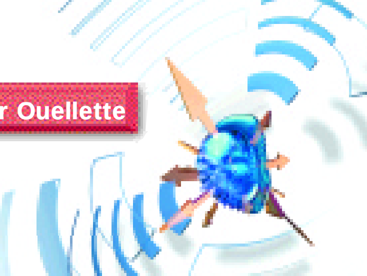


Radio on a Chip Expedites Wireless Web

by Jennifer Ouellette

Imagine a wireless telephone that combined all the essential elements of transmission and reception on a single silicon chip small enough to fit into an earpiece. This wireless device could put a mobile person in touch with just about any other communications device, transforming the lives of business people, performers, and consumers. Researchers at the University of California, San Diego (UCSD), and Lucent Technologies' Bell Laboratories (Murray Hill, NJ) are leaders among those laboring to make this vision a reality by devising a revolutionary radio-on-a-chip technology that uses microelectromechanical systems (MEMS). Their research is pushing the technological envelope to achieve an unprecedented convergence between computing and mobile telephony.

The potential market payoff is huge (see *The Industrial Physicist*, September 1998, pp. 17–18). Mobile telephones are becoming ubiquitous in the consumer marketplace. It is estimated that there will be as many as 1 billion devices worldwide by 2003. Nokia says that it ships approximately 3 million new devices each week. About 6 million people use Palm, Inc.'s Palm Pilot device. And thanks to the recent Wireless Internet Protocol (WAP), the new generation of cellular phones now being introduced by Motorola, Ericsson, Nokia, and others are fitted with micro Web browsers that enable users to access specially tailored services offered by such providers as Sprint PCS, GTE Wireless, and Nextel.

Industry leaders are banking on the widespread conviction that the number of wireless Web users will quickly eclipse those who access the Internet from home PCs. "The story of the Web has been utility and convenience," says Robert Tercek, president of Packet Video Networks (San Diego, CA). "There's nothing more convenient than a cell phone." Philippe Kahn, chief executive officer of Starfish Software (San Diego, CA), agrees: "The wireless Internet is growing so fast because one of the most popular devices in the world is the cell phone." Kahn predicts that within three years, most digital cell phones will double as wireless Internet devices. "We are talking about the Internet becoming a complete, empowering, universal way of networking, not just in your cubicle, but anywhere, anytime," he says. "We haven't seen anything yet compared to what is going to happen with the wireless Internet."

With that potential for mass-market penetration, huge sums of capital are being invested in research to develop technologies for the next generation of wireless Internet devices. The latest innovation is called Bluetooth, a universal wireless protocol developed and promoted by an industry consortium of nearly 2,000 members that enables various devices to communicate with one another in a specific area without plug-ins. Ericsson recently announced a Bluetooth-enabled headset for its cell phones. Other companies in the consortium have announced plans to embed Bluetooth devices in laptops to allow users to connect to the Internet through their cell phones without a cable. The ultimate goal is to develop single-chip Bluetooth transceivers and to embed them in every conceivable electronic device, from PCs, laptops, and cell phones, to personal digital assistants and pagers.

A Bluetooth-enabled cell phone, for example, could connect with a Bluetooth-based keyboard in a home or office PC, allowing the user to remotely make changes in a presentation. One major advantage of such a capability would be its effect on data storage. "Even with miniaturization, data storage takes up space," says Tercek, adding that with Bluetooth, the user could leave all data on a central server instead of on a PC hard drive. "You don't need to carry the data, you just need to access the data," he says. "You are going to have a world where you don't need to have a personal computer anymore."

MEMS-based innovation

According to Rich Nesin, senior manager of strategy and development for Lucent Technologies Microelectronics Group, the key to achieving all of this is fewer off-chip components, which will save design and manufacturing costs and reduce the overall device size. Lower power is also critical, particularly for battery-powered devices such as cell phones. "In the wireless area, we're definitely moving toward smaller and cheaper," Nesin says.

Above all, the next generation of devices will need a fully integrated radio that fits onto a single chip to serve as an interface between a user's mobile device and other communications sources. This radio on a chip is the focus of much research at Bell Labs and UCSD. Scientists there have advanced the technology to the point that it is now possible to integrate such components as digital signal processing, microprocessors, and random access memory with amplifiers and transceivers, for example, onto a single chip. However, a few of the larger, more complex radio components, such as front-end filters and microphones, have yet to be feasibly integrated.

The ultimate goal is to attain a complete system on a chip, which integrates microphones, sensors, and transducers, as well as novel electrical components. Nesin estimates that by taking a systems approach and focusing on integration, the cost of such a radio interface can be reduced by as much as 50%. "The idea is to make radio interfaces ubiquitous and inexpensive, so that every single toy you buy for Christmas has a wireless interface to it," adds Peter Gammel, director of materials research at Bell Labs.

Although advances in integrated circuit (IC) technology have proven critical to achieving the current level of integration, researchers are now looking to MEMS to help them integrate some of these larger, complex components. MEMS devices perform both electrical and mechanical functions. They are made by using the same technology used to build ICs, except that a final etching step allows a part of the device to move. "We currently have hundreds of discrete components in cell phones and other such systems, and we'd like to replace

those with about 5 to 10 mm^2 of silicon, which is very simple to manufacture and much more reliable," says Nathan Belk, a physicist in Bell Labs' wireless research laboratory. His team has made significant progress toward doing just that.

A chip radio needs to handle signals at much higher frequencies (roughly 5,000 MHz) than traditional ICs, which currently handle frequencies up to 500 MHz. However, "With technologies such as silicon germanium used as an active thin-film layer, and advances in the design of on-chip passive components, especially in the area of MEMS, we can start to reliably handle those frequencies on ICs," says Belk. "That enables us to decode wireless signals and process them on a single IC."

Bringing radio components aboard a chip also makes it easier to suppress distortion and crosstalk among the different signals one is trying to decode, which range from 1 V to 1 μV. Belk constructs his architectures from groups of precisely matched components and builds an identical path that mirrors the same distortion mechanisms, which cancels out distortion and signal contamination. "So we are able to achieve the very high frequencies of the IC and also use some of its advantages, such as precise component matching and precise control of the currents, in order to eliminate distortion problems that have routinely plagued the wireless industry and discrete radios," he says.

One promising application is instrumentation, according to Ramesh Rao, director of UCSD's Center for Wireless Communications, an industry-sponsored R&D effort. "What is required is a device that would have a MEMS-based sensor integrated with the transceiver, which would be extremely low cost and low power," says Rao. "Integrating MEMS with radios is an approach that will serve multiple needs, from health care, to environmental monitoring, to infrastructure and seismic monitoring."

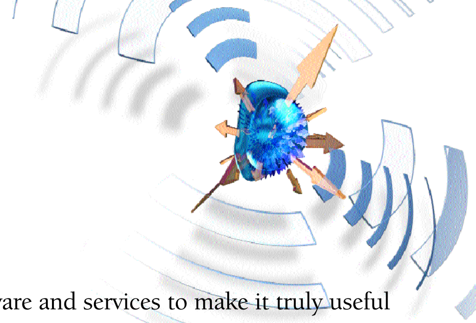
For example, simple MEMS-based sensors are already being embedded in structures such as bridges and older buildings to monitor structural integrity and, in southern California, their ability to withstand earthquakes. UCSD's Supercomputer Center recently set up a prototype wireless computer network with a 20-mile range and operating at a data rate of 11 Mb/s as a practical experiment in networking and data communication technology. The UCSD team is working with geophysics researchers at the Scripps Institute of Oceanography to develop the network as an inexpensive method of transferring data from remote seismic sensors to their laboratory.

The experimental radio link is intended as the precursor to a wireless net that will ultimately connect the UCSD campus to remote sites, including automated seismic stations and researchers conducting fieldwork. "Networking is moving in a direction where we won't be thinking just about hooking up PCs or laptops, but having lots of little sensors that gather information and transmit the data over a wireless network," says Rao. Once transmitted to a Web-based server, "this information can be mined on the Web," he adds. MEMS-based sensors could also be used to track the flow of water through streams and rivers, enabling earlier detection of floods or droughts. Ultimately, they could be implanted in the human body for medical monitoring of problems such as erratic heartbeats and deteriorating artificial joints.

Challenges

On a logistics level, updating the existing wireless-network infrastructure is a major challenge, because the next generation of wireless Internet devices will require much higher data-transmission speeds. Billions of dollars are currently being invested worldwide—particularly in Europe and Japan—to attain higher data speeds, and the upgrades should be completed within three years.

However, some remaining technological barriers, most of which derive from the need to lower costs and power usage, will require more complex solutions. For example, some functions for wireless Internet



applications still need to be integrated into the chip, most notably the filtering function, the largest and most expensive component in a cell phone. Today's devices use a ceramic radio-frequency filter or a surface acoustic wave device, but these technologies are not compatible with integration on silicon components. To address that challenge, Brad Barber, technical manager of Bell Labs' wireless components research, has devised a bulk acoustic wave (BAW) resonator—which he terms a thin-film resonator—made from the piezoelectric material aluminum nitride. This MEMS-based device uses layers of thin films, each one roughly 2.5 μm thick, to determine resonant frequencies. "So not only do you finally have a materials compatibility, but instantly you have a length scale compatibility," says Gammel, because micrometers are the unit of length for ICs.

"We've got all the components that we need," says Barber of his batch-fabricated micromachined device. "We have a good material that can be integrated onto a silicon chip, we've found a way to couple electrical energy and sharply define a frequency, and thus we can achieve a good filtering function from a mechanical structure." The key remaining challenge for his filtering MEMS device is the need to vastly improve film-deposition techniques, because the film thickness is what enables the filter to define a specific frequency. The deposition techniques currently employed by the semiconductor industry can achieve 1% uniformity across an 8-in. wafer, but Barber's MEMS filtering device requires a film thickness uniformity of 0.1%.

Ideally, a single-chip radio interface would be applicable to many types of devices, including cell phones, Bluetooth networking, and wireless local area networks (LANs). "In the communications industry, the vision is that the last connection to you as a user will be a wireless connection, whether you're talking about using a cell phone, a computer, or a LAN," says Gammel. "You want to be able to walk around and use whatever technology you have without a wire attached to it. That requires a wireless interface that is universal, inexpensive, and can be deployed in any format."

Supporting technologies

While the single-chip integrated radio is a critical enabling component, the wireless Internet also requires a host of supporting software and services to make it truly useful for consumers. Besides the wireless telecommunications industry, many start-up companies are focused on providing the software and data services to support a wireless Internet.

Symbian (London; Redwood City, CA), a British company formed as a joint venture by Nokia, Ericsson, Motorola, and Psion in

1998, specializes in a low-power, high-performance operating system called EPOC, which is initially aimed at the emerging market for pocket computers. However, Nicholas Myers, Symbian's chief executive officer, has publicly acknowledged that the company's long-term strategy is primarily focused on the mobile telephone market and the potential of the revolutionary convergence between computing and wireless devices. EPOC-based mobile phones are expected to hit the market by the end of the year.

Starfish Software, founded in 1994 and acquired by Motorola in 1998, focuses exclusively on technology that links Web applications to cell phones, handheld organizers, pagers, and other devices. Last year, Starfish's Kahn launched a second start-up, Light Surf, aimed at expanding wireless Internet capabilities to encompass imaging and photographic applications.

Video-enabled features are another vision for the future. Packet Video Networks, a 1998 start-up with investments from Intel and Siemans, plans to market technologies allowing content providers to stream a continuous flow of video and other rich media to cellular phones, personal digital assistants, and other wireless devices. Unlike video data streams today, which are encoded separately for the various modem speeds, Packet Video's core technology is only encoded once and, hence, is scalable to many different modems, which eliminates the need for consumers to know their connection speed.

This video capability could be available soon. The company recently collaborated with Sony to deliver film trailers to cell phones at 14.4 kb/s. "Imagine a world where processors are embedded in everything, wireless bandwidth is abundant, and flat and flexible screens are available," says Tercek. "That will be a world where video images are as ubiquitous as paper is today. Wireless will give you not just the choices you have on the Internet—and eventually cable and satellite—but the ability to decide when, where, and how to consume all this content."