[EN-0015] Global surveillance system based on 1090ES ADS-B and satellite-transmitters

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Abstract: Application of ADS-B solution significantly decreases a cost of surveillance system in comparison with the traditional radio location means. An ADS-B technology with 1090ES frequency is developed and widely exploited. Currently, the most of aircrafts are equipped with 1090ES ADS-B systems of sufficient power enabling signal transmitting on the large distances. If a spacecraft can receive the aircraft signals and then transmission them to ATM complex, this stipulates for a global aviation surveillance system.

There are several approaches to satellite surveillance system development, i.e. low-orbit constellation based, high-orbit constellation based and combination of the above-mentioned constellations with geostationary satellites.

One of the possible method of this idea realization is modernization of Gonets Space communication system developed by the Russian space agency. Gonets system consists of 24 spacecrafts flying on 1500 km orbit and providing with a global coverage and message transmitting. It is necessary to equip Gonets spacecraft with a system receiving ADS-B messages in 1090 MHz range for further their transmission via existing data links.

Keywords: ATM, ADS-B, satellite, orbit, HEO/GEO, communication, data link

1. INTRODUCTION

All over the world pays special attention to the questions of safety and effective application of aviation transport. And this task is comprehensive one. It is of high importance to design safety aviation units, to find the right ways to explore them, and to organize effective air route network, to equip it with various communication, navigation, surveillance means as well.

Development of the new surveillance technologies along with modernization of navigation and communication means is the base of CNS/ATM concept of ATM system development realized by ICAO.

Traditionally, the surveillance systems are based on primary and secondary radio locators.

Radars application is hardly possible to be overestimated. Primary radar is the only one to provide independent air traffic control information. Unfortunately, radar use is very expensive from installation and exploitation point of view. Besides, their coverage area does not allow to control flights at small altitudes and oceanic spaces.

That's why it is proposed to develop the automatic dependent surveillance technology at the frames of CNS/ATM concept. ADS concept is the further development of secondary location, i.e. an aircraft calculates its location in a space, direction and flight velocity using the special on-board systems, generates a message which is broadcasted.

Global surveillance system. Operational concept

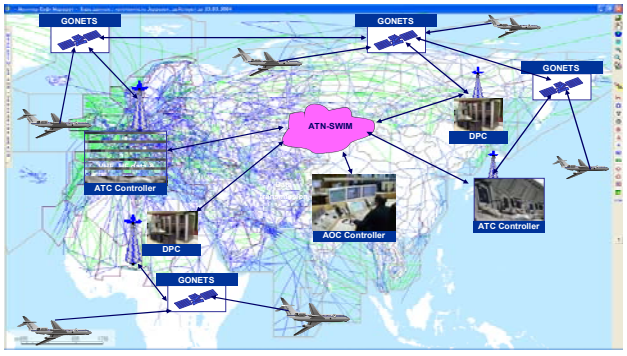

Fig. 1 Global surveillance system

2. AUTOMATED DEPOENDANCE SURVEIILANCE

Two types of ADS messages transmitting are the contractual and broadcasting. Contract type of ADS messages transmission is possible when there is a data link between an aircraft and a user (control center). Broadcasting regime is provided when the messages go to the air with the defined frequency. Center of ADS messages receipt is equipped with simple and cheap transmitter.

Presently, there are three different standards of ADS signal transmission non-compatible with each other: 1090ES, VDL4 и UAT. All of them are approved by ICAO.

The most widely-spread ADS-B transmitters are1090ES system responders. All the modern aircraft like Boeing, Airbus are equipped with them and ADS-B in 1090ES is obligatory for upper air space in Europe starting from this year. The system is also compulsory for all the aircraft in Australia including general aviation flying in low flight level (lower than 5400 m). Please take into account that procurement and installation of the systems is funded by the states.

Wide application of this standard is stipulated by economy efficiency factors. A secondary radio locator responder which is obligatory installed at the most civil aircraft is used for realization of this regime. Hence the task can be solved relatively minor modifications in the main software. The leading manufacturers of on-board equipment propose various means for ADS-B in 1090ES signals receipt for both on-ground control centers and for aircraft. Installation equipment realizing ADS-in regime into on-board complex enables the pilot to receive information about nearby aircraft movements.

Digital data link VDL mode 4 uses the standard aviation frequencies from a frequency range 108-118 MHz while UAT uses a frequency of 978 MHz. Both standards have their advantages and disadvantages which are not sufficient from a user's point of view. Please refer to attachment to find a all the technologies' comparison made by IATA experts. Any way both VDL regime and UAT require not only the whole earth coverage by a network of receiving radio stations but also extra equipping of the aircraft. Therefore, these technologies are limited and not supported by the most of the states due to significant expenses for these two technologies deployment (VDL mode 4 is deployed in Sweden, there are experimental areas in Russia; while UAT is applied in USA low flight levels.

Summing up, presently, the most of aircraft in operation and new aircraft are equipped with ADS-B in 1090ES. These signals are radiated to both low and upper semispheres. Performed research evidences a possibility of signal propagation on significant distances in the condition the current aircraft transmitters' power.

The ground and on-board receivers with 300-500 km operation radius are used for capture of these signals. However, installation of these on-board and ground stations in hardly reached or remote areas or oceanic spaces is a problem.

A possible solution can be application of the satellite retransmitters receiving ADS-B in 1090ES signals transforming them in a data flow in order to pass to the ground control stations via traditional satellite channels and wire communication lines. In this situation the entire aircraft fleet does not need any modification. Besides, there is no need to modify the most of automated air flow control systems since the satellite information is packed in accordance with surveillance data exchange standard, i.e. ASTERIX.

3. GONETS and ARCTICA

There are several approaches to development of a space surveillance system: based on low orbit constellation, based on high-orbit constellation, based on combination of the two constellations and geostationary satellites.

Roscosmos performs activities on deployment of several space systems which can enable ADS-B messages processing like Gonets and Arctica.

The space federal target programme stipulated for deployment of Gonets low-orbit satellite constellation (22 satellites) in the coming five years. This constellation will provide continuous global coverage of earth surface aiming at organization of a mobile documentary communication among the mobile objects (analog of IRIDIUM constellation). Modernization of satellite on-board equipment (including ATM/ATC tasks) is planned at the frames of above-mentioned federal target programme.

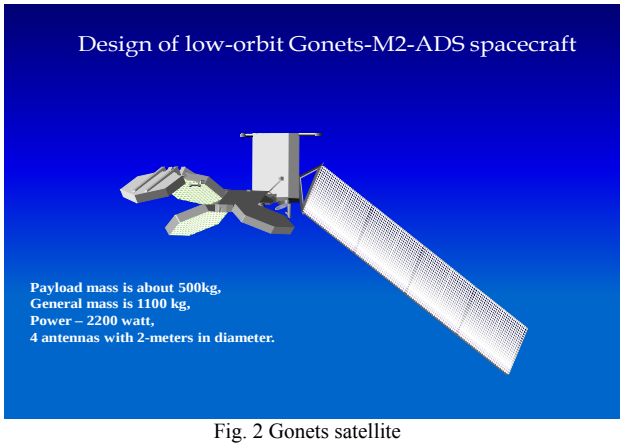

Fig. 2 Gonets satellite

Arctica project is aimed at deployment of satellite constellation at high orbits also covering the global surface. ATM part is involved to the project as well.

Technical exploration of the project performed by Russian and foreign experts has proved feasibility thereof. Taking global approach to system application into account, Roscosmos considers a possibility to establish an

international cooperation in this direction. ESA expressed its support to the project and actively participates in the process of organization of the joint working group dedicated to standards generation and equipment development.

As it was mentioned before, Roscosmos develops the components of the spacecrafts together with ground equipment for satellite signals receipt in the frames of GONETS and ARCTICA projects. In order to realize the projects, ATM enterprises then need to create several ground receiving centers with the functions of processing and transmitting the coming information to the end users via existing or developing communication network of civil aviation

Application of satellite Gonets constellation for aeronautical purposes, i.e in air traffic management and aircraft surveillance, enables the following:

- significant increase of flight safety level all over the world;
- increase of air navigation accuracy and flight management reliability;
- distribution of the leading high-end solutions world-wide;
- high level of information safety.

4. PROPOSALS ON DEVELOPMENT OF SATELLITE SEGMENT OF ATM SYSTEM ON HEO AND GEO ORBITS

Presently, "Satellite Information Systems" studies an opportunity to develop the dedicated spacecraft insuring aircraft ADS-B signals receipt and transmission to control centers via gateway stations.

Transmitters of ATM systems' ADS-B messages shall ensure the following:

- receipt of aircraft ADS-B signals on a frequency of 1090 MHz;
- transmission of aircraft ADS-B messages in 1090 MHz frequency to Ku range (e.g. 17 GHz).

The following coordinates of spacecraft location used for Eurasia, Africa and Indian sea are taken for numeric calculations: 45 degrees of eastern longitude (e.l.) and 95 degrees e.l.

However, the most preferable points can be 15 degrees of w.l. and 120 degrees of e.l. since these areas are characterized by flight routes over Atlantic, Indian oceans, a part of Pacific oceans, Eurasia, Africa and Australia.

Information support of the flight over the North Pole can be done at account of "Molniya" ("M") and "Tundra" ("T") satellites types application.

Nominal values of the satellites are given in the table 1 below.

Table 1 Nominal values of the satellites

Parameter	Orbit type	
	«M»	«T»
Revolution period, h	about 12	about 24
Orbit inclination, degree	63,4	63,4
Argument of perigee latitude, degree	270,0	270,0
Perigee altitude, km	1000	24585
Apogee altitude, km	39369	47001

Hence, ADS-B signals retransmission system can be formed out of 2-4 satellites on geostationary orbit (GEO) and of 3-6 satellites on high elliptical orbit (HEO). Please refer to picture 3 below to see the system structure.

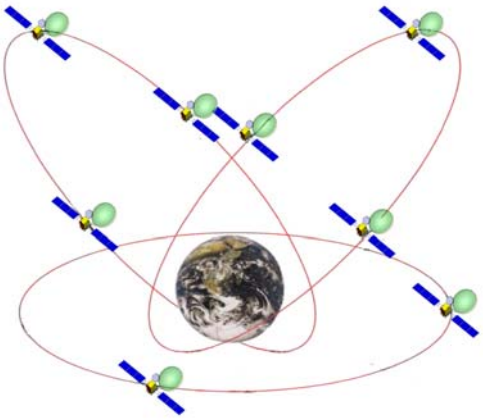

Fig. 3: Satellite constellation layout on GEO and HEO

A hybrid mirror antenna generating 61 beams with the following parameters is needed in order to cover the required operation zone:

- reflector diameter is 7 m;
- feeder sizes are 2790X2460X450 mm;
- 61-element flat phase-locked array out of conic spiral emitters;
- Spiral emitter is used as a single element of phase-locked array;
- Each spiral is 100 mm in diameter at bottom part and 60 mm at top while height is 200 mm;
- Polarization is rounded right one;
- Amplification coefficient in operation zone in a level of minus 3 db is not less than 27,8 dB;
- Width of a beam directional diagram is 2,4ºx2,4º

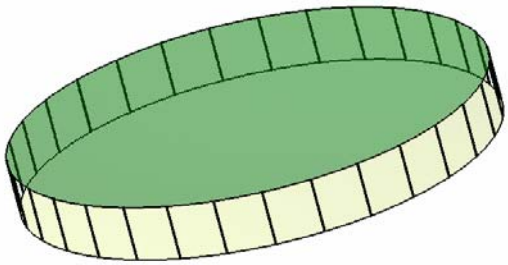

Fig. 4. 3D model of 61-beam 7m-diameter hybrid mirror antenna

Figure 5 represents the operational zone of hybrid mirror antenna beams at 1090 MHz frequency.

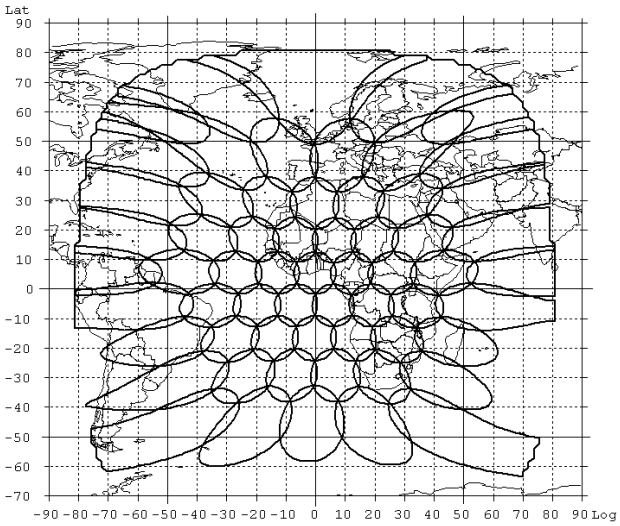

Fig.5. Coverage of operation zone by Ø7 m antenna beams directional patterns.

Frequency is 1090 MHz. Amplification coefficient in maximum beams directional patters is from 33.3 dB (central) up to 30.8 db (peripheral). Directional patterns layouts of all the beams are minus 3.0 dB.

Amplifier coefficient in operational zone is not less than 27.8 db in the area of peripheral beams crossing.

A hybrid mirror antenna generating 16 beams with the following parameters s is needed in order to cover the required operation zone:

- reflector diameter is 0.22 m;
- feeder sizes are 94X1130X100 mm;
- 16-element phase-locked array out of smooth-wall conical horns;
- Spiral emitter is used as a single element of phase-locked array;
- Polarization is rounded right one;
- Amplification coefficient in operation zone in a level of minus 3 db is not less than 22.3 dB;
- Width of a beam directional diagram is 5ºx5º

3D model of 16-beam hybrid mirror antenna is given below in Picture 6.

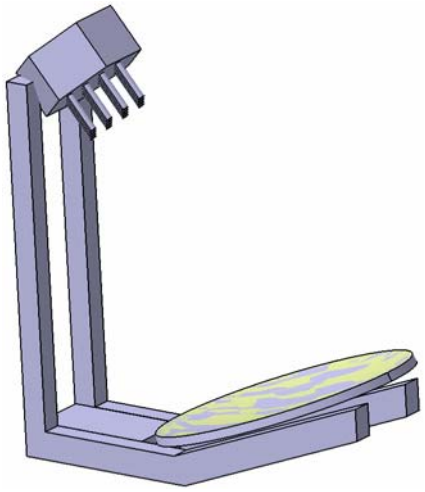

Fig. 6. 3D model of 16-beam 0.22m-diameter hybrid mirror antenna

Coverage of operation zones by hybrid mirror antenna beams with 17 GHz frequency in location of 45 e.l. and 95 e.l. is given on pictures 7 and 8.

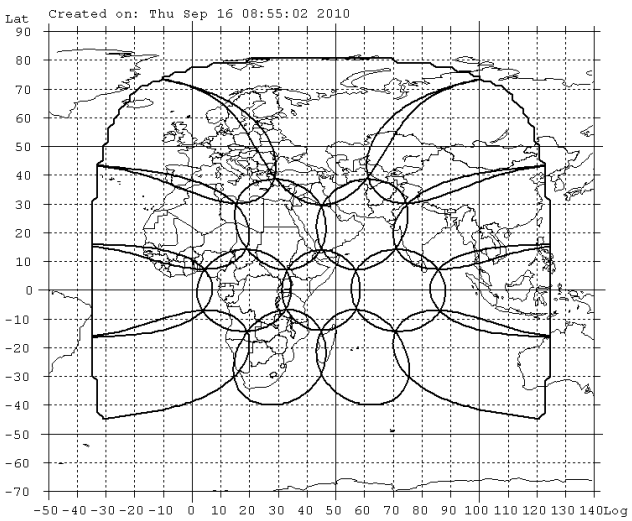

Fig. 7 – Coverage of operational zone by directional patterns of Ø220 mm multi-beam feeder antenna

Spacecraft location at GEO is 45º eastern longitude.

Frequency is 17 GHz. Amplification coefficient in maximum beams directional patters is 25.3 dB (peripheral). Directional patterns layouts of all the beams are minus 3.0 dB.

Amplifier coefficient in operational zone is not less than 22.3 db in the area of peripheral beams crossing.

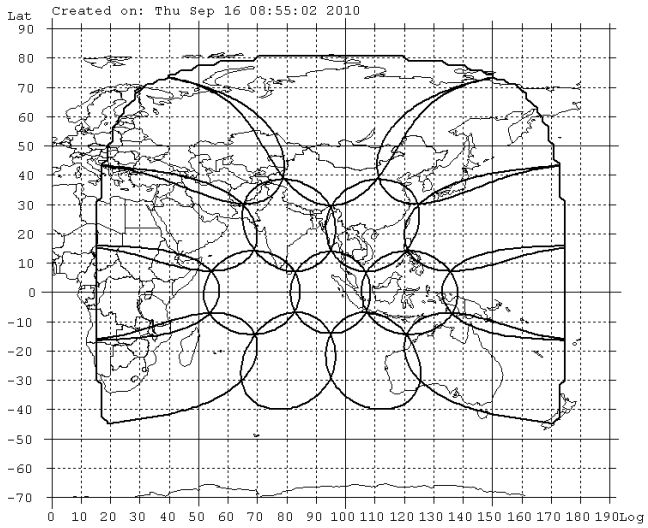

Fig. 8 – Coverage of operational zone by directional patterns of Ø220 mm multi-beam feeder antenna

Spacecraft location at GEO is 95º eastern longitude.

Frequency is 17 GHz. Amplification coefficient in maximum beams directional patters is from 26.4 dB (central) upto 25.3 db (peripheral). Directional patterns layouts of all the beams are minus 3.4 dB.

Amplifier coefficient in operational zone is not less than 22.3 db in the area of peripheral beams crossing.

5. PROPOSALS ON SATELLITE PAYLOAD

The main technical characteristics of on-board radio technical complex for a spacecraft with ATM ADS-B system are given in the table2:

Basing on requirements analysis, a dedicated structural architecture of a spacecraft payload module was generated (please refer to picture 9)

Payload module consists on the following functionally interacting systems and modules:

- On-board receiving and transmitting complexes;
- On-board computational complex including communication matrix;
- Antenna-feeder systems;
- Technological mechanical devices

Each receiving channels out of 61 and each transmitting channel out of 16 has a back up channel.

Transmitting data links contain frequency L/IF/L converter and a narrow band filter at intermediate frequency enabling the necessary selectivity.

Computer complex includes communication matrix and it transfers receiving beams to corresponding transmitting beams.

Table 2. Main technical characteristics of on-board radio technical complex

Parameters	Value
Frequency range	L – up Ku -down
Polarization in upstream curve	rounded
Polarization in downstream curve	rounded
Bandwidth of receivers, kHz	500
Number of served operational zones	61
Width of directional pattern of a single receiving beams, degrees	2,4ºx2,4º.
Number of served transmitted operational zones	16
Width of directional pattern of a single transmitting beams, degrees.	5ºx5º
Effective Isotropically Radiated Power, dbwatt Maximum In operational zone	 46,5 43,1
Figure of merit, db/k Maximum In operational zone	 1,2 -2,2
Power of a single beam transmitter, watt	120
Total radiated power, watt	1920
Total power consumption of on-board radio complex, watt	4500
Active operational life	15 years

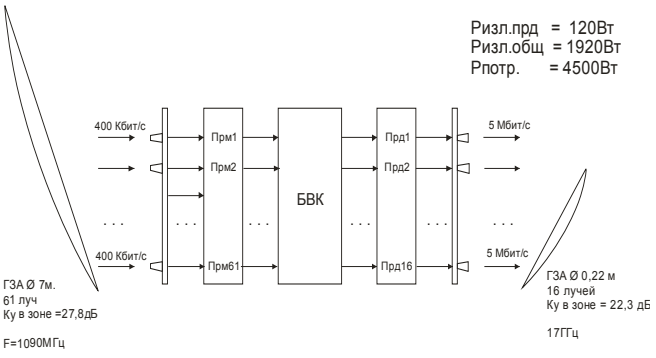

Fig. 9 – Detailed layout of payload module

Low-noise amplifiers and L/IF/L transducers are used in receiving data links.

The companies like NEC, Thales Alenia Space Italia, Thales Alenia Space, MDA, EADS SAS can possibly be involved as designers and manufacturers of on-board retransmitting complex.

There are several platforms option designed by "Reshetnev Information Satellite Systems" company which fits ATM ADS-B purpose.

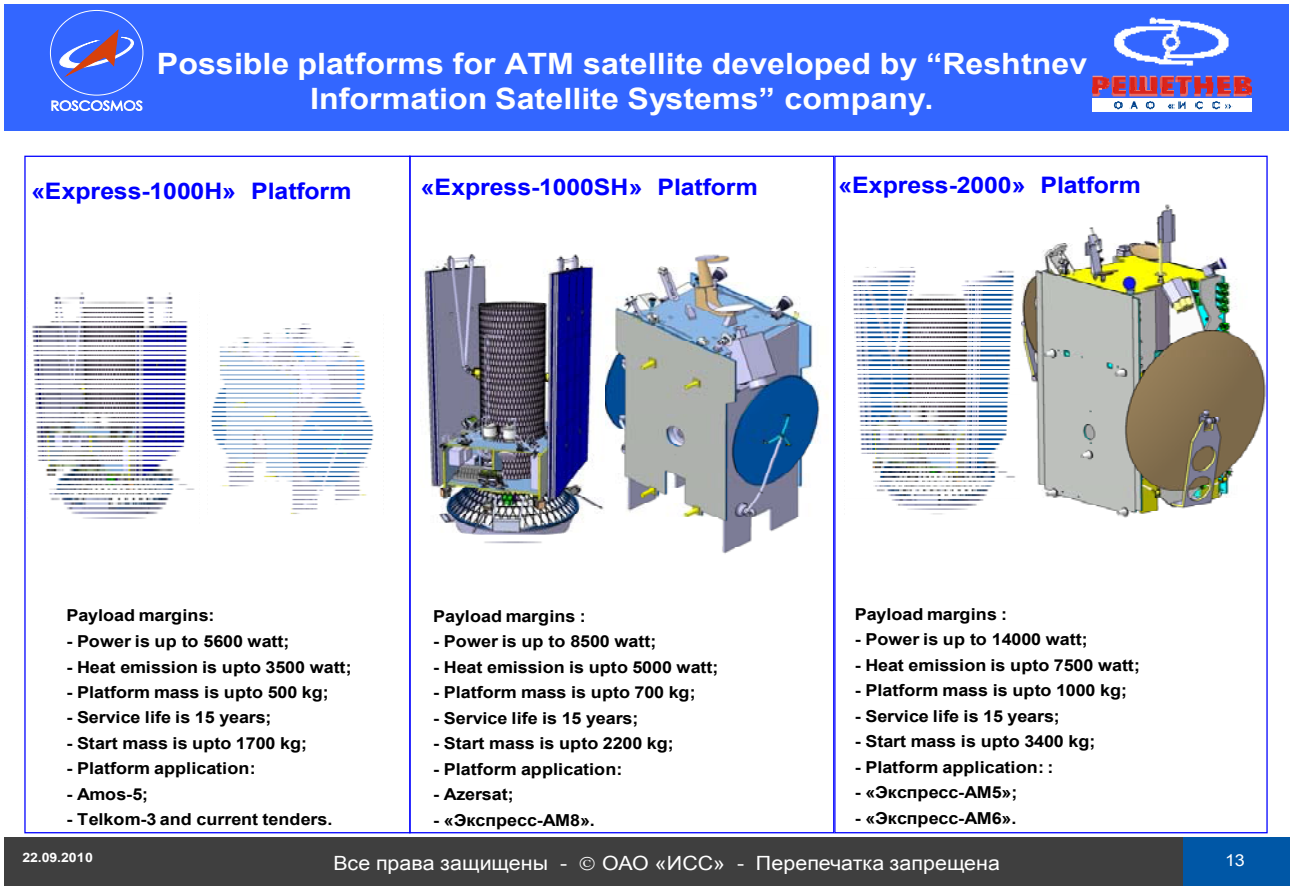

Fig. 10. Platforms which can be used for ATM purposes

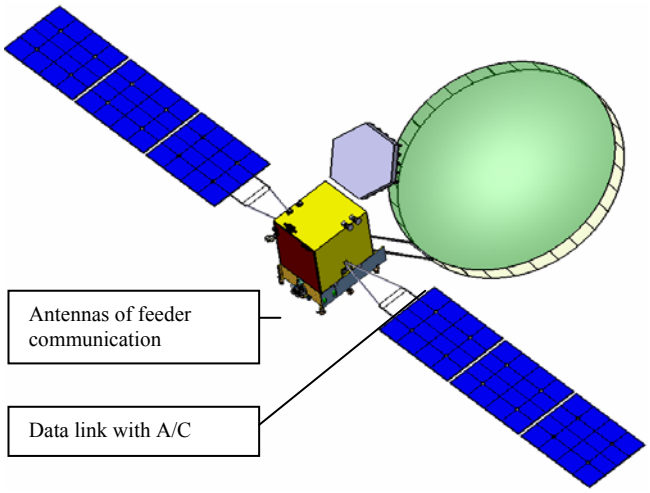

Fig. 11. 3D model of a satellite with ATM ADS-B module

The most optimal platform which is a base for a series of satellites developed by "Reshetnev Information Satellite Systems" company is Express-1000H.

Basing on preliminary analysis of the satellite performance fitting ATM needs, a satellite shall have the following characteristics:

- Mass 1700 kg
- Power consumption 6200 watt
- Platform mass 450 kg
- Platform power consumption 4500 watt
- Accuracy of holding at orbit (three axis) 0,1°
- Accuracy of holding at orbit (longitude and latitude) 0,05 °
- Service life 15 years

This satellite can be launched by "Proton-M" spacecraft accelerator "Breeze-M".

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