That's just rad! Radiation-hardened chips take space tech and nuclear energy to new heights

The next generation of rad-hard chips is helping bring devices used in high-radiation environments into the 21st century at last.

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THEY'RE SMALL, THEY'RE smart, and they can tolerate radiation levels that would bring most other chips to their knees. Deloitte Global predicts that the radiation-hardened (rad-hard) electronics market will top US$1.5 billion in sales globally in 2023.[1] That's just a fraction of the expected US$660 billion-plus total chip market for the year,[2] but these chips are mighty because of what they enable, not how much money they represent.

Advanced rad-hard chips could transform whole industries

Ionizing radiation, about a trillion times more energetic than the UV that causes skin cancer, is bad for chips. Ionizing radiation can damage chips cumulatively over time (measured by total ionizing dose or TID), degrading performance and eventually making the device useless. Another radiation effect is caused by high-energy particles.

These cause single-event effects and flip the value of a transistor from one to zero or vice versa on a processor or in memory—a phenomenon called a "bitflip." After enough of those flips, calculations are ruined, or a permanent and fatal error called a "latch-up" can occur.[3]

Even on Earth, bitflips can be caused by solar flares of high-energy particles entering the Earth's atmosphere. In space, single-event effects are a concern, given the small transistor sizes. Meanwhile, TID is a concern in longer-term missions. Several terrestrial applications (such as nuclear fusion and cleanup at Fukushima[4]) require hardness towards gamma radiation. In another example, making the medical devices that are exposed to X-rays radiation-tolerant will help extend their longevity.[5]

Although rad-hard chips can be useful for all sorts of applications, two of the biggest are in space and nuclear energy.

Space. Space is a harsh environment for chips. Vibration, severe thermal variations, electrostatic discharge, and G-forces on launch all require space-bound chips to be tougher than those in the average smartphone. Of these dangers, radiation is arguably the biggest of them all. Earth's atmosphere is a highly effective radiation shield. But satellites in orbit, especially higher orbits, are above much of the atmosphere and thus continuously exposed to high levels of damaging radiation, and intermittently exposed to even higher radiation levels when the sun is at its most active. Except for inside the shielded portion of the International Space Station, most chips in space today are "legacy chips", radiation tolerant, but made with older technologies that render them incapable of the kind of processing we take for granted on even a mid-range smartphone: AI image processing, graphics manipulation, and so on. For this reason, many space-based devices are "dumb terminals": They capture images, provide connectivity, and maneuver themselves, but require Earth-based processing to assist in all those things. They need to send everything down to Earth, wait for Earth to figure out what to do, then wait for Earth to transmit the right commands back. This can be slow.

New generations of rad-hard electronics for space environments will likely change that, with potentially enormous benefits. For example, NASA's Space Cube is a family of FPGA onboard systems that help boost onboard computing capability, autonomy, and artificial intelligence/machine learning (AI/ML) in space.[6] With such advancements, spacecraft can become smarter, last longer, and be more reliable, all at the same time. Imaging satellites could observe a natural disaster

HOW RAD-HARD CHIPS ARE MADE

There are two approaches to make chips rad-hard: the physical and the logical. In the first (the focus of this prediction) chips are physically made differently: They are made of different materials such as silicon carbide (SiC) or gallium nitride (GaN) (see companion prediction on these materials), or the processing layer of silicon can be on an insulating layer or substrate. Other options include using bipolar integrated circuits instead of traditional CMOS, leveraging DRAM instead of SRAM, shielding with depleted boron, or radiation hardening by design. Moreover, in case of space applications, normal packages won't be able to withstand the G-force and other environmental conditions. Therefore, rad-hard chips require special packages (e.g., ceramic) that can withstand higher G-forces and wider temperature ranges better than other common materials. Design and layout techniques can also be used to harden a technology. Logical hardening can be accomplished via various kinds of redundancy, but also special hardened latches, layout techniques, and timing circuits.

such as an undersea earthquake and send tsunami alerts hours earlier, potentially saving millions of lives. Illegal methane emissions (methane contributes to short-term global warming 85 times more than CO_2)[7] could be detected in real time, and offenders more quickly caught and fined. Satellites at risk of collision could move—on their own initiative—much faster than they can today, mitigating the risk of runaway collisions and debris in orbit.[8]

Nuclear energy. Although nuclear fission energy production has decreased in the last 20 years due to concerns about safety and waste, the clock is ticking on reaching the Paris Agreement’s 2030 climate goals, and fission is attracting renewed attention as a result.[9] Multiple new, modern nuclear power plants, smaller and safer than those from the past, have been proposed for the next decade. These new kinds of nuclear reactors are already being enabled by increasingly advanced rad-hard chips.

However, the Holy Grail of nuclear energy is not fission, but likely fusion. Cleaner, greener, and (theoretically) even more powerful, successful fusion reactors could help solve the planet’s greenhouse gas emissions in a few decades. But making fusion work requires magnetic fields, high pressures, and constantly fluctuating temperatures, all of which need to be sensed, interpreted, and controlled with chips that are both extremely powerful and extremely radiation-resistant.[10] With recent progress making fusion power possibly more feasible than previously thought,[11] the need to run these reactors could be a key driver of demand for rad-hard chips by the end of the decade.

THE BOTTOM LINE

As the recent chip shortage has highlighted, it isn't a great idea to have the manufacturing of any given kind of chip in only one or two plants. Countries and regions will likely want to make sure that they have local suppliers and makers of rad-hard chips. As an example, the US federal government is spending US$170 million to advance rad-hard chip manufacturing in Minnesota.[12]

Rad-hard chips are important for military and national security too. Secret military surveillance satellites and nuclear weapons would both be key examples. Chip self-sufficiency for all military applications is low: As of 2021, only 2% of the chips used by US military systems were made in trusted US-based foundries.[13]

Interestingly, shorter-duration missions at lower altitudes could even use commercial, off-the-shelf (COTS) chips that are radiation hardened at the system level instead of dedicated, special rad-hard chips. This could represent a marked shift in the rad-hard field, lowering the cost of chips for certain space applications.[14]

As mentioned above, another area of using rad-hard chips in space is integrating AI/ML capabilities and bringing edge computing to space applications. This could alleviate the need to send all the pictures and images they capture back to the Earth for further analysis and insight—and over a limited network bandwidth. By integrating AI/ML capabilities alongside rad-hard chips onboard, the space equipment can potentially handle all the advanced analytics by itself—image detection, image classification, automated decision, and timely action.[15]

Besides bolstering onboard analytics, companies are experimenting with launching analytics-heavy payloads into orbit, dedicated to performing advanced data processing and analytics. Such dedicated, compute-intensive satellites can serve as hubs in delivering edge computing services to other orbiting satellites.[16]

Companies and governments will likely want to encourage continued research and development of rad-hard technologies. Recent initiatives, such as NASA's High-Performance Spaceflight Computing (HPSC) project, focus on enabling next-generation space missions using advanced chips and modern architecture—all with the intent of supporting the ambitious plan of taking humans back to the Moon and forward to Mars. NASA and Microchip have recently collaborated on a US$50 million project to develop a spaceborne processor that will outperform current industry processors by 100 times.[17]

Paths to continue exploring include materials such as compound semiconductors (GaN and SiC), use of traditional silicon in new ways (FinFET and SOI), and creating rad-hard versions of popular and useful commercial technologies such as ARM or RISC-V.[18] Moreover, the advanced tech nodes and smaller linewidths at sub-10 nm—which several chip majors are piloting today—can help reduce the overall weight of the launch unit. This can be critical to containing the overall project cost, while improving the mission's success probability.

The biggest challenge will likely be for the satellite industry. For decades, space-based sensors relied on Earth-based processing. Significantly increasing onboard processing and memory is a whole new opportunity: It will be exciting to see what the industry can do with these new capabilities over the next few years.

Endnotes

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