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Extensive Reference Explores Every Aspect Of Space Power

Spacecraft Power Systems, Mukund R. Patel, CRC Press, 2005, 691 pages, hardback; ISBN 0-8493-2786-5.

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This book is intended for those in power electronics interested in spacecraft power systems. While this is not a new publication, references such as this are somewhat rare and the concepts discussed are ones that have been developed over decades of spacecraft development. So this book remains relevant and informative. For those power system developers working in other fields and unfamiliar with space requirements, this book may be an eye opener as it sheds light on a set of environmental challenges that are literally and figuratively, out of this world.

The text is divided into four parts. The first part presents an overview of satellite systems, the various design considerations of the space environment, and power-source options and their requirements. Design tradeoffs are emphasized.

In the second part, the focus is on components: solar array, battery, power electronics and magnetics, power distribution and protection. In the third part, energy management and system dynamics are addressed, including EMI, ESD, reliability and other necessary but mundane aspects of doing a complete engineering job.

The fourth and final part covers specialized systems for interplanetary and deep-space missions that include radioisotope thermoelectric generators (RTGs), thermodynamic systems with an alternator, high-power and high-voltage systems, electric propulsion, flywheel and superconducting energy storage, fuel cells and microwave beam-power satellites.

To the author's credit the book provides (in the front pages) a list of the many acronyms and abbreviations used. In reviewing this large book, I did not read it in detail and my comments are based on a perusal of it. The emphasis is on system-level considerations, as the title states, and although a few circuit diagrams appear, circuit-level explanations are secondary in emphasis. However, enough detail is covered on components for system consideration. The breadth of coverage shows the depth of experience of the author in that essentially every conceivable aspect of the topic is touched upon, making the book valuable as a bench reference for anyone involved in spacecraft power design.

The opening chapters are particularly good in providing an understanding of satellites, their orbits and stabilization methods, and the periods when the sun is not available for solar charging, such as when a geosynchronous satellite is eclipsed in the penumbra of the earth. Spacecraft power requirements increase, of course, with satellite mass. A small scientific satellite of 1000 kg typically requires 5 kW while a large geosync communication satellite can weigh 4000 kg and need 15 to 20 kW.

A wide range of deleterious effects occur in space for satellite power systems. Not only meteoroids and space debris pose a hazard, so does atomic oxygen, which erodes materials such as silver on solar arrays. Charged particles of various kinds and the Van Allen Belts complicate the electrical circumstances, as do solar flares and geomagnetic storms. Manmade nuclear detonations can also be threatening.

Some of the subject matter is similar to off-grid alternative energy. Chapter 4 on "Photovoltaic-Battery System" is in that category. Batteries for space use are covered, and the most widely used is the NiH_2 cell, which is a combination of two electrochemistries, the nickel oxide electrode from NiCd batteries and the hydrogen catalyst electrode from fuel cells. The NiH_2 counterpart in off-grid electric systems on earth is the NiFe battery. Though the NiH_2 battery has low energy density and very long cycle life, as does the NiFe battery, it has a higher specific energy than its earth-bound counterpart that uses iron instead of hydrogen for its negative electrode.

Of particular interest for *How2Power* is chapter 10, "Power Electronics and Magnetics". Spacecraft power is supplied via a power bus, controlled for a constant voltage. Other power converters supply loads from it. With solar arrays, excess power requires a shunt bus-voltage regulator. To minimize heat dissipation onboard the craft, some arrays are shorted to minimize their power. The array heats and dissipates the excess power to space. These shunts which short the array can be PWMed for linear control.

Buck converters charge the batteries; boost converters discharge them to the loads. The magnetics concepts presented are very basic in a *How2Power* context. Other chapters describe power distribution harnesses, solar array tracker drives, thermal control and EMI shielding.

Under Part C, Power System Performance, are chapters on power management, including load budgeting, taking orbits in consideration. (There are no clouds but the sun is obscured in other ways.) Bus dynamic performance involves bus impedance over frequency, transients, and high-frequency ripple. Then there are sections on fuse blowing and the voltage transients caused by them. (The author does not address why fuses, which cannot be replaced, are even used on unmanned spacecraft.)

EMI and EMC are covered, presenting basic concepts. The description of an electromagnetic pulse (EMP) from a nuclear detonation was interesting (page 417): "A nuclear burst can upset electronic systems hundreds of miles away. Therefore, it is usually included in the defense spacecraft power system requirements." The Figure 15.23 caption reads: "A nuclear burst in LEO [low earth orbit] altitude can destroy many satellites."

ESD is a particular problem in space because spacecraft are floating in worse than a vacuum—in space plasma, which can charge various insulating surfaces and cause arcing between them. The plasma current density is much higher in LEO—at low orbital latitudes—than at GEO, but at low energy, resulting in low-voltage differences on isolated insulating spacecraft surfaces, while at GEO, the differences can be 1 kV or higher. The solution at LEO is to cover surfaces with a coating of insulation while at GEO, conductive coating is used to drain charge across voltage differences of surfaces. Reliability and redundancy comprise another chapter as do integration and testing.

The final part of the book is about "Special Power Systems" and begins with a discussion of what is involved in interplanetary and deep-space missions. On such long missions with inadequate solar power, RTGs can supply several hundred watts for years. They run on the heat generated by the nuclear decay of safe, expensive fuels such as plutonium 238 or curium 244, or cheap, dangerous isotopes such as strontium 90. Thermoelectric (TE) conversion is achieved with arrays of thermocouples in TE converters (TECs) that have an efficiency of about 7%, or in new segmented TECs, 15%. An alternative to TECs is a Stirling-cycle engine (the subject of another chapter) which can be made with one moving part and operate at a low temperature difference.

Closing chapters are on electric or magnetic propulsion, flywheel energy storage, and satellites powered by microwave beams.

The book is driven more by illustrations, graphs, and tables than by equations, though a few appear here and there. Even so, the information density in the book is moderately high. Anyone interested in the big view of engineering power systems for space will benefit from a copy of this book. It covers essentially every conceivable aspect of the subject.

About The Author

Dennis Feucht has been involved in power electronics for over 30 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.

To read Dennis' reviews of other texts on power supply design, magnetics design and related topics, see How2Power's Power Electronics Book Reviews.

For news and information about power converters and power components for space applications, see How2Power's special section on Space Power.