Проведений аналіз особливостей фазорізницевої модуляції при визначеному типі систем передачі і завади. Розглянуті особливості завадозахищеності фазорізницевої модуляції відносно адитивної завади при умові, що параметри системи передачі є змінними. Проведено дослідження інваріантності системи зі змінними параметрами до адитивної перешкоди

Ключові слова: фазорізницева модуляція, мультиплексування з ортогональним частотним розділенням каналів, інваріантність, оптимальний прийом, адитивна завада, ефект Доплера, сфокусована завада

Проведен анализ особенностей фазоразностной модуляции при определенном типе систем передачи и помехи. Рассмотрены особенности помехозащищенности фазоразностной модуляции относительно аддитивной помехи при условии, что параметры системы передачи являются переменными. Проведено исследование инвариантности системы с переменными параметрами к аддитивной помехе

Ключевые слова: фазоразностная модуляция, мультиплексирование с ортогональным частотным разделением каналов, инвариантность, оптимальный прием, аддитивная помеха эффект Допплера, сфокусированная помеха

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ANALYSIS OF SYSTEM WITH VARIABLE PARAMETERS, INVARIANT TO ADDITIVE INTERFERENCE

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1. Introduction

Modern communication networks allow customers to reach formidable data transmission speed, with a considerable stability of connection. Long Term Evolution (LTE) networks belong to modern communication networks. LTE signal use Orthogonal Frequency Division, which is a method of encoding digital data on multiple carrier frequencies, and use orthogonal subcarriers, which provide the following benefits: each orthogonal subcarrier can be modulated with a conventional modulation scheme (quadrature amplitude modulation or phase-shift keying for example) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. The difficulties of the OFDM usage are as follows:

– guard bands, used for protection from interferences created by the multipath signal spread, are required between signal frequency bands;

– strict frequency synchronization is required;

– OFDM is vulnerable to the Doppler effect, which limits its usage possibility for mobile systems.

LTE systems use phase modulation (or amplitude-phase modulation) for subcarriers, which is a special case of quadrature amplitude modulation. Usage of phase-difference modulation instead of phase modulation will allow to decrease the Doppler effect influence and lower frequency shift negative influence on the signal, which will bring great possibilities to increase the signal quality and interference immunity for mobile terminals in LTE network [1–6].

Phase-difference modulation (PDM) is a special case of difference modulation and has a great practical value for modern communication systems. Usage of phase-difference modulation in modern communication systems allows to drastically decrease interference, which appear due to the Doppler effect, in the case of uniform or uniformly accelerated source speed change, relative to the signal receiver. Besides, the usage of phase-difference modulation allows to avoid interference, which appear due to the non-strict coherence of the signal and carrying oscillation of the demodulator, or instability of generators in communication networks. Possessing high speed and low error rate, phase-difference modulation have the ability of invariance to linearly varying and non-linearly varying interference types, including invariance to signal phase and frequency change. Last ability is also available for (FDM) frequency-difference modulation, but with other equal condition phase-difference modulation provides higher information transfer speed and higher interference protection.

In the paper, the system with variable parameters was reviewed, to which systems which the use of phase difference modulation of second order belong. Also, interference immunity abilities compared to the system with constant parameters was reviewed, to which systems using phase difference modulation of the first order belong.

2. Analysis of the literature data and problem statement

Long Term evolution systems use the following key technologies: multi antenna array systems (MIMO) and orthogonal frequency division multiplexing (OFDM). Due to the phase-difference modulation (PDM) is a special case of phase modulation, and realization of PDM is more complicated than phase modulation, usage of phase modulation is considered for LTE radio networks, although ideas of phase-difference modulation are used in the development of differential methods of signal transmission in MIMO systems [7].

To suppress generic types of interferences present in mobile networks, OFMA symbol consists of the useful information field, and the cyclic prefix (CP) – retransmitted fragment of the previous symbol code. Such prefix allows to suppress inter symbol interference, due to the signal multipath spread. But OFDM systems are still highly vulnerable to interferences, which are present in non-stationary communication systems. But due to requirements to minimize step between OFDM subcarriers (15 kHz) and requirement to decrease the relative length of CP, OFDM systems have very high requirements to the process of composite signal forming. Frequency mismatch between the signal source and receiver and phase noise can lead to inter symbol interference on separate subcarriers. Due to small step between subcarriers, Doppler effect also can lead to the same interference types, which is highly important for mobile communication operators, which provide services to highly mobile terminals [8, 9].

Further investigation on LTE radio interface possibilities of protection from additive focused interferences and Doppler effect interferences resulted in the conclusion that LTE systems, and OFDM to be specific have no mechanisms of protection against such interferences [10].

To provide immunity to LTE systems, the modulator/demodulator system should be synthesized or chosen to provide such ability [11].

As per further investigation of modulation types, which can provide immunity to such interference types [12], PDM is chosen, as it provides immunity to focused interference and Doppler effect interference.

As per further research, system with variable parameters is chosen, since such system type will be required to implement PDM of the second order, and all its benefits to LTE radio network.

It's obvious that systems with variable parameters, in general, possess grand possibilities. For example, potential interference immunity of discrete data transfer systems is reached by the usage of the coherent receiver. Coherent reception in practice may be realized only in adaptive device, since carrying oscillation, which is coherent with signal, is formed from the received mixture of signal and interference, by using special devices of automatic frequency and phase adjustment.

From the point of view of reaching invariance to interference focused by the specter, systems with variable parameters also have their benefits over systems with constant parameters. Since the implementation of such system to LTE radio network will bring great benefit in terms of lowering signal interference for terminals with high mobility, such research is considered as valuable.

3. Purpose and objectives of the study

The key purpose of the paper is to define invariance abilities of systems with variable parameters, in case of additive interferences, and to proof that systems with variable parameters can achieve better invariance abilities than systems with constant parameters.

In accordance with the set goal, the following research objectives are identified:

1. General phase difference modulation characteristics and their characteristics are described. Modulation required for the system with variable parameters is defined.

2. The ability of invariance of systems with variable parameters to additive interferences was researched and compared with the ability of invariance of systems with constant parameters to additive interferences.

3. The process of signal reception for the corresponding system is reviewed, with the usage of receiver scheme ordinary for radio wave receivers, belongs to systems with variable parameters.

4. Method of mathematical analysis and parallel signal receiver scheme analysis

The abilities of invariance of the described systems are researched by means of mathematical analysis of function of signal oscillation, which is ordinary for systems which use phase – difference modulation. Based on the function analysis, the ability ~~if~~ of invariance of the corresponding system is concluded, based on possible interference influence on each of the signal parameters. The ability of the invariability of corresponding systems is applied and reviewed based on the scheme of the signal receiver scheme, typical for modern radio wave receivers. Based on the receiver scheme structure, which is ordinary for systems with variable parameters, corresponding conclusions have been done, regarding its physical ability to surpass additive interference.

5. Results of research of system with variable parameters invariance ability

For PDM of the k-th order, information is displayed as a sequence of the k-th differences of bearing oscillation phases, which can form a limited quantity of values: $\Delta^k\phi_1, \Delta^k\phi_2, \cdots, \Delta^k\phi_m$. Corresponding system is called "t-positions system with PDM of the k-th order", or with $m = 2^N$ – "system with N-fold PDM of the k-th order". For N-fold systems, variants of the k-th transferred phase differences taking values of $\Delta^k\phi_i = \Delta^k\phi_0 + (i-1)\pi / 2^{N-i}$ $(i = 1, 2, \ldots, 2^N)$, where $\Delta^k\phi_0$ is the starting value of the k-th phase difference, which is chosen depending on modulation and demodulation operations realization convenience.

Choice of PDM or FDM order depends on the nature of non-additive actions, which leads to instability of the phase and frequency of the signal, and a priori data about these actions.

Let us further develop this question.

Let the carrier signal have oscillation of the following shape:

$$S(t) = a \sin \psi(t) . \qquad (1)$$

We will isolate the linear component $\omega_0 t$ from this trigonometric function, as this component change does not lead to change of starting phase in moments of time, which are multiple to message length T, which is right for $\omega_0 = 2\pi l / T$, where l is the integer. In this case, phase difference $\psi(t) - \omega_0 t = \phi(t)$ will describe the starting phase change in previously mentioned moments of time, and signal (1) may be written as:

$$S(t) = a \sin[\omega_0 t + \phi(t)]. \qquad (2)$$

For digital message transmitted over phase modulated communication channels, the function $\phi(t)$ displays both information signals being transmitted and signal fluctuations. Those fluctuations are called interferences, or non-linear and parametric conversion of the signal in communication channels. That conversion usually can be displayed on the limited interval by the polynomial model with random coefficients $\phi_0,\phi_1,\phi_2,\ldots,$ which characterize constant, linear, quadratic, etcetera changes of the signal staring phase:

$$\phi(t)=\sum_{i=0}^{k-1}\phi_i t^i+\phi_u(t), \qquad (3)$$

where ϕ_u is the signal information base.

Let us consider a system which is invariant to additive interference, which has the shape of harmonic oscillation with random amplitude, frequency and phase, but without restriction by receiver interference immunity.

Let's research, if there any possibility exists for the system with variable parameters to achieve better invariance results, than for the system with constant parameters.

Let us consider most typical interference cases:

1. Undefined, but stable signal starting phase:

$$\phi(t)=\phi_u(t)+\phi_0; \quad \omega(t)=\omega_u(t). \qquad (4)$$

This interference appears as a result of the instability of generators of carrier oscillation in the communication line, or nonstrict coherence of signal and carrier oscillation in the demodulator (coherence with accuracy not lower than discrete shift). As in this case

$$\frac{d^k[\phi(t)-\phi_u(t)]}{dt^k}\equiv 0,$$

$$\frac{d[\phi(t)-\phi_u(t)]}{dt}\equiv 0; \quad \omega(t)-\omega_u(t)\equiv 0,$$

then

$$\Delta^1\phi=\Delta^1\phi_u=\mathrm{in\,var}\,\phi_0; \quad \Delta^0\omega=\omega_u=\mathrm{in\,var}\,\phi_0. \qquad (5)$$

This means that PDM of the first order and FDM of zero order (simple frequency modulation) can provide invariance of signal to the constant phase shift.

2. Undefined or linearly changing starting phase and undefined, but constant signal frequency:

$$\phi(t)=\varphi_u(t)+\phi_0+\phi_1 t; \quad \omega(t)=\omega_u(t)+\phi_1. \qquad (6)$$

Such condition appears as a result of the instability of carrier oscillation generators in the communication line, and by the Doppler effect in the case of communication with the mobile object, which linearly change its distance between the transmitter and the receiver. Due to in this case:

$$d^2[\phi(t)-\phi_u(t)]/dt^2\equiv 0; \quad d[\omega(t)-\omega_u(t)]/dt\equiv 0,$$

then

$$\Delta^2\phi=\Delta^2\phi_u=\mathrm{in\,var}(\phi_0,\phi_1); \quad \Delta^1\omega=\Delta^1\omega_u=\mathrm{in\,var}(\phi_0,\phi_1). \qquad (7)$$

This means that absolute invariance to the linear deviation of the signal phase may be provided by PDM of the second order and FDM of the first order.

3. Undefined and square varying signal phase and undefined and linearly changed signal frequency:

$$\phi(t)=\phi_u(t)+\phi_0+\phi_1 t+\phi_2 t^2; \quad \omega(t)=\omega_u(t)+\omega_1+2\omega_2 t. \qquad (8)$$

Such situation may be created by generators of carrying oscillation instability, or because of the Doppler effect in the case of a uniformly accelerated change of the distance between the signal source and the signal receiver. As in this case

$$d^3[\phi(t)-\phi_u(t)]/dt^3\equiv 0; \quad d^2[\omega(t)-\omega_u(t)]/dt^2\equiv 0,$$

then

$$\Delta^3\phi=\Delta^3\phi_u=\mathrm{in\,var}(\phi_0,\phi_1,\phi_2),$$

$$\Delta^2\omega=\Delta^2\omega_u=\mathrm{in\,var}(\phi_0,\phi_1,\phi_2). \qquad (9)$$

This means that absolute invariance to square varying signal phase change and to linear frequency change may be provided by PDM of the 3rd order and FDM of the second order. The last case is most complicated, and for such signal to be invariant to the described interference, usage of the adaptive system is required.

In the proposed paper, the system with variable parameters is reviewed, to which systems with phase division modulation of the second order belong, while systems with phase difference modulations of the first order belong to systems with constant parameters.

As displayed in the paper [13], for systems with constant parameters, invariance to such focused by specter interference (absolute or relative) can be reached only in a way of signal complexity increase, meaning an increase of its base ΔfT. Usually, the base size cannot be increased infinitely, because, with the defined symbol transmission speed, which is equal to $1/T$, this can be done only by increasing the channel frequency band, which is always difficult. For example, in shortwave radio channel frequency band dedicated to a single station cannot be wider than few tens of kilohertz. Even if $\Delta f=100$ kHz, with the manipulation speed of 300 messages per second (T=3,33 ms), the system base is $\Delta fT\approx 330$. With such base, maximal possible interference strength excess over signal strength is equal to ten ($P_i/P_s=10$), if a decrease of the equivalent signal energy by half ($q=Q/Q_{equ}=2$) is considered as possible.

Besides, in the case of an increase of the channel bandwidth, there is a possibility that few narrowband interferences will be added to it, which will lead to further complications [14, 15].

Reasons, which lead to the signal frequency change, are very different: instability of generators in communication channels, quick movement of the source of electromagnetic oscillations, or environments which reflect those oscillations (Doppler effect). Also, there are situations; when the signal frequency is fixed and stable, but not known on the receiver side. The system with constant parameters which is using phase-difference modulation can obtain invariance to non-additive interference. Although, invariance to non-additive interference have cost – payment for invariance to non-additive interference is lowering immunity to additive interference. In other words, for the system with constant parameters, error probability is invariant to signal frequency, but it's higher than the error probability for the system with no invariance ability, in the case if the frequency is constant. This is illustrated on Fig. 1, on which relation between interference of invariant and non-invariant systems are shown [16].

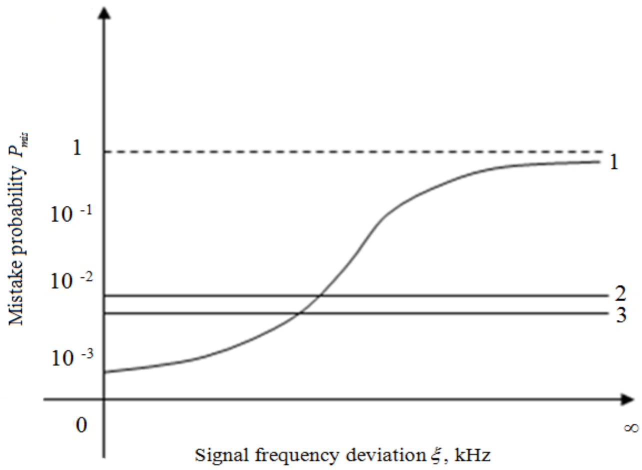

Fig. 1. Characteristics of interference immunity of invariant and non-invariant systems: 1 — possibility of error in the non-invariant system ($p \neq \mathrm{in\,var}\,\xi$); 2 — allowed error possibility; 3 — possibility of error in the invariant system ($p = \mathrm{in\,var}\,\xi$)

Please also remember that ξ is the random signal frequency deviation, and P_{mis} is the error probability.

In this way, possibilities to reach invariance in frames of the system with constant parameters are limited, which should not lead to a conclusion that these possibilities should be ignored. In the general case, non-additive interference cause sudden changes of signal parameters, for example, frequency.

Let us consider wide band system with complex signal and adaptive receiver (Fig. 2). Let the harmonic oscillation with frequencies $\omega_1, \omega_2, ..., \omega_m$ be used as elements of the composite signal, and the signal itself is a sum of these oscillations.

Such signal is called parallel complex signal because each information signal is transferred in the same time by each and every element of the signal. The modulation shape of complex signal elements is not significant in the current example: it can be, for example, frequency or phase-difference modulation. The only important thing is that the specters of modulated signals of complex signal elements do not overlap.

In the receiver (Fig. 2), the signal passes through the voice filter system $\varphi_1, \varphi_2, ..., \varphi_m$ with configured frequencies of $\omega_1, \omega_2, ..., \omega_m$, which lead us to the result; that separate frequency components (elements of the complex signal) become completely separated on the outputs of bandpass filters. After that, each element of the complex signal passes through the signal amplifier AMP with variable transmission gain in the reached demodulator. After that, modulated elements of the complex signal are processed altogether, for the purpose of making a decision regarding transmitted information symbol. Due to the fact that they carry the same information, transmitted symbol can be defined by "voting method" by the majority of results of signal elements modulation. In this case, the adder Σ fulfills a role of the major logical scheme. There is also a possibility to sum analogue voltages of the demodulator outputs (before making decisions regarding the transmitted symbol on each demodulator), then the adder is a device of analogue signals addition [17].

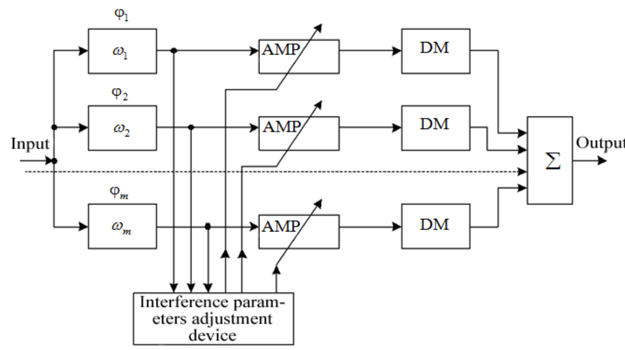

Fig. 2. Structural scheme of the adaptive receiver of the parallel complex signal: $\varphi_1, \varphi_2, ..., \varphi_m$ — voice filters; $\omega_1, \omega_2, ..., \omega_m$ — voice filters frequencies; AMP — amplifiers; DM — demodulators; Σ — adder

We will not deepen into the details of the working process of the described adaptive receiver input part. Essential part right now is that it has m signal processing flows, which carry the same information, and that the resulting effect consists of private effects on the outputs of dividing filters.

The possibility to reach invariance in the system being discussed is based on the point; that interference focused by the specter passes through only one of dividing filters, so it damage only one of the m-th receiver areas.

If damaged area will be excluded from further processing procedure, the system should be fully invariant to interference ξ. Which means for it, the following rule is fulfilled: $p = \mathrm{in\,var}\,\xi = 0$.

To define the signal area damaged by interference, device of interference parameters measurement is used on the receiver. Its working algorithms may be different. Due to complex signal have high redundancy, area with least "quality" can be chosen by comparing results of summary signal processing with results of each area processing results. The device of interference parameters measurement also can determine interference levels in areas by comparing of signal level on each filter output with the average signal level on the output of all dividing filters. In any interference measurement device working algorithm, it should produce a command on proper transmission gain coefficient setting of the corresponding amplifier. In the case of very strong interference in the i-th area, the transmission gain coefficient of the i-th amplifier is practically equal to zero.

In the case if beside focused interference ξ, fluctuation interference is present in the described system with variable parameters, in the same way as in the system with constant parameters, only partial invariance is possible to interference ξ. It is true that in case of one of receiver area is covered with interference, together with interference part of useful signal data is erased. Due to that, the possibility of error in the case of focused interference is slightly higher, than without it. Although, this increase can be made insufficient by increasing signal redundancy and by an increase of signal reception areas [18]. Nevertheless, as it was pointed in the previous example, on the way of increase of redundancy (signal base) there are definite problems.

Advantage of the system, invariant to focused interference with variable parameters comparing with the system with constant parameters, which is invariant to the same interference consists in the ability to provide invariance (absolute or relative) to much bigger range of amplitudes. In the system with constant parameters, invariance is achieved for interference with amplitude, which does not exceed the defined value, which depends on the base (redundancy) of the complex signal. In the referred system with variable parameters, as it can be seen, maximal allowed amplitude of the interference does not depend on the signal base, and is defined only by the ability of bandpass filters to suppress signals, which belong to frequencies outside of the throughput band.

Because it is not a problem to built filters with signal fading of hundred times outside of throughput band, such system may provide an interference signal fade, which considerably increase the useful signal level. But to provide non-significant loss in the interference immunity to the fluctuation interference influence in the system with variable parameters, large enough signal base is required, so suppression of focused interference would not lead to a significant decrease of the useful signal energy.

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