

## Superconductor products poised for market

Superconductors are heating up in more ways than one. Ten years ago the critical temperature—the temperature at which a material loses all resistance to the flow of electricity—took a sudden jump above the temperature at which liquid nitrogen boils, and since then there's been further progress as the critical temperature continues to work its way upward. Some of the current theories about high-temperature superconductors (HTSs) hint that room-temperature superconductivity is possible.

From a commercial point of view, however, existing HTS materials, while they might not be superconducting at temperatures above the freezing point of water, are by no means anything to dismiss either.

"The materials are good enough for many of the things we want them for," said Randy Simon, vice president of technology programs at Conductus, Inc. (Sunnyvale, CA). Conductus is in the business of commercializing superconductors and offered in 1991 the first commercial product using HTS materials, a superconducting quantum interference device (SQUID) for undergraduate laboratories.

This isn't to say that the current HTS materials, bismuth strontium calcium copper oxide (BSCCO), yttrium barium copper oxide (YBCO), and thallium barium calcium copper oxide (TBCCO), don't still need improvement and aren't still the targets of a great deal of research and development work. "They are not good enough for everything we can imagine doing with them, so there's plenty of impetus for materials improvement," confirmed Simon.

The commercial applications that are the most mature all involve sensors or electronics and use either YBCO or TBCCO. There has been significant progress in bulk applications, such as motors and power transmission, but commercial products in these

areas are still several years off.

The sensors include SQUIDs made of HTS materials, which may replace those made of low-temperature superconductors in some applications. HTS receiver coils

number is expected to top 30,000 within a year, and estimates are that there will be as many as 50,000 within 10 years. Moreover, each cellular base station typically requires a minimum of six filters.



**Conductus's front-end receiver subsystem for the wireless industry incorporates HTS thin-film preselector filters with an advanced cryogenic refrigerator.**

also are being developed to replace the copper receiver coils in nuclear magnetic resonance spectrometers and the copper antennae in low-field magnetic resonance imaging devices. These sensors and coils have yet to meet with much commercial success.

### Need for filters

The most viable products so far are radio frequency (rf) and microwave filters. The failure of other devices partly explains why firms trying to commercialize superconductors have increasingly targeted filters. But filtering also seems to be an ideal application for the current crop of HTS materials.

First of all, there's a large and growing market for rf and microwave filters. According to the Cellular Telecommunications Industry Association and market analysts, there are some 25,000 cellular-telephone base stations in the United States today. That

A cellular telephone system locates and tracks the mobile stations and attempts to connect each mobile station with the best available base station based on evaluations of the quality of the radio links with alternative base stations. The available spectrum is partitioned among the base stations and a given frequency is reused at the closest station the radio link will allow. The current trend in the cellular industry is toward spectrally efficient cellular systems, whose radio links make efficient use of power and bandwidth and can tolerate high levels of noise and interfer-

ence. Among other things, this requires sharper and less lossy filters.

In the future, cellular phone systems may be supplemented by personal communication systems (PCSs). Each subscriber to such a system will be assigned a personal telephone number and intelligent networks will be employed to locate the called party, leaving the subscribers free to roam anywhere in the world. Projections are that there will be 70,000 PCS base stations in a few years and perhaps twice as many within a decade. A PCS base station will require a minimum of 12 filters.

Together PCS and cellular telephone systems will provide a large market for filters. The question is what type of filters these will be: the garden-variety copper filter or a more futuristic HTS filter?

HTS technology offers significant advantages over conventional technology. For instance, the noise floor of an HTS receiver is lower than that of a conventional receiver, thereby extending the receiver's range and improving coverage within a given cell site.

That's an important advantage in rural or remote settings. Another plus is that HTS receivers are smaller than conventional ones, even when the cryogenic cooler is taken into account. That's useful in urban settings or where there's a high density of base stations. Given the increasingly stringent limits municipalities are imposing on the size and location of base stations, this advantage is likely to become more important with time.

The third and most fundamental advantage is that HTS filters are much more selective and yet less lossy than filters based on standard technology. That's vital when the electromagnetic spectrum is very crowded, which is the case everywhere.

"If you look at the frequency response of our filters, we are just orders of magnitude better at rejecting out-of-band interference than existing, conventional technology," noted James Hodge, chief scientist at Illinois Superconductor Corporation (Mt. Prospect, IL). In field tests conducted by Ameritech Cellular Services (Hoffman Estates, IL), and Illinois Superconductor, HTS filters rejected up to 10,000 times more out-of-band noise and allowed as much as 35% more voice signal through than did conventional filters.

Just as important, cellular-phone receiver filters can be built with current superconductor fabrication techniques. The filters are passive devices and, at least on the receiving end, don't have to handle much power. That translates to easier manufacturing. Several HTS-based filter systems have passed the acceptance, reliability, and quality testing of various telecommunication companies. There have also been some sales of HTS filters to retrofit base stations.

## Thick and thin

Although all HTS electronic companies are concentrating on making wireless filters, not all of them are using the same techniques. Most are using one or another thin-film process to make a resonant circuit. An HTS film is deposited on a substrate, and photolithographic techniques similar to those used by the semiconductor industry are employed to create the filter elements. The capacitors, for example, might consist of interdigitated fingers of HTS material and the inductors of spirals of HTS material.

Illinois Superconductor is the only company that's using a thick (greater than 50  $\mu\text{m}$ ) film. A precursor paste is deposited on a substrate or preform of arbitrary shape, and

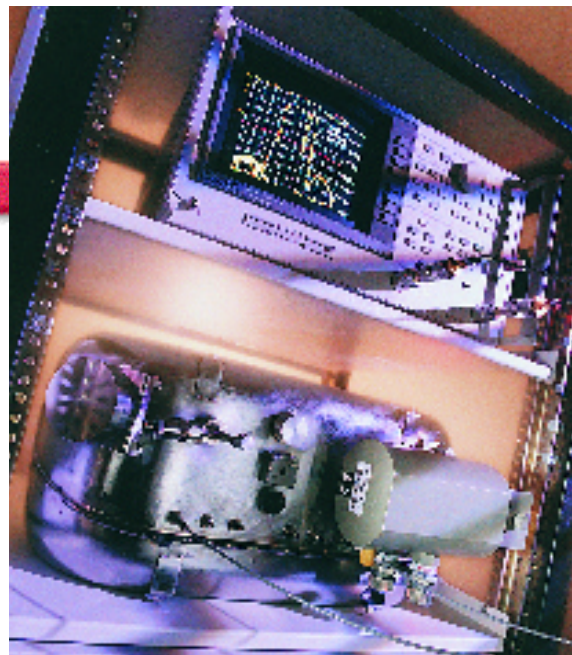
the paste is then fired to form the superconducting compound. In this way it is possible to make a resonant structure with an intrinsically high-Q geometry. (Q, the conventional figure of merit for a filter, is related to its power loss and to the selectivity of its frequency response.)

Each approach has its adherents, with thick-film advocates claiming their manufacturing technique is more controllable while thin-film champions contend their process results in smaller filters. Ease of manufacturing is a rather large advantage, but the possibility of shrinking base-station size is also important. This is especially true in the case of PCSs, where base stations may end up mounted on telephone poles.

PCSs will use more base stations and those stations will need filters on the outgoing signal as well. Because they will have to handle substantial current, filters for transmitters will be harder to make than filters for receivers. In general, current-carrying applications for superconductors have proved difficult because the phenomenon of superconductivity is self-destructive; as the current or the magnetic field increases, the ability to carry current is diminished. Although both low- and high-temperature superconductors respond in this way, the inhomogeneity of HTSs aggravates the problem.

“That’s one challenge yet for the field, to reproducibly handle some tens of watts, which they’ll need on the PCS system,” said John Rowell, a consultant to the superconductor industry. It’s thought that solutions may come from better manufacturing techniques that eliminate film defects, optimize materials properties, and boost current-handling capacity.

At present it’s unclear which type of technology—thick or thin film—will ultimately triumph in the marketplace. Although results so far have been promising, the similarity of products may mean that if any one company stumbles, all will



**Illinois Superconductor’s filters, based on a thick HTS film, enhance the range of base stations, reduce channel interference, and decrease dropped calls.**

be affected. If a major problem arose in either the technology or customer acceptance of communications products, for example, the fledgling industry could face a bleak future. “The emphasis of the whole industry on communications does make me a little nervous,” admitted Rowell.

The success of HTS systems is contingent on the development of efficient, compact, reliable, and inexpensive cryogenic coolers. For this reason coolers have been the focus of intense research and development, and this quest is meeting with some success. For instance, Superconductor Technologies (Santa Barbara, CA) has developed an extremely efficient gas-compression cooler using helium gas as the working fluid. It consumes the same power as a lightbulb and can reach temperatures as low as 73K.

None of the companies making superconductor products is yet making a profit. For several of them, as much as 80% of their total revenue comes from R&D contracts on HTSs. Much of this funding is from the government. These research efforts improve the technology, lead to new products, and keep the firms going. However, successful product sales would increase revenue, allowing firms to achieve profitability. These improvements might in turn trigger the flow of product development money from an investment community made skeptical by the hype that accompanied the discovery of HTSs. □