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Usage of different modulation applications in OFDM systems and performance comparison

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Abstract: OFDM (orthogonal frequency division multiplexing) systems are the most efficient use of today's radio frequency spectrum. The system is the simultaneous splitting of a signal into small signals and sending them to the receiver. It is mainly a need in high-capacity data transfer and multi-user systems. Depending on the usage purpose, the OFDM method provides a data transmission with maximum accuracy at the highest speed as long as an appropriate and high-performance modulation type is used. This study performed an FDM communication simulation primarily for multiple data transmissions over a single line. After selecting the carrier frequencies used in FDM, the necessity of the OFDM communication method is proved when considering the high quality of the communication. In the next phase, performance comparisons were made by calculating the BER (Bit error rate) value at different SNR (signal to noise ratio) and multipath fading values of the modulations used in the OFDM method. Specific variable values that the modulation type providing the highest accuracy data transmission has been determined in this study. As a result of the comparison, the best BER value at 8-way communication and 0 SNR was found at 0.28 in the BPSK modulation type. In 8-way transmission and 30 SNR measurements, the lowest BER value was 0.016. In all comparisons made among the used modulation types 'BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM', the lowest BER values were determined in the BPSK modulation type.

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OFDM sistemlerinde farklı modülasyon uygulamalarının kullanımı ve performans karşılaştırması

Öz: OFDM (ortogonal frekans bölmeli çoğullama) sistemleri günümüz radyo frekans spektrumunun en verimli kullanımıdır. Sistem, bir sinyalin eş zamanlı olarak küçük sinyallere bölünerek alıcıya gönderilmesidir. Özellikle yüksek kapasiteli veri iletimi ve çok kullanıcılı sistemlerde ihtiyaç duyulmaktadır. OFDM yöntemi, kullanım amacına bağlı olarak, uygun ve yüksek performanslı bir modülasyon tipi kullanıldığı takdirde en yüksek hızda maksimum doğrulukla veri iletimi sağlamaktadır. Bu çalışmada, öncelikle tek bir hat üzerinden çoklu veri iletimi için bir FDM haberleşme simülasyonu gerçekleştirilmiştir. FDM'de kullanılan taşıyıcı frekansları seçildikten sonra, haberleşmenin yüksek kalitesi de göz önüne alındığında OFDM haberleşme yönteminin gerekliliği kanıtlanmıştır. Bir sonraki aşamada, OFDM yönteminde kullanılan modülasyonların farklı SNR (sinyal gürültü oranı) ve çok yollu sönümlenme değerlerinde BER (Bit hata oranı) değeri hesaplanarak performans karşılaştırmaları yapılmıştır. Bu çalışmada, en yüksek doğrulukta veri iletimini sağlayan modülasyon tipinin belirli değişken değerleri belirlenmiştir. Karşılaştırma sonucunda 8 yollu haberleşme ve 0 SNR'da en iyi BER değeri 0,28 olarak BPSK modülasyon tipinde bulunmuştur. 8 yollu iletim ve 30 SNR ölçümünde ise en düşük BER değeri 0,016 olmuştur. Kullanılan modülasyon tipleri 'BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM' arasında yapılan tüm karşılaştırmalarda en düşük BER değerleri BPSK modülasyon tipinde belirlenmiştir.

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1. Introduction

OFDM is a multi-carrier communication system that provides narrowband transmission with multiple carrier signals [1]. OFDM is similar to FDM (Frequency division multiplexing), allowing multiple user logins by dividing the available bandwidth into many channels [2]. However, in the OFDM method, as seen in Fig.-1, higher efficiency is reached when a carrier is closer to the other. In this case, a phase difference of 90 degrees is created to avoid interference between carriers. In this communication method, the 90-degrees phase difference between carriers is realized by Inverted Fast Fourier Transform (IFFT) in transmitters [3]. Each carrier is modulated separately, and all modulated signals are transmitted in the same bandwidth. The most used modulation techniques in OFDM communication are PSK (phase-shifted switching), which provides the phase of the carrier signal, QAM (quadratic amplitude modulation), which provides data transmission according to the amplitude and phase change of the signal [4][5]. All carriers are collected at the transmitter output and sent to the transmission channel when any modulation techniques are used. Just as the incoming signal is taken, the signal is transformed to the frequency spectrum by the Fast Fourier Transform (FFT) on the receiving side. The information signals are decomposed and converted to their original form using a balanced modulator for each carrier. As it is well-known, OFDM communication is used in digital communication systems such as WLAN, LTE, DVB-T, and 5G [6][7][8]. Thanks to the more efficient use of bandwidth, more users are accessed in each channel. In passband modulations (ASK, FSK, PSK), data transmission is carried out by successive transmission of each symbol [9][10]. The symbol for belonging to each bit used in modulation uses the entire frequency spectrum. As the communication speed increases, the symbol rate should be reduced. In this case, the spectral components of each symbol interfere with each other on the receiving system side; this is called ISI (inter-symbol interference) effect [11]. The spread of signals in the time spectrum also creates an ISI effect, and negative effects increase the BER rate on the receiver side. The energy of each symbol affects the energy of the neighboring symbol. This is seen in PDF (power density factor) graphics of symbols [12]. In this case, the channel selectivity decreases in the receiver systems. In passband modulations, instead of sending data of certain bit lengths step by step in a large time slot with a single carrier, sending a carrier to each group with the formed bit groups also increases the communication speed. By multiplying the number of bits grouped here, the communication speed increases by the number of carriers. The larger the number of carriers, the longer the time used for each symbol. Thus, the ISI effect is also reduced. The basic principle of the OFDM communication technique is based on this sub-channel method. Data is transmitted with selected subcarriers at frequencies very close to each other. The 90-degree phase difference between the carriers allows the carriers to be selected at very close frequencies. Compared to classical methods, the frequency band used by subcarriers is narrower. This way, the number of grouped bits is increased by using more subcarriers. In the literature studies, by comparing the performance of four different modulation types in Sharma et al.'s OFDM system, the BER ratios ranged from 0.4 to 0.9. [13]. Thai et al. studied estimating the BER analysis of QPSK modulation on the OFDM system [14]. Hoxha et al. examined the performance of only QPSK and 16QAM modulations in the OFDM communication system at different SNR ratios in their study [15]. In this study, six different modulation types (BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM), six different SNRs (0,5,10,15,20,30) and four multipath (1,2, 4,8) performances were compared using the OFDM system. The biggest advantage of this research over existing studies is communication was carried out by changing the SNR and multipath (multipath communication channel) via the OFDM system by using the most frequently used modulation techniques (BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM) and CP (Cyclic Prefix) constant [16]. As a result of the study, the BER performances of each modulation technique were compared separately. Different simulation applications have been made in variable SNR, Multipath, and modulation types, and it has been revealed which modulation type is more efficient in which situations.

2. Basic block diagram of OFDM method

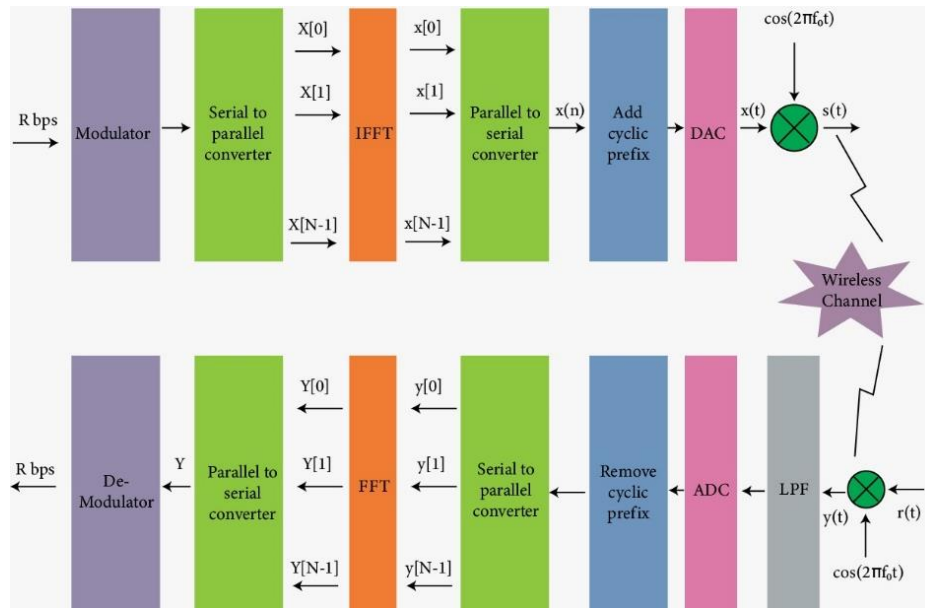OFDM basic block diagram is shown in Fig. 1.

Figure 1. Basic block diagram of OFDM system [17]

The data used in the system is a random numeric bit generator. The aim here is to reproduce the produced bit series in the last layer of the receiver part. The modulation used in the OFDM communication system is modulated by the bit series produced in the desired size, depending on the type. Modulation types such as PAM, QPSK, QAM, 16PSK, BPSK can be used as needed. The modulated signal is split into as many parallel segments as it needs to be divided into carriers. These subcarriers form the frequency multiplexing part. The number of carriers can be 2n (4, 8, 16, 32, 64). The signal converted into parallel blocks is converted into signals perpendicular to each other by taking the inverse Fourier to transform separately. The operation in Fig. 2 constitutes the main part of the OFDM system. Perpendicular symbols allow maximum carrier transmission within the transmission band.
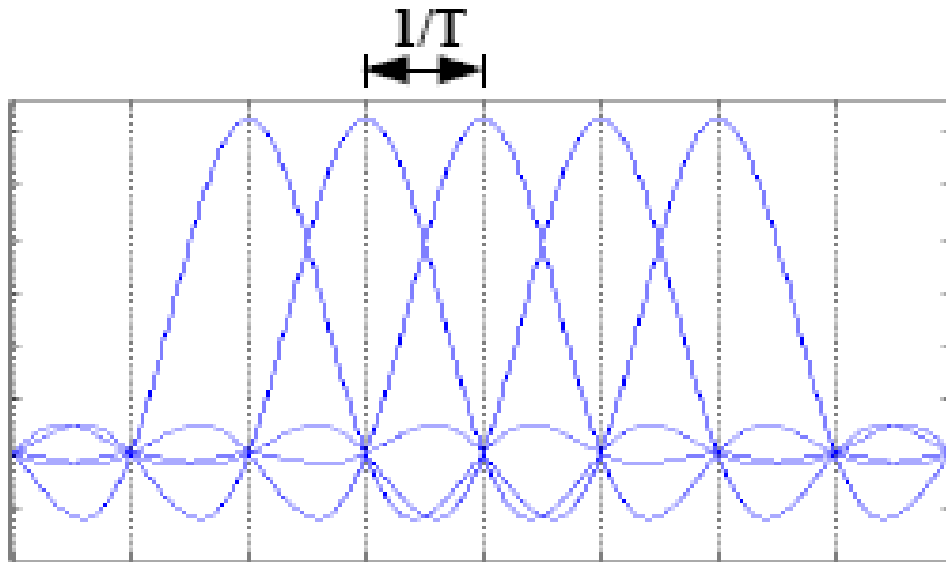

Figure 2. OFDM transmission spectrum

Adding the end of the signal to the beginning of the signal to prevent time shifts between symbols is called Cyclic Prefix insertion. This situation is used to avoid carrier interaction (ICI) and inter-symbol interaction (ISI) that occur in signal transmission [16][18].
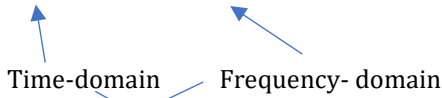
In OFDM communication, time-frequency domain transformations are performed in Fourier transform operations on the transmitter and receiver sides. When expressed in the equation; OFDM encoding processing applies the IFFT. This method:

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Encode (IFTT Processing):

frequency domain samples → time-domain sample

$$x(t) = \sum_{k=N/2}^{\frac{N}{2}-1} X[k]e^{j2\pi kt/N} \qquad (1)$$

Time-domain   Frequency- domain

$$X[k] = \frac{1}{N}\sum_{t=N/2}^{\frac{N}{2}-1} x(t)e^{-j2\pi kt/N} \qquad (2)$$

3. Different modulation techniques

3.1. PSK Modulation

In phase-shift keying (PSK), the binary signal to be transmitted changes the phase of the sine signal depending on whether 0 or 1. PSK modulation is one

If numeric 0 is to be sent:
$$A\cos(\omega t + \pi) = -A\cos(\omega t) \qquad (4)$$

If numeric 1 is to be sent:
$$A\cos(\omega t) \qquad (5)$$

In the phasor space, it appears as in Fig. 3.

Decode (FFT Processing): time-domain samples frequency domain sample;

Orthogonality of any two bits:
$$\sum^{\frac{N}{2}-1} e^{-j2\pi kt/N}e^{-j2\pi pt/N} = 0, \forall p \neq k \qquad (3)$$

The IFFT transformation ensures that the carriers are orthogonal on the transmitter side.

of the modulation types that is least affected by noise. For this reason, it is used in satellite communication and high-speed digital communication systems. There are varieties such as BPSK, QPSK, 8PSK. For example, BPSK can be expressed by the following mathematical equation.
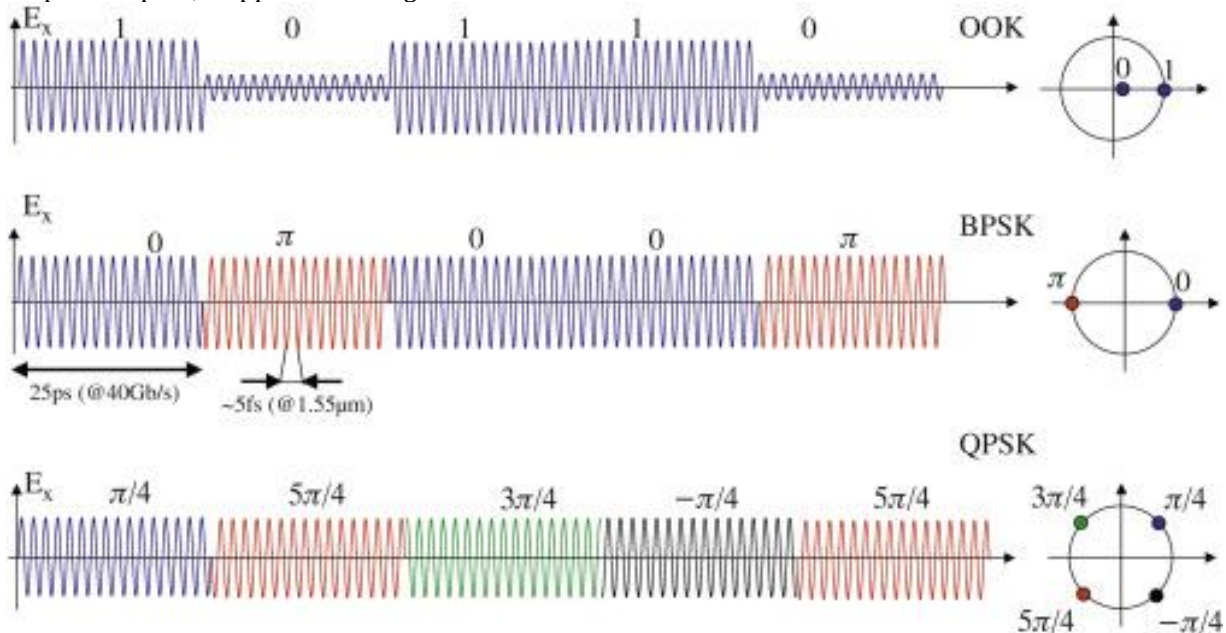

Figure 3. PSK Phasor space shapes

3.2. QAM Modulation

Quadrature amplitude modulation QAM (quadrature amplitude modulation) is a combination of amplitude modulation and PSK modulation. It is a type of modulation that contains phase and amplitude information to express a signal. It is expressed with numbers such as 16 QAM, 32 QAM, 64 QAM. 16 QAM = 4 amplitude levels + 4 different phases. Generally, the purpose of use; is to transmit

different signals in different phases with a single carrier. Today, due to the development of signal processing and communication electronics techniques and the need for more information transmission, it is mostly used as 256 QAM [2]. QAM modulation in each sub-channels formed by the DMT modulation used in the ADSL connection type can be given as an example of the above type of use. It is obtained by placing the carriers to form a square in the phasor space.

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4. Implementation of basic FDM modulation simulation and OFDM requirement

FDM effectively allows for the simultaneous transmission of multiple signals by utilizing distinct frequency bands, ensuring that each signal can be retrieved without interference during the demultiplexing process. When FDM expressed in the equation 4 and basic part of the balanced modulator(multiplier) shown in Fig-4. In Fig. 5, the

$$S(t) = \sum_{i=1}^{n} s_i(t). \cos(2\pi f_i t) \tag{4}$$

Where:
(t) is the combined signal.
(t) are the individual signals.

simulation application of the FDM communication system, which forms the basis of the OFDM communication system, is seen. In addition, 4 separate low-frequency information signals were collected by modulating in a balanced modulator with four respective carriers signals and applied to the transmission line. On the receiving side, each channel was filtered with a coherent type receiver, and four separate information signals were obtained again.

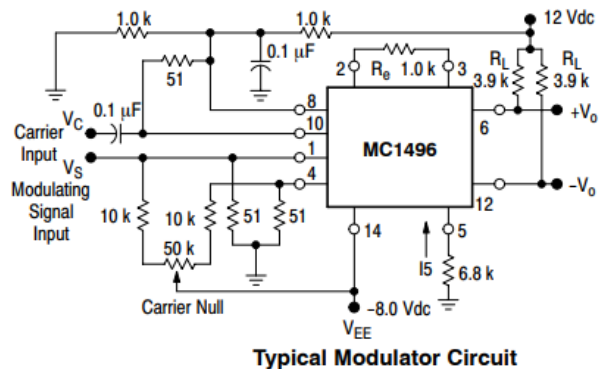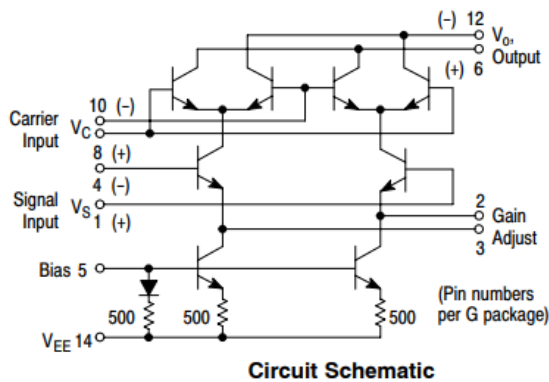are the corresponding carrier frequencies for each signal.
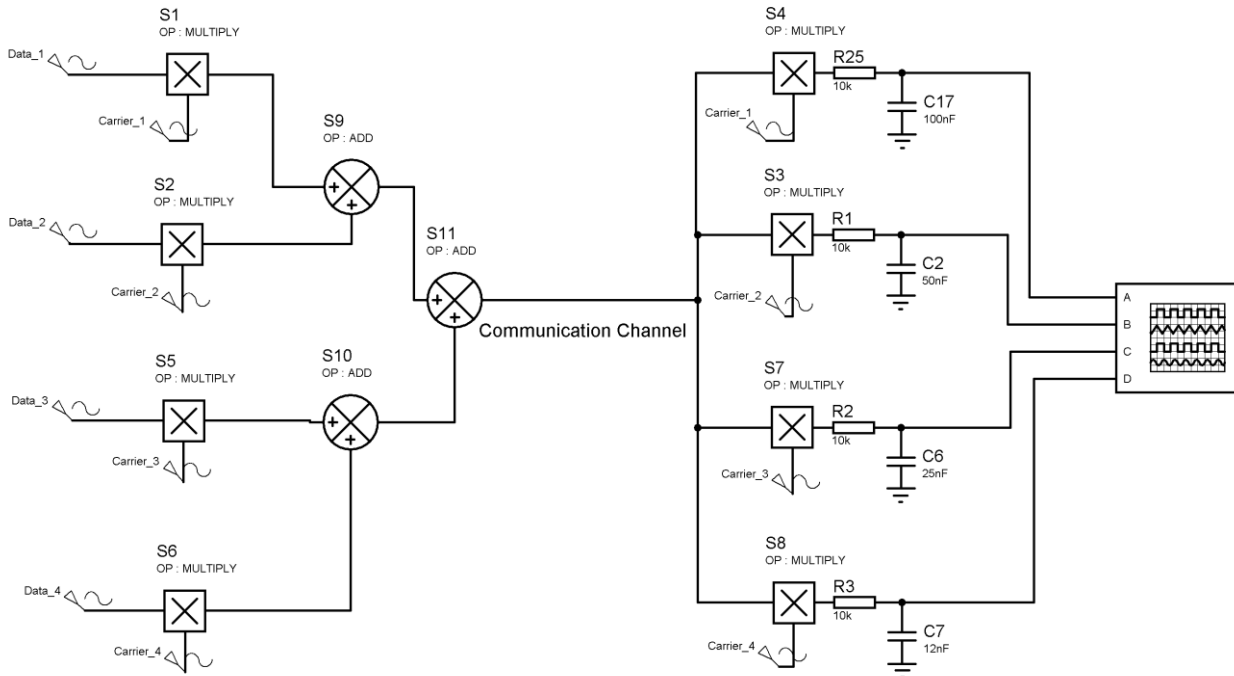

Figure 4. Balanced modulator circuit

Figure 5. FDM Communication simulation

As shown in Fig. 6, when the system bandwidth is too narrow, that is, when the carrier frequencies are too close to each other, channel information is mixed on the receiving side. For this reason, OFDM has been the reason for choosing to communicate from a single channel using minimum bandwidth [25]. In

Table 1, the carrier frequencies selected close to each other are shown to prove data interference in FDM communication.

In order to show the correct transmission of information signals in communication and to see

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them separately visually, their frequencies were selected differently.

Table 1. Frequencies selected for minimum BW in FDM communication

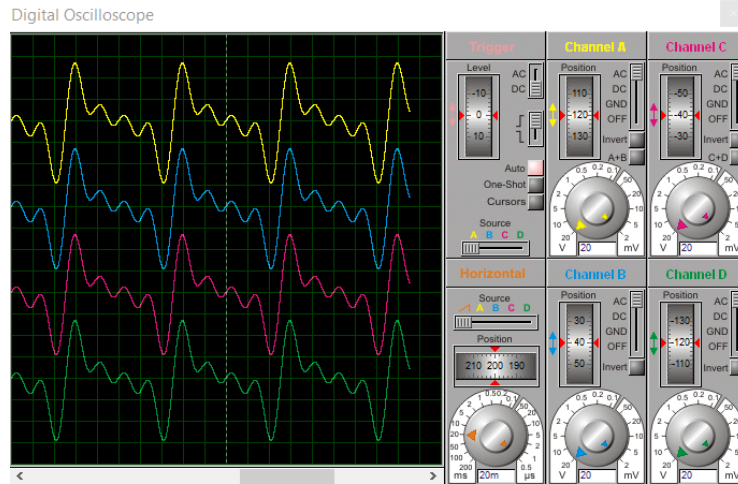| Carrier Frequency	Information signal Frequency
10 kHz	10 Hz
10.2 kHz	20 Hz
10.3 kHz	30 Hz
10.4 kHz	40 Hz

Figure 6. Signals obtained in 4 separate channels on the receiving side when carrier frequencies are selected too close for minimum BW

Fig. 7 shows that four separate information signals received from a single channel in FDM communication are separated adequately at the receiving point when the carrier frequencies are selected far from each other.

In Table 2, it is seen that the carrier frequencies are selected far from each other.

Table 2. Different carrier frequencies to avoid data interference

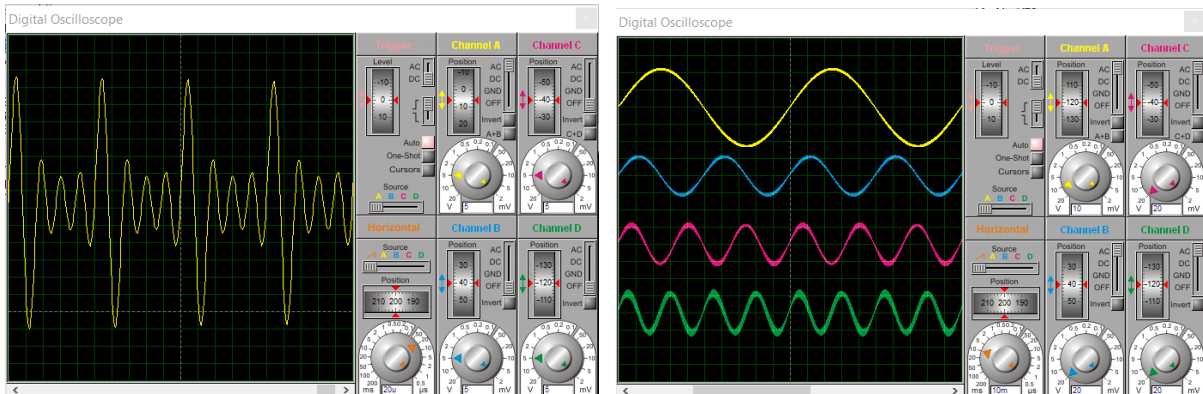| Carrier Frequency	Information signal Frequency
10 kHz	10 Hz
12 kHz	20 Hz
14 kHz	30 Hz
16 kHz	40 Hz

Figure 7: FDM communication signal and four separate information signals obtained on the receiving side

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Because selecting carrier frequencies far from each other in FDM communication increases bandwidth, its frequencies can be chosen close to each other by making the carriers perpendicular to each other (OFDM). Thus, the bandwidth used is minimal.

5. Efficiency (performance) analysis of modulation techniques

The two most efficient modulations in the OFDM technique were examined. In these modulation types, Multipath (multipath) and SNR (signal to noise ratio) are taken as variables; BER (bit error rate) was calculated by comparing the signal at the receiver output with the original signal as a result of six different modulations, respectively simulation. Other variables Cyclic Prefix (CP) 16, FFT size 64, channel estimation method LS (Least Square), are

taken as constant in the simulation program. The values obtained from seventy-two (72) different simulations have been interpreted [19].

5.1. BPSK Modulation

In the simplest form of PSK, the digital input signal alternates between 1 and 0, while the carrier's output phase shifts between two angles 180° apart. In the simulation, taking Multi-Path from 1 to 8 (1, 2, 4, 8 values), SNR (Signal-to-Noise Ratio) 0 to 30 dB (0 dB, 15 dB, 30 dB values), respectively. results have been recorded [20]. Here, the results of the highest and lowest BER values are shown in Fig.-8. According to eight different simulations of BPSK modulation, the lowest BER value was taken at 0 SNR in two channels, and the highest BER value was 30 dB in one channel.
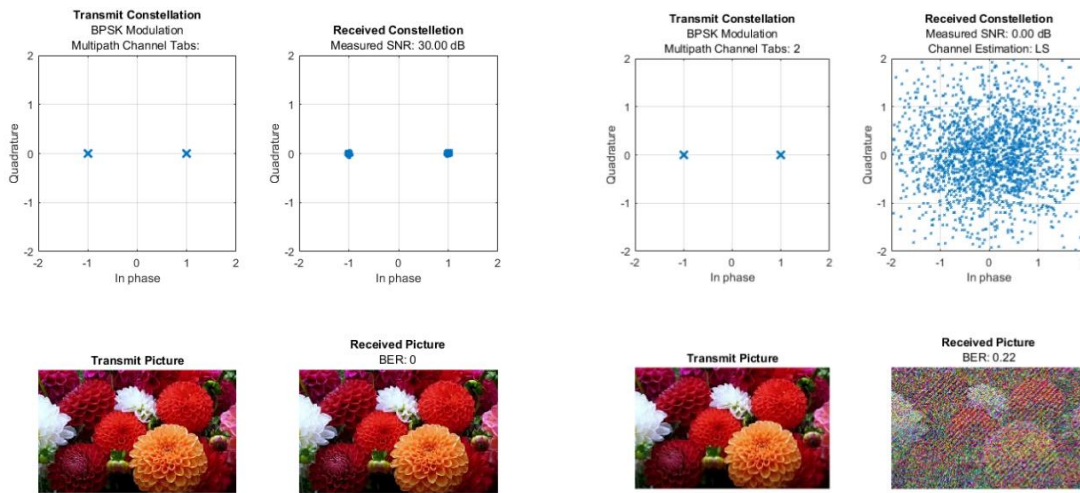

Figure 8. BPSK modulation highest and lowest BER values

5.2. QPSK Modulation

QPSK provides four different outputs for a single carrier frequency. Four different input states must occur for these four different output phases. For four different input combinations to happen in the QPSK modulator, the input signal of the QPSK modulator

must be in the form of a digital binary system [14]. With the two bits to be given to the input, four different states are created as 00,01,10,11. The same variables as in BPSK were tried in the simulation, respectively, and the highest and lowest BER values were shown in Fig. 9.
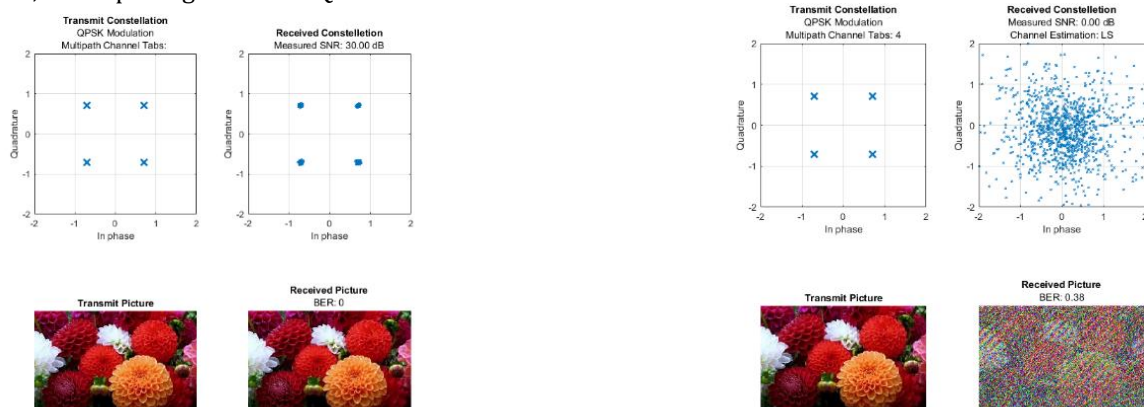

Figure 9. QPSK modulation highest and lowest BER values

5.3. 8PSK modulation

In 8PSK, eight possible states of three consecutive bits are assigned to a carrier signal's eight specified phase positions. Three bits are moved with each phase change. Phase changes are 0, 45, 90, 135, 180, 225, 270 and 315 degrees [21] . The same variables as in QPSK were tried in the simulation, respectively, and the highest and lowest BER values were shown in Fig. 10.
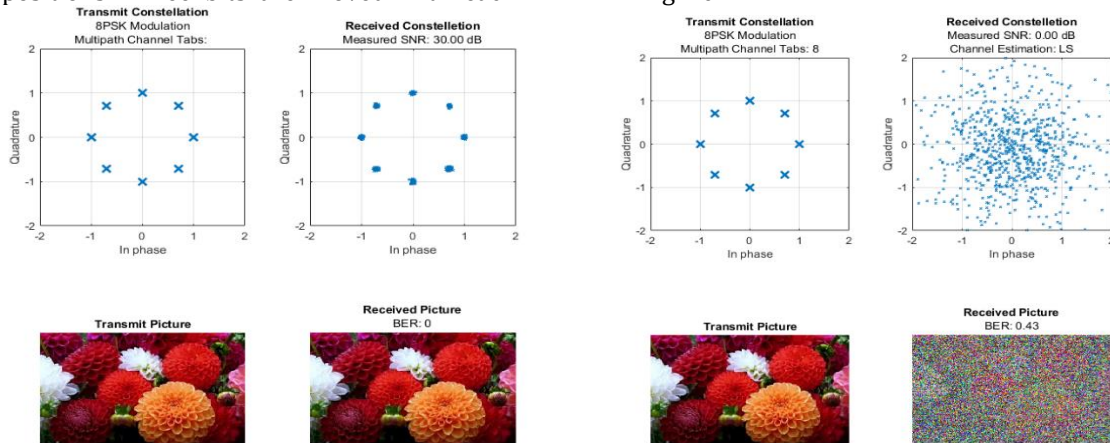

Figure. 10. 8PSK modulation highest and lowest BER values

5.4. 16-QAM Modulation

16-QAM provides 16 different outputs for a single carrier frequency. For these 16 different outputs, 16 different input states must occur. For different input combinations to occur in the 16-QAM modulator, the input signal of the 16-QAM modulator must be in the form of 4 digital bits [22]. The same variables as in 8PSK were tried in the simulation, respectively, and the highest and lowest BER values were shown in Fig. 11.
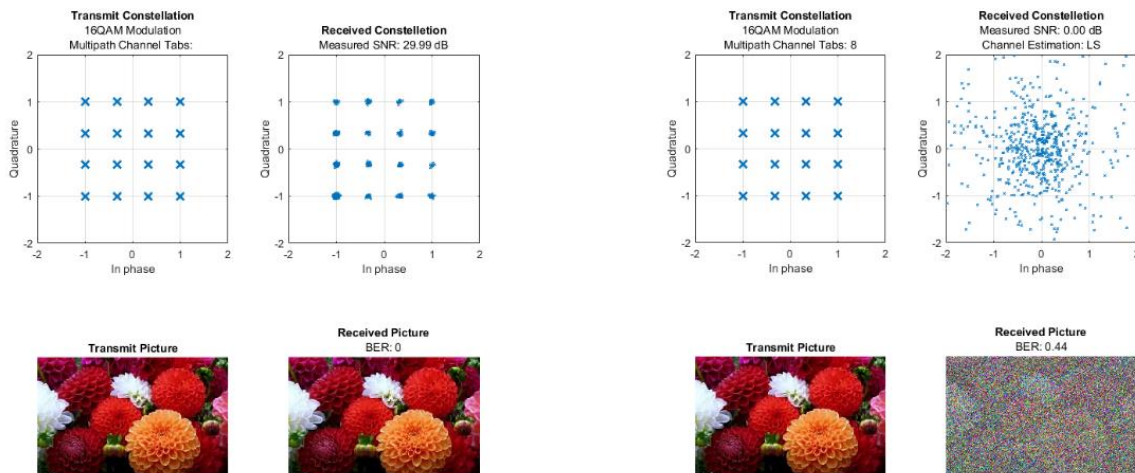

Figure 11. 16 QAM modulation highest and lowest BER values

5.5. 32-QAM Modulation

32-QAM provides 32 different outputs for a single carrier frequency. For these 32 different outputs, 16 different input states must occur. For different input combinations to occur in the 32-QAM modulator, the input signal of the 32-QAM modulator must be in the form of 5 digital bits [23]. In the simulation, the same variables as in the 16-QAM modulation were tried, respectively, and the highest and lowest BER values are shown in Fig. 12.
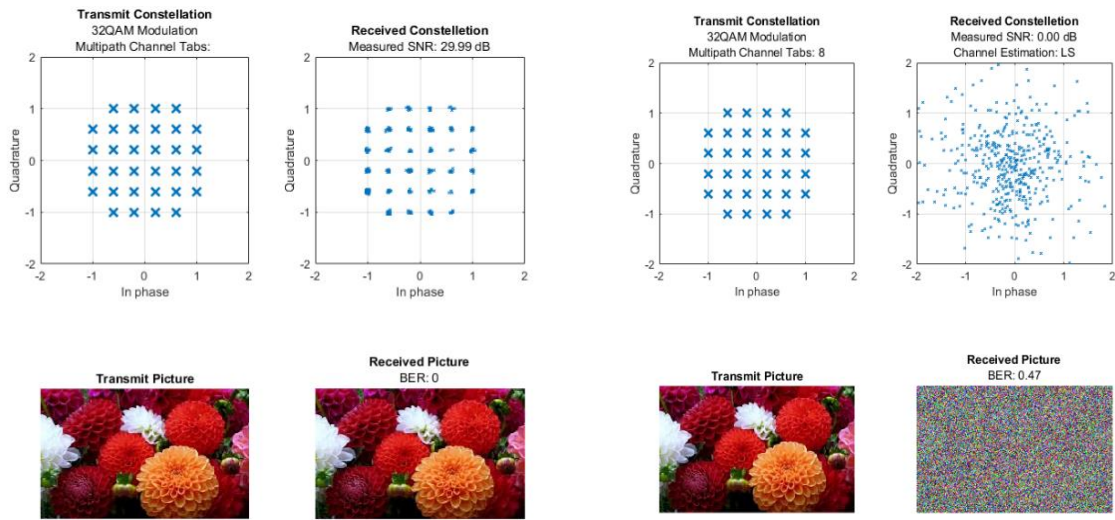
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Figure 12. 32 QAM modulation highest and lowest BER values

5.6. 64-QAM Modulation

64-QAM provides 64 different outputs for a single carrier frequency. For these 64 different outputs to occur, 64 different input states must occur. For different input combinations to occur in the 64-QAM modulator, the input signal of the 64-QAM modulator must be in the form of 6 bits [24]. The same variables were tried in the simulation as in 32-QAM modulation, respectively, and the highest and lowest BER values are shown in Fig. 13.
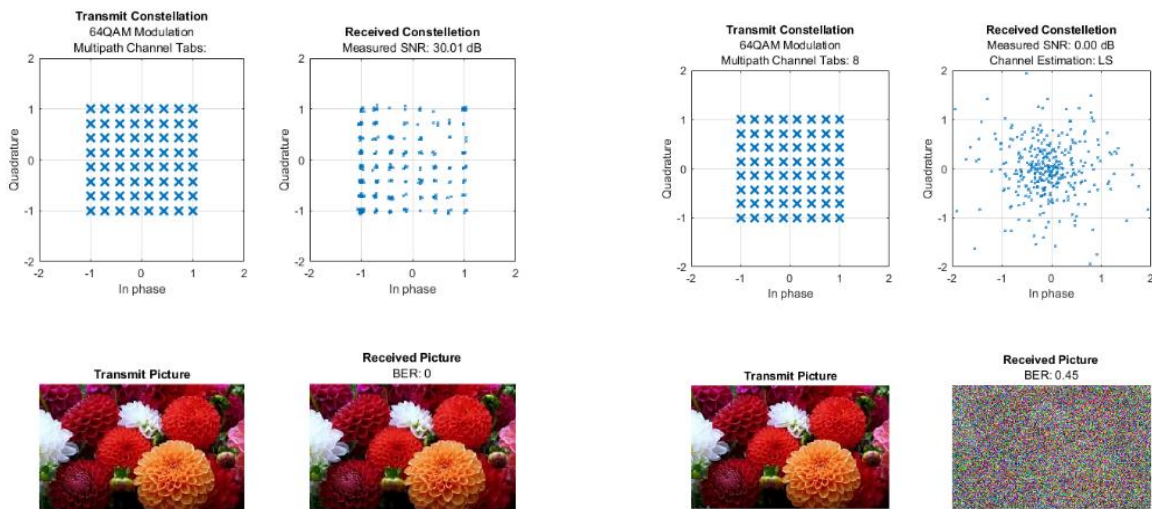

Figure 13. 64QAM modulation highest and lowest BER values
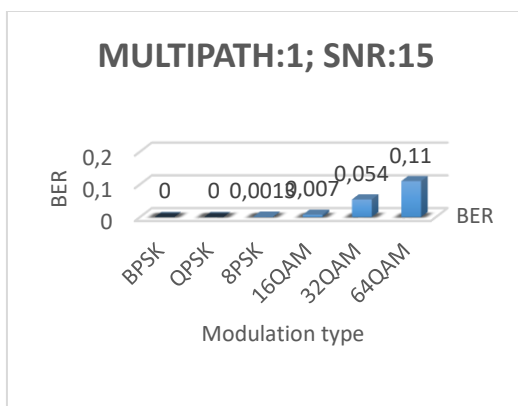

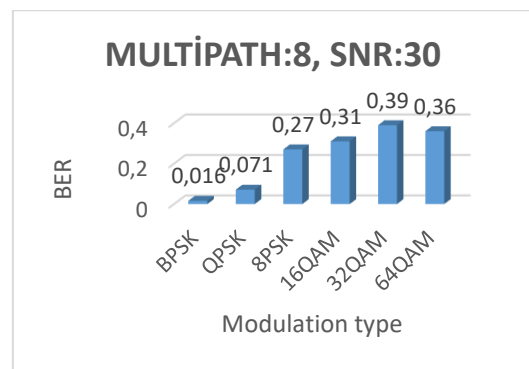Figure 14. BER ratios for single-channel and signal-to-noise ratio of 15dB

Figure 15. BPSK is the modulation type with the most successful BER rate in all simulation situations

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6. Conclusions

The study proved the necessity of an OFDM system by simulating the transmission of multiple information signals from a single channel as FDM with a coherent structure. Here, reducing bandwidth in band-modulated data transmission is the most significant advantage of the OFDM system. The study compared the types of modulation used in OFDM communication.

As a result of seventy-two (72) simulations, it was observed that there was no change in the BER values of 30 dB and beyond and that the BER ratio was 0 in all modulation types when the multi-channel was single and the SNR ratio was 30 dB. Therefore, it is seen in Fig.-14 that PSK modulation is more successful against noise than other QAM modulations in all modulation types. Furthermore, BPSK modulation has been the most successful BER ratio among all modulation types in PSK modulation, as seen in Fig.-15. Therefore, when speed and error rate are considered, BPSK and QPSK modulation is the most commonly used modulation type in OFDM communication

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