ОПУБЛИКОВАННЫЕ СТАТЬИ В ПЕРЕВОДЕ НА АНГЛИЙСКИЙ ЯЗЫК

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Research of the Influence of the Quadrature Components Mismatch on the Noise Immunity of OFDM and UFMC Signals*

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The method of direct modulation using complex signals is used to implement signal paths of transmitters in base stations of cellular communication systems. In the process of modulation, there are mismatches of the gain coefficient and the phase of the quadrature components of the signal. Mismatch degrades the Error Vector Magnitude (EVM) at the receiver, which in turn results in an increased Bit Error Rate (BER). The quality of the received signal is expressed in bit error rate. The mismatch of the amplitude and phase of the quadrature components is one of the most important factors making the greatest contribution to the amplitude of the error vector, and which must be investigated. The paper presents a research of the influence of the mismatch on the OFDM (Orthogonal frequency-division multiplexing) and UFMC (universal filtered multi-carrier) technologies. A model of the transmitter, communication channel and receiver for OFDM and UFMC signals has been developed. The model was built in the MatLab software environment.

In the work, by studying the simulation model, the dependence of the noise immunity of technologies was studied by changing the parameters of the communication channel, such as the amplitude and phase mismatch of the quadrature components of the signal, as well as the signal-to-noise ratio. Also, a comparative analysis of such signal parameters as the occupied bandwidth, peak to average ratio, frequency of occurrence of bits with an error was carried out. Based on the results of the study, graphs of the dependence of the error probability and the signal peak to average ratio on the mismatch of the quadrature components were obtained for two technologies, OFDM and UFMC. The study allows us to highlight the advantages of UFMC technology, which are expressed in spectral efficiency, noise immunity and the level of the signal peak to the average ratio.

Keywords: OFDM, UFMC, signal modulation and demodulation, quadrature imbalance, noise immunity.

Introduction

Technology of OFDM is currently used in many wireless communication standards, as well as digital television. At the same time, the technology has a number of disadvantages, such as a high signal crest factor [1] and intersymbol interference [2]. UFMC technology is proposed as a replacement for OFDM. The UFMC technology makes it possible to abandon the cyclic prefix and thereby increase the spectral efficiency of a mobile communication network compared to OFDM technology [3, 4]. In addition, UFMC technology reduces out-of-band emissions by filtering.

The purpose of the investigation is to evaluate the dependence of the noise immunity of the signals of the two technologies on the mismatch of the quadrature components and compare the results obtained.

Fig. 1, *a*, *b* shows a block diagram of the transmitter and receiver of OFDM signals [5].

The signal is formed in the following way. Using the s/p (serial to parallel) block, a sequence of bits is converted from serial to parallel. Each bit stream is then modulated with a different modulation scheme, such as QPSK or QAM [6]. We add a guard interval to the left and right of the bit sequence, while the guard interval is equal to a sequence of zeros, which usually occupies 1/4, 1/8, 1/16 or 1/32 of the OFDM symbol, after which the IFFT is performed. With the sum of the in-phase and quadrature components of the signal, we obtain a signal for transmission over the communication channel.

On the receiving side, FFT and guard interval removal are performed. Each stream is then demodulated with the appropriate circuitry. Using the p/s (parallel to serial) block, the parallel stream is

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converted to serial and the original sequence of information bits is restored.

The second modulation method considered is multi-frequency transmission with UFMC universal filtering.

UFMC is a generalization of OFDM and FBMC (Filter Bank Multi-carrier) multi-carrier transmission. If FBMC filters individual subcarriers, then UFMC filters subbands of the combined subcarriers [7, 8].

This grouping of subcarriers makes it possible to reduce the filter order (compared to FBMC) [9, 10]. In addition, with UFMC it is also possible to use modulation schemes such as QAM [11].

Fig. 2, a, b shows the transmitter and receiver of UFMC signals [12].

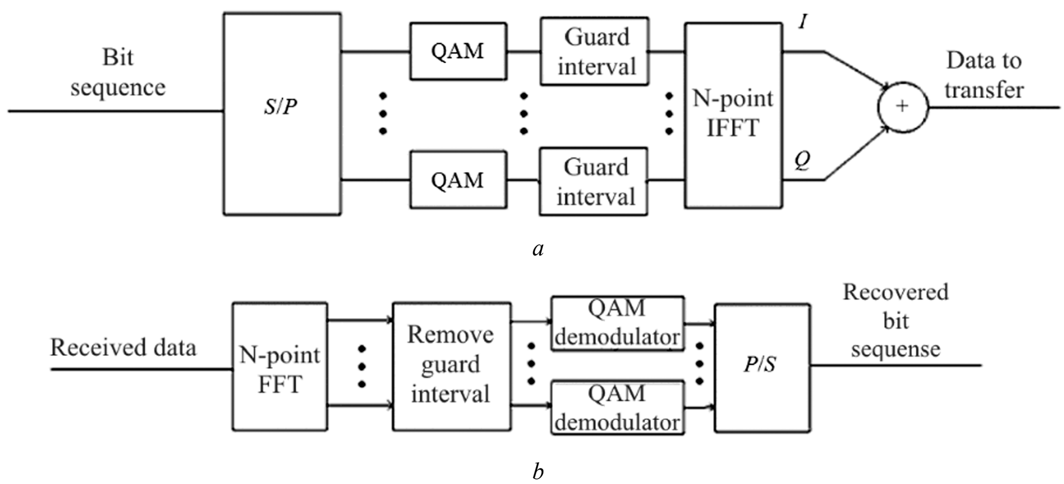

Fig. 1. Transmitter (*a*) and receiver (*b*) of OFDM signals

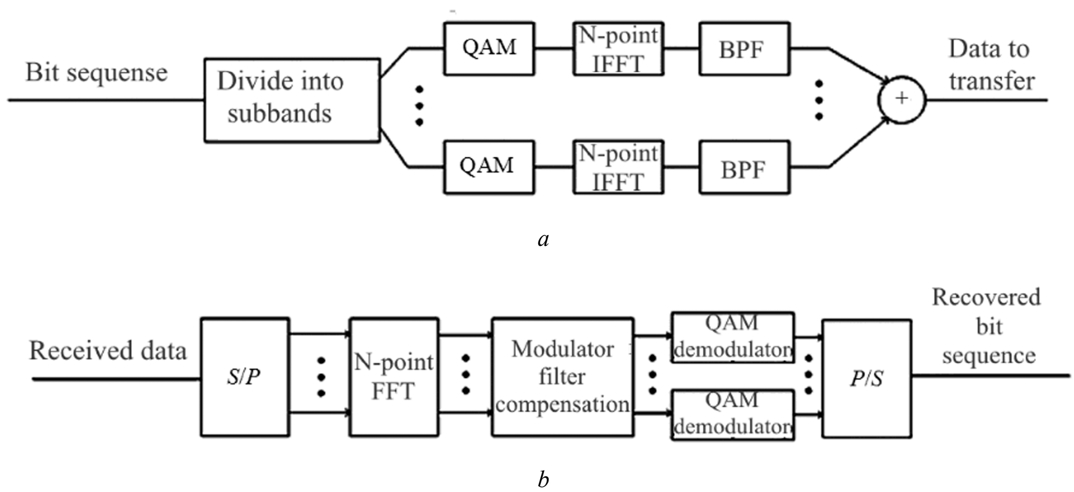

Fig. 2. Transmitter (*a*) and receiver (*b*) of UFMC signals

First, the subcarrier band is divided into subbands. Each subband is modulated with the appropriate modulation scheme. An N-point IFFT is then performed. Each subband is then filtered with a corresponding band pass filter of a specific order. A filter with a Dolph-Chebyshev window is usually used; an example is shown in fig. 3. Filter type, order, and bandwidth directly affect the cancellation filter at the receiver side, where an inverse impulse response filter is used. The filtering results are summed to obtain a signal for transmission through the communication channel.

When a UFMC signal is received, N-point FFT. Then, the influence of the communication channel and the subband filter are compensated. In this example, there is only subband filter compensation. For compensation, a filter with the inverse impulse response of the subband filter is used, while the guard interval is taken into account. The impulse response of the compensation filter, taking into account the guard interval, is shown in fig. 4. After that, each subband is demodulated by the corresponding circuit. Then the parallel data stream is converted to serial, and the original bit sequence is restored [13].

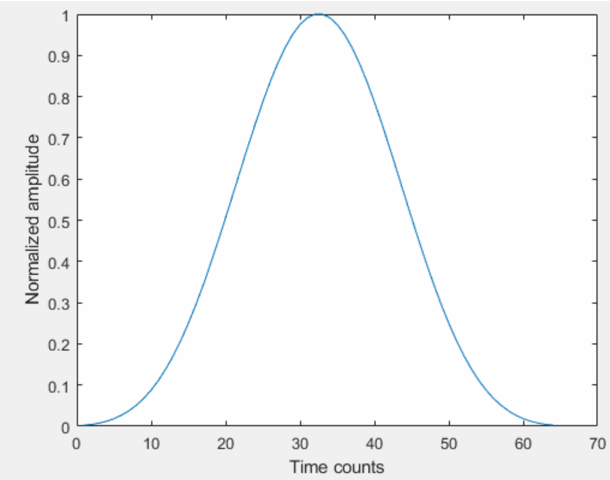

Fig. 3. Impulse response of the filter

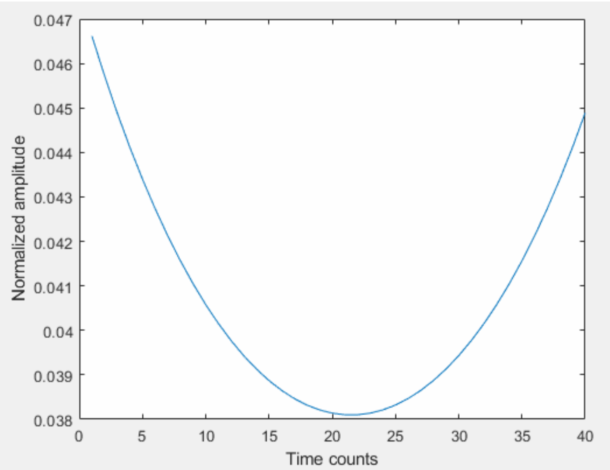

Fig. 4. Impulse response of the compensation filter taking into account the guard interval

On the basis of theoretical data, a mathematical model was built in the MatLab program [14, 15]. The model corresponds to the receiver and transmitter circuits of OFDM and UFMC signals shown in fig. 1 and 2. Simulation options:

– number of FFT points, N – 2048;
– number of UFMC subbands – 10;
– number of subcarriers in the UFMC subband – 40;
– filter order – 64;
– attenuation in the filter stopband – 80 dB;
– type of modulation – 16-QAM;
– signal-to-noise ratio – 20 dB.

Fig. 5 shows the combined ten subband spectrum of the generated UFMC signal. When adding the subbands, we obtain the total spectrum of the UFMC signal, which is shown in fig. 6.

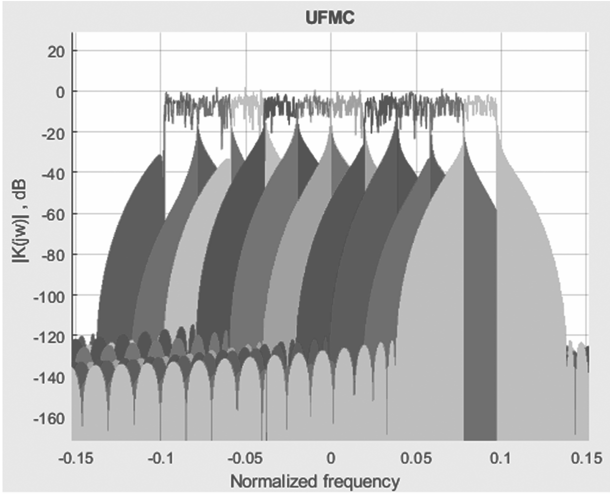

Fig. 5. Spectrum of UFMC signal subbands

The simulation results from fig. 6 and 7 show that the bandwidth of the UFMC signal is narrower, and the attenuation of out-of-band emissions is greater than that of the OFDM signal, which confirms the theoretical data. Graphs are plotted by normalized frequency with respect to the Nyquist frequency.

Fig. 8 shows the result of the study of noise immunity with a mismatch of the quadrature components. The study was carried out at different values of the signal-to-noise ratio at fixed mismatch values for OFDM and UFMC signals.

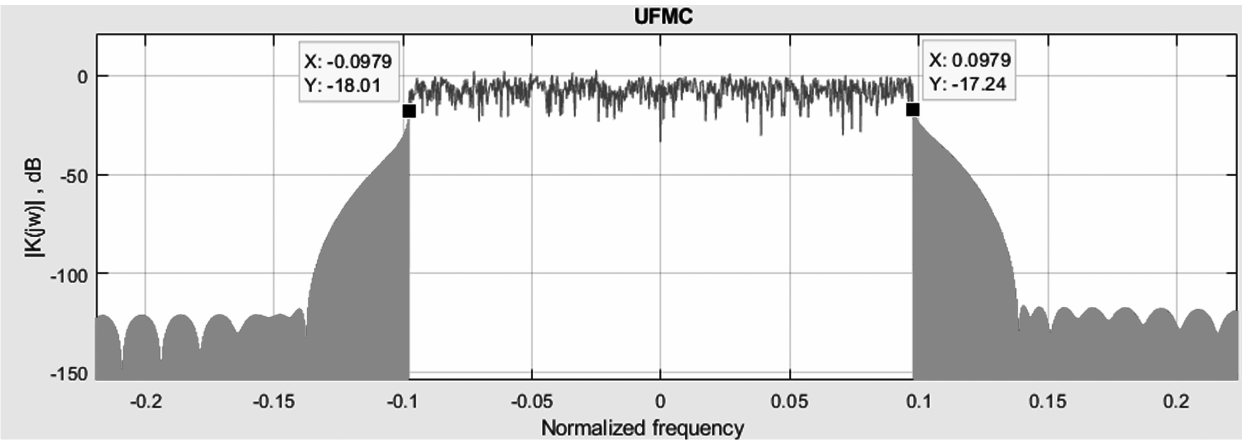

Fig. 6. Spectrum of UFMC signal

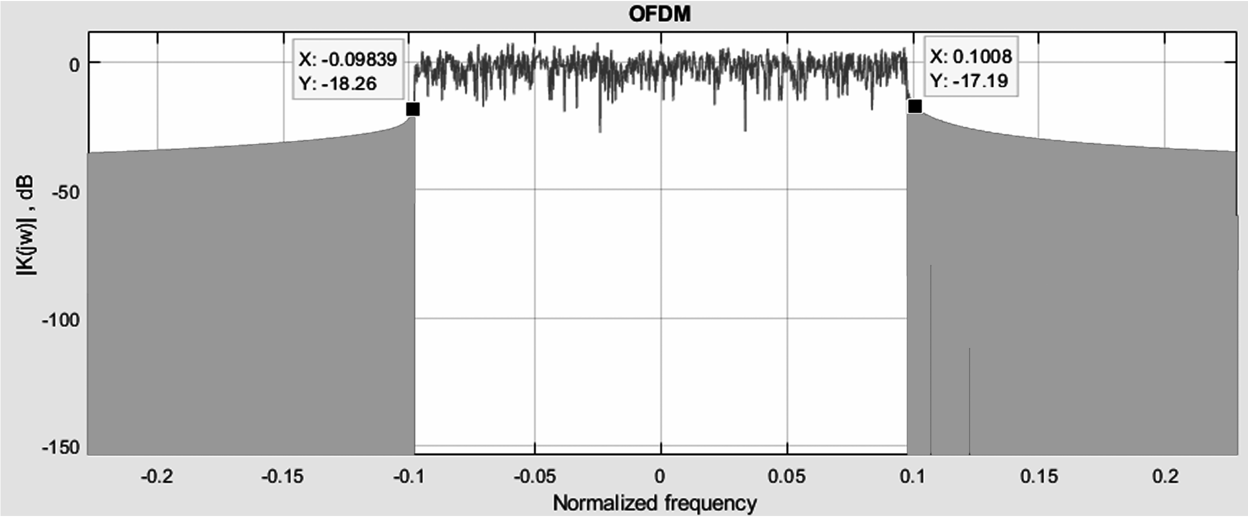

Fig. 7. Spectrum of the OFDM signal

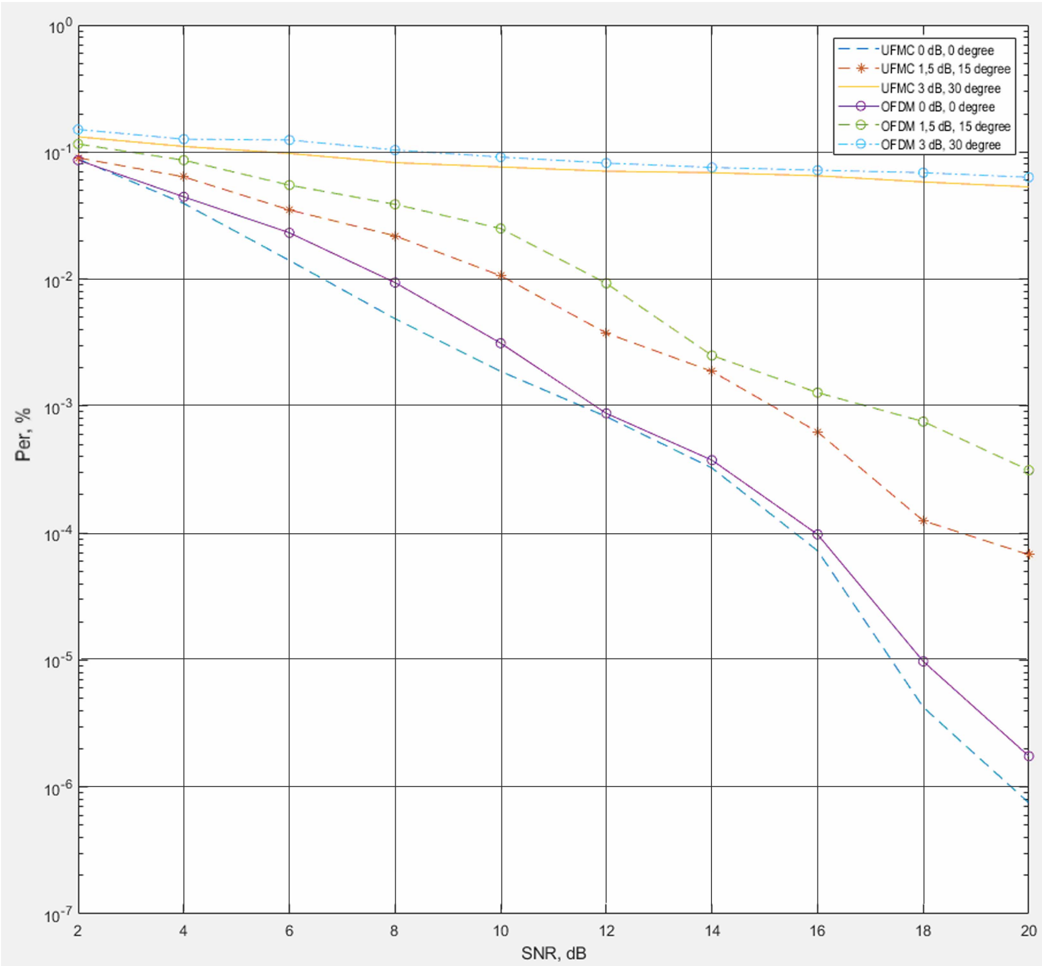

Fig. 8. Graph of the dependence of the probability of a bit reception error on SNR with a fixed imbalance of the signal quadrature components

Fig. 9 and 10 show the result of studying the dependence of the signal crest factor on the parameters of the mismatch of the quadrature components, where *dA* is the amplitude mismatch, *dB*; *dP* - phase mismatch in degrees.

Changing parameters in *dA* ranges ([0; 3], *dB*) and *dP* ([0; 30], deg) is due to the fact that with an increase in the mismatch, the maximum error probability reaches 0.5, and further research into the increase in the mismatch of the quadrature components does not make sense.

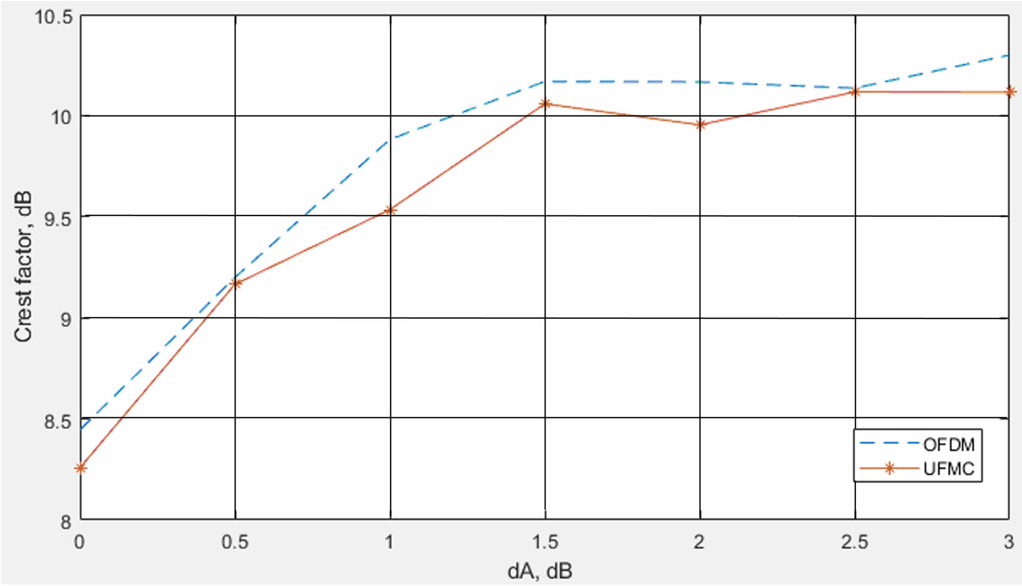

Fig. 9. Graph of the dependence of the peak to average ratio on the amplitude mismatch

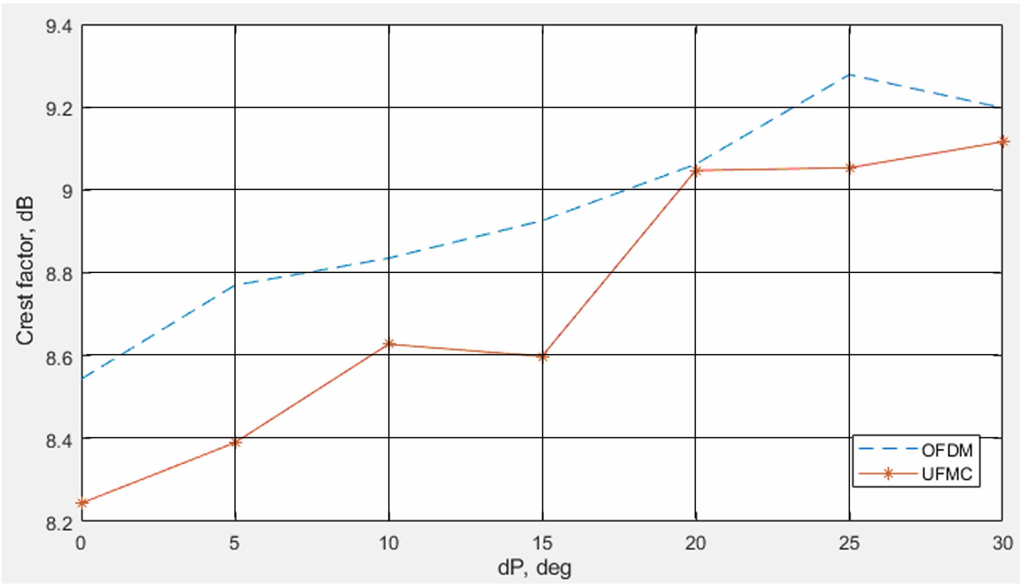

Fig. 10. Graph of the dependence of the peak to average ratio of the signal on the phase mismatch

Research results and conclusions

In accordance with the goal, the noise immunity of OFDM and UFMC signals was studied depending on the mismatch of the quadrature components of the signal and a comparative analysis was carried out. The results of the study confirmed that the UFMC method is spectrally more efficient than OFDM due to subband filtering.

Subband filtering in the UFMC method eliminates the cyclic prefix required in the OFDM method to prevent intersymbol interference, which, in turn, reduces the number of blocks in the signal generation process.

The result of the study shows that the UFMC signal has a lower crest factor compared to the OFDM signal by an average of 2.4 %; You can also highlight a number of the following features:

1) when an imbalance of the quadrature components is introduced, the error probability of the received bit and the crest factor of the signal increase;

2) the amplitude imbalance has a greater effect on the increase in the crest factor of the signal;

3) phase imbalance has a greater impact on the error probability;

4) the UFMC method shows better noise immunity compared to the OFDM method.

When using the UFMC technology, the gain in signal-to-noise ratio with an error order of 10^{-4} is 0,9 dB, and with an error order of 10^{-6} it is 1,2 dB relative to OFDM technology.

The results of the study can be extended to other values of the number of subbands and subcarriers.

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Исследование влияния рассогласования квадратурных составляющих на помехоустойчивость сигналов OFDM и UFMC

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Метод непосредственной модуляции с использованием комплексных сигналов применяется при реализации сигнальных трактов передатчиков в базовых станциях систем сотовой связи. В процессе модуляции возникают рассогласования коэффициента усиления и фазы квадратурных составляющих сигнала. Рассогласование ухудшает модуль вектора ошибки (Error Vector Magnitude, EVM) в приемнике, что, в свою очередь, приводит к повышению частоты появления ошибочных битов (Bit Error Rate, BER). Качество принимаемого сигнала выражается в частоте появления битовых ошибок. Рассогласование амплитуды и фазы квадратурных составляющих является одним из важнейших факторов, вносящих наибольший вклад в амплитуду вектора ошибки, который необходимо исследовать.

В статье приведено исследование влияния рассогласования квадратурных составляющих сигналов технологий OFDM (Orthogonal frequency-division multiplexing) и UFMC (universal filtered multi-carrier). Разработана модель передатчика, канала связи и приемника для сигналов OFDM и UFMC. Модель построена в программной среде MatLab при помощи языка MatLab и представляет собой программную модель m-script.

В ходе работы путем исследования имитационной модели изучена зависимость помехоустойчивости технологий путем изменения параметров канала связи, таких как амплитудное и фазовое рассогласование квадратурных составляющих сигнала, а также отношение сигнал/шум. Проведен сравнительный анализ таких параметров сигналов, как занимаемая полоса частот, пик-фактор, частота появления битов с ошибкой. По результатам исследования получены графики зависимости вероятности ошибки и пик-фактора сигнала от рассогласования квадратурных составляющих для двух технологий – OFDM и UFMC. Проведенное исследование позволяет выделить преимущества технологии UFMC, которые выражаются в спектральной эффективности, помехоустойчивости и уровне пик-фактора сигнала.

Ключевые слова: OFDM, UFMC, модуляция и демодуляция сигнала, квадратурный дисбаланс, помехоустойчивость.

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