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COMPUTER MODELING OF RADIO FREQUENCY SATELLITE TRANSPONDER FOR TRANSMISSION OF ADS-B MESSAGES SATELLITE COMMUNICATION CHANNEL

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Abstract. *For investigation of ADS-B messages transmission via radio frequency satellite link the original model of a communication channel "Aircraft-to-Satellite-to-Ground Station" was built using MATLAB Simulink. Model consists of aircraft transmitter, uplink/downlink path, satellite transponder, ground station receiver. BER dependencies on Free Space Path Losses, Noise Temperatures and Satellite Transponder Amplifier Gain were received and analyzed.*

Keywords: ADS-B; BER; free space losses; noise temperature; radio frequency satellite transponder; satellite communication.

1. Introduction

Air-traffic control services in accordance with Communication, Navigation, Surveillance / Air Traffic Management (CNS/ATM) concept should be enhanced using Automatic Dependent Surveillance-Broadcast (ADS-B) function [10].

The EUROCONTROL CASCADE Programme co-ordinates the deployment of initial ADS-B applications and Wide-Area Multilateration in Europe.

The Programme covers both ground Surveillance (i.e. “ADS-B out”) as well as airborne Surveillance applications (i.e. “ADS-B in”) [4].

The widespread introduction of ADS-B within European airspace is being facilitated through legislation published by the European Commission (derived from the Surveillance Performance and Interoperability Implementing Rule).

ADS-B is a Surveillance technique that relies on aircraft broadcasting their identity, position and other aircraft information.

This signal can be captured for Surveillance purposes on the ground (ADS-B out) or on board other aircraft/vehicles (ADS-B in).

The latter will enable airborne traffic situational awareness spacing, separation and self-separation applications [1].

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 [2].

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

International Civil Aviation Organization 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 [14].

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 [5].

2. Analysis of researches and publications

Due to the high cost of the space segment for the construction of a satellite communication system such design principles are applied, which should allow the use of a satellite transponder by a large number of ground users.

Resource allocation of satellite transponder can be accomplished by forming multiple trunks by using multiple satellite transponders operating on different frequency bands [12, 13].

A transponder is a broadband radiofrequency channel used to amplify one or more carriers on the downlink side of a communication satellite.

It is part of the microwave repeater and antenna system that is housed onboard the operating satellite.

Even a small degradation of satellite link will affect the system data rate or coverage, both of which are related to capital and operating expenses. It is crucial to have all of the system design parameters optimized before a heavy commitment to implementation.

Furthermore, when things go wrong during construction or initial operation, a simulation model can be used to track down the offending element.

The simulation will also be useful for pre-testing any corrective action before attempting it either in space or on the ground [3].

Modeling of satellite telecommunications baseband channels was realized previously in papers [6, 7, 8, 9].

Issues related to the ADS-B messages transmission via radiofrequency satellite link still are not investigated in detail.

The **aim** of this paper is:

1) to design computer model for “Aircraft-to-Satellite-to-Ground Station” link with radio frequency satellite transponder using MATLAB Simulink software;

2) to investigate dependencies of a Bit Error Rate (BER) on Free Space Path Losses for different carrier frequencies, Noise Temperatures and Satellite Transponder Amplifier Gain.

3. “Aircraft-to-Satellite-to-Ground Station” link model

Satellite communication link was analyzed using original model designed on the base of MATLAB Simulink demo model simrf_friis (Fig. 1).

Model consists of “Aircraft Transmitter”, “Uplink/Downlink”, “Satellite Transponder”, and “Ground Receiver”.

“Aircraft Transmitter” comprise:

– Random Integer Generator block, which generates uniformly distributed random integers in the range [0, M-1], where M is the M-array number defined in the dialog box;

– OQPSK Modulator Baseband block, which modulates data using the Offset Quadrature Phase Shift Keying method;

– Raised Cosine Transmit Filter block, which upsamples and filters the input signal;

– Transmitter Dish Antenna Gain block, which multiplies the input by a constant value (gain).

“Uplink/Downlink” consists of:

– Normalization block, which multiplies the input by a constant value (gain);

– Free Space Path Losses block, which simulates the loss of signal power due to the distance between transmitter and receiver and reduces the amplitude of the input signal by an amount that is determined;

– Noise Floor block, which apply receiver thermal noise to complex baseband signal;

– Unbuffer block, which unbuffer input frame into sequence of scalar outputs.

“Satellite Transponder” consists of;

– Receiver Dish Antenna Gain block;

– Radio Frequency (RF) block;

– Amplifier; Phase/Frequency Offset block;

– Transmitter Dish Antenna Gain block.

Radio Frequency block (Fig. 2) consists of:

– SimRF Inport block, which convert Simulink input signal to SimRF signal;

– Low-Noise Amplifier (LNA) block;

– Mixer block, which models a mixer in the SimRF circuit-envelope simulation environment;

– SimRF Outport block, which converts SimRF signal to Simulink output signal;

– Continuous Wave block, which models a constant modulation on a carrier in the SimRF circuit-envelope simulation environment;

– Solver Configuration block, which represents Physical Networks environment and solver configuration;

– SimRF Parameters block, which specifies system-wide parameters for circuit-envelope analysis.

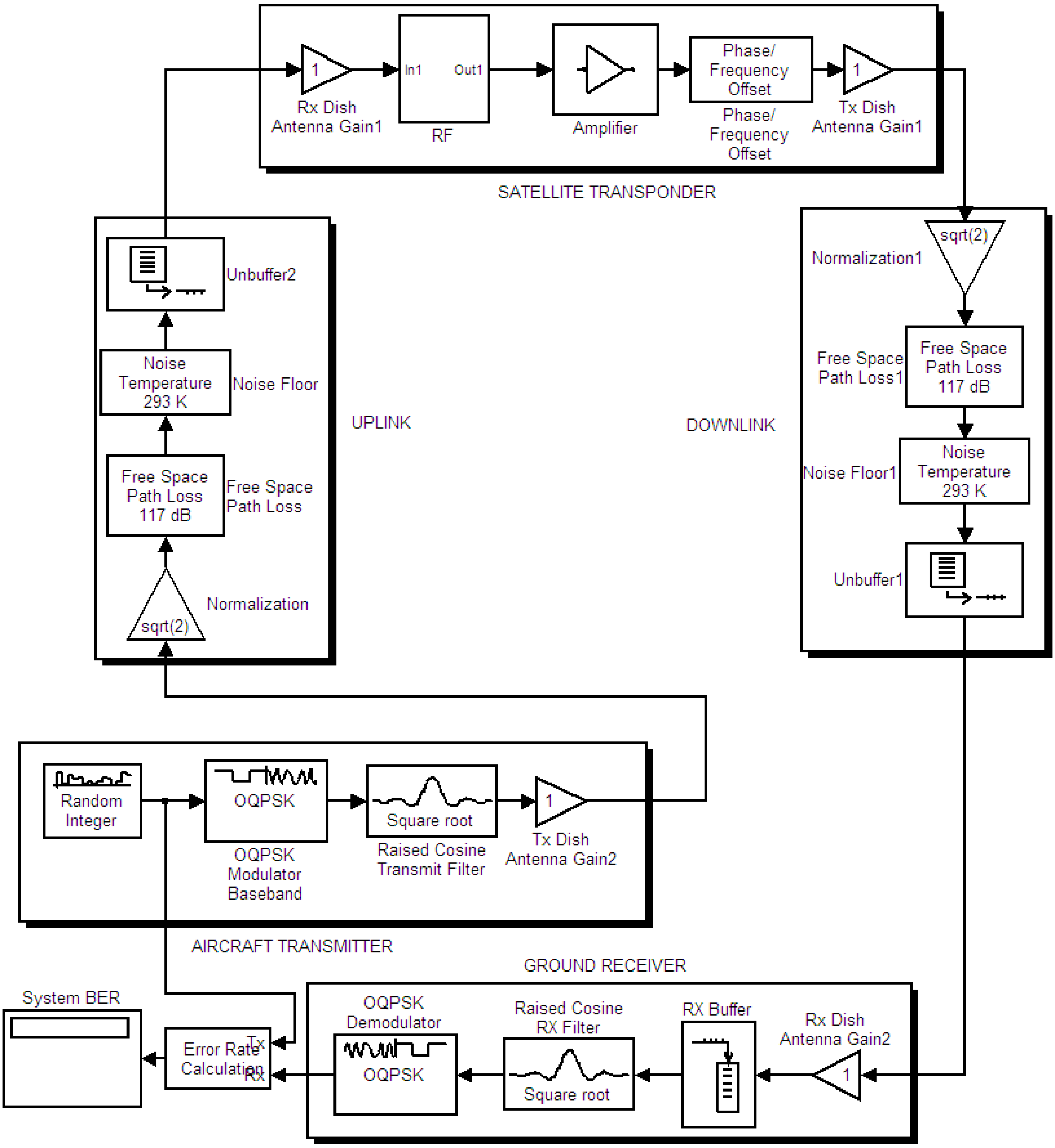

Fig. 1. “Aircraft-to-Satellite-to-Ground Station” Link

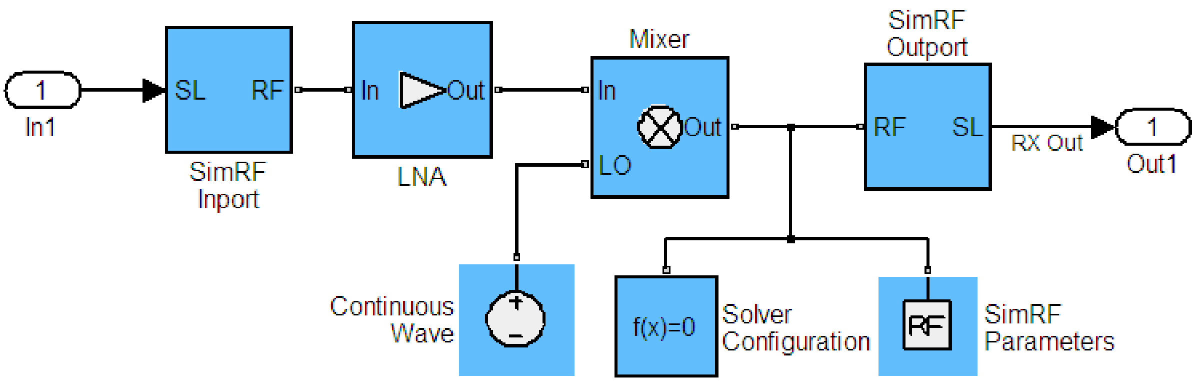

Fig. 2. Scheme of RF block

Amplifier block allows selecting linear and five different methods to model the nonlinear amplifier. In this paper the linear method was chosen. During modeling linear amplifier gain was 1 dB.

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

Transmitter Dish Antenna Gain block multiplies the input by a constant value (gain).

"Ground Receiver" comprises Receiver Dish Antenna Gain block and RF System Demodulator block.

RF System Demodulator block consists of:

– Receiver Buffer block, which buffer input sequence to smaller or larger frame size;

– Raised Cosine Receiver Filter block, which filters the input signal;

– OQPSK Demodulator block, which demodulates a signal that was modulated using the Offset Quadrature Phase Shift Keying method.

"Error Rate Calculation" block displays 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 MIMO channels simulation

Aeronautical satellite channel simulation was provided for carrier RF 1,6 GHz (L-band) and 2,1 GHz, 3,1 GHz (S-band).

Low Noise Amplifier block has modeled linear amplifier with gain 100 dB, noise figure 6 dB and input/output impedance 50 Ohms.

Mixer block had power gain -5 dB, noise figure 15 dB and input/output impedance 50 Ohms.

SimRF Outport block had converted SimRF voltage/current to Simulink signal with carrier frequency 500 MHz.

Continuous Wave block had carrier frequencies of Local Oscillator (LO) 1,1 GHz, 1,6 GHz and 2,6 GHz.

Satellite transponder amplifier linear gain was 1 dB. All antennas gain was G=1.

On Fig. 3 dependencies of a BER on free space path loss for different RF and LO are given.

On Fig. 4 dependencies of a BER on free space path loss for different noise temperatures are shown.

On Fig. 5 dependencies of a BER on free space path loss for different satellite amplifier linear gain are given.

5. Conclusions

In multiple trunks satellite transponders operate on different frequency bands.

The satellite transponder is a central element in the end-to-end communications link, illustrated in Fig. 1.

That's why it is important to investigate ADS-B messages transmission via radio frequency satellite link.

The original model of RF communication channel "Aircraft-to-Satellite-to-Ground Station" was created in this paper for the first time and fundamental dependencies of a BER on Free Space Path Losses, Noise Temperatures and Satellite Transponder Amplifier Gain were received and analyzed.

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.

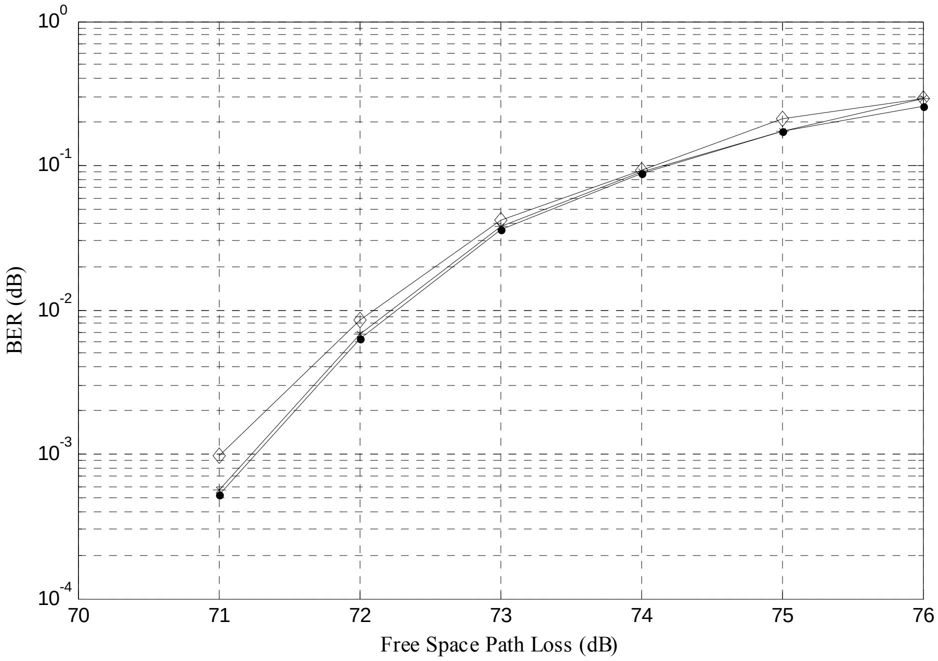

Fig. 3. Dependencies of BER on free space path loss for different RF and LO:
points: RF=1,6 GHz, LO=1,1 GHz;
circles: RF=2,1 GHz, LO=1,6 GHz;
diamonds: RF=3,1 GHz, LO=2,6 GHz;
noise temperature T=20 K;
satellite transponder linear gain 1 dB;
antennas gain G=1

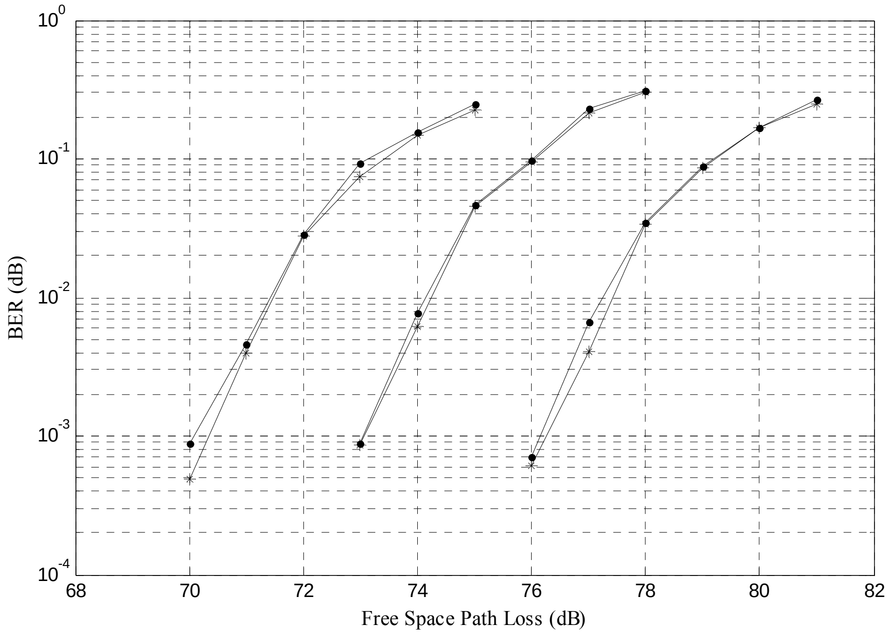

Fig. 4. Dependencies of BER on free space path loss for different noise temperatures:
left: T = 20K;
middle: T = 100K;
right: T = 290K; points: RF=1,6 GHz, LO=1,1 GHz;
circles: RF=2,1 GHz, LO=1,6 GHz;
satellite transponder linear gain 1 dB;
antennas gain G=1

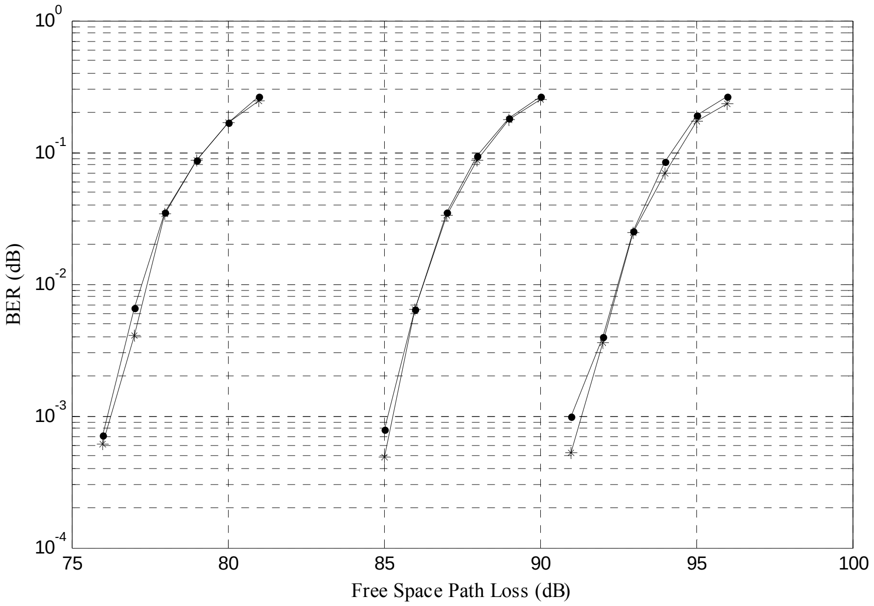

Fig. 5. Dependencies of BER on free space path loss for different satellite amplifier linear gain:
left: 1 dB;
middle: 2 dB;
right: 3 dB (SFRF = 2.1GHz SFLO= 1.6 GHz is marked with circles and SFRF =1.6 GHz SFLO = 1.1 GHz marked with points);
points: RF=1,6 GHz, LO=1,1 GHz;
circles: RF=2,1 GHz, LO=1,6 GHz;
noise temperature T=20K;
antennas gain G=1

References

[1] *An Introduction to Aircraft Satellite Tracking.* 2009. Available from Internet: <http://www.indigosat.com/marketing/About satellite tracking.pdf/>.

[2] *Comparetto, G.* Satellite Communications: Current Features and Future Trends. Conference Proceedings. Anaheim Convention Center. Anaheim, California. 1996. Paper N ICS35.4. P. 22–24. Available from Internet: <http://www.docstoc.com/яяdocs/90747335/SATELLITE-COMMUNICATIONS-CURRENT-FEATURES-AND-FUTURE-TRENDS>.

[3] *Elbert, B.; Elanix, M.* Simulating the Performance of Communication Links with Satellite Transponders. 2003. Available from Internet: <http://www.applicationstrategy.com/Communications_simulation.htm>.

[4] *EUROCONTROL.* ADS-B Sites. 2012. Available from Internet: <http://www.eurocontrol.int/ads_b_sites/>.

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

[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.

[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.

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

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

[10] *Manual on detailed technical specifications for the Aeronautical Telecommunication Network (ATN).* ICAO. Doc. 9880-AN/466. 2010. Available from Internet: <http://portal.aerocivil.gov.co/>.

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

[12] *Osborne, W. P.; Xie, Y.* Propagation Characterization of LEO/MEO Satellite Systems at 900-2100 MHz. Conference Proceedings. 1999. Available from Internet: <http://opensiuc.lib.siu.edu/ece_confs/52>.

[13] *Roddy, D.* Satellite Communications. The McGraw Hill Companies,Inc.Fourth Edition. 2006. 656 p.

[14] *The* Satellite *Industry Association.* 2012. Available from Internet: <http://www.sia.org/>.

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В. П. Харченко[1], Wang Bo[2], А. М. Грехов[3], П. А. Стаховський[3]. Комп'ютерне моделювання радіочастотного супутникового транспондера для передачі ADS-B повідомлень
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Для дослідження передачі ADS-B повідомлень по радіочастотному супутниковому каналу зв'язку з використанням програмного комплексу MATLAB Simulink побудовано оригінальну модель каналу зв'язку «Літак-Супутник-Наземна станція», яка включає передавач повітряного судна, каналів передачі даних нагору/униз, супутникового ретранслятора, приймача наземної станції. Проаналізовано залежності коефіцієнта двійкових помилок від втрат у вільному просторі, шумових температур і підсилення супутникового транспондера для різних частот несучої.

Ключові слова: втрати у вільному просторі; канал; наземний приймач; передавач літака; підсилення; супутник; супутниковий транспондер; частота; шумова температура; BER.

В. П. Харченко[1], Wang Bo[2], А. М. Грехов[3], П. А. Стаховский[3]. Компьютерное моделирование радиочастотного спутникового транспондера для передачи ADS-B сообщений
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Для исследования передачи ADS-B сообщений по радиочастотному спутниковому каналу связи с использованием программного комплекса MATLAB Simulink построена оригинальная модель канала связи «Самолет-Спутник-Наземная станция», включающая передатчик воздушного судна, каналов передачи данных вверх/вниз, спутникового ретранслятора, приёмника наземной станции. Проанализированы зависимости коэффициента двоичных ошибок от потерь в свободном пространстве, шумовых температур и усиления спутникового транспондера для разных частот несущей.

Ключевые слова: канал; наземный приемник; передатчик самолета; потери в свободном пространстве; спутник; спутниковый транспондер; усиление; частота; шумовая температура; BER.

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