 By Graham Prophet, Editor

New antenna designs reach for the sky

COMPARED WITH PROGRESS IN SILICON INTEGRATION, INNOVATIONS IN ONE AREA OF PORTABLE-RADIO DESIGN–ANTENNAS–HAVE BEEN RELATIVELY MODEST. NOW, NEW MATERIALS AND STRUCTURES ARE TAKING ANTENNA DESIGN FORWARD AND WILL, IN TURN, ENABLE NEW MULTIFUNCTION HANDSETS.

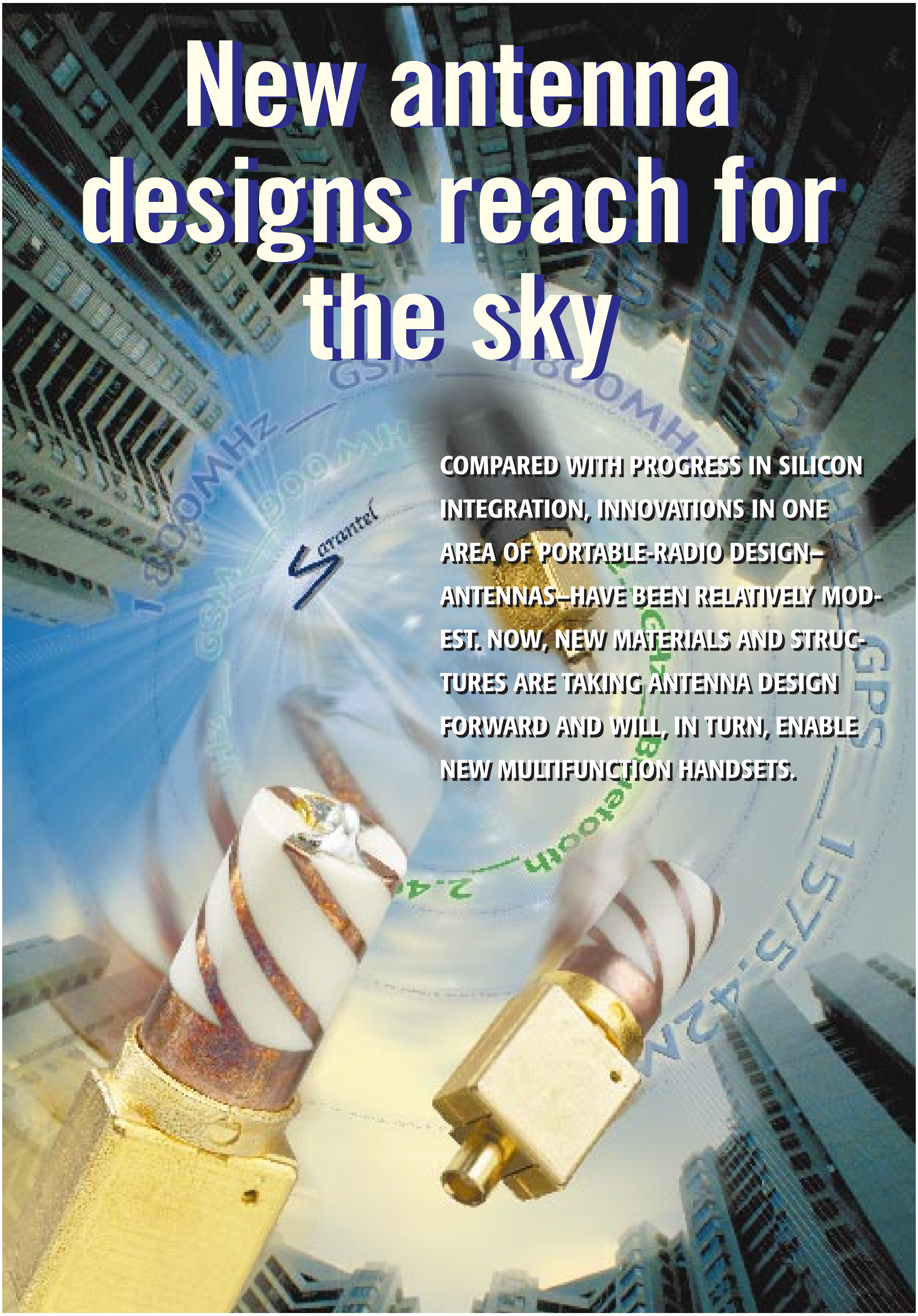

Photo courtesy Sarantel

Handheld communications products have now evolved enough so that the space that their necessary circuitry requires no longer determines their design constraints. Therefore, the smallest practical cell-phone format is defined by the space needed to mount a keypad that is operable by the "average finger" and the need for a legible display. The human interface is, to a large extent, the defining factor. As portable phones have evolved, another key interface component has developed along the same path—the antenna. Recall that when a cell phone occupied about half of an average briefcase, its antenna was usually a flexible, moulded unit about 10 cm long. More recently, antennas on cell phones have transformed into the familiar 1- to 2-cm stub mouldings, then into formats that mount completely within the case moulding of the phone.

So far, so good. Now, however, the problems that you face when specifying an antenna for your portable product are multiplying. A new generation of products that will have not one, but two or more independent (or semi-independent) RF interfaces is in development. You might have a cell phone—whether GSM (Global System for Mobile communications) or third generation—that also has a Bluetooth interface. Or, it might incorporate GPS (global-positioning-system) functions. Or, conceivably, it could incorporate all of these factors. It could also combine one of these interfaces with an IEEE 802.11 (wireless-LAN) interface. Whatever the combination, you now have multiple transmit-and-receive systems, each requiring its own antenna, operating in close proximity. Although their frequencies may be well-spaced, the possibility of interaction among them still exists. Each system is in a frequency band in which the proximity of the human body (that is, the user of the handheld product) is material to the function of the antenna.

Interaction with the human body raises another issue that is relevant to the development of antenna designs—the desire to minimise the absorption into the body of energy that radiates from a handheld product. The debate over whether the effects of such low-level RF exposure are harmful continues energetically in many places. But for equipment design, the debate has only one outcome. Faced with the impossibility of proving a negative (that there are no significant biological effects), the only course open to designers is to minimise the energy that is directed toward the user. This challenge is known as "the SAR problem." (SAR, or specific absorption rate, is the standard measure of RF energy that the human body receives.)

Adding to these two issues—multiple services in one product and the SAR problem—is the challenge that system capacity and the efficient use of spectrum and RF energy poses. These issues have triggered a spate of development in an area that was fairly static (or, at least, an area that has seen much less development than the internal structure of the cellular phone to which antennas attach). When phones were nearly the size of a brick, the flexible antennas they sported were, in all probability, simple one-quarter-wave elements, or perhaps one-half-wave dipoles. In the intervening years, developers have wound that format into a helix to create the familiar "stubby" an-

Figure 1

One of a new generation of ceramic antennas, Phycomp's Bluetooth unit is surface-mountable, with enough bandwidth to cover the 2.4-GHz band without tuning.

tenna that first shrank atop the phone, then migrated entirely inside the case. But few innovations in antenna design have appeared. Smaller cell phones use other antenna designs within their cases—for example, slot antennas. In slot antennas, a metal occupies the top section of the phone's case, where the RF section usually resides, and a slot in the outward side of the can (away from the user) acts as the radiating element. This design has the advantage of offering some directivity to help with the SAR problem, but it is still fairly conventional.

EMBEDDING THE ANTENNA

The pace at which wireless-LAN and Bluetooth products are developing has stimulated a new generation of antenna designs. Such products regard and handle the antenna as just another component rather than as a major part of the RF design. Evidence of this trend is the variety of antenna types that you can now use with Bluetooth products. For use with access points or with PC-based Bluetooth nodes, one-quarter- or one-half-wave devices are available that swivel-mount or retract into case mountings, or you can obtain a Bluetooth patch antenna. The patch antenna is, as its name suggests, a flat, low-profile, rectangular antenna with a hemispherical response pattern. You can also obtain slot antennas and planar inverted F-type antennas (PIFAs). For embedded use with an antenna mounted on or adjacent to a pc board, however, the simple antenna pattern may still be too big for convenience. Bluetooth operates in the 2.4-GHz band, and a single wavelength is therefore 12.5 cm; one-quarter wavelengths still measure more than 3 cm. This size problem has led to the development of the "meander-line" antenna. As its name suggests, this type of antenna is a component usually designed for pc-board or internal-case mounting in which the required length of radiating conductor folds into a suitable form to reduce the external dimensions. This folding, however, generally somewhat compromises response pattern or efficiency.

More pronounced moves in the direction of miniaturisation and "componentisation" of the Bluetooth antenna come in the form of ceramic-bodied antenna components. The usual calculation of wavelength—12.5 cm at 2.4 GHz, in this case—applies to the free-space speed of light. In the case of an antenna, the same calculation is appropriate when the radiating element is launching energy into air. If the interface is not to air but to a material with a higher dielectric constant, the dimensions can be much short-

AT A GLANCE

▷ Antenna design for handheld products has seen conventional designs become more compact but few innovations.

▷ Antennas that depend on a substantial ground plane fall short of ideal performance when you use them in small, moulded-case products.

▷ When products host two or more coexisting RF services, the performance compromise becomes intolerable.

▷ Better performing designs can help reduce broadcast power and increase system capacity.

▷ Design directions focus on very small size (driven by Bluetooth) and improved performance.

ANTENNA BASICS

Despite new physical formats and design concepts, the basic parameters of antenna design remain the same: You need to pay attention to gain, VSWR (voltage standing-wave ratio), bandwidth, and impedance. Gain is a measure of the antenna's ability to enhance the received signal and relates to the directional response of the design. A quoted gain is invariably that of the spatial peak of the response profile. Data sheets may present it as a response in a single plane (expect to see a slice in a horizontal plane for a cellular or Bluetooth antenna and one in a vertical plane for a Global Positioning System) or as a 3-D plot (**Figure A**). As with any circuit design, if you pay for a certain gain from your antenna, you should aim to degrade that figure as little as possible with well-matched connections

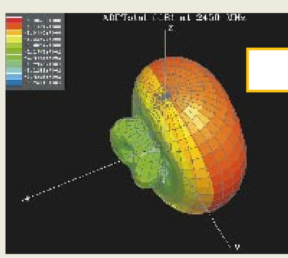

Figure A

You can present distribution of an antenna's response as a 3-D volume plot. This example is for the Phycomp antenna in Figure 1.

and a carefully designed signal path from antenna terminal to transmitter-output device (or low-noise amplifier for the receive path).

Careful impedance matching also minimises VSWR, which is a measure of the proportion of the transmitter-output energy that reflects back from the antenna and is not radiated. (The reciprocal function means the same efficiency limit applies to the receive path.) The antenna has an intrinsic VSWR that, again, you should try not to degrade with inadequate impedance matching. For comparison, if your task is sending hundreds of watts of high-frequency RF from a transmitter to an antenna, you would not be satisfied with a VSWR of more than 1 to 1.1 or 1 to 1.2. With the circuit conditions that prevail in handsets and at Bluetooth frequencies, anything less than 1 to 2.5 is acceptable. Impedances are traditionally and almost invariably 50Ω, but some novel antenna designs may require a different figure.

Antennas may be broadband or, as in some of the new designs, extremely narrowband. In data sheets, you'll see quoted figures, usually to a −3-dB point, of bandwidth in megahertz or of fractional bandwidth, which you calculate as bandwidth divided by operating frequency. If some of these new designs live up to the predicted figures (such as 1% fractional), you might be able to use the antenna alone to provide receiver-front-end bandpass filtering, which is part of the circuit-cost equation in many Bluetooth designs.

There are fundamental limits to the design space that an antenna operates in, bounded by electrical size (with respect to wavelength in whatever dielectric medium you are working), bandwidth, and efficiency. Gains in any one area mean compromise in the others, but the new designs now appearing look ready to push the overall envelope further than has ever been possible.

er. However, there is more to the design of such an antenna than simply embedding a radiating element in ceramic. These components are complex resonant structures; the radiated energy must still cross the boundary from ceramic to air, and the design must recognize this challenge, or internal reflections will account for much of the electrical energy that is input to the antenna.

An example of a ceramic-bodied antenna is the Bluetooth/wireless-LAN antenna that Phycomp (www.phycomp-components.com), formerly part of Philips Components, introduced earlier this year (**Figure 1**). This design yields a component that measures $7.3\times5.5\times1.4$ mm. The company designed it for direct surface mounting on a pc board, and a 50Ω microstrip line feeds it (see **sidebar** "Antenna basics"). The device's specification sheet quotes an omnidirectional response, gain of 1.2 dBi, and a maximum bandwidth of 140 MHz in the 2.4-GHz industrial, scientific, and medical band. Its maximum voltage standing-wave ratio is 2.0.

In at least one case, a company has combined this approach with the packaging of a Bluetooth semiconductor component. Alcatel Microelectronics' (www.alcatel.com) single-chip Bluetooth device offers you the option of having an antenna fired into the ceramic of the chip package.

CAN YOUR SIGNAL GET OUT?

Although developments of this type make for a small overall product profile and remove the need for an external antenna or antenna connection, they require you to carefully consider the environment in which the antenna operates. Obviously, the antenna needs to be outside any screening metal structures, but you also need to consider the proximity of other metallic structures and pc-board ground planes (which may be material to the operation of the antenna in the first place). The price of a neat package with no external antenna may be that it compromises the antenna's potential to deliver an omnidirectional radiation pattern. In many Bluetooth applications, this issue may not matter. You may be designing for a short-range link, or you may be able to rely on reflections in the local environment to fill in the geometric coverage. Still, you cannot ignore this factor.

The use of advanced ceramics characterises design of these small embedded antennas and of similar products from other sources. Therefore, you can expect to see such products coming from companies with expertise that you probably previously associated with components, such as capacitors and ceramic resonators.

Figure 2

Sarantel can equip its PowerHelix GPS antenna with a low-noise amplifier mounted in the base of the antenna.

A new antenna design from UK company Sarantel (www.sarantel.com) also draws on technologies you would not normally expect to encounter in antenna production; in this case, the company has adapted manufacturing techniques from semiconductor and hybrid-circuit production.

Sarantel's first production design is for a GPS antenna, but the company claims the design is equally applicable to cellular or Bluetooth use (**Figure 2**). The antenna takes the form of a short ceramic cylinder that carries a helical conductor pattern; the lower portion of the cylinder is fully metallised and forms a sleeve balun (unbalanced-to-balanced transformer). The antenna element is a twisted loop that wraps helically around the cylinder; a coaxial feed that passes through the axis of the cylinder drives the element. Precise geometry (to less-than-1-micron levels) and knowledge of the dielectric properties of the base ceramic cylinder are necessary for this design to function correctly. Sarantel characterises each batch of ceramic, prints the antenna pattern using photolithography techniques, and actively tunes each production unit with an automated laser-trimming process.

NO SOLID GROUND

Sarantel claims that one of the advantages of this design is operation independent of a ground plane. Sarantel's CEO Barrie Foley points out that the average handset case is now too small to offer a realistic ground for, say, a one-quarter-wave element to act against. You may get away with using an antenna that needs to have an associated ground plane in a product that does not have one if you accept the limitations that doing so places on performance and if you have just one RF link out of your handset. But with two or more RF links, independence from ground becomes necessary to avoid interaction. Interaction manifests itself as an increased noise floor and through the presence of common-mode signals. Whatever ground-plane performance you can achieve degrades and varies through interaction with the user's hands and body.

In addition to operation independent of a ground plane, Sarantel says that the field pattern of its design is such that the null response falls in the region of the user's head. The radiation pattern is strongest above and below the antenna (when you orientate it vertically), and the near-field region is restricted to very close proximity to the antenna surface. These two factors together, Foley says, minimise the energy dissipated in the user's head, thereby addressing the SAR issue. The reciprocal property also applies to the antenna's use as a handheld GPS antenna; it minimises loss of the low-level signal by absorption into the user.

Foley believes that the antenna's GPS-reception performance will be an important factor in designing handsets for the US E-911 emergency-location specification. Now, Sarantel is building this design with a very narrow response (for GPS use)—a fractional bandwidth of about 1%—but Sarantel expects to develop wider bandwidth versions for use with cellular systems. Foley is skeptical that you can achieve good GPS performance with a simpler antenna and more signal processing. The Sarantel GPS antenna has, as noted above, a hemispherical field pattern and a mirror response that enables it to use ground reflections. It has a 3-dB margin (as it is circularly polarised) over a simpler antenna, which, combined with its independence from loading and interaction effects, Foley believes is a margin that signal processing cannot recover. "In an E-911 application," Foley says, "this performance becomes a public-safety issue."

Another UK start-up, Antenova (www.antenova.com) promises an intriguing alternative development. Few details are available, as the first product from the company is due for release at the beginning of the fourth quarter of 2001. The product is a "component" antenna that is both directional and steerable. The company has not yet disclosed how the component works, but CEO Dr Graham Cooley emphasises that it is not a phased array and it does not involve a DSP. The directionality is around 60°, so you would therefore divide the "world view" of the antenna into six zones. You can use this attribute to reduce transmitted-power levels by selecting the highest directional response, allowing greater frequency reuse in cellular systems and increasing network capacity. The device, Cooley says, is a 3-D, "volumetric" structure (as opposed a 2-D patch antenna or a single-dimension regular dipole). However, the electrical model is of a dipole; therefore, the device has immunity to ground-plane and circuit-interaction effects. Because of the beam-forming response of the antenna, gain is 4 dBi. According to Cooley, by virtue of its directionality and independence from interaction effects, Antenova's design attacks the twin issues of efficiency and system capacity, the problem of multiple RF systems coexisting in one product, and the SAR issue. The near-field zone is confined to a region close to the antenna, the far-field response dominates from just outside its surface (helping to avoid interaction problems), and the front-to-back ratio of the directional beam is close to 20 dB. These characteristics mean that you can direct 99% of the transmitted energy from a handset away from the user's head. Other possibilities include dual-band, dual-polarisation versions, possibly with sufficient separation to allow you to build a system without transmit-and-receive switching. Antenova will first introduce a product for a location-monitoring system and progress via Bluetooth-access-point designs to products for handsets within about a year.

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As well as the new start-ups highlighted in this article, look for new antenna developments from established vendors that have been providing antennas to the cellular business for some time, including Galtronics (www.galtronics.com), Centurion Wireless Technologies/Xertex (www.centurion.com), and Panorama Antennas (www.panorama.co.uk). For the new generation of embedded and surface-mountable antennas, companies that have ceramics expertise, such as TDK (www.tdk.com) and Murata (www.murata.com), have an interest. The Bluetooth-product phenomenon has generated a growing list of companies selling antennas. You can find more information at the Bluetooth SIG site (www.bluetooth.com) and a useful but incomplete list of potential suppliers at www.palowireless.com/bluetooth/antenna.as.□