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MODELING OF ADS-B MESSAGES TRANSMISSION VIA SATELLITE USING MIMO SYSTEMS

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Abstract. *The original model of aeronautical satellite MIMO communication channel "Aircraft–to–Satellite–to–Ground Station" was created using MATLAB Simulink software. MIMO 2×1 and 3×2 fading uplink/downlink channels with antenna diversity were analyzed. Results were compared with AWGN uplink/downlink channels. On the base of these models channels integrity was investigated and dependences of Bit Error Rate on the ratio E_b/N_0 were received.*

Keywords: aeronautical satellite communication channel; MIMO 2×1; MIMO 3×2.

1. Introduction

In January 2005 the requirement of ICAO 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 [7]

ADS-B is a surveillance technology for tracking aircraft as part of the Next Generation Air Transportation System [4].

When using ADS-B system both pilots and controllers will see the same radar picture.

ADS-B systems based on Low Earth Orbit (LEO) satellites are of special interest [8].

Telecommunications satellite systems are widely used in aviation due to advantages of satellite communication which is connected with possibility of operation with many airplanes at long distances and with independence of communication expenses on distances to airplanes [3, 6].

During the communication through a wireless channel the transmitted signals are attenuated and faded due to multipath in the channel, making it difficult for a receiver to determine these signals.

Wireless communication using Multiple-Input Multiple-Output (MIMO) systems enables increased spectral efficiency for a given total transmit power in aeronautical satellite communication networks.

Increased capacity is achieved by introducing additional spatial channels that are exploited by using space-time coding.

2. Analysis of researches and publications

MIMO – is a technology used in wireless communication systems, which allows significantly improve the spectral efficiency of the system, the maximum data rate and the capacity of the network.

The main way of achieving these benefits is data transmission from source to destination through a few radio connections.

MIMO is the technology for transmission of information, which is based on the principle of multiplexing in space for many streaming data in one communication channel.

Sensitivity to fading is reduced by the spatial diversity provided by multiple spatial paths [11, 12].

The main advantages of MIMO channels over traditional Single-Input-Single-Output (SISO) channels are the array gain, the diversity gain, and the multiplexing gain.

Array gain is the improvement in Signal to Interference-plus-Noise Ratio (SINR) obtained by coherently combining the signals on multiple transmit or multiple receive dimensions and is easily characterized as a shift of the Bit Error Rate (BER) curve due to the gain in SINR [1, 10].

Diversity gain is the improvement in link reliability obtained by receiving replicas of the information signal through independently fading links, branches, or dimensions.

It is characterized by an steepen slope of the BER curve in the low BER region.

Orthogonal Space-Time Block Codes (OSTBCs) are an attractive technique for MIMO wireless communications.

They exploit full spatial diversity order and use symbol-wise maximum likelihood decoding.

The combiner for OSTBC at the receiver side provides soft information of the transmitted symbols, which can be utilized for decoding or demodulation of an outer code [1, 5].

MIMO antenna unit is a special case of the Adaptive Antenna Array (AAA).

The technology AAA suggests the use of intelligent algorithms implemented as digital signal processors.

These algorithms divide the signals in accordance with the vectors of their propagation.

Then a pattern of transmit antennas are adaptively adjusted.

Widespread use of MIMO devices has substantially changed the world of wireless data transmission, allowed significantly increase the speed and range of channels without increasing the transmitter power.

The lower correlation signals at the antenna are, the higher is the efficiency of this technology.

The **aim** of this paper is:

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

2) to analyze MIMO 2×1 and 3×2 fading uplink/downlink channels with antenna diversity;

3) to compare results with AWGN uplink/downlink channels;

4) on the base of these models investigate channels integrity and receive dependences of Bit Error Rate (BER) on the ratio E_b/N_0.

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

Our model comprises “Aircraft Uplink Transmitter” (Source of Data – Bernoulli Binary Generator, M-PSK modulator, High Power Amplifier), “Uplink/Downlink Paths” (MIMO 2×1 (Fig. 1, *a*), 3×2 (Fig. 1, *b*) fading uplink/downlink channels with antenna diversity, and Additive White Gaussian Noise (AWGN) uplink/downlink channels without antenna diversity), “Satellite Transponder” (Noise Temperature block, Complex Baseband Amplifier with Noise, Phase Noise block); “Ground Station Receiver” (Noise Temperature block, M-PSK demodulator), Error Rate Calculation block and Display (Fig. 2).

In this paper during a simulation BPSK and QPSK modulation schemes were considered only.

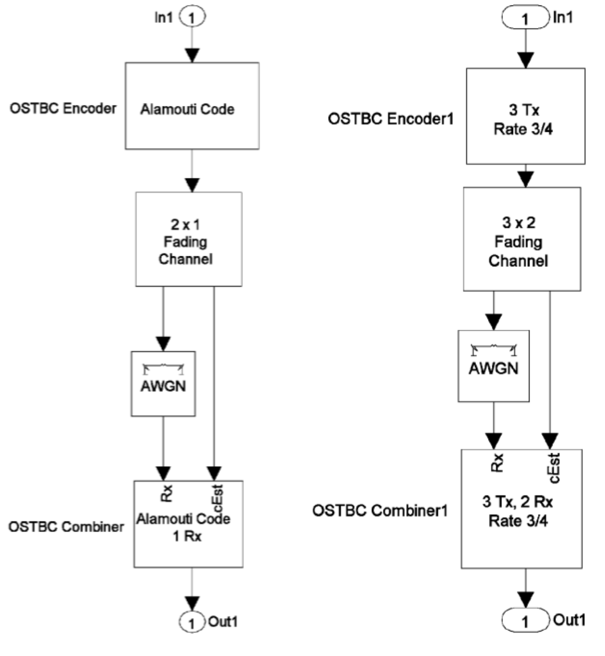

Fig. 1. MIMO 2×1 Channel (*a*), MIMO 3×2 Channel (*b*)

A BER was calculated as function of a ratio E_b/N_0 (the energy per bit to noise power spectral density ratio).

The value of a ratio E_b/N_0 was changed symmetrically in all uplink and downlink channels. Noise temperatures in “Satellite Transponder” and “Ground Station Receiver” were taken as 290 K (typical noise level).

The High Power Amplifier (HPA) block applies memoryless nonlinearity to complex baseband signal and provides five different methods for modeling the nonlinearity.

In this paper results only for Saleh model with standard AM/AM and AM/PM parameters are given [9].

A HPA backoff level is used to determine how close the satellite high power amplifier is driven to saturation.

The following selected backoff is used to set the input and output gain of the Memoryless Nonlinearity block: 30 dB (negligible nonlinearity) – the average input power is 30 decibels below the input power that causes amplifier saturation (in this case AM/AM and AM/PM conversion is negligible).

Complex Baseband Amplifier block in satellite transponder generates a complex baseband model of an amplifier with thermal noise.

It too simulates Saleh model with negligible nonlinearity.

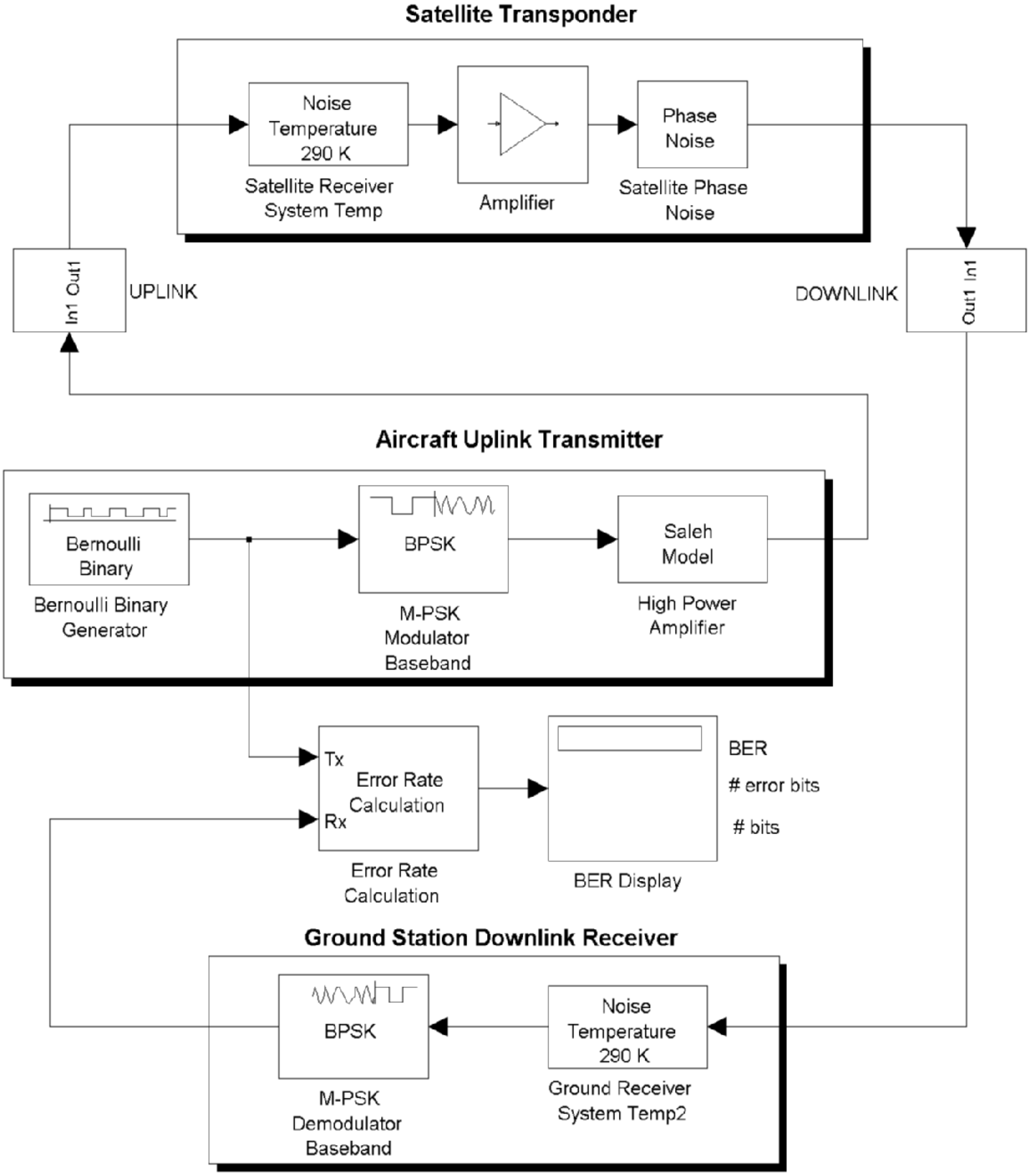

Fig. 2. "Aircraft-to-Satellite-to-Ground Station" Link

The Phase Noise block adds phase noise to a complex baseband signal.

The block applies the phase noise as follows: generates additive white Gaussian noise and filters it with a digital filter; adds the resulting noise to the angle component of the input signal.

The level of the spectrum is specified by the noise power contained in a one hertz bandwidth offset from a carrier by a certain frequency.

Modeling was provided for negligible level of phase noise (phase noise level: -100dBc/Hz, frequency offset: 0 Hz).

The OSTBC Encoder block encodes an input symbol sequence using Orthogonal Space-Time Block Code (OSTBC).

The block maps the input symbols block-wise and concatenates the output codeword matrices in the time domain.

The MIMO 2x1 uplink/downlink channel uses two transmit antennas and one receive antenna.

The MIMO 3×2 uplink/downlink channel uses three transmit antennas and two receive antennas.

The 2x1 and 3×2 Fading Channels use the Multipath Rayleigh Fading Channel block to simulate the flat Rayleigh fading subchannel from one transmit antenna to the receive antenna.

The Maximum Doppler shift parameters of the Multipath Rayleigh Fading Channel blocks were set to 1 Hz.

The reason for using this value is to make the MIMO channel behave like a quasi-static fading channel, i.e., it keeps constant during one frame transmission and varies along multiple frames.

The Initial seed parameters of the Multipath Rayleigh Fading Channel blocks are set to different values in order to simulate independent fading subchannels.

All subchannels have normalized gains.

The AWGN Channel block adds white Gaussian noises at the receiver side.

The Mode parameter is set to the ratio E_b/N_0 mode, the number of bits per symbol is 1, the input signal power, referenced to 1 ohm is set to 1 watt, and the symbol period is 1 s.

The OSTBC Combiner block combines the input signal (from all of the receive antennas) and the channel estimate signal to extract the soft information of the symbols encoded by an OSTBC.

4. Aeronautical satellite MIMO channels simulation

During modeling two types of channels were considered: MIMO 2×1 and MIMO 3×2 fading uplink/downlink channels. Obtained dependencies of a BER on a ratio E_b/N_0 for these channels were compared with SISO channels – AWGN uplink/downlink channels (Fig. 3).

These dependencies allow clarifying the effect of each channel on the probability of errors during data transmission.

Alamouti scheme provides considerable signals diversity and high-speed transmission by introducing phase orthogonality between the signals simultaneously transmitted and the pairs of signals emitted successively from each antenna.

The generalization of this code in case of more transmitter antennas led to the creation of another codes.

On Fig. 3, *a* the dependencies of an error probability for a BPSK modulation scheme on a ratio E_b/N_0 for MIMO 2×1 and AWGN channels are compared.

For small values of a ratio E_b/N_0 MIMO 2×1 uplink/downlink channels give lower values of a BER, but for E_b/N_0 > 16 dB AWGN uplink/downlink channels give lower values of a BER.

On Fig. 3, *b* the dependencies of an error probability for a QPSK modulation scheme on a ratio E_b/N_0 for MIMO 2×1 and AWGN channels are compared.

In this case a situation is similar – for E_b/N_0 > 22 dB AWGN uplink/downlink channels give lower values of a BER.

MIMO technology includes broadcasting signal through one channel by a number of transmitters and receivers.

The more spaced antennas are, the stronger the improvement of productivity is.

In MIMO 3×2 there are 3 transmitting and 2 receiving antennas.

Due to such "compression" a channel capacity can be increased by two times or more.

On Fig. 3, *c* the dependencies of an error probability for a BPSK modulation scheme on a ratio E_b/N_0 for MIMO 3×2 and AWGN channels are compared.

In this case a situation is quite different. In the whole range of changes E_b/N_0 the channel MIMO 3×2 provides lower values of a BER.

On Fig. 3, *d* the dependencies of an error probability for a QPSK modulation scheme on a ratio E_b/N_0 for MIMO 3×2 and AWGN channels are compared.

The character of dependencies here are similar to a Fig. 3, *c*.

On Fig. 3 satellite and ground receivers noise temperatures are 290 K, HPAs backoff level is 30 dB, phase and frequency offsets are equal to zero, satellite transponder phase noise is negligible.

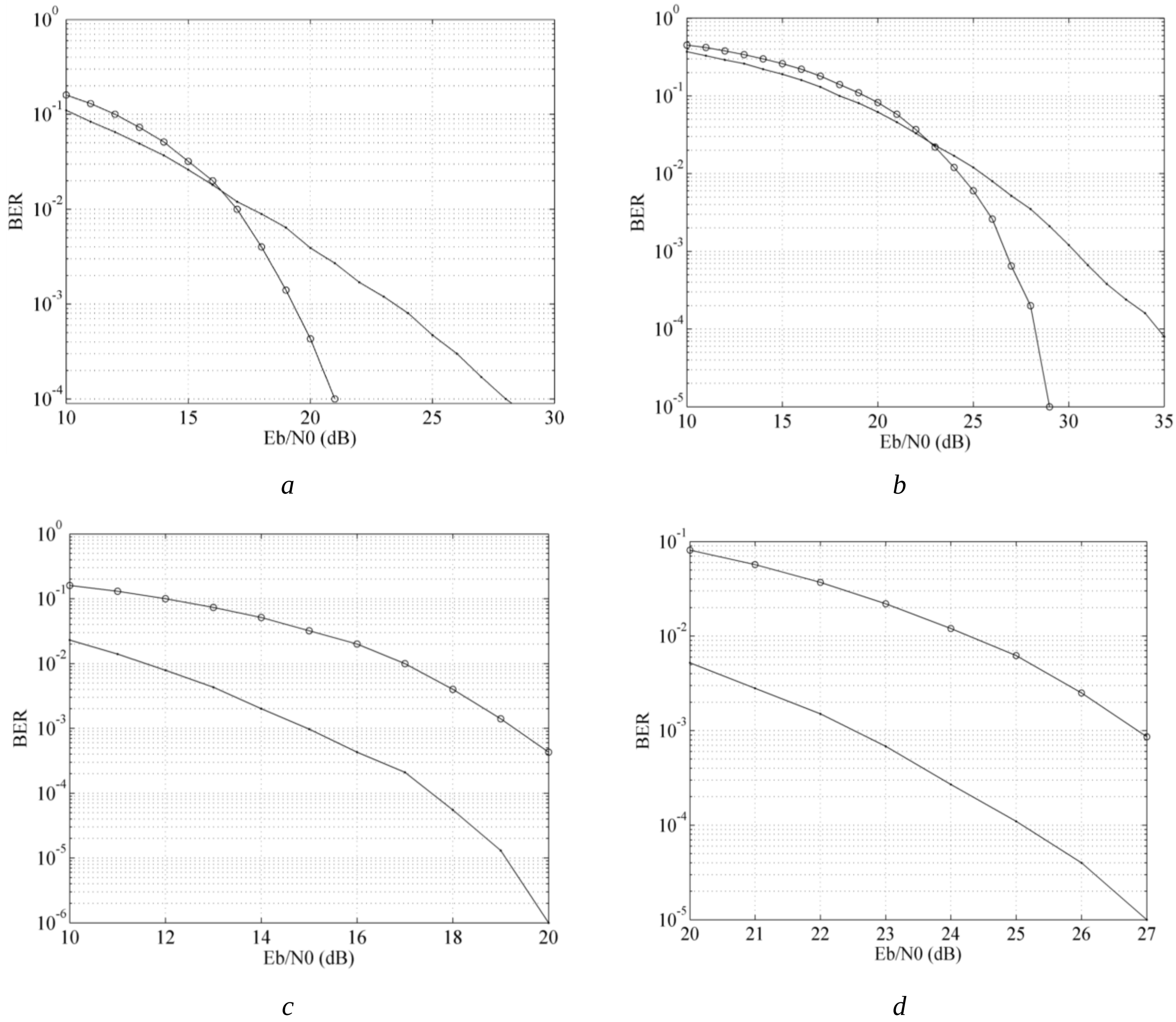

Fig. 3. Dependence of an error probability for a BPSK (*a, c*) and a QPSK (*b, d*) modulation scheme on a ratio E_b/N_0 in uplink/downlink channels:
a, b: dots – MIMO 2×1 uplink/downlink channels, circles – AWGN uplink/downlink channels;
c, d: dots – MIMO 3×2 uplink/downlink channels, circles – AWGN uplink/downlink channels

After modeling let's estimate the reduction of a BER for MIMO channels in comparison with SISO AWGN channels.

From Fig. 3 follows that:

$\Delta BER_{BRSK}(AWGN - MIMO\ 2\times 1) = 0,050,$

for $E_b / N_0 = 10\ dB;$

$\Delta BER_{QPSK}(AWGN - MIMO\ 2\times 1) = 0,080,$

for $E_b / N_0 = 10\ dB;$

$\Delta BER_{BPSK}(AWGN - MIMO\ 3\times 2) = 0,0043,$

for $E_b / N_0 = 20\ dB;$

$\Delta BER_{QPSK}(AWGN - MIMO\ 3\times 2) = 0,077,$

for $E_b / N_0 = 20\ dB;$

Received reduction of a BER is a rather big value. Note that the decrease in a BER for modulation QPSK is more than for BPSK modulation.

5. Conclusions

1. Original model of aeronautical satellite MIMO communication channel "Aircraft–to–Satellite–to–Ground Station" was created.

2. This model was used for modeling of transmission data from aircraft to ground station via satellite using MIMO 2×1 and 3×2 channels with antenna diversity.

3. On the base of these models channels integrity was investigated and dependences of BER on the ratio E_b/N_0 were received.

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В.П. Харченко[1], Ванг Бо[2], А.М. Грехов[3], Ю.В. Костинська[4]. Моделювання передачі ADS-B повідомлень через супутник із використанням MIMO систем

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Оригінальну модель авіаційного супутникового MIMO каналу зв’язку «Повітряний корабель – Супутник – Наземна станція» створено з використанням програмного комплексу MATLAB Simulink. Розглянуто MIMO 2×1 та 3×2 канали з затуханням догори/донизу з різною кількістю передавальних і приймальних антен. Результати порівняно з каналами AWGN догори/донизу. На основі запропонованих моделей проаналізовано якість передачі інформації. Отримано залежності коефіцієнта двійкових помилок від співвідношення E_b/N_0.

Ключові слова: авіаційний супутниковий канал зв’язку; MIMO 2×1; MIMO 3×2.

В.П. Харченко[1], Ванг Бо[2], А.М. Грехов[3], Ю.В. Костинская[4]. Моделирование передачи ADS-B сообщений через спутник с использованием MIMO систем

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Оригинальная модель авиационного спутникового MIMO канала связи «Воздушное судно – Спутник – Наземная станция» создана с использованием програмного комплекса MATLAB Simulink. Рассмотрены MIMO 2×1 та 3×2 каналы с затуханием вверх/вниз с разным количеством передающих и принимающих антенн. Результаты сравнены з каналами AWGN вверх/вниз. На основе предложенных моделей проанализировано качество передачи информации. Получены зависимости коэффициента двоичных ошибок от соотношения E_b/N_0.

Ключевые слова: авиационный спутниковый канал связи; MIMO 2×1; MIMO 3×2.

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