

# Standard

## Electrical Power Systems for Unmanned Spacecraft

AIAA standards are copyrighted by the American Institute of Aeronautics and Astronautics (AIAA), 1801 Alexander Bell Drive, Reston, VA 20191-4344 USA. All rights reserved.

AIAA grants you a license as follows: The right to download an electronic file of this AIAA standard for storage on your computer for purposes of viewing, and/or printing one copy of the AIAA standard for individual use. Neither the electronic file nor the hard copy print may be reproduced in any way. In addition, the electronic file may not be distributed elsewhere over computer networks or otherwise. The hard copy print may only be distributed to other employees for their internal use within your organization.



## Standard

# Electrical Power Systems for Unmanned Spacecraft

### Sponsored by

American Institute of Aeronautics and Astronautics

### Approved

5 January 2007

### Abstract

This document, when followed in its entirety, will yield a robust EPS design suitable for very high-reliability space missions. This document specifies general design practices and sets minimum verification and validation requirements for power systems of unmanned spacecraft. The focus of the document is on earth orbiting satellites using traditional photovoltaic/battery power, but does not exclude other primary power generation and storage methods. This document does not address specific launch vehicle requirements however much of the design philosophy used here is applicable to launch vehicle power systems.

Library of Congress Cataloging-in-Publication Data

Standard electrical power systems for unmanned spacecraft. / sponsored by American Institute of Aeronautics and Astronautics.

p. cm.

ISBN 1-56347-913-3 (hardcopy) -- ISBN 1-56347-914-1 (electronic)

1. Space vehicles--Auxiliary power supply. I. Artificial satellites--Power supply. I. American Institute of Aeronautics and Astronautics.

TL1100.S83 2006  
629.47'445--dc22

2006038837

Published by  
**American Institute of Aeronautics and Astronautics**  
**1801 Alexander Bell Drive, Reston, VA 20191**

Copyright © 2007 American Institute of Aeronautics and  
Astronautics  
All rights reserved

No part of this publication may be reproduced in any form, in an electronic retrieval system  
or otherwise, without prior written permission of the publisher.

Printed in the United States of America

## Contents

Foreword .....	vii
1 Scope .....	1
2 Tailoring .....	1
3 Applicable Documents .....	1
4 Vocabulary .....	2
4.1 Acronyms and Abbreviated Terms .....	2
4.2 Terms and Definitions .....	4
5 Purpose of EPS .....	10
5.1 Functional Description .....	10
5.1.1 Power Generation/Energy Conversion .....	10
5.1.2 Energy Storage .....	10
5.1.3 Power Management and Distribution (PMAD) .....	11
5.1.4 Flight Software .....	11
5.1.5 Harness .....	11
5.2 Functional and Performance Requirements .....	12
5.2.1 Orbital Profile .....	12
5.2.2 Mission Life .....	13
5.2.3 Mission Phases .....	13
5.2.4 EPS Architecture .....	13
5.2.5 Power Generation .....	14
5.2.6 Energy Storage .....	16
5.2.7 Power Management .....	19
5.2.8 Power Distribution .....	20
5.2.9 Grounding and Bonding .....	22
5.2.10 Energy Management .....	22
5.2.11 Telemetry and Command .....	24
5.2.12 Power Quality .....	25
5.2.13 EMI/EMC .....	27
5.2.14 Fault Detection, Isolation, and Recovery .....	27
5.3 Design and Construction Requirements .....	28
5.3.1 Parts, Materials and Processes (PMP) .....	28
5.3.2 Product Markings .....	29
5.3.3 Manufacturing Management .....	29
5.3.4 Interchangeability & Replaceability .....	29
5.3.5 Testability .....	29

5.3.6	Maintainability .....	30
5.3.7	Safety .....	30
5.3.8	Human Performance/Human Engineering .....	31
5.4	Interface Requirements .....	31
5.4.1	Launch Vehicle .....	31
5.4.2	Launch Complex .....	32
5.4.3	Ground Support Equipment (GSE) .....	32
5.4.4	Inter-subsystem Interface Requirements .....	33
5.5	Physical Requirements .....	36
5.5.1	Power Consumption .....	36
5.5.2	Mass .....	36
5.5.3	Volume .....	36
5.5.4	Handling .....	37
5.5.5	Preservation .....	41
5.5.6	Transportation .....	41
6	Verification .....	42
6.1	Verification Responsibility .....	42
6.2	Verification Method Definitions .....	42
6.2.1	Test .....	42
6.2.2	Inspection .....	42
6.2.3	Demonstration .....	42
6.2.4	Analysis .....	42
6.2.5	Similarity .....	43
6.3	Test .....	43
6.3.1	EPS Test Requirements .....	43
6.4	Analysis .....	45
6.4.1	Power Margin Analysis .....	45
6.4.2	Voltage Drop .....	45
6.4.3	Parts Stress .....	46
6.4.4	Limited Life Items .....	46
6.4.5	Electrical Fault Analysis .....	46
6.4.6	FMECA .....	47
6.4.7	Worst Case Analysis (WCA) for Circuits .....	47
6.4.8	Solar Array Statistical Damage Assessment .....	48
6.4.9	Solar Array Radiation Environment .....	48
7	Best Practices .....	48

7.1	Energy Balance Analysis.....	48
7.1.1	Design Reference Cases .....	48
7.1.2	Worst-Case Approach .....	48
7.1.3	Analysis Quantities .....	49
7.2	Stability .....	51
7.2.1	Feedback Stability .....	51
7.2.2	Intermode Stability .....	52
7.2.3	Interface Stability .....	53
7.3	Power Quality .....	54
7.3.1	Bus Ripple .....	54
7.3.2	Transients.....	55
7.4	Grounding, Bonding, and Isolation .....	56
7.4.1	VRS Architectures.....	57
7.4.2	Isolation .....	58
7.4.3	Bonding of EPS Components to Structure .....	58
7.5	Wiring and PMP .....	58
7.6	EPS Worst-Case Analysis.....	59
7.7	EPS Failure Modes, Effects, and Criticality Analysis (FMECA) .....	60
7.8	Contingencies and Margins.....	61
8	Bibliography .....	62

## Figures

Figure 1	— Conducted Susceptibility of Loads .....	35
Figure 2	— Canonical Negative Feedback System .....	51
Figure 3	— Bode Plot .....	52
Figure 4	— Interface Between Source and Load Subnetworks .....	53
Figure 4a	— Interacting Source and Load .....	53
Figure 4b	— Non-interacting Source and Load.....	54
Figure 5	— Nyquist Plot of $Z_S, Z_L$ .....	54
Figure 6	— VRS Architectures .....	57

## Tables

Table 1	— Power Generation Uncertainty Factors .....	15
Table 2	— Minimum Growth Contingency Factors .....	23
Table 3	— Minimum Standard Load Margin .....	23
Table 4	— The Allowed Ripple for Commonly Employed Bus Voltages .....	26
Table 5	— Conducted Susceptibility of Loads .....	35
Table 5	— Ripple Requirement.....	55

Table 6 — Recommended (low-frequency) CS Levels.....55

Currently in preview, click buy full version

## Foreword

This standard has been developed under the auspices of the Chief Engineer's office of the United States Air Force Space and Missile Systems Center (SMC). It is one in a series of standards planned to codify industry best practices to ensure the very highest level of performance and reliability for the next generation of high-reliability military satellites. It follows in the footsteps of MIL-STD-1539, "Electrical Power, Direct Current, Space Vehicle Design Requirements," but has been thoroughly updated to reflect current industry design practices. It also contains new power quality requirements to replace those that were formerly called out in MIL-STD-1541A.

The starting point for this document was "Electrical Power Systems Direct Current Space Vehicle Requirements," TOR 2005(8583)-2, developed by Brian Lenertz of the Power and Analog Engineering Section of the Engineering and Technology Group at The Aerospace Corporation. Substantial improvements and additions were made to the TOR content based on the experience of the committee.

For missions that do not require all the provisions of this standard, it is understood that tailoring may be performed to balance performance, risk, and cost to suit the needs of a particular program.

The final product reflects the best design and verification practices for high-reliability satellite electric power systems. For almost all requirements, consensus was readily achieved. Three requirements, found in sections 5.2.11.1 (b), 5.2.11.3, and 5.5.4.1.7, were prescribed to meet specific needs for some government missions.

At the time of approval, the members of the AIAA Power Systems Committee on Standards were:

Brian Koch	Aerojet
Brien McCrea	Aerojet
Henry Yoo	AFRL
Derek DeVries	ATK Thiokol
Rich Merrel	ATK Thiokol
Craig Flora	Ball Aerospace and Technologies Corporation
Robb Pinkerton (co-chair)	General Dynamics Spectrum Astro Space Systems
Abbas Salim	Lockheed Martin Space Systems
Michael Piszcz	NASA Glenn Research Center
Anisa Ahmed	NASA Goddard Space Flight Center
Gregory Carr	NASA Jet Propulsion Laboratory
Charles Cunningham	NASA Marshall Space Flight Center
Farout Ayvazian	Northrop Grumman
Uno Carlsson	Orbital Sciences Corp.
Quang Lam	Orbital Sciences Corp.
Tom Danza	Space Systems/Loral
Jerry Kukulka	Spectrolab, Inc.
Brian Lenertz (co-chair)	The Aerospace Corporation

Brad Reed	The Aerospace Corporation
David Landis	The Aerospace Corporation
Azam Arastu	The Boeing Company
Stanley Canter	The Boeing Company
Winnie Choy	The Boeing Company

The above consensus body approved this document in December 2006.

The AIAA Standards Executive Council (Mr. Amr ElSawy, Chairman) accepted the document for publication in January 2007.

The AIAA Standards Procedures dictate that all approved Standards, Recommended Practices, and Guides are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement between industry or trade, in general or specific, and AIAA to adhere to any AIAA standards publication and no commitment to conform to or be guided by standards reports. However, should a procuring authority choose to use this standard and contractually impose it on a contractor or subcontractor, the use of this standard will be as defined by that particular contract.

In formulating, revising, and approving standards publications, the committees on standards will not consider patents that may apply to the subject matter. Prospective users of the publications are responsible for protecting themselves against liability for infringement of patents or copyright or both.

## 1 Scope

This document, when followed in its entirety, will yield a robust EPS design suitable for very high-reliability space missions. This document specifies general design practices and sets minimum verification and validation requirements for power systems of unmanned spacecraft. The focus of the document is on earth orbiting satellites using traditional photovoltaic/battery power, but does not exclude other primary power generation and storage methods. This document does not address specific launch vehicle requirements however much of the design philosophy used here is applicable to launch vehicle power systems.

## 2 Tailoring

When viewed from the perspective of a specific program or project context, the requirements defined in this Standard may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in consultation with the procuring authority where applicable.

NOTE Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

## 3 Applicable Documents

The following documents contain provisions, which, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to or revisions of, any of these publications do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

DoD-W-83575A	Wiring Harness, Space Vehicle, Design and Testing, General Information For
AIAA S-111	Qualification and Quality Requirements for Space Solar Cells
AIAA S-112	Qualification and Quality Requirements for Space Solar Panels
MIL-STD-1547B	Electronic Parts, Materials and Processes
MIL-STD-1543B	Reliability Program Requirements For Space & Launch Vehicles
MIL-STD-1629A	Procedures for Performing FMECA
AFSPC Man 90-710	Range Safety User Requirements
MIL-STD-883C	NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List
MIL-STD-1528A	Manufacturing Management Program
MIL-STD-1522	Standard General Requirements for Safe Design
MIL-STD-461C	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference