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EE Times: Design News

# MEMS launches software-defined radios in space

R. Colin Johnson
(08/06/2007 9:00 AM EDT)
URL: http://www.eetimes.com/showArticle.jhtml?articleID=201202977

The National Aeronautics and Space Administration has begun a program to develop MEMS technologies that reduce the size, weight and power of its radio transceivers. Of particular concern to NASA is miniaturizing the radios for its space-constrained extra-vehicular activities (EVAs) known as "space walks."

NASA proposes that industrial partners begin developing reconfigurable multiband MEMS chips that can be inserted into future frequency-agile software-defined radios.

The exploration of space imposes daunting specification goals on component suppliers--demanding a combination of small size, light weight, low power, radiation immunity, vibration tolerance and extreme longevity. Luckily, those specifications read almost like a definition of microelectromechanical systems, putting MEMS in space from the earliest Shuttle launches.

"I would be surprised if there was a single Shuttle launch that did not have one of our MEMS devices on board," said Harvey Weinberg Sr., applications engineer at Analog Devices Inc. (Waltham, Mass.).

The market for any space application is naturally small, since relatively few spacecraft are launched annually, and the market for MEMS in space is no exception. On the other hand, NASA has often pioneered areas that trickle down to the military and commercial arenas, such as in the case of Teflon, which began as a coating for the Shuttle's fireproof tiles and ended up in consumers' pots and pans. However, the reverse seems to be true for MEMS.

"In many MEMS devices, it was the commercial and military applications that came first," said John Vig, a 36-year veteran military researcher. Vig advises the Defense Advanced Research Projects Agency on its RF MEMS development program. "Darpa has a very aggressive RF MEMS program, and I'm sure that many of its developers will want to submit proposals to NASA, too," said Vig.

MEMS specifications for Earthly automotive applications also dovetail well with those of space explorations; after all, the safety of drivers and passengers in cars is not so different from the safety of astronauts in space vehicles. Likewise, automobile applications typically specify at least a 15-year life span, which matches well with the longevity requirements for deep-space probes.

"MEMS sensor development for harsh environments, such as those found in automotive, military, and telecommunications markets, has resulted in their increased adoption and expanded usage for space applications," said Jim Walker, vice president of research in semiconductor manufacturing at Gartner/Dataquest.

**RF MEMS**

SiTime Inc. (Sunnyvale, Calif.) already makes MEMS oscillators that operate as high as 125 MHz and is developing chips that gang multiple MEMS resonators on the same die to form the banks of RF filters needed to implement NASA's ultra-miniature software-defined radios.

"MEMS is the ideal technology for space exploration," said Aaron Partridge, chief technology officer at SiTime. "MEMS leverages the IC infrastructure to produce extremely reliable devices with very small size, very low in power consumption and insensitivity to the radiation and extreme temperatures of space."

Discera Inc. (San Jose, Calif.) also makes MEMS oscillators and is developing RF MEMS filters and other radio

components. The company has had its MEMS chips tested for shock and vibration immunity by the U.S. military, via a contract with Tyco Electronics unit M/A-Com (Lowell, Mass.), which is using Discera's MOS-1 MEMS oscillator in a wireless transmitter for smart munitions. During military testing regimes, the explosives were removed from some warheads, allowing artillery shells to be retrieved after impact--and Discera's oscillators were still ticking.

"Our parts have been tested by the military for up to 50 G's of vibration, for 14,000 G's impacts, and for 25,000 G's of acceleration in a centrifuge, with 100 percent reliability--every part performed within spec with only 1.4 parts per million variation in the frequency of oscillation," said Wan-Thai Hsu, chief technology officer at Discera.

NASA has begun qualifying MEMS oscillators for space exploration and has found that MEMS oscillators also operated over a wide range of temperatures. In an internal paper co-authored with Ahmad Hammoud at ASRC Aerospace Inc. (Cleveland), titled "MEMS Silicon Oscillators at Extreme Temperatures," NASA program manager in extreme temperature electronics, Richard Patterson, at its Glenn Research Center (Cleveland), said, "The small size of the MEMS oscillators along with their reliability and thermal stability make them ideal candidates for space exploration missions."

As a first step to qualifying MEMS oscillators for space missions, Patterson and Hammoud tested an off-the-shelf MEMS oscillator from SiTime at extremely low and high temperatures.

"NASA got an absolutely typical part, and we frankly do not have the equipment to test for temperatures as cold as spacecraft can get," said SiTime's Partridge.

Patterson and Hammoud discovered that SiTime's MEMS oscillator functioned from +100°Cdown to –110°C, a range that exceeded their specified –40°C to +85°C. Also, the MEMS oscillator was able to cold re-start at –110°C and exhibited no change in performance during thermal cycling up and down between the extremes. NASA proposes to evaluate SiTime's MEMS oscillators for extended space exploration missions under extreme temperatures.

MEMS oscillators are just the latest MEMS devices used by NASA's exploration of space. MEMS accelerometers, gyroscopes and other specialized inertial devices have been keeping astronauts safe and spacecraft navigational systems on track for a decade.

Like MEMS oscillators, the big advantage of MEMS inertial devices is their resistance to vibration and shock, as well as their small SWAP (NASA-speak for size, weight and power).

"MEMS gyroscopes are orders of magnitude smaller and use much less power, but they are also much more tolerant to vibration and electromagnetic pulses," said Adam Champy, an applications engineer at ADI. "Their immunity to vibration and shock comes from their being so small that their resonant frequency is very high--around 14 KHz--compared to normal gyros, whose resonant frequency is only about 100 Hz, which makes conventional gyros much more sensitive to the vibrations of launching."

MEMS devices in space also share many of the requirements for other earthly applications, in particular the same need for ultrahigh reliability as ADI's accelerometers in cars, which are used to trigger airbags.

"MEMS is ultrareliable compared to other types of inertial sensing technologies, which have many moving parts that are put together by watch makers," said Weinberg. "Those big, bulky inertial sensors also need circuit boards for their controllers, which can develop broken solder joints and all sorts of other failures. Our accelerometers and gyros, on the other hand, use a single piece of silicon to replace all that complexity. There is just not very much that can go wrong."

The failure mechanisms of electronic devices are most often their interconnects, according to NASA. So by getting the interconnects off the board and integrated into on-chip circuitry, a MEMS chip all but eliminates the sources of fatigue in a mechanical device.

"Silicon is an almost ideal mechanical element when it is used over a small range," said Weinberg. "There are simply no wear-out mechanisms. As proof, ADI has 300 million MEMS devices in the field, and we have never had a single case of one wearing out."

In addition, even when MEMS devices do fail, by virtue of mechanisms unrelated to fatigue, they often have built-in self-testing capabilities that enable ground-based NASA engineers to diagnose the problem remotely.

"There is nothing that humans have, can or will build that has 100 percent reliability, so we build our MEMS devices to tell you when something is wrong," said Weinberg. "All of our MEMS devices are built with internal self-test systems with very high coverage--meaning that if our part says it passes self-testing, then you can have a very high confidence that our part is OK."