Electronic Design

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Power Density in NASA Small Spacecraft Systems

Achieving the power density required for small spacecraft systems such as CubeSats involves determining their individual power needs, solar-cell type, and overall operational environment.

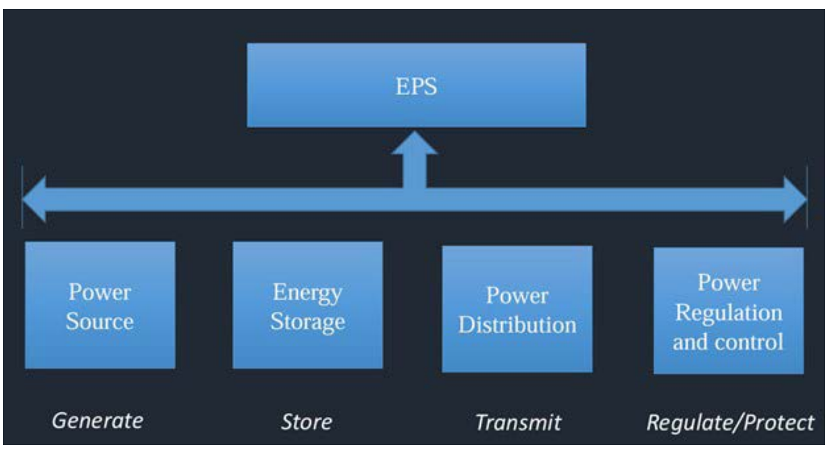
Electrical power system (EPS) designs for NASA's spacecraft have a powerful and essential subsystem that surrounds the electrical power generation, storage, and distribution. It encompasses a large portion of volume and mass in any spacecraft.

Continuously powering these electrical subsystems requires solid power density. Controlling the generated power while focusing on capability gaps that may exist within the spacecraft transportation power systems, especially for astronaut exploration vehicles, requires high-efficiency power systems, as well as surface nuclear and mobile power systems.

Electrical Power Systems in Spacecraft

The spacecraft EPS must safely supply continuous power to all subsystems throughout the mission life, which includes eclipses as well as adequate nighttime power. And it must provide enough power margin during average as well as peak loads.

Power converters have to supply downstream energy for various voltage loads. And bus isolation is critical between upstream and downstream loads. EPS health and status must be provided, too, such as current, voltage, temperature, and more. A typical EPS subsystem is shown in *Figure 1*.



1. This is a typical EPS subsystem. (Courtesy of NASA)

NASA spacecraft power-generation technology encompasses such things as photovoltaic cells, panels and arrays, and radioisotope or other thermonuclear power generators. Power storage is usually applied via batteries such as single-use primary batteries or rechargeable secondary batteries.

NASA's power management and distribution (PMAD) systems strongly promote power control to all spacecraft electrical loads. These loads take on an assortment of forms that are typically custom-designed to meet specific mission requirements.

EPS engineers will typically target a high specific power or power-to-mass ratio watt-hour per kilogram (W-h/kg) when selecting power-generation and storage technologies that will minimize system mass. The EPS volume will most likely be the constraining factor for nanosatellites.

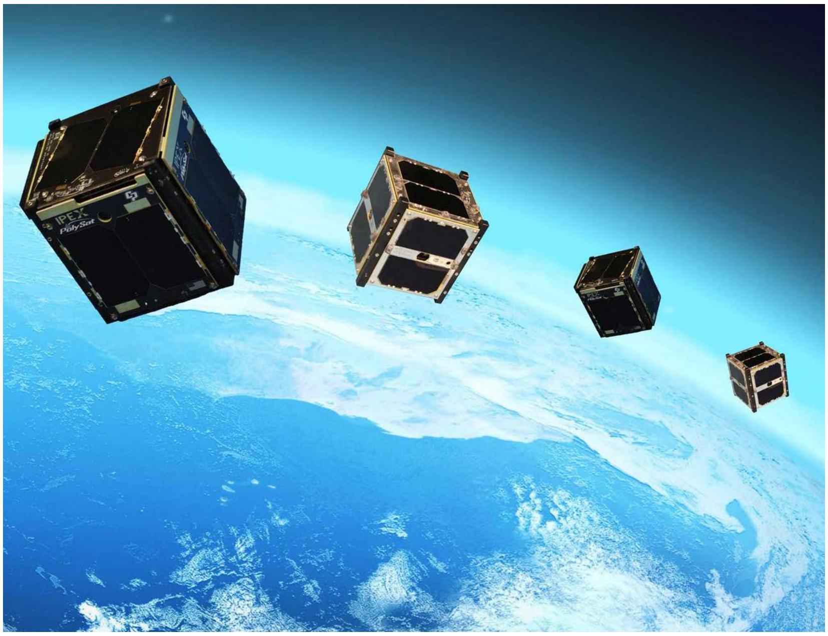
Power Density of CubeSats and SmallSats

NASA CubeSats are nanosatellites in a standard size and form factor *(Fig. 2)*.

SmallSats, for instance, have a mass that's usually smaller than 180 kg—they're generally the size of a large refrigerator. They come in a variety of sizes and mass, listed in descending size order below:

- Mini-satellite, 100-180 kg
- Microsatellite, 10-100 kg
- Nanosatellite, 1-10 kg
- Picosatellite, 0.01-1 kg
- Femtosatellite, 0.001-0.01 kg

NASA Ames' SmallSat mission timeline began March 1972 when Pioneer 10



2. Shown are CubeSats and SmallSats. (Courtesy of NASA JPL)

was launched, followed by Pioneer 11's launch in April 1973. These two missions were the trailblazers for the Voyager 1 and 2 missions.

NASA Ames' recent SmallSat program focused on Lunar exploration, with the Lunar Prospector's launch in January 1998. LCROSS explored the lunar landscape in June 2009.

In September 2013, the LADEE program explored the lunar landscape.

What's a CubeSat?

The CubeSat nanosatellites have a standard size and form factor. CubeSat size has a "one unit" or "IU" measuring 10 × 10 × 10 cm, with the ability to extend to larger 1.5, 2.3.6, and 12U sizes.

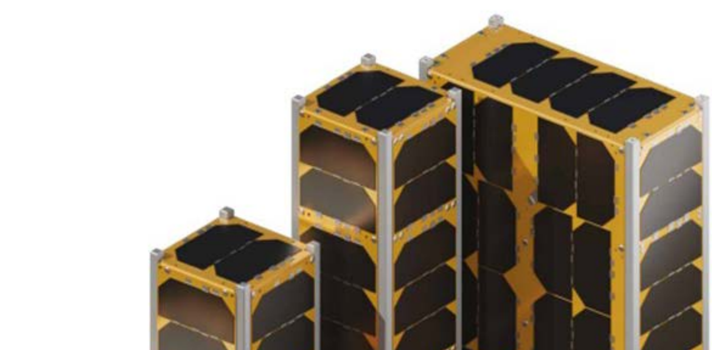
The CubeSat was first developed at California Polytechnic State University in 1999 at San Luis Obispo (Cal Poly) and Stanford University. It enables a cost-effective platform for science investigation, demonstration of new technology, and advanced mission concepts employing constellations, swarms, and disaggregated systems:

- **Constellations** are multiple small groups of satellites (GPS, Iridium, and more) individually controlled by ground, in different orbits, which provide for a predictable and stable communication link emanating from a particular location in outer space (GPS, Iridium, and more). The spacecraft can exchange data but may not know each other's movements and motions
- **Swarms** are more autonomous systems that can reconfigure and adapt to reach mission goals. These multiple, large groups of spacecraft may operate in close proximity of each other and require spatial configuration. And they may actively work as a "collective" that completes a common task, such as redundancy (spatial coverage, communication, and more).
- **Disaggregated systems** tend to be smaller, more numerous, and more easily produced, which leads to a resilient constellation.

High-priority science investigations in the future will need data from constellations or swarms of 10 to 100 spacecraft. Thus, for the first time, it will enable the temporal and spatial coverage that can map out and characterize the physical processes leading to shape the space environment of near Earth.

These 10 to 100 constellations of science spacecraft will allow for measurements that are critical in space science, along with related space weather and climate as well as astrophysics and planetary science topics.

Ultimately, NASA will be able to implement large-scale constellation missions that can take advantage of CubeSats or CubeSat-derived technology, along with a philosophy of evolutionary development.



3. These solar panels were developed for CubeSat platforms. (Courtesy of CubeSat Power Solutions)

Solar-Panel Power for Small Satellites

DHV Technology, based in Spain, manufactures and designs solar panels for space applications.[3] They include custom and standard solar-array solutions for any kind of CubeSat platform, such as 1U, 2U, 3U, 6U, 12U and 16U *(Fig. 3)*. One example is the DHV-2U Series 2U CubeSat Solar Panel, which offer high-efficiency power generation, useful telemetry date for thermal aspects and attitude, plus determination and control.

The DHV-2U Series provides power generation in low-Earth-orbit (LEO) missions for a minimum of at least three years and temperatures between −50 and +125°C. It also ensures good protection against atomic oxygen, a highly reactive form of oxygen (O and O_1) whereby individual atoms of oxygen will tend to bond with any nearby molecules.

On the surface of the Earth, atomic oxygen exists naturally for only a very short time. When in outer space, the presence of enough ultraviolet radiation will result in a LEO atmosphere where 96% of the oxygen will occur in atomic form. Atomic oxygen has been detected on Mars by Mariner, Viking, and the SOFIA observatory.

Summary

NASA power density, in a small spacecraft system, is driven by size and weight limitations. Small spacecraft will tend to use storage technology and advanced power generation, including higher than 32% efficient solar cells and lithium-ion batteries.

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