considering electrical parts and environmental conditions in orbit and obtained its reliability with 99.9% based on the part count methods that considered all the parts used in the analysis.

2. 300 W SOLAR CELL ARRAY

2.1 Solar Cell Array Configuration

In outer space, the solar cells are unique for generating a electrical power by photovoltaic power conversion. Photons from the Sun might be irradiated on the surface of a solar cell, and then they are converted into electricity. Therefore, a total of 352 GaInP/GaAs/Ge solar cells are needed to generate 300 W electrical power. In this study, we selected a solar cell that is a size of 80 mm × 40 mm × 16 μm for system configuration and design to do reliability analysis. It is fabricated by a GaInP/GaAs/Ge technology based on Ge substrate (Chiang et al. 1995; AL-Naser et al. 2009; AZUR 2018). Fig. 1 shows a solar cell consisted of a GaInP/GaAs/Ge technology.

The GaInP/GaAs/Ge solar cell has electrodes on the top side of the cell in Fig. 1 and the other one has the bottom side of the cell since that is the rear side of the GaInP/GaAs/Ge solar cell. By using those GaInP/GaAs/Ge solar cells, an electrical configuration of the 300 W solar cell array consists of a total of 325 solar cells as shown in Fig. 2. In more details, there are 11 strings in this solar cell array and each string consists of 33 solar cells in a string to make a proper operating voltage such as a maximum voltage and a maximum current in the maximum power generation. In other words, a solar cell array will work at the peak power mode to increase a photovoltaic conversion power. A power controller will track a peak point of power in the V-I characteristics which shall find the maximum point along the current and voltage curves, and then the maximum power of the 300 W solar cell array is generated at the operating point by some hardware characteristics.

2.2 Design of 300 W Solar Cell Array

Prior to reliability analysis of the 300 S solar cell array, the configuration was reviewed in the section 2.1. and a required solar cell was also occurred considering the operating point in V-I characteristics. In addition to the configuration, a detailed schematic was needed for reliability analysis. Thus, a schematic for analysis was proposed like Fig. 3 and total parts were also included in this schematic.

In Fig. 3, red ones are the solar cells consisted of GaInP/GaAs/Ge technology with 11 strings and 32 cells in series and 1N5417 diodes to make isolation between adjacent circuits are designed and considered for electrically isolated power in this solar cell array. Furthermore, the outputs of the 1N5417 diodes are tied together.

3. RELIABILITY ANALYSIS OF THE 300 W SOLAR CELL ARRAY

3.1 Parts List for Reliability Analysis

In this study, parts count method (PCM) is used for reliability analysis and PCM requires total parts used in the

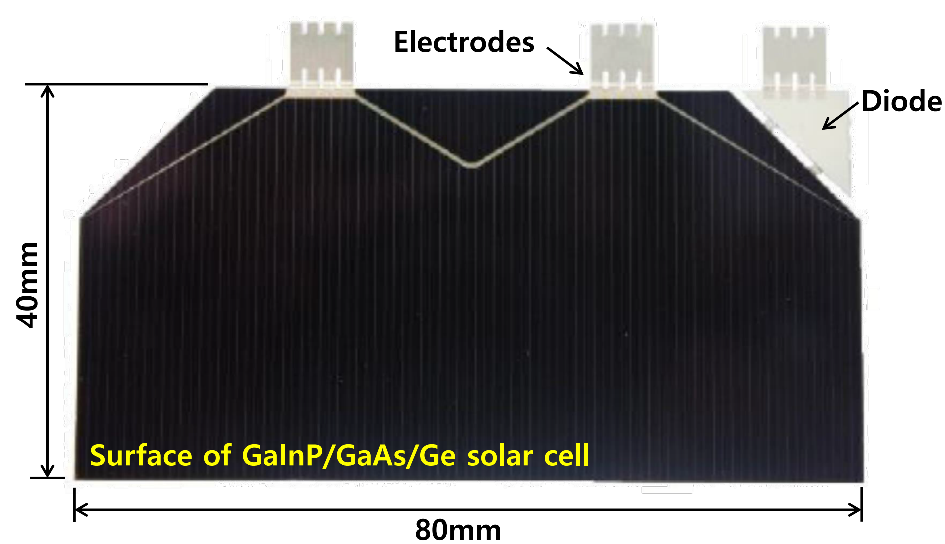

Fig. 1. Solar cell and dimensions with GaInP/GaAs/Ge technology.

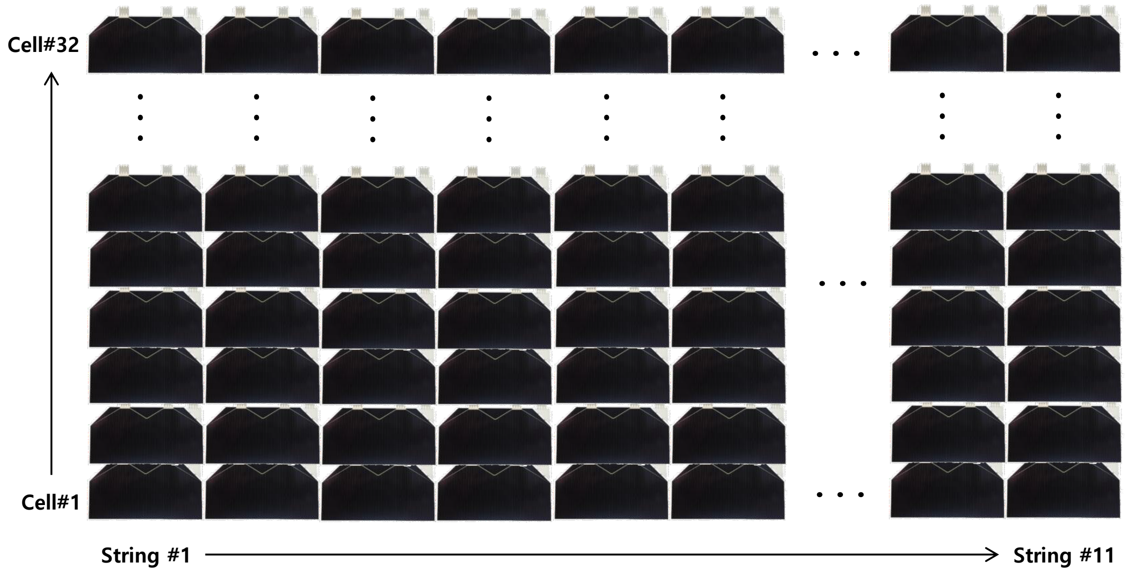

Fig. 2. Configuration of a GaInP/GaAs/Ge solar cell array.

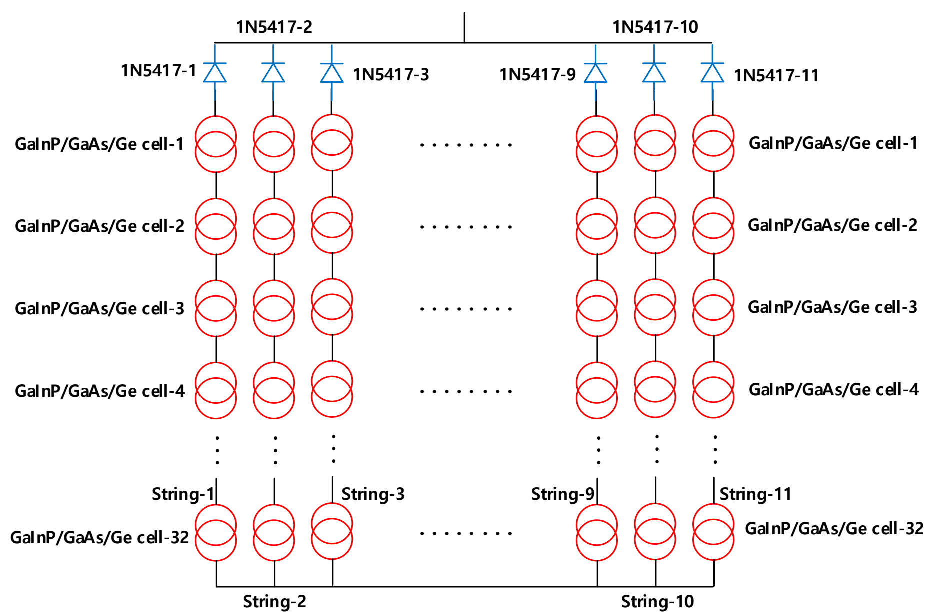

Fig. 3. Schematic diagram of the 300 W solar cell array with strings and blocking diodes.

300 W solar cell array. Thus, total parts should be recognized by a bill of material (BOM) which includes all the parts in the 300 W solar cell array. The parts used in reliability analysis are described in Table 1 and those are accompanied by analysis.

A total of 352 solar cells are used to make a required power and those shall be accompanied by this reliability analysis. Not only diodes are used for this array, but one resistor and connector are also applied in the reliability. In addition, an interconnection between cells should be responsible for bonding and current flowing from each cell to another cell.

Table 1. Parts list used in the 300 W solar cell array

Part name	Parts specifications	Quantity
Solar cell	GaInP/GaAs/Ge	352
Diode	1N5417	11
Wire	AWG #26	10
Connector	D-Sub Connector	1
Resistor	RW81	1

3.2 Reliability Prediction

A space program requires an analysis on the reliability for ensuring its mission life time, because it might be very hard to do trouble shooting in orbit after launch. Therefore, an reliability analysis should be followed in design. However, a solar cell array was not performed a reliability analysis before. Thus, in this study, an analysis of the 300 W GaInP/GaAa/Ge solar cell array was conducted and obtained the results to check and review its reliability for mission life time 4 years. In this study, "MILITARY HANDBOOK ELECTRONIC RELIABILITY DESIGN HANDBOOK" was referred to reliability analysis based on PCM described in section 3.1, this hand book is approved for use by all Departments and Agencies of the Department of Defenses (DoD) (Military Handbook 1991). This handbook contains two configurations for reliability analysis in series and parallel configurations like Fig. 4 with parallel and series interconnections.

In this study, there are two configurations consisting of the 300 W soalr cell array using GaInP/GaAs/Ge solar cells. Therefore, two approaches are considered in this works. And also, this hand book is for guidance only for space applications. A reliability prediction is based on the failure rate such as Mean Time Between Failure (MTBF) in 50,000 hours as well as a modeling of individual EEE solar cells shall be as following Eq. (1). In addition, reliability prediction of electronic equipment for solar cells and diodes, MIL-HDBK-217F, was referenced for this analysis as well (Military Handbook 1991).

$$\lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E \tag{1}$$

where λ_p is the part failure rate, λ_b is a base failure rate, π_T is a temperature factor, π_S is an electrical stress factor, π_C is a failure rate of each particular component, π_Q is quality factor and π_E is an environmental factor.

A reliability prediction of electronic equipment for resistors, MIL-HDBK-217F, was referenced for this analysis and its equation shows like Eq. (2).

$$\lambda_p = \lambda_b \pi_R \pi_Q \pi_E \tag{2}$$

where λ_p is the part failure rate, λ_b is a base failure rate, π_R is a resistance factor, π_Q is quality factor and π_E is an environmental factor.

A reliability prediction of electronic equipment for connectors, MIL-HDBK-217F, was referenced for this analysis and its equation shows like Eq. (3).

$$\lambda_p = \lambda_b \pi_K \pi_P \pi_E \tag{3}$$

where λ_p is the part failure rate, λ_b is a base failure rate, π_K is a mating factor and π_E is an environmental factor.

A reliability prediction of electronic equipment for wire and connectors, MIL-HDBK-217F, was referenced for this analysis and its equation shows like Eq. (4).

$$\lambda_p = \lambda_b \pi_Q \pi_E \tag{4}$$

where λ_p is the part failure rate, λ_b is a base failure rate, π_Q is a quality factor and π_E is an environmental factor.

The failure rate of the 300 W solar cell array will simply be estimated by Eq. (1) to Eq. (4) and then all the reliabilities of the 300 W solar cell array might be calculated by mathematical calculations using failure rates.

A total failure rate of 0.004506 was occurred and a total reliability was found about 99.960538%. It means there

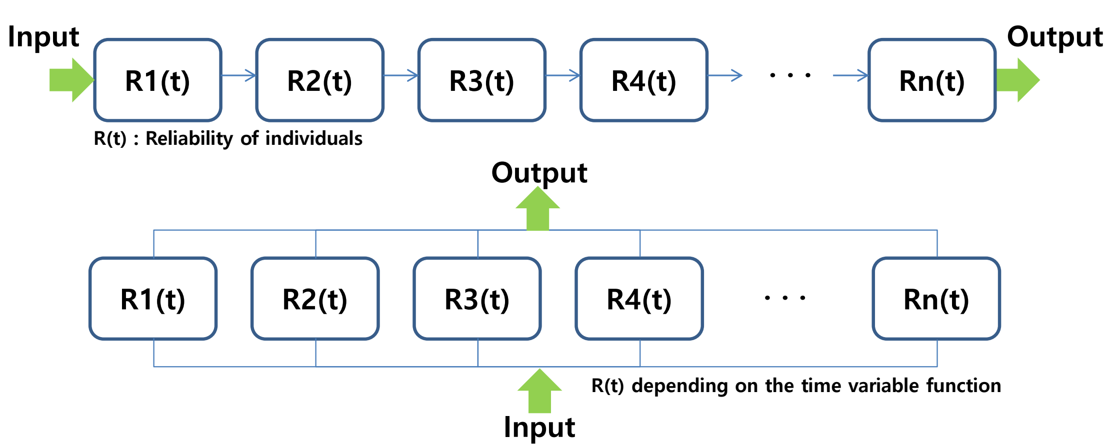

Fig. 4. Reliability block diagram: (upper) series configuration and (lower) parallel configuration for analysis.

could be found the failure rate in 1,000,000 hours and it was very high reliability for mission operation.

4. RESULTS AND DISCUSSION

In this PCM, we have used a total of 352 GaInP/GaAs/Ge solar cells, 11 diodes for blocking a current against strings, a resistor for a grounding path of the substrate and a connector. Those parts were accompanied by reliability analysis. Based on the PCM, the reliability analysis was conducted shown in Table 2, which found out 99.960535% for 11 years. It means that there will be 0.03% in failure for 11 years. The 300 W solar cell array requires a series connection to provide a proper operating voltage and a parallel interconnection to make a required current at peak power. So, we choose those solar cells and diode as a primary power source in orbit.

Fig. 5 shows individual parts reliability for this study, and then we obtained that of those parts connector and wire based on guidelines had a little higher than other parts. It means that those parts should be controlled for high reliability among them. Therefore, we had a reliability of 99.9% which has a higher reliability compared to electronics used in space products. Similarly, Next Generation Small Satellite-1 (NEXTSat-1) consisted of many solar cells using GaInP/GaAs/Ge technology had been launched last year and contained operational scenario considering the reliability for mission life time (Shin et al. 2014). That program showed us its reliability and presented its performance according to reliability analysis. In addition to this reliability, some radiation effects of solar cells should be considered in system design. A radiation effects was conducted by Co60 source and obtained its degradation ratio by yearly (Shin et al. 2008; Lee et al. 2008; Choi HY at al. 2015; Choi et al. 2017; Oh et al. 2018).

Table 2. Reliability of the 300 W GaInP/GaAs/Ge solar cell array

EEE parts	λ_p, failure rate	Remarks
GaInP/GaAs/Ge solar cell	0.000657	352 each
1N5417, diode	0.000002	11 each
RWR81, resistor	0.000155	Wire wound resistors
AWG#26, wire	0.003690	SPEC55, for space
DB25, d-sub connector	0.003690	For space
Total failure rate (λ)	0.004506	
Reliability (%)	99.960538	

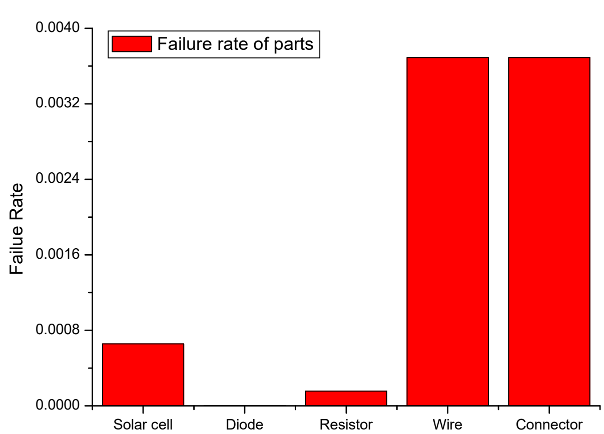

Fig. 5. Parts failure rate used in the 300 W solar cell array.

5. CONCLUSIONS

Spacecraft requires a sufficient power in orbit to perform its mission. So as to comply with system requirements, the sufficient power should be made by a solar cell array by photovoltaic power conversion using GaInP/GaAs/Ge solar cell array in this study. A life time of space program depends on its mission considering parts reliability and parts grade. Based on the mission life time, a required power might be designed and analyzed to meet specifications. In outer space, a required power might be generated by solar cell array by photovoltaic conversion effects using GaInP/GaAs/Ge solar cells. Space programs that require more than five years should choose parts for high reliability for ensuring its mission. Therefore, Space program required more five years should perform a reliability analysis to check its fulfilment of the requirements. This program should also require more five years for its mission and we performed its analysis using PCM for its reliability. Finally, we obtained its reliability analysis and quantitative figures found out 99.9%. In reliability analysis, important variables were recognized by the following individual parameters of the parts, Table 3.

From Table 3, a reliability analysis for ensuring its life time shall be referred to those variables and they should be dependable orbit conditions such as radiation effects and thermal effects. Thus, environmental conditions should be reflected on the reliability analysis. Therefore, we presented the reliability analysis of the 300 W GaInP/GaAs/Ge solar

Table 3. Major reliability variables for analysis to provide a proper life time considering parts frage

Part name	Parts spec	Remarks
Solar cell	$\lambda_b, \pi_T, \pi_S, \pi_C, \pi_Q$ and π_E	
Diode	$\lambda_b, \pi_T, \pi_S, \pi_C, \pi_Q$ and π_E	Solar cells are similar to diode
Wire	λ_b, π_Q and π_E	Wire and connectors are similar to the integration point of aspect
Connector	λ_b, π_Q and π_E	
Resistor	λ_b, π_R, π_Q and π_E	

cell array considering the radiation and on-orbit thermal effects as well. By using those results, a prediction of the 300 W solar cell array was presented.

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