BMDO Update
Linking American Businesses to Ballistic Missile Defense Technology
www.bmdotechnology.net

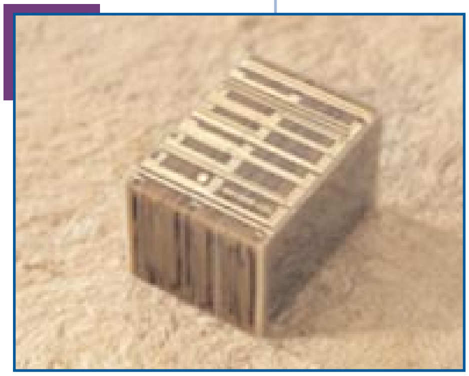
This article is reprinted from the *BMDO Update* newsletter, a publication of the BMDO Technology Applications program.

FALL 2001
ISSUE #39

Superconductivity Calls —*by Joab Jackson*

BMDO-funded superconductor research leads to revolutionary new communications products.

Superconductivity isn't science fiction anymore. For nearly a century, researchers have known that certain materials have no resistance to the flow of electricity and possess unique magnetic properties when cooled to near-absolute zero temperatures. Only recently, however, has this phenomenon been harnessed for commercial gain. Superconductivity propels a magnetically levitated superfast passenger train running through Japan. In medicine, the phenomenon aids magnetic resonance imaging devices in peering inside the human body with greater detail. It enables supercolliders to find new elements in the field of quantum physics. Energy-storage devices, electric power generators and transformers, cellular phone towers, and computers are all being enhanced by superconducting materials. And since September 2000, the first superconducting power line is being fieldtested in Detroit.



Stacked, packed. *Chip-stacking technology facilitates extreme miniaturization of superconducting electronics, potentially enabling them to eliminate bottlenecks currently plaguing Internet and telecommunications traffic. Using this technology, Irvine Sensors is packaging SuperRouter™ switch electronics into a space comparable to the size of a fiber-optics cable.*

Telecommunications may soon be another field to benefit from superconductivity's superior efficiencies. The Ballistic Missile Defense Organization (BMDO), which has done a lot of pioneering work in superconducting technologies, has been instrumental in supporting superconductivity research to produce the fastest communications and processing systems. At present, much of the data and voice traffic moves across the country in laser light pulses over fiber-optic cables. Because Internet usage and, to a lesser extent, telephone traffic continues to increase in volume, telecommunications carriers are seeking ways to pack more signals into existing lines, forestalling costly installation of additional underground and undersea cables. Clearly, new and leaner technol-ogies are needed, and leveraging the superior performance characteristics of superconduc-tivity may be the key.

Many companies have conducted BMDO-funded research in this area, and below, you will read about three of them with technologies that are the furthest along: a next-generation Internet router is being developed by Irvine Sensors, a packet-reading switch from HYPRES, and an optical transceiver being built by Tera-Comm Research. All of these technologies achieve levels of operation unattainable by basic electronics alone, thanks to superconductivity.

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Irvine Sensor's Super-Cooled Router

Routers are the traffic cops of the Internet. When you send an e-mail or retrieve a Web page, the contents are broken into small packets to be transmitted across the Internet. It is the router that reads the packets' headers to direct them through the network to the appropriate end-computers.

While the typical router these days can sort and forward data at speeds between 2 and 10 gigabits per second (Gb/s), Irvine Sensors Corporation (Costa Mesa, CA) is developing a superconductor-based router that will be able to sift through more than 40 Gb/s. Earlier this year, the company received a second $1 million research and development contract from the BMDO Small Business Innovation Research (SBIR) program to develop its so-called Super-Router™, which utilizes numerous earlier aspects from BMDO-funded work in opto-electronic circuits, chip-stacking technologies, neural interconnections, and superconductor-based memories.

iNetworks, an Irvine Sensors subsidiary, is developing a superconductor-based router that offers 100 times more throughput than what is available today.

The superconducting components of the router are crucial to the unit's superior performance. "What superconducting does is that it gives you very high speeds with almost no power penalty," explained John Carson, Irvine Sensors' co-founder, senior vice president, and chief technical officer. He notes that the company is developing a 512 x 512 switch at 4 Kelvin (K) with only one-quarter-watt dissipation. "If we were to do that using conventional techniques, the power required would be many kilowatts," Carson said. Once power for the cryocoolers is taken into effect, the unit reduces power up to 30 percent over today's configurations.

But the greatest advantage of Irvine Sensors' superconductor-based router is its simple design. Carson said that the device could replace 16 regular routers. The chip-stacking technology allows 48 chips to be stacked in a thumb-sized space. This close proximity helps speed processing times by reducing interchip communications distances and enabling a high level of parallel interconnectivity. This interconnectivity springs from earlier BMDO-funded work at Irvine Sensors to build a Silicon Brain™ computer with neuron-like wiring.

The router's memory, which queues incoming packets awaiting output slots, also benefits from superconductor-enabled circuit density. As Carson explained, routers "have huge memory requirements. You need gigabits of memory to buffer the inputs for hundreds of milliseconds because you get port contention [or data from two input ports vying for the same output port]. . . At OC-768 [the telecom standard for transmitting data at 40 Gb/s], 200 milliseconds turns into an awful lot of gigabits, so getting that memory extremely close to the processor is critical. We actually put the memory stack right on top of the processor."

While competitors are also developing 40 Gb/s routers forged from traditional semiconductor-based components, Carson dismissed such designs as essentially slower throughput devices running in parallel. As a result, they will take up more space and use more power. Also, such routers may not be equipped to handle different protocols. Today, a large company running both asynchronous transfer mode and Internet protocol-based networks needs separate routers for each. However, Irvine Sensors' routers have sufficient memory and processing muscle to handle multiple protocols. The router will also improve security and enable load balancing and packet prioritization—much valued items currently on the wish lists of the Internet's chief architects.

Irvine Sensors formed a subsidiary, iNetworks, to manufacture and market the router, which is expected to be released in 2003. In June, the company received $1.6 million in strategic bridge financing from Zimmer Lucas Partners, LLC, and Vertical Ventures, LLC.

HYPRES' Packet-Level Switch

Today's telecommunications network backbone (or core) is based on circuit switching, which is the preferred mode for voice traffic. On the other hand, packet switching and routing is preferred for data traffic, which used to be a small fraction of the voice traffic. The spectacular growth of the Internet during the last decade has reversed the balance between

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voice and data. Packet routers need to perform a lot more data processing than circuit switches, such as reading the "destination address" of each incoming packet, storing them in memory if necessary, and then individually routing them towards their final destination. All-optical solutions for the implementation of high-speed packet routers for the core network do not exist. Moreover, electronic router switches made with semiconductor technology are not fast enough.

HYPRES, Inc. (Elmsford, NY), is interested in developing a switch technology by exploiting the intrinsic speed and power advantages of superconductor electronics. "Our switching operations only take 10^{-18} Joules, so that gives us tremendous benefits in terms of low-power dissipation on chips. If you have high-power dissipation, you cannot increase circuit density," said HYPRES researcher Dr. Deepnarayan Gupta. And it is the increased circuit density that allows for greater processing of data packets up to 40 Gb/s. While other companies are developing optical-core switches that can match that data rate, optical switches cannot read packet headers, hence they are incapable of packet switching. HYPRES' switch can equal the throughput of these optical switches plus offer packet-switching capabilities. While the data transport between circuits on a single chip occurs at extremely high speed on superconducting transmission lines, the switch is expected to comprise multiple chips on a superconducting multi-chip module (MCM). Under BMDO-funding, HYPRES is currently developing a high-speed interchip data transfer technology for superconducting MCMs that will allow transport of data between chips at the same high intrachip speed.

It's not IBM. *But what you will find at HYPRES' facility is former IBM researchers working on superconducting digital integrated circuits that clock in above 100 GHz—300 times higher than semiconductor-based devices.*

This switch technology is the culmination of years of research and development. With the help of multiple BMDO SBIR contracts dating back to 1990, HYPRES has been working on several superconductor-based components that can work in conjunction with one another or as discrete entities. (Additional research funding was provided by the U.S. Navy, National Science Foundation, Department of Energy, and other Department of Defense agencies.) HYPRES' circuitry is based on Rapid Single Flux Quantum (RSFQ) logic, in which tiny magnetic fields switch current flow through a Josephson junction (an insulator sandwiched between two superconductors) at picosecond speeds.

HYPRES plans to have a 40 Gb/s superconductor switch on the market within 3 to 5 years, and a 160 Gb/s model to follow afterwards. Formed in 1983 by a research group from IBM, HYPRES has received over $30 million in venture capital to commercialize its switch as well as pursue other superconductor circuit-based applications. The company plans to manufacture the switches in-house and sell them to hardware system integrators.

TeraComm's Terabit Transceiver

Another way to squeeze more optical data through fiber-optic lines is by making the laser pulses that carry the light shorter in duration. While even the fastest modulators in development now are expected to encode signals only at 40 Gb/s per second, TeraComm Research, Inc. (Essex Junction, VT), is testing a fiber-optic transceiver that uses a superconductor-driven modulator and will be capable of data rates exceed-ing one terabit per second (or 1,000 Gb/s).

TeraComm's modulator is based on the superconducting properties of a high-temperature superconductor (HTS) material, yttrium barium copper oxide (YBCO). YBCO has zero electrical resistance at low temperatures (< 92 K) and possesses very high optical reflectance in its superconducting state. With the application of electric current through a modulator circuit, it can switch between a partially trans-

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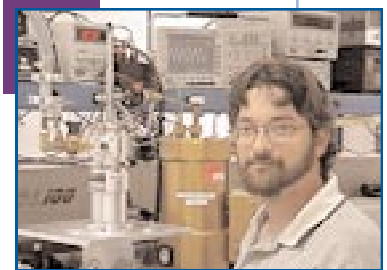
parent non-superconducting state and a substantially non-transparent superconducting state at picosecond rates. The resulting modulator would operate at 1,000 Gb/s—well over 25 times the throughput per wavelength of today's modulators.

To complete the transceiver, TeraComm is developing a patented frequency conversion component that makes the switch compatible with existing near- and mid-infrared communications systems. In these regions of the spectrum, the photon energy of the light is high enough to break the binding energy of the Cooper electron pairs (large, weakly bound pairs of electrons responsible for the superconductivity phenomena). Therefore, pulse modulation is actually done in the far-infrared range (around 100 microns), where the photon energy is lower and the output is converted to wavelengths between approximately 1.3 and 1.55 microns.

This technology, supported by the BMDO SBIR program, was developed through a collaboration including TeraComm, the University of Vermont, the University of Florida, and the University of Rochester. TeraComm is the first company to successfully demonstrate control of optical transmission in HTS films using electric current. A venture capital company has provided $1 million in development funds and a prototype is being developed. TeraComm expects the transceiver to be available in 2003. It will be sold in a standard 19-inch or 23-inch rack-mountable chassis, with inputs of 16 to 64 SONET OC-192 tributaries and a dual optical output.



Now that's fast. *Ken Puzey, president of TeraComm Research, says his company's fiber-optic transmitter will incorporate a superconductor-driven modulator to achieve terabit speeds. Prototypes have been successfully demonstrated, and the company is proceeding with an accelerated product development program.*

Path of Least Resistance

The promise of superconductivity to endow components with improved performance characteristics is certain to keep the interest in such technologies thriving. And BMDO, due to the urgency of its mission, will remain in the forefront of this exciting field of research. The organization's ongoing interest in super-fast communications, combined with the innovative work from such researchers at Irvine Sensors, HYPRES and TeraComm, will ensure a bright future for superconductor-based telecommunications. Irvine's router, HYPRES' switch, and TeraComm's transceiver are, without doubt, only three of many BMDO-sponsored technologies that will boost telecom carriers' bottom lines while providing us with more seamless Internet and telephone communications.

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