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Time on a Chip: The Incredible Shrinking Atomic Clock

By IAN AUSTEN

People who are pressed for time often complain that clocks rule their lives. But for most electronic devices, the claim is absolutely true. Vibrations from tiny quartz crystals act like a metronome, producing precise time pulses that, among other things, keep the various operations of microchips in step.

Variations of quartz oscillators are used in everything from the least expensive digital wristwatch to complex battlefield navigation gear. But various external factors, particularly heat, can alter the precision of their time beats.

Atomic clocks, which rely on the oscillations of atoms, not quartz crystals, are far more precise. But the smallest models currently on the market are about the size of a pack of cigarettes, bigger than most devices in which they might find a home. Now several researchers are developing tiny atomic clocks that could be made using standard semiconductor processes and slipped into cellphones, hand-held computers and Global Positioning System receivers.

"If you have a small, low-power clock available, all kinds of technologies or innovations will flow from it," said R. Michael Garvey, the chief technology officer at Symmetricom, a maker of atomic clocks. Mr. Garvey's company is among the research groups looking at miniature atomic clocks under a program funded by the military.

John Kitching, a physicist with the National Institute of Standards and Technology in Boulder, Colo., compares crystal oscillators to a diving board. The flexibility of both changes with the temperature: in warm weather they snap back and forth at a different rate than under cold conditions. Most consumer products ignore the problem, Dr. Kitching said, and leave it to the customer to periodically adjust his wristwatch. Navigation devices used by pilots rely on oscillators that can make discrete adjustments to their signals depending on the temperature.

The surest (and most power-hungry) solution is to surround the crystal with a small oven that keeps it at a constant temperature. But for those who value ultraprecise timekeeping, even temperature-regulated crystal oscillators have a problem.

"Over long periods of time - days, week or months - their signals drift around," Dr. Kitching said. A clock with such an oscillator may be accurate, but within a given unit of time the frequency of the oscillations will vary. With an atomic clock, however, the oscillation frequency - measured in billions of cycles per second - is precise and unvarying.

Using military money, Dr. Kitching has developed a physics package, the equivalent of a mainspring in an atomic clock, so small that he believes it could be used to build a complete clock just one cubic centimeter in size.

Like the Boulder institute's NIST-F1 atomic clock, which is more than six feet tall and provides the national time reference, Dr. Kitching's design uses cesium atoms, oscillating at 9.2 billion cycles per second, to create its basic reference signal.

But the glass containers used to hold the atoms in the F1 clock and other most atomic clocks cannot be squeezed down to microchip sizes. So Dr. Kitching borrowed from the microchip world. Using standard microchip fabrication technologies, he created a tiny cavity surrounded by silicon to hold the cesium, using glass only to seal in about one billion atoms.

To tell time, the clock passes light from a semiconductor laser - similar to those found in CD players - through one side of the silicon cavity. The laser light pulse is adjusted until its pulses start the cesium atoms jumping around. The light pulses that come out the other side match the cesium atom's constant oscillation rate. A photo cell on the other side measures the changes in the average power of the laser light to create an electrical signal for the clock's microprocessor.

The miniature clock is not as accurate as its giant atomic siblings. Among other things, its signal is distorted somewhat by the cesium atoms bouncing off the sides of their tiny silicon prison, Dr. Kitching said. However, he estimates that his device is 1,000 times more accurate than the best quartz oscillators and 10,000 times better than most crystal units now in use. By his calculations, the tiny clock's signal is precise to 1 second within 300 years.

The F1 clock, by comparison, varies within 1 second every 30 million years.

Like the high-end quartz oscillators, Dr. Kitching's clock has some temperature issues. Cesium is a nonradioactive metal that melts at room temperature. But to keep the clock working under all conditions, its design includes a small heater that maintains a temperature of about 212 degrees Fahrenheit. That heating requires a lot of power, a fact that may keep the clock out of many battery-powered products.

"I think we will get there in terms of size and stability," Dr. Kitching said of his clock. "The power goal will be a challenge."

The power drain, Dr. Garvey estimates, could be the equivalent of a AA battery every couple of days, a rate that few consumers would accept in their portable gadgets.

Price will also keep tiny atomic clocks out of consumers' hands, at least initially. Dr. Kitching estimates that a full clock based on his technology should cost about one-third the price of an extremely accurate quartz oscillator clock. But that puts it at about $100, which is well beyond the reach of, say, cellphone makers.

Initially Dr. Garvey believes that tiny atomic clocks will mostly be used for military purposes. He said, for example, that an extremely precise time signal can allow military G.P.S. units to point the way even when some satellite signals are being jammed. Similarly, they may find a civilian home in some navigation equipment as well as in radio astronomy.

But Dr. Garvey expects that because tiny atomic clocks are made using more or less the same technology as microchips, they will follow a similar downward price spiral. While they may be substituted for jobs now performed by quartz oscillators, their introduction into cellphones and hand-held computers may also allow those devices to perform new tricks. A highly stable time signal, for example, could allow extremely high levels of encryption for e-mail and other wireless communications.