COMMUNİCATİON SYSTEM OF KAZAKHSTANİ SCİENTİFİC NANOSATELLİTE KAZSCİSAT

Meirbek MOLDABEKOV1), Suleimen YELUBAYEV1),2), Anna SUKHENKO1), Timur BOPEYEV1)
1)Institute of Space Technique and Technology, Almaty, Kazakhstan
2)al-Farabi Kazakh National University, Almaty, Kazakhstan
yelubayev.s@istt.kz

The article is devoted to the creation of a communication system of a Kazakhstani scientific nanosatellite kazscisat. The nanosatellite was developed on the basis of CubeSat 3U technology and is intended for operation in a sun-synchronous orbit with an altitude of ~600 km. The nanosatellite included a payload, an onboard control system, an attitude determination and control system, a communication system, a power supply system, a structure and mechanisms.

Key Words: Nanosatellite, Communication system, VHF/UHF link budget

1. Introduction

Scientists and specialists of the Institute of space technique and technology created and successfully launched the KazSciSat scientific spacecraft in December 2018. The main mission of the nanosatellite was to monitor the Earth's magnetic field in order to study physical processes in near space and their relationship with terrestrial processes. The KazSciSat nanosatellite was developed on the basis of CubeSat 3U technology and ECSS standards1),2),3). The nanosatellite is intended for operation in a sun-synchronous orbit with an altitude of ~600 km.

One of the important subsystems of the nanosatellite is the communication system, which is designed for radio communication with Earth - receiving command information and reset service telemetry and target scientific information4). This article is devoted to the process of design of communication system for KazSciSat.

2. Structure of nanosatellite communication system

Communication system of nanosatellite KazSciSat include:
- VHF/UHF transceiver;
- VHF/UHF antenna system;
- S-band transmitter;
- S - band antenna system.

VHF/UHF transceiver is designed to communicate with the Earth in the amateur VHF/UHF and receives command information, transmission service telemetry data. The VHF/UHF transceiver is equipped with radiobeacon to nanosatellite identification in orbit to send signals in emergency situations. The transition to radiobeacon mode is after the efflux of certain amount of time unless there is no any activity on I2C bus.

VHF/UHF transceiver has the support of tunable DTMF commands transmitted from the Earth for the receiving of main telemetry information from transceiver and manual reload of C&DH through the direct access to RESET on PC/104 bus. There is no direct access from VHF/UHF transceiver to PDM by I2C bus (Figure 1).

The VHF/UHF antenna system is used for converting the electrical signal into an electromagnetic wave. The antenna is of dipole type with near-isotropic directional pattern what allow transmitting of information in any angular position of nanosatellite (Figure 2).

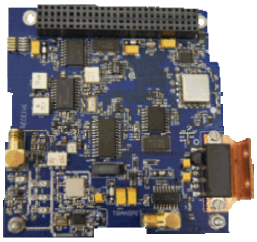

Fig. 1. VHF/UHF-transceiver (ECM GmbH).

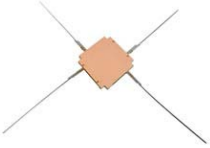

Fig. 2. Deployable antenna system (ClydeSpace) general view.

S-Band transmitter is a device for high-speed transmission target information to the Earth. The antenna system of the S-band is intended for converting electrical signals to electromagnetic waves. Is a poorly directed patch antenna (Figure 3).

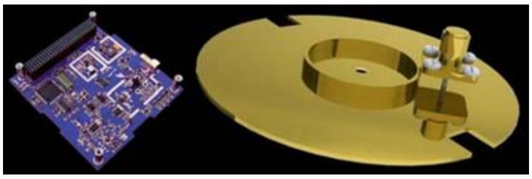

Fig. 3. S-band transmitter (ClydeSpace) and S-band patch antenna (ClydeSpace) general view

3. Nanosatellite link budget of UHF/VHF radio channel

Nanosatllite link budget was developed for radio channels UHF/VHF "up" and "down". Next conditions were made for the assessment of the stability of the communication in UHF/VHF frequency range: orbit altitude – 650 km, elevation - 5°.

Let consider the link budget of UHF/VHF radio channel "up".

The initial conditions for the transmission system of ground station are:

- radiated power: 25 W (13.98 dBw);
- transmission antenna power gain: 13.2 dBi;
- transmitter loss: adopted as 3 dBw;
- transmission frequency: 145 MHz.

Taking into account the presented above values, the EIRP of ground station in UHF/VHF frequency range is 24,17 dBw.

Let consider the losses along the pass of signal propagation. We adopted next value of losses:

- atmosphere losses: 1 dBw;
- ionosphere losses: dBw;
- rain losses: 1 dBw;
- polarization losses: 1 dBw;
- pointing losses 1 dBw.

Also, let determine the natural attenuation of the signal in space which, taking into account the distance from ground station to nanosatellite and frequency, is 143,47 dBw. Thus, the summary losses of the signal are 148,47 dBw.

Taking into account the determined value and that the satellite's UHF/VHF receiving antenna does not have gaining, the level of receiving signal on nanosatellite on the input of the transceiver is -124,29 dBw.

Taking into account the technical characteristics of UHF/VHF transceiver, its threshold limit value of receiving signal for the BER = 10E-5 and AFSK modulation is -130 dBw.

Thus, the margin of radio channel power is 5,71 dBw, which shows the stable radio channel.

Let consider the link budget of UHF/VHF radio channel "down" using analogue scheme.

Initial data for satellite's transmitting system is:

- radiated power: 0.5 W (-3.01 dBw);
- transmission antenna power gain: 0 dBi;
- transmitter loss: adopted as 3 дБВт;
- transmission frequency: 450 МГц.

Taking into account the presented above values, the EIRP of satellite's UHF/VHF system is -6,01 dBw.

Space losses:

- atmosphere losses: 1 dBw;
- ionosphere losses: dBw;
- rain losses: 1 dBw;
- polarization losses: 1 dBw;
- pointing losses 1 dBw.
- the attenuation of a signal: 153,3 dBw.

Summary losses of the signal are 158,3 dBw.

Taking into account the values presented above the level of receiving signal on the ground is -164,31 dBw.

UHF/VHF antenna system of ground station has gain coefficient equaled 13.6 dBi.

More detailed representation of the calculation of link budget in UHF/VHF frequency range "down" is presented below (Table 1).

Table 1. Nanosatellite link budged, UHF, downlink

№	Parameter	Value	
		Eb/No Method	C/N Method
1	Orbit Height, km	650,00	
2	Elevation Angle, °	5,00	
3	Distance to Satellite, km	2 447,96	
4	Boltzmann's constant, J/K	1,38E-23	
5	Frequency, MHz	450,00	
6	Transmit Power, W	0,50	
7	Transmit Power, dBW	-3,01	
8	Transmitter Antenna Gain, dBi	0,00	
9	Transmitter Loss, dBW	3,00	
10	Effective Isotropic Radiated Power (EIRP), dB	-6,01	
11	Free Space Loss, dBW	153,30	
12	Atmospheric Loss, dBW	1,00	
13	Ionospheric Loss, dBW	1,00	
14	Rain Loss, dBW	1,00	
15	Polarization Loss, dBW	1,00	
16	Pointing Loss, dBW	1,00	
17	Receive Signal Power, dBW	-164,31	
18	Receiver Antenna Gain, dBi	16,30	
19	Receiver Noise Figure, dBW	2,00	
20	System Noise Temperature, K	339,24	
21	Data Rate, bit/s	9 600,00	
22	G/T, dB/K	-9,01	
23	Signal/Noise Ratio (C/N), dBHz	55,28	
24	Bit Energy/Noise Ratio (Eb/No), dBW	15,46	
25	Bit Error Rate (BER)	1,00E-05	
26	Required Eb/No, dBW	9,60	
27	Bandwidth, Hz		11 520,00
28	LNA Signal Power (Ps), dBW		-148,01
29	Receiver Noise Power (Pn), dBW		-162,68
30	Receiver Carier/Noise Ratio (C/N), dBW		14,67
31	Required Receiver Signal/Noise Ratio (S/N), dBW		9,60
32	Margin, dBW	5,86	5,07

System noise temperature of ground station, in accordance with its description, is equaled to 169.62 K. It was found out, that this value, presented by the supplier, it not a measured value, but was calculated using known formulas. Thus, for the system noise temperature was adopted 2x margin, what as a result is 339.24 K.

Next, let determine noises level. For this task, it is necessary to find frequency resource occupied by the communication channel. Data rate speed is this radio channel is 9600 bit/s. The modulation is BPSK, what tells that symbol rate is equaled to bit rate. Knowing the symbol rate, we can find the emission frequency band, which is 11.520 kHz. Taking into account this fact, we can determine the noise level which is -162.68 dBw.

On the basis on signal and noise levels obtained, let determine their relation which is 14.67 dB.

Taking into account the type of modulation – BPSK, for BER=10E-5 the relation signal/noise is about 9.6 dBw.

On the basis of obtained values of signal/noise, let determine the margin of radio channel, which is 5.07 dBw. The adequate value of the stability of communication is about 4 dBw, which tells that the communication with nanosatellite has good stability.

4. Nanosatellite link budget of S-band

The link budget of S-band "down" was developed. For the assessment of the stability of the communication in S-band next values were adopted:

- orbit altitude – 650 km;
- elevation - 5°.

Initial data for satellite's S-band transmitting system is:

- radiated power: 1 W (0 dBw);
- transmission antenna power gain: 8 dBi;
- transmitter loss: adopted as 3 дБВт;
- transmission frequency: 2.43 GHz.

Taking into account the presented above values, the EIRP of satellite's S-band system is 5 dBw.

Space losses:

- atmosphere losses: 1 dBw;
- ionosphere losses: dBw;
- rain losses: 1 dBw;
- polarization losses: 1 dBw;
- pointing losses 1 dBw.
- the attenuation of a signal: 164.94 dBw.

Summary losses of the signal are 169,94 dBw.

Taking into account the values presented above the level of receiving signal on the ground is -164,94 dBw.

S-band antenna system of ground station has gain coefficient equaled 29.2 dBi.

System noise temperature of ground station, in accordance with its description, is equaled to 66.78 K. For this value, the margin of 50% was taken additionally and the total noise temperature is 100.17 K.

Next, let determine noises level. For this task, it is necessary to find frequency resource occupied by the communication channel. Data rate speed is this radio channel is 2 Mbit/s. The modulation is QPSK, what tells that symbol rate is a half of bit rate, e.g. 1Mbit/s. Knowing the symbol rate, we can find the emission frequency band, which is 1.2 MHz kHz. Taking into account this fact, we can determine the noise level on the input of the transceiver, which is -147.8 dBw.

On the basis on signal and noise levels obtained, let determine their relation which is 12.06 dB.

Taking into account the type of modulation – QPSK, for BER=10E-5 the relation signal/noise is about 9.6 dBw.

On the basis of obtained values of signal/noise, let determine the margin of radio channel, which is 2.46 dBw. The adequate value of the stability of communication is about 4 dBw, which tells that the communication with nanosatellite in S-band has weak stability. The margin of 4 dBw in accordance with the calculation, might be reached from the elevation of 21°.

More detailed representation of the calculation of link budget in S-band "downlink" is presented below (Table 2).

Table 2. Nanosatellite link budged, S-Band, downlink

№	Parameter	Value	
		Eb/No Method	C/N Method
1	Orbit Height, km	650,00	
2	Elevation Angle, °	15,00	
3	Distance to Satellite, km	1 731,40	
4	Boltzmann's constant, J/K	1,38E-23	
5	Frequency, MHz	2 430,00	
6	Transmit Power, W	1,00	
7	Transmit Power, dBW	0,00	
8	Transmitter Antenna Gain, dBi	8,00	
9	Transmitter Loss, dBW	3,00	
10	Effective Isotropic Radiated Power (EIRP), dB	5,00	
11	Free Space Loss, dBW	164,94	
12	Atmospheric Loss, dBW	1,00	
13	Ionospheric Loss, dBW	1,00	
14	Rain Loss, dBW	1,00	
15	Polarization Loss, dBW	1,00	
16	Pointing Loss, dBW	1,00	
17	Receive Signal Power, dBW	-164,94	
18	Receiver Antenna Gain, dBi	29,20	
19	Receiver Noise Figure, dBW	0,90	
20	System Noise Temperature, K	100,17	
21	Data Rate, bit/s	2 000 000,00	
22	G/T, dB/K	9,19	
23	Signal/Noise Ratio (C/N), dBHz	72,85	
24	Bit Energy/Noise Ratio (Eb/No), dBW	9,84	
25	Bit Error Rate (BER)	1,00E-05	
26	Required Eb/No, dBW	9,60	
27	Bandwidth, Hz		1 200 000,00
28	LNA Signal Power (Ps), dBW		-135,74
29	Receiver Noise Power (Pn), dBW		-147,80
30	Receiver Carier/Noise Ratio (C/N), dBW		12,06
31	Required Receiver Signal/Noise Ratio (S/N), dBW		9,60
32	Margin, dBW	0,24	2,46

5. Conclusion

The process of design of communication system for KazSciSat was considered in this article. The result of this work was used for development of communication system of KazSciSat that was successfully launched in December 2018.

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References

1. ECSS-E-ST-10-06C – Technical requirements specification https://ecss.nl/standard/ecss-e-st-10-06c-technical-requirements-specification/
2. ECSS-E-ST-10-03C Rev.1 – Testing https://ecss.nl/standard/ecss-e-st-10-03c-rev-1-testing-31-may-2022/
3. ECSS-E-ST-40C – Software https://ecss.nl/standard/ecss-e-st-40c-software-general-requirements/
4. Wertz R.J., Larson W.J. Space Mission Analysis and Design, 3rd edition (1999), Springer, 996 p.