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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

members were mainly trained in Germany, France, the United States, and Canada, and every university had its own EE program. Since 1982, these programs have been unified across the country.

Admission to higher education is through a nationwide entrance exam, called *Concourse*. Some 850,000 students participate in this exam yearly. Engineering and science programs in general and EE in particular are highly popular. According to the 2017 *Global Innovation Index* (p. 333), in 2014, Iran ranked second in the world in terms of the number of graduates in science and engineering.

Microwaves in Iran

Microwave engineering was introduced in Iran in the late 1960s when the first terrestrial microwave radio links were operated by the Telecom Company of Iran (TCI) nationwide. Alongside TCI and starting in 1967, the Iranian Oil Pipelines and Telecommunications Company, a subsidiary of the National Iranian Oil Company, installed and operated microwave radio links throughout the company's network.

All telephone companies were integrated into TCI in 1971. Two years later, in 1973, the Iran Telecom Industries was established to provide the required hardware for TCI. In 1968, the first operational satellite communication Earth station was constructed to facilitate international telephone communications and international satellite TV links for the country.

In 1970, the Iran Telecom Research Center was established to introduce a new dimension for developing microwave engineering and radio science in the country. The first Iranian analog and digital microwave radios as well as satellite Earth stations were designed and fabricated at this center later in the decade. The establishment of Iran Electronics Industries in the late 1970s and Iran Communication Industries in the 1980s further contributed to the development of microwave engineering in the country.

In the 1960s and in accordance with concurrent industrial development, courses in electromagnetic fields and waves and later radio transmission systems were taught in major Iranian universities such as the University of Tehran, Sharif University of Technology, Tehran Polytechnic (now the Amirkabir University of Technology), Iran University of Science and Technology, Shiraz University, and K.N. Toosi University. Later, in the 1970s, microwave and antenna laboratories were operational in these universities, as a result of which academic research in the area bore fruit in late 1980s, i.e., when graduate studies in microwave engineering were firmly established.

Research on the theory and technology of microwave engineering in Iranian universities is carried out in areas such as wired and wireless communications, wave propagation, satellite communications, imaging, measurements, scattering, and bioelectromagnetics.

Currently, EE students majoring in communication engineering must pass a course on electromagnetics followed by a course on fields and waves. They also take several theoretical and experimental courses in microwaves and antennas as part of their B.Sc. degree program. For graduate studies, a large number of courses are offered, beginning with advanced electromagnetics and computational techniques and moving to photonics and millimeter-wave/terahertz technologies.

To date, there are about 150 public universities, higher education institutions, or science and technology parks in Iran. Approximately 10,000–11,000 students are admitted to these institutions in the field of EE each year, out of which 20–25% opt for the telecommunications major. Approximately 1,500–2,000 students study microwave engineering yearly at the B.Sc. degree level in public universities. Furthermore, there are open (Islamic Azad University) and private universities to which some 35,000–40,000 students are admitted in EE each year.

M.Sc. degree programs in microwave engineering were introduced in the late 1980s, and Ph.D. degree programs in the same field were established in the 1990s. Yearly, some 9,000–10,000 students are admitted to the M.Sc. programs in EE nationwide. Out of these students, approximately 600 opt for the M.Sc. degree in fields and waves or microwaves. There is also an enrolment of about 90–100 students in Ph.D. degree programs in fields and waves or microwaves each year.

Private-sector industries have developed in the country during the past three decades, and many startup companies now exist alongside well-established private companies. Iran is a relatively large nation, so it has a wide domestic market for telecommunications. Private sector companies fabricate a range of equipment, from telephone switching centers to analog and digital radios, satellite earth stations, base transceiver stations, and satellite transponders. Recently, Iran has had a growth rate of about 20% in the telecommunications sector as well as rural development of telecommunications, which brought the country a UNESCO recognition award in 2014. Currently, Iran has about 30 million fixed telephone lines, approximately 95 million wireless cell phone lines, and around 45 million Internet users, making up an estimated telecommunications market worth about US$14.7 billion in 2016. This market is promising for a thriving microwave community.

Iranian Researchers in Microwave Engineering Worldwide

Iran has invested intensively in human development during the last several decades, so there is a wide spectrum of graduates from Iranian universities throughout the world. Prof. Nader Engheta, Prof. Yahya Rahmat-Samii, Prof. Behzad Razavi, Prof. Reihaneh Safavi-Naeini, Prof. Kamal Sarabandi, and Prof. Bahram Shafai are among these world-class graduates who are active in microwave engineering in

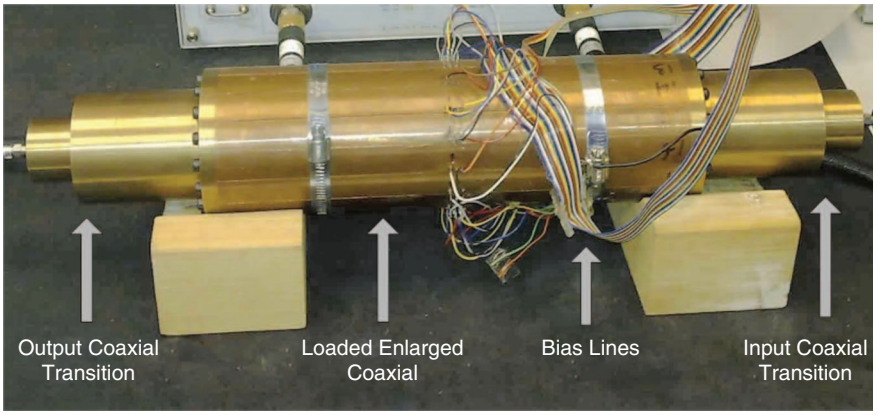

Figure 1. *A 16-way spatial power combining amplifier [26].*

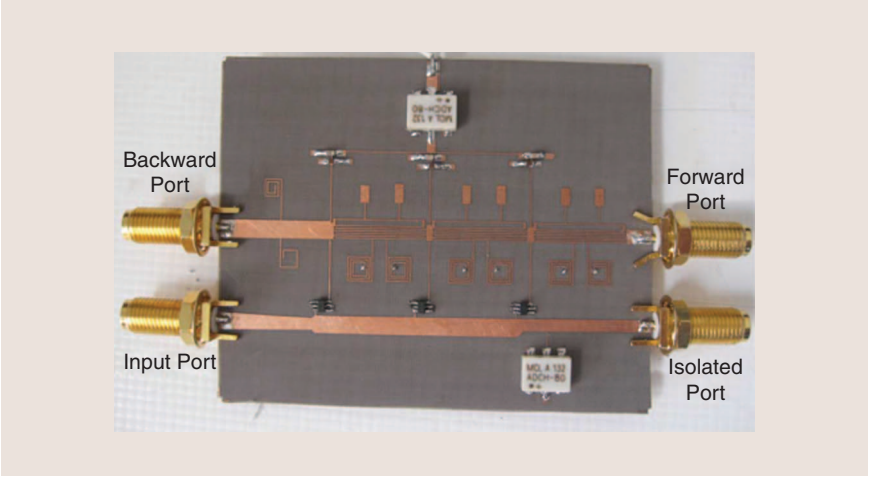

Figure 2. *The fabricated prototype of a proposed quad-band distributed amplifier based on an extended composite right-/left-hand transmission line [27].*

North America. These outstanding engineers and scientists have contributed greatly to the peaceful application of technology for the benefit of the international community.

Microwave Engineering Research in Iran

Research on the theory and technology of microwave engineering in Iranian universities is carried out in areas such as wired and wireless communications [3], wave propagation [4], satellite communications, imaging, measurements, scattering, and bioelectromagnetics [5]. There have also been several research activities in the modeling, analysis, design, and simulation of microwave devices, circuits, and systems.

In electromagnetic wave propagation research, the focus has been on subjects such as modeling, characterization, and performance analysis of the channel and its corresponding losses and of delay profiles in urban and nonurban environments. Electromagnetic properties of transmission media are analyzed for different microwave bands. Scattering and inverse problems are other subjects of interest in Iran's universities [6], [7].

In microwave device research, we can point to subjects such as analytical

Figure 3. *Keynote speakers and members of the Technical Committee for the Third Conference on Millimeter-Wave and Terahertz Technologies (2014), Tehran, Iran. From left: R. Faraji-Dana, M. Fujishima, K. Wu, M. Madihian, M. Kamarei, A. Shishehgar, A. Abdipour, H. Oraizi, J. Rashed-Mohassel, M. Shahabadi, M. Neshat, A. Ghorbani, K. Moez, and A. Mohammadi.*

and numerical modeling and, in particular, research on solid-state devices. In analytical and numerical modeling, to evaluate the signal and noise performance of these devices, different lumped, distributed, and full-wave models have been developed and considered for transistors [8]–[12]. This work is mainly conducted in the microwave, millimeter-wave, and terahertz frequency bands (Figures 1 and 2).

Regarding passive microwave circuits, we can point to topics such as the design, analysis, implementation, and fabrication of a variety of circuits such as couplers, antennas [13]–[18], and (planar and nonplanar) transmission lines [19]–[25]. For active microwave circuits, work in Iran focuses mainly on the linear and nonlinear analysis of signal and noise in the subsystems associated with microwave transceivers. Also investigated are the performances of different subsystems, e.g., power amplifiers [26]–[30], oscillators [10], mixers [31], frequency multipliers, power combiners/dividers, modulators, and demodulators. Other topics such as microelectromechanical systems, metamaterials, dielectric resonator antennas, superconductors, and substrate integrated waveguides for the design and implementation of passive and active microwave circuits have attracted the attention of Iranian researchers.

Concerning communications systems, we can point to the architectural design and implementation of transceivers and of radio links and networks, mobile communication and wireless networks, local multipoint distribution services, WiMAX, third-/fourth-/fifth-generation technology, software radio systems, cognitive radio systems, wireless sensor networks, satellite systems, and information technology systems, all based on international standards.

Academic Publications

As part of their work, Iranian students and faculty members present the results of their research at renowned local and international conferences (Figure 3) and/or publish them in international journals. For instance, Figure 4 summarizes recent publications by university research groups in *IEEE Transactions on Microwave Theory and Techniques* (*T-MTT*), *IEEE Microwave and Wireless Components Letters* (*MWCL*), *IEEE Transactions on Antennas and Propagation* (*T-AP*), and *IEEE Antennas and Wireless Propagation Letters* (*AWPL*). Also illustrated in the figure are statistics about papers presented at the IEEE International Microwave Symposium (IMS), IEEE International Symposium on Antennas and Propagation (ISAP), European Microwave Conference (EuMC), and European Conference on Antennas and Propagation (EuCAP).

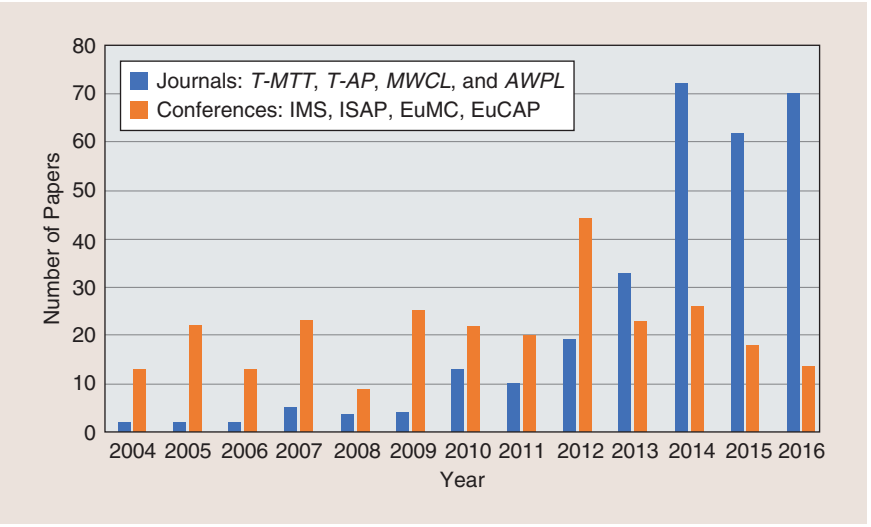

Figure 4. *The total number of papers by Iranian authors published in* T-MTT, MWCL, T-AP, *and* AWPL *as well as those presented at the IMS, ISAP, EuMC, and EuCAP.*

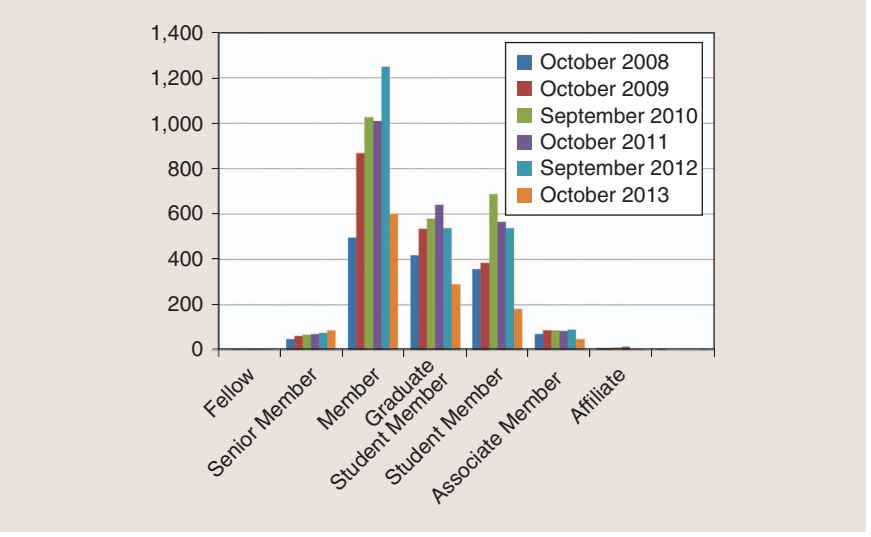

Figure 5. *Statistical data about active Members of the IEEE in Iran [32].*

IEEE Iran Section

The IEEE Iran Section was founded in 1970 by the late Dr. Abbas Tchamran [32]. This was the 13th Section established in IEEE Region 8, and, with approximately 1,800 Members, is among the top ten Sections of Region 8 in terms of membership (Figure 5). The Iran Section oversees the operation of about 45 Student Branches and supports a large number of national conferences, events, meetings, and workshops.

Concluding Remarks

As the historical and scientific background in this article clearly reveals,

Iranian scientists and engineers are highly motivated to contribute to cutting-edge scientific research in microwave engineering to benefit the global environment, stability and peace, and sustainable development. We always welcome expansion of international scientific collaboration with our counterparts around the world.

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