

Electronic Muscle: Advanced Microelectromechanical Systems

Although electricity has been used to do work and make our lives easier for over 100 years, the technology that converts electrical current to mechanical force has evolved little in the last century. Electric motors, sensors, circuit breakers, and almost all electromechanical devices utilize magnetic fields to create motion from the flow of an electric charge. While machines in general have become smaller per unit of power and more technically efficient, magnetic-based power sources still require large mass and high currents.

COMPOSITE PERFORMANCE SCORE

(Based on a four star rating.)



Integrated Force Arrays (IFAs)

One potential improvement in this area utilizes the attraction of objects with opposite charges to create motion. The phenomenon, known as electrostatics, is similar to the static cling of a sock to a towel coming out the clothes dryer. Tiny devices using electrostatics convert these electrical charges into precise motion. Combinations of the tiny devices offer the possibilities of larger devices capable of exerting significant force, so-called integrated force arrays (IFAs).

Made up of millions of microscopic cells, the IFA resembles a thin, flexible, plastic membrane. IFAs are part of a group of technologies called microelectromechanical systems (MEMS). Ranging in size from micrometers to millimeters, MEMS are currently used to sense, control, and actuate in such devices as optical scanners, fluid pumps, and pressure and chemical flow sensors.

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An IFA can be thought of as analogous to muscle tissue: when an electric signal is sent to the array, it contracts like a muscle, causing displacement and movement. The way



This tiny IFA membrane contains more than 100,000 cells, or building blocks.

this works is that each cell has two conducting sides; when they are charged to opposite electrical polarities, they are attracted like opposite poles of a magnet. Thus, when voltage is applied, the membranes on the individual cells contract, causing the muscle (the IFA) to shrink about 30 percent in length. The motions created are precisely controllable, and the mass of the device can be about three orders of magnitude less than that of a magnetically driven solenoid of equivalent power.

IFAs are more durable and lighter than their electromagnetic MEMS counterparts currently in use. They also use less power and can be positioned with more precision than existing mechanisms that create motion from electricity. Although IFAs appear to offer great advantages in principle, processes for making them with large forces and at low cost have yet to be fully developed.

PROJECT HIGHLIGHTS

PROJECT:

To develop a muscle-like microelectromechanical technology based on electrostatically driven structures called integrated force arrays.

Duration: 6/15/92 – 6/14/95

ATP Number: 91-01-0258

FUNDING (in thousands):

ATP	\$1,206	67%
Company	593	33%
Total	\$1,799	

ACCOMPLISHMENTS:

The research conducted by MCNC was successful in meeting many of the project's technical goals. Specifically, the researchers:

- produced several IFA working prototypes with desirable force outputs;
- fabricated IFAs of polyimide coated with chromium and gold that were considerably lighter than previous electric mechanisms;
- published eight articles in refereed journals, and also in conference proceedings and professional society reports; and
- applied for and were granted three patents:

“Fabrication method for microelectromechanical transducer”
(No. 5,290,400: filed 12/17/1992, granted 3/1/1994);

“Pleated sheet microelectromechanical transducer”
(No. 5,479,061: filed 12/31/1992, granted 12/26/1995); and

“Unidirectional supporting structure for microelectromechanical transducers”
(No. 5,434,464: filed 5/23/1994, granted 7/18/1995).

CITATIONS BY OTHERS OF PROJECT'S PATENTS: See Figure 6.4.

COMMERCIALIZATION STATUS:

Although the laboratory work to build the first large integrated force array was largely a technical success, the near-term effort for commercialization has been unsuccessful to date. Potential investors have been concerned about the reliability and cost-effectiveness of production processes for large-scale IFA devices. As a result, MCNC has been unable to attract businesses willing to use IFAs in commercial production.

OUTLOOK:

Although IFA technology continues to be in the early stage of development, numerous applications are envisioned in the future. Potential uses include data storage actuator arms, biomedical devices, robotics, biomechanical prostheses, and optical shutters. The most promising of these applications in the near term is use of IFAs for secondary actuators for the reader arm of disk drives. The dissemination of the research knowledge gained by the ATP project should pay dividends for years to come as the microelectronics machine industry continues to grow and businesses become willing to use IFAs commercially. While the outlook for widespread commercial use of the technology in the near term is weak, the outlook further in the future is strong.

Composite Performance Score: ★

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North Carolina Research Center Proposes Project to ATP

Researchers at the Microelectronics Center of North Carolina (MCNC) saw substantial opportunity in IFAs as an enabling technology. They aimed to create an IFA with millions of cells that together would generate linear contractions with high force ratios. IFAs fabricated from lightweight polyimide, coated with a combination of gold and chromium, could fit more easily into machines, which would not need to be designed to accommodate the mass and heat dissipation requirements of bulky, heat-generating electric motors. Smaller IFAs could be used in micro-machines that utilize its high power-to-weight ratio over small distances and loads. And, if the technology could be pushed far enough, artificial muscle for prostheses might even be possible.

In 1992, the Microelectronics Center of North Carolina (MCNC) proposed a two-stage, three-year project to the ATP. The first stage was to develop prototype IFA

arrays using common very large-scale integration (VLSI) fabrication techniques. In the next phase of the project, MCNC proposed to develop larger scale and more economical methods of IFA production with the potential of building more powerful and useful IFA devices with potential future applications in fields ranging from robotics and biomedicine to computer data storage. It was a long reach, but one they hoped would bring IFA technology into actuality.

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Founded in 1980, MCNC began as a private, nonprofit corporation that brought together partners in industries, research universities, and state government to encourage

research, education, and development of electronic information technologies. Today, the nonprofit center collaborates with companies worldwide in a range of microfabrication and related technology programs.¹

Successful Prototypes Developed

During the ATP project, MCNC scientists were able to produce several tiny working prototype IFAs with desired force outputs. They built an IFA actuator that weighed about 60 micrograms, and exerted a force of 12 dynes (enough to push a large sugar cube over a 0.7-millimeter range). While microscopic, these IFAs have proved both powerful and durable: the work-to-volume ratio for the IFA was among the largest reported in the MEMS literature, and cycle lifetimes of over 10 billion contractions have been measured.

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IFA Commercialization Awaits Further Development

The success in the laboratory—building the first large-scale (although still microscopic) arrays—was significant. But at the end of the project, the process technology was not considered by businesses sufficiently robust to entice them to invest in new product development. Companies have seemed interested in the technology but have been

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hesitant to license IFAs from MCNC without further testing and development. Potential investors have continued to express concern over the capability to produce large-scale devices in quantity, both reliably and cost-effectively.

At the conclusion of the ATP program, MCNC made numerous contacts within the magnetic disk drive industry to explore the use of IFAs for secondary actuators. In this application, they had the capability of increasing hard drive storage capacity and data reading rates. The short product cycle of this industry, however, led it to prefer commercially available technology that is ready for immediate inclusion into a new product. The IFA was not at that stage of development, and these attempts failed to lead to commercial development of the IFA. The disk drive industry, however, has shown interest in exploiting such a technology when larger-scale IFAs can be produced by more cost-effective methods.

Interest in IFAs Continues

MCNC subsequently developed several concepts for fabricating thicker, stronger, and more robust IFA structures. At the time of this study, however, MCNC had continued to be unable to secure additional private sector funds to demonstrate these fabrication methods.

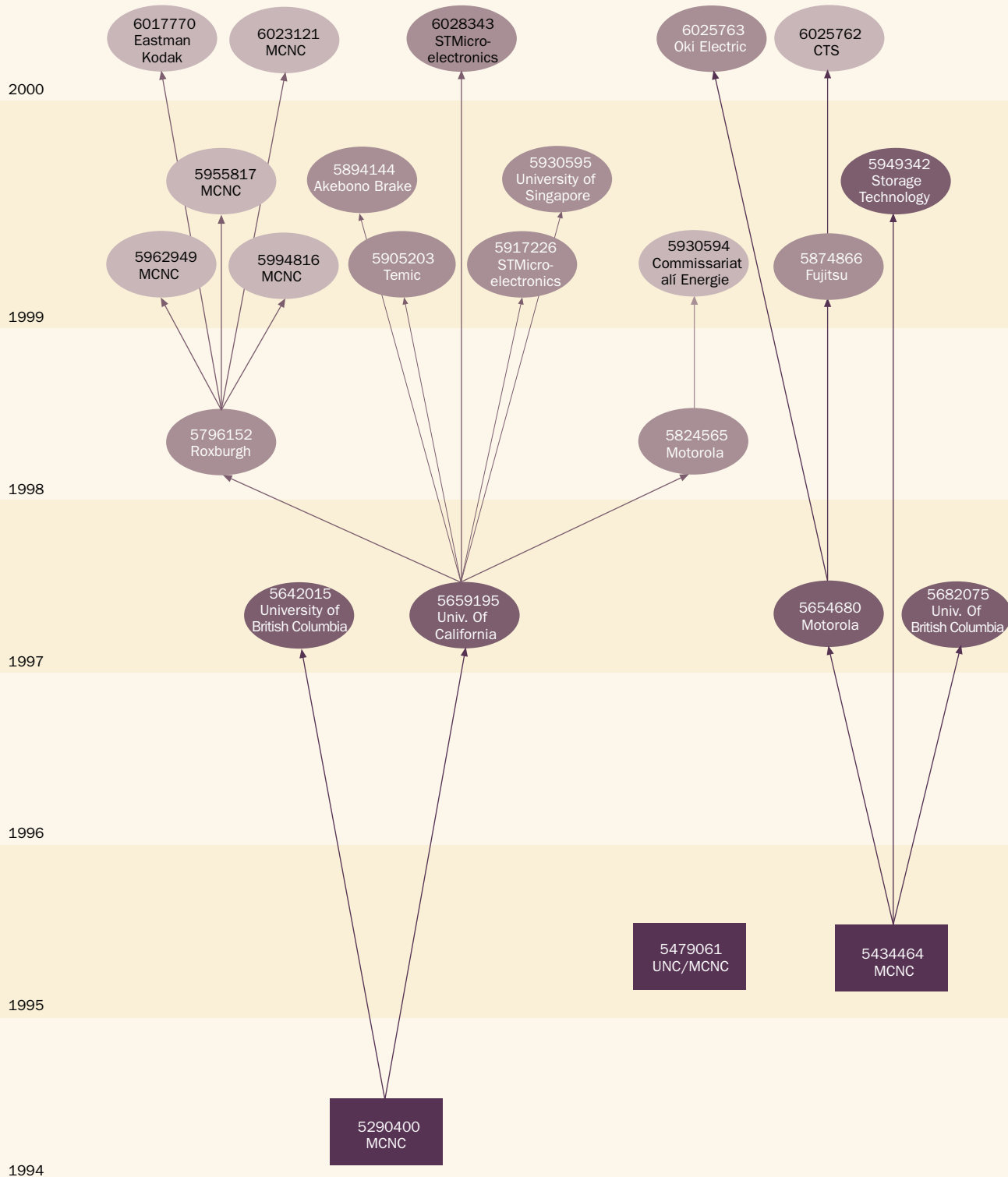
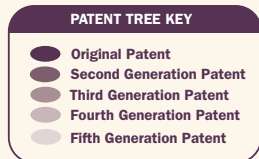
The work, however, has continued to attract government and university attention, as well as research groups in companies. MCNC entered into two contracts with the U.S. military to verify the results of the ATP program and to examine new methods for low-cost fabrication of IFAs. Since late 1999, MCNC has been working on a new DOD contract to explore two of the proposed concepts for

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fabricating the IFA in larger, more robust structures. MCNC expects to fabricate prototypes in 2002. At the time of the study, MCNC was also working with Duke University on a National Institutes of Health (NIH) contract to fabricate IFAs for an ultrasound scanner.

¹ Nonprofit institutions, such as MCNC, were eligible to apply to ATP as single applicants only in the first two years of ATP's operation.

Figure 6.4 Patent Tree for Project Led by Microelectronics Center of North Carolina: Citations by Others of Microelectronics Center of North Carolina Patents



Patents and Publications Spread Research Knowledge

There has been a relatively rapid and diverse dissemination of knowledge from this ATP-sponsored technology. MCNC and its scientists have been granted three IFA-related patents. As illustrated by the patent tree for this project in Figure 6.4, the knowledge gained from the research has begun to spread to other companies and researchers through extensive citing of MCNC's patents by others. Companies and research groups as diverse as Honeywell, Texas Instruments, Cornell Research Foundation, and Siemens, all have cited the MCNC patents developed during the ATP project.

In addition MCNC and its research scientists have spread the knowledge gained from their ATP-sponsored research through publications. As of May 1997, eight refereed journals, including the *Journal of Microelectromechanical Systems* and *Micromachining and Microfabrication*, had published articles resulting from the project. Conference and professional society proceedings provided other avenues through which the research results were disseminated.²

Growing Interest in MEMS

MCNC has helped raise the visibility of MEMS devices in the scientific and engineering community. After the ATP project, MCNC created a MEMS Technology Applications Center, jointly funded by the state of North Carolina, the Defense Advanced Research Projects Agency (DARPA), and several large corporations. The MEMS Technology Center focused on developing low-cost fabrication techniques for the development of MEMS devices, including IFAs, for practical applications. In April 1999, MCNC spun off its MEMS business unit into a new company, Cronos Integrated Microsystems, Inc., subsequently bought by JDS Uniphase in April 2000. Although the IFA technology did not go to Cronos (this follow-on effort), the ATP-funded IFA project boosted interest and proved that the technology concepts were valid. Although the ATP project did not take the development of IFAs to the point that private capital alone would take them into commercial development, the ATP investment brought the technology a step closer to realization and helped speed progress in a wide range of MEMS devices.

What Does the Future Hold?

Although IFA technology continues to be in the early stage of development, numerous applications are envisioned within the next five to ten years, including secondary actuators for hard disk drives, robotics, optical shutters, pumps, valves, and medical devices. A reverse technology is also being developed, where force on the array would cause a current to be generated. These might be used, for example, to make sensors that produce a current when they touch an object. This touch response could be used in robotic sensing systems.³ Similar reverse IFAs could also generate power from a person's natural motions, thus, for example, powering devices such as wearable computing systems. Having taken the IFA to its current state of development, MCNC is now looking to customize the technology for use in these and other MEMS applications.

² MCNC website, February 1998, <<http://www.mcnc.org>>.

³ *Solid State Technology*, Vol. 36, No. 10 (October 1993), p. 36.

