UDC 621.396:621.396.933:629.783:621.396.946
DOI: 10.18372/2306-1472.72.11979

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INFLUENCE OF TRANSMITTER NONLINEARITIES ON DATA TRANSMISSION FROM REMOTELY PILOTED AIR SYSTEM

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Abstract

Purpose: *1) to develop a model of a communication channel of an unmanned aerial vehicle "UAV-Ground station" with adaptive modulation and orthogonal frequency division of channels; 2) to calculate the channel parameters with different types of fading for different levels of satellite transponder nonlinearity.* ***Method:*** *MATLAB Simulink software was used to simulate the channel operation.* ***Results:*** *Based on the IEEE 802.16d standard, a realistic model of the communication channel of the unmanned aerial vehicle "UAV-Ground Station" was developed, which is used to estimate the channel parameters. The channel model with adaptive modulation consists of a source of information, a transmitter, a downlink channel with fading, and a terrestrial station receiver. Dependences of the signal-to-noise ratio of the terrestrial receiver on the signal-to-noise ratio in the channel down for different types of nonlinearity of the unmanned aerial transmitter, various modulations (BPSK, QPSK, 16QAM, 64QAM), various types of fading are obtained. The signal constellations of the received signals for different Doppler frequency shifts are compared.* ***Conclusion:*** *The developed model allows determining the conditions under which the channel is "open" for a given type of a modulation and a data rate. The proposed approach can be considered as a method for estimating the parameters of the satellite communication channel of an unmanned aerial vehicle with fading.*

Keywords: OFDM channel; transmitter nonlinearity; unmanned aerial vehicle communication channel.

1. Problem statement

The aviation authority and people in general wants partially cover the aviation transportation system with the help of unmanned machines. Remotely piloted aircraft systems (RPAS) are a new way of using flying machines. This is only the first step in transition from fully controlled manned vehicles into fully guided unmanned vehicles. This is impossible without information exchange through wireless communication systems. Nevertheless, even perfect in researchers minds wireless systems in practice confront with quality of data transfer [1].

Currently there are many methods and technics via which this imperfection in receiving and sending of data can be reduced. One of them is Orthogonal Frequency Division Multiplexing (OFDM) technology [2]. This technology is a method of encoding of digital data on multiple carrier frequencies. The main feature and advantage of this technology is ability to resist when severe difficulties in channel are take place. For example, confront with fading at high frequencies or narrow band interferences caused by multipath propagation.

The information transmitting by means of OFDM signals became the standard for many modern radio systems in connection with a number of advantages - high spectral efficiency, low level of an intersymbol interference, high quality of transmitting in the conditions of frequency-selective fading.

At the same time OFDM systems are sensitive to phase and frequency instability of carriers. It is especially important to provide power efficiency for an information transmitting in aviation complexes with rigid restriction of spatially-frequency parametres for onboard radio-electronic equipment. For this, simulations are mandatory to infer the performance of RPAS communication systems.

However, issues related to the RPAS channel nonlinearities still are not investigated in detail.

2. Analysis of researches and publications

Basic requirements for RPAS data rate are stated in the NATO standards [3-5].

Nonlinear distortion is a source of major degradation of modulation fidelity in multicarrier systems with OFDM signals. OFDM signals significantly improve spectrum efficiency, reduce frequency-selective fading problems, but are sensitive to nonlinear distortion [6]. The primary source of this nonlinear distortion is the radio frequency transmitter power amplifier. Nonlinear power amplifiers for wireless communications were modeled [7] and nonlinear power amplifier effects in multi-antenna OFDM systems were analyzed [8]. Modulation schemes effect on radio frequency power amplifier nonlinearity were considered in paper [9]. A new reduction technique of OFDM system with nonlinear high power amplifier was proposed [10]. The use of OFDM radio interface for satellite digital multimedia broadcasting systems [11], a BER for MIMO-OFDM systems [12], performances of weighted cyclic prefix OFDM with equalization [13] were studied.

3. Aim of the work

The aim of this paper is: 1) to design model of RPAS OFDM communication channel "RPAS–Ground Station" with adaptive modulation using MATLAB Simulink software; 2) to calculate parameters of a channel with different fading types for several nonlinearities level.

4. Model for "RPAS-Ground Station" channel

RPAS communication channel was analyzed using demo model *commwman80216d* designed on a basis of IEEE 802.16 standard.

The model consists of "RPAS Transmitter" (Fig.1), "Ground Station" (Fig.2), and "Downlink" with Rician fading (Fig.3).

The tasks performed in the communication system include: generation of random bit data that models a downlink burst consisting of an integer number of OFDM symbols; Forward Error Correction (FEC), consisting of a Reed-Solomon (RS) outer code concatenated with a rate-compatible inner convolutional code (CC); data interleaving; modulation, using one of the BPSK, QPSK, 16-QAM or 64-QAM constellations specified; OFDM transmission using 192 sub-carriers, 8 pilots, 256-point FFTs, and a variable cyclic prefix length.

An optional memoryless nonlinearity can be driven at several backoff levels. An optional digital pre-distortion capability can correct the nonlinearity.

It is possible to choose a non-fading, flat-fading, or dispersive multipath fading channel.

Ground Station OFDM receiver includes channel estimation using the inserted preambles. Hard-decision demodulation followed by deinterleaving, Viterbi decoding, and Reed-Solomon decoding. Both models also use an adaptive-rate control scheme based on SNR estimates at the receiver to vary the data rate dynamically based on the channel conditions. The model uses the standard-specified set of seven rates, each corresponding to a specific modulation and RS-CC code rate.

The model includes blocks for measuring and displaying the bit error rate after FEC, the channel SNR and the rate. Spectrum Scope blocks display the spectra of both the OFDM transmitter output and the faded AWGN channel output. A Scatter Plot scope displays the AM/AM and AM/PM characteristics of the signal at the output of the memoryless nonlinearity. A Scatter Plot scope displays the received signal, helping to visualize channel impairments and modulation adaptation as the simulation runs.

The Model Parameters configuration block allows choosing and specifying system parameters, such as channel bandwidth, number of OFDM symbols per burst and the cyclic prefix factor. Varying these parameter values allows to experiment with the different WiMAX profiles.

It is possible to vary the state of the nonlinearity and the digital pre-distortion via the Amplifier nonlinearity and Digital pre-distortion parameters. A Saleh model implements the nonlinearity, with three different backoff options. The digital pre-distortion function fits polynomials to the empirically determined AM/AM and AM/PM characteristics of the nonlinearity, and then creates a lookup table by which to pre-distort the signal. Since the nonlinearity induces a gain compression on the input signal, the pre-distortion applies a "gain expansion" on the signal, such that the composite gain is linear.

The Low SNR thresholds [4 10 12 19 22 28] (dB) for rate control parameter directly affects the adaptive-rate control. This parameter is a sixelement vector representing the boundaries between the adjoining seven SNR ranges that correspond to the seven rates. Ideally, the simulation should use the highest throughput mode that achieves the desired bit error rate.

The following blocks display numerical results: the Bit Error Rate Display block shows the bit error rate, number of errors and the total number of bits processed; the Est. SNR (dB) display block at the top level shows an estimate of the SNR based on error vector magnitude; the SNR block in the Channel subsystem shows the SNR based on received signal power; the Rate ID corresponds to the specific modulation RS-CC rate currently in use.

The model allows varying the fading parameters and the AWGN variance (in SNR mode) added to the signal. As a result, it is possible to examine how well the receiver performs with different fading characteristics (choosing the appropriate K factor, maximum Doppler shift, number of paths, path gains) and generate BER curves for varying SNR values.

The Multipath Rician Fading Channel block implements a baseband simulation of a multipath Rician fading propagation channel. This block models mobile wireless communication systems when the transmitted signal can travel to the receiver along a dominant line-of-sight or direct path.

Relative motion between the transmitter and receiver causes Doppler shifts in the signal frequency. It is possible to specify the Doppler spectrum of the Rician process. For channels with multiple paths, it is possible to assign each path a different Doppler spectrum, by entering a vector of Doppler objects in the Doppler spectrum field.

Because a multipath channel reflects signals at multiple places, a transmitted signal travels to the receiver along several paths, each of which may have differing lengths and associated time delays. In the block's parameter dialog box, the discrete path delay vector specifies the time delay for each path. The number of paths indicates the length of discrete path delay vector.

Fading causes the signal to become diffuse. The K-factor parameter, which is part of the statistical description of the Rician distribution, represents the ratio between the power in the line-of-sight component and the power in the diffuse component. The ratio is expressed linearly, not in decibels. The K-factor parameter controls the gain's partition into line-of-sight and diffuse components.

It is possible to specify the K-factor parameter as a scalar or a vector.

5. RPAS Communication Channel Nonlinearity Simulation

For calculations, the following parameters in the model were set up: RPAS antenna gain was taken 12.4 (an antenna diameter ≈ 0.4 m at 4 GHz), ground station antenna gain – 62.1 (an antenna diameter ≈ 2.0 m at 4 GHz).

In the Model Parameters configuration block channel bandwidth was taken 3,5 MHz and 7 MHz , number of OFDM symbols per burst was taken 1, 20 and 100. Obtained results were similar and are given on figures for channel bandwidth 7 MHz and OFDM symbols per burst 20.

Modelling of RPAS communication channel was realized for no fading, frequency-flat fading and frequency-dispersive fading when RPAS amplifier nonlinearity is disabled (Fig. 4), moderate and digital pre-distortion is enabled (Fig. 5), moderate and digital pre-distortion is disabled (Fig.6), severe and digital pre-distortion is disabled (Fig. 7).

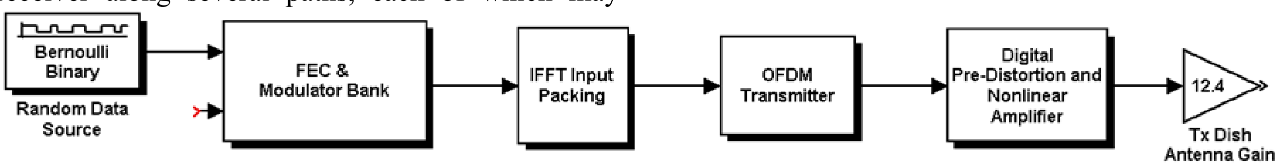


Fig. 1. “RPAS Transmitter”

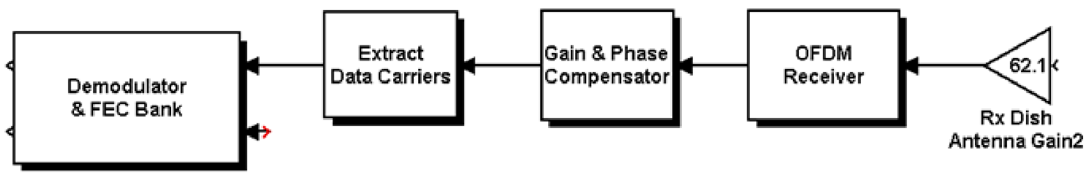


Fig. 2. “Ground Station”

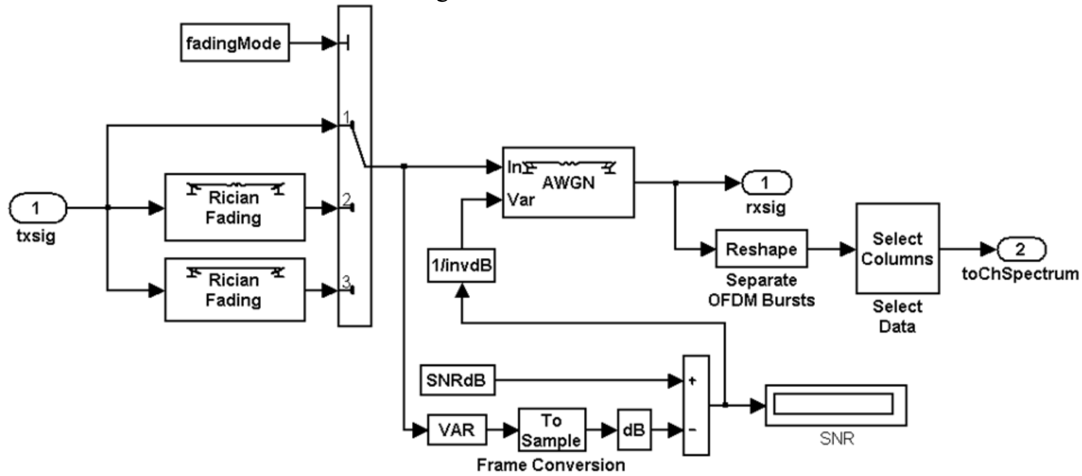


Fig. 3. “Downlink”

The downlink (Fig. 3) contains two channels with Rician fading. If the K-factor parameter is a scalar, then the first discrete path of the channel is a Rician fading process (it contains a line-of-sight component) with the specified K-factor, while the remaining discrete paths indicate independent Rayleigh fading processes (with no line-of-sight component).

For the first Rician channel (Fig. 3) K = 0,5; the Doppler frequency shift of the line-of-sight component is 0 Hz; an initial phase of the line-of-sight component is 0 rad; maximal Doppler frequency shift of the diffusive component is 0,5 Hz; the Doppler spectrum type is Rounded; the discrete path delay is 0 s; the average path gain is 0 dB.

For the second Rician channel (Fig. 3) K = 0,5; the Doppler frequency shift of the line-of-sight component is 0 Hz; an initial phase of the line-of-sight component is 0 rad; maximal Doppler frequency shift of diffusive components is 0,5 Hz; the Doppler spectrum type is Rounded; the discrete path delay vector is $[0\ 0{,}4\ 0{,}9]\cdot e^{-6}$ s; the average path gain vector is [0 -5 -10] dB. In this case, the line-of-sight component is Rician and two dispersive components is Rayleigh.

Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier *nonlinearity is disabled* are shown on Fig.4. It can be seen that the curve for the frequency-flat fading coincides with the curve for no fading curve and grows linearly with grows of SNR in downlink. The frequency-dispersive component has a nonlinear character and goes to “saturation” at $SNR_{est} \approx 22$ dB. A transition to higher types of modulation occurs at large values of SNR in downlink. The highest modulation for the frequency-flat component is 64QAM3/4 and for the frequency-dispersive component 64QAM2/3.

Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier *nonlinearity is moderate and digital pre-distortion is enabled* are shown on Fig. 5. It can be seen that the curve for the frequency-flat fading coincides with the curve for no fading curve and grows linearly with grows of SNR in downlink. For the frequency-dispersive component, the channel begins to work without errors at SNR in downlink ≈10 dB (and not at 8 dB as in the previous case), but the transition to higher modulations occurs at lower values of SNR in downlink. The curve goes to “saturation” at the same values of ≈ 22 db. The highest modulation for the frequency-flat component is 64QAM3/4 and for the frequency-dispersive component 64QAM2/3.

Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier *nonlinearity is moderate and digital pre-distortion is disabled* are shown on Fig. 6. It can be seen that the curve for the frequency-flat fading coincides with the curve for no fading curve and both has non-linear character. Both curves go to “saturation” at $SNR_{est} \approx 16{,}5$ dB and have the highest modulation 16QAM1/2.

Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier *nonlinearity is severe and digital pre-distortion is disabled* are shown on Fig. 7. All curves are non-linear and "split". Only one type of modulation is observed QPSK1/2. "Saturation" in the absence of fading and frequency-flat fading takes place at $SNR_{est} \approx 8.9$ dB, and for the frequency-dispersive fading at $SNR_{est} \approx 8.5$ dB.

The data on Fig. 4-7 are obtained for the diffuse component Doppler shift of 0,5 Hz. Changes in the time of the channel impulse response and signal constellations for the Doppler shift of 100 Hz are shown on Fig. 8.

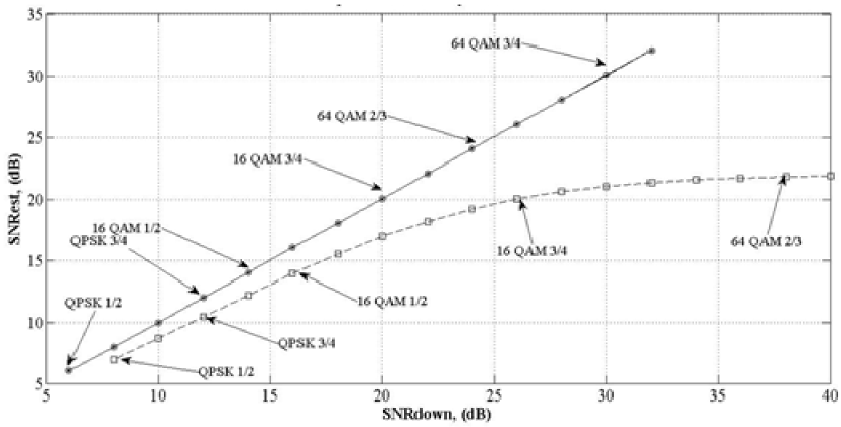


Fig. 4. Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier nonlinearity is disabled: no fading (points), frequency-flat fading (circles), and frequency-dispersive fading (squares); Max diffusive Doppler shift is 0,5 Hz

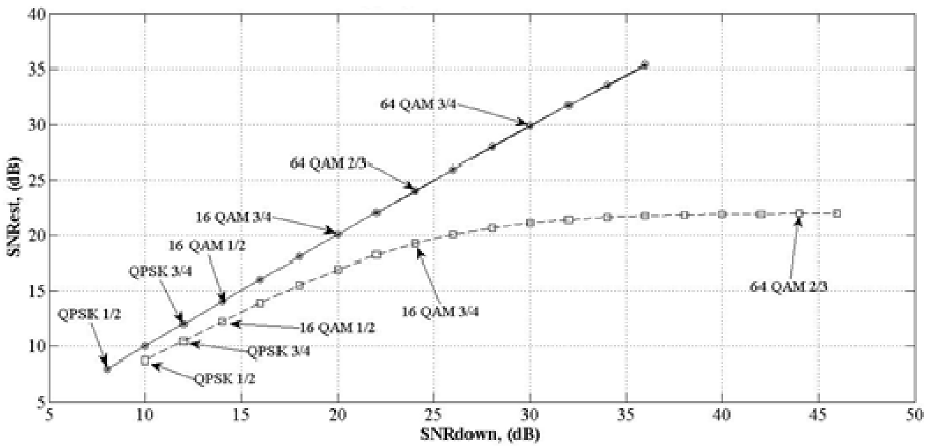


Fig. 5. Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier nonlinearity is moderate and digital pre-distortion is enabled: no fading (points), frequency-flat fading (circles), and frequency-dispersive fading (squares); Max diffusive Doppler shift is 0,5 Hz

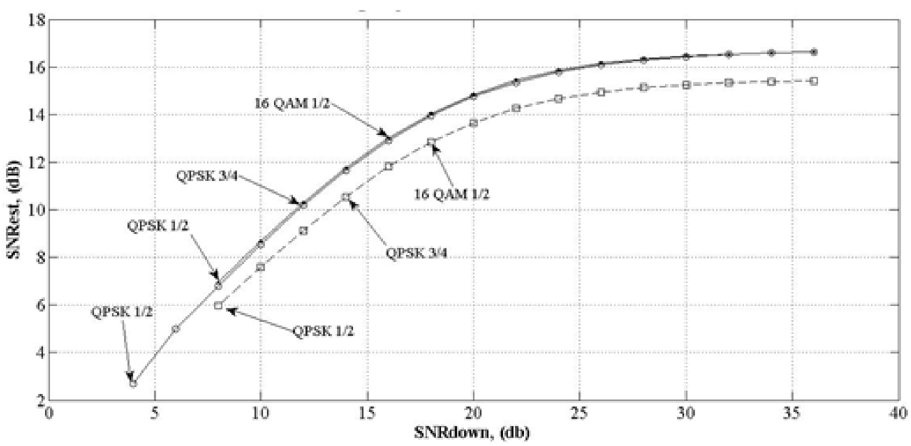


Fig. 6. Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier nonlinearity is moderate and digital pre-distortion is disabled: no fading (points), frequency-flat fading (circles),

and frequency-dispersive fading (squares); Max diffusive Doppler shift is 0,5 Hz

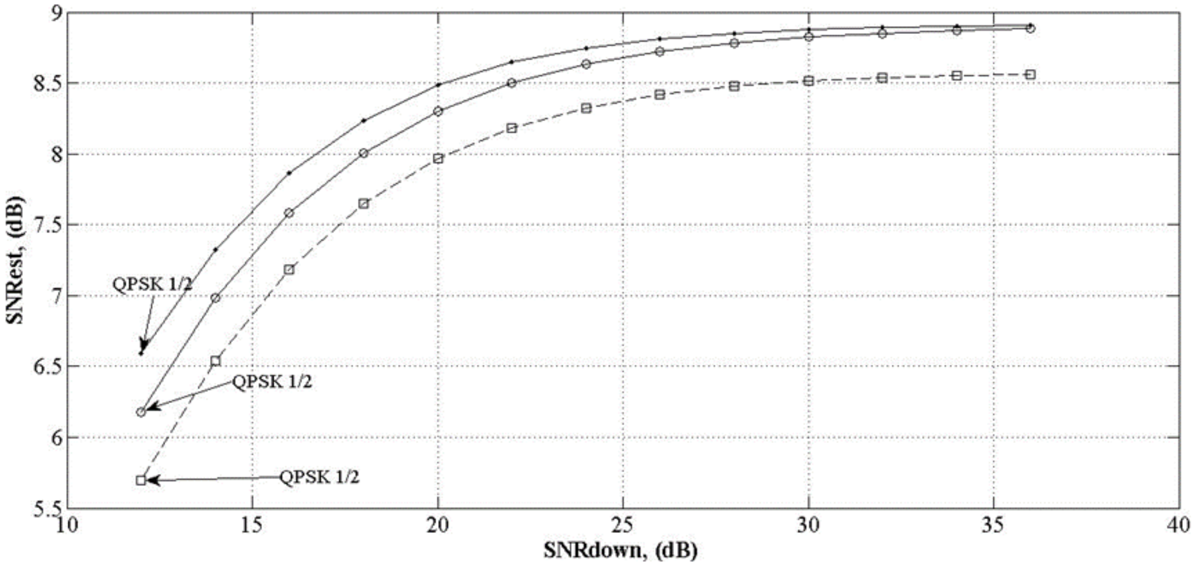
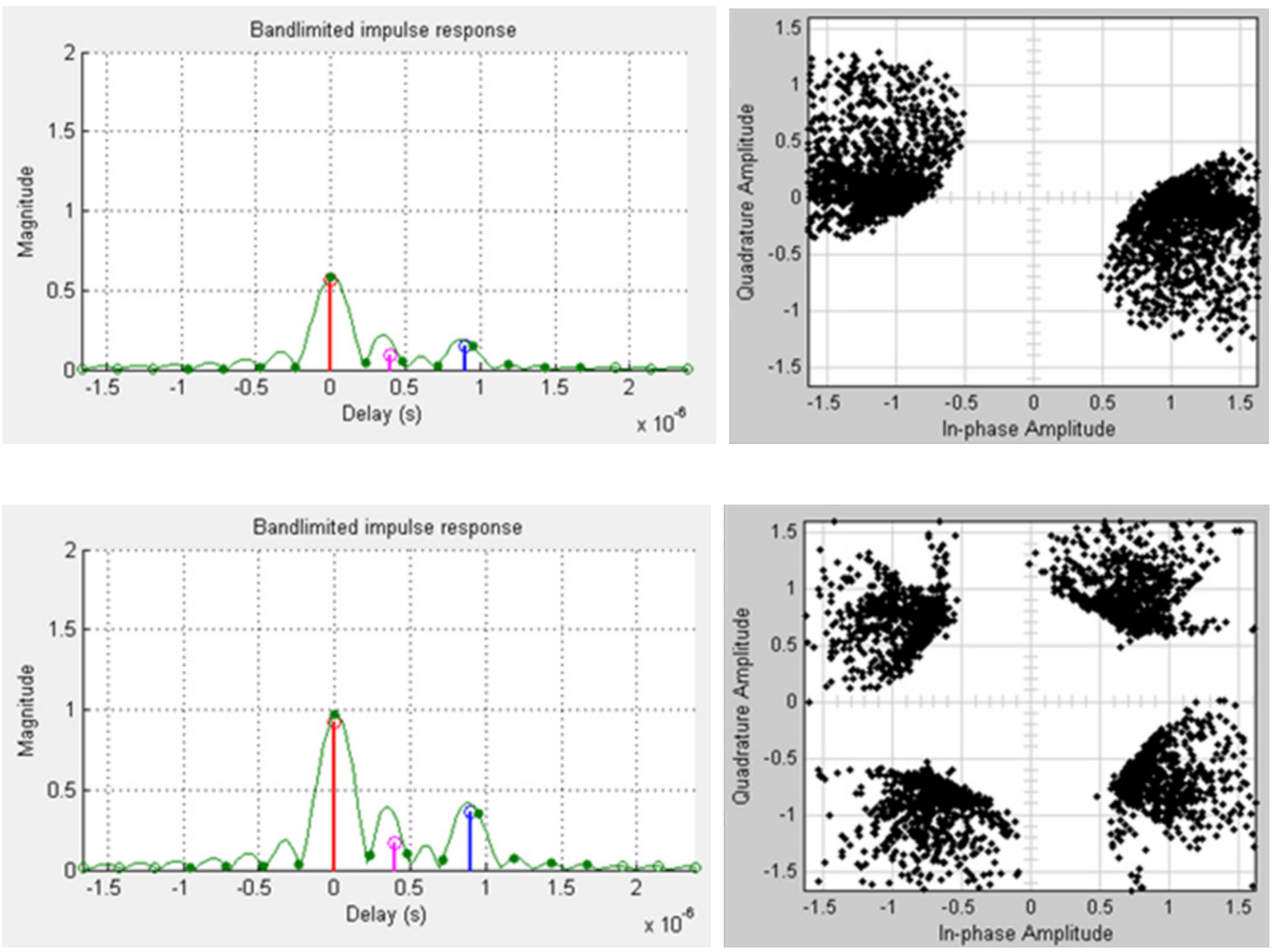


Fig. 7. Dependences of SNR in ground receiver on SNR in downlink when RPAS amplifier nonlinearity is severe and digital pre-distortion is disabled: no fading (points), frequency-flat fading (circles), and frequency-dispersive fading (squares); Max diffusive Doppler shift is 0,5 Hz



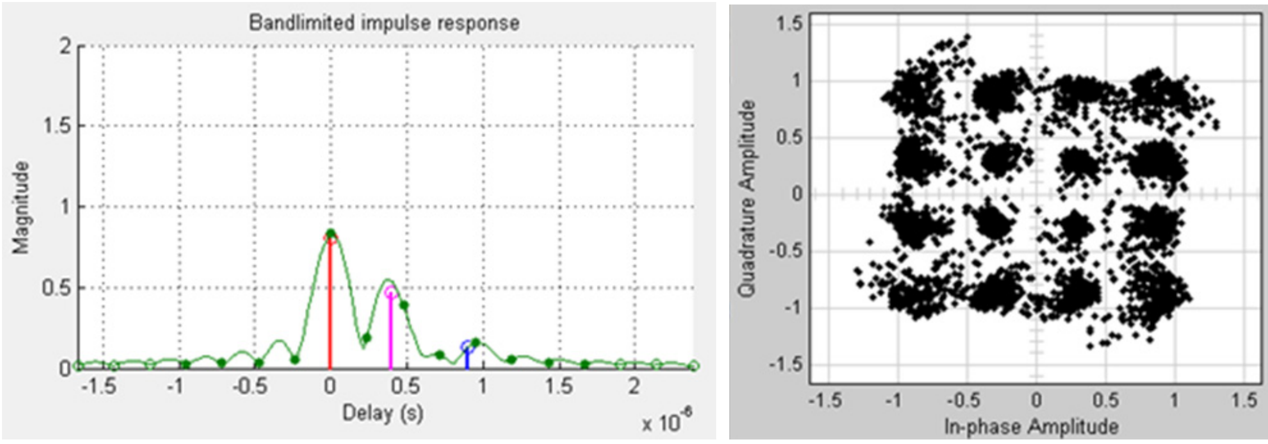


Fig. 8. Time variations in the impulse response of RPAS communication channel and signal constellations for Max diffusive Doppler shift 100 Hz; a nonlinearity is moderate and a pre-distortion enabled for the frequency-selective fading; SNR_{down} = 30 dB

Conclusions

For investigation, the influence of RPAS amplifier nonlinearity the model was developed with adaptive modulation for RPAS OFDM communication channel.

Dependences of SNR in ground receiver on SNR in downlink were received on the type of a modulation (BPSK, QPSK, 16QAM, 64QAM), a bit rate for different nonlinearities levels and types of a fading. Signals constellations were compared for different Doppler shifts.

On the basis of received is this paper data (under the given conditions: a type of nonlinearity, a number of OFDM symbols, gains of antenna dishes and the RPAS amplifier nonlinearity type) the channel parameters were estimated: the level of a SNR, for which the RPAS communication channel is "open"; the type of a modulation and data transfer rate, which are possible under the given conditions.

Created model and received results can be used for further development and improvement of communication channel integrity and efficiency as well as for modeling and investigation of channel characteristics under other parameters and conditions of information transmission.

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Received 04 June 2017

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Вплив нелінійностей передавача на передачу даних з безпілотного літального апарата

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Мета: 1) розробити модель каналу зв’язку безпілотного літального апарата «БПЛА-Наземна станція» з адаптивною модуляцією та ортогональним частотним розділенням каналів; 2) розрахувати параметри каналу з різними типами завмирань для різних рівнів нелінійності супутникового транспондера. **Метод:** для моделювання роботи каналу використано програмне забезпечення MATLAB Simulink. **Результати:** на основі стандарту IEEE 802.16d розроблено реалістичну модель канала зв'язку безпілотного літального апарата «БПЛА-Наземна станція», яка використовується для оцінки параметрів каналу. Модель канала з адаптивною модуляцією складається із джерела інформації, передавача, каналу униз із завмираннями та приймача наземної станції. Отримано залежності співвідношення сигнал-шум наземного приймача від співвідношення сигнал-шум в каналі униз для різних типів нелінійності передавача безпілотного літального апарата, різних модуляцій (BPSK, QPSK, 16QAM, 64QAM), різних типів завмирань. Порівняно сигнальні сузір’я прийнятих сигналів для різних допплерівських зсувів частоти. **Обговорення:** Розроблена модель дозволяє визначати умови, при яких канал є «відкритим» для даного типу модуляції та швидкості передачі даних. Запропонований підхід може розглядатися як метод оцінки параметрів каналу супутникового зв'язку безпілотного літального апарата із завмираннями.

Ключові слова: канал зв'язку безпілотного літального апарата; OFDM канал; нелінійність супутникового транспондера.

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Влияние нелинейностей передатчика на передачу данных с безпилотного летательного аппарата

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Цель: 1) разработать модель канала связи беспилотного летательного аппарата «БПЛА-Наземная станция» с адаптивной модуляцией и ортогональным частотным разделением каналов; 2) рассчитать параметры канала с различными типами замираний для различных уровней нелинейности спутникового транспондера.

Метод: для моделирования работы канала использовано программное обеспечение MATLAB Simulink.
Результаты: на основе стандарта IEEE 802.16d разработана реалистичная модель канала связи беспилотного летательного аппарата «БПЛА-Наземная станция», которая используется для оценки параметров канала. Модель канала с адаптивной модуляцией состоит из источника информации, передатчика, канала вниз с замираниями и приемника наземной станции. Получены зависимости соотношение сигнал-шум наземного приемника от соотношения сигнал-шум в канале вниз для различных типов нелинейности передатчика беспилотного летательного аппарата, различных модуляций (BPSK, QPSK, 16QAM, 64QAM), различных типов замираний. Проведено сравнение сигнальных созвездий принятых сигналов для различных доплеровских сдвигов частоты.
Заключение: Разработанная модель позволяет определять условия, при которых канал является «открытым» для данного типа модуляции и скорости передачи данных. Предложенный подход может рассматриваться как метод оценки параметров канала спутниковой связи беспилотного летательного аппарата с замираниями.

Ключевые слова: канал связи беспилотного летательного аппарата; нелинейность передатчика; OFDM канал.

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