency; producing real values from the complex transmitted OFDM signal. At the receiver, a reverse operation takes place; producing a complex version of the received photo-detected signal. A complex baseband signal $x_t(t)$ is separated into $x_I(t)$ and $x_Q(t)$ where $x_I(t)$ represents the baseband signal's In-phase component and $x_Q(t)$ represents the baseband signal Quadrature component. $P_I(t)$ and $P_Q(t)$ refers to the cosine and sine carrier waves used to modulate and demodulate the I/Q components of the baseband signal respectively. Now [3];

$$P_I(t) = \sqrt{2}\cos(2\pi f_c t) \qquad (4)$$

and[3];

$$P_Q(t) = -\sqrt{2}\sin(2\pi f_c t) \qquad (5)$$

where f_c represents the carrier frequency [3].

2.2.1 Modulation

Now, the complex baseband signal $x_t(t)$ is separated into $x_I(t)$ and $x_Q(t)$;

$$x_t(t) = x_I(t) + x_Q(t) \qquad (6)$$

The In-phase baseband signal multiplied by the respective carrier wave is represented by s_I;

$s_I(t) = x_I(t). P_I(t) = x_I(t). \sqrt{2}\cos⁡(2\pi f_c t$(7)
and the Quadrature baseband signal by the respective carrier wave is represented by s_Q;

$s_Q(t) = x_Q(t). P_Q(t) = -x_Q(t). \sqrt{2}\sin⁡(2\pi f_c t)$(8)
By adding $s_I(t)$and $s_Q(t)$, a real Signal, $s_t(t)$ is produced;

$s_t(t) = s_I(t) + s_Q(t)$ (9)

$s_t(t) = x_I(t). \sqrt{2} \cos(2\pi f_c t) - x_Q(t). \sqrt{2}\sin⁡(2\pi f_c t)$ (10)
The signal $s_t(t)$ is the electrical current that drives the LED to produce light which is detected by the PD at the receiver after which demodulation occurs.

2.2.2 Demodulation
The transmitted signal, $s_t(t)$ received by the PD has to be demodulated into a baseband signal $y_r(t)$. For In-phase demodulation, $s_t(t)$ is multiplied by the carrier wave $P_I(t)$ to produce the In-phase component, $y_I(t)$ as follows [3];

$y_I(t) = s_t(t). \sqrt{2} \cos(2\pi f_c t)$ (11)

$y_I(t) = (x_I(t). \sqrt{2} \cos(2\pi f_c t) - x_Q(t). \sqrt{2}\sin⁡(2\pi f_c t)). \sqrt{2} \cos(2\pi f_c t)$ (12)

$y_I(t) = x_I(t) + x_I(t). \cos(2\pi(2f_c)t) - x_Q(t). \sin(2\pi(2f_c)t)$ (13)
And after low pass filtering [3];

$y_I(t) = LPF[y_I(t)]$ (14)
For Quadrature demodulation, $s_t(t)$ is multiplied by the carrier wave $P_2(t)$ to produce the Quadrature component, $y_Q(t)$ as follows [3];

$y_Q(t) = -s_t(t). \sqrt{2} \sin(2\pi f_c t)$ (15)

$y_Q(t) = -[x_I(t). \sqrt{2} \cos(2\pi f_c t) - x_Q(t). \sqrt{2}\sin⁡(2\pi f_c t)]. \sqrt{2} \sin(2\pi f_c t)$ (16)

$y_Q(t) = x_Q(t) - x_I(t)\cos(2\pi(2f_c)t) - \sin⁡(0) + x_Q(t). \sin(2\pi(2f_c)t)$ (17)
And after low pass filtering [3];

$y_Q(t) = LPF[y_Q(t)]$ (18)
The received In-phase and Quadrature components are then added together to produce the received baseband signal, $y_r(t)$[3];

$y_r(t) = y_I(t) + y_Q(t)$ (19)
An I/Q modulation OFDM system model developed with the Matlab/Simulink software is shown in figure 5 below;
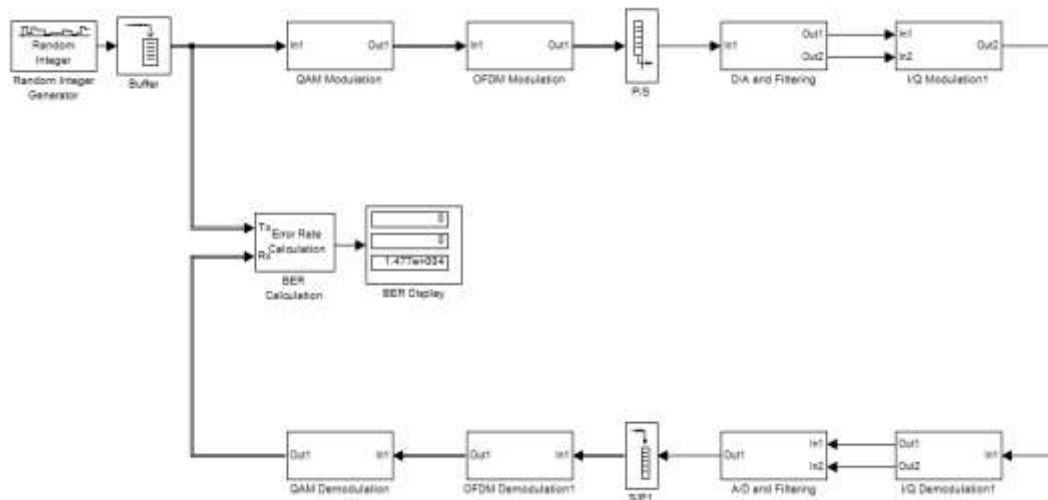

Figure 5: A DMT OFDM system model

Figure 5 above shows an I/Q modulation OFDM system model designed with the Matlab/Simulink software. A detailed description and explanation the variations (i.e. compared to the DMT case initially considered) used in figure 5 is given in figure 6 below;
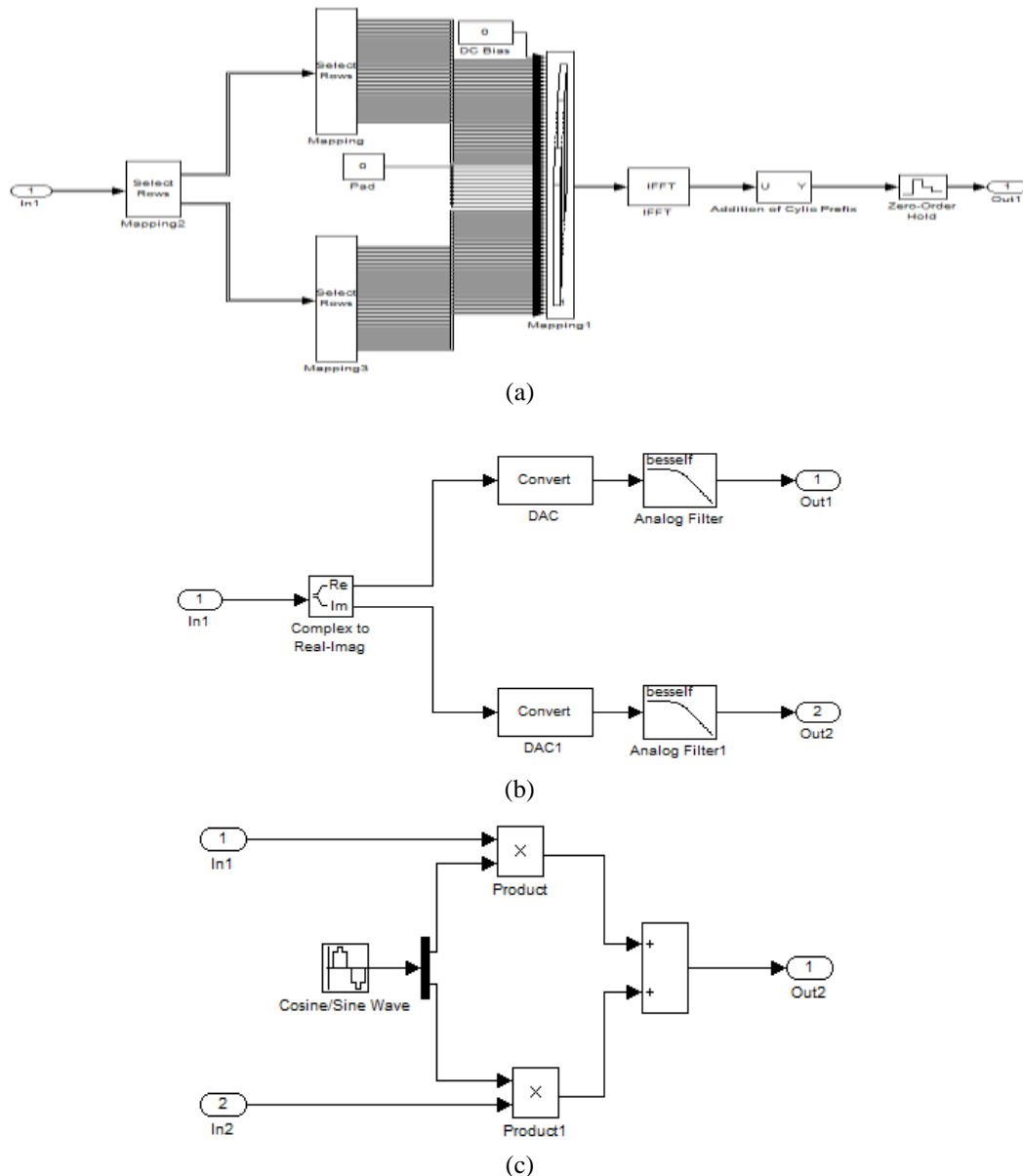
(a)

(b)

(c)

Figure 6: (a) Symbol Mapping, Inverse Fast Fourier Transform (IFFT) Operation and the addition of Cyclic Prefix in the OFDM Modulation block in figure 5(b) Digital to Analogue (D/A) Conversion and Analogue Filteringin the D/A and filtering block in figure 5(c) I/Q Modulation in the I/Q Modulation 1 block in figure 5

Figure 6(a) shows the Symbol Mapping, Inverse Fast Fourier Transform (IFFT) Operation and the addition of Cyclic Prefix for the I/Q modulation model, its different from the DMT case as there is no need to introduce a Hermitian Symmetry in the symbol mapping. The complex term generated by the QAM modulation is separated into real and imaginary parts as shown in figure 6 (b) before a DAC conversion and analogue filtering. The I/Q modulation is shown in figure 6 (c). The received signal is detected and an error rate calculation takes place at the receiver section where a reverse operation takes place. Also, there was no error in the model because a no-noise/channel scenario was assumed in order to ascertain the accuracy of the model [3].

III. CONCLUSION

In this paper, the Matlab/Simulink software was used for the design an OFDM system model using the discrete multitone modulation and in-phase/quadrature modulation techniques. In addition to the complete system models presented, a detailed description and explanation of each block in the model was shown. 15500 bits were transmitted using the discrete multitone modulation technique and 14770 bits were transmitted using the in-phase/quadrature modulation technique. BER calculations in both OFDM designs show that since no noise was present in the system, no error bits were detected.

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