UDC 621.396:621.396.933:629.783:621.396.946

Volodymyr Kharchenko[1]
Wang Bo[2]
Andrii Grekhov[3]
Daria Bezsmertna[4]

INVESTIGATION OF MODULATION SCHEME AND TRANSMITTER NONLINEARITY IMPACT ON ADS-B MESSAGES TRANSMISSION VIA OFDM SATELLITE LINK

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]wangbo@nau.edu.ua; [3]grekhovam@ukr.net; [4]dasha_bezsmertna@mail.ru

Abstract. *For investigation of modulation scheme impact on ADS-B messages transmission via satellite link the original model of a communication channel "Aircraft-to-Satellite-to-Ground Station" was built using MATLAB Simulink. Model consists of a source of information, aircraft transmitter, uplink/downlink path, satellite transponder, ground station receiver. The dependencies of a signal to noise ratio on free space path loss for different types of modulation (BPSK, QPSK, 16QAM, 64QAM), for different satellite transponder noise temperatures, channel bandwidth, number of OFDM symbols and different types of aircraft transmitter nonlinearity were received and investigated.*

Keywords: ADS-B; convolutional coding; free space loss; OFDM; satellite communication; satellite transponder; Viterbi decoder.

1. Introduction

Air-traffic control services in accordance with CNS/ATM (Communication, Navigation, Surveillance / Air Traffic Management) concept should be enhanced using ADS-B (Automatic Dependent Surveillance-Broadcast) function [9].

Satellite telecommunications use artificial satellites, which relay analog and digital signals carrying voice, video, and data, in order to provide communication links between various points on Earth and aircraft.

Satellite communication systems provide secure and essential communications, navigation, weather, and imaging services around the world.

The important aspect of the satellite communications network is that it continues in operation under conditions when other methods of communications are inoperable.

The provision of safe, regular and efficient operation of air transport is the primary task of the International Civil Aviation Organization (ICAO).

ICAO is currently developing a satellite system, which will satisfy future needs of civil aviation in communications, navigation, radar surveillance and air traffic control.

Today, the increase airport traffic is constrained by the fact that in order to determine the coordinates of object and display information on the radar screen required from 6 to 12 s, during which flying plane has time to change his position.

Therefore air traffic controllers to provide safety flight have to increase time intervals between aircraft landing which leads to an incomplete use of airport infrastructure.

As a solution of increasing performance requirements in the developed system there are used the latest satellite and computer technology, data links and on-board avionics.

On February, 7, 2012, the U.S. Congress adopted a law about equipment of civil aircraft and ground cellular stations by Global Positioning System (GPS) and for broadcast by ADS-B, which together should replace the radar in the existing air traffic control systems.

On 20 June 2012 satellite operator Iridium has decided that from 2015 they will be putting ADS-B receivers on its next-generation satellite constellation, aimed at bringing global, real-time aircraft surveillance for air navigation service providers [3].

ADS-B is all about communications between aircraft, and also between aircraft and ground.

Both are vital in ensuring safe flights and efficiency in terms of fuel use, time and emissions.

ADS-B is designed to ease Air Traffic Control (ATC) as the number of approaches grows, enhancing safety and increasing airport capacity.

In the air, the information provided by ADS-B enhances the pilots' traffic awareness, allowing more optimal flight levels leading to fuel savings.

The main objective of ADS-B system is to process the information which is coming from GPS system, separation of accurate data about speed, altitude, heading of the aircraft.

The obtained data are added by the information from the airport services about weather conditions.

This allows pilots in the cockpit and controllers in the control center to monitor the movement of all aircraft in the terminal area.

Orthogonal frequency-division multiplexing (OFDM) is attracting more attention for satellite communication systems [2, 11].

Nevertheless issues related to the ADS-B messages transmission via OFDM satellite link still are not investigated in detail.

2. Analysis of researches and publications

OFDM as digital multi-carrier modulation technique has been adopted as physical layer scheme of broadband wireless air interface standards, such as IEEE 801.11/WiFi, IEEE 802.16/WiMAX.

Simultaneously OFDM modulation is attracting more attention for delivering multimedia services over hybrid satellite/terrestrial networks to a variety of small mobile and fixed terminals with compact antennas.

On the other hand, OFDM technique is also being applied in military communications [1].

OFDM is a method of encoding digital data on multiple carrier frequencies. OFDM has developed for wideband digital communication [4].

A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels.

Each sub-carrier is modulated with a conventional modulation scheme at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [10].

Modeling of satellite telecommunications channels without OFDM multiplexing was realized previously in our papers [5, 6, 7, 8].

The **aim** of this paper is:

1) to design the model of aeronautical satellite OFDM communication channel “Aircraft–to–Satellite–to–Ground Station” using MATLAB Simulink software;

2) to investigate the impact of modulation scheme type, satellite transponder noise temperatures, channels bandwidth, number of OFDM symbols and different types of aircraft transmitter nonlinearity on ADS-B messages transmission via satellite link.

3. Model for “Aircraft-to-Satellite-to-Ground Station” link

Satellite communication link was analyzed using original model designed on the base of IEEE 802.16d standard and MATLAB Simulink demo model commwman80216d (Fig. 1).

Model consists of a source of information (Bernoulli Binary block), “Aircraft Uplink Transmitter” (Modulator bank, OFDM Transmitter, Digital Pre-Distortion and Nonlinear Amplifier, Transmitter Antenna Gain), “Uplink and Downlink Path” (Free Space Path Loss, Phase/Frequency Offset), “Satellite Transponder” (Receiver and Transmitter Dish Antenna Gain, Phase/Frequency offset, Amplifier), “Ground Earth Station (GES) Receiver” (Receiver Dish Antenna Gain, OFDM receiver, Gain and Phase Compensator, Extract Data carrier, Demodulator bank), “SNR estimation block”, “Rate ID block”, “Error Rate Calculation block”.

In digital communications, the probability of error depends on the normalized signal to noise ratio, reduction of which can be caused by a decrease of signal power or by increasing of noise power or power of signals, interfering with the desired signal.

Data transmission allows achieving any desired accuracy of information transmission, but this occurs at the expense of speed decreasing or bandwidth expansion.

High capacity of the system is achieved through the ability to support long-range high symbol rate.

Symbol rate characterizes the rate of information transmission and represents the rate of the sequence of symbols transmission, which is realized by signal modulation.

Low-SNR thresholds parameter is a seven-element vector [10 11 14 18 22 26 28]:

10 - for BPSK 1/2,
11 - for BPSK 3/4,
14 - for QPSK 1/2,
18 - for QPSK 3/4,
22 - for 16-QAM 1/2,
26 - for 16-QAM 3/4,
28 - for 64-QAM 2/3.

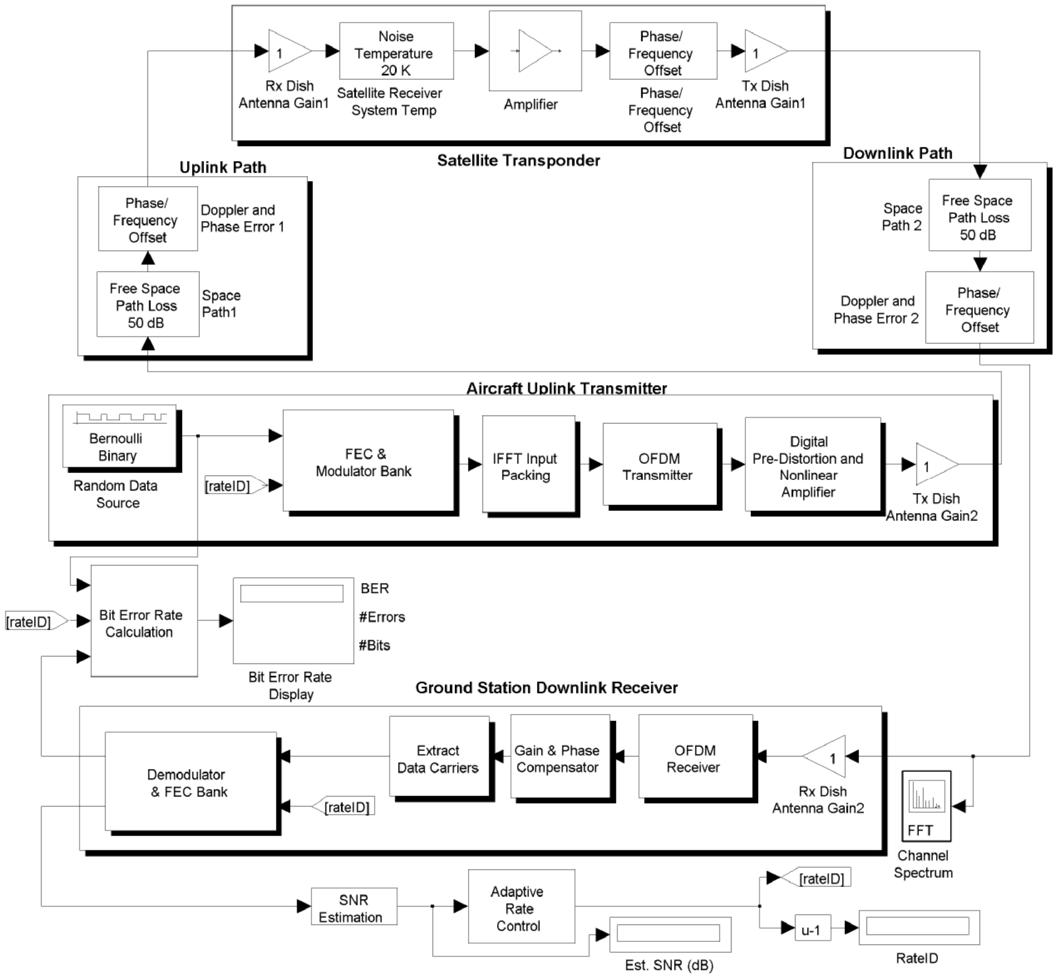

Fig. 1. “Aircraft-to-Satellite-to-Ground Station” Link

The “Bernoulli Binary Generator” block generates random binary numbers using a Bernoulli distribution.

Block generates a discrete signal and updates the signal at time interval which is equal to 1.

The probability is equal to 0.

The “Modulator bank” consists of Convolutional encoder, Reed-Solomon encoder, Interleaver and block of mentioned types of modulation. The Convolutional encoder encodes a sequence of binary input vectors to produce a sequence of binary output vectors. It uses a poly2trellis(7,[171 133]) command and encoder with a length of 7, code generator polynomials of 171 and 133. The Reed –Solomon encoder block creates a Reed-Solomon code with message length, K, and codeword length, (N – number of punctures). The input and output are binary-valued signals that represent messages and code words, respectively. The input is frame-based column vector whose length is an integer K=24. The output is a frame-based column vectors whose length is the same integer N-number of punctures, and whose data type is inherited from the input.

Interleaver block rearranges the elements of its input vector using a random permutation.

The “OFDM Transmiter” block carriers signal, the sum of a number of orthogonal sub-carriers, with baseband data on each sub-carrier being independently modulated commonly using some type of Quadrature Amplitude Modulation (QAM) or Phase-Shift Keying (PSK).

This composite baseband signal is typically used to modulate a main RF carrier.

An inverse FFT is computed on each set of symbols, giving a set of complex time-domain samples. These samples are then quadrature-mixed to passband in the standard way.

The real and imaginary components are first converted to the analogue domain using digital-to-analogue converters; the analogue signals are then used to modulate cosine and sine waves at the carrier frequency. These signals are then summed to give the transmission signal.

During formation of the OFDM-signal digital data stream is divided into several sub-streams, and each subcarrier is associated with its data substreams.

The amplitude and phase of a subcarrier is calculated on the base of selected modulation scheme.

According to the standard, the individual subcarriers can be modulated using Binary PSK (BPSK), Quadrature PSK (QPSK) or QAM of about 16 or 64.

Transfer rate is completely determined by the type of modulation, that is, each type of modulation provides a specific symbol rate.

During modulation, each subcarrier of the OFDM signal is modeled by the useful signal simultaneously by amplitude and phase forming the signal, position of which in coordinate of phase and amplitude carries information about the coded symbol in it.

Vector 16 QAM signal has 16 possible positions in the coordinate of the amplitude and phase, which encodes the 16 symbol values from 0000 to 1111.

Vector 64 QAM signal has 64 positions that codes 64 values.

Modulation BPSK and QPSK encoded 2 and 4 symbol value with respectively two and four possible phase values.

The amplitude of the signal during QPSK and BPSK modulation does not vary.

Thus, these two types of modulation can be viewed as a special case of phase-amplitude modulation QAM.

Memoryless Nonlinearity (High Power Amplifier) is a model of a Traveling Wave Tube Amplifier (TWTA) using the Saleh model. HPA backoff level is a parameter which is used to determine how close the satellite high power amplifier is driven to saturation.

There are three different types: the first is 30 dB (negligible nonlinearity) at which the average input power equal to 30 decibels below the input power that causes amplifier saturation (that is, the point at which the gain curve becomes flat).

This causes negligible AM-to-AM and AM-to-PM conversion.

AM-to-AM conversion is an indication of how the amplitude nonlinearity varies with the signal magnitude.

AM-to-PM conversion is a measure of how the phase nonlinearity varies with signal magnitude.

The second is 7 dB (moderate nonlinearity) at which the average input power equal to 7 decibels below the input power that causes amplifier saturation.

This causes moderate AM-to-AM and AM-to-PM conversion.

And the third type is 1 dB (severe nonlinearity) at which the average input power equal to 1 decibel below the input power that causes amplifier saturation.

This causes severe AM-to-AM and AM-to-PM conversion.

During investigation I have been used different types of memoryless nonlinearity such as:

– negligible nonlinearity with the input parameter – 21.5457 and output-32.9118,

– moderate nonlinearity with input – 1.40444 and output – 9.91183,

– severe nonlinearity with input – 7.40433 and output- 3.91183.

The “Free Space Path Loss” block simulates the loss of signal power due to the distance between the aircraft uplink transmitter and the satellite transponder receiver.

The block reduces the amplitude of the input signal by an amount that is determined by the loss (dB) parameter.

The Phase/Frequency Offset block applies phase and frequency offsets to an incoming signal.

During the research the value of phase/frequency offset was set zero.

The “Phase/Frequency Offset” block applies a frequency and phase offset to the input signal.

Transmitting and receiving antenna diameters is an element in the vector of “Antenna Gain” block.

The first element in the vector, which is used to calculate the gain in the Transmitting Antenna, the second element represents the receive antenna diameter and is used to calculate the gain in the Receiving Antenna.

The antenna gain is equal to 1.

The “Receiver Thermal Noise” block simulates the effects of thermal noise on a complex, baseband signal.

There are 3 noise temperatures: 0 (no noise), 20 (very low noise level) and 290 (typical noise level).

The investigation was made for 20 K and 290 K.

The “Amplifier” block allows selecting five different methods to model the nonlinear amplifier.

Power amplifiers are an important component in modern communications systems, providing the transmit signal levels needed to overcome the loss between the transmitter and receiver.

Two of the nonlinear methods fit curves to measured data provided by the gain and third order intercept point parameters.

The other three nonlinear methods use models originated by Saleh, Ghorbani, and Rapp.

The Saleh and Ghorbani models are based on normalized nonlinear transfer functions.

In this paper the linear method was chosen. During modeling linear amplifier gain was 1 dB.

The "Ground Station Downlink Receiver" consists of OFDM Receiver, Gain and Phase Compensator, Extract Data Carriers, Demodulator bank.

The "OFDM Receiver" block picks up the signal, which is then quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency.

The baseband signals are then sampled and digitized using analog-to-digital converters and a forward FFT is used to convert back to the frequency domain.

This returns N parallel streams, each of which is converted to a binary stream using an appropriate symbol detector.

These streams are then re-combined into a serial stream, which is an estimate of the original binary stream at the transmitter.

The demodulator bank consists of Viterbi decoder, Deinterleaver, Punctured Reed-Solomon decoder, Demodulators of BPSK, QPSK1/2, QPSK3/4, 16QAM1/2, 16QAM3/4, 64QAM2/3, 64QAM3/4 modulation.

The Viterbi Decoder block decodes input symbols to produce binary output symbols. Decoder block recovers a message vector from a Reed-Solomon codeword vector.

Demodulator block demodulates a signal that was modulated using, using definite type of modulation.

The accuracy of the information transfer is determined by such factor as signal to noise ratio, using "SNR estimation" block.

Signal-to-noise ratio is a measure used to compare the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels.

A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.

The block "Error Rate Calculation" display three-element vector consisting of the error rate, followed by the number of errors detected and the total number of symbols compared.

"Error Rate Calculation" block shows the bit error rate as a percentage and should always equal 0 during investigations.

4. Aeronautical satellite channel simulation

Dependencies of a SNR on free path losses for different modulation modes, transponder noise temperatures and channel bandwidths are given in Fig. 2, *a*.

During modeling the value of a BER was kept at zero by changing the type of modulation (using SNR estimation and adaptive rate control).

In accordance with this a ratio SNR was changed.

Phase and frequency offsets were zero, all antennas gain was 1, number of OFDM symbols was 1, cyclic frequency - 1/8, aircraft uplink amplifier nonlinearity – disabled.

Free space path loss values were changed simultaneously in uplink and downlink channels.

From Fig. 2, *a* follows that 64QAM3/4 modulation has the highest value of SNR ratio in comparison with other types of modulation. Moreover the lower transponder noise temperature and channel bandwidth are the higher the value of SNR ratio is.

Fig. 2, *a* shows how big SNR ratio should be and what type of a modulation to be used for data transmission without errors at specified free space path losses, transponder noise temperature, channel bandwidth and the minimum number of OFDM symbols.

Dependencies of a SNR on free path losses for different modulation modes, transponder noise temperatures, fixed channel bandwidth and different number of OFDM symbols are given in Fig. 2, *b*.

Fig. 2, *b* shows how big SNR ratio should be and what type of a modulation to be used for data transmission without errors at a fixed channel bandwidth, given the free space path losses, transponder noise temperature and different number of OFDM symbols.

Fig. 2, *c* shows how big SNR ratio should be and what type of a modulation to be used for data transmission without errors at a fixed channel bandwidth, the number of OFDM symbols and transponder noise temperature for different levels of non-linearity of the aircraft transmitter.

5. Conclusions

For investigation of modulation scheme and aircraft transmitter non-linearity on ADS-B messages transmission via low-orbit satellite link the original model of a communication channel "Aircraft-to-Satellite-to-Ground Station" was built using MATLAB Simulink software.

Dependencies of a SNR ratio on free space path for different types of modulation (BPSK, QPSK, 16QAM, 64QAM), for different satellite transponder noise temperatures, channel bandwidth, number of OFDM symbols and different types of aircraft transmitter nonlinearity were received and investigated.

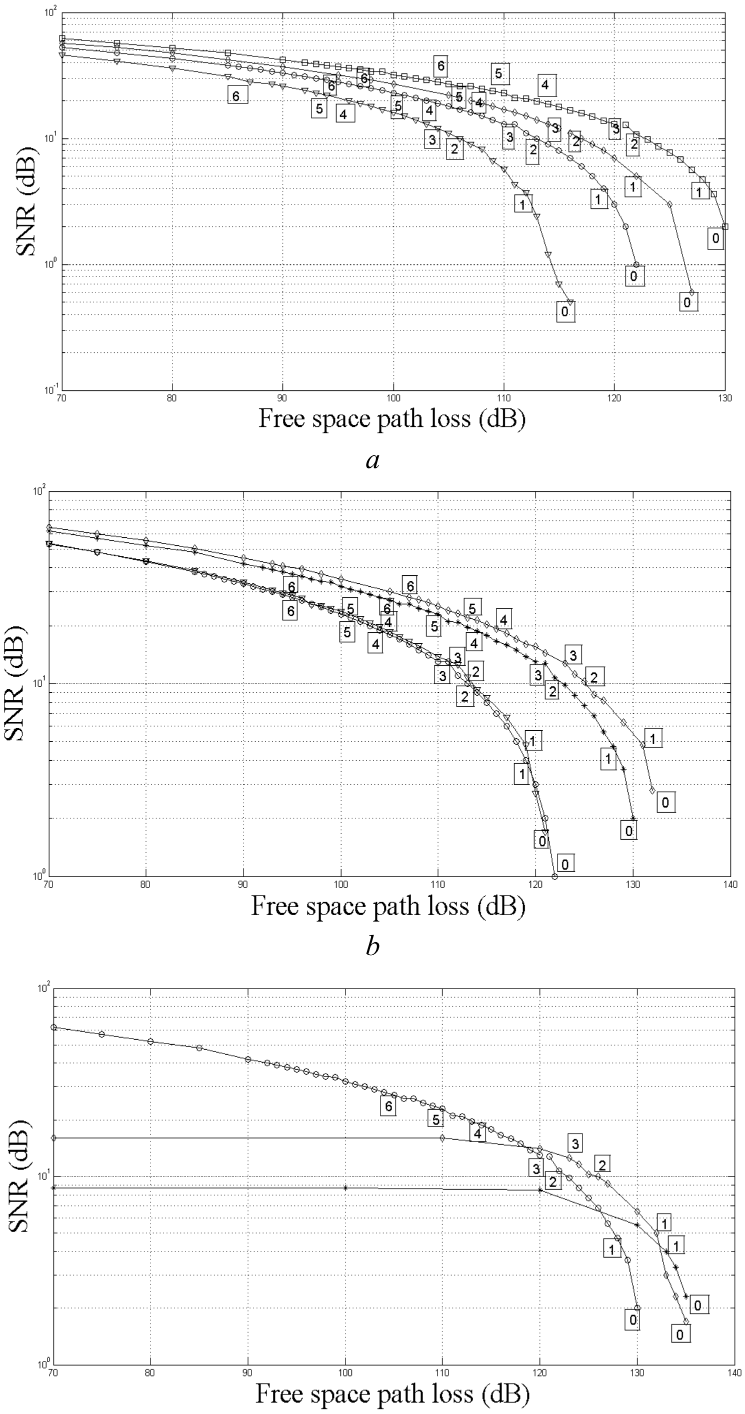

Fig. 2. The dependence of SNR on free space path loss in uplink/downlink for different types of modulation:
a – transponder noise temperatures and channel bandwidth: squares – noise temperature 20 K, channel bandwidth 3.5 MHz; diamonds - noise temperature 20 K, channel bandwidth 10 MHz, circles - noise temperature 290 K, channel bandwidth 3,5 MHz, triangles - noise temperature 290 K, channel bandwidth 10 MHz; number of OFDM symbols is 1; aircraft uplink transmitter nonlinearity is disabled; transponder amplifier linear gain is 1 dB;
b – transponder noise temperatures and number of OFDM symbols: diamonds – noise temperature 20 K, number of OFDM symbols is 100, stars – noise temperature 20 K, number of OFDM symbols is 1, triangles – noise temperature 290 K, number of OFDM symbols is 100, circles – noise temperature 290 K, number of OFDM symbols is 1; channel bandwidth 3.5 MHz;
c – types of nonlinearity: stars – severe nonlinearity, diamonds – moderate nonlinearity, circles – disabled nonlinearity; transponder noise temperature 20 K, number of OFDM symbols is 1; channel bandwidth 3.5 MHz;
0 – BPSK1/2, 1 – QPSK1/2, 2 – QPSK 3/4, 3 – 16QAM1/2, 4 – 16QAM 3/4, 5 – 64QAM2/3, 6 – 64QAM3/4

The 64QAM modulation is the most fast, because it allows to transmit the 64 possible values in one symbol data, which provides a higher symbol rate and, consequently, higher data transmission rate compared to the lower modulation.

The higher the modulation type, the smaller the amplitude and phase vectors difference of the adjacent values of the transmitted messages.

Thus for error-free message reception requires more powerful signal, or rather a high signal to noise ratio.

Proposed model can be used as basic model for investigation of communication between two airplanes and ground stations using several satellites.

Developed model can also be used for finding optimal methods of error-correcting coding.

References

[1] *Baddeley, A.* Going Forward with JTRS. Military Information Technology. 2005. 9(7). P. 8-13.

[2] *Cioni, S; Corazza, G.E.; Neri, M.; Vanelli-Coralli, A.* On the use of OFDM radio interface for satellite digital multimedia broadcasting systems. International Journal of Satellite Communications and Networking. 2006. 24(2). P. 153-167.

[3] *Iridium-Adds-ADS-B-to-Iridium-NEXT-Constellation*. 2012. Available from Internet: <http://www.aviationtoday.com/the-checklist/76558.html>

[4] *Jeon, W.G.; Chang, K.H.; Cho, Y.S.* An equalization technique for orthogonal frequency-division multiplexing systems in time-variant multipath channels. IEEE Transactions on Communications. 1999. 47(1). P. 27–32. doi:10.1109/26.74781.

[5] *Kharchenko, V. P.; Barabanov, Y. M.; Grekhov, A. M.* Modeling of ADS-B Data Transmission via Satellite. Aviation. 2013. 17(3). P. 119-127.

[6] *Kharchenko, V. P.; Barabanov, Y. M.; Grekhov, A. M.* Modeling of Aviation Telecommunications. Proceedings of the National Aviation University. 2012. N 1. P. 5-13 (in Ukrainian).

[7] *Kharchenko, V. P.; Barabanov, Y. M.; Grekhov, A. M.* Modeling of Satellite Channel for Transmission of ADS-B Messages. Proceedings of the National Aviation University. 2012. N 3. P. 9-14 (in Ukrainian).

[8] *Kharchenko, V. P.; Barabanov, Y. M.; Grekhov, A. M.* Modelling of 'Satellite-To-Aircraft' Link for Self-Separation. Transport. 2013. N 28(4). P. 120-128.

[9] *Minimum Aviation System Performance Standards for Automatic Dependent Surveillance-Broadcast (ADS-B).* RTCA. Inc. 2002. DO-242A.

[10] *Roque, D.; Siclet, C.* Performances of Weighted Cyclic Prefix OFDM with Low-Complexity Equalization. IEEE Communications Letters. 2013. N 17(3). P. 439–442. doi:10.1109//LCOMM.2013.011513.121997.

[11] *Sagias, N.; Zogas, D.A.; Karagiannidis, G.K.; Tombras, G.S.* Burst Timing Synchronization for OFDM-based LEO and MEO Wideband Mobile Satellite Systems. The Seventh International Workshop on Digital Signal Processing Techniques for Space Communications. 2001.

Received 10 June 2014.

В.П. Харченко[1], Ванг Бо[2], А.М. Грехов[3], Д.В. Безсмертна[4]. Вплив модуляції та нелінійності передавача на трансмісію ADS-B повідомлень через супутниковий OFDM канал зв'язку

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680

E-mails: [1]kharch@nau.edu.ua; [2]wangbo@nau.edu.ua; [3]grekhovam@ukr.net; [4]dasha_bezsmertna@mail.ru

Для дослідження впливу схеми модуляції та нелінійності передавача на трансмісію ADS-B повідомлень по супутниковому каналу побудовано оригінальну модель каналу зв'язку «Літак-Супутник-Наземна Станція» з використанням програмного комплексу MATLAB Simulink. Модель складено із джерела інформації, передавача літака, каналу нагору/вниз, супутникового транспондера, приймача наземної станції. Отримано залежності співвідношення сигнал-шум від втрат у вільному просторі для різних видів модуляції (BPSK, QPSK, 16QAM, 64QAM), різних температур шуму супутникового транспондера, ширини каналу, кількості символів OFDM і різних рівнів нелінійності передавача літака.

Ключові слова: втрати у вільному просторі; декодер Вітерби; згорнуте кодування; супутниковий зв'язок; супутниковий транспондер; ADS-B; OFDM.

В.П. Харченко[1], Ванг Бо[2], А.М. Грехов[3], Д.В. Бессмертная[4]. Влияние модуляции и нелинейности передатчика на трансмиссию ADS-B сообщений через спутниковый OFDM канал связи

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua; [2]wangbo@nau.edu.ua; [3]grekhovam@ukr.net; [4]dasha_bezsmertna@mail.ru

Для исследования влияния схемы модуляции и нелинейности передатчика на трансмиссию ADS-B сообщений по спутниковому каналу построена оригинальная модель канала связи «Самолет-Спутник-Наземная Станция» с использованием программного комплекса MATLAB Simulink. Показано, что модель состоит из источника информации, передатчика самолёта, канала вверх/вниз, спутникового транспондера, приемника наземной станции. Получены зависимости соотношения сигнал-шум от потерь в свободном пространстве для разных видов модуляции (BPSK, QPSK, 16QAM, 64QAM), разных температур шума спутникового транспондера, ширины канала, количества символов OFDM и различных уровней нелинейности передатчика самолёта.

Ключевые слова: декодер Витерби; потери в свободном пространстве; сверточное кодирование; спутниковая связь; спутниковый транспондер; ADS-B; OFDM.

Kharchenko Volodymyr (1946). Doctor of Engineering. Professor.
Holder of a State Award in Science and Engineering of Ukraine.
Winner of a State Prize of Ukraine in Science and Engineering.
Vice-Rector for Scientific-Research Work, National Aviation University, Kyiv, Ukraine.
Head of the Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute with a Degree in Radio Engineering, Kyiv, Ukraine (1967).
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 405.
E-mail: knarch@nau.edu.ua

Wang Bo (1980). Associate Professor.
College of Economics and Management, Ningbo University of Technology, China.
Education: National Aviation University, with a Degree in aviation fuel cost control, Kyiv, Ukraine.
Research area: presided over a "high-end project" launched by Chinese Bureau of Foreign Experts; presided over and accomplished a longitudinal project launched by the provincial education department; presided over a 800-thousand Yuan horizontal project launched by Ningbo Traffic Detachment; took a major part in a project on international cooperation launched by Ministry of Science and Technology of China (2/6); took part in a municipal project on social sciences and quite a number of horizontal projects in Ningbo.
Publications: 20.
E-mail: wangbo@nau.edu.ua

Grekhov Andrii (1951). Doctor of Physics and Mathematics Sciences (1990). Professor (1991).
Expert of EUROCONTROL for ADS-B systems.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: Physical Department, State Taras Shevchenko University, Ukraine (1973), M.Sc. Degree with Honors confirming qualification of Physicist Theorist.
Research area: air satellite communications and information channels, computer modeling of information flows transmission in airborne collision avoidance systems, ADS-B systems, onboard recorder and communication channels, surveillance processes and modern signal processing, expansion of terrestrial surveillance systems for ADS-B using satellite system IRIDIUM, noise resistant codind and forward error correction, aviation security assessment based on simulation.
Publications: 180.
E-mail: grekhovam@ukr.net

Bezsmertna Daria (1990). Student.
National Aviation University, Kyiv, Ukraine.