

## GOOD TIMING FOR NANOSCALE ATOMIC CLOCKS

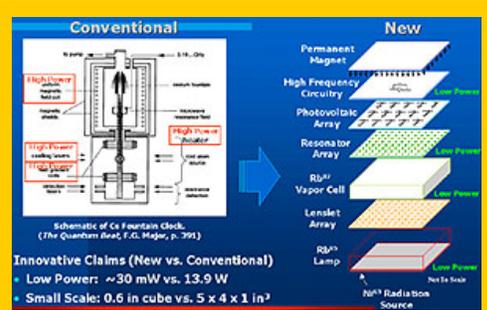
by David Pescovitz

*The science-fiction fantasy of nanotechnology — building novel structures, devices, and materials at the atomic or molecular scale — is becoming a reality. For the great potential of nanoscience and nanotechnology to be fully realized, however, research efforts must cross many disciplines, from electrical engineering, mechanical engineering, materials science, and computer science to bioengineering, chemistry, and physics.*

*Nowhere is this cross-disciplinary approach fostered more than at UC Berkeley. Each month, Lab Notes is proud to present the work of nanotechnology researchers from the College of Engineering and our collaborators across the campus.*

The radio spectrum is a dwindling natural resource. By some estimates in less than a decade there will be no more frequencies left for the next-generation of palmtop computers and handheld communicators.

But according to mechanical engineering professor Albert P. Pisano, director of Berkeley's Electronic Research Laboratory, outfitting every wireless device — from a next-generation palmtop computer to a basic FM radio — with a nano-mechanical clock that's accurate down to ten quadrillionths of a second per day could reopen the radio spectrum for tomorrow's new business.



This slide compares the components of a conventional atomic clock with the design for the Integrated Nano Mechanical Regulated Atomic Clock.

Image courtesy Al Pisano

VOLUME 2

ISSUE 7

SEPTEMBER 2002

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Lab Notes is published online by the Public Affairs Office of the UC Berkeley College of Engineering.

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Updated 7/25/02.



Professor Al Pisano is also a director of the Berkeley Sensor and Actuator Center.  
*Peg Skorpinski photo*

"Nanotechnology is going to revolutionize how you divide the frequency spectrum and what you use it for," says Pisano, who several months ago with Berkeley professors Liwei Lin and Luke P. Lee, Cornell University professor Amit Lal, and industrial partner Frequency Electronics, Inc. launched the Integrated Nano Mechanical Regulated Atomic Clock project.

"Now, FM stations are .2 MHz apart," Pisano adds. "But what if they could be .02 MHz apart?"

Of course, atomic clocks — which calculate the passage of time (not the time of day) based on the resonant frequency of specific kinds of atoms — are nothing new. In most homes, atomic clocks have eliminated the frustration of VCRs that annoyingly blink "12:00" by setting themselves via an onboard radio receiver that "sets" itself based on a radio signal from a centrally-located atomic clock maintained by NIST (US National Institute for Standards and Technology) in Fort Collins, Colorado. Traditional atomic clocks like the ones that tell your VCR the time and are used in myriad scientific applications are table-top rigs of power-hungry lasers, mirrors, and high-frequency electronic circuitry that cost upwards of \$1,000. Less accurate atomic clocks that regulate data flow for the Internet are shoe-box sized devices that consume 150 watts of power and cost \$2000. Pisano and his team hope to shrink the package down to 1-cm cubed, reduce the power consumed down to 50 milliwatts, and cut the cost to possibly \$100.

With atomic clocks the size of sugar cubes, Pisano says, next-generation wireless devices can share radio frequencies based on time.

"Currently, signals are divided into different wavelengths," he says. "But there's a limit to how close you can pack those wavelengths together. To this "wavelength division" multiplexing you can now add economical time-division multiplexing. You can pack far more data into a spectrum if you not only spread it across frequencies but also across time."

The approach, Pisano explains, is not so different than two people communicating on walkie-talkies. Each user takes a turn talking, or transmitting over the specified frequency. But with onboard atomic clocks, devices could take turns that might last only 250 nanoseconds to so. That's where the Integrated Nano Mechanical Regulated Atomic Clock comes in. To prevent transmissions from stepping on each other's toes, the devices need to track the passage of time with far more accuracy than provided by classic crystal oscillator-based clocks like those on your wall or wrist. Chip-scale atomic clocks are of great interest to the military as well, potentially enabling "jam resistance and strong-encryption in data communication...and missile and munitions guidance," according to a project overview from the Defense Advanced Research Projects Agency that sponsors Pisano and his team's research.

Pisano's approach exploits much the same physics as full-size atomic clocks but, he says, "we've taken everything that makes an atomic clock large and require a lot of power and thrown it out."

So far, the group has developed a preliminary design and begun work on several of the individual components necessary for a fully-fledged, centimeter-cubed atomic clock. A "modestly-functioning" prototype is still three years away, Pisano says.

The Integrated Nano Mechanical Regulated Atomic Clock will work by using photons to pump the atoms in rubidium vapor to a higher energy state. Once the atoms are pumped to a higher physical layer inside the device, they're disturbed by radio frequency microwaves generated by an oscillator so that they drop down again to a lower layer. A tiny laser determines the opacity of that layer caused by the quantity of atoms there and adjusts the frequency of the oscillator to depopulate the higher layer as efficiently as possible.

"Basically, I have a bottle full of molecules that soak up light if I shake the molecules at the right frequency," Pisano says. "Once I know that the frequency is correct, I can compute how long it takes for exactly one second to pass."

There are several technical and scientific challenges that the research team will face, but one of the researchers' biggest hurdles will be reducing the power consumption of the device so it's not dwarfed by its batteries. The most practical way to ease power consumption, Pisano explains, is by using the atomic clock as a periodic reference for a standard crystal oscillator. Once a day or so, the atomic clock could be "woken up" to recalibrate the crystal oscillator.

"We're essentially making a fat atomic wristwatch," Pisano says.

SOURCE: <http://www.coe.berkeley.edu/labnotes/0902/pisano.html>

