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Development And Implementation Of OFDM Transceiver For WLAN Applications

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ABSTRACT
Multi-Carrier modulation is a technique for data transmission by multiplexing a low bit-rate data streams to modulated carriers into signal Wideband Carrier. Multi-Carrier transmission has a lot of useful properties such as delay-spread tolerance and spectrum efficiency that encourage their use in untethered broadband communication. OFDM is becoming the chosen modulation technique for wireless communications. OFDM is a multi-carrier modulation scheme with densely spaced sub-carriers that has gained a lot of popularity among the broadband community in the last few years. OFDM can provide large data rate with sufficient robustness to radio channel impairments. OFDM works on the principle of Orthogonality. The orthogonality between subcarriers which is at the core of OFDM modulation requires a perfect synchronization. OFDM has properties like high spectral efficiency, Resiliency to RF interference and Lower multi-path distortion. This work is concentrated in implementing both transmitter and receiver using Matlab software and also to verify whether the transmitted data is obtained at the receiver side. As we are using the OFDM technique we will be having bandwidth efficiency when compared to the normal FDM technique.
Keywords – Digital Baseband modulation, IQ modulation, Orthogonality, OFDM, PAPR.

I. Introduction

In older multi-channel systems using FDM, the total available bandwidth is divided into N non-overlapping frequency sub-channels. Each sub-channel is modulated with a separate symbol stream and the N sub-channels are frequency multiplexed. Even though the prevention of spectral overlapping reduces inter channel interference, this leads to an inefficient use of spectrum. The guard bands on either side of each sub-channel are a waste of precious bandwidth. To overcome the problem of bandwidth wastage, we can instead use N overlapping (but orthogonal) sub-carriers, each carrying a baud rate of 1/T and spaced 1/T apart. Because of the frequency spacing selected, the sub-carriers are all mathematically orthogonal to each other. This permits the proper demodulation of the symbol streams without the requirement of non-overlapping spectra. Another way of specifying the sub-carrier orthogonality condition is to require that each sub-carrier have exactly integer number of cycles in the interval T.

OFDM is a multicarrier modulation technique. Multicarrier transmission is a method devised to deal with frequency selective channels. In frequency selective channels different frequencies experience disparate degrees of fading. The problem of variation in fading levels among different frequency components is especially aggravated for high data rate systems due to the fact that in a typical single carrier transmission the occupied bandwidth is inversely proportional to the symbol period. The basic principle of multicarrier transmission is to translate high rate serial data stream into several slower parallel streams such that the channel on each side of slow parallel streams can be considered flat. Parallel streams are modulated on subcarriers. In addition to that, by making symbol period longer on parallel streams the effect of the delay spread of the multipath channel, namely inter-symbol interference (ISI), is greatly reduced.

In multipath channels multiple copies of the transmitted signal with different delays, which depend on characteristics of the material from which the transmitted signal has been reflected, are received at the receiver. The delay spread of a channel is a measure of degree of multipath effect - it is equal to the difference between arrival times of the first and the last multipath components. Due to the fact the length of the symbol period of each parallel stream scales proportionally to the number of subcarriers used the percentage of overlap between two adjacent symbols due to delay spread and resulting from it inter-symbol interference (ISI) also decreases proportionally to the number of subcarriers. The OFDM symbols have relatively long time duration as compared to single carrier modulation with a narrow bandwidth. This increases the robustness against multipath deteriorations and results in less complex equalizers which helps in performing the channel equalization easily in the frequency domain through a bank of one-tap multipliers. The main advantage of using OFDM system is to increase the robustness against frequency selective fading or narrowband interference. Due to its advantageous features (like high data transmission rate, high bandwidth efficiency, robustness against multi-path fading and less complex equalizer), the OFDM has also been adopted as a major data transmission technique by many wireless communication standards. In spite of several advantageous features, the OFDM systems have two major concerns i.e. high PAPR of transmitted signal and synchronization (timing and frequency) at the receiver. The effects of all these issues are appearing in the form of inter-carrier and inter-symbol interference.

II. Digital Baseband modulation

The move to digital modulation provides more information capacity, compatibility with digital data services, higher data security, better quality communications, and quicker system availability. Developers of communications systems face these constraints:

- Available bandwidth
- Permissible power
- Inherent noise level of the system

The RF spectrum must be shared, yet every day there are more users for that spectrum as demand for communications services increases. Digital modulation schemes have greater capacity to convey large amounts of information than analog modulation schemes. There is a fundamental tradeoff in communication systems. Simple hardware can be used in transmitters and receivers to communicate information. However, this uses a lot of spectrum which limits the number of users. Alternatively, more complex transmitters and receivers can be used to transmit the same information over less bandwidth. The transition to more and more spectrally efficient transmission techniques requires more and more complex hardware. Complex hardware is difficult to design, test, and build. This tradeoff exists whether communication is over air or wire, analog or digital. In digital communication systems, the source to be transmitted is discrete both in time and amplitude. Digital information carrying signals must be first converted to an analog waveform prior to transmission. At the receiving end, analog signals are converted back to a digital format before presentation to the end user. The conversion process at the transmitting end is known as modulation. The receiving end is known as demodulation or detection [1].

III. IQ modulation

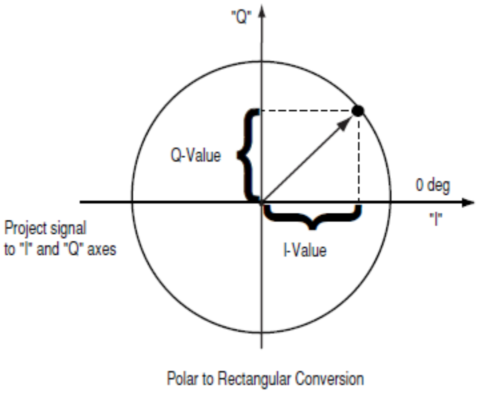


Fig 3: Polar to rectangular form

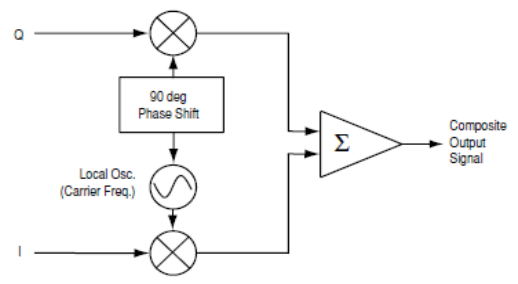
In digital communications, modulation is often expressed in terms of I and Q. This is a rectangular representation of the polar diagram. On a polar diagram, the I axis lies on the zero degree phase reference, and the Q axis is rotated by 90 degrees. The signal vector's projection onto the I axis is its "I" component and the projection onto the Q axis is its "Q" component [1].

3.1 Why use I and Q

Digital modulation is easy to accomplish with I/Q modulators. Most digital modulation maps the data to a number of discrete points on the I/Q plane. These are known as constellation points. As the signal moves from one point to another, simultaneous amplitude and phase modulation usually results. To accomplish this with an amplitude modulator and a phase modulator is difficult and complex. It is also impossible with a conventional phase modulator. The signal may, in principle, circle the origin in one direction forever, necessitating infinite phase shifting capability. Alternatively, simultaneous AM and Phase Modulation is easy with an I/Q modulator. The I and Q control signals are bounded, but infinite phase wrap is possible by properly phasing the I and *Q* signals [1].

3.1. I and Q in a Radio Transmitter

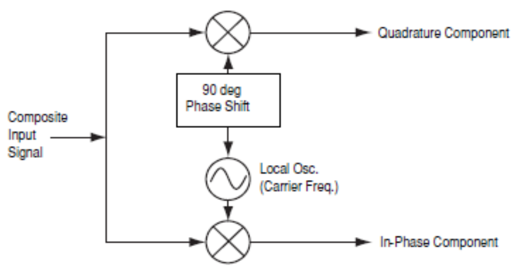
I/Q diagrams are particularly useful because they mirror the way most digital communications signals are created using an I/Q modulator. In the transmitter, I and Q signals are mixed with the same local oscillator (LO). A 90 degree phase shifter is placed in one of the LO paths. Signals that are separated by 90 degrees are also known as being orthogonal to each other or in quadrature. Signals that are in quadrature do not interfere with each other. They are two independent components of the signal [1].



When recombined, they are summed to a composite output signal. There are two independent signals in *I* and *Q* that can be sent and received with simple circuits. This simplifies the design of digital radios. The main advantage of *I/Q* modulation is the symmetric ease of combining independent signal components into a single composite signal and later splitting such a composite signal into its independent component parts [1].

3.3 I and Q in a Radio Receiver

The composite signal with magnitude and phase (or *I* and *Q*) information arrives at the receiver input. The input signal is mixed with the local oscillator signal at the carrier frequency in two forms. One is at an arbitrary zero phase. The other has a 90 degree phase shift. The composite input signal (in terms of magnitude and phase) is thus broken into an in-phase, *I*, and a quadrature, *Q*, component. These two components of the signal are independent and orthogonal. One can be changed without affecting the other. Normally, information cannot be plotted in a polar format and reinterpreted as rectangular values without doing a polar-to-rectangular conversion. This conversion is exactly what is done by the in-phase and quadrature mixing processes in a digital radio. A local oscillator, phase shifter, and two mixers can perform the conversion accurately and efficiently [1].



IV. Orthogonality

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time Division Multiplexing (TDM) allows transmission of multiple information signals over a single channel by assigning unique time slots to each separate information signal. During each time slot only the signal from a single source is transmitted preventing any interference between the multiple information sources. Because of this TDM is orthogonal in nature. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well spaced out in frequency preventing interference. Although these methods are orthogonal the term OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced as close as is theoretically possible while maintain orthogonality between them. The subcarriers in an OFDM signal are spaced as close as is theoretically possible while maintain orthogonality between them. OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different subcarriers. OFDM signals are made up from a sum of sinusoids, with each corresponding to a subcarrier. The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol [2]. As a consequence the subcarriers are orthogonal to each other. If any two different functions within the set are multiplied, and integrated over a symbol period, the result is zero, for orthogonal functions. Another way of thinking of this is that if we look at a matched receiver for one of the orthogonal functions, a subcarrier in the case of OFDM, then the receiver will only see the result for that function. The results from all other functions in the set integrate to zero, and thus have no effect.

The definition of orthogonality was given in [3] as

$$\int \text{Cos}\,(2\text{pifnt})*\cos(2\text{pifmt})dt = \delta(n-m) \quad \text{---4.1}$$

Where $\delta(n-m)$ is a Dirac-Delta function

In OFDM modulation, the subcarrier frequency fn is defined as

$$fn = n\Delta f, \quad \text{----------- (4.2)}$$

$$\text{Where } \Delta f = fs/N = 1/NT \quad \text{----------- (4.3)}$$

Here fs=1/T is the entire bandwidth, and N is the number of subcarriers.

Substituting Eq.4.2 and Eq.4.3 in Eq.4.1, Orthogonality can easily be justified.

V. OFDM Basics

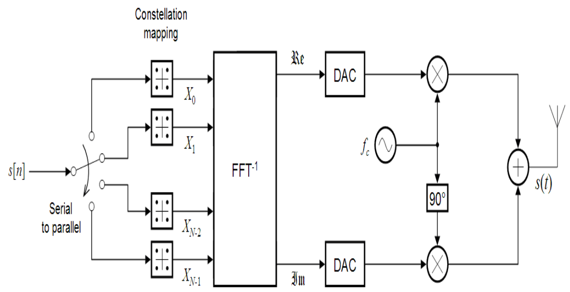
It is worth mentioning that OFDM is a special class of Multicarrier modulation. OFDM data are generated by taking symbols in the spectral space using encoding techniques such as *M*-PSK, QAM, etc., and convert the spectra to time domain by the Inverse Discrete Fourier Transform (IDFT). Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead [4]. Once the OFDM data are modulated to time signal, all carriers transmit in parallel to fully occupy the available frequency bandwidth [5]. During modulation, OFDM symbols are typically divided into frames, so that the data will be modulated frame by frame. Long symbol periods diminish probably leads to have inter-symbol interference (ISI). To make ISI nearly eliminated, a cyclic extension (or cyclic prefix) is added to each symbol period. An exact copy of a fraction of the cycle, typically 25% of the cycle, taken from the end is added to the front.

5.1 OFDM System Design

OFDM system design, as in any other system design, involves a lot of tradeoffs' and conflicting requirements. The following are the most important design parameters of an OFDM system. The following parameters could be a part of a general OFDM system specification [6].

- Bit Rate required for the system.
- Bandwidth available.
- BER requirements. (Power efficiency).
- RMS delay spread of the channel.

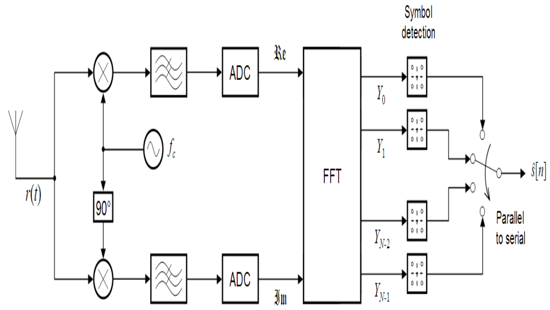
5.2 OFDM Transmitter



An OFDM carrier signal is the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of quadrature amplitude modulation (QAM) or phase-shift keying (PSK). This composite baseband signal is typically used to modulate a main RF carrier. S[n] is a serial stream of binary digits. By inverse multiplexing, these are first demultiplexed into parallel streams, and each one mapped to a (possibly complex) symbol stream using some modulation constellation (QAM, PSK, etc.). Note that the constellations may be different, so some streams may carry a higher bit-rate than others.

An inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples. These samples are then quadrature-mixed to pass band in the standard way. The real and imaginary components are first converted to the analogue domain using digital-to-analogue converters (DACs); the analogue signals are then used to modulate cosine and sine waves at the carrier frequency, fc, respectively. These signals are then summed to give the transmission signal, s[t] [7].

5.3 OFDM Receiver



The receiver picks up the signal r (t), which is then quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency. This also creates signals centered on 2fc, so low-pass filters are used to reject these. The baseband signals are then sampled and digitized using analog-to-digital converters (ADCs), and a forward FFT is used to convert back to the frequency domain. This returns parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then re-combined into a serial stream, Ŝ (n), which is an estimate of the original binary stream at the transmitter [7].

VI. Mathematical description

If sub-carriers are used, and each sub-carrier is modulated using M alternative symbols, the OFDM symbol alphabet consists of M^N combined symbols. The low-pass equivalent OFDM signal is expressed in [7] as:

$$v(t) = \sum_{k=0}^{N-1} Xke^{j2pikt}/T,\ 0 \le t < T, \qquad \ldots 6.1$$

Where {Xk} are the data symbols, is the number of sub-carriers, and is the OFDM symbol time. The sub-carrier spacing 1/T of makes them orthogonal over each symbol period; this property is expressed as:

$$1/T \int_0^T \left(e^{j2pik1t}/T\right) * \left(e^{j2pik2t}/T\right)dt \qquad ..6.2$$

$$1/T \int_0^T \frac{e^{j2pi(k2-k1)t}}{T}\, dt = \delta k1k2 \qquad ..6.3$$

Where (.)* denotes the complex conjugate operator and is the Kronecker delta.

To avoid inter-symbol interference in multipath fading channels, a guard interval of length Tg is inserted prior to the OFDM block. During this interval, a cyclic prefix is transmitted such that the signal in the interval $-Tg \le t < 0$ equals the signal in the interval $(T - Tg) \le t < T$. The OFDM signal with cyclic prefix is thus:

$$v(t) = \sum_{k=0}^{N-1} Xke^{j2pikt}/T,\ -Tg \le t < T,\ \ldots 6.4$$

The low-pass signal above can be either real or complex-valued. Real-valued low-pass equivalent signals are typically transmitted at baseband wire line applications such as DSL use this approach. For wireless applications, the low-pass signal is typically complex-valued; in which case, the transmitted signal is up-converted to a carrier frequency fc. In general, the transmitted signal can be represented as:

$s(t) = K\{v(t)e^{\wedge}j2pifct\}$ …6.5

$= \sum_{k=0}^{N-1} |Xk| \cos(2pi\left[fc + \frac{k}{T}\right]t + \arg[Xk])$ …..6.6

VII. Software implementation results

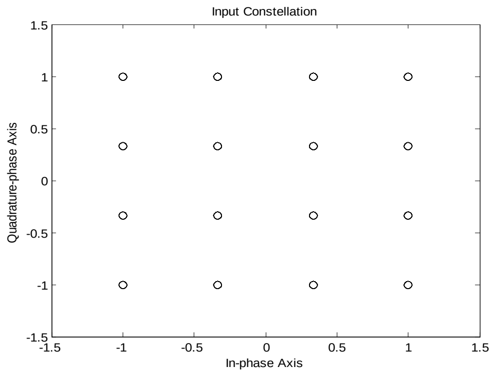


Fig7.1: Input constellation

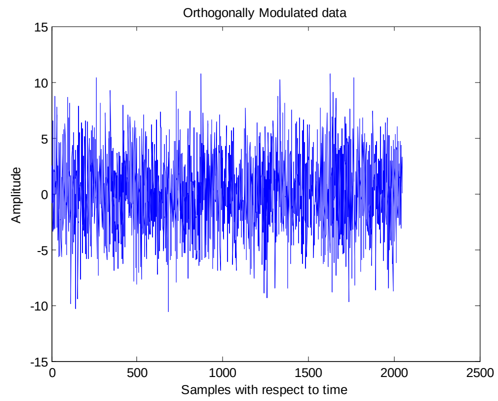


Fig 7.2: Orthogonally modulated data

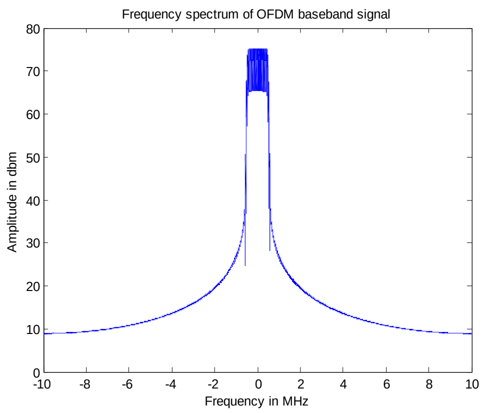


Fig 7.3: Frequency spectrum of OFDM baseband signal

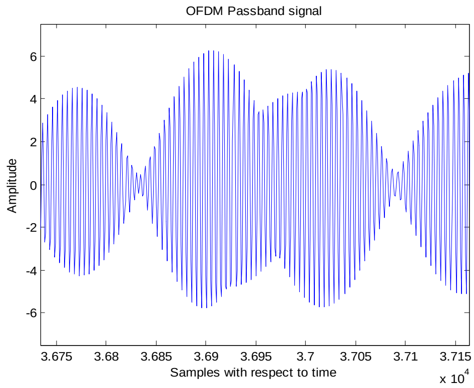


Fig 7.4: OFDM pass band signal

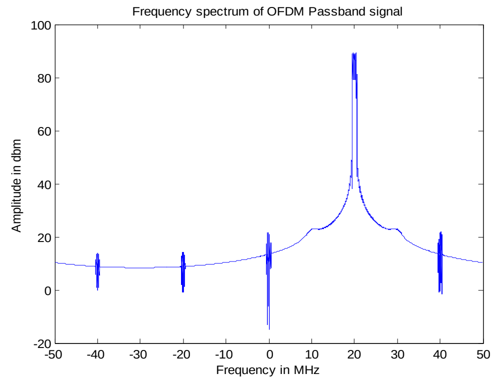


Fig 7.5: Frequency spectrum of OFDM pass band signal

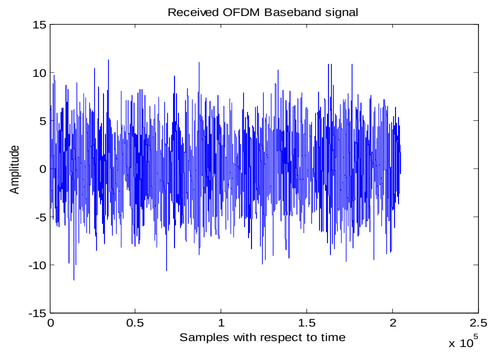


Fig 7.6: Received OFDM baseband signal

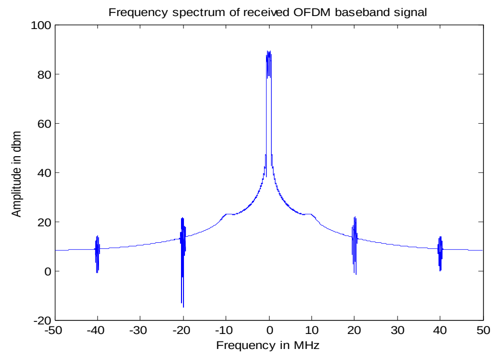


Fig 7.7: Frequency spectrum of received OFDM baseband signal

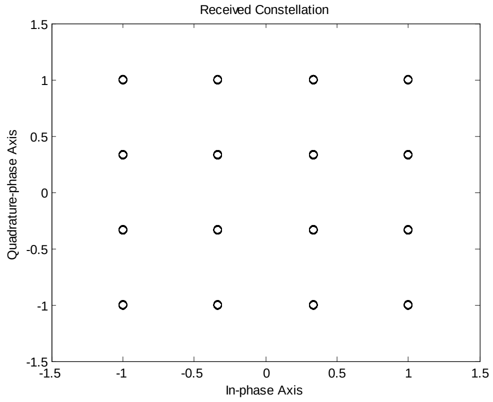


Fig 7.8: Received constellation

VIII. Conclusion

OFDM is a multi-carrier modulation technique. Each subcarrier can be independently modulated to any type of modulation such as BPSK, QPSK, QAM & FSK. It has several interesting properties that suit its use over Wireless channels. Many Wireless standards have started to use OFDM for its *modulation* and *multiple accesses*. Method for generation and demodulation of OFDM were analyzed. As an example, a 16-QAM modulated data has taken and obtained results are satisfactory with the theoretical results.

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