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Evaluation of the Frequency Spectrums of an Orthogonal Frequency Division Multiplexing (OFDM) for Signaling Transmission

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***Abstract*—** The continuous increase in global data traffic, such as audio and video signals, has imposed many improvements for the quality of telecommunication systems, hence several solutions in digital signal processing systems have been proposed in the last decades. In this approach, is presented a review and frequency spectrum simulations of OFDM (Orthogonal Frequency Division Multiplexing) in the four different time domains (16s, 24s, 32s and 48s), respectively. It also simulated six OFM frequency spectrums in MATLAB. A (GUI) interface also shows basic signaling transmission, and performance of the developed algorithm has been examined in terms of frequency, which increases in function of the time domain bands. In general, the results obtained were about a maximum frequency of 3MHz in 50% of the time-domain extraction, and a minimum frequency of -3MHz in 75% of the time-domain extraction, thus the results obtained were satisfactory to show the feasibility of OFDM modulation in a MATLAB environment.

***Keywords*—** OFDM modulation; Frequency spectrum; Time-domain; MATLAB simulation; Communication systems

I. INTRODUCTION

With the signal digital processors technology, the Orthogonal Frequency Division Multiplexing (OFDM) comes as solution to increase the capacity of various technologies which demands high-tax transmissions in the RF (Radiofrequency) domain as in the wireless networking standard (IEEE 802.11a and 802.11g), WiMAX (IEEE 802.16) and Digital TV patterns (DVBT, ISDBT). More examples of current applications using OFDM include HDTV and broadcasting [1, 2].

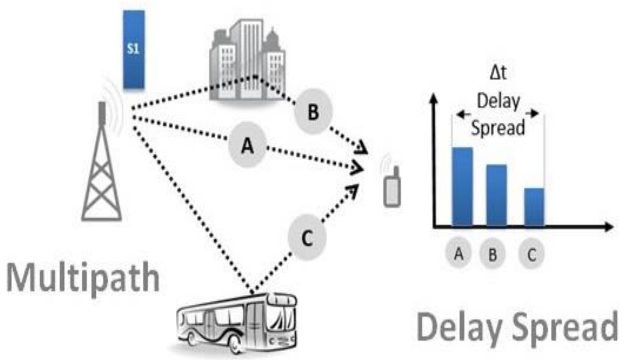

Figure 1. Multipath demonstration.

This project will focus on the Orthogonal Frequency Division Multiplexing in MATLAB. Figure 2 shows the Traditional vs. OFDM communication:

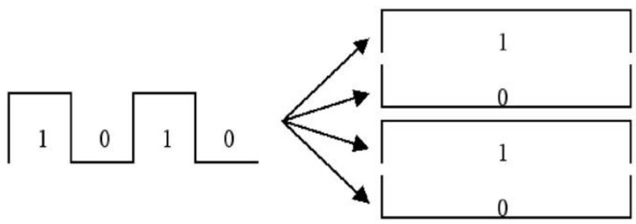

Figure 2. Traditional vs. OFDM communication.

In concern to simulation design utilized in this work, was utilized the MATLAB R2019 App to develop all the OFDM spectrums in the four different time domains (16s, 24s, 32s and 48s) for $N = 256$.

The Figure 3 shows the schematic about an OFDM Transmitter:

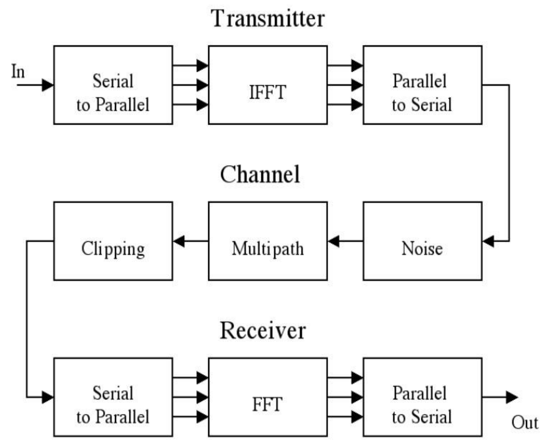

Figure 3. OFDM Transmitter.

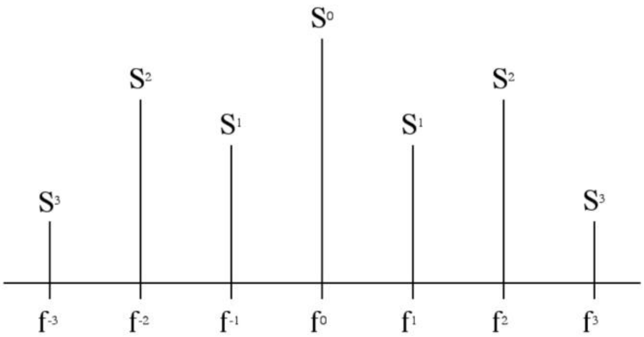

Figure 4. Distribuitions in the frequency domain.

Concepts about OFDM modulation definitions describes modeling of signal representation; section IV describes FFT (Fast Fourier Transform) modeling to binary signal recovery; results and discussion for the MATLAB simulations are also and conclusions appoints the main observations of this signaling transmission system.

II. Related Work

A. OFDM Modulation Definitions

Multicarrier paths within a minor throughput in each one are defined in [3]. The Figure 5 illustrates an OFDM signal. The Figure 5(a) illustrates each multicarrier separately in time-domain. The Figure 5(b) represents the sum of all the multicarriers. And Figure 5(c) presents each multicarrier in frequency-domain.

As previously highlighted, one of the advantages about the OFDM utilization is the spread advantages representing an easy spectrum. Although, this signalling transmission system has disadvantages in concern to its signal properties, such as the high-peak power in relation to mean power (PAPR) and sensibility to frequency noise and spectrum [4].

One of the main OFDM challenges concerns with the necessary biggest multicarrier number to the transmission channel affects each multicarrier as a fading plan channel. It requires a very complex architecture, involving a lot of oscillators and filters, both at transmitter and receiver.

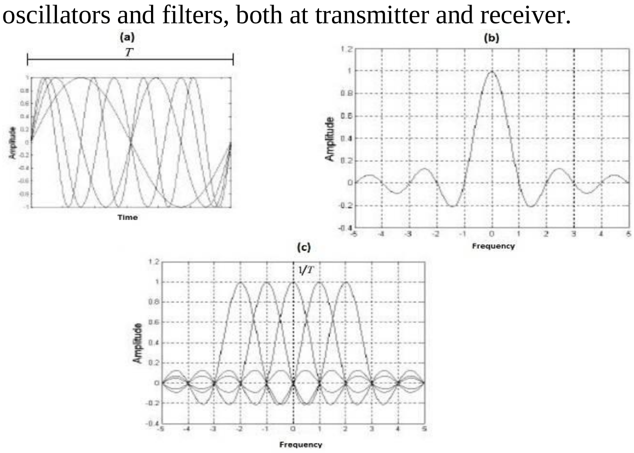

Figure 5. OFDM signal: (a) Multicarriers in time-domain; (b) Multicarriers sum in frequency-domain; (c) Multicarriers in frequency-domain.

Among the various advantages of a multicarrier system in relation to the single-carrier systems, can be highlighted: high-immunity to multipath, significative reduction of the channel signaling rate, the spread band filled by each subcarrier is N times smaller than the fixed width band filled by the modeled signaling through a single-carrier. On another side, the multicarrier systems have some disadvantages, such as peak-power problems in the broadcasting, and the symbol synchronism difficulty [5].

The OFDM systems appears in the 60s decade, when Chang [6] published your article about transmission synthesis with various band limited channels. Chang has presented the messages transmission principle in various band limited channels without induce interferences among carriers (ICI) [7].

In relation to the OFDM transmitter, the Figure 6 illustrates the block diagram of a basics OFDM modulator. At this block diagram, $m(t)$ represents the sequence which is desired to spread, and $cn = in + jqn$ the complex signal charted in the in signals in phase and qn in quadrature. In sequence, the converter series-parallel transforms the signal in N symbols bundles parallel complex, which modulates the complex sub-carriers. The modulation is then applied from the cosine and sine functions of angular frequency ωn to obtain the OFDM signalling, respectively. The equation of OFDM signal can be resumed as:

$$f_{OFDM}(t) = \sum_{n=0}^{N-1} \Re\left\{c_n e^{-j\omega_n t}\right\}, \tag{1}$$

$$f_{OFDM}(t) = \sum_{n=0}^{N-1} \Re\left\{(i_n + jq_n)\cdot[\cos(\omega_n t) - j\,\mathrm{sen}(\omega_n t)\right\}, \tag{2}$$

$$f_{OFDM}(t) = \sum_{n=0}^{N-1} \Re\left\{i_n\cos(\omega_n t) - ji_n\,\mathrm{sen}(\omega_n t) + jq_n\cos(\omega_n t) + q_n\,\mathrm{sen}(\omega_n t)\right\}, \tag{3}$$

Hence, we have:

$$f_{OFDM}(t) = \sum_{n=0}^{N-1} \Re\left\{i_n\cos(\omega_n t) + q_n\,\mathrm{sen}(\omega_n t)\right\}, \tag{4}$$

Elapsed OFDM symbol in T seconds, the amplitude value of each sub-carrier is updated with data in the next symbol. Case the signal-peak given various sub-carriers, visible in time-domain, stay in phase, the summary of Eq. (4) can resonate in high-levels, which can lead transmitters to work in the saturation regions, as cited at the beginning of this section.

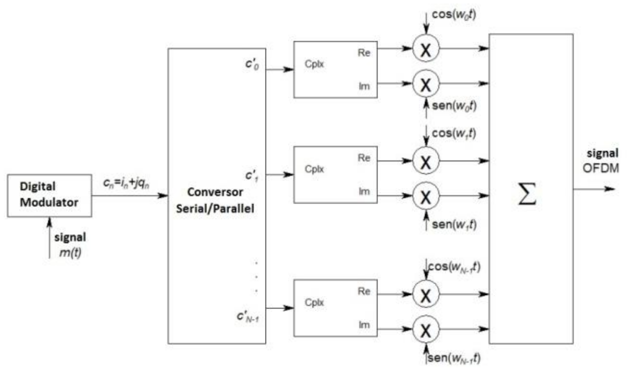

Figure 6. Basics OFDM signal modulator.

Beyond this, in an OFDM system, all the N complex transmitter and receptor oscillators must be in phase. As the bigger system complexes, a higher difficulty is to obtain the synchronism among the oscillators, increasing the implementation complexity, which can make this technique unviable.

Now, in relation to the OFDM receptor, the OFDM signal reception is realized through correlators banks, as presented in Figure 7. For a channel without distortions and noise, the detection is realized without errors, once all there is no interference among received N sub-channels. Observing all the sub-carriers we can highlight received components i_N, as:

$$i'_n = \frac{2}{T}\int_0^T r(t)\cos(\omega_n t)dt. \tag{5}$$

Taking as example the reception of the component *i0* and remembering that for a channel without noise neither distortion $r(t) = s_{OFDM}(t)$, we have:

$$i'_0 = \frac{2}{T}\int_0^T \sum_{n=0}^{N-1}[i_n\cos(\omega_n t) + q_n\,\mathrm{sen}(\omega_n t)]\cdot\cos(\omega_0 t)dt, \tag{6}$$

$$i'_0 = \frac{2}{T}\int_0^T \sum_{n=0}^{N-1} i_n\cos(\omega_n t)\cdot\cos(\omega_0 t)dt + \underbrace{\frac{2}{T}\int_0^T \sum_{n=0}^{N-1} q_n\,\mathrm{sen}(\omega_n t)\cdot\cos(\omega_0 t)dt}_{0}, \tag{7}$$

$$i'_0 = \frac{2}{T}\int_0^T i_0\cos(\omega_0 t)\cdot\cos(\omega_0 t)dt, + \underbrace{\frac{2}{T}\int_0^T \sum_{n=0}^{N-1} i_n\cos(\omega_n t)\cdot\cos(\omega_0 t)dt}_{0}, \tag{8}$$

The previous procedure is the same for all the components of signal $r(t)$, once all the carriers have an integer number of cycles in the T seconds interval.

The OFDM signal generation and detection method presented in the previous equations is named "Brute Force Method". With the increase of sub-carriers numbers, your implementation becomes impracticable, because of the complex oscillators building complexity presented on the transmitter and receptor. Although, the digital technology advancement allows the OFDM system to be implemented through a method which simplifies the transmitter and receptor building, as described next.

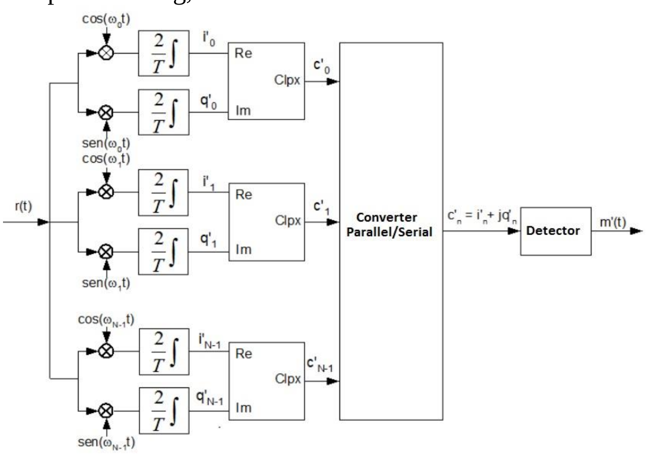

Figure 7. Basics OFDM signal demodulator.

$$i'_0 = \frac{2i_0}{T}\int_0^T \cos^2(\omega_0 t)dt = i_0. \tag{9}$$

Starting from the Eq. (4), the *in* and *qn* can represents, respectively, the orthogonal basis coefficients, $\cos(\omega_n t)$ and $\sin(\omega_n t)$, in mode of the OFDM signal can be analyzed as a Fourier series with N elements and coefficients *in* and *qn*. First of all, it's necessary to show the OFDM signal. It should facilitate the utilization of DSPs (Digital Signal Processor) in the generation and detection of this signal, which requires a discrete system analysis.

In relation to the Interval Guard, in many transmission environments, there are multipaths and much reflection between transmitter and receptor, the carrier orthogonality belonging to the received signal would be prejudiced. To avoid this, a block can be inserted, after the OFDM modulation [8].

The proposal of the guard interval is to smooth the problems in concern to intersymbol interferences. Tough, for this to be functional, it's necessary that guard interval size be higher than channel temporal dispersion, it means that reflected signal maximum delay which comes to the antenna should have a minor relation that guard interval duration.

The guard interval also would be built from an empty interval, although when the channel is dispersive, the delay of each sub-carrier would be different, bringing an intersymbol interference and orthogonality losing. On the time-domain it means that do not exists a sub-carrier integer number inside a cycle (useful part of the OFDM symbol).

The Eq. (10) shows this case, assuring that if signal dispersion be lower than guard interval width the delayed sub-carriers of the OFDM symbol always will have a cycle integer number on the useful part of the OFDM symbol [9]. The Eq. (10) shows this method.

$$x_g(n) = \begin{cases} x(N+n) & n = -N_g, -N_g+1, \cdots -1 \\ x(n) & n = 0, 1, \ldots N-1 \end{cases}, \tag{10}$$

III. METHODOLOGY

A. IFFT (Inverse Fast Fourier Transform) Modeling to OFDM Signal Representation

The Inverse FFT equation is:

$$x(n) = \frac{1}{N}\sum_{n=1}^{N-1} X(k)e^{-j2\pi kn/N} \quad ,n=0,\ldots,N-1 \tag{11}$$

The 8-point IFFT representation of an OFDM signaling is shown in the Figure 8:

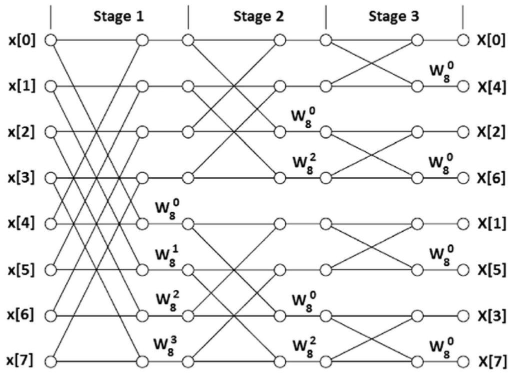

Figure 8. 8-point IFFT (DIF).

B. FFT (Fast Fourier Transform) Modeling to Binary Signal Recovery

The basic equation of the FFT:

$$X(k)=\sum_{n=1}^{N-1} x(n)e^{-j2\pi kn/N} \quad ,k=0,\ldots,N-1 \tag{12}$$

The sampled signal utilizes this transformation effectively for various applications like speech signal processing, radar communication, sonar and wireless communication applications [10].

The OFDM transmission is done by packing parallel channels of low bite rate into closely carrier signals in a frequency band. Each channel is modulated by a carrier. For instance to transmit 10 parallel channels we need 10 oscillators to generate the carrier. To avoid the use of a large number of oscillators, the IFFT technique is applied to the input. It theoretically means that input is a spectrum, so it creates an illusion that each channel is modulated by a carrier. At the receiving end the FFT is used to retrieve the original signal. The Figure 9 shows Channel Noise for a FFT system.

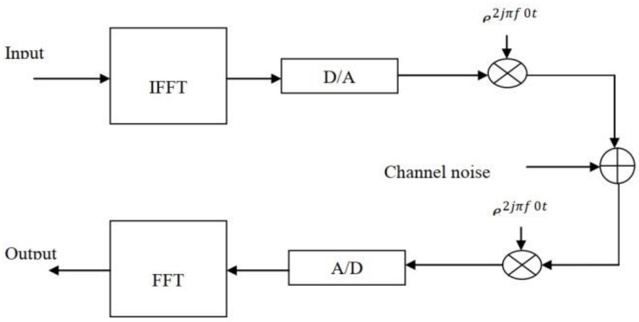

Figure 9. Channel noise for a FFT system.

IV. RESULTS AND DISCUSSION

An OFDM signaling algorithm was implemented to the spectrum analysis of the OFDM signal at time-domain bands at 16s, 24s, 32s and 48s, respectively, with the N parameter defined as N=256. Thus, with the purpose of comparison with the previous works done in the area of OFDM signaling transmission, in terms of measurement analysis on the peak to average frequencies, was realized estimations and appointments about the main time-domains where these frequencies were distributed.

A. The OFDM signaling algorithm

An OFDM signaling algorithm was developed in MATLAB to generate the six main OFDM frequencies spectrums, including the spectrum of overlapping of sub-carriers which the peak to average frequencies are also analyzed and estimated.

The parameters N and T of the algorithm were pre-defined during the script development to modeling the OFDM frequencies spectrums. Some rules of the algorithm are summarized, to decompose three major steps involved in this technique:

Algorithm 1: OFDM Frequency Spectrum

```
% Create UIFigure and components
function createComponents(app)

% Create UIFigure and hide until all
components are created
app.UIFigure = uifigure('Visible', 'off');
app.UIFigure.AutoResizeChildren = 'off';
app.UIFigure.Position = [100 100 825 617];
app.UIFigure.Name = 'UI Figure';
app.UIFigure.SizeChangedFcn =
createCallbackFcn(app, @updateAppLayout,
true);

% Create GridLayout
app.GridLayout =
uigridlayout(app.UIFigure);
app.GridLayout.ColumnWidth = {205, '1x'};
app.GridLayout.RowHeight = {'1x'};
app.GridLayout.ColumnSpacing = 0;
app.GridLayout.RowSpacing = 0;
app.GridLayout.Padding = [0 0 0 0];
app.GridLayout.Scrollable = 'on';
```

The spectrum of overlapping of subcarriers in OFDM is shown below:

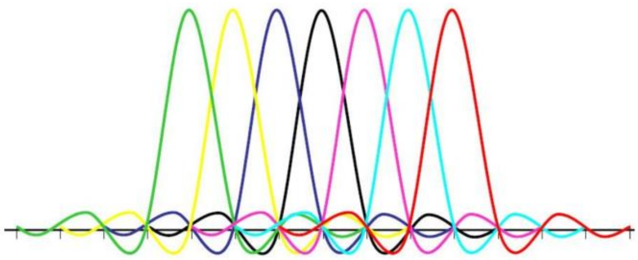
Figure 10. Overlapping of sub-carriers in OFDM.

B. Comparison with previous works

In comparison with previous work developed by S.S. Ghorpade and S.V. Sankpal, the OFDM algorithm has a small number of parameters to be tuned. The simulation results 1, 2, 3 and 4 for MATLAB code is related only to the 3 OFDM frequency spectrum samplings, as well as 1 sample about the original message and recovered message.

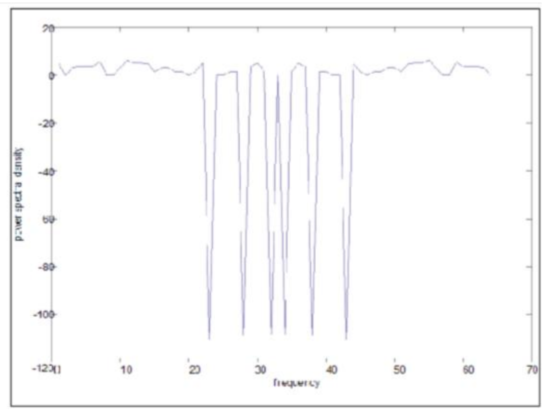

Figure 11. Frequency spectrum sampling.

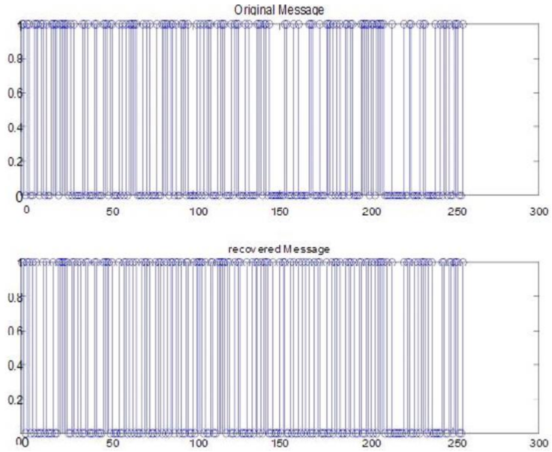

Figure 12. Initial parameters.

At this current work, to demonstrate the OFDM frequencies at the time-domain bands in 16s, 24s, 32s and 48s, within a length N=256, the first demonstration of the developed MATLAB code. Figure 13 shows the sequence of these frequencies for a time-domain about 16s. This code was developed on the MATLAB using a Graphic User interface (GUI).

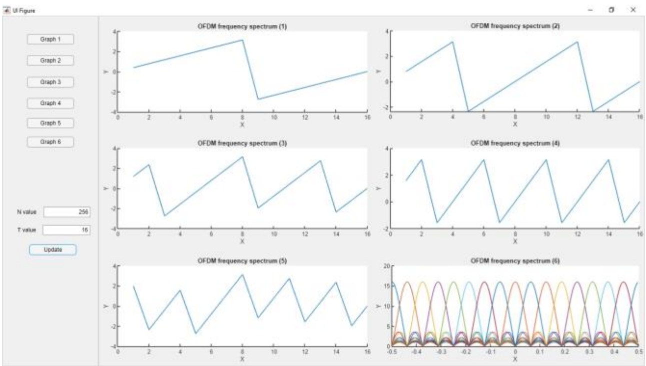

Figure 13. OFDM frequencies spectrums for a time T = 16s.

C. OFDM frequency spectrum representation

The choice of the OFDM frequency spectrum graphic influences the execution time of the developed algorithm. If the choice of the OFDM frequency length N is not well adjusted, the optimization procedure can be determined by the time-domain in 16s, 24s, 32s and 48s. Although, for a frequency band length higher or lower than N=256, some graphics about the OFDM frequency spectrum would be loose. One of the following three frequency length N choose criteria can be adopted for optimization algorithms:

- A predetermined number of iterations;
- A considered satisfactory result;
- The OFDM frequency spectrum variation over iterations is equal to a predetermined N frequency length value.

Thus, the OFDM frequency spectrums generated for a length N=256, in the time-domains 16s, 24s, 32s and 48s can be represented in the Figure 14 to Figure 17, respectively:

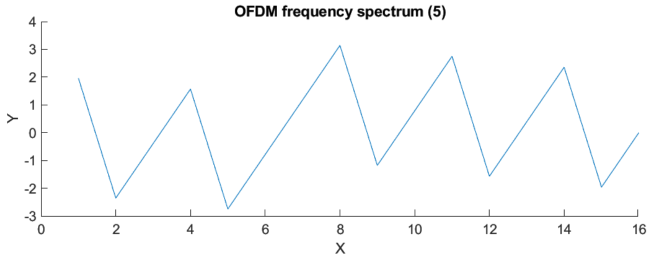

Figure 14. OFDM frequency spectrum for T = 16s.

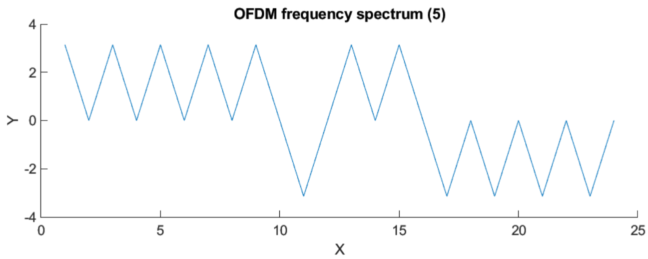

Figure 15. OFDM frequency spectrum for T = 24s.

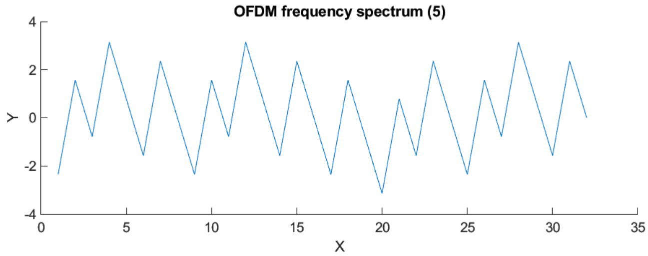

Figure 16. OFDM frequency spectrum for T = 32s.

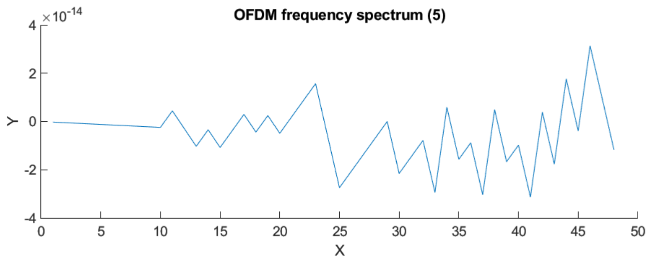

Figure 17. OFDM frequency spectrum for T = 48s.

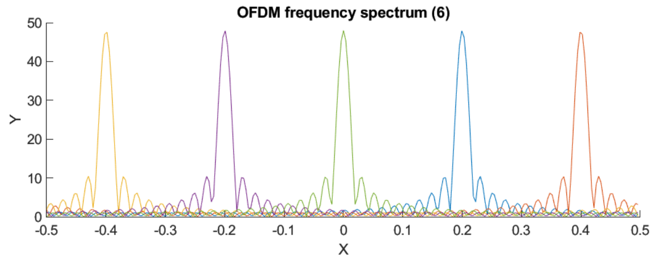

Figure 18. Spectrum of overlapping of sub-carriers in OFDM for T = 48s.

In order to analyze the quantitative results of the OFDM frequencies spectrums developed in MATLAB, generated by the six frequency graphics in the GUI interface, we should measure the peak to average values to plot in three graphics the Max. Frequency Spectrum, Min. Frequency Spectrum and Max. Overlapping Sub-Carriers Spectrum, respectively.

In each execution, the same frequencies initial values as well as the same values of OFDM Spectrum of Overlapping Sub-Carriers were used for the composition of three main graphics showing the OFDM frequencies distribution at the time-domain of 16s, 24s, 32s and 48s, respectively. All tests were performed for the OFDM signaling algorithm, and are represented in Table 1 to Table 4, to summarize the Max. Frequency and Min. Frequency at the time-domain bands as described before. It's necessary to distribute the OFDM frequency values in the graphics of summarization.

D. OFDM frequency distribution analysis

The quantitative analysis about OFDM frequencies spectrum was defined as the time-domain variation over iterations with a frequency band length N = 256, a Max. Frequency concentration of 3MHz (50% of the full OFDM frequency spectrum), and a Min. Frequency concentration of -3MHZ (75% of the full OFDM frequency spectrum). The Table 1 to Table 4 shows the OFDM frequency distribution at the time-domain of 16s, 24s, 32s and 48s, respectively. This leads to the observation that, although OFDM signaling algorithm shows only frequency spectrums, it can be useful to measure peak to average parameters, which can identify the majority frequencies distribution during a broadcasting spread for example. Hence, the Figure 19, Figure 20 and Figure 21 show this distribution at the time-domain bands predefined values.

Table 1. Peak to Average at T = 16s.

OFDM Spectrum	Max. Frequency (MHz)	Min. Frequency (MHz)
1	4	-3
2	3	-2
3	3	-3
4	3	-1,5
5	3	-3
6	**15**	**0**

Table 2. Peak to Average at T = 24s.

OFDM Spectrum	Max. Frequency (MHz)	Min. Frequency (MHz)
1	3	-2
2	2,5	-2,5
3	3	-2
4	2,5	-2,5
5	3	-3
6	**25**	**0**

Table 3. Peak to Average at T = 32s.

OFDM Spectrum	Max. Frequency (MHz)	Min. Frequency (MHz)
1	3	-2
2	3	-3
3	3	-3
4	3	-3
5	3	-3
6	**30**	**0**

Table 4. Peak to Average at T = 48s.

OFDM Spectrum	Max. Frequency (MHz)	Min. Frequency (MHz)
1	2,5	-2,5
2	2,5	-2,5
3	2,5	-2,5
4	2,5	-2,5
5	30E-15	-3,00E-14
6	**50**	**0**

Now in order to analyze the quantity of the OFDM frequencies spectrums distributions, during the time-domain bands of 16s, 24s, 32s and 48s, there are three main developed graphics which shows the Max. Frequency, Min. Frequency, as well as the Spectrum of Overlapping of Subcarriers in OFDM distributions for each time *T* values.

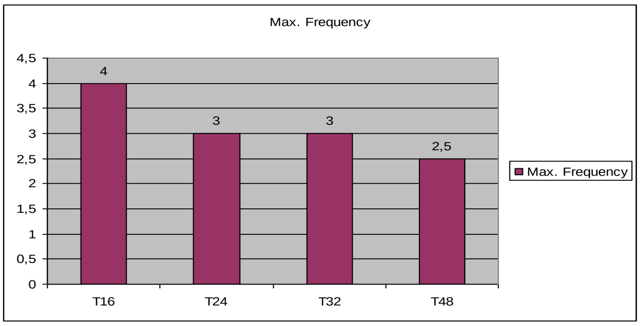

Figure 19. OFDM Max. Frequency distribution at time-domain bands.

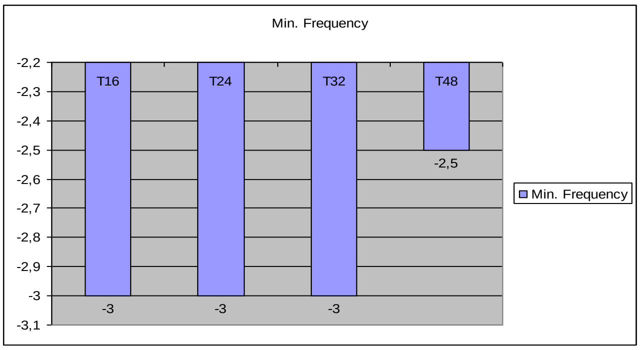

Figure 20. OFDM Min. Frequency distribution at time-domain bands.

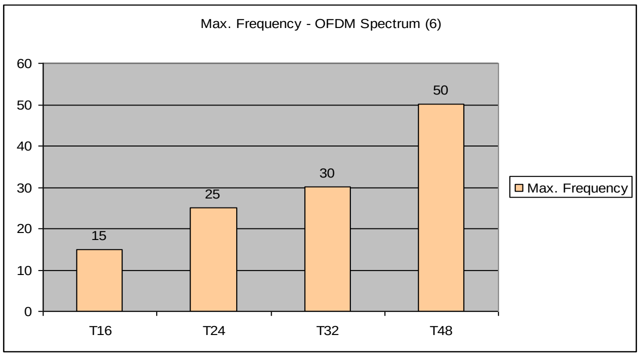

Figure 21. OFDM Max. Frequency distribution at time-domain bands for Spectrum of Overlapping of Sub-carriers.

As described before, looking for these three developed graphics about the OFDM frequency spectrum distribution, it's possible to notice that 50% of the Max. Frequency spectrum occurs at the time T = 24s and T = 32s, respectively, with a peak to average of 3MHz as shown in the graphic in Figure 19.

Now in relation to the Min Frequency spectrum distribution, it occurs 75% at the time-domains of T = 16s, T = 24s and T = 32s, respectively, with a peak to average of -3MHz as shown in the graphic the Figure 20.
Now in relation to the OFDM Max. Frequency distribution at time-domain bands for the Spectrum of Overlapping of Sub-carriers, there are different peak to average values for the time-domains of 16s, 24s, 32s and 48s, where the maximum peak occurs at T = 48s where the noticed Max. Frequency was about 50MHz as shown in Figure 21.

V. CONCLUSION AND FUTURE SCOPE

This paper presented a comparison among six OFDM frequencies spectrums obtained from a developed MATLAB code which generates Max. Frequencies and Min. Frequencies at the time-domain values of 16s, 24s, 32s and 48s. It has been shown that it is possible to model the OFDM signaling broadcasting and to size it by using FFT and IFFT mathematical modeling in order to generate the OFDM signal, which can be used for audio, video or radio transmission, to meet the target frequency-domains measurement values as acceptable for broadcasting transmission while optimizing the Spectrum of Overlapping of Sub-carriers desired values.

The OFDM signaling algorithm was implemented with the GUI interface developed in MATLAB, in order to ensure the frequency signals transmissions which are distributed in six main graphics at the GUI interface in MATLAB. All these graphics presented quite similar results performance than recent literature results, while the differential presented in this research is that algorithm can generate various OFDM frequency spectrums, which can provide information about peak to average frequency values.

Hence, these values are utilized to compound the mean frequency values distribution at the three main graphics developed to notice the percentage distribution of the Max. Frequency, Min. Frequency as well as the OFDM Overlapping of Sub-carriers frequencies during the time-domain distribution within a frequency length N value of N = 256.

In concern to Max. Frequency and Min. Frequency peak to average spectrum measurement, a Max. Frequency of 3MHz was observed at the time-domain of T = 24s and T = 32s, respectively, corresponding to the 50% of the full OFDM frequency spectrum observed during the running MATLAB code in the GUI interface. Now in relation to Min. Frequency peak to average spectrum measurement, a Min. Frequency of -3MHz was observed at the time-domain of T = 16s, T = 24s and T = 32s, respectively, corresponding to the 75% of the full OFDM frequency spectrum observed during the running code.

This information would be useful to predict the main time-domain T bands which the OFDM peak to average frequencies occurs often in an audio, video or radio broadcasting transmission, where the communication system can be modeled to a time-domain channel which can be more suitable for the signaling transmission in pre-determined N frequency length conditions.

Therefore, we demonstrate that the use of OFDM MATLAB codes to modeling the signaling transmission in function of frequency-length domain N and time-domain T is suitable for the broadcasting transmission of this signal in the communications systems. The modeling of FFT and IFFT mathematical concepts is also important to the OFDM algorithm understanding, and the entire frequency spectrums are filled with the Max. Frequencies and Min. Frequencies efficiently. The samplings of the OFDM Overlapping of Sub-carriers frequencies are done also in a satisfactory form, in which the frequency spectrum for time-domains of 16s, 24s, 32s and 48s are measured and distributed.

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