 By Gary Legg, Contributing Editor

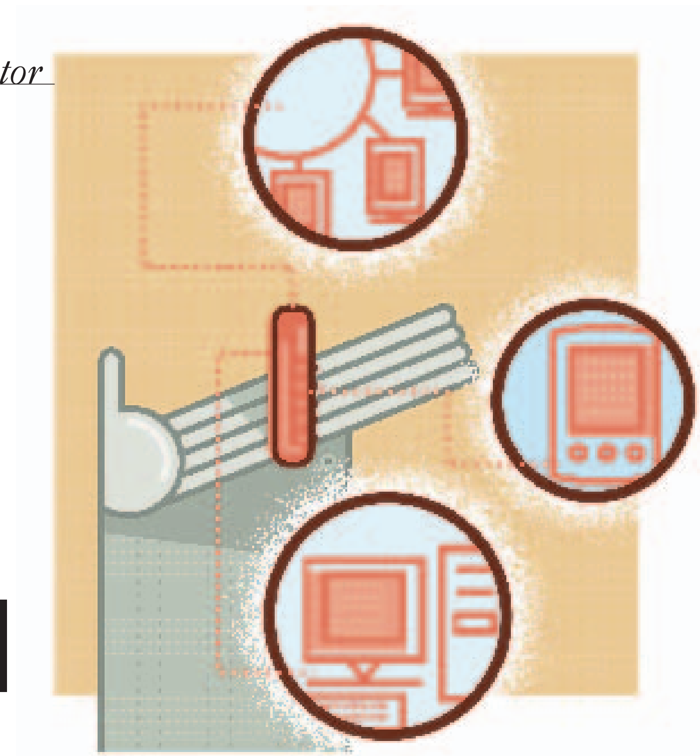


Illustration by Daniel Guidera

EMBEDDED ANTENNAS get the signal

NEW TECHNOLOGIES ARE PRODUCING ANTENNAS THAT WORK AS WELL INSIDE AN ELECTRONIC DEVICE AS TRADITIONAL ANTENNAS DO ON THE OUTSIDE.

It isn't enough that our cell phones are small. We want them even smaller and sleeker and with no protruding antenna. We want them combined with our PDAs, so we can carry one device instead of two. We also want our wireless wonders to be Bluetooth-enabled—to connect with our PCs—and wireless-LAN-enabled—so we can hook up to just about anything anywhere. We always want more. We're never satisfied. And so, we've handed antennas for portable wireless applications an almost impossibly tough job description. Now, antennas have to work inside wireless devices, not outside. They have to get signals into and out of a device despite being denied open-air interfaces. They have to contend with antenna detuning from adjacent electronic components and from users' hands that completely envelop them. They're asked to do double duty, serving more than one wireless application on different frequencies. All of this work, plus we expect them to work so efficiently that a wireless device's battery will last as long as—or longer than—ever before. Pity the poor antenna.

Some antennas, though, don't sweat their new job description. They use new and innovative technologies, and they're very small, so they fit into places where traditional antennas can't go. They have excellent isolation, so nearby electronic components and users' hands and heads have little effect on them. They operate—and operate well—on multiple frequencies. They're so efficient that they increase the range of the device they're in over what it could achieve with other antennas. They seldom drop a signal, and they're miserly with battery power. They're star performers, even though their job is very hard.

IMPRESSIVE CLAIMS

Those features are what the providers of the new antennas are claiming anyway. SkyCross, Ethertronics, and e-tenna are all two-year-old companies that are commercializing either new technologies or technologies that only military applications have previously used. Each company has innovative, perhaps even revolutionary, new antennas that are just now becoming available, and if these antennas perform as well as their developers claim, they could forever alter the antenna landscape for handheld wireless devices.

Consider these claims for various antennas that work in the 800-MHz to 5-GHz frequency bands:

- Size is 9×13×2.2 mm (about the size of a cuff link);
- weight is 0.12g;
- bandwidth is 800 MHz to 2.7 GHz;
- isolation is so high you can mount

the antenna on top of other components;

- efficiency is 75 to 85%, even when embedded; and
- cost is less than 50 cents.

You don't get all of those parameters in a single antenna, but even separately they're impressive.

Of course, performance claims are just that—claims. But e-tenna, Ethertronics, and SkyCross all have new antennas either on the market or available in samples, with production volumes slated to be available this fall. In addition, all three companies say they are working with major providers of wireless consumer devices, and that their antennas will appear in new, mass-market products within the next few months to a year. So, unless the companies' claims are gross exaggerations, these antennas could be for real.

Real or not, the new antennas are definitely different. In physical form, they seem about as far removed from a dipole as a transistor is from a vacuum tube, and some of them, at least, incorporate esoteric technologies that are hardly everyday terms. For example, e-tenna uses AMCs (artificial magnetic conductors), derived from photonic bandgap technology, which in turn is based on photonic crystals. SkyCross uses a variation of meander-line technology, which is fairly well-known, but the emphasis here is on variation, which SkyCross doesn't say much about. Ethertronics reveals little about its technology except to refer to its antennas as field-controlled magnetic dipoles.

THE GOODS

All three companies are eager to make impressive performance claims, however. For example, SkyCross claims its antennas are the smallest available for a given bandwidth. According to Al Haase, chief executive officer of SkyCross, any other antenna that matches a SkyCross antenna's electrical characteristics will be "dramatically larger." On the other hand, SkyCross and Ethertronics both offer multiband (multiple-frequency) antennas, and Ethertronics claims its multiband antennas are the smallest. Other multiband products, says Ethertronics marketing vice president Mark Penman, are "physically much larger than ours." Greg Mendolia, executive vice president of e-tenna, says that his company's approach isn't to have the smallest or highest performing antennas but to hit a market "sweet spot" with the best combination of size, performance, and cost.

AT A GLANCE

▷ New technologies are creating antennas with unprecedented size, isolation, and efficiency.

▷ Because of their high isolation, some of the new antennas supposedly can reside on a pc board along with other electronic components and still work as well as conventional external antennas.

▷ The new antennas are inexpensive and are compatible with automated manufacturing procedures, such as pick and place and reflow soldering.

▷ The antennas don't yet have a track record, and they all use different technologies, so market success isn't assured.

One key performance parameter that all the companies claim for their antennas is remarkably high isolation, which enables the antennas to be embedded in products, rather than be used externally. Each company touts the ability to place its antennas near other electronic components or near a user's hand or head and still give good performance. Conventional antennas can detune dramatically in those situations, the companies say, sometimes even rendering them essentially inoperable. Ethertronics and SkyCross increase isolation by controlling and shaping their antennas' near-field radiation patterns, but they don't say how they do this job. E-tenna uses an artificial magnetic conductor to achieve high isolation.

The artificial magnetic conductor that e-tenna uses is, as its name implies, an exceptionally good magnetic conductor. Just as copper is a nearly perfect electrical conductor, an AMC is a magnetic counterpart. The e-tenna AMC includes a patterned, reactive material consisting of many inductors and capacitors printed on a thin film, such as FR4, a common material often used to make pc boards.

Antennas based on new technologies work well even when embedded in products (courtesy SkyCross).

According to e-tenna's Mendolia, an artificial magnetic conductor transforms "a short-circuit ground plane to a high-impedance surface." In other words, Mendolia explains, you can place an antenna on top of an AMC—and parallel to it, not perpendicular—and the AMC will reflect the antenna's radiation, not with a phase change of 180°, as copper would, but with no phase change.

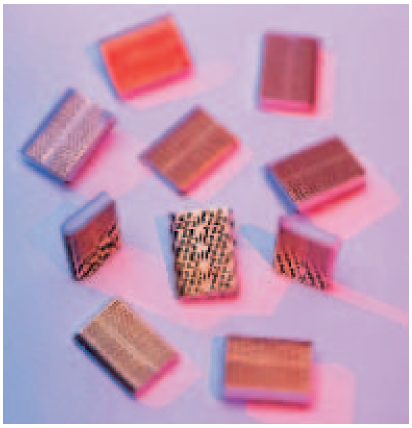
"In essence," Mendolia says, "the antenna thinks it's in free space." Also, because the AMC folds the antenna's radiation pattern in half and enhances it with its own in-phase reflection, antenna efficiency is high. "We've seen efficiencies as high as 80 to 90%," Mendolia claims.

The reflective properties of e-tenna's AMC, which the company calls RF Mirror, make the material suitable for use as a shield under a horizontally, rather than vertically, mounted antenna. Therefore, you can not only mount an antenna on a pc board, Mendolia says, but also use the other side of the board, directly underneath the shielded antenna, to install other electronic components; you can't mount conventional antennas in that way. In addition, according to Mendolia, components beside the antenna are fairly well-isolated, because transverse waves in the AMC die out exponentially and thus are small by the time they reach the edges of an AMC shield of sufficient size.

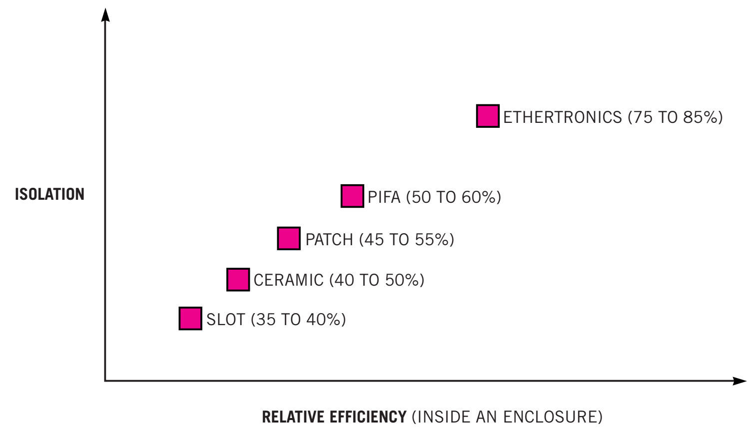
To be effective as a reflector and shield, however, an AMC must have a certain minimal size. For 1.9-GHz PCS signals, Mendolia says, an area of perhaps 1×2 in. is necessary, and that's too much space in today's tiny mobile phones. Similarly, the space required for 2.4-GHz Bluetooth and 802.11b applications might be acceptable in a laptop, but not in a PDA. So, for applications with severe size restrictions, e-tenna ditches RF Mirror and uses a technology derived from it.

MAKING ANTENNAS SMALL

To make its antennas small, e-tenna uses part of the AMC as an FSS (frequency-selective surface). By specifying



A frequency-selective surface, created by printing patterns of inductors and capacitors on film, is the basis for these 9×13×2.2-mm ClearLink antennas from e-tenna, which work for 2.4-GHz Bluetooth and 802.11b applications.



Antennas based on new technologies provide greater isolation and higher efficiency than conventional embedded antennas, their manufacturers say (courtesy Ethertronics).

appropriate values for the printed inductors and capacitors of the AMC, e-tenna makes this surface perform the function of an electromagnetic slow-wave structure. This structure slows wave propagation, thus reducing wavelength and enabling antennas—whose characteristics depend on wavelength—to be small. Appropriate values for the printed components can also make the surface resonant at multiple frequencies, Mendolia notes, making possible multiband antennas. In addition, says Mendolia, the FSS traps a significant part of near-field radiation, making antennas much less sensitive to near-field effects, such as detuning caused by nearby components.

SkyCross also uses slow-wave technology to make its antennas small, although its approach apparently differs in at least some respects. SkyCross creates slow-wave structures by folding meander lines in a zigzag pattern with a dielectric in between. The structures slow wave propagation, enabling antennas to be small, and the multiple folded segments couple electrically to increase antenna performance. Some of the SkyCross antennas use active components, the company says, and one apparent use of the active circuitry is to switch frequency bands in a multiband antenna. Separate meander-line structures provide efficient radiation and frequency tuning.

Ethertronics, even though claiming to have the smallest multiband antennas available, doesn't say how it makes them small. The impetus behind the company's founding two years ago, however, was photonic bandgap technology developed by Eli Yablonovitch (www.ee.ucla.edu/labs/photon), from which the technology of artificial magnetic conductors derived. Ethertronics says that the technology it now uses isn't photonic bandgap technology but is based on it. Conceivably, then, its approach to small antennas is similar to that of e-tenna.

How small are these new antennas? SkyCross says its antennas can be smaller than an IC and, in fact, are close to the theoretical minimum size for a given bandwidth. The ClearLink 2400 antenna from e-tenna is also impressively small, measuring 9×13×2.2 mm (about the size of a cuff link) and weighing 0.12g. Not to be outdone, Ethertronics cites one of its antennas as having roughly the shape of a knife blade measuring 1 in. long by 1/4 in. tall. Compare those dimensions with 2×1/2 in. for a typical PIFA (planar inverted-F antenna), currently the most common embedded (internally installed) antenna.

Just as important as size, though, says Ethertronics, is antenna footprint. A PIFA, notes Ethertronics product marketing manager Greg Hill, mounts horizontally about a quarter inch above a pc board's surface, and the "keep-out" space underneath the antenna can't contain any components. In contrast, Hill says, a smaller Ethertronics blade antenna mounts vertically, somewhat like a postage stamp standing on its side, so the keep-out space is much smaller. Hill says that smaller space is an advantage for retrofitting designs—adding GPS to a cell phone, for example—because you can sometimes put the antenna between components. The antenna's high isolation, Hill adds, can enable the antenna to work between components where other antennas couldn't.

Footprint could be almost irrelevant with e-tenna's RF Mirror technology, however. E-tenna's Mendolia notes that a fairly large sheet of RF Mirror material underlying an antenna can fit over a pc board, not only shielding the antenna from the board's components but also serving as a quasi EMI shield to retain the board's

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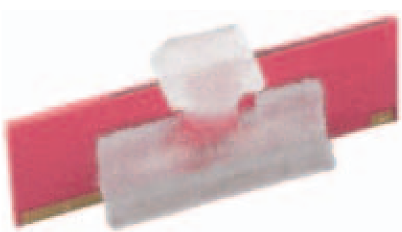
emissions. When you use it in that way, Mendolia says, the material could even eliminate some components normally required to suppress emissions.

MULTIBAND OPERATION

Another space- and cost-saving feature of the new antenna types is multiband operation. SkyCross, for example, says its antennas can handle as many as six frequency bands ranging from 800 MHz to 2.7 GHz. Conceivably, then, one antenna could work for AMPS (800 MHz), GPS (1.5 GHz), PCS (1.9 GHz), Bluetooth and 802.11b wireless LAN (2.4 GHz), and 802.11a wireless LAN (5 GHz). Furthermore, say SkyCross, Ethertronics, and e-tenna, their new multiband antennas work far better than conventional antennas that have been applied to multiband applications. For example, SkyCross' Haase notes that mobile phones often use one antenna for both the 800-MHz AMPS band and the 1.9-GHz PCS band, but the antenna typically is optimized for 1.9 GHz, and 800-MHz performance is subpar.



A blade-shaped Ethertronics m-type antenna measures approximately 1×0.25 in. Its vertical mounting position and high isolation allow it to fit into tight spaces on circuit boards. The white material facilitates pick-and-place installation of the antenna.

The new antennas, however, apply new technologies to improve multiband operation. SkyCross, for example, uses its meander-line technology to create separate structures for radiation and frequency tuning. The radiation structures are designed for highly efficient radiation; the separate frequency-tuning structures control only an antenna's electrical length, or resonant frequency. Ethertronics, in contrast, uses its blade-configuration antenna technology for multiband antennas—one blade per frequency band. E-tenna uses its frequency-selective surface technology, wherein appropriate inductor and capacitor values for a surface produce natural dual resonance, according to the company.

The bottom line for antennas, of course, is how well they perform, and efficiency is probably the best—although an inadequate—indicator of performance. As you might expect, the new antennas boast superior efficiency and performance to go along with their reduced size and superior isolation.

Ethertronics, for example, claims its antennas perform similarly to "whip" antennas, even when embedded, with an efficiency of 75 to 85%. A PIFA, currently the most widely used embedded antenna, offers 50 to 60%, the company says. In addition, says Hill, an embedded PIFA's efficiency can drop to 20% when

SkyCross antennas, such as this 5.25-GHz antenna for wireless-LAN applications, use meander-line technology, folding lines in a zigzag form, for compactness. The folded structures couple electrically to enhance performance.

the antenna is surrounded by the hand of a cell-phone user. Hill says that the efficiency of an Ethertronics antenna, because of higher isolation from hand effects, may fall to only 50 to 60% in that situation.

E-tenna likewise claims efficiency as high as 80 to 90% with antennas that use its RF Mirror technology. There's no loss mechanism with RF Mirror, notes Mendolia, and the radiation reflected from an RF Mirror enhances the original radiation.

SkyCross, on the other hand, apparently shies away from efficiency numbers; its data sheets simply say "very effi-

TRADITIONAL ANTENNA ALTERNATIVES

Unless you need the best performance in the least space, a traditional antenna type can probably serve you as well as one of the new exotic antennas. If your antenna doesn't have to be internal to a wireless device, for example, then high isolation isn't usually a major requirement, and a quarter-wave stub antenna can be a good option. A "stubby" is fairly small and, because it mounts externally, has a fairly clear path for transmission and reception without interference from nearby electronic components. It does, however, require a ground plane, such as a chassis or a metal plate. If your design can tolerate a slightly larger antenna, using a ground-independent half-wave dipole gets around this requirement.

If your antenna needs to be internal, you still have several good options. As noted in Centurion Wireless Technologies' Design Guide for Wireless Device Antenna Systems (www.centurion.com/pdf/centurion-designguide-043002.pdf), a chip antenna is small but requires a large ground plane. A meander-line antenna performs well if it is kept away from the ground plane or other metallic surfaces. A PIFA (planar inverted-F antenna) provides good electrical performance but is much thicker than a patch antenna. Patch antennas are noted for their low profiles.

Production volume can also be a deciding factor in antenna choice. An embeddable antenna can require customization, not only of its design for a particular application but also of the application's design itself, particularly in component placement. Its resulting performance may be impressive, but you need high product volume to recover your upfront costs.

Don't expect to embed any antenna simply by plugging it in, though. For that matter, don't expect a simple plug-in job even for an external antenna. So many things can affect antenna performance: case material, nearby components, even cables and connectors.

As Dax Craig, vice president of business development for Centurion Technologies, notes, "Antennas are funny little devices, but they can have a bigger impact on system performance than any other component."

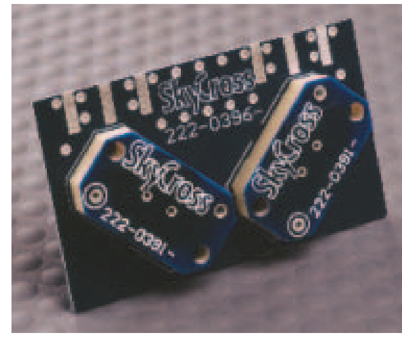
The Ethertronics GY multiband antenna measures 8×16×2.5 mm and covers the 2.4- and 5-GHz bands. Each of the two main parts of the metal structure covers a different band.

cient" and "high efficiency." The company does emphasize performance, however. It cites a "drive test," for example, in which Agilent Technologies (www.agilent.com) tested a variety of mobile phones with the phones' original OEM antennas and with the original antennas replaced by SkyCross antennas. In 20% of the situations encountered, says SkyCross' Haase, the OEM and the SkyCross antennas performed equally; in the other 80%, the SkyCross antennas excelled.

CHEAPER MANUFACTURING

Ultimately, though, cost may dictate whether the new antennas succeed. And cost, in this case, means not just the purchase price of an antenna, but also the overall system cost of using an antenna. The new antennas themselves are cost-competitive with conventional antennas, their manufacturers say, and reduced system costs could make them even more competitive. All of the new antennas can mount on a pc board, and they can do it with automated manufacturing procedures, such as pick and place and reflow soldering. That ability means simpler and cheaper manufacturing than with many conventional antennas. Chip antennas offer the same manufacturing savings, of course, but they're not known for high performance.

Conceivably, antenna-related cost savings could even move upstream—to a wireless phone carrier, say. If the new antennas perform as well as their manufacturers claim, they can extend cell towers' ranges, meaning that a carrier could get by with fewer towers. Indeed, makers of the new antennas claim that their antennas do extend operating range. And,



This SkyCross antenna module, measuring 11×22×2.5 mm, contains two 5.25-GHz wireless-LAN antennas mounted in different orientations for diversity reception. Diversity schemes allow switching between antennas for best reception in difficult situations, such as multipath fading.

because carriers—in the United States, at least—decide which phones to offer with their service, they could well decide to address coverage gaps with consumer products instead of with infrastructure.

That scenario puts the cart before the horse, however, because the new antenna technologies don't yet have a track record, and one obvious step that the new antennas will have to take is to become familiar to designers. Just as one example, many of the new antennas have different radiation patterns from those of more familiar antennas. Some are less omindirectional than conventional antennas, for example, and users usually prefer omindirectional antennas for portable applications. However, an antenna's overall better performance could mean that the lowest gain its radiation pattern indicates might be higher than the highest gain of a more familiar antenna.

POSSIBILITIES

Ultimately, it might not be familiar, but different, antenna applications that decide the new antennas' fate. Consider, for example, a joint project that Ericsson (www.ericsson.com), the Swedish mobile-phone giant, and e-tenna completed. The two companies have put a radio transceiver inside one of e-tenna's antennas, measuring 10×14×2.5 mm. Imagine the possibilities.□

AUTHOR'S BIOGRAPHY

Contributing editor Gary Legg is a Boston-based free-lance writer. You can reach him at garylegg@media16.com.