Comment on Metamaterial Antenna Debate and Related Topics

By Karl Warnick

The metamaterial concept has been an exciting area in electromagnetic theory and has had useful impact on antenna design. The debate on what should be called a metamaterial antenna shows that it is not easy to decide when and how to use this term. I offer three issues that should be considered as one decides how heavily to advertise the metamaterial nature of a new antenna design:

First, in some published designs, a periodic or repeated structure built from smaller structures to achieve certain propagation characteristics is clearly evident in the final design, and the metamaterial moniker is justified without qualification. In other published and patented antennas, however, the metamaterial that may have been present at some point in the design process has morphed in the design tuning and optimization process until it becomes only an electrically small, vestigial aspect of the design. The resulting design really is not much more than a minor variant of a known antenna type. In these cases, "metamaterial-inspired" might be appropriate, or, more honestly, the design should have been published or marketed without reference to the metamaterial concept.

Second, surveying the literature on antennas shows that an endless variety of geometrical shapes can be tuned and optimized to achieve specific goals for frequency, bandwidth, gain, polarization, and size. Circles, flared tapers, squares, slots, patches, one's university logo, and even jeans buttons have been reported in the antenna literature. As long as a geometry has a few tunable dimensions, there is likely a configuration in the design space that has a useful property as an antenna. In this light, metamaterial antennas play a role as a source of inspiration for an initial design geometry, but once a significant amount of tuning of the structure has been done to achieve an antenna design goal, the design process becomes more or less standard.

Lastly, antennas that actually have a recognizable metamaterial aspect often exhibit poor performance relative to standard antennas. This is well captured in the excellent paper by D. Sievenpiper and collaborators, "Experimental validation of performance limits and design guidelines for small antennas," TAP, vol. 60, Jan. 2012, pp. 8-19. Figure 3 in that paper shows that reported metamaterial antennas are larger and less efficient or have narrower bandwidth than nearly all existing antenna designs. The commercial value of an antenna is in its electrical performance, size, cost, and manufacturability, without regard to the design philosophy that was used. Using the metamaterial concept in the design process is academically interesting, but the final product can be inferior to traditional antennas.

These considerations show how important it is for antenna experts to use caution when evaluating purported breakthroughs in antenna theory, even when a new direction like metamaterial antennas is interesting and offers real promise for new capabilities in antenna applications. With a nod to R. C. Hansen's great book "Electrically Small, Superdirective, and Superconducting Antennas", Wiley, 2006, which should be read by all aspiring antenna engineers, the overarching issue is that antenna design as an optimization process is not really research anymore. Hundreds of papers are published each year on variants of antennas for new frequencies, multiple bands, and new applications, but the underlying idea, that a structure can be tuned to achieve a set of design goals, has been exhaustively explored already. What is needed at this stage in the history of antenna theory are catalogs of design approaches, comparisons of performance to fundamental limits, and unifying reviews that place all known designs into a taxonomy that can be used in the research world and the wireless industry. This framework will provide a solid backdrop against which to evaluate the performance of exotic new designs and results proposed in the antennas and propagation community.