SMC-TR-05-10

AEROSPACE REPORT NO.
TR-2005(8582)-1

Distributed Power System for Microsatellites

15 December 2004

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Prepared for

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This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. FA8802-04-C-0001 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by B. Jaduszliwer, Principal Director, Electronics and Photonics Laboratory; A. D. Yarbrough, Principal Director, Electronics Engineering Subdivision; and W. C. Krenz, Principal Director, System Planning and Engineering. Lt. Dung Do was the project officer for the program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

For Lt. Dung Do Capt. John Burtoft
SMC/TD

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (*DD-MM-YYYY*)
15-12-2004

2. REPORT TYPE

3. DATES COVERED (*From - To*)

4. TITLE AND SUBTITLE
Distributed Power System for Microsatellites

5a. CONTRACT NUMBER
FA8802-04-C-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
E. J. Simburger, D. Rumsey, D. Hinkley, S. Liu, and P. Carian

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Aerospace Corporation
Laboratory Operations
El Segundo, CA 90245-4691

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-2005(8582)-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Space and Missile Systems Center
Air Force Space Command
2450 E. El Segundo Blvd.
Los Angeles Air Force Base, CA 90245

10. SPONSOR/MONITOR'S ACRONYM(S)
SMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
SMC-TR-05-10

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Aerospace Corporation has independently developed a distributed "Ring Bus" electric power system for Picosatellites. This distributed power system architecture is being implemented on a number of upcoming Picosatellite missions. The first implementations of this architecture will be flown on the PowerSphere Flight Experiment and the Pico Satellite Inflatable Reflector Experiment (PSIREX).
To date not all Picosatellite missions have attitude control or deployable solar array structures. Solar cells are body mounted on the various sides of the Picosatellite. The "Ring Bus" architecture was conceived to solve the problem of obtaining maximum electric power from a solar array with multiple panels that are not arranged on a single planar surface.

Aerospace Corporation researchers working on developing viable power systems for Picosatellites were awarded patents 6,127,621 October 2, 2000, "Power Sphere;" and 6,396,167 May 28, 2002, "Power Distribution System" for this unique solution for distributed power system architecture for a multifaceted solar array.

The authors have developed a prototype of the ring bus and have completed initial testing of its performance.

15. SUBJECT TERMS
Pico Satellite power, Thin-film photovoltaics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Ed Simburgerr
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*include area code*)
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		11	(310)336-7126

Acknowledgment

This work was supported by NASA under Contract NAS-01115 and the USAF under Contract FA8802-04-C-0001.

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1. PowerSphere Flight Experiment

The PowerSphere is a Picosatellite bus that will provide NASA and DoD users with an effective, flexible approach for communications, inspection, sensing, and surface surveying.

The PowerSphere development (begun March 2001 under NASA contract NAS3-01115) is a collaborative effort with team members from The Aerospace Corporation, ILC Dover, Lockheed Martin, and NASA GRC. This technology development effort has been completed with the fabrication and testing of an engineering development unit shown in Figures 1–3.

The PowerSphere is a highly capable spacecraft bus with attitude-insensitive power generation and multi-beam redundant communications systems capabilities that could be used on a variety of future NASA and DoD missions. Potential missions for these small satellites could include communications relays in a space-based wide-area network. They can also be deployed for autonomous surveillance of a manned spacecraft, and on-orbit monitoring of Lunar and Mars exploration vehicles. Another application would be a mini Global Positioning System (GPS) constellation for surface coverage of the Moon or Mars. The use of these extremely small satellites will allow NASA to build and deploy the basic infrastructure needed for robotic and human exploration of the solar system at an affordable cost, in a highly reliable manner that is effective and flexible to changing requirements.

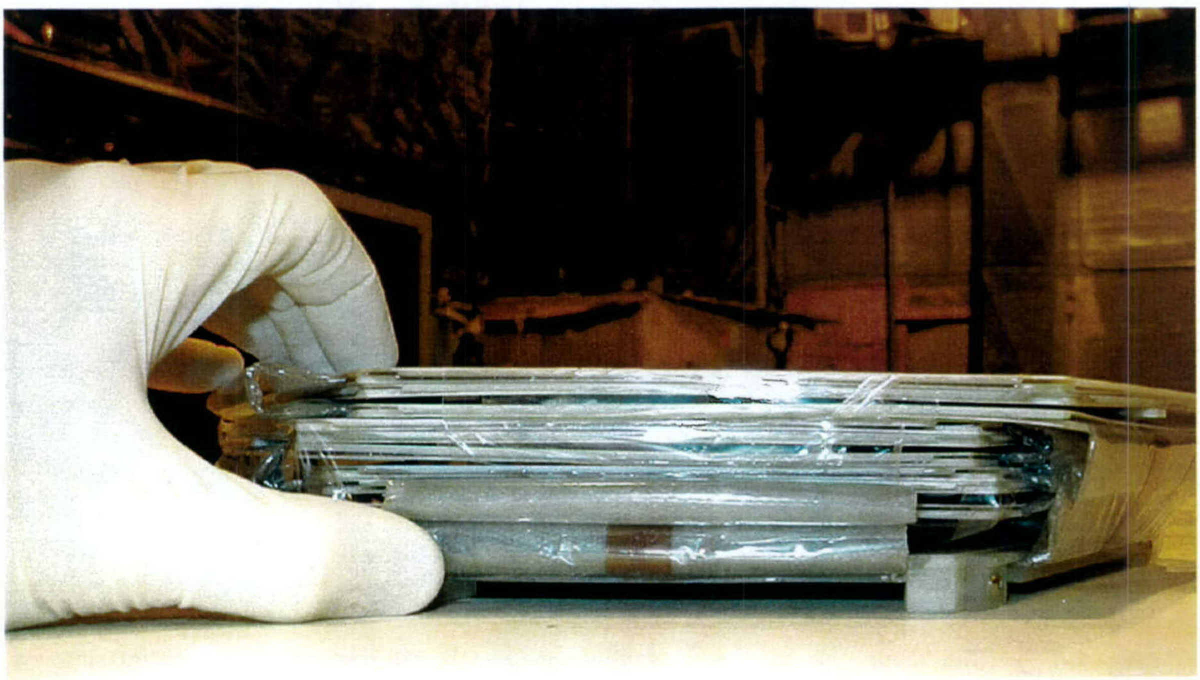

Figure 1. Stowed PowerSphere hemisphere.

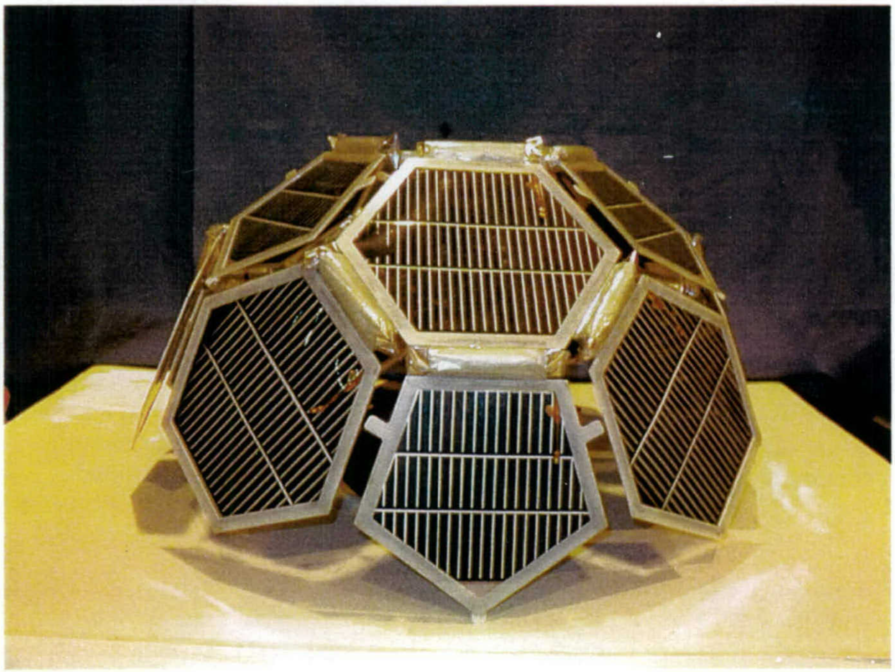

Figure 2. Deployed PowerSphere hemisphere.

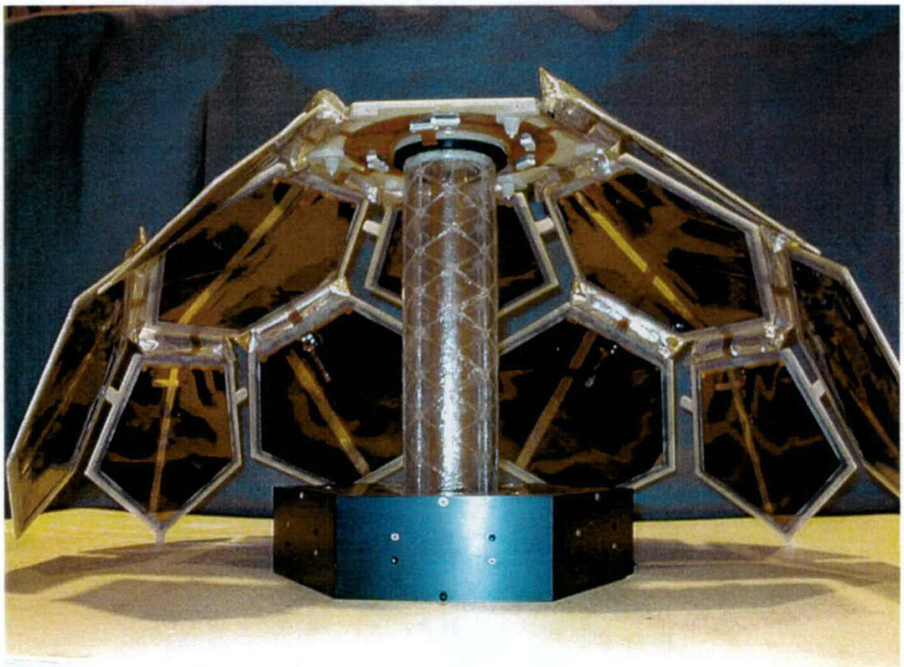

Figure 3. Cutaway view of deployed PowerSphere hemisphere.

A PowerSphere with a deployed diameter of 0.6 m and >10 kg can supply 10 W orbit average of power. A PowerSphere with electric thrusters would be capable of 60 m/s delta over the mission life. This maneuvering capability would enable long-duration inspection of host spacecraft or for station keeping for a communication relay satellite.

2. PicoSatellite Inflatable Reflector Experiment (PSIREX) Flight Experiment

The PSIREX flight experiment is designed to provide the United States Air Force with space flight data that will be used to validate performance models for large inflatable structures and solar collectors. The experiment will stow a 1-m-dia thin-film optical reflector in a space that is 5 in. by 5 in. by 2.5 in. The total size of the PSIREX Picosatellite is 5 in. by 5 in. by 10 in. The satellite will have four Emcore ATJ solar cells mounted on each of the four sides, which have dimensions of 5 in. by 10 in. Figure 4 shows the engineering development unit PSIREX Picosatellite body with the Emcore Solar Cells mounted on it. Figure 5 shows the orbital configuration of the PSIREX with the reflector deployed.

The PSIREX Picosatellite will have an orientation during flight that will keep the side of the spacecraft body perpendicular to the direction of flight. This orientation will result in a less than optimal orientation of the solar cells on the spacecraft body during each orbit. In addition, it is expected that the spacecraft will spin at some undetermined rate around this axis. Figure 6 provides a simulation of the power producing capability of the PSIREX Solar array.

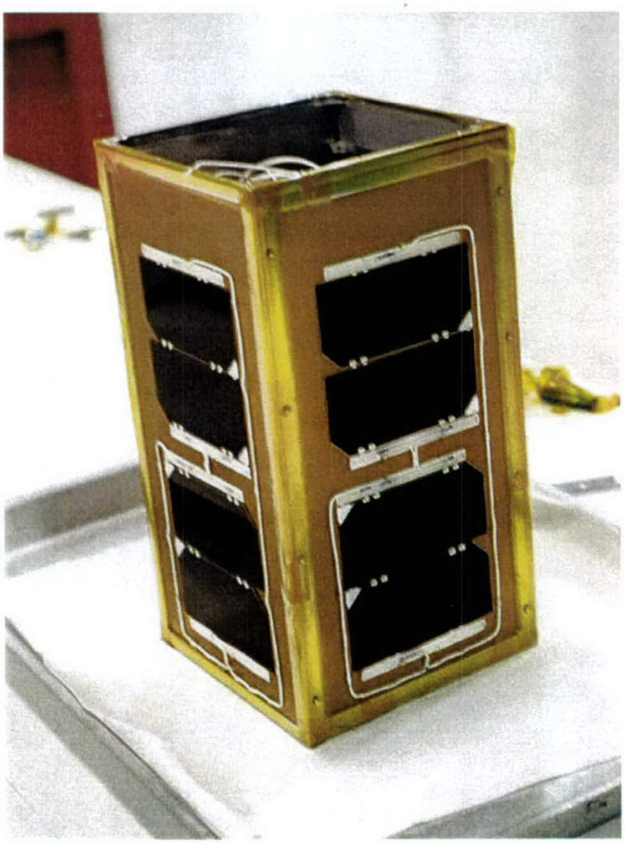

Figure 4. Photograph of PSIREX spacecraft body with Emcore ATJ Solar Cells.

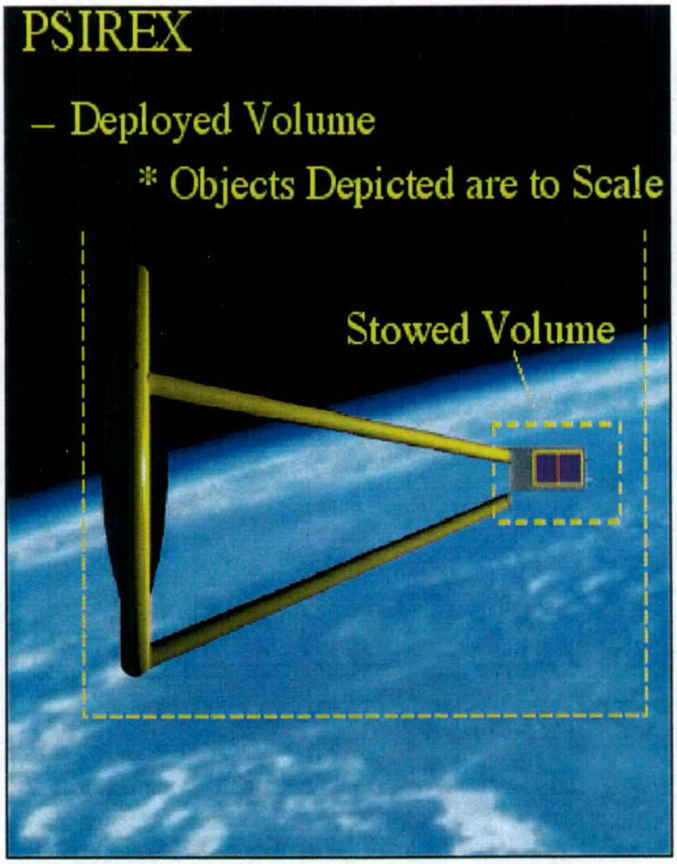

Figure 5. Artist rendition of PSIREX with 1-m inflatable reflector deployed in low Earth orbit.

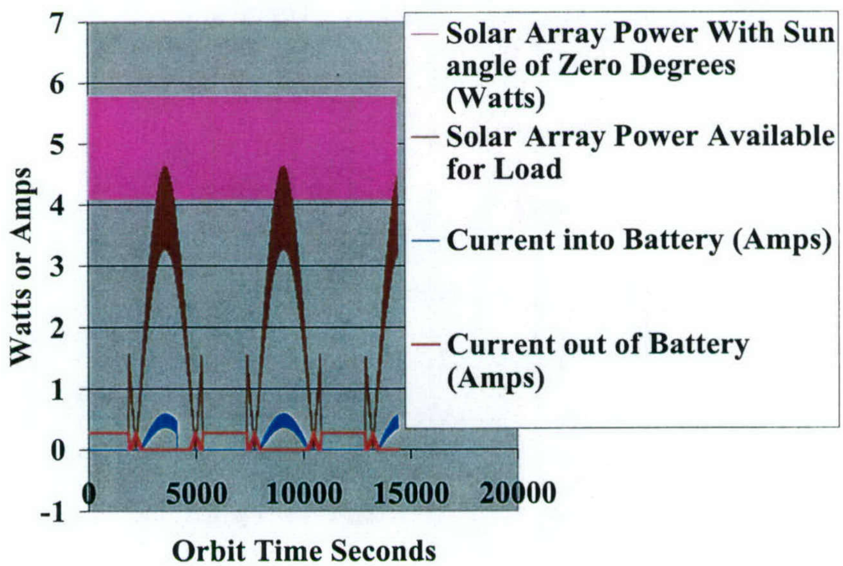

Figure 6. Power producing capacity of the PSIREX Solar Array.

3. Description of Operation of PMAD

The PowerSphere and PSIREX Power Management and Distribution (PMAD) systems utilize the "Ring Bus" power system architecture. This architecture was originally developed for the PowerSphere. The configuration of the major elements of the PMAD for the Ring Bus is shown in Figure 7. In this configuration, each of the individual power modules sense the voltage on the "Ring Bus," which is set nominally at 5 VDC for PowerSphere or 10 VDC for the PSIREX Picosatellite. The PSIREX ring bus is more mature at this juncture and will be discussed first.

The Solar array regulators each have a microprocessor and a DC-DC converter. The solar array on each face of the PSIREX has the four solar cells connected two in series with the two series strings connected in parallel. Two of these arrays on opposing faces of the PSIREX spacecraft are connected to a single solar array regulation unit through blocking diodes. For operation in the sunlight portion of the orbit, the first level of the control loop is the Pulse Width Modulated (PWM) DC-DC boost converter, which provides a regulated bus with voltages between 9.5 and 10.5 V. If left alone, this PWM DC-DC converter would increase the current demand on the controlled solar array beyond the peak power point. If this happens, the power output of the converter would collapse to zero. To prevent this from happening, a microprocessor monitors the bus voltage and output current and implements a peak-power-tracking algorithm. Thus if an increase in current demand from the PWM DC-DC converter results in a decrease in power output, the microprocessor commands a lower current demand by the PWM DC-DC converter. The microprocessor also monitors the solar array voltage and turns the PWM DC-DC converter off if the solar array voltage drops below 3.0 V and turns it back on when the voltage exceeds 3.2 V. The battery subsystems provide power to the "Ring Bus" when the bus voltage drops below 10.0 V. When the bus is supported by the batteries, the battery microprocessors turn off all of the battery chargers, sets a flag in memory to swap the battery to be charged when in sunlight again, and goes to a low power sleep state. The basic building block for the battery subsystem is a battery control element that controls the operation of two individual battery

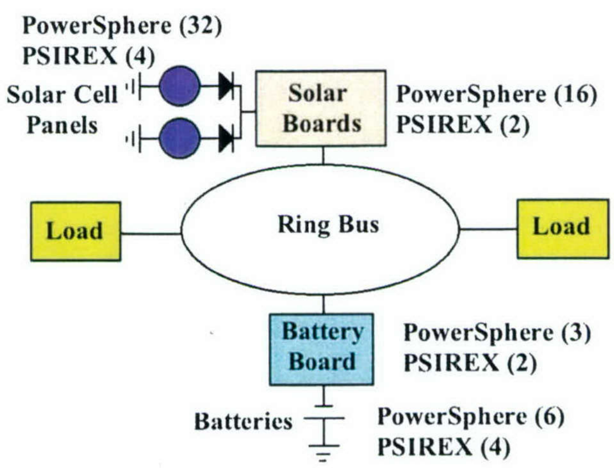

Figure 7. Schematic diagram of Ring Bus architecture.

associated chargers and boost regulators. During the sunlight portions of the orbit, the battery building-block microprocessor turns off one of the battery boost regulators and turns on the associated battery charger. As the bus voltage increases, the microprocessor allows the battery charge current to increase slowly to a maximum of 0.75 A. If the bus voltage decreases due to an increase in load or decrease in solar illumination, the battery charger immediately decreases the charge current to the maximum amount available after supplying all other loads. If the bus voltage drops below 10.1 V, the charger is turned off and the boost regulator is turned back on.

4. Test Results

A Representative Ring Bus for the PowerSphere was assembled with two solar array regulators and two battery charger/regulators. The overall system efficiency was measured at two different load conditions. The results of this test are presented in Table 1.

The schematic for the PSIREX solar array regulator board is shown in Figure 8. A test was performed on this board, and the operating efficiency was measured as a function of solar array input voltage with two different loads. The results of this test are presented in Table 2.

Table 1. Efficiency Measurements of PowerSphere Ring Bus

5 Volt Ring Bus with Solar Board (Rev B -no mods) and Battery Bd (Rev B with charger mods) Efficiency Test										
2 Solar source inputs and 2 Battery inputs (all current metered)										
Solar Input watts = SA1V*SA1C+SA2V*SA2C Load Watts =BAT1V*BAT1C + BAT2V*BAT2C + (5V)^2/RLoad + 5V*(the 2*PIC's current in non sleep mode) Note: 5V*(the 2*PIC's current in non sleep mode) ~ 5V*12ma = .06 Watt										
Case 1 Battery 2 Charging with RLoad=371 ohm										
Solar Input Data					Battery Data				Load	Efficiency
SA1V	SA1C (ma)	SA2V	SA2C (ma)	(watts)	BAT1V	BAT1C	BAT2V	BAT2C (ma)	watts	(%)
4.8	95	4.8	95	0.91	3.8	0	4.0	130	0.58	63.6
Case 2 Battery 2 Charging with RLoad=47 ohm										
4.5	290	4.4	310	2.67	3.8	0	4.0	80	1.63	61.1
Note: each MAX608 with it s ORing diode is about 75% efficient Each MAX1926 is about 90% efficient with a 5 Volt input For the above, the BAT1 608 draws no current, the BAT2 608 is off (its charging). The solar 608s are supplying all the current										

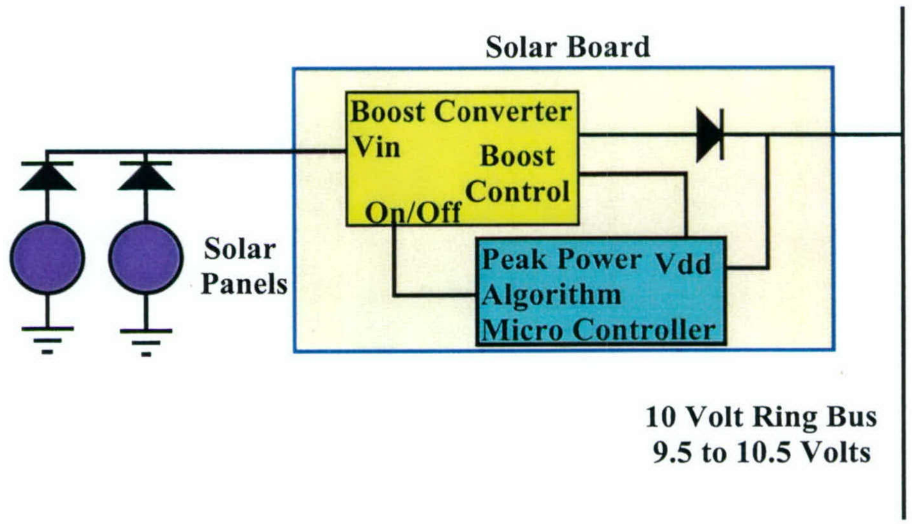

Figure 8. Schematic of PSIREX Solar Array Regulator Board.

Table 2. Efficiency Measurements of PSIREX Solar Array Board

10 Volt Ring Bus Solar Board (Rev B with mods) Load Test						
Case 1 Rload=20 ohm						
Solar (volts)	Solar Current (Amps)	Solar (Watts)	Vbus	Measured I Load (ma)	Load (Watts)	Efficiency (%)
4.0	1.78	7.12	10.60	494	5.24	73.5
3.5	2.04	7.14	10.53	478	5.03	70.5
3.3	2.17	7.16	10.50	475	4.99	69.6
3.2	2.30	7.36	10.40	472	4.91	66.7
3.1	2.35	7.29	10.35	465	4.81	66.1
3.0	Drops Out - Because PIC turns 608 off at 3.0V					
	Bringing Vsolar Back up to 3.5, VBus kicks back in to 10.53					
Case 2 Rload=15 ohm						
4.1	2.20	9.02	10.48	637	6.68	74.0
4.0	2.26	9.04	10.43	631	6.58	72.8
3.9	2.32	9.05	10.40	630	6.55	72.4
3.8	2.40	9.12	10.33	627	6.48	71.0
3.7	2.17	8.03	9.70	588	5.70	71.0
3.6	2.17	7.81	9.50	578	5.49	70.3
3.5	2.18	7.63	9.30	568	5.28	69.2
3.4	2.18	7.41	9.20	558	5.13	69.3
3.3	2.19	7.23	9.00	547	4.92	68.1
3.2	2.20	7.04	8.80	536	4.72	67.0
3.1	2.20	6.82	8.60	525	4.52	66.2
3.0	Drops Out - Because PIC turns 608 off at 3.0V					
	Bringing Vsolar Back up to 3.5, VBus kicks back in to 9.3					

5. Conclusions

The Ring Bus developed for this small satellite solves the problem of maximizing the outputs of multiple solar array panels, each of which may be at different temperatures and have different orientations with respective to the sun. The voltage of the ring bus should be selected to directly power the satellite's largest load. The solar array controller must have a peak-power-tracking algorithm to automatically provide the peak power output of the solar arrays to the power bus under all conditions.

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