# Investigation of the Distorting Methods of Reducing the Peak-Factor of the OFDM Signal

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***Abstract*— The paper investigates the distorting methods of reducing the peak factor of the OFDM signal that can actually reduce the ratio of peak signal power to average. For this purpose, MathCad was used to investigate three distorting Methods. It is shown that the use of any of the studied methods gives a peak factor value two and a half times lower than without any peak limitation.**

***Index Terms*— modulation, OFDM, peak factor, LTE.**

## I. Introduction

The LTE standard uses a hierarchical OFDM modulation method to improve the quality of the signal at the receiving side, which can be considered as a means of dividing one radio frequency channel into two virtual channels, each of which will have its own transmission speed and noise immunity [1].

A well-known drawback of OFDM modulated systems is a high peak-to-average power ratio (PAPR) or high peak factor [2]. For a certain OFDM symbols, the phases of the subcarriers may add up, giving a short-term peak in radiated power. High PAPR requires power amplifiers (AM) with wide linear dynamic range. In addition, if bursts occur often enough, this leads to a limitation signal, and, as a result, the appearance of in-band and out-of-band radiation. In addition, nonlinear distortions of the transmitted signal occur, which worsens, and in some cases, makes impossible demodulation of the signal on the receiving side. The block diagram of the OFDM scheme is shown in Fig.1 [3].

Based on the analysis of literary sources, it can be concluded that information related to the distorting methods, which are used for reducing the ratio of peak-power to the average is practically missing; therefore, the further research will be aimed at studying exactly the distorting methods.

The main objective of this work is to study various methods for reducing the ratio of peak-power to the average regarding the signals with orthogonal frequency division of channels.

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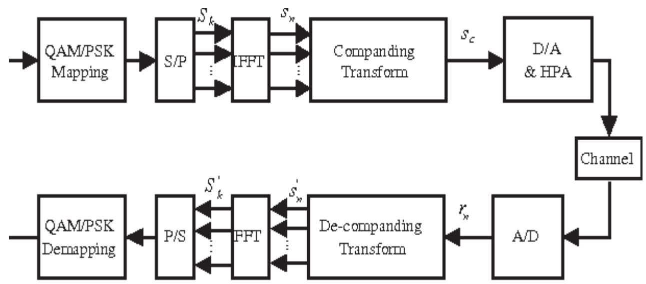


Fig. 1. Diagram of an OFDM scheme [3].

In order to achieve the required level of quality of the received signal, various manipulations with the signal must be performed based on the use of complex modulation methods and channel coding [2].This paper will consider the use of non-linear converters, also called companders, with different amplitude characteristics in order to identify their advantages and disadvantages relative to each other.

## II. Simulation Parameters and Results

To conduct/implement studies of distorting methods for reducing the peak factor of the OFDM signal, it is necessary to elaborate a physical model of the communication channel to transmit a test message. This model was designed in the programming environment MathCad 15.0 based on [4].The block diagram of an OFDM system using companding transform is shown in Fig.2 [3].

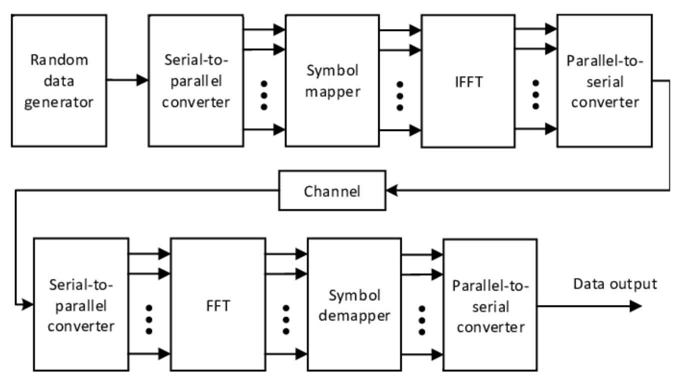


Fig. 2. Block diagram of an OFDM system using companding transform [3].

For modeling a signal with a signal-constellation was chosen, which will be used when transmitting a message. In this model, a 16QAM complex group with an angle of 17˚will be used, as shown in Fig.3.

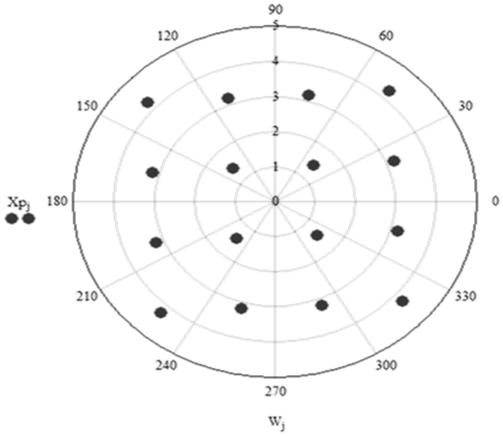


Fig. 3. Signal constellation 16QAM.

An example of the obtained phase constellation superimposed on the initial one is presented in Fig.4. The developed model made it possible to carry out the studies necessary for a full comparison of distorting methods for reducing the ratio of peak signal power to the average. Fig.5 presents the original signal transmitted to the output. This signal was transmitted in all subsequent studies. After all these transformations as well as adding the imitation of the noise of a real communication channel, the following picture of the received signal was obtained, which is shown in Fig.6. As seen from Fig.6, the model was able to identify only 9 characters out of 16 transmitted. At the same time, many symbols are so close to each other that it would be at least wrong to speak of an unambiguously correct identification. The estimated peak factor for this channel is $P = 3.25dB$, which is a rather critical value.

Next, a compander with a logarithmic characteristic, shown in Fig.7, was studied. When transmitting the same source signal in the communication channel, which uses the non-linear converter for PAPR limitation, the following phase constellation of the output signal was obtained (see Fig.8).

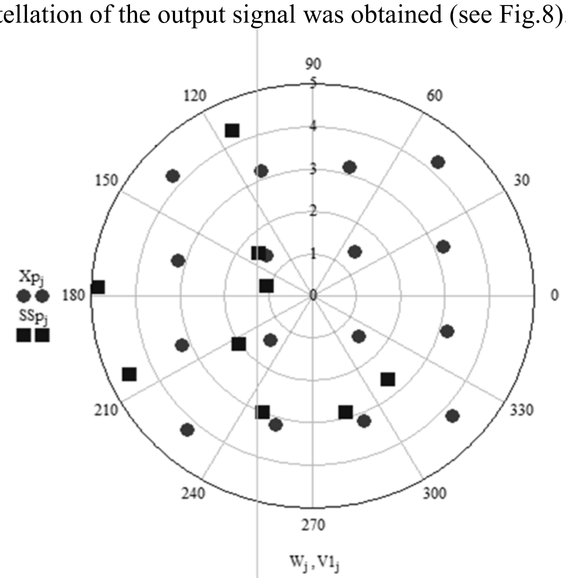


Fig. 4. Phase constellations of the source and received signal. Xpj is the original signal, SSpj is the received signal

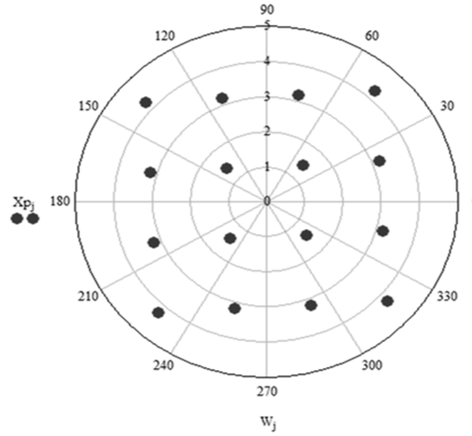


Fig. 5. Phase constellation of the original signal.

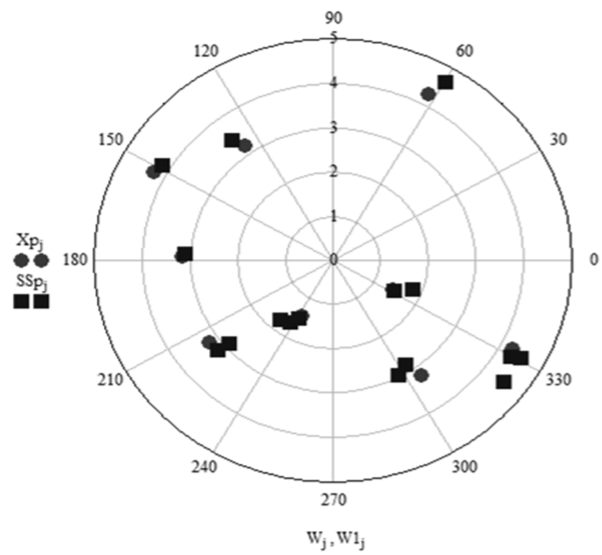


Fig. 6. Phase constellation of a received message without the use of a compander. Square - received message, circle - original message

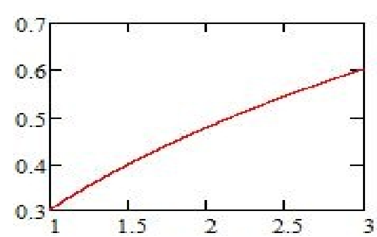


Fig. 7. Amplitude characteristic of a compander with logarithmic characteristic.

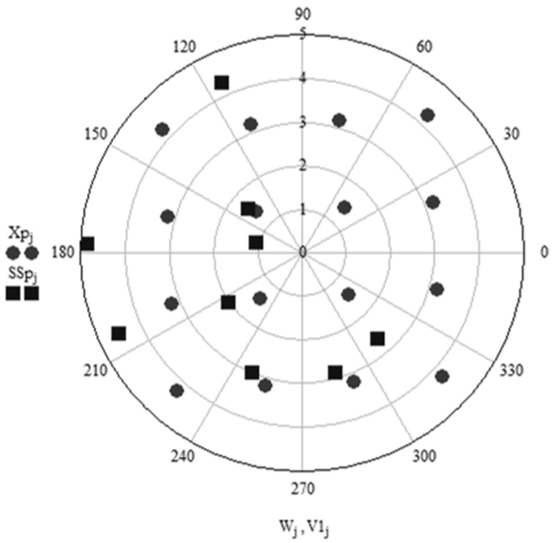


Fig. 8. Phase constellation of a received message when using a compander with a logarithmic characteristic. Square - received message, circle - original message

The estimated peak factor for this channel is *P=1.516* dB, which is two times lower than without using any compander.

Also, an important indicator of the converter when it is used is the noise immunity criterion. To evaluate this criterion, a measure of modulation error is calculated. For this compander, it's equal to *M=2,313*.

Next, a compander was examined limiting the peaks with a piecewise linear amplitude characteristic, shown in Fig.9.

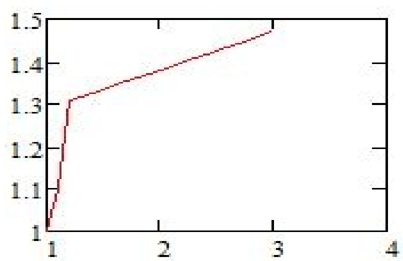

Fig. 9. Amplitude characteristic of a compander with piecewise linear approximation

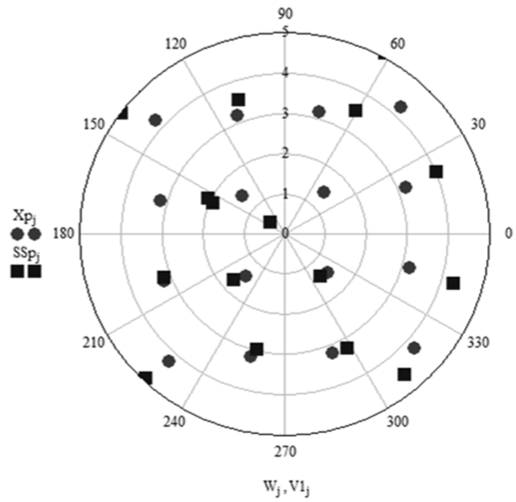


Fig. 10. Phase constellation of a received message when using a compander with piecewise linear approximation. Square - received message, circle - original message

The use of a compander with piecewise linear approximation made it possible to reduce the ratio of peak signal power to the level of *P=1.942 dB*, which is somehow inferior to the value obtained in the previous paragraph. However, the value of the measure of modulation error is equal to *M=0.731*, which means that this compander has more noise immunity.

Next, a compander with a cubic characteristic shown in Fig.11was studied. It allowed to obtain the picture of the phase constellation of the output signal shown in Fig.12.

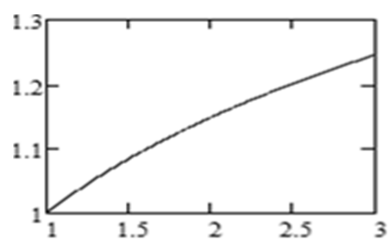

Fig. 11. Amplitude characteristic of a compander with a cubic characteristic

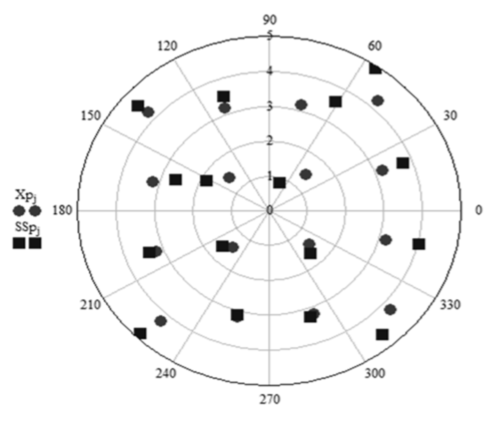


Fig. 12. Phase constellation of a received message when applying a quadratic characteristic compander.Square - received message, circle - original message

When applying this method, the PAPR value reached a value of *P=1.303 dB*, and the noise immunity, determined by the measure of modulation error, became equal to *M=0.509*.

## III. Summary and Discussion of Results

Throughout the study of three distorting methods for reducing the signal peak factor with the orthogonal frequency distribution of channels based on the mathematical model of the communication channel implemented in the MathCad software environment, the ratio of the peak power of the OFDM signal to the average, as well as noise immunity, differ by a fairly wide spread. For clarity, all values are summarized in the table below.

TABLE I. Research Results For various Companders

| parameters | Logarithmic characteristic | piecewise linear approximation | cubic characteristic |
|---|---|---|---|
| PAPR, db | 1.516 | 1.942 | 1.303 |
| M | 2.313 | 0.731 | 0.509 |

Based on the results, we can conclude that the use of any of the studied companders gives a peak factor value much lower than without any peak limitation. So, when modeling a communication channel without limiting the power peaks by any nonlinear converter, the peak factor value was fixed at 3.25 dB, which is more than 1 dB inferior to the closest obtained results.

As can be seen from the Table, a nonlinear converter with a logarithmic characteristic showed a peak factor of 0.426 dB lower than a nonlinear converter with piecewise linear approximation. However, modeling revealed that this compander turned out to be the most unstable to interference, which is not the case with the same converter with piecewise linear approximation.

According to the results of the study, the best performance is demonstrated by a nonlinear converter with a cubic characteristic. When physically limiting the peaks in the power of the transmitted signal in the mathematical model of the communication channel by this compander, the peak factor was recorded almost two and a half times lower than without the procedure for limiting the peaks by any method.

In addition to this, the non-linear converter proved to be the most noise-protected of all simulated samples. This fact suggests that the use of a quadratic characteristic compander in difficult noise conditions of the transceiver makes it possible to receive a message with greater probability than all the analogues studied in this work.

## IV. Conclusion

Based on the study, we can conclude that the distorting methods of reducing the peak factor of the OFDM signal can actually decrease the ratio of peak signal power to the average. The results exhibit that the most successful compander is the one with a cubic characteristic that surpasses all samples under study both in the level of reduction in the ratio of peak signal power with orthogonal frequency distribution of channels to average power and in noise immunity. As for converters with piecewise linear approximation and with a logarithmic characteristic, thus, choosing one of them, the operating conditions should be taken in consideration. Therefore, a piecewise linear approximation compander has slightly worse peak-factor reduction relative to a non-linear converter with a logarithmic characteristic, but its calculated measure of modulation error is several times smaller, which indicates greater immunity to interference.

A significant advantage of the physical limitation of power peaks is the simplicity of the circuit implementation, which makes the application of this method much cheaper than reducing the PAPR level with non-distorting methods. However, there is a nuance that can negate all the results of this system. The fact is that when the signal is limited by the threshold, both in-band and out-of-band noise can occur. Furthermore, with incorrectly defined parameters for limiting the power peaks, this radiation can reach values at which useful information completely cease to be distinguishable on the receiving side, which makes further functioning of the communication channel absolutely impossible.

This fact means that it is necessary to carefully approach the determination of the parameters of a nonlinear amplifier for each specific system.

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