Around the Globe

A Glimpse of Microwave Education and Research Activities in Egypt

■ **Amr M.E. Safwat, Tamer M. Abuelfadl, Ahmed M. Mahmoud, and Hadia Elhennawy**

Over the past several decades, Egypt has been one of the Middle East's leading countries in electromagnetics and microwave engineering education and research. It has well-established graduate/undergraduate curricula, extensive laboratory facilities, and well-trained lecturers who have proven successful in preparing excellent candidates to meet the field's continuously growing interests and accompanying challenges, in both academic and industrial settings. This article briefly describes the main topics addressed in the Egyptian microwave curriculum and some of the research activities conducted in one of the fastest-growing research areas in microwave engineering: periodic structures and metasurfaces.

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Educational Activities

The need for microwave, antenna, and RF engineers is constantly increasing. Due to device miniaturization and the continuous increase in requirements for bandwidth and speed, a deep understanding of electromagnetic concepts, such as transmission-line theory and propagation effects, has become a necessity in modern-day electronics/communications engineering.

Dealing with the main governing equations in this field (Maxwell's equations) is mathematically complicated compared to other areas of study. Moreover, visualizing and grasping the concepts involved in electromagnetic phenomena are not straightforward processes. On early exposure to such topics, most students grapple with these two hurdles, and, consequently, the number of students who decide to specialize in electromagnetics and microwave engineering is rather small.

Faculty members at Ain Shams University—one of Egypt's (and the entire region's) leading universities in terms of teaching and research activities—have always been aware of these two challenges and have carefully designed courses to help students acquire a strong understanding of and real interest in the field. Three extensive mathematics courses are offered for undergraduates. The courses cover a broad range of mathematical concepts and tools including, but not limited to, partial differential equations, vector calculus, and special functions.

In parallel with these courses, undergraduates are also offered six courses focused on electromagnetic phenomena. Starting from the basics of electromagnetism, the course Electromagnetic Fields investigates foundational topics such as Coulomb's law, Gauss's law, electric energy and potential, Poisson's equation, and Laplace's equation. The course also introduces students to Maxwell's equations and the concept of displacement current and builds upon that to offer a solid understanding of electromagnetic wave propagation and the laws of reflection and refraction. After completing this course and the parallel mathematics courses, students are ready to deal with more complex, application-oriented microwave engineering material.

Another course, Electromagnetic Waves, covers topics such as transmission-line theory, the Smith chart and impedance matching, metallic waveguide analysis and the concept of cut-off frequencies (in both Cartesian and cylindrical coordinates), dielectric waveguides, and optical fibers. Next offered is an application-oriented course, Applications of Electromagnetic Waves, that covers topics such as planar transmission lines, microwave components, filter design (insertion-loss method), and amplifiers, with the aim of giving students hands-on experience dealing with the most recent challenges in the field analytically and even numerically using commercially available software.

An extensive antenna design course is also offered, with the aim of introducing students to the fundamentals and definitions of transmitting and receiving antennas; in addition, students receive a mathematical foundation for the design and analysis of radiating structures, which they then apply to numerous structures, starting with simple dipole antennas and antenna arrays and then moving all the way to broadband and aperture antennas. Feeding networks for wire antennas, arrays, and reflectors are also extensively discussed throughout the course

This comprehensive and well-designed coursework plan for undergraduates at Ain Shams University has proven very successful in achieving its goals, preparing good candidates in the field who are ready to get involved in front-end research and/or commercial and industrial activities. Over the past decade, numerous journal and conference publications have appeared based on undergraduate research and senior projects [1], [2]. The department's faculty members are continuously adapting the coursework and details of the courses and laboratories to keep up with the rapidly changing field and maintain the flow of well-prepared candidates.

Research Activities: Periodic Structures

In addition to these extensive curricula and teaching activities targeting the field of microwave engineering within Egypt, numerous research efforts take place in the country within various universities and research institutions. In this section, we focus on the very rapidly growing field of periodic structures and metasurfaces.

The concept of the high-impedance surface (HIS), also known as the *artificial magnetic conductor* (*AMC*), was first introduced by Sievenpiper et al. in 1999 [3]. An HIS consists of a dielectric slab sandwiched between a metallic sheet on the bottom layer and metallic patches on the top layer connected through vias. The HIS imitates, in performance, a perfect magnetic conductor, where the signal is fully reflected with a 0° phase rather than the 180° reflection phase for the conventional ground plane [3]. The 0° reflection phase makes it possible to design highly efficient yet compact and conformal broadband antennas. Also in 1999, the concept of uniplanar electromagnetic bandgap (EBG) was introduced by Yang et al. [4]. The EBG consists of metallic structures spread over a two-dimensional (2-D) dielectric layer and is capable of preventing the propagation of the electromagnetic wave within a specific operating band [4]. With the emergence of metamaterials in 2001–2002, HISs and EBGs became major constituents of that field and were treated, in a more general sense, as 2-D periodic structures [5], [6].

In Egypt, research on periodic structures has followed the international trend. Composite right-/left-handed transmission lines (i.e., CRHL-TLs) were implemented on microstrip [2], [7] and in rectangular [8] and circular [9] waveguide configurations with various applications in antennas [10], [11] and components design [1]. A novel numerical technique was proposed to solve such periodic structures [12], and 2-D planar periodic structures and their different applications have also been investigated [13].

In the following, we briefly describe two ongoing projects with the aim of introducing the community to the research interests and efforts occurring in Egypt.

Highly Efficient Dipole Antenna Above a Two-Layered High-Impedance Surface

Complementary–metal-oxide-semiconductor (CMOS) integrated antennas suffer from significant radiation losses due to the high conductivity of the silicon substrate $(\sigma = 10\ \mathrm{s/m})$. Moreover, the high relative dielectric constant of silicon ($\varepsilon_r \backsim 11.9$) results in poor antenna efficiency, as the substrate absorbs most of the radiated power. Recently, it has been shown that the AMC improves radiation efficiency by shielding the on-chip antenna from the substrate [15]. In [14], it was shown that there is room to increase antenna efficiency by implementing the AMC on two metal layers instead of one.

Figure 1(a) shows the design of a conventional single-layer AMC implemented in 65-nm CMOS technology, while Figure 1(b) shows the stack layer. The metal patches are located on one of the metal layers (*M1–M7*), while

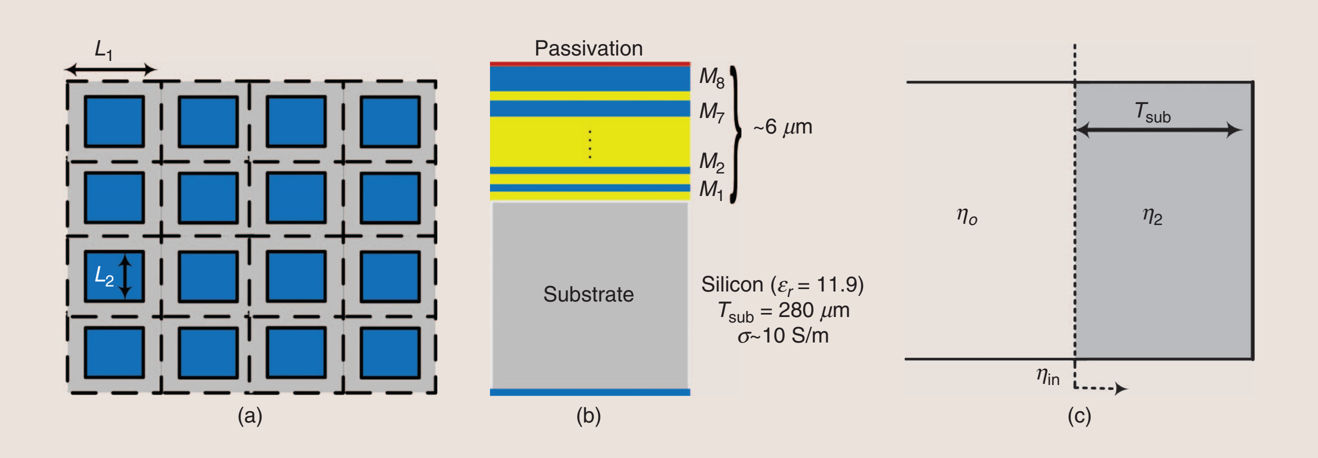


Figure 1. *(a) A conventional patch AMC, (b) a silicon substrate stack, and (c) an equivalent circuit model [14].*

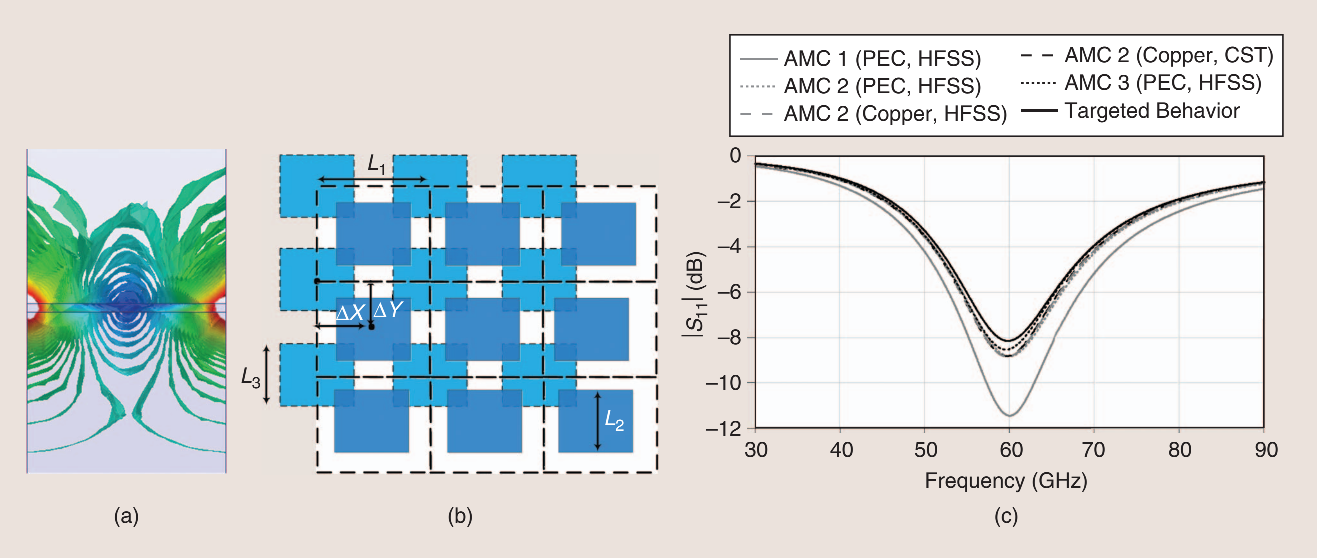


Figure 2. *(a) The magnitude of the electric field in the unit cell's solution boundary. (b) The proposed two-layered AMC. (c) The reflection coefficient of the proposed two-layered unit cell with AMC 1 $\Delta x = \Delta y = 0$; AMC 2 $\Delta x = L_1/2$ and $\Delta y = L_1/2$; and AMC 3 $\Delta x = 0$ and $\Delta y = L_1/2$. [14]. PEC: perfect electric conductor; HFSS: Ansys High-Frequency Structure Simulator; CST: Microwave Studio Computer Simulation Technology.*

the second metal layer is located at the bottom surface of the substrate. This layer, along with the substrate, forms a short-circuited transmission line that has the input impedance η_{in} and 79-GHz quarter-wavelength resonance frequency [Figure 1(c)]. Adding metallic patches on the first metal layer, *M1*, of dimensions, $L_1 = 150$ μm and $L_2 = 139$ μm, forms a capacitance of 9 pF that shifts the resonance frequency to 60 GHz. Comparing the analytical and simulated S_{11} reveals that there is good agreement in terms of the resonance frequency; however, there is a significant discrepancy in terms of the loss performance [14].

To investigate this discrepancy, the electric field is plotted across the unit cell, as shown in Figure 2(a). Near the edges, the field intensity is maximum, and, at the center, it bends toward the high-dielectric constant lossy substrate. To reduce this interaction and restore the analytical return-loss value, one solution is to move the metal patches to the upper metal layers. Unfortunately, this solution does not significantly improve the loss performance [14].

The proposed unit cell, consisting of two metal layers implemented on *M6* and *M7* as shown in Figure 2(b), minimizes the penetration of the electric field in the lossy substrate and confines the field between the two layers. This leads to a better loss performance as depicted in Figure 2(c), which shows the magnitude of the reflection coefficient for three different designs. Design AMC 2 provides a good loss performance and is a polarization-independent structure. A dipole antenna above this surface achieves a total efficiency of 55% and a front-to-back ratio of 8.8 dB [14].

Solution of Periodic Structures Using Eigenmode Projection Techniques

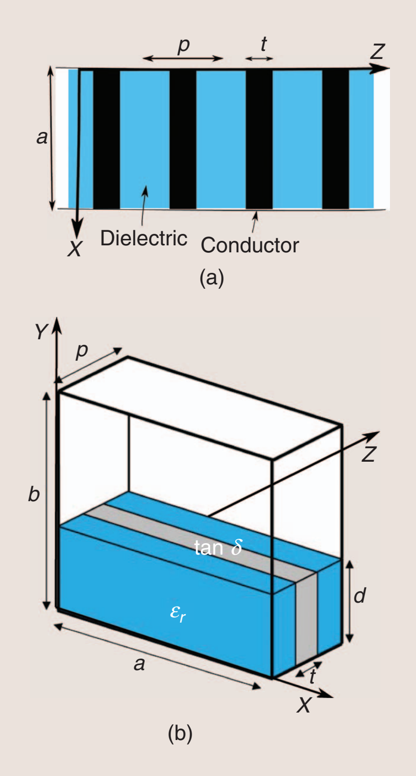
The emergence of metamaterials has created a need for computationally efficient numerical tools to handle electrically large and geometrically complex structures. The eigenmode projection technique (EPT) is presented here for solving problems of a waveguide periodically loaded with dielectrics and conductors. The EPT is based on the classical work in expanding fields in terms of many modes in a closed cavity [16].

The EPT has been used to solve various types of electromagnetic problems, such as cavity resonance irregularities, waveguide discontinuity, scattering of dielectric objects [17], [18], and even electrostatic problems [19]. Although the analysis we present deals with one-dimensional periodicity, it can be easily extended to 2-D and three-dimensional ones.

With this technique, the electromagnetic fields are expanded in the region of interest in terms of known canonical modal solutions within a simple region—such as a cuboid, cylinder, or sphere—with boundary conditions conforming to the structure of interest. These boundary conditions could be perfect electric, perfect magnetic, or a mixture of both. For periodic structures, Floquet conditions are imposed on the twin parallel surfaces along the periodic dimension(s) of the problem unit cell.

As an example, Figure 3(a) shows a periodic waveguide loaded with dielectrics-filled slots. A unit cell with a length equal to the structure periodicity p is shown in Figure 3(b). The boundary conditions on the rectangular waveguide surfaces parallel to the xz and the yz planes are simply perfect electric, while the parallel xy surfaces separated by p along the z direction satisfy the Floquet condition [20].

The canonical eigenmodes for the cuboid empty cell shown in Figure 3(b) can be divided into irrotational and solenoidal ones. The irrotational mode fields have zero curl, while the solenoidal ones are divergenceless fields. Both types satisfy the Helmholtz equation [20] and are solved subject to the proper boundary conditions imposed on the outer surface of the canonical cavity, where they would be either perfect electric, perfect magnetic, or in the Floquet condition. Mathematical details about those modes are discussed in [12].



(a)

(b)

Figure 3. *(a) The top view of the periodic structure and (b) an isometric view of one unit cell of periodicity. A rectangular waveguide with dimensions* a × b *is periodically loaded with dielectrics and conductor strips with thickness* t *and height* d *with period* p. *The considered canonical cavity is the cavity shown after removing the dielectrics and conductors, with same boundary conditions as the original problem [12].*

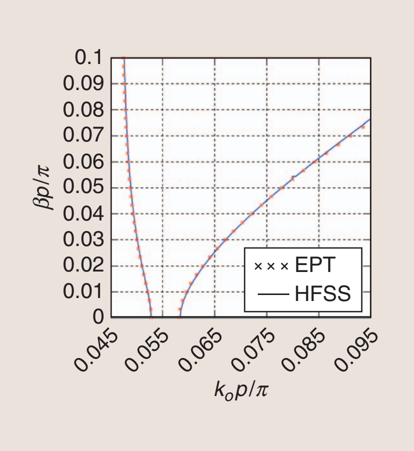


Figure 4. *The dispersion characteristics of the metaguide having* a = *17 mm,* b = *6.46 mm, corrugation depth* d = *3.7 mm, thickness* t = *0.2 mm, dielectric filling* $\varepsilon_{rd} = 10.2$, *and period* p = *1 mm [12].*

When those expansions are substituted in the source-free Maxwell's equations, a system of linear algebraic equations in terms of the expansion coefficients is obtained. Those equations can be set as an eigenvalue problem, where the eigenvalue is given in terms of the resonance frequency. When considering the material loaded inside the guide, the perfect dielectric will have a real dielectric constant, while conductors are modeled as a material with a complex dielectric constant, such that $\epsilon_{rc} = 1 \tan\delta$, with $\tan\delta \gg 1$.

Figure 4 shows the normalized dispersion relation ω-β for the first two bands of the metaguide [8]. The lower band exhibits backward wave or left-hand dispersion. Results show excellent agreement between the dispersion relations obtained using HFSS and the proposed method.

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Microwave Engineering in Iran's Academia

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Persia, once a great empire extending from the Indus River to Eastern Europe, was an early cradle of civilization and science [1]. In 1935, the official name of the country was changed to Iran. Today, about 81 million Iranians inhabit a country of 1,648,195 km^2 that possesses the world's fourth-largest verified oil reserves as well as the world's first-largest verified natural gas reserves. Academia plays an important role in Iran, as the number of Iranian students (4.5 million) shows.

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A Brief History of Electrical Engineering in Iran

Although the use of electrical energy in Iran dates back to 1915, with the introduction of a 400-kW steam power plant, the country's first serious move toward the emergence of electrical engineering (EE) began in 1931 in the context of a contract with a Belgian company [2]. Rapid development in the industrial sector occurred from 1957 to 1966.

However, engineering education, in general, and EE, in particular, started many years earlier. Although certain institutions in the country unofficially offered some courses related to EE, formal academic education in the subject began with the establishment of the University of Tehran in 1934. The university's Faculty of Engineering established an electromechanics program dominated mostly by mechanical engineering courses, except for some senior-level courses in EE. The electromechanics program was divided into EE and mechanical engineering in 1967 with different curricula.

The first optional telecommunication courses offered in the curriculum were integrated in 1960. The number of these courses was increased to include communication systems, fields and waves, microwaves, and antennas during 1960–1970. At the end of this period, bachelor of science (B.Sc.) degree programs (both four and five year) were well developed in several universities across the country. By then, a number of institutions had also developed master's of science (M.Sc.) degree programs, as well. The four-year B.Sc. engineering degree programs generally consisted of 140 credit hours, while the EE M.Sc. disciplines required, at a minimum, 32 credit hours.

The development of universities and their facilities as well as different programs continued up to 1979. Faculty