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RPAS ADS-B AND TRAJECTORY CONTROL DATA TRANSMISSION VIA SATELLITE

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Abstract

Purpose: *to develop a model of the satellite communication channel for an remotely piloted air system with adaptive modulation and orthogonal frequency division of channels; 2) to calculate the channel parameters with Rayleigh fading and various types of satellite transponder nonlinearity; 3) analyze the effect of fading and the type of nonlinearity on the parameters of the satellite communication channel.* ***Method:*** *MATLAB Simulink software was used to simulate the channel operation.* ***Results:*** *For the first time, based on the IEEE 802.16d standard, a realistic model of the satellite communication channel of an unmanned aerial vehicle was developed, which is used to estimate the channel parameters. The created model takes into account the Rayleigh fading in the downlink and the nonlinearity of the satellite transponder amplifier. Dependences of the signal-to-noise ratio in the terrestrial receiver on the signal-to-noise ratio in the downlink for various types of modulation (BPSK, QPSK, 16QAM, 64QAM) and data transmission rates are obtained. The nonlinearity of satellite amplifiers was analyzed on the basis of a linear model, a cubic polynomial model, a hyperbolic tangential model, the Gorbani model, and the Rapp model. The results for the cubic polynomial model and the hyperbolic tangential model are similar to the linear model, but differ significantly from the Gorbani model and the Rapp model. For the Gorbani and Rapp models, very low values of the signal-to-noise ratio in the receiver are observed.* ***Conclusion:*** *The proposed approach can be considered as a method of estimating the parameters of the satellite communication channel of an unmanned aerial vehicle with fading. It is shown how the type of modulation varies depending on the level of the signal-to-noise ratio and the type of fading. The developed model allows to predict the operation of the channel with Rayleigh fading and can be useful for the design of communication systems.*

Keywords: OFDM channel; RPAS; transponder nonlinearity; UAV; vehicle communication channel.

1. Problem statement

Remotely piloted air systems (RPAS) are a new way of using flying machines. RPAS are distinguished from manned aircraft by the data link connecting the remote pilot station with the remotely piloted aircraft and used for command and control (C2) of RPAS and as a relay for communications between the air traffic control (ATC) operator and the remote pilot. The combination of these two functions is termed C3 – command, control and ATC communications [1].

The use of RPAS is characterized by a wide range of applications (military, emergency services, surveying applications, agriculture, etc.) as well as a huge increasing in the complexity of flight tasks in each individual area. These circumstances call for RPAS flight control systems capable of performing a variety of tasks, including complex radio navigation and communication conditions. Basic requirements for RPAS data rate are stated in the NATO standards [2-4].

Standards define two classes of data: sensor and support. Sensory data comes from sensors forming synthetic aperture radar, infrared and television cameras, etc.

RPAS satellite mobile communications system has to integrate high-speed radar and trajectory control data, video and multimedia traffic. The promising approach for this is adaptive Orthogonal Frequency Division Multiplexing (OFDM) [5].

ADS-B (Automatic Dependent Surveillance – Broadcasting) signals transmitted from RPAS via satellite are affected by a free path loss, a frequency offset, a phase noise, a fading, a noise temperature, and amplifier nonlinearities. Data traffic for RPAS networks must take into account propagation delays, limited energy and power, relatively high channel error rates, and time-varying channel conditions [6].

2. Analysis of researches and publications

Digital multi-carrier modulation technique OFDM has been adopted as physical layer scheme of broadband wireless air interface standards.

Nonlinear distortion is a source of major degradation of modulation fidelity in multicarrier systems with OFDM signals. Compared with conventional single carrier communication systems, OFDM signals significantly improve spectrum efficiency and reduce frequency selective fading problems. However their consisting of large numbers of independent subcarriers, means the composite signal's peak to average power ratio can be significant. This makes them sensitive to nonlinear distortion [7].

The source of nonlinear distortions is the radio frequency transmitter power amplifier. Nonlinear power amplifiers for wireless communications were modeled [8] and nonlinear power amplifier effects in multi-antenna OFDM systems were analyzed [9]. Modulation schemes effect on radio frequency power amplifier nonlinearity were considered in a paper [10]. A new peak to average power ratio reduction technique of OFDM system with nonlinear high power amplifier was proposed [11]. The use of OFDM radio interface for satellite digital multimedia broadcasting systems [12] and Bit Error Rate (BER) for MIMO-OFDM systems [13] were studied.

RPAS satellite communication channels are random and time-variant. Multipath fading is the dominant propagation factor for RPAS digital communication systems operating at frequencies below 10 GHz. Fading due to multipath propagation may distort and attenuate received signals and impair the performance of RPAS communication systems [1, 2].

3. Aim of the work

RPAS satellite channel fading and nonlinearity are critical for wireless communications systems. Therefore the aim of this paper is: 1) to design model of RPAS satellite OFDM communication channel "RPAS–Satellite–Ground Station" with adaptive modulation using MATLAB Simulink software; 2) to calculate parameters of a channel with Rayleigh fading and differrent types of nonlinearities; 3) to analyze the impact of fading and the nonlinearities type on parameters of satellite communication channel.

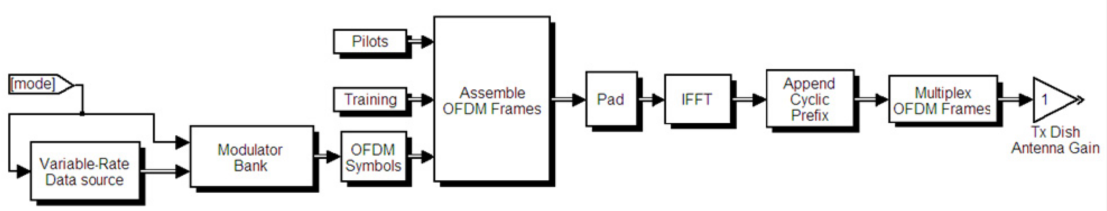

Fig. 1. "RPAS Transmitter"

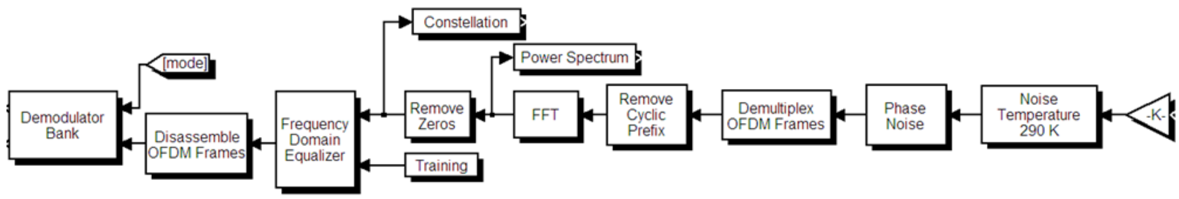

Fig. 2. "Ground Station"

4. Model for "RPAS-Satellite-Ground Station" channel

RPAS satellite communication channel was built on the base of IEEE 802.16d standard using MATLAB Simulink software.

The model consists of "RPAS Transmitter" (Fig.1), Ground Station" (Fig.2), "Uplink", "Downlink" (Fig.3), and "Satellite Transponder" (Fig.4). This paper is devoted to consideration of an uplink with Additive White Gaussian Noise ("AWGN") and a downlink with "Rayleigh Fading".

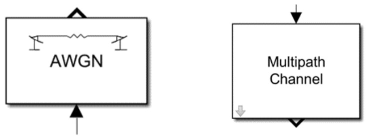

Fig. 3. “Uplink” and “Downlink”

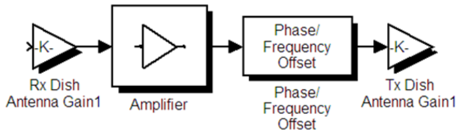

Fig. 4. “Satellite Transponder”

Parameters settings for the model are the following: a number of OFDM symbols per transmit block is 20, a number of OFDM symbols in training sequence is 4, OFDM transmission uses 52 subcarriers, 4 pilots, 64-point Fast Fourier Transform, and 16-sample cyclic prefix. Low-SNR thresholds (dB) vector is [10 11 14 18 22 26 28] (where the SNR less than 10 dB is for BPSK ½, between 10 dB and 11 dB - for BPSK ¾, between 11 dB and 14 dB - for QPSK ½, between 14 dB and 18 dB - for QPSK ¾, between 18 dB and 22 dB - for 16-QAM ½, between 22 dB and 26 dB - for 16-QAM ¾, between 26 dB and 28 dB – for QAM 2/3 and more than 28 dB - for 64-QAM ¾).

5. RPAS Satellite Communication Channel Simulation

For calculations the following parameters were set up: RPAS antenna gain (Fig.1) was taken 12.4 (an antenna diameter ≈ 0.4 m at 4 GHz), ground station antenna gain (Fig.2) – 62.2 (an antenna diameter ≈ 2.0 m at 4 GHz), satellite antennas gain (Fig.4) – 31.1 (an antenna diameter ≈ 1.0 m at 4 GHz); phase/frequency offsets at a satellite transponder are equal to zero; noise temperatures of a satellite amplifier and a ground receiver are equal to 290 K.

Dependences of the SNR in a ground receiver on the SNR in downlink for the SNR in uplink 40 dB for different types of satellite amplifier nonlinearity and modulation modes are given in Fig.5–9. During modeling the value of a packet error rate was kept at zero by changing the type of modulation (using the SNR estimation in a ground receiver and adaptive rate control). In accordance with this, the SNR was changed.

The options for the modeling of satellite amplifier nonlinearity are Linear, Cubic Polynomial, Hyperbolic Tangent, Ghorbani model [14], and Rapp model [15].

For Cubic Polynomial and Hyperbolic Tangent Models the satellite Amplifier block applies the AM/AM nonlinearity by using the third-order input intercept point IIP3= 100 dBm parameter and uses the AM/PM conversion (10 degrees per dB) parameter.

For Ghorbani Model the Input scaling (-1.5957 dB) parameter scales the input signal before the nonlinearity is applied. The AM/AM parameters [x1 = 8.1081 x2 = 1.5413 x3 = 6.5202 x4 = -0.0718] are used to compute the amplitude gain for an input signal. The AM/PM parameters [y1 = 4.6645 y2 = 2.0965 y3 = 10.88 y4 = -0.003] are used to compute the phase change for an input signal. For Rapp Model the amplitude gain for an input signal is computed with the Smoothness factor S=0.5 and the Output saturation level Osat = 1. The Rapp model does not apply a phase change to the input signal.

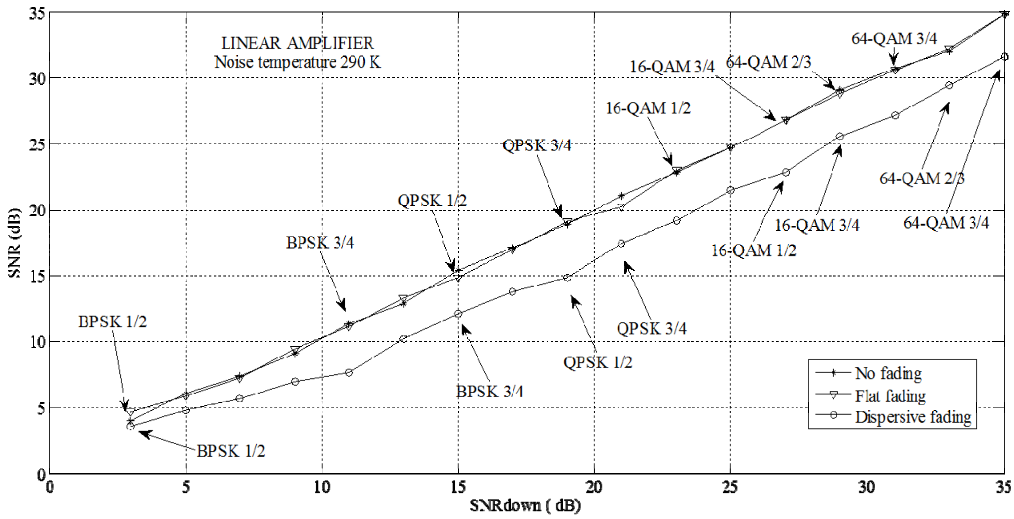

Fig. 5. Dependence of the SNR in a receiver on the SNR in downlink

at the SNR in uplink 40 dB for Linear Amplifier model

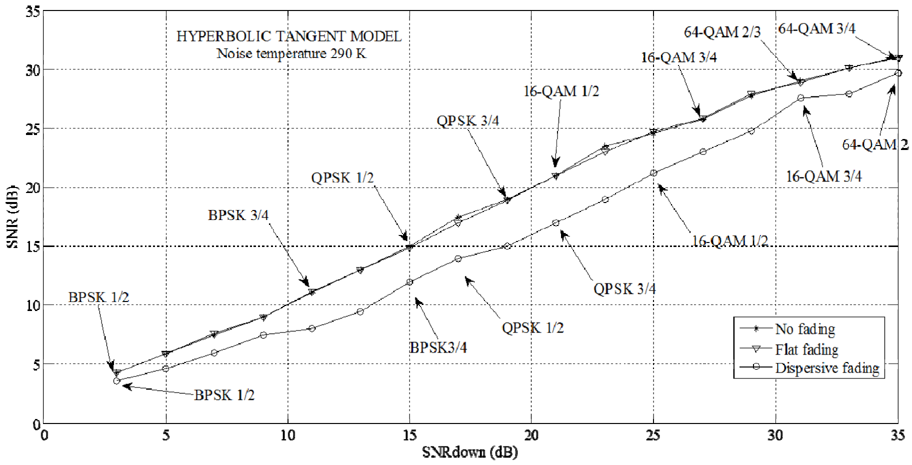

Fig. 6. Dependence of the SNR in a receiver on the SNR in downlink at the SNR in uplink 40 dB for Hyperbolic Tangent model

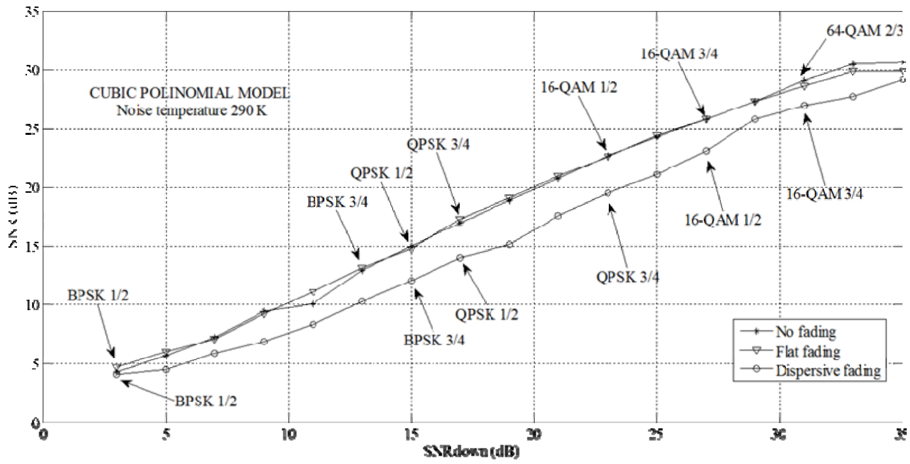

Fig. 7. Dependence of the SNR in a receiver on the SNR in downlink at the SNR in uplink 40 dB for Cubic Polinomial model

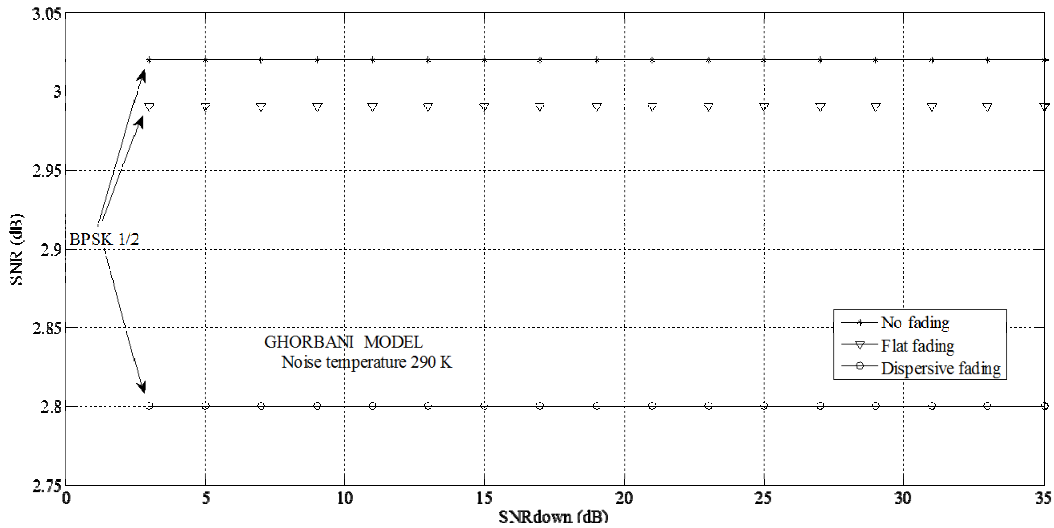

Fig. 8. Dependence of the SNR in a receiver on the SNR in downlink at the SNR in uplink 40 dB for Ghorbani model

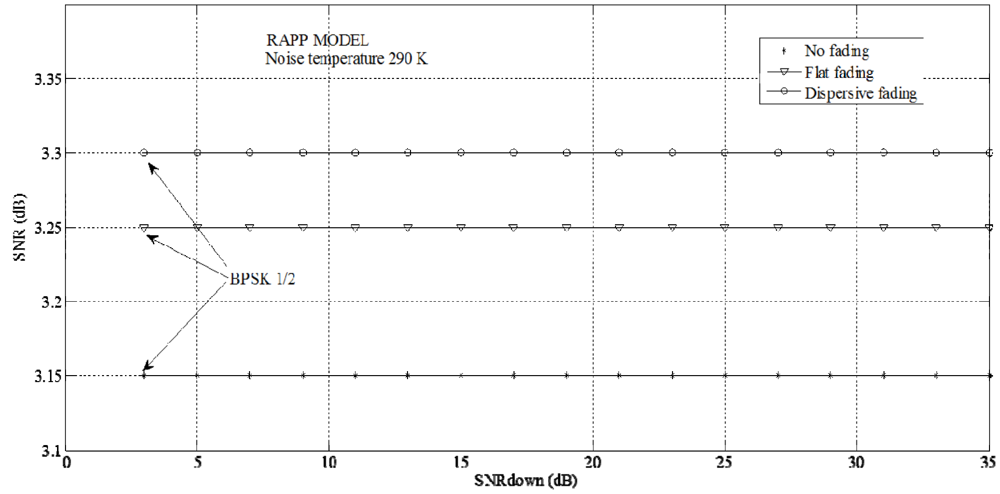

Fig. 9. Dependence of the SNR in a receiver on the SNR in downlink at the SNR in uplink 40 dB for Rapp model

6. Conclusions

The realistic model of RPAS satellite OFDM link is developed for the first time on a basis of IEEE 802.16d standard and used for RPAS channel parameters evaluation. Created model takes into account the Rayleigh fading in downlink and nonlinearities in satellite transponder. Proposed approach can be considered as a method for estimating parameters of RPAS satellite communication channel with fading.

Dependencies were received of the SNR in a receiver on the SNR in downlink for different types of a modulation (BPSK, QPSK, 16QAM, 64QAM) and bit rates for memoryless nonlinear satellite amplifiers (the Cubic Polinomial Model, the Hyperbolic Tangent Model, the Ghorbani Model and the Rapp Model).

For the selected values of a third-order intercept point results for the Cubic Polynomial Model and the Hyperbolic Tangent Model are similar to the Linear Model, but substantially differ from the Ghorbani Model and the Rapp Model. For the Ghorbani and Rapp Models data are observed at very low meanings of the SNR in a receiver and fluctuate. These data substantially differ for no fading, flat and dispersive fading cases and are given for average meanings.

A downlink with “Rayleigh Fading” has three modes: no fading, flat and dispersive fading. For dispersive fading, the results turn out to be the worst for all the types of considered nonlinearities.

It is shown how the type of modulation varies depending on the level of the SNR and the type of fading.

The developed model allows predicting the operation of the channel with Rayleigh fading and can be helpful for designing of communication systems.

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Передача даних ADS-B та траєкторного управління політом з безпілотного літального апарата через супутник

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Мета: 1) розробити модель супутникового каналу зв'язку безпілотного літального апарата з адаптивною модуляцією та ортогональним частотним розділенням каналів; 2) розрахувати параметри каналу з релеєвськими завмираннями та різними типами нелінійності супутникового транспондера; 3) проаналізувати вплив завмирань та типу нелінійності на параметри каналу супутникового зв'язку. **Метод:** для моделювання роботи каналу використано програмне забезпечення MATLAB Simulink. Результати: Вперше на основі стандарту IEEE 802.16d розроблено реалістичну модель супутникового канала зв'язку безпілотного літального апарата, яка використовується для оцінки параметрів каналу. Створена модель враховує завмирання Релея в лінії зв'язку донизу і нелінійності підсилювача супутникового транспондера. Отримано залежності співвідношення сигнал-шум в наземному приймачі від співвідношення сигнал-шум в лінії зв'язку донизу для різних типів модуляції (BPSK, QPSK, 16QAM, 64QAM) і швидкості передачі даних. Нелінійність супутникових підсилювачів аналізувалась на основі лінійної моделі, кубічної поліноміальної моделі, гіперболічної тангенціальної моделі, моделі Горбані та моделі Раппа. Результати для кубічної поліноміальної моделі та гіперболічної тангенціальної моделі подібні до лінійної моделі, але значно відрізняються від моделі Горбані та моделі Раппа. Для моделей Горбані та Раппа спостерігаються дуже низькі значення співвідношення сигнал-шум в приймачі. **Обговорення:** Запропонований підхід може розглядатися як метод оцінки параметрів каналу супутникового зв'язку безпілотного літального апарата із завмираннями. Показано, яким чином тип модуляції змінюється залежно від рівня співвідношення сигнал-шум та типу завмирань. Розроблена модель дозволяє прогнозувати роботу каналу з завмиранням Релея і може бути корисною для проектування систем зв'язку.

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

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Передача данных ADS-B и траекторного управления полётом с безпилотного летательного аппарата через спутник

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Цель: 1) разработать модель спутникового канала связи беспилотного летательного аппарата с адаптивной модуляцией и ортогональным частотным разделением каналов; 2) рассчитать параметры канала с релеевской замираниями и различными типами нелинейности спутникового транспондера; 3) проанализировать влияние замираний и типа нелинейности на параметры канала спутниковой связи. **Метод:** для моделирования работы канала использовано программное обеспечение MATLAB Simulink. **Результаты:** Впервые на основе стандарта IEEE 802.16d разработана реалистичная модель спутникового канала связи беспилотного летательного аппарата, которая используется для оценки параметров канала. Созданная модель учитывает замирания Релея в линии связи вниз и нелинейности усилителя спутникового транспондера. Получены зависимости соотношения сигнал-шум в наземном приемнике от соотношения сигнал-шум в линии связи вниз для различных типов модуляции (BPSK, QPSK, 16QAM, 64QAM) и скорости передачи данных. Нелинейность спутниковых усилителей анализировалась на основе линейной модели, кубической полиномиальной модели, гиперболической тангенциальной модели, модели Горбани и модели Раппа. Результаты для кубической полиномиальной модели и гиперболической тангенциальной модели подобны линейной модели, но значительно отличаются от модели Горбани и модели Раппа. Для моделей Горбани и Раппа наблюдаются очень низкие значения соотношения сигнал-шум в приемнике. **Заключение:** Предложенный подход может рассматриваться как метод оценки параметров канала спутниковой связи беспилотного летательного аппарата с замираниями. Показано, каким образом тип модуляции меняется в зависимости от уровня соотношения сигнал-шум и типа замираний. Разработанная модель позволяет прогнозировать работу канала с замираниями Релея и может быть полезна для проектирования систем связи.

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

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