Acta Scientific COMPUTER SCIENCES

Volume 3 Issue 4 April 2021

Research Article

Comparative Study for LEO Satellites Solar Arrays Design Using Single and Multi-junctions Solar Cells

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Received: March 03, 2021

Published: March 29, 2021

Abstract

In recent years, there has been an extensive interest in small satellites that accomplish cost effective space oriented missions in low earth orbit LEO. Reduced reliability and short delivery schedules are two key issues relating to the design of such satellites for minimizing their overall costs. These issues are important factors in the design of spacecrafts power systems which are considered the heart of the entire satellite during their orbital lifetime.

A satellite power system is a highly critical subsystem. All the platform and payload electronics are dependent on it for the entire mission lifetime. No single fault of the electrical power system is bearable as it can cause partial or even permanent loss of the spacecraft.

Nowadays, for most satellites, solar energy is becoming the primary source of energy for space missions. The power generated from the sun flux is at an extremely low operating cost when compared to already existing power generation technologies. Therefore, the development of space systems depends on the study of space itself, materials and especially energy. Solar arrays are the only non-nuclear means that enable space vehicles and satellites in orbit to be fed continuously. Increasing the efficiency of solar cells is a major goal and a prominent factor in space photovoltaic systems research.

The need for high performance solar arrays for space applications continues to increase, as the energy budget of satellites becomes even higher, and power systems become constrained by either the total mass or the stowed volume. Solar cells industries have stepped up to this challenge by developing new innovative designs that will increase the solar cells efficiency and decrease the cells weight. Solar cell efficiency is the most significant parameter to optimize in order to achieve minimum mass and volume of the solar cell and therefore the power system.

Due to the extreme nature of the low earth orbit environment and for the correct design of a LEO satellite's solar arrays, an analysis of the satellite's orbital life within this space environment is necessary. In this paper, the requirements for the design of the solar arrays are defined considering all loss factors for a LEO satellite. In addition, the power capability of the solar arrays is analysed considering the interface between the solar arrays and the battery charge regulator BCR and how the system design satisfies mission objectives.

The present paper details the design of solar arrays for a low earth orbit spacecraft based on single and multi-junction (triple) solar cells. The solar arrays will use aluminium substrates for a more efficient shielding for the spacecraft's payload and plate form subsystems.

Keywords: Single Junction; Solar Cells; Multi Junction; Efficiency; Aluminium Substrates; GaAs/Ge; Azur 3G30A; Beginning of Life; End of Life; Cover Glass

Introduction

Small satellites are nowadays becoming a more attractive mean for small space emerging nations to develop space technology in their country through technology transfer in partnership with well-known developed space nations. Small satellites have enormously established themselves within the aerospace community because of their low cost and high return on investment. Many small satellites are developed in a short time scale and often use commercial off the shelf components COTS for quick turnaround missions.

It is clear that space technology know how transfers needs to be implemented responsibly as part of a long-term capacity-building plan to be a sustainable one. It needs also to be supported with the appropriate policy and legal frameworks, the institutional development, including community participation, human resources development and strengthening of managerial systems.

With regard to the Electrical Power System EPS, commercially available products typically use a centralised architecture. However, a centralized architecture is not reusable, since missions that require additional solar arrays or batteries would necessitate a new analysis and therefore a redesign of the power system.

Methodology

Power system topology: The baseline 28V unregulated bus

Primary power to the satellite is supplied via four (04) body mounted solar panels. The power generated from the solar panels feed into dual battery charge regulators BCRs. The BCRs are selected by means of a relay on the input. A BCR Logic monitors the BCR operation and switches to the other BCR should a failure occur. The BCR selection can be overridden by a command from the TTC system. The BCR estimates the maximum power point MPP of the solar arrays using a temperature compensation method, and tracks the end of charge EoC of the single battery also by using a temperature compensation method that reduces the charge current when the EoC is reached. This temperature compensation, both for the battery and the solar arrays, is based on thermistors potted with adhesive in the battery pack and the solar panel substrates. Both the EoC and the MPP tracking can be overridden using the on board computer OBC control.

Results and Discussion

The circuit, figure 1, shows a power system configuration based on a 28V unregulated bus. Figure 1 depicts that a failure of BCR1 (primary BCR) results in the automatic switch over to the redundant system BCR2. Each BCR design can sustain a continuous power of 80W with sufficient de-rating.

Figure 1: 28V unregulated power system bus.

In general, for a 60cm*60cm solar panel using super single junction GaAs solar cells, assuming a fill factor of 80% and an effective area of 80%, the power from a single panel can reach 60W. This would result in an instantaneous array power of over 80W when two (02) adjacent panels are illuminated at an angle of 45° to the sun direction. Therefore, the BCRs need a redesign to support the increase of power.

Nowadays, the new enhanced microsatellites are power hungry and therefore the design must take into account these power requirements and this paper is naturally looking at these details. With regard to the battery, a solution would be the use of a single high capacity battery (15-20 Ah) to satisfy the predefined requirements especially when the satellite is in full operation.

Mechanical properties

Each of the four solar arrays are based on a lightweight structure built of an aluminium honeycomb with kapton foil to electrically insulate the cell area from the array structure. Each of the arrays is 60cm*60cm and 20mm thick. All four panels together weighed about 15 kg.

Satellite's mission power requirements estimation

Table 1 summarises the satellite's payload and bus power consumptions with margins. Here, the margins are large assumptions and must be modified each time a subsystem power consumption is precisely tuned. Duty cycle percentages are expressed as a ratio to a full orbit duration, i.e., 98.76 minutes at an altitude of 700 km (baseline).

Payload power requirements	Duty cycle %	Average power value W	Peak power value W
Camera	2%	3	10
GPS	100%	3	6
Communica-tions	5%	5	5
Bus power requirements	**Duty cycle %**	**Average power value W**	**Peak power value W**
Thermal	100%	1	1
Structure	0	0	0
Propulsion	0	0	0
ADCS	100%	10	10
OBC	100%	5	5
Mass memory	10%	4	4
TM/TC	100%	4	10
Power	100%	5	5
Margin 5 - 10%		2	5.6
Total power requirements		42	61.6

Table 1: Preliminary power requirements for the satellite's mission.

Figure 2: Satellite's power budget.

To create a system's power budget, information about the electrical power consumption of each subsystem is required. In general, the bus voltage is defined and the peak and average power consumptions are estimated. Some subsystems have their own DC/DC converters. Figure 2 shows preliminary power requirements for the satellite's mission.

Solar cells selection

The solar cells used in this study were manufactured from Energies Nouvelles et Environment ENE (Belgium) in the size (2 cm x 4 cm) using the MOCVD process (Aix 2400) and fully evaporated metals (Figure 3).

Figure 3: Sample single junction solar cells, sizes (2cm*2cm) and (2cm*4cm).

The solar cells are single junction SJ GaAs/Ge cells, mounted on an aluminium face sheet and an aluminium honeycomb substrate. At the beginning of life BOL and ambient temperature 25°C, the solar cells have on average 21.5% efficiency.

The solar panels substrates are made of a 20 mm aluminium core honeycomb with 0.5 mm aluminium face skins front and rear. The front of the panels has an insulating thin layer of 75 μm kapton. The solar arrays have an average weight of 3.8 kg, with a set of holes for fastening, protection covers fixing and wiring feed through.

The cells lay down design of two panels (+X and -X) was identical consisting of six (06) strings of 48 cells in series (288 solar cells per panel), see figure 4. The other two panels (+Y and -Y) consist of two identical strings composed of 26 TJ solar cells in series each, see figure 6. The solar cells were then individually measured (at 0.89V) to arrange them into their respective current classes. Table 2 illustrates the single junction solar cells into their respective classes.

Single Junction GaAs/Ge solar cells, with an average efficiency of 21.5% at beginning of life BOL and ambient temperature 25°C, are used on the +X and -X solar panels (+X, -X) in order to fulfil the mission power requirement design. The solar cells of area 2cm*4cm are made by ENE/CESI.

Solar cells classes
254 - 257 mA at 0.89V
258 - 261 mA at 0.89V
262 - 265 mA at 0.89V
266 - 269 mA at 0.89V
270 - 273 mA at 0.89V
274 - 277 mA at 0.89V

Table 2: Solar cells classes.

The solar cell assemblies will be made using ultra-sonic welding of gold plated molybdenum interconnects. The solar cells assemblies produced are then integrated onto the solar panel substrate using screen printed CV-2566 adhesive.

CMG 150μm coverglass will be used to cover the solar cells using DC 93-500 a space-grade encapsulate transparent, room-temperature-curing, solventless silicone material designed for use in the space environment. The following parameters are used, as a baseline performance for the cells, in the solar arrays design:

- Isc (short circuit current) 276 mA
- Voc (open circuit voltage) 1.02 V
- Vpmax (max power point voltage) 0.89 V
- Ipmax (max power point current) 262 mA
- Pmax (max power) 233 mW
- FF (fill factor) 0.82
- Eff (solar cell efficiency) 21.5%.

For the +Y and -Y solar panels, we are using TJ solar cells. The following parameters are used, as a baseline performance for the cells, in the solar arrays design.

- Isc (short circuit current) 510.8 mA
- Voc (open circuit voltage) 2.708 V
- Vpmax (max power point voltage) 2.410 V
- Ipmax (max power point current) 495.4 mA
- Pmax (max power) 1194.2 mW
- FF (fill factor) 0.8634
- Eff (solar cell efficiency) 28.9%.

Solar cells production

The solar cells were manufactured in the size 2cm*4cm using metal organic chemical vapour deposition MOCVD process from ENE. the delivery consists of 900 SJ GaAs/Ge solar cells submitted to reverse screening. The solar cells were manufactured on large area Ge substrates (114.5 mm) in diameter. Eight (08) solar cells were manufactured on each Ge wafer. Figure 4 shows the 900 SC efficiency distribution. The efficiencies of SC are in the range [20.8 to 21.8%] as shown on figure 4. The average efficiency is 21.5% at AM0.

Figure 4: Efficiency distribution of 900 single junction solar cells.

Solar arrays design calculations

Single junction solar cells design

Each solar array is composed of six (06) strings of 48 solar cells of GaAs/Ge as shown in figure 5.

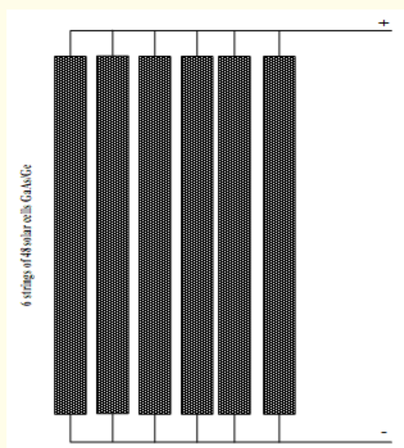

Figure 5: +X and -X solar cells strings layout.

Citation: Mohammed Bekhti. "Comparative Study for LEO Satellites Solar Arrays Design Using Single and Multi-junctions Solar Cells". *Acta Scientific Computer Sciences* 3.4 (2021): 30-37.

On average V_{mp} = 0.89 V. For most solar cells dV_{mp}/dT = -2.07 mV/°C. For the 48 solar cells in series, the output voltage of the array is equal to 0.89 V*48 = 42.72 V.

Assuming a 1% degradation over 05 years in LEO and 2% loss in cabling and interconnects. This will reduce the voltage to 42.72 V*3% = 1.2816 V. The array voltage at 25°C becomes then equal to 41.4384 V.

Due to the solar cells temperature coefficient, the 48 solar cells mounted in series produce a total voltage drop of -2.07 mV/°C*48 = -99.36 mV/°C.

At low temperature (-40°C), this gives a voltage increase of (-40°C - 25°C)*(-99.36 mV/°C) = 6.4584 V. The solar array voltage at low temperature becomes equal to 47.8968 V.

At high temperature (+80°C), we get a voltage drop of: (+80°C - 25°C)*(-99.36 mV/°C) = -5.4648 V. thus, the panel voltage at high temperature reaches 35.9736 V.

On average Imp = 262 mA. For most single junction solar cells used, dI_{mp}/dT = 0.16 mA/°C. For six (06) strings in parallel, the average current delivered by the solar panel is 262 mA * 6 = 1.572 A.

Assuming a 1% solar cell mismatch over 05 years in LEO and 1% degradation.

Taking into account the solar cells degradations (1% solar cell mismatch, 1% degradation) in LEO, at ambient temperature 25°C, the current delivered by the solar array is equal to 1526 mA.

Due to solar cells temperature coefficients, the six (06) strings in parallel produce a current drop of +0.16 mA/°C*6 = 0.96 mA/°C.

At low temperature (-40°C), we expect a drop of the solar array current value of (-40°C - 25°C)*(+0.96 mA/°C) = - 62.4 mA. The solar array output current at low temperature becomes equal to 1463.6 mA.

At high temperature (+80°C), the temperature coefficients of the solar cells produce an increase of the output current equal to 1578.8 mA.

Figure 6 shows the +X and -X solar arrays performance with temperature taking into account the orbit environment degradation and the temperature coefficient of the solar cells.

Solar Arrays	Temperature °C	Estimated Power Outputs
+X and -X	-40°C	70.10 W @ 47.90 V, BOL
+X and -X	+25°C	63.23 W @ 41.44 V, BOL
+X and -X	+80°C	56.79 W @ 35.97 V, BOL

Table 3: +X and -X solar arrays power with temperature.

Figure 6: +X and -X solar panels performance with temperature.

Multi junction solar cells 3G30A design

Each solar array is composed of two (02) strings of 26 solar cells triple junction TJ 3G30A as shown in figure 7.

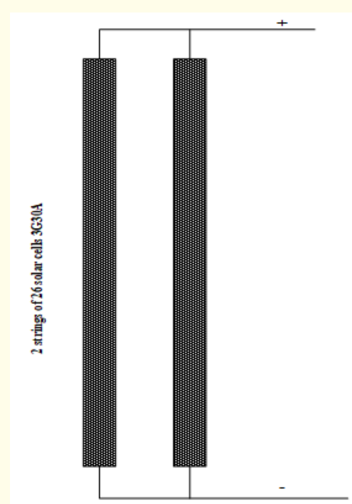

Figure 7: +Y and -Y solar cells strings layout.

On average V_{mp} = 2.410 V. For most TJ solar cells dV_{mp}/dT = -6.7 mV/°C. For the 26 TJ solar cells in series, the output voltage of the array is equal to 2.410 V*26 = 62.66 V.

Assuming a 1% degradation over 05 years in LEO and 2% in cabling and interconnects. This will reduce the voltage to 62.66 V*3% = 1.8798 V. The array voltage at 28°C becomes then equal to 60.7802 V.

Due to the solar cells temperature coefficient, the 26 TJ solar cells mounted in series produce a total voltage drop of -6.7 mV/°C*26 = -174.2 mV/°C.

At low temperature (-40°C), this gives a voltage increase of (-40°C - 25°C)*(-174.2 mV/°C) = 11.8456 V. The solar array voltage at low temperature becomes equal to 72.6258 V.

At high temperature (+80°C), we get a voltage drop of: (+80°C - 28°C)*(-174.2 mV/°C) = -9.0584 V. Thus, the panel voltage at high temperature reaches 51.7218 V.

On average Imp = 495.4 mA. For most triple junction TJ solar cells used, dI_{mp}/dT = 0.24 mA/°C. For two (02) strings in parallel, the average current delivered by the solar panel is equal to 495.4 mA * 2 = 990.8 mA.

Taking into account the solar cells degradations (1% solar cell mismatch, 1% degradation) in LEO, at ambient temperature 28°C, the current delivered by the solar array is equal: 961.1 mA.

Due to solar cells temperature coefficients, the two (02) strings in parallel produce a current drop of +0.24 mA/°C*2 = 0.48 mA/°C.

At low temperature (-40°C), we expect a drop of the solar array current value of: (-40°C - 28°C)*(+0.48 mA/°C) = - 32.64 mA. The solar array output current at low temperature becomes equal to 928.46 mA.

At high temperature (+80°C), the temperature coefficients of the solar cells produce an increase of the output current equal to 986.06 mA.

Solar Arrays	Temperature °C	Estimated Power Outputs
+Y and -Y	-40°C	67.43 W @ 72.63 V, BOL
+Y and -Y	+28°C	58.42 W @ 60.78 V, BOL
+Y and -Y	+80°C	51.00 W @ 51.72 V, BOL

Table 4: +Y and -Y solar arrays power with temperature.

Figure 8: +Y and -Y solar panels performance with temperature.

Figure 8 shows the +Y and -Y solar arrays performance against temperature taking into account the orbit environment degradation and the temperature coefficient of the solar cells [1-29].

Conclusion

In general, solar arrays design is an extremely interesting and fascinating experience. The solar array engineer will have a clear vision and a deep knowledge of the entire process in the design of microsatellite power system.

The present paper details the design of solar arrays for a low earth orbit spacecraft based on single and multi-junction (triple) solar cells. The study constitutes a trade-off regarding the use of single and multi-junctions solar cells on aluminium substrates. Aluminium substrates have proved to have a more efficient shielding for the spacecraft's payload and plate form subsystems.

This paper is mainly focused on the solar array assembly design all four solar panels and design calculations are reported for evidence.

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