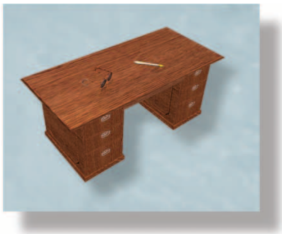

From the Editor's Desk

Nanotechnology–The Last Frontier?

■ **Madhu S. Gupta**

Many readers of this magazine, myself included, work on *micro*wave devices that have cutoff frequencies in the *milli*meter-wave frequency range and are fabricated with *nano*technology. Apparently, the size, which was always an essential part of the specifications of electronic devices, chips, components, modules, and systems, has also become an inescapable part of describing the crucial or distinctive aspects of our professional work, even if only through prefixes that designate an order of magnitude. Physical size is important to microwave engineers, much as the size of a database or a computer code is for a software engineer or the size of a communication network or the data rate for a telecommunications engineer.

Besides the two extremes of specifying a size precisely as a number and roughly as an order of magnitude, we also use other, fuzzy ways of conveying the size information, both in words and graphically. In electronics literature, as in colloquial writing, the size of an object is frequently described in an anthropomorphic manner by comparing it to a human hair, a thumbnail, or a breadbox. Graphically, the size scale has long been conveyed visually through photographs of objects placed alongside a measuring scale or ruler. As we become more image oriented, and with the attendant emphasis on eye appeal, the ruler is increasingly being replaced by postage stamps and coins; indeed, those are becoming the dominant means to place the object of interest in perspective, not only in technical presentations, but also in published material. Parenthetically, I had long wondered how readers would know the actual size of a coin from some other country, but my fears proved to be unfounded: *NTT Technical Review*, published in Japan, showed a U.S. coin as the size indicator on the cover of its inaugural issue—apparently U.S. coinage must be internationally recognized!

The business reasons for why the size of an electronic object is important are easy to understand. The first is the cost. For many products, size determines material costs, although it is often dominated or masked by other costs. While the material cost would normally increase with the size of the object, the processing cost would typically increase with decreasing size of critical dimensions or tolerances. For integrated circuits, the cost scales with the size of the chip—measured in area, at least until we start making three-dimensional chips. Second,

Madhu S. Gupta is with San Diego State University, 5500 Campanile Drive, San Diego, CA 92182-1309 USA, +1 619 594 7015, microwave.editor@ieee.org.

and equally important, size could be the enabling factor that controls the usability or feasibility of a component or product. In applications constrained by volume or weight, such as in satellites or aircraft electronics, or in portable or embedded products or where the electronic objects must fit nonobtrusively, blend in, or be camouflaged for cosmetic, safety, or stealth reasons, size is obviously crucial. Third, while the application dictates the permissible product size, the most frequent reason for pursuing size reduction technologies is not so much for decreasing the possible product size but to accommodate a higher level of system complexity within it.

The technological reasons for the importance of size are particularly well understood by engineers who work in the microwave region, where a conductor is no longer a "trace" with its size limiting the current handling capacity but an interconnect line with its size governing the characteristic impedance and, therefore, serious implications. The size of an electronic component influences: the reactive parasitics with which it is associated; the parasitic effects, such as signal loss, propagation delay, and dispersiveness; whether lumped or distributed models must be used for simulation; the level of electromagnetic interference it generates or suffers; and a host of other issues. Tolerances are also specified by the smallest feature size that can be fabricated or measured reliably. In semiconductor devices, certain phenomena, such as quantum tunneling, can be made dominant for only a limited range of device dimensions. Moreover, critical dimensions, such as gate length in FETs and base width in BJTs, determine the cutoff frequency of devices, the performance of the devices, and, ultimately, the capability of the technology. As a result, successive generations of fabrication technology are identified by that critical size and described by terms like submicron devices, quarter-micron design rules, and nanotechnology.

Is nanotechnology only a way station along the path of continued technological advancement, with picotechnology and femtotechnology coming up as the next stations? For those of us, the progeny of Maxwell et al., who make a living from electromagnetic fields, it is a sobering thought to recognize that the reach of our technology may be limited. The atomic sizes span the range 0.1 to 1 nm, while nuclear sizes range from 1 to 5 fm, dimensions where much stronger nuclear forces dominate and make electromagnetic forces a minor consideration. So enjoy the excitement of technological frontiers while the spotlight is on nanotechnology.