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SMALLSAT COMMUNICATION SYSTEM DESIGN

Introduction. One of the common intentions is to bring many countries the opportunity to operate SmallSat for Earth observation (EO) missions and utilize the data effectively at low costs, as well as to develop and build application-driven missions [1]. There are some new advances that may show to significantly improve the abilities of SmallSat EO missions [1, 2]:

1. The merging of data acquisition and data visualization knowledge.
2. The complete disposal of new small launchers and the increase of space tourism.
3. The progress of smaller, lighter, lower power satellites that can action as a constellation or independently.

In this regard a great role is played by the communication system. The communication system is a particular on-board electronic complex of tools, together with the ground segment, which solves the following tasks: downlink (to on-board receiving) and decoding on-board control commands and numerical data, collecting, storing, pre-processing and uplink (transmitting information to receptions), as well as trajectory measurements. The antenna devices for uplink and downlink of high frequency radio signals are separate systems. This system includes are antennas, coaxial cables and waveguides, switching and locking devices [3].

Usually, the SmallSat mission payload involves the communications equipment with the antennas and repeater comprising the transponders. The rest of the satellite is called the satellite bus. The bus transports the communications payload around in its orbit, offers electrical power, maintains attitude, points the payload, keeps the satellite on station, and makes orbit variations. The thermal control subsystem keeps the electronics and other components inside a safe temperature range over the life of the SmallSat. The SmallSat structure grips all together and defends the components throughout launch and after deployment on orbit. An on-board beacon transmits signals to aground tracking, telemetry, and command (TT&C) station (Fig. 1) [4].

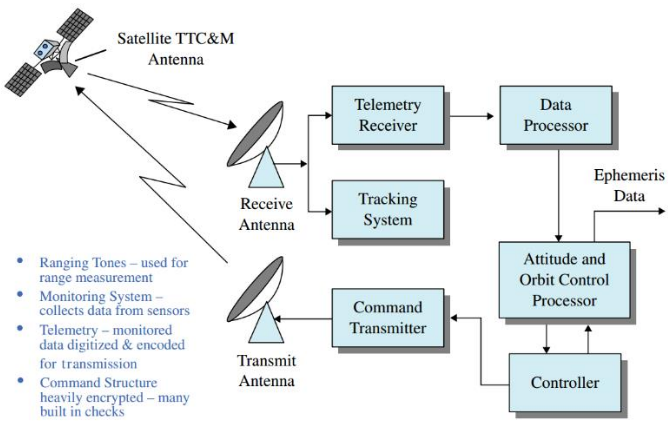


Fig. 1. SmallSat Tracking, telemetry, command, and monitoring (TTC&M) [4]

In these circumstances antenna systems have greatly enlarged in complexity. Space segment antennas are: 1) deliver high gain capabilities to comfort user requirements; 2) can spatially separate different portions of the field of view, permitting the existing bands to bare used; and 3) can ease interference. Of all the know-hows used in the space segment, antenna systems are the most varied as an outcome of different operating frequencies and system requirements [5].

So, the goals of this research are next:

1. Review SmallSat Earth observation systems and study their main characteristics.
2. Estimate the on-board antennas design background and provide some analytical investigations.
3. Design a passband quadrature phase shift keying transmitter and receiver in Simulink.
4. Obtain bit error rate curves by using a Simulink design in conjunction with an m-file.
5. Generate an offset quadrature phase shift keying wave form and investigate its characteristics.
6. Observe the diagrams, constellation, and the signal trajectories of quadrature phase shift keying.

SmallSat Earth Observation System. A planned charge chain for EO organisations, on basis of structural optimization technique, straight from the EO earner and to the end users as achievement that information is shown in Fig. 2. The main ideas useful to the value chain are the EO projects analysed, cost estimating methods and financing options [1].

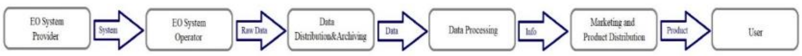


Fig. 2. EO value chain [1]

The system design concepts are likened with launch vehicle constraints for the space segment and compared with production costs for the user segment [5]. In these circumstances, antenna technology to provision system description and development plays a main role in planning practical system designs. This antenna technology base has importantly contributed to existing system aptitudes. At the low earth orbit (LEO), the earth-satellite links are much shorter, leading to minor pathlosses, which results in lower power, smaller antenna systems. In this case propagation delay is also less because of shorter path distances.

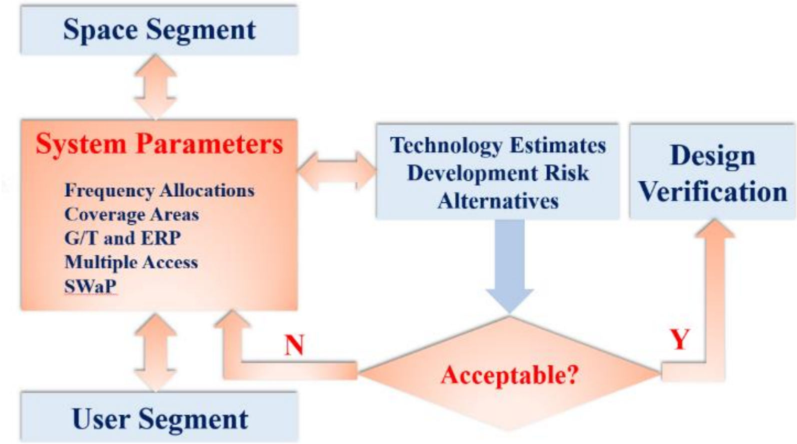


Fig. 3. The system design process

Fig. 4 shows the on-board processing transponder, also called a regenerative repeater, or “smart satellite.” The uplink signal at f_{up} is demodulated to baseband, $f_{baseband}$.

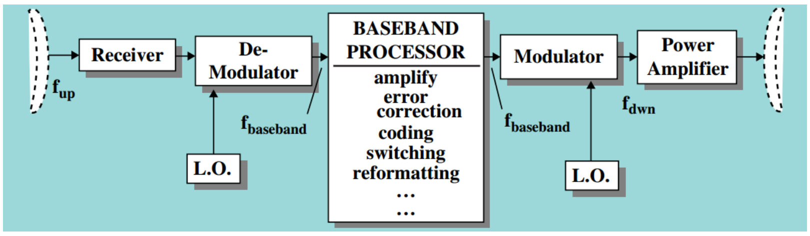


Fig. 4. On-board processing transponder [4]

The most frequently used antennas on LEO spacecraft are [11]: 1) N-Turn Helix; 2) 1/2 wave Quadrifilar Helix; 3) full wave Quadrifilar Helix; 4) patch; 5) horn (at microwaves); 6) dish (mostly at microwaves).

The half wave quadrifilar antenna has a 1 GHz bandwidth and a peak antenna gain of about 4 dB. Usually, it provides Earth Coverage from LEO. A full wave quadrifilar has improved gain, but it is used mainly because its antenna pattern peaks at 60° (30° down from the spacecraft horizontal). This is the angle of the horizon from about 600 km. Moreover, the antenna gain is compact at nadir, better matching the slant range path loss [6]. The link margin versus elevation angle is shown in Fig. 5.

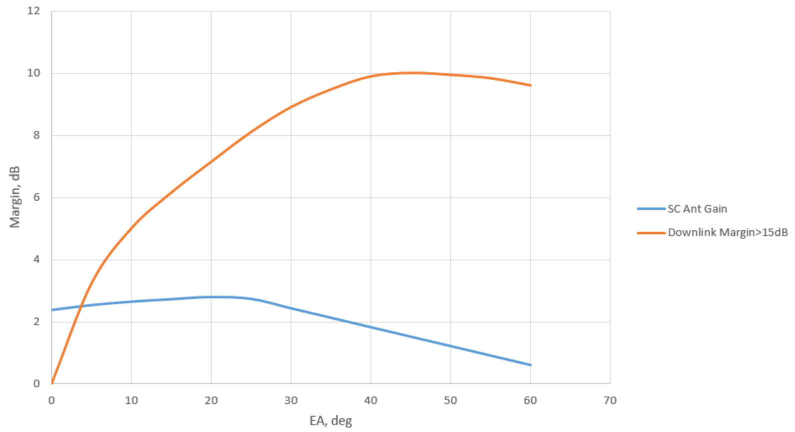


Fig. 5. Improving the low lavation link margin through use of full wave quadrifilar antenna (Downlink from 200 km LEO, 10 km SC FSK Xmitter at 2.25 GHz, 2.4 m ground antenna (32 dB gain), 3 dB NF 3.9 GHz and antenna Beam width)

Communications from and to a SmallSat use digital data and one of some modulation types. The most often used modulation types and their general characteristics are given in Table 1 [6].

Table 1. Modulation types and their characteristics used in SmallSats [6]

Modulation Type	**Description**	**Comments**
FSK (Incoherent)	Carrier frequency is toggled between 2 values	Heritage modulation, simple, Doppler insensitive, Modulation Index is 0.3
FSK (coherent)	Carrier frequency is changed with continuous phase shift	Requires less S/N for the same BER
GMSK (Gaussian Minimum Shift Keying)	Binary data is first Gaussian rounded before Applying to FSK	Similar to FSK except the Spectrum is more contained
PSK (Phase Shift Keying)	Carrier phase is changed ±90°	Improved BER performance
BPSK (Bi-Phase Shift Keying)	Carrier is modulated by a signal that is +1 or -1	Efficient but Doppler sensitive
QPSK (Quadrature Phase Shift Keying)	Carrier phase is changed to one of four phases	Improved spectral efficiency. Two bits per step. Phase changes occur for every two bits of information
O-QPSK (Offset QPSK)	One of the two phase changes are delayed by one bit	Improved spectral efficiency. Phase changes occur every bit

From Ref. [6] it is seen that presenting FEC has an important influence on reducing the Eb/No required for a given BER.

This is seen from the summary given in Table 2, showing the Eb/No required for biological equivalent of radiation (BER) ranging from 10^{-5} to 10^{-7}.

Table 2. Eb/No requirements for different modulations and BER

Modulation	**Approximate Eb/No(dB) required for**		
	BER=10^{-5}	**BER=10^{-6}**	**BER=10^{-7}**
FSK (incoherent)	13.2	14.2	14.8
BPSK or QPSK	9.8	10.6	11.7
FSK with FEC*	7.8	9.0	9.6
QPSK with FEC*	4.5	5.6	5.9
* FEC is Viterbi Rate 1/2 with k=7			

Results and Discussion. On-board satellites antenna from the point of view of the requirements that they impose systems of the apparatus can be divided into three classes: 1) omnidirectional; 2) unidirectional; 3) highly directional. Omnidirectional antennas are in the directional diagram of which there is no sufficiently pronounced maximum, and also there are no long dips in angle and depth. The directional coefficient of such antennas is in the range from 0.01 to 0.1. Since the exact calculation of the radiation pattern of such antennas is a rather time-consuming process, the installation location and its design are finally checked on a special SmallSat antenna layout.

Unidirectional antennas have a radiation pattern enclosed only in part of the space. As a rule, their diagrams are less indented. Unidirectional antennas require SmallSat to be oriented in space with at least one axis, since outside the working angles the directional coefficient is close to zero (Fig. 6).

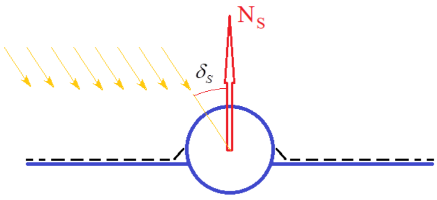


Fig. 6. Scheme fixed stationary planar antenna with solar panels

Such antennas are used on the orbital compartments of interplanetary automatic vehicles with a flat stationary solar battery, the normal of which N_S (Fig. 7) throughout the mission, is continuously oriented to the sun with some maximum error δ_S.

This is typical because during the reception of signals, both the working angles of the antennas and the distance from the ground to the satellite change.

Pulse Shaping and Instantaneous Signal Amplitude. The main parameters of the modulator are set as follows: 1) QPSK symbol duration $t_s = 1$ sec; 2) carrier frequency $f_c = \frac{\omega_c}{2\pi} = 30$ Hz; 3) bit energy $E_b = 16$; 4) the number of samples per symbol in passband QPSK waveform are equal to 256.

Based on calculations we can design an mdl/slx-file for the QPSK transmitter (Fig. 8). After identified that blocks whose outputs corresponds to $b_1, b_Q, \psi_1(t), \psi_2(t), x(t), y(t)$ and $s_i(t)$in equations (1) and (2) respectively, the setting parameters represented in Table 3.

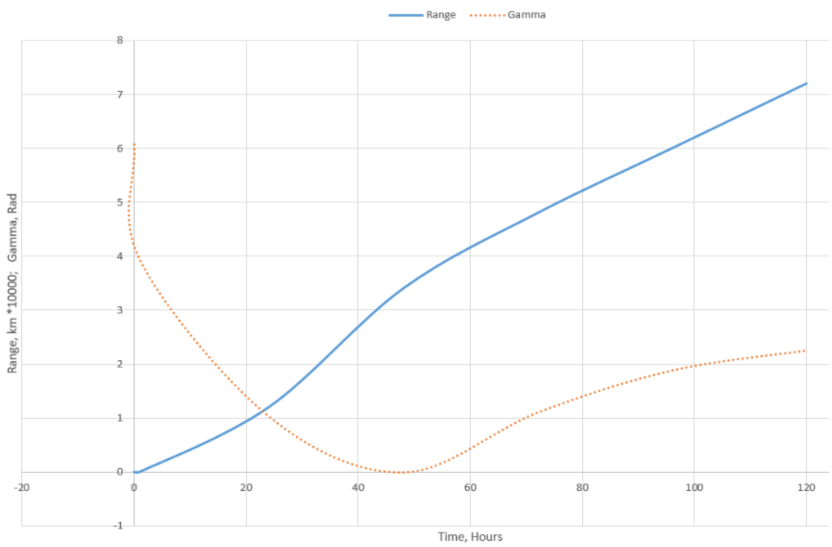


Fig. 7. Dependence of range L and angle γ of the Sun-SmallSat-Earth

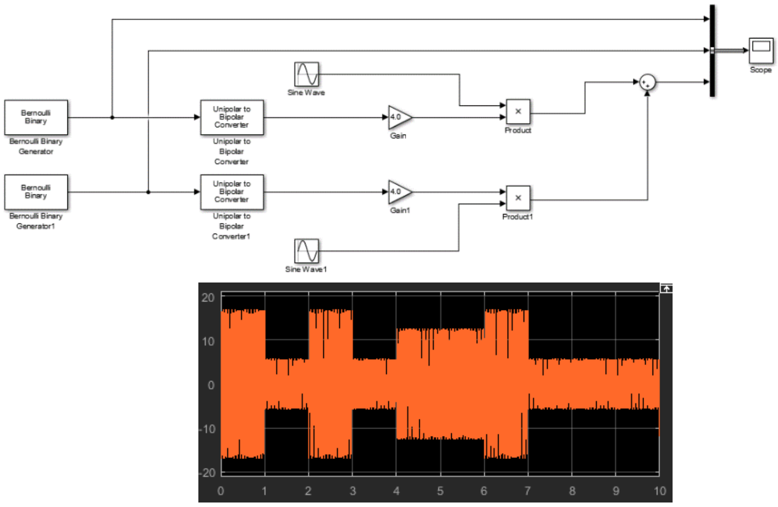


Fig. 8. QPSK transmitter simulation

Table 3. Setting Parameter for the QPSK Transmitter

Block	**Parameter setting**	**Reason**
Bernoulli Binary Generator	Sample time=1	QPSK symbol duration T_s=1
Bernoulli Binary Generator1	Output data type=Boolean	To convert into Boolean type
Bernoulli Binary Generator	Initial seed = 1234	
Bernoulli Binary Generator1	Initial seed =Default setting (do not change)	
Unipolar to bipolar convertor		
Unipolar to bipolar Convertor1	M-ary number=2	
Gain, Gain1	Gain=4 Amplitude=sqrt(2)	
Sine wave, Sine wave1	Frequency (rad)=60*pi Sample time=1/256	
Sine wave	phase=pi/2	
Sine wave1	phase=0	

From [7] we can express $s_i(t)$ in next equation as:

$$s_i(t) = x(t) + y(t), \tag{1}$$

$$\text{where } x(t) = \begin{cases} \sqrt{E_b}\psi_i, & if\ b_1 = 1, \\ -\sqrt{E_b}\psi_i, & if\ b_1 = 0. \end{cases} \tag{2}$$

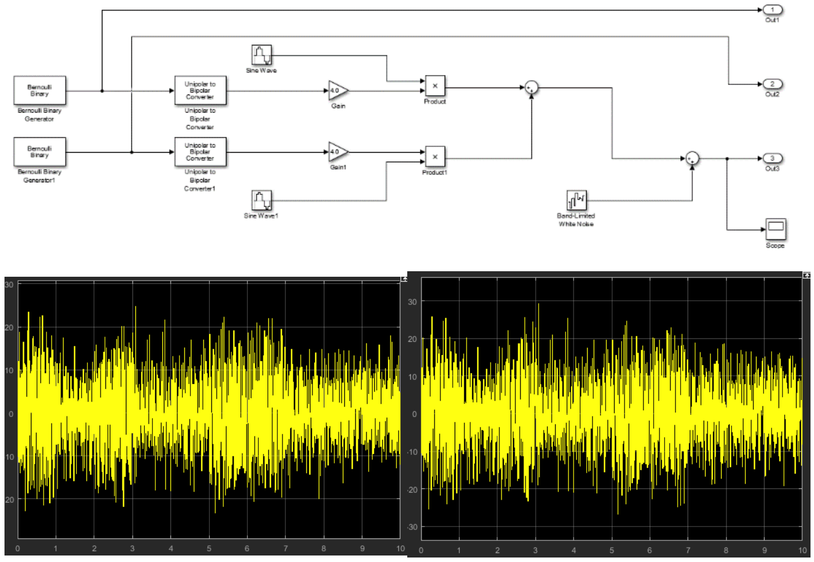


Fig. 9. Modelling of the received QPSK signal over an AWGN channel ($E_b/N_0 = 13$ and =30 dB)

According to equation (2), $x(t)$ and $y(t)$ can be viewed as follows:

- $x(t)$ is an antipodal binary phase shift keying signal, which transmits the bit b_1 using the basis function $\psi_1(t)$ - the dimension along the x axis;
- $y(t)$ is an antipodal binary phase shift keying signal, which transmits the bit b_Q using the basis function $\psi_2(t)$ - the dimension along the y axis.

Therefore, the QPSK signals $i(t)$ can be viewed as the sum of two independent binary phase shift keying signals, one carrying b_1 and one carrying b_Q.

Phase Error. In this step, let us open the subsystem QPSK TX and insert a Bernoulli Noise Generator block, connected as shown in Fig. 9, and set its parameter Sample time to 1/256.

The following procedure allow verifying the setting parameter Variance of the Bernoulli Noise Generator block, assuming $E_b/N_0 = 13$ dB in proposed experiment: 1) convert E_b/N_0 [dB] into the linear scale value; 2) find N_0 from E_b/N_0 and the current E_b set in the mdl/slx file; 3) substitute N_0 into the noise variance setting expression, that is, the variance of noise sample=$N_0/(2t_{step})$. The parameter $2t_{step}$ denotes the sample interval of the sampled waveforms. Thus, it is set to be equal to 1/256, as was mentioned earlier.

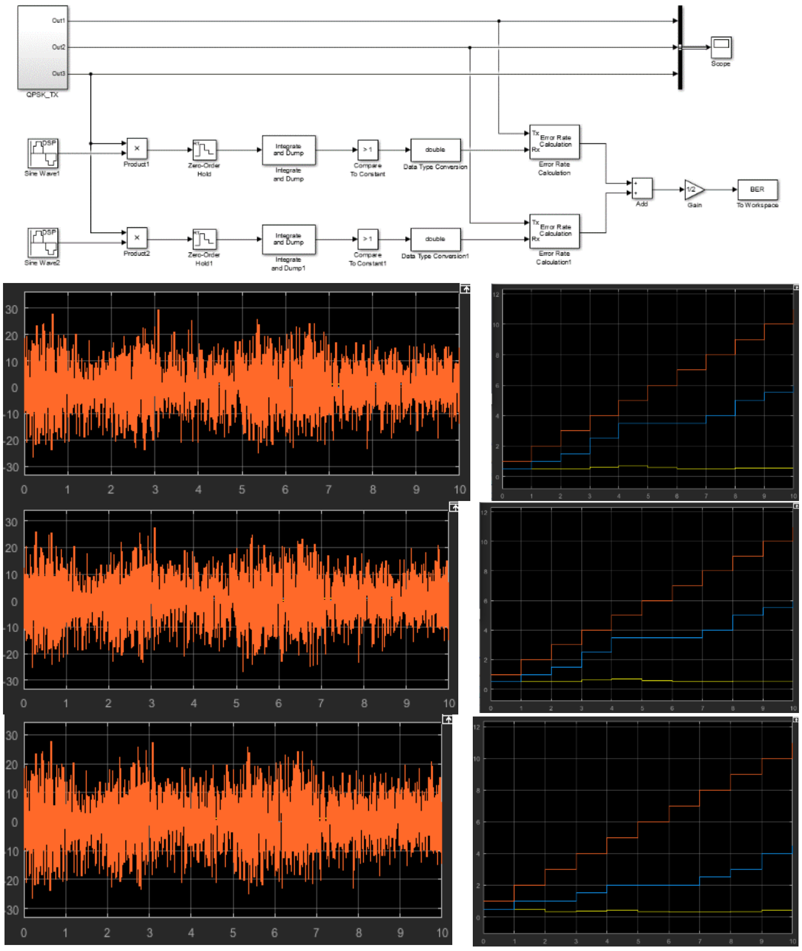


Fig. 10. Completed mdl/slx file for QPSK BER simulation

After that capture the display window of Constellation Diagram and prior to capture, select the automatic axis scaling option in the display window menu. In this part, we observed the constellation diagram when there is a phase error. For this purpose, set the parameter Variance of the Band-Limited White Noise block to 0 to simulate the noiseless case. Then, open the parameter setting windows of Sine Wave and SineWave1and add pi/4 to the current setting of their parameter Phase (rad). After that let us run the simulation and capture the display window of Constellation Diagram (Fig. 10). At the end was repeated for phase errors of 150, 300, and 600, and justified the results generated in the simulation (Fig. 10).

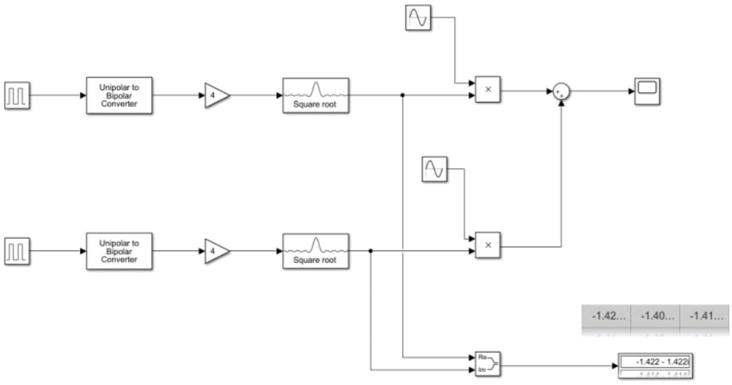
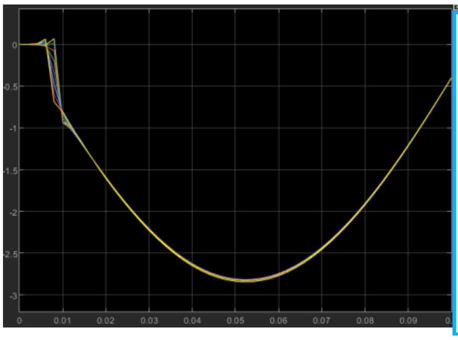
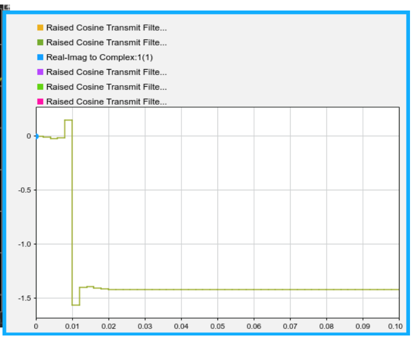


Fig. 11. Pulse-shaped QPSK system with signal trajectory





Pulse Shaping and Instantaneous Signal Amplitude. Here we investigate the pulse shape of the baseband signals in the current design. It connected the outputs of Gain andGain1 to the Scope and ran the simulation for 10 seconds. Then captured the display window of Scope.

The rectangular pulse in the time domain corresponds to a sinc function in the frequency domain. Thus, pulse-shaping using a rectangular pulse is bandwidth inefficient. Let us perform the raised cosine pulse shaping. To this end, was inserted a Raised cosine Transmit Filter block between the Gain and Product blocks and another one between the Gain1 and Product1 blocks. Later was set the MathWorks simulation parameters as follows (Fig. 11): Roll-off factor: 0.75; Output samples per symbol: 256; Input processing: Element as channels (sample-based).

Conclusion. This paper proposes a communication system for SmallSat Earth observation preliminary design technique. Earth Observation data are useful tools for managing and improving various aspects of regional and national resources. As small satellites are amongst the cheapest systems to develop and launch, this will often be the preferred option of small countries and regions, and the selection tool is thus likely to bring benefits to the small satellite industry. In these circumstances may find EO as a powerful tool that has great potential for assisting with environmental management and other important applications for small countries and regions.

System design processes have been estimated for low Earth orbit SmallSat and most frequently used space segment antennas were studied.

During analysis of the SmallSat Earth observation system value chain, on-board processing transponder functions have been estimated and proposed. As a result, the system design process for unidirectional antennas was built. MathWorks modelling allows finding characteristics of quadrature phase shift keying signals. Pulse shaping and instantaneous signal amplitude have been modelling and innovative design parameters were found.

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