CONCEPTUAL MODEL OF A NANOSATELLITE WITH LASER BEAM TRANSMISSION AND ITS IMPORTANCE IN RENEWABLE ELECTRICAL POWER HARVESTING

Mehman HESENOV
"Radiotechnics and telecommunication" department in Azerbaijan Technical University
mhasanovnew@gmail.com

Nadir ATAYEV
Engineer in the R&D department at the Space Agency of Azerbaijan (Azercosmos)
nadiratayev@gmail.com

ABSTRACT

The concept of placing huge solar-powered satellite systems (SPS) in space represents one of several new technology options that could provide large-scale, green base power to terrestrial markets. NASA has already launched the multi-megawatt SSP systems and wireless power transmission (WPT) for government missions and commercial markets (in space and on the ground). In the new space approach satellite technology Nanosatellites with benefits such as low price, resource use, and compatibility with COTS, have huge potential to be the next generation of renewable electrical solar power harvesting satellite systems. With that in mind, it is important to conduct research and development processes for achieving high-efficiency satellite systems. As a result, an initial conceptual model of the new generation low earth orbit nanosatellite with solar power harvesting to laser beam conversion and transmission sub-system was developed with an estimated solar radiation harvesting calculus, part selection along with the structural scheme and its working principle have been proposed [3].

Keywords: Solar-powered satellite systems (SPS), Nanosatellite, CubeSat, System.

INTRODUCTION

Huge amounts of solar energy are continuously available in outer space in the form of light and heat. Therefore, the use of satellites aimed primarily at collecting solar energy and transmitting it back to Earth is being considered. No need for expensive storage devices when the sun is not visible. Only a few days on the day of the spring and autumn equinoxes, the satellite will be in the shadow. Unused heat is radiated back into space. Energy can be channeled to where it is needed and there is no need to invest in a grid as big as the grid [1].

Electricity makes up the majority of the energy consumed. On the one hand, the main loss of control occurs during transmission from generating stations to end users. Wire resistance in a power distribution system result in a loss of 26% to 30% of the generated power. So the losses mean that our current power transmission system is between 70% and 74% efficient. On the other hand, generation is predominantly based on fossil fuels, which will not last long (say, by 2050).

The solar energy collector converts solar energy into DC electricity. DC to microwave converter. Large antenna array for transmitting microwave power to the ground. A means of receiving energy from the earth is through microwave antennas. The cosmic part will be in free fall, in a vacuum environment, and will not need to support itself against gravity, other than relatively weak tidal loads. The main advantages of SBSP are that they do not pollute the environment, they 100% replacement of fossil fuels shortly, no power lines, overhead lines, and cables since electricity can be sent to a specific point around the world. No air or water pollution is created during generation Figure 1 [4].

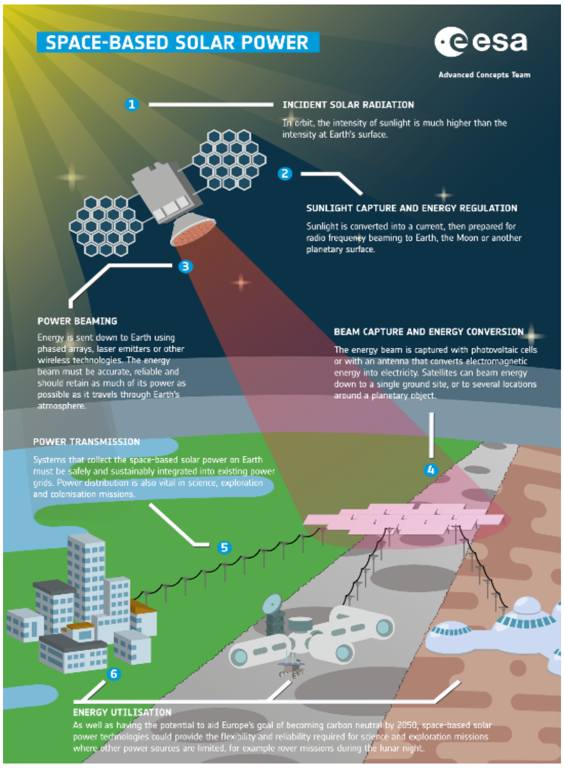

Fig. 1. Illustration of Space-Based Solar Power

Looking at the statistics of satellite platforms launched into orbit over the past decade, we can see that Nano Satellite space systems are in high demand compared to other small and mostly large satellite platforms. In short, Nano Satellite platforms mean any 1 kg to 10 kg and 1U (Unit) 10x10x11cm range satellites. The brightest group member of them is CubeSat satellites. The following are the main factors in the high-trend design of CubeSat platforms [1]:

- Relatively low pricing of CubeSat purchase, transport, and launch;
- The possibility to use the off-the-shelf parts;
- The standard-sized shape, size;
- Low level of difficulty with development based on standardized (U) structure, etc.
- With that regard SPS platforms are much more convenient with using Nanosatellite platform representative CubeSat's based on their pros mentioned earlier.

DATA AND METHODOLOGY

The initially designed CubeSat prototype model has a structure and functionality designed to perform all the necessary tests and procedures.

As shown in Figure 2, the 2U CubeSat platform consists of a series connection of two electromechanical 1U parts. These include 1 - 2U mechanical subsystem with active and passive components, 2 - Active transponder and data exchange/communication subsystem, 3 - Altitude and position determinant subsystem, 4 - Microcontroller-based on-board computer subsystem, 5 - Electricity generation, power supply, and control subsystem, 6, 7 - Two-plane laser beam optical Nano wave transponder, 8, 9 - Two-plane laser beam-controlled 3D optical switch, 10 - Solar panels.

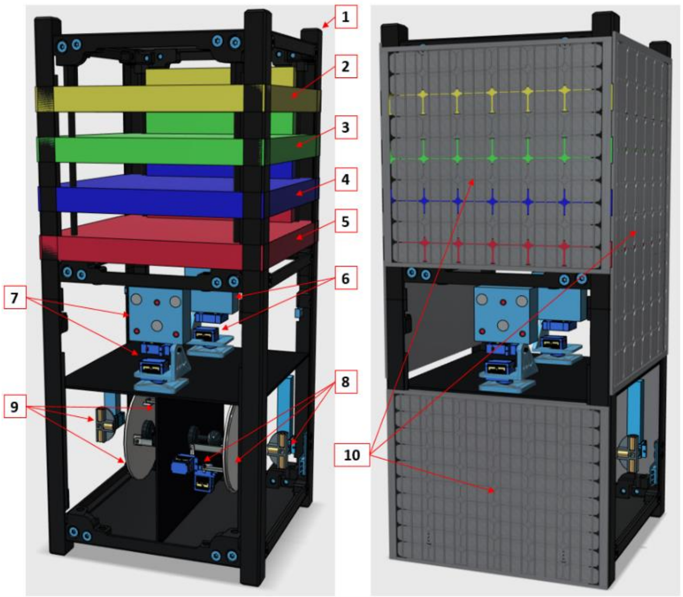

Fig. 2. A simplified view of the prototype model of the 2U CubeSat platform.

Figure 3 shows the functional block diagram of the previously presented subsystems of the 2U CubeSat platform. In short, the circuit is divided into two (1U and 2U) subsystems, and the corresponding operating processes can be described as follows.

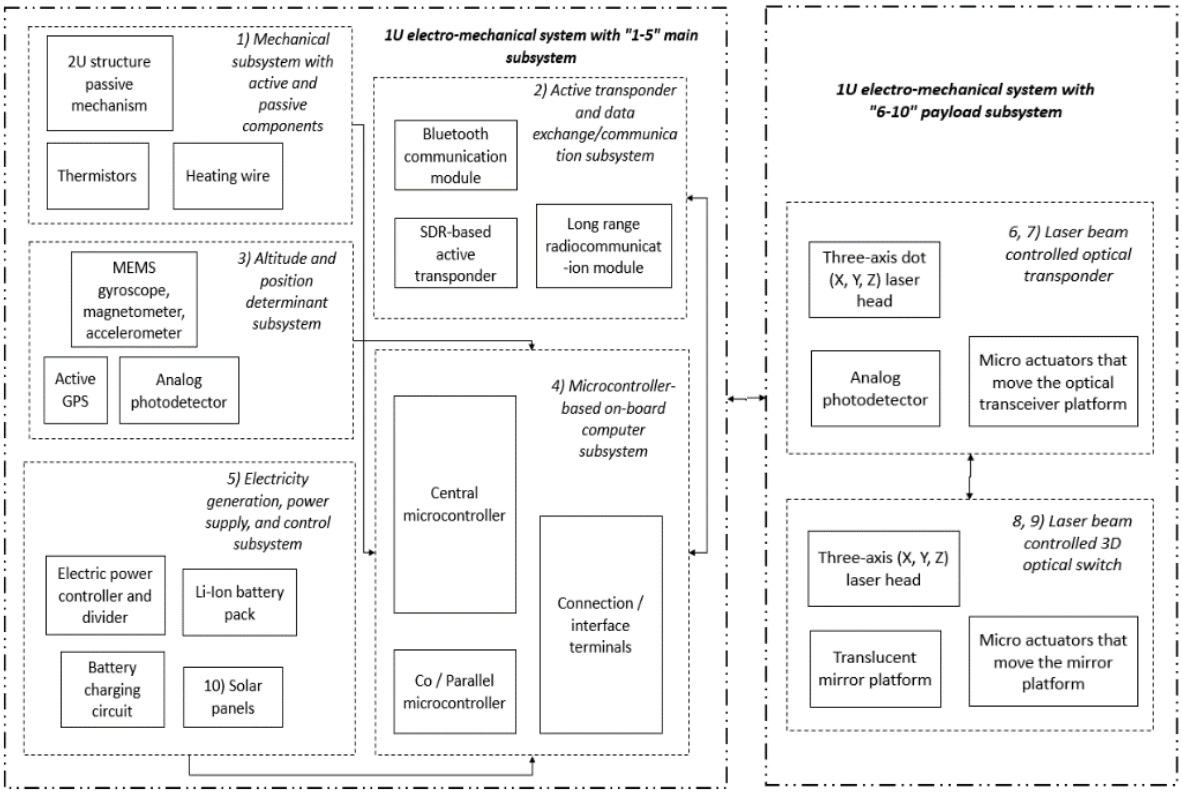

Fig. 3a and 3b. 3a Electro-mechanical structural diagram of the first U part of the 2U CubeSat platform; 3b Figure 4. Electro-mechanical structural diagram of the second U part of the 2U CubeSat platform.

A. *Mechanical subsystem with active and passive components*

By providing a secure system structure within a single body, protecting it from external interference sources, determining the internal thermal performance of the platform with thermistors, and ensuring the stability of operation with heating wires.

B. *Active transponder and data exchange/communication subsystem*

As an important communication subsystem of the CubeSat platform, it is equipped with a long-distance radio communication module and a Bluetooth module to perform necessary tests on the desktop. In addition, it is planned to integrate a Software designed Radio (SDR) device due to the active radio transponder functionality of the platform.

C. *Altitude and position determinant subsystem*

A gyroscope, accelerometer sensors, GPS module, and photo detectors were used to determine the platform's position in a free environment and determine the geographical position coordinates.

D. *Microcontroller-based on-board computer subsystem*

It performs the function of central control with an external connection interface/terminal, with functions such as the reading of data packets provided by all subsystems, and execution of appropriate autonomous and managed commands.

E. *Electricity generation, power supply, and control subsystem*

For autonomous power supply of the whole platform, from the second type of solar-electric converter panels "10) Solar panels" from a set of Li-Ion batteries as a constant power source, from these two-parts power control and distribution, as well as circuit to charge batteries for desktop tests.

F. *Laser beam-controlled optical transponder and Power generation SA design*

Unlike the active radio communication transponder, and in addition, this optical transponder subsystem consists of a three-axis point (X, Y, Z) laser-headed nanovawe transmitter and microwave directional power transmittion antennas. As for the EPS and direct power transmission, the incidence or absence of solar radiation drives the selection criteria for each component, which utilises converted solar energy during the presence of the sun in orbit (light time) and uses batteries to supply power during eclipse periods (shadow time). The amount of power generation depends on the available energy at the observation location. The total solar irradiance at 1AU distance between sun and earth could harvest up to ~1353 W/m^2 of electrical power by solar cells, but this estimation follows geometrically driven with $1/r^2$ so, between sun and moon of 1.003 AU could ideally deliver up to ~1339 W/m^2 power generation [6].

For COTS selection some units are known as:

WSS = 1.1W (2.5V, 0.44A) - power harvesting by one GaInP/GaAs/Ge substrate 30% efficient triple-junction solar cell; kSP = 99% - sun irradiance efficiency between sun and moon; $\eta MPPT$ = 0.85, ηREG = 0.85, ηSW = 0.95, ηBAT = 1 – various power generation and conversion efficiency by each power parts; $Torbit$ = 2.64h.

After determining load power consumption of $Pload$ = 30 W/h (with worst case margin) period durations of the worst case at ~30% of light and shadow times can be determined as [5],

$$T_{shadow} = T_{orbit} * 30\% = 0.79h \tag{1}$$

$$T_{light} = T_{orbit} - T_{shadow} = 1.84 \tag{2}$$

By defining the above orbital change variables, power, capacity, max. Depth of discharge for the battery pack, appropriate solar cell/panel power number, and power can be calculated.

$$P_{SA} = \frac{\frac{1}{T_L * \eta_{MPPT}} * \left(\frac{W_{BAT}}{\eta_{MPPT}} + \frac{P_{Load} * T_L}{\eta_{Reg} * \eta_{Sw}}\right)}{k_{SP}} = 63.07\ W \tag{3}$$

$$W_{BAT} = \frac{P_{Load} * T_{shadow(h)}}{\eta_{REG} * \eta_{SW}} = 29.4\ W \tag{4}$$

$$C_{BAT} = \frac{W_{BAT}}{3.7V} = 7.9\ A/h \tag{5}$$

$$N_{SS} = \frac{P_{SA}}{W_{SS}} = 57.33\ \approx 60\ W \tag{6}$$

Based on the calculated values, EPS parts including solar cells/panels, Li-ion battery pack, and available Control/distribution for Battery & Solar panels can be selected, among the available COTS on the market [2].

Fig. 5. Functional solar cell configuration schematic in array and panel's structure

Besides the above results, there are still some essential points that must be considered for the right choice, which are described below [4, 7]:

Solar cells/panels:

- Selected solar panels for both sides of the solar tracking array consist of 2 panels, each having 15 SC. As illustrated in Fig. 1. an array of "1-2" and "3- 4" panels are connected in series (25V, 1.3A, 32.5 W/h) and "1-2; 3-4" connected parallel (25V, 2.6A, 65 W/h) and B array is the same configured as an array but each array rotates in one axes reverse to each other for maximizing solar power harvesting of the CubeSat during different sun incidence and orbit plane changes around the North Pole of the Moon;
- All 4 sides of the satellite have 8 SC, along with zenith, nadir ones having 4 cells. Here 2 cells of each panel are connected in series (5V, 0.45A, 2.25 W/h), and the left cells are connected in parallel for higher capacity. These cells will be used when their sufficient light radiation is hit on them and will get in series contact with A and B arrays generating 30V, 4.4A, and 132 W/h to meet extra maneuver capability which would have been required by propulsion during orbit maneuvering and decommissioning;
- One of the future improvements for sustaining high efficiency and triple junction GaAs SC used on the panels would be to apply a backside coating layer for use in harsh radiated space solar applications.

Li-ion battery pack:

- Featuring 135 W/h, 28V electrical, and 0.7U, <815g of mechanical parameters within highly effective and radiation tolerant Li-Ion batteries. Built-in battery interface electronics provide storage inhibits in battery voltage and current fault protections.

Control/distribution for Battery & Solar panels:

- The "Ibeos SmallSat Electric Power System" as a battery and solar panels unit and converter.
- Featuring 150 W/h solar panel input power, MPPT system, and different voltage outputs, with additional built-in battery electrical and 0.3U, 140g of mechanical parameters this EPS board is radiation tolerant and fully compatible with a selected battery pack.

G. *Laser beam-controlled 3D optical switch*

As the most important subsystem of the CubeSat platform, this subsystem combines the new application direction of previous scientific and practical research (New Generation 3D Optical Switch).

As a brief recall, the studied 3D optical switch offered three main advantages over other existing optical switches for creating high-speed and efficient communication transitions in optical communication networks [8 - 10]:

- Compact assembly of lenses, depending on the number of beam sources, the arrangement of light sources in one way or another on a 360-degree rotation head, thereby reducing the size, amount of material consumed, and the financial cost of the final device;
- Multiply the switching time of the incoming optical signals by controlling the laser heads in the final device via two high-precision microactuators and by controlling the movement of the translucent mirror in the switching direction;
- Possibility for constant control of the switch and effective diagnostics of the problems through the integrated electronic control and measuring system.

These points will pay for themselves on the designed CubeSat platform, allowing the effective exchange of high-volume and fast optical information between two or more satellites on the level of interlink satellite batch (the inter-satellite link between satellite constellations).

RESULTS

The concept of space solar energy (SCSE) is attractive in that it is much more profitable than ground-based solar energy. Based on current research, space solar power should no longer be viewed as requiring an unimaginably large upfront investment. Moreover, space solar power systems appear to offer many significant environmental benefits over alternative approaches to meeting growing terrestrial energy needs, including the need for a much smaller land area than terrestrial solar power systems.

Such as in this article a new-generation 2U CubeSat satellite platform model prototype was developed, combining the advantages of existing RF and OC communication technologies of the NanoSat satellite system, as well as 3D laser beam control, nanowave transponder, and SDR-based RF active transponder subsystems with a 3D optical switch, and its structural scheme, as well as a simplified working principle, are given.

At the same time, the 2U nano-satellite can harvest up to 60W of renuvable solar irradiance and transmit it in both laser nanowave and microwave with directional active antennas.

A nanosatellite (CubeSat) suitable for a final flight can be developed and sent to low earth orbit (LEO, 1000-2000km) and can be applied in the following areas:

- Ensuring high-volume and high-speed full optical beam data exchange between an orbiting nano-satellite and full-suplex transmittion with GS;
- By establishing SPS platforms with CubeSat constellation the amount of efficent could increase significantly.

REFERENCES

1. NASA, CubeSat 101 Basic Concepts and Processes for First-Time CubeSat Developers. California Polytechnic State University, October 2017.
2. Laser communication in space. Available at: https://en.wikipedia.org/wiki/Laser_communication_in_space [Accessed April 13, 2022]
3. J. O. Mcspadden and J. C. Mankins, “Space solar power programs and microwave wireless power transmission technology,” IEEE Microwave Mag., pp. 46–57, Dec. 2002.
4. H. Matsumoto, “Research on solar power station and microwave power transmission in Japan: Review and perspectives,” IEEE Microwave Mag., pp. 36–45, Dec. 2002.
5. Brown., W. C. (September 1984). "The History of Power Transmission by Radio Waves." Microwave Theory and Techniques, IEEE Transactions on (Volume: 32, Issue: 9 on page(s): 1230- 1242 + ISSN: 0018-9480).
6. Hemani Kaushal and Georges Kaddoum. Optical Communication in Space: Challenges and Mitigation Techniques. – India, 2017.
7. Alberto Carrasco-Casado and Ramon Mata-Calvo. Free-space optical links for space communication networks. – Japan, 2020.
8. M. H. Hasanov, NEW GENERATION 3D OPTICAL SWITCH. – Baku, 2020.
9. MH Hasanov, KR Hacıyeva, SF Qodjaeva. Multifunctional adaptive piezoelectric switch of optical channels - T-Comm. Telecommunications and transport, 2018.
10. MH Hasanov, NB Agayev, NA Atayev, VM Fataliyev. A new generation of controlled optic switch - T-Comm-Телекоммуникации и Транспорт, 2021