From the Guest Editor's Desk

Metamaterials: The First Ten Years

■ **George V. Eleftheriades**

This special issue is devoted to metamaterials, a now vibrant and still emerging field that formally started just over a decade ago. The field began in the physics community, but related work, in what was called "artificial dielectrics," was carried out in the 1940s, 1950s, and 1960s in the microwave/antenna engineering community. Formally, one could define electromagnetic metamaterials as artificial materials with unusual or difficult-to-obtain electromagnetic properties. This definition immediately points to electromagnetic quantities such as the permittivity, the permeability, and the refractive index. What would be possible if materials with user-defined permittivity and permeability tensors were made available? Perhaps the most representative metamaterial is the so-called "left-handed" one, which is isotropic and characterized by having simultaneously a negative permittivity and a negative permeability, conditions which lead to a negative index of refraction. This metamaterial is also known by the names "double negative," "negative-refractive-index (NRI)," or simply "negative-index material (NIM)." Since the experimental demonstration of NRI metamaterials a little over a decade ago, substantial progress has been made and many new metamaterials have been proposed that are not necessarily isotropic or homogeneous, their peculiar properties have been charted out and exploited to show new phenomena or demonstrate new applications. For a limited treatment of this topic, including a brief historical survey, see the article by George Eleftheriades and Michael Selvanayagam in this issue of *IEEE Microwave Magazine* [1]. In addition, see the October 2011 issue of *Proceedings of the IEEE*, which is devoted to metamaterials. In my opinion, the greatest contributions so far by the metamaterial community have been made to the conceptual and scientific fronts. For example, we now know that Snell's law can be extended to include the phenomenon of negative refraction, flat lenses are possible, which can focus microwaves down to subwavelength spots, the near field can be manipulated in ways that were not previously considered, and materials can be prescribed that can mold the spatial distribution of the electromagnetic field almost at will. Furthermore, in an exciting recent development, we can now understand how to utilize the rich palette of design techniques available for microwave circuits to design their nanoscale optical counterparts, including lumped-element resonators and filters (see [2] and the article by the same author that will appear in an upcoming issue of *IEEE Microwave*

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Magazine [3]). All these new conceptual developments are quite remarkable considering that electromagnetics is the oldest branch of electrical engineering and over 150 years have passed since Maxwell established his ground-breaking equations. It is truly surprising that a mature field such as classical electrodynamics still hides new and exciting phenomena and possibilities at such a fundamental level.

As with any new discovery, the question arises: How useful are these metamaterials and how can they be used in practice? To this end, in the past few years, several innovative applications have been proposed and demonstrated. For example, see the articles in this issue by Yuandan Dong and Tatsuo Itoh on novel microwave guided-wave structures and devices [4] and by Martin Schüssler, Christian Mandel, Margarita Puentes, and Rolf Jakoby on microwave sensor applications [5], as well as the October 2011 issue of the *Proceedings of the IEEE* and [1]. However, in my opinion there is much more room for further work on the applications front. It can be argued that this is because most of the initial research in metamaterials has been carried out in academia and was driven mainly by scientific curiosity and the excitement of discovering new physical phenomena. However, as the field is maturing, this is changing. Today, not only are applications more actively pursued in academia but also several companies are starting to invest research and development resources to develop practical applications and products (or to improve existing ones) using metamaterial concepts. A limited search in recently issued U.S. patents revealed that companies with activities relating to microwave metamaterials include Boeing, Lockheed Martin, Northrop Grumman, Raytheon, BAE systems, Hewlett Packard, Alcatel-Lucent, Toyota Motors, Intel, Mitsubishi, and Samsung, covering diverse technical fields in defense, telecommunications, satellites, navigation, automotive radar, computers, and wireless power transfer. Moreover, venture capital money is flowing to establish start-ups attempting to commercialize innovative products based on metamaterial concepts. In conclusion, the story of metamaterials is still unfolding, and I believe that there is ample opportunity for new, ground-breaking scientific and practical developments.

References

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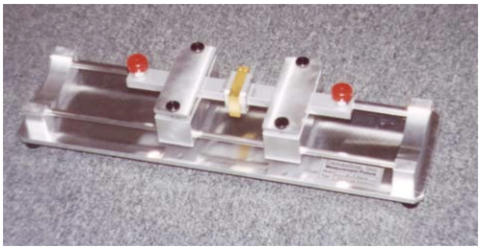

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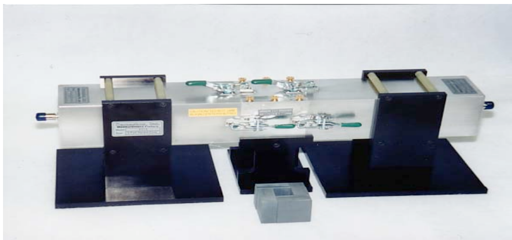

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