Sandia Labs News Releases

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World's smallest atomic clock on sale

Sandia researchers develop tiny laser that reduced power consumption 1,000-fold

ALBUQUERQUE, N.M. — A matchbook-sized atomic clock 100 times smaller than its commercial predecessors has been created by a team of researchers at Symmetricom Inc. Draper Laboratory and Sandia National Laboratories.

The portable Chip Scale Atomic Clock (CSAC) — only about 1.5 inches on a side and less than a half-inch in depth — also requires 100 times less power than its predecessors. Instead of 10 watts, it uses only 100 milliwatts.

"It's the difference between lugging around a device powered by a car battery and one powered by two AA batteries," said Sandia lead investigator Darwin Serkland.

Despite common implications of the word "atomic," the clock does not use radioactivity as an energy source. Instead, where an old-fashioned alarm clock uses a spring-powered series of gears to tick off seconds, a CSAC counts the frequency of electromagnetic waves emitted by cesium atoms struck by a tiny laser beam to determine the passage of time. (*There's a fuller, more interesting description of this process below.)*

Still, given that the CSAC does not actually display the time of day — measured in millionths of a second, its passage would defy the ability of human eyes to read it — why would anyone want it?

The clock's uses are, indeed, specialized. Miners far underground or divers engaged in deep-sea explorations, blocked by natural barriers from GPS signals, could plan precise operations with remote colleagues who also had atomic clocks, because their timing would deviate from each other by less than one millionth of a second in a day.

A CSAC timekeeper would be invaluable to experts using electromagnetic interference to prevent telephone signals from detonating improvised explosive devices, or IEDs. Though GPS signals also would be blocked, a CSAC timekeeper would still function.

On a nationwide scale, relay stations for cross-country phone and data lines, which routinely break up messages into packets of information and send them by a variety of routes before reconstituting them correctly at the end of their voyages, would continue functioning during GPS outages.

The clock's many uses, both military and commercial, are why the Defense Advanced Research Projects Agency (DARPA) funded the work from 2001 until the CSA Clock hit the commercial market in January.

"Because few DARPA technologies make it to full industrial commercialization for dual-use applications, this is a very big deal," said Gil Herrera, director of Sandia's Microsystems and Engineering Sciences Application (MESA) center. **"**CSAC now is a product with a data sheet and a price."

Cesium atoms are housed in a container the size of a grain of rice developed by Cambridge, Mass.-

based Draper Lab. The cesium atoms are interrogated by a light beam from a vertical-cavity surface-emitting laser, or VCSEL, contributed by Sandia. Symmetricom, a leading atomic clock manufacturer, designed the electronic circuits and assembled the components into a complete functioning clock at its Beverly, Mass., location.

"The work between the three organizations was never 'thrown over the wall,'" said Sandia manager Charles Sullivan, using an expression that has come to mean complete separation of effort. "There was tight integration from beginning to end of the project."

Nevertheless, the reduced power consumption that was key to creating the smaller unit required, in addition to a completely new architecture, a VCSEL rather than the previous tool of choice, a rubidium-based atomic vapor lamp.

"It took a few watts to excite the rubidium lamp into a plasmalike state," Serkland said. "Use of the VCSEL reduced that power consumption by more than a thousand times to just two milliwatts." (Serkland's success in attaining this huge power reduction caused some in the clock business to refer to him as "the VCSEL wizard.")

The way the clock keeps time may best be imagined by considering two tuning forks. If the forks vary only slightly in size, a series of regular beats are produced when both forks vibrate. The same principle works in the new clock.

The VCSEL — in addition to being efficient, inexpensive, stable and low-power — is able to produce a very fine, single-frequency beam. The laser frequency, at 335 terahertz (894.6 nanometers), is midway between two hyperfine emission levels of the cesium atom, separated in terms of energy like the two differently sized tuning forks. One level is 4.6 gigahertz above and the other 4.6 gigahertz below the laser frequency. (Hyperfine lines are the energy signatures of atoms.) A tiny microwave generator sends an oscillating frequency that alternates adding and subtracting energy from the incoming laser carrier frequency. Thus, the laser's single beam produces two waves at both hyperfine emission energies. When they interact, the emitted waves produce (like two tuning forks of different sizes) a series of 'beats' through a process known as interference.

A photodiode monitors the slight increase in light transmission through the cesium vapor cell when the microwave oscillator is tuned to resonance. According to the international definition of the second (since 1967) the clock indicates that one second has elapsed after counting exactly 4,596,315,885 cycles (nearly 4.6 gigacycles) of the microwave oscillator signal.

Because magnetism has an influence on cesium atoms, they are shielded from Earth's magnetic field by two layers of steel sheathing.

While this sounds cumbersome, atomic clocks are simpler to maintain than timepieces of a century ago, when a pendulum clock in Paris was the source of the world's exact time. Kept in a room that was temperature- and humidity-controlled, not only would a change of one degree affect the pendulum's swing, but the difficulty of bringing accurate time to the U.S. was extreme: one synchronized a portable clock in Paris and then had to transport it across the ocean by ship, during which time the mechanical clock would inevitably drift from the time of the Paris clock.

A description of the technical details of the clock, available for approximately $1,500, can be found at Symmetricom's website.

Sandia is developing a follow-on technology for DARPA: a trapped-ion-based clock. It will improve timing accuracy at similar size, weight and power to the CSAC. Researches are working on the first compact prototype.

Sandia National Laboratories is a multiprogram laboratory operated and managed by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration. With main facilities in Albuquerque, N.M., and Livermore, Calif., Sandia has major R&D responsibilities in national security, energy and environmental technologies, and economic competitiveness.

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Darwin Serkland measures the wavelength of a tiny laser called a VCSEL, or vertical-cavity surface-emitting laser. The image on the monitor (left) shows a bright circle of light emitted from a VCSEL operating at the wavelength of 894 nanometers needed to drive the atomic clock. The objects that look like black baseball bats are tiny wire needles carrying milliampere currents. The round white plastic containers on Serkland's workbench each contain about 5,000 VCSELs fabricated from one-quarter of a 3-inch diameter gallium arsenide wafer. Each wafer is designed differently to yield a unique type of laser. (Photo by Randy Motoya)