Fortifying computer chips for space travel

September 7 2015, by Kate Greene

Dec. 4, 2014 — At Space Launch Complex 37 at Cape Canaveral Air Force Station in Florida, fueling of the Delta IV Heavy rocket has been completed. The countdown continues for launch of NASA's Orion spacecraft. Credit: NASA

Space is cold, dark, and lonely. Deadly, too, if any one of a million things goes wrong on your spaceship. It's certainly no place for a computer chip to fail, which can happen due to the abundance of radiation bombarding a craft. Worse, ever-shrinking components on microprocessors make computers more prone to damage from high-energy radiation like protons from the sun or cosmic rays from beyond our galaxy.

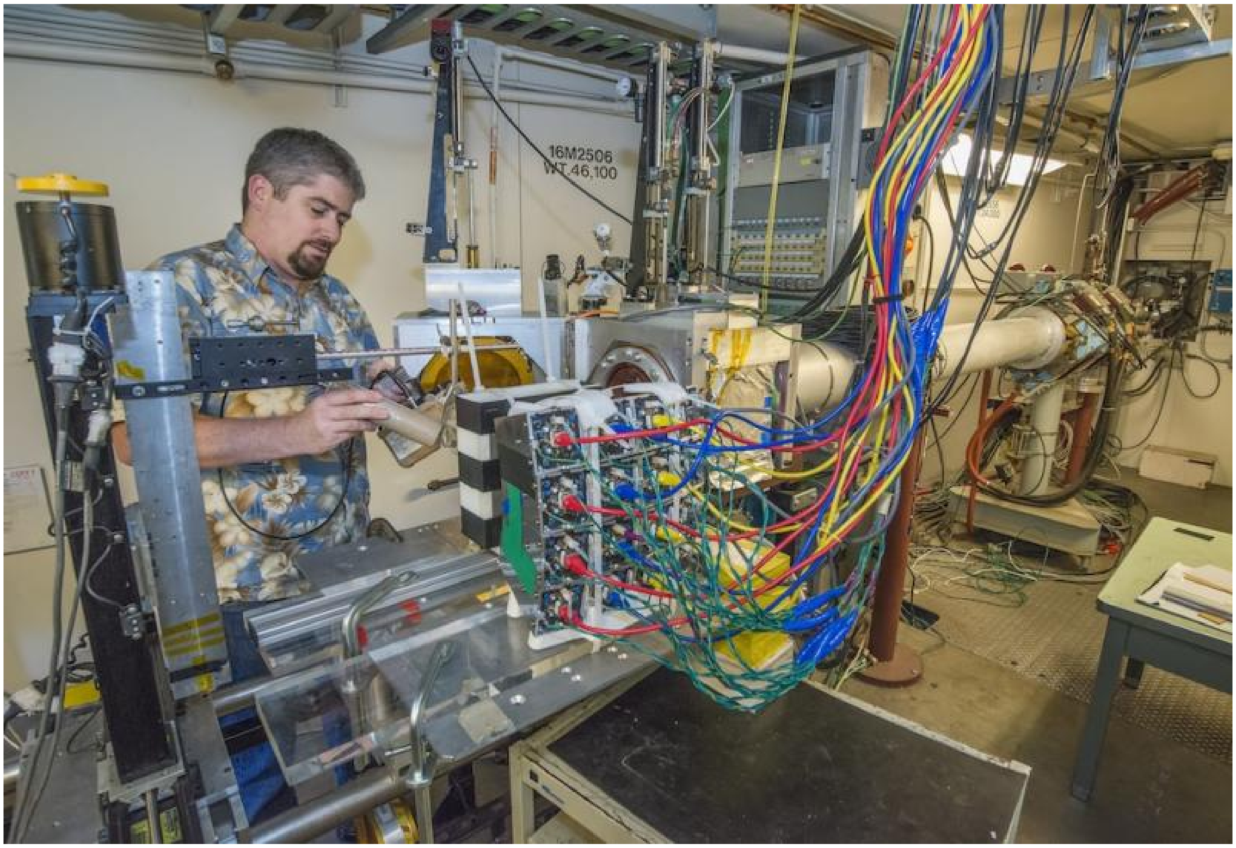
It's a good thing, then, that engineers know how to make a spaceship's microprocessors more robust. To start, they hit them with high-energy ions from particle accelerators here on Earth. It's a radiation-testing process that finds a chip's weak spots, highlighting when, where, and how engineers need to make the microprocessor tougher.

One of the most long-lived and active space-chip testing programs is at the U.S. Department of Energy's Lawrence Berkeley National Lab (Berkeley Lab). Sitting just up the hill from UC Berkeley, in Berkeley Lab's Building 88, is the 88-Inch Cyclotron, a machine that accelerates ions to high energies along a circular path.

Since 1979, most American satellites have had one or more electronic components go through Berkeley Lab's cyclotron, says Mike Johnson, research coordinator at the 88-Inch Cyclotron. Chips on the Mars rover Curiosity, chips on the Solar Dynamics Observatory, chips on the space shuttles, and chips on the International Space Station have all been put through the paces in the particle accelerator before launch. The goal is relatively simple, says Johnson: it's to "piece together a curve of the likelihood that there's going to be an error."

Mistake-free Mars

NASA has publicly announced that it plans to send astronauts to Mars by the 2030s. A Mars trip would be a multi-year mission that will expose the crew and vessel to more radiation than any other manned mission in history. Currently, Johnson says, some electronics destined for NASA's new Mars-bound space craft called Orion are being tested at the facility.



Michael Johnson, Nuclear Science Division, in caves 4A,4B of the 88 inch Cyclotron. Credit: Roy Kaltschmidt, Berkeley Lab

As with any chip under testing, the Orion processors are mounted in a vacuum chamber in the direct line of fire from a so-called cocktail beam. This beam, Johnson says, mimics protons from coronal mass ejections and cosmic rays, but at lower energies. Because it's actually a mixture of different ion energies, the cocktail beam lets scientists easily step the energy up or down, depending on the application. For instance, a satellite orbiting Earth feels a different kind of radiation–thanks to protection by the Earth's magnetic field–than a capsule taking people to Mars where there's no magnetic field to deflect protons from the sun.

What happens when radiation hits a chip? "As an ion goes through a microprocessor, it leaves a destructive trail of charged particles that can cause temporary disruption or permanent damage," says Johnson. Bombarding a chip in a cyclotron is one of the best ways to see how it fails. "Once you know how the microprocessor is going to behave, you can make parts stronger, re-engineer it, add redundancy or shielding," Johnson says. "It can also help with designing software" that can, for example, automatically reboot a system or reroute certain functions.

In the case of Orion, which last December had its first (unmanned) test flight around Earth, a number of radiation safeguards have already been put in place. Specifically, the microprocessors are, by design, more than a decade old. This is because older electronics contain larger transistors, which means they're less sensitive to interaction with an ion.

And importantly, the chips themselves are housed within significant radiation shielding. Engineers think the processors in the flight computer won't be at great risk of radiation thanks to their well-tested design and shielding. But plenty of fail-safes have been included just in case. Orion has two backup flight computers that can go online if the main one needs to reboot, a process that takes about 20 seconds. Additionally, there are two other processors within the flight computers running error-checking software to make sure the outputs of the primary processors aren't off. Thus, radiation is unlikely to cause catastrophic electronic failures on Orion.

Cyclotron Past and Future

Berkeley Lab's cyclotron splits its time between chip radiation testing

(40 percent) and conducting U.S. Department of Energy nuclear physics research on superheavy elements (60 percent). The elements 110 and 114 were verified at the facility, and numerous new isotopes have been discovered over the last decade. Other Berkeley Lab accelerators, under Glenn Seaborg, were responsible for the discovery of 16 new elements on the periodic table.

The 88-Inch cyclotron was built in the 1960s. The venerable machine is still competitive and relevant today, explains Johnson, because of its ion source, which inject particles into the accelerator. The VENUS Ion Source is currently the most powerful in the world with several world records in terms of its ability to remove electrons from atoms. "Since we can't change the cyclotron magnet, we have one of the most advanced ion sources in the world," Johnson says.

As well as keeping the ion source powerful, engineers at the cyclotron are also making improvements to the beam that blasts the microprocessors during testing. A current project aims to shape the particle beam to be much smaller and more focused. Right now, a microbeam is available that comes in at about 10 microns by 10 microns, but within a year, says Johnson, his team hopes to shrink the size to the sub-micron level to better pinpoint the radiation problems in chips.

In the meantime, engineers come from all over the country to test electronics for a variety of space and terrestrial applications. High-energy particles aren't just in space, after all. A small number of these particles reach the surface of the planet too. Therefore, versions of next-generation chips for phones and computers are currently under evaluation at the cyclotron. More-reliable electronics in space and on Earth: brought to you by the 88-Inch Cyclotron.

Provided by Lawrence Berkeley National Laboratory