



# MAKING SUPERCONDUCTIVITY **USEFUL**

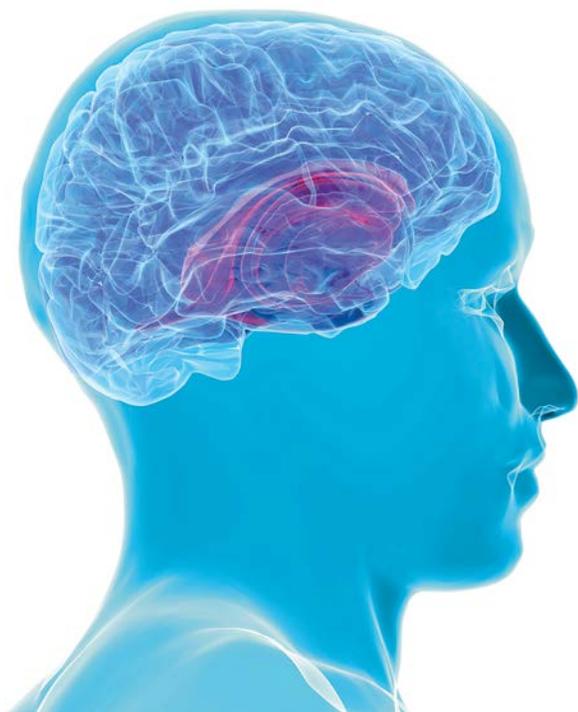
When you make a video call or watch NFL game highlights on your smart phone or other mobile device, the microwave signals between your phone and the mobile base station must transfer millions of bits of data while contending with the signals from thousands or tens of thousands of other users. A critical part of the technology that enables the base station to sort out each signal and keep your Apple Facetime call from interfering with someone else's Instagram post or Google query is a tiny superconducting microwave filter cooled to temperatures more than 300°F below freezing.

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Superconducting microwave filters in cell phone towers enable high speed transmission of many signals without interference. (*Vlad Teodor / Shutterstock.com*)

Superconductivity—the property of certain materials to conduct electricity with no resistance, no heating, no power loss—remains one of nature’s most intriguing and still puzzling phenomena. Initially discovered more than 100 years ago in mercury cooled to the temperature of liquid helium (about  $-452^{\circ}\text{F}$ ), it remained a mystery for nearly 50 years. Then in 1957, three physicists explained how electrons in such materials could interact in unusual ways that allow them to flow with no energy dissipation. That theory and the discovery of other superconducting materials (such as an alloy of *niobium* and *titanium* that could be readily formed into wires) enabled the production of superconducting wires and powerful magnets and, in the 1970s, MRI machines used for medical imaging.

Superconducting electrons do much more than carry an electrical current with no resistance. When two layers of superconductor are separated by a thin layer of insulating material, superconducting electrons can “tunnel” through the barrier and interfere with each other. That phenomenon gave rise to a device—called a superconducting quantum interference device or SQUID—that is an extremely sensitive detector of magnetic fields. SQUIDS



Superconducting devices known as SQUIDS enable mapping of neuron activity in the human brain. (*Goa Novi / Shutterstock.com*)

can detect magnetic fields 100 billion times smaller than those generated by an ordinary refrigerator magnet. One promising application is their use to map magnetic fields within the human brain that are generated by the tiny currents within specific neurons, and thus measure the neural activity involved in specific human activities.

However, applications of what is now called low temperature superconductivity are limited by the need to surround magnets or other devices with massive insulation and cooling systems to handle liquid helium, making such machines bulky and requiring lots of energy for cooling. That’s why there was great excitement when, in 1986, so-called high temperature superconductivity—meaning anything above the still frigid temperature of liquid nitrogen ( $-321^{\circ}\text{F}$ )—was discovered in a copper-based ceramic material. These materials are not normally good conductors of electricity, let alone superconductors, so the discovery raised many basic questions. The discovery also raised the prospect—so far not realized—of many more practical applications if a material could be found that is a superconductor at room temperature: replacing the electrical grid with superconducting transmission lines that could carry large currents over long distances with no losses; levitating trains that could glide over a metal track without touching it.

Efforts to characterize and understand these high-temperature superconducting materials have been supported by the Basic Energy Sciences (BES) office of DOE for several decades and continue today. Much of the research uses BES shared research facilities, applying neutron beams to probe the materials’ magnetic properties and X-ray or ultraviolet beams to study their electronic structures. High-temperature superconductivity is fundamentally different from its low-temperature counterpart. In fact, despite intensive research, explaining high-temperature superconductivity remains one of the great unsolved challenges of fundamental science. Nonetheless, scientists have learned a great deal about these superconducting materials, including how to “tune” their composition such that superconductivity is enhanced or appears at a higher temperature and how to double their current-carrying capacity by irradiation at an accelerator. These discoveries were handed off to a separate DOE office for more applied research and joint work with industry on specific applications.

The current generation of high-temperature superconductors are much more practical for many applications. They operate at temperatures that can be easily achieved with inexpensive liquid nitrogen as a coolant or, for many applications, with small, highly efficient refrigeration systems known as cryo-coolers. The cryo-coolers can maintain superconducting systems like those on mobile towers or in satellites at optimum temperatures without liquid nitrogen and massive insulation.

High-temperature superconducting materials are brittle ceramics that are extremely difficult to form into wires. But with detailed understanding of their structure, manufacturers have developed ways of making thin tapes of the material that can be wound to make magnets or layered to make cables. Development of a practical approach to fabricating these cables has led to the industrial capability of producing many miles of enhanced cables capable of carrying very high currents—as much as 100 times that of a similar-sized ordinary copper cable.

One application of these high-temperature superconducting cables is to build very light-weight electrical generators that are now being considered for use in massive off-shore wind turbines. Despite the need for cooling systems, the smaller size and weight of these generators (about half that of a conventional iron core generator) makes installing them atop a wind tower much easier and the entire system less costly.

Another emerging application is to protect parts of the electrical grid—where the superconducting cables act as fail-safe devices (known as fault current limiters) to guard a portion of the grid or a substation against a sudden electrical outage. Several pilot installations at grid intersection points have been built. Another version of this application is being piloted with support from the Department of Homeland Security in cities such as Chicago, where a superconducting loop will connect many substations, allowing them to share load, thus increasing capacity, grid resilience, and public safety. This approach is also being considered for financial centers such as New York City and elsewhere. Since a single superconducting cable can replace many bundles of copper wire, such a deployment in dense urban areas saves space in existing conduits,



Compact high-temperature superconducting cables (right) replace much larger conventional copper cables (left).  
(Courtesy American Superconductor Corp.)

improves already-strained electrical capacity, and protects against disruption of the grid from lightning strikes or terrorist bombs.

Another rapidly growing application for high-temperature superconductors is as the microwave frequency filters that prevent interference among the thousands of mobile signals described above. These superconducting filters are now installed on more than 10,000 mobile communications towers—helping you connect from your mobile device more clearly and with less interference. They are also found on the communication satellites used by telephone and satellite TV companies. These filters are likely to be even more important as mobile networks roll out next-generation systems that carry even more data and transmit it more rapidly.

Behind these commercial applications lies more than 30 years of basic science research supported by BES. One reason that the mechanism for high-temperature superconductivity remains unresolved is that the ceramic materials in which it occurs are very complex. The research has enabled steady progress on understanding their structure, as well as theoretical calculations on high-performance computers to model the strongly-interacting electron behavior. Such persistence is likely, sooner or later, to lead to understanding of how high-temperature superconductivity works, and perhaps, how to design still better superconducting materials.