Microwave Engineering Teaching at the Aeronautics Institute of Technology

Daniel B. Ferreira and Daniel C. Nascimento
Laboratory of Antennas and Propagation - LAP
Aeronautics Institute of Technology - ITA
Sao Jose dos Campos, Sao Paulo, Brazil
danielbf@ita.br, danielcn@ita.br

***Abstract*—As part of the commemoration of the 40th anniversary of the Brazilian Microwave and Optoelectronics Society and 25 years of the first issue of the Journal of Microwaves, Optoelectronics and Electromagnetic Applications, this paper presents the history of microwave education at the Aeronautics Institute of Technology, which has been recognized as a professional reference and a national pioneer in this field. The paper reports the legacy and activities of the first foreign professors, who arrived in the early 1950s to create the Electronics Engineering course. Similarly, the activities of the first Brazilian faculty members are described. A historical overview of the educational model adopted in the last seventy years, the infrastructure, the beginning of the graduate program, and teaching during the pandemic period are also addressed in this work.**

Keywords—Aeronautics Institute of Technology, microwave engineering, education, history

I. The Genesis of ITA

The history of the Aeronautics Institute of Technology dates back to 1943 when the Brazilian Air Force Lieutenant-colonel Casimiro Montenegro Filho was appointed Deputy Chief of the Aeronautical Material Directorate and Deputy Director of Aeronautical Technique of the Brazilian Air Force [1]. In July of that year, Colonel Montenegro visited the Massachusetts Institute of Technology (MIT), in Boston, United States of America, where he met the Brazilian Air Force Major Oswaldo do Nascimento Leal, one of the Brazilian officers sent to MIT by the Brazilian Ministry of Aeronautics to study Aeronautical Engineering. Two other Brazilian Air Force Colonels, José Vicente de Faria Lima and Guilherme Aloysio Telles Ribeiro, accompanied Montenegro on that mission. During the visit, they gathered at Major Leal's home and came up with the idea of creating an Aeronautical Engineering course in Brazil, similar to that of MIT, instead of sending the Brazilian students to the United States [2, 3]. Since Montenegro was a student at the Army Technical School (EsTE), where he graduated as an Aeronautical Engineer, he wanted Brazil to have a high-level teaching and research center to prepare qualified professionals capable of leading the technological advancement in the nation [4].

Colonel Montenegro returned to the United States in 1944 as a representative of the Ministry of Aeronautics at the Inter-American Technical-Economic Conference held in Washington. Following Major Leal's advice sent in a letter, Montenegro took with him a draft of his plan to create an Aeronautical Engineering school in Brazil. He intended to present the draft to Professor Richard Harbert Smith, chairman of the Department of Aeronautical Engineering at MIT and consultant to the US government [4]. They could not meet in person on that occasion, but Prof. Smith read the draft and became very interested in Montenegro's plan [2].

At the beginning of 1945, Colonel Montenegro was a member of a delegation of Brazilian Air Force officers in charge of visiting some US Air Force Bases, including the Wright-Patterson Air Force Base [4]. The structure of this base served as a model for the creation of the Aeronautics Technical Center (CTA) in which the new Brazilian Engineering school would be established as well as an Air Force Research and Development Institute. At that time, the Minister of Aeronautics, Salgado Filho, had authorized the negotiations with Prof. Smith, who would study the feasibility of creating an Aeronautical Engineering school in Brazil.

In June 1945, Prof. Smith came to Brazil and conducted a careful analysis of Brazilian industry and education – both high school and higher education – with the assistance of Colonel Montenegro, other Brazilian Air Force officers, and some Brazilian engineers [5]. A few months later, Prof. Smith presented to the Air Force General Staff (EMAer) his final report titled "Recommendations for the CTA Law," which described a progressive plan for the development of truly Brazilian aviation and comprised the creation of both engineering schools owning high-quality laboratories and a research institute [6]. The then newly appointed Minister of Aeronautics, Brigadier Trompowsky, received the so-called "Smith's Plan" and forwarded it to be approved by the then Brazilian President José Linhares. The Plan was approved on November 16, 1945. Thereafter Prof. Smith returned to the USA to hire the first professors for the Aeronautics Institute of Technology (ITA), as was called this new engineering school in Brazil, where he would serve as the first president [5].

Owing to the large territory of Brazil, knowledge of long-distance transport and communications was of great importance for the integration and development of the country. Hence, to address these fields of knowledge, ITA initially offered undergraduate programs in Aeronautical and Electronics Engineering [7]. It is worth noting that Army Technical School offered an undergraduate program in Aeronautical Engineering, from 1939 to 1941, when it was interrupted together with the creation of the Ministry of Aeronautics, and there was no Electronics Engineering course in Brazil by that time [8]. The Aeronautical Engineering undergraduate program with concentration in aircraft started at ITA in 1947. Next, in 1949, ITA began to offer the concentration in airways [9]. Finally, the undergraduate program in Electronics Engineering was created in 1951, with a duration of five years [5].

II. The Electronics Engineering Course in the 1950s

ITA's educational model resembled that of the top-ranked US universities and introduced relevant changes to Brazilian higher education. First, the majority of ITA's faculty members were tenured professors fully committed to the institute and actively involved in research projects. In addition, professors and students lived on campus, so they had close relationships, contributing to the student's learning and personal growth. On the other hand, until 1948, the sixteen Brazilian engineering schools existing at that time [8] had the vast majority of their professors working part-time, not involved in research, and whose contact with students was limited to class hours only [7].

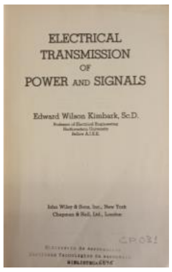
Another innovation brought by ITA was that its curriculum should be revised annually. Moreover, its professors were associated with departments, in contrast to the European (especially French) system of *cathedras* adopted in the other schools in the country, in which each course was associated with a professor (in practice being the "owner" of the course). Consequently, the curriculum at ITA could easily be updated through insertions and removals of topics, to reflect technological advancement and obsolescence, thus improving the quality of the engineering programs. Whenever possible, the courses at ITA should provide laboratory classes, and the curriculum should include classes in the humanities to prepare the students for adult life [7]. This educational model became a reference for Brazilian universities and is used to this day.

ITA created an Electronics Division responsible for the undergraduate program in Electronics Engineering. This program had courses grouped into four areas: 1) Circuits, Fields, and Waves; 2) Applied Electronics; 3) Communications; 4) Control and Energy Conversion. The intention was to prepare professionals able to work in the various fields of activities of Electronics Engineering, such as research, development, industry, production, and use of electronic equipment. To achieve this goal, the program covered the foundations and main techniques of the four areas listed above and presented an introduction to typical electronic systems applying the techniques taught in class previously. Thus, the curriculum was not only adapted to the Brazilian needs at that time but also to the technical progress that certainly would come to the country soon [10].

From this point on, this paper will focus on the activities and personnel of the Department of Circuits and Microwaves of the Electronics Division, which was in charge of the area of Circuits, Fields, and Microwaves. As previously mentioned, at the end of the 1940s ITA hired foreign professors to establish its undergraduate programs due to the lack of native specialists in the fields of aeronautics and electronics. Below one may find short biographies of the pioneer professors who had a background in microwaves or antennas and were essential for the development of these areas in the country, highlighting their main achievements and roles in the Electronics Division.

- Edward Wilson Kimbark from Northwestern University, author of the book Electrical Transmission of Power and Signals, published in 1949, which presents a detailed analysis of transmission lines, covering topics such as impedance matching, filters, skin effect, and waveguides [11, 12] (Fig. 1). Prof. Kimbark served as the first dean of the Electronics Division, collaborated to prepare the first experiments on applied electromagnetic waves, and taught the first Automatic Control course at ITA. He stayed in Brazil from 1950 to April 1955 [13].

Edward Wilson Kimbark [12].



Kimbark's book published in 1949.

Fig. 1. Prof. Kimbark.

- Karl Ralph Spangenberg from Stanford University, who published a book about vacuum tubes in 1948 [14] (Fig. 2), served as dean of the Electronics Division from 1952 to 1954 [15, 16]. Prof. Spangenberg also contributed to the planning of the syllabi of the courses on applied electromagnetic waves.

Karl Ralph Spangenberg [16].

Spangenberg's book published in 1948.

Fig. 2. Prof. Spangenberg.

- Howard S. Stokes was an Electronics Engineer who had worked for 19 years with the US Civil Aeronautics Administration before coming to Brazil and was experienced in antennas and in air navigation aids [17, 18] (Fig. 3). He stayed at ITA from 1948 to 1954 as an associate professor [17, 19].

Howard S. Stokes [17].

Donald K. Reynolds in the 1960s [23].

Fig. 3. Profs. Stokes and Reynolds.

- Donald K. Reynolds obtained his doctorate in engineering and applied physics from Harvard University and had experience in antenna theory and propagation in the ionosphere (Fig. 3). He was an associate professor at the Electronics Division of ITA from 1954 to 1956, when he returned to the US to serve as the head of the Department of Electrical Engineering at Seattle University and later moved to the University of Washington [20]. During his stay at ITA, Prof. Reynolds together with Profs. Jacques Roger Lignon and Pedro Américo Szente (other ITA faculty members) designed an antenna to operate at 150 MHz with a gain of 20 dBi based on the principle of the Yagi antenna. A prototype was built and tested in Brazil, and they published the results of this research in [21]. The first impressions of Prof. Reynolds about ITA were registered in an article he wrote for "O Iteano" in 1954 [22]. In that journal, Prof. Reynolds pointed out that the Electronics Engineering curriculum at ITA was comparable to that of the main engineering schools in the world and emphasized the need for developing research programs in the school.

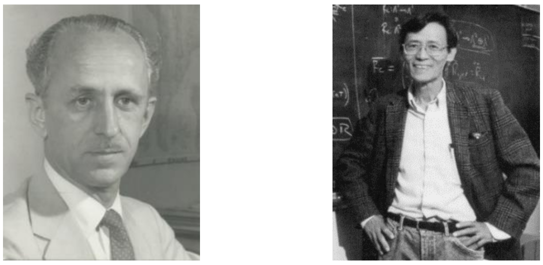
- Chen-To Tai received his Ph.D. from Harvard University and was an associate professor at the Ohio State University (OSU) before joining the Electronics Division at the end of 1955 [13] (Fig. 4). Dr. Tai was a specialist in antennas, propagation, and electromagnetic theory. He is widely known for his works on dyadic Green's functions in electromagnetic theory, for his passion for teaching and education, and for the clarity of his lectures [24]. While in Brazil, Dr. Tai taught many courses on antennas and electromagnetic theory at the undergraduate level and prepared antenna course handouts (which are still available at ITA's Library). He studied with Prof. Yutze Chow, another ITA faculty member, the scattering by a single ferrite cylinder [25], and supervised the final projects of some fifth-year Electronics Engineering students. Dr. Tai returned to OSU in 1961.

Chen-To Tai [24]. Cover of one of Tai's book.

Fig. 4. Prof. Tai.

- Richard Robert Wallauschek (Fig. 5) obtained his doctorate from the University of Prague in 1936 with the thesis "Contributions to Optoelectronics: Electronics Microscope with Electronic-Cylinder Lenses." He worked at Telefunken, where he organized a laboratory for microwave research. New types of microwave tubes, antennas, and circuit devices were designed under his supervision in that laboratory. After World War II, in 1946, he started working at the Laboratoire de Tubes et Hyperfréquences of the Centre National d'Etudes des Télécommications (CNET) in Paris. At CNET, Dr. Wallauschek was granted three patents for developments he made with traveling-wave tubes. In 1951, guided by his desire to teach and share his knowledge, he moved to India to collaborate with the organization of the Madras Institute of Technology [26] and served as the director of the Instrumentation Engineering Department, where he installed a microwave laboratory. Three years later, Dr. Wallauschek received a message from an acquaintance of his period in Paris, Prof. Jacques Roger Lignon, who had joined the ITA faculty, talking about ITA and inviting him to succeed Prof. Spangenberg as dean of the Electronics Division [27]. Prof. Wallauschek accepted the offer and remained in this position until his death in 1962. During his stay at ITA, he taught courses on electromagnetic theory, microwave circuits, lines and filters, and circuit analysis, as well as supervised the final projects of many fifth-year Electronics Engineering students.

Two other foreign professors, Jacques Roger Lignon from France, who worked on microwaves, antennas, and propagation, and Yutze Chow (Fig. 5), who worked on electromagnetic theory [25], joined the Electronics Division faculty in the 1950s. For the sake of curiosity, in 1958, Profs. Lignon and Tai designed the first antenna used in the Santos Dumont University Radio (RUSD), a shortwave radio operated by students and professors of ITA at that time [29].



Richard Robert Wallauschek [28]. Yutze Chow [30].

Fig. 5. Profs. Wallauschek and Chow.

The Electronics Division also hired teaching assistants in the 1950s who had recently graduated from Engineering at Brazilian schools, such as the Polytechnic School of the University of Sao Paulo and the Federal University of Rio de Janeiro (UFRJ). As part of the so-called "Ponto IV" program, a financial and technical cooperation program between the governments of Brazil and the US that started in the 1950s [31], these teaching assistants had the opportunity to enroll in top-ranked US universities to get a master's degree and/or to carry out a doctorate (Ph.D. thesis). Consequently, in the following decade, the Division could count on a Brazilian faculty with expertise in areas that were very little known or even unknown among Brazilians by that time. It certainly would enhance the quality of ITA undergraduate programs and would collaborate for the establishment of graduate courses. In addition, it was an important plan for the replacement of most foreign professors that would leave the country, maintaining ITA's high-quality education.

Among the first teaching assistants of the Electronics Division, one can mention José Thomaz Senise [32], Pedro Américo Szente [33], and Gabriel Felisberto de Oliveira Freire [34], who completed their master's and Ph.D. in the microwave laboratory at Stanford University. There, they acquired a solid background in electromagnetic and microwave theories and researched topics related to microwave tubes (e.g., analysis of klystron efficiency, generation of sub-millimeter radiation, and interaction between a plasma and a velocity-modulated electron beam). It is opportune to say that Professor Spangenberg had spent years teaching in the Electrical Engineering Department of Stanford University and greatly influenced the research area of those three young teaching assistants. Professor Senise left ITA in 1971 to dedicate himself fully to the Maua Institute of Technology, Sao Caetano do Sul, where he created a laboratory for research and development of microwave industrial applications. He remained there for the rest of his career [32]. Professor Szente left ITA in 1967 to join Hewlett-Packard in the USA [33] and Professor Freire remained at ITA until his retirement in the 1980s [34]. Plínio Tissi and José Luiz Rodolpho Muzzio were two other teaching assistants who joined the Division in the late 1950s and worked on microwaves and antennas [10].

Attílio José Giarola was another teaching assistant at the Electronics Division in the 1950s. He went to the University of Washington and got his master's and Ph.D. degrees in 1959 and 1963, respectively. During his master's, Giarola worked on continuously excited traveling wave antennas under the supervision of Prof. Donald K. Reynolds, who also taught at ITA in the 1950s, as already mentioned. Near the end of his Ph.D., Giarola was hired by Boeing in Seattle to research infrared detectors and microwave devices. He returned to ITA as an assistant professor in 1964 and was promoted to associate professor the following year. Professor Giarola held this position until 1967 when he joined the Texas A&M University (TAMU) faculty. Later, in 1975, Prof. Giarola returned to Brazil to work at Unicamp, where he stayed until his retirement [35]. Prof. Giarola was a contemporary of Rubens Adolpho Sigelmann at the University of Washington [36]. Dr. Sigelmann also served as a teaching assistant at the Electronics Division in the 1950s [10] and worked on electromagnetic theory in his graduate research.

At this point, it is important to emphasize that Profs. Senise, Freire, and Giarola greatly contributed to the development of the fields of antennas, microwaves, and optoelectronics in Brazil. They supervised the research program of the first master's and Ph.D. students in these areas in Brazil, in addition to various undergraduate and graduate courses for which they were responsible. Many of their ex-students joined Brazilian companies and Universities across the country and have collaborated in the expansion of research and development of antennas, microwaves, and optoelectronics.

From the very beginning, the Electronics Engineering undergraduate program offered courses focused on microwaves and antennas to prepare the students for entry-level work as RF Engineers or for graduate studies. As an example, Table I summarizes the courses related to these areas that were offered in 1956 [10]. The corresponding academic year and semester of these courses and their weekly hours are described in this table.

TABLE I. Courses offered in 1956.

Year / Semester	Courses	Hours (Lecture - Lab)
3rd / 2nd	CEM-09 - Fields and components	3 – 1
4th / 1st	CEM-11- Electromagnetic theory	3 – 2
4th / 2nd	CEM-20 - Antennas and propagation	3 – 2
4th / 2nd	CEM-30 - Foundations of microwaves	3 – 3
5th / 2nd	SEL-50 - Microwave systems	3 – 2

The first course listed in Table I, CEM-09, started with a review of electrostatics and magnetostatics. Then Maxwell's Equations for time-varying fields were presented. From these equations, the boundary conditions and the Poynting theorem were addressed, both in time and phasor domains. The last topic of CEM-09 dealt with the propagation of plane waves in simple media (i.e., linear, homogeneous, and isotropic materials). Laboratory classes complemented the course lectures.

The second course, CEM-11, focused on the fundamentals of electromagnetic engineering and covered the reflection and transmission of electromagnetic waves, skin effect, transmission lines, including coaxial cables, waveguides as well as the basic concepts of radiation, that is, retarded potentials, the Hertz oscillator, and thin wire antennas. This course also included laboratory classes. In one of the experiments, an artificial transmission line composed of a cascade of series inductors and shunt capacitors (Fig. 6) was used to demonstrate how voltage is distributed along actual transmission lines depending on the load impedance. The main advantage of this experiment is that it illustrates a high-frequency phenomenon using only ordinary low-frequency laboratory equipment – a sub-MHz signal generator and an oscilloscope – that is familiar to a fourth-year student. In another experiment, the artificial transmission line was used to analyze transients on actual transmission lines. The high-frequency measurement techniques were presented using a 3 m long two-wire transmission line mounted in a wooden gutter that had a probe carriage and a graduated scale. The probe could ride between the two wires to sample the transmission line voltage. A detector (silicon diode cascaded to a filter) was connected to the probe to rectify the high-frequency voltage samples, and the resulting DC voltage could be read using an SWR meter or an oscilloscope. With this apparatus, the voltage envelope of the standing wave on the line was easily extracted, and so the students were able to determine unknown load impedances, for example. Profs. Kimbark and Spangenberg significantly contributed to the experiments of this course.

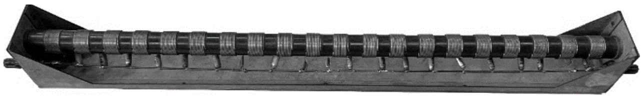


Fig. 6. Artificial transmission line used in the 1950s.

CEM-20 extended the study of antennas initiated in CEM-11 and covered the analysis of antenna arrays of isotropic elements and of electric dipoles. Some practical antennas for long, medium, short, and ultra-short wave radio frequencies as well as directive arrays were addressed in this course. CEM-20 also introduced radiofrequency propagation and discussed topics such as tropospheric propagation, transmission of electromagnetic waves through ionized gases, structure of the ionosphere, and propagation of short and ultra-short waves. This course had laboratory classes in an open field site where the students measured the input impedance and the radiation pattern of some usual antennas, e.g., dipole, monopole, and Yagi-Uda antenna (Fig. 7). ITA acquired a field intensity measuring set from Stoddart Company for use in these experiments [37].

(a) (b)

Fig. 7. Antennas used in CEM-20 laboratory classes. (a) electric dipole. (b) Yagi-Uda antenna.

The foundations of microwave engineering were studied in CEM-30. This course presented a detailed discussion of rectangular, cylindrical, and coaxial waveguides, including the analysis of discontinuities and the excitation of waveguides. Resonant and reentrant cavities, waveguide directional couplers, waveguide magic-T, striplines, and impedance matching techniques were covered in CEM-30. The course also addressed the basic operational principles of microwave tubes (klystrons, magnetrons, traveling-wave tubes, and carcinotrons). CEM-30 had laboratory experiments to investigate, for example, power measurements of microwave tubes and impedance matching using single and double stub tuners (the two-wire transmission line mentioned above was used in this case).

Finally, SEL-50 covered radar systems and microwave communication systems, including transmitters and receivers. General applications of microwaves were part of the course and comprised tests of materials, dielectric heating, microwave spectroscopy, and particle accelerator. The students tested some microwave systems in the laboratory classes. The Electronics Engineering program also had courses offered by the Department of Applied Electronics that addressed the analysis and design of filters, amplifiers, oscillators, modulators, and demodulators to complement the education in microwaves.

III. Department of Microwaves in the 1960s

In January 1961, the first Brazilian President of ITA, Prof. Marco A. G. Cecchini, with the approval of the Academic Board of ITA (called “Congregação” in Portuguese), appointed a permanent committee to organize graduate programs in Mathematics, Physics, Structures, Aerodynamics, and Electronics. Prof. Alexander J. Allen, on leave of absence from the University of Pittsburgh, was named president of the committee, and Prof. Senise from the Electronics Division accumulated the functions of executive secretary and coordinator of the Electronics program. It is worth noting that a few months ago, in September 1960, Prof. Samuel S. Steinberg, the previous President of ITA, had already appointed a special committee also chaired by Prof. Allen that assessed the conditions for ITA to offer Master’s and Doctoral degrees. In addition, during the 1950s, ITA already offered university extension courses with advanced content mainly attended by graduate engineers and ITA’s teaching assistants [7, 38].

As said earlier, Prof. Senise received his Ph.D. from Stanford University in 1958 where he acquired in-depth knowledge of the structure of the American graduate programs in engineering. With his guidance, the committee established the program rules and the requirements for obtaining the Master’s degree (and later the Doctor’s degree). In summary, the candidate should have a bachelor’s degree, should be approved in a list of courses proposed by his supervisor, and should make a public presentation of his research work, which would be evaluated by his supervisor and a board of examiners designated by the graduate program committee. This model of a graduate program, referred to as *stricto sensu* in Brazil, is similar to those of the main American Engineering schools and was the first one with such characteristics in the country. Four years after the beginning of the graduate programs at ITA, in 1965, Prof. Newton Sucupira from UFRJ and counselor of the Federal Education Council was appointed as the rapporteur of a commission responsible for defining the model for graduate programs in Brazil. Prof. Sucupira proposed in his final report (Parecer 977/1965) a model based on the American graduate programs and the experience of ITA with this model certainly contributed to the commission choice. Since then, all graduate programs in Brazil have adopted this model, even those in Arts and Law [7, 39].

Prof. Freire from the Electronics Division supervised the first master’s and doctoral theses in engineering at ITA (and consequently in Brazil). Both dealt with topics in microwaves and were developed by Prof. Aroldo Borges Diniz, an Electronics Division faculty member and alumnus of the 1960 class. His master’s thesis addressed the propagation of electromagnetic waves in waveguides filled with plasma and was presented on January 22, 1963. In his doctoral thesis, defended on November 17, 1970, Prof. Diniz studied microwave oscillations due to the Gunn effect [8, 34].

One must point out that in addition to the pioneering nature of his master’s and doctoral theses, Prof. Diniz was a dedicated teacher and carefully prepared many class handouts in Portuguese for the microwave and antenna courses during the 1960s. These materials are still available at ITA’s Library, as illustrated in Fig. 8(a), which shows the handouts for the laboratory practices of the CEM-11 course.

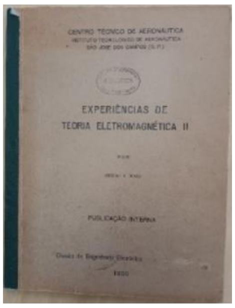
During the 1960s, the presence of foreign professors in the Department of Circuits and Microwaves was gradually reduced, and the Department started offering advanced courses on microwaves and antennas for the students enrolled in the graduate program in Electronics. The study of semiconductor devices in microwaves, such as pin, tunnel, and varactor diodes, was included in the microwaves courses.

IV. Department of Microwaves in the 1970s and 80s

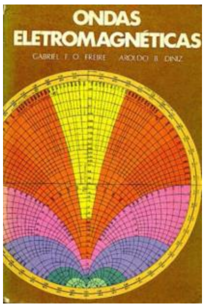
A. *Research and Education*

In the first half of the 1970s, the first microstrip and stripline circuits (e.g., matching sections, filters) were built at the Electronics Division under the supervision of Dr. François Pompignac from France, who served as a visiting scholar at ITA from 1971 to 1973 [40]. Dr. Pompignac also published an internal technical report titled “Microstrip and Stripline Engineering: Theory and Construction” during his stay at the Division. This report was used in the course ELE-215: Experimental Topics in Microwaves offered to graduate students and taught by Prof. Edgard Garcia Villarinho [41].

In 1973, Profs. Diniz and Freire published the book “Electromagnetic Waves,” written in Portuguese, based primarily on the class handouts prepared by prof. Diniz during the 1960s [42] (Fig. 8(b)). To the best of our knowledge, this is the first book by Brazilian authors with an in-depth analysis of time-harmonic electromagnetic fields that includes examples of experiments on applied electromagnetic waves.



(a)

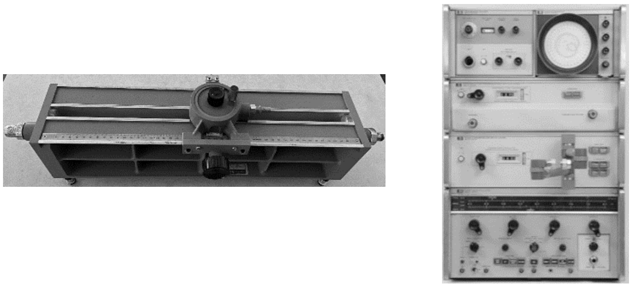


(b)

Fig. 8. Works of Prof. Diniz. (a) CEM-11 handouts. (b) Cover of the book “Electromagnetic Waves” [42].

Another Brazilian professor who taught antennas and propagation at ITA from 1957 to 1974 and that deserves mention in this paper is Luiz Gonzaga Rios. He is the author of the book "Antenna Engineering," co-authored by Eduardo Barbosa Perri, first published in 1982 [43]. The content of this book is based on an internal publication with the same title prepared by Prof. Rios in 1970. It is one of the first books on the subject written in Portuguese and published in Brazil. Prof. Rios also supervised many final projects on antennas developed by fifth-year Electronics Engineering students and took part in the creation of the antenna measurement facilities on top of the ITA's E2 building.

In the second half of the 1970s, the two-wire transmission line mounted in a wooden gutter, used in experiments to characterize standing waves, was replaced by the HP 805C slotted line (Fig. 9(a)). With this change, more accurate measurements were allowed at higher frequencies (from 500 MHz to 4000 MHz) since the fields remained confined between the center conductor and the parallel plates of the slotted line, thus almost not disturbed by near objects (unlike the two-wire transmission line). Also, in the 1970s, the Electronics Division purchased its first vector network analyzer, an HP 8410, from Hewlett-Packard (Fig. 9(b)). This equipment was initially used by professors and graduate students of the Department of Circuits and Microwaves and was the first of its kind in Brazil.



(a) (b)

Fig. 9. Lab equipment. (a) Slotted transmission line. (b) HP 8410 vector network analyzer.

The contents of the introductory course on electromagnetic fields offered to undergraduate students were reformulated in that decade. The topics of electrostatics and magnetostatics were removed from the course since they were already studied in the electricity course taught by the Department of Physics. Therefore, more emphasis could be given to the study of electromagnetic waves, comprising the analysis of reflection and transmission of plane waves at planar interfaces and the standing-wave pattern that arise due to the reflected wave.

In the 1980s, Gunn oscillators from Philips Sivers Lab replaced the klystron tubes used in the experiments involving slotted waveguides at the X band (Fig. 10). This change improved the measurement accuracy because the frequency stability of the Gunn devices was superior to that of the klystrons available in the lab. Moreover, the course on applied electromagnetic waves incorporated the analysis of microstrip lines.

B. The Use of Microwave Software

In the 1960s, the use of computers in microwave engineering was being discussed by the scientific community [44], mainly due to its accurate calculation of a diversity of items, e.g., polar patterns from near-field parameters, microwave filters, the performance of microwave junctions, etc. The first commercially successful software for microwave engineering was the COMPACT (Computerized Optimization of Microwave Passive and Active CircuiTs), created by Les Besser in 1973. Just out of curiosity, a description of COMPACT software was submitted to the IEEE Transactions on Circuit Theory in the early seventies, being rejected, similarly to Phillip H. Smith's original article on the Smith Chart that was also rejected with a "No practical contribution" comment. According to Besser, after rewriting the COMPACT article (removing most of the explanations and adding lots of complex matrix equations) it was published. In this context, the use of computers in the academic environment as a teaching tool also became a subject of discussion in the 1970s [45].

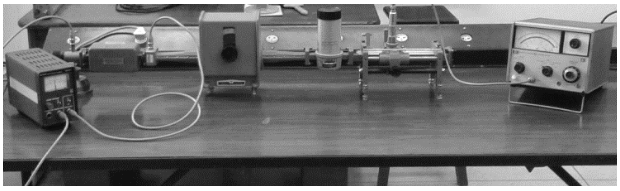


Fig. 10. Experimental setup with a slotted waveguide at the X band.

Due to the shortcomings in the dissemination of new technologies in the middle of the twentieth century and the military dictatorship policies in Brazil (1964-1985), computers turned out to be an important tool in the Department of Circuits and Microwaves only in the late 1980s. The first dedicated software used in that period was a package of nineteen GW-BASIC programs for antenna design using personal computers [46], which at the beginning of 1990 gave rise to the PCAAD (Personal Computer Aided Antenna Design) from the Antenna Design Associates, founded in 1990 by Dr. David M. Pozar [47]. This package allowed the analysis of transmission lines, antenna arrays (Fig. 11), microstrip antennas, telecommunication links, and wire antennas using the Method of Moments (MoM). Despite not being used directly in teaching, this tool was used to support research and lecture preparation.

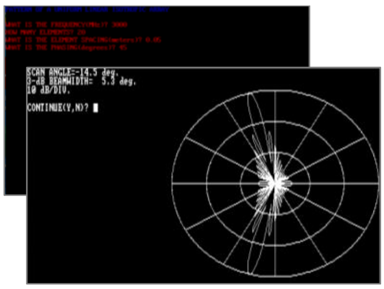


Fig. 11. Antenna design using a personal computer.

V. DEPARTMENT OF MICROWAVES IN THE 1990S

In the 1990s, the Department had four professors dedicated to teaching and research in the area of microwave engineering:

- José Carlos da Silva Lacava (D.Sc., from ITA, Brazil). In 1985, as part of his doctoral research, Prof. Lacava developed and tested the first prototype of a microstrip antenna made in Brazil [48]. During his academic career, he was responsible for conceiving the Laboratory of Antennas and Propagation –

LAP/ITA, which has become an important research group of electromagnetic theory, antenna array, and microstrip antennas, especially those conformed on cylindrical surfaces.

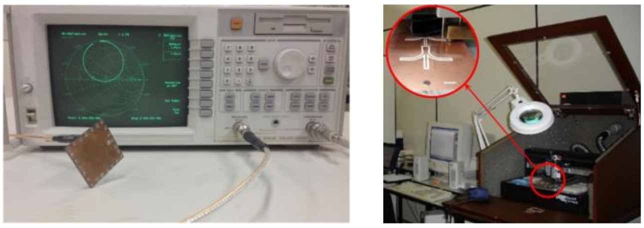
• Alberto José de Faro Orlando (Ph.D., from the University of Sheffield, UK). Prof. Faro researched guided waves, periodic structures, phase shifters, and magnetic materials. He served as the general chair of the II Microwave Brazilian Symposium (SBMO), held in São José dos Campos, SP, in 1986 [49].

• Flavio Pillon Richards (Ph.D., from University College London, UK) performed research on microwave devices, antennas, and optical systems.

• Paulo José Cunha Rodrigues (Ph.D., from the University of Leeds, UK). He published the book *Computer-Aided Analysis of Nonlinear Microwave Circuits* (Artech House Publishers, 1997). His research was based on the analysis and design of nonlinear microwave and optoelectronic subsystems.

In this decade, the Department proposed an instrumentation upgrade for its laboratories, based on the acquisition of microwave generators, spectrum analyzers, vector network analyzers (VNAs), and a machine for the construction of printed circuits. At the end of that decade, with an infrastructure composed of three Hewlett-Packard VNAs model 8714, the undergraduate students of the Electronics Engineering course received training in modern equipment employed in the high-frequency industries worldwide. Fig. 12(a) illustrates an undergraduate experiment carried out on the premises of ITA, where an introduction to microwave instrumentation, experiments for the characterization of passive circuits (S-matrix measurement), resonant cavities (Q-factor measurement), and antennas (input impedance measurement) were performed.

The acquisition of the printed circuit board milling machine, shown in Fig. 12(b), which was a novelty for the academic Brazilian community, allowed the group to manufacture printed microwave circuits, such as power dividers, couplers, amplifiers, and antennas. This facility significantly improved the quality of undergraduate final projects and graduate theses, when experiments started to be employed in the validation of theoretical models and brought knowledge related to the aspects of the construction process to the students.

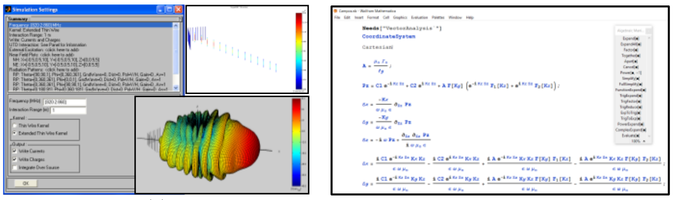


(a) (b)

Fig. 12. Lab equipment. (a) VNA HP-8714. (b) T-Tech milling machine.

With the rapid evolution of personal computers in that decade, the use of commercial easy-to-use RF tools became more popular in the academic community. Among the several commercial software that emerged at that time, ITA purchased the full-wave electromagnetic solvers Ansoft Ensemble [50], acquired with resources from ICAO (International Civil Aviation Organization) and SuperNec [51] (Fig. 13(a)), bought with resources from Embraer (Brazilian Aeronautics Company). The Ansoft Ensemble, a powerful MoM tool for the analysis of multilayer printed circuits and antennas, was initially applied to validate graduate research involving theoretical models [52]. The SuperNec, a hybrid MoM-UTD antenna and electromagnetic simulation program, developed by Poynting Software Ltd., was used in the group for the analysis of wire antennas and radiators integrated into large structures, such as airplanes [53].

In this period, another computational tool incorporated into the Department was the Wolfram Mathematica [54] (Fig. 13(b)), which allows symbolic computation. Initially, significant results were obtained by using this tool in the formulation of Green's functions of anisotropic multilayer media [52]. This software is still used in graduation research [55], undergraduate final projects [56], and as an auxiliary instrument for teaching [57].



(a) (b)

Fig. 13. Software packages. (a) SuperNec interface. (b) Wolfram Mathematica.

VI. Department of Microwaves from 2000 to 2020

At the beginning of the 21st century, due to its undeniable benefits, computer-aided design became crucial for the RF industry around the world, allowing the design of new devices in reduced time, improving the quality of the project, and saving money. This new philosophy created a challenge in teaching microwave engineering to undergraduate students. In this period, to stay in tune with the industry, dedicated software for the design of RF circuits and antennas was introduced in the training offered to students at ITA. Covering the knowledge areas of the Department of Circuits and Microwaves, the following tools were acquired: Agilent Genesys [58], Ansoft HFSS [59], Ansoft Designer [59], and Zeland IE3D [60]. These tools were introduced to the students in class and lab classes.

Currently, in the electromagnetic theory courses taught in the third year, full-wave software, such as HFSS, is employed as an auxiliary teaching tool, complementing the theoretical demonstrations with the dynamic presentation of the electromagnetic field inside transmission lines, waveguides, and resonant cavities (Fig. 14(a)). This approach contributes to the discussions of themes related to the devices, and the functionalities of the software [61, 62].

In the fourth-year courses, theoretical classes of high-frequency systems and devices are complemented by demonstration of Keysight Genesys (Fig. 14(b)) and Ansoft Designer software packages. The design and analysis of amplifiers, filters, and RF systems are carried out during the lectures. In the antennas and propagation course, the Radio Mobile tool [63] is used to illustrate the analysis of radio links.

Until the previous decade, practical training in the laboratory was based on experiments for the characterization of devices using the concepts introduced in the theoretical classes, and the introduction to RF instrumentation. Due to the relevance of software in student training, as above mentioned, nowadays, half of the time spent in laboratory practices is offered to exercises based on commercial software tools.

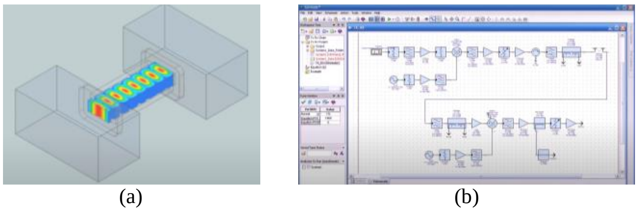


Fig. 14. Software packages. (a) HFSS interface. (b) Genesys interface.

Today, there is huge competition from microwave analysis tools vendors, and an effective way of advertising their products is by presenting these tools to university students. In this scenario, some tools for educational purposes are available at zero cost, such as Ansys Electronics Desktop Student [64] and CST Studio Suite [65]. Once the students have access to personal computers, laboratories based on simulation can be created at low cost and, alternative methods for theoretical classes integrated with simulations can be proposed.

Still, on the topic of educational tools, the Department has dedicated efforts to the codification of programs based on the Wolfram Mathematica language [66-69], mainly in the microstrip antennas area. In addition to these works, some educational techniques for laboratories have been proposed and released to the community [70-72].

In the 2000s, LAP was reconfigured. A new infrastructure of computers with up to 48 processors and 500GB of RAM in parallel processing was acquired, allowing the design of antennas in large structures such as rockets and airplanes. The experimental laboratory of research with operating frequency up to 13 GHz also received modernization in this period, with the acquisition of two VNAs, one signal analyzer, one spectrum analyzer, and one microwave generator. These laboratories are also available for undergraduate students during their final-year projects (Fig. 15).

Fig. 15. Laboratory modernization. (a) Computers. (b) Measurement equipment.

The theoretical classes, laboratory of experimental practices, and software-based learning make up the base of engineering education. In this context, the Department has dedicated efforts to applying these methods in microwave courses without missing the aspects of a solid theoretical basis, which has always been a characteristic of ITA's courses.

VII. TEACHING IN THE PANDEMIC ERA

The years 2020-2021 were marked by the presence of the COVID-19 pandemic. The rapid dissemination of the virus forced the lockdown around the world, impacting the activities in the universities [73]. To minimize the risks to the students, professors, and members of staff, the ITA management, in the first semester of 2020, officially adopted the distance education method for the undergraduate and graduate programs. To maintain academic activities during this period, the Department created a diversity of distance learning courses based on digital communication technologies. Initially, professors interrupted all research activities and dedicated all their time to creating materials for distance e-learning. Two types of activities were adopted, real-time online teaching (synchronous virtual classrooms) and recorded class lectures (asynchronous distance learning).

Using the Google Classroom platform integrated with Google Meet, the synchronous virtual classes were offered to the students using a digital board to present the contents, which was complemented by slide presentations and software simulations. These synchronous classes were also recorded and made available to the students on the platform to be accessed during the semester. The asynchronous classes were mainly based on recorded videos with animations. These videos were created and edited by professors using specific software and made available weekly. At the end of each video, a quiz was proposed to verify the student attendance and the level of understanding of the subject. Demonstration videos were also recorded in the laboratories to show some RF devices and the use of equipment, such as VNA and spectrum analyzer. It is important to emphasize that in both synchronous and asynchronous classes, the studies were complemented by textbook reading and exercises.

Although virtual teaching is not being applied in the post-pandemic period, the material produced at that time is of great value and is currently being used as teaching support material. The recorded videos and the documents for the presentation of laboratory equipment are some examples of reusable materials.

VIII. FINAL COMMENTS

This paper described how microwave education has developed at ITA since the 1950s. We presented the first foreign professors at the Electronics Division, who played a key role in structuring the undergraduate program in Electronics Engineering, particularly the courses on microwaves and antennas. The importance of the Brazilian professors for the creation of graduate programs and supervision of the first master's and Ph.D. students in the microwave area was also highlighted. We discussed the evolution of the microwave courses at ITA over the years focusing on the contents, the changes in the laboratory infrastructure, and the use of software tools. We talked about the teaching experiences during the COVID-19 pandemic and how the developed online resources can be used to complement the classes in the post-pandemic period. As technology is evolving at a fast pace and the new generations of students use electronic gadgets from an early age, microwave courses will need to be adapted to this new reality. The basics for the design of RFICs and circuits at mmWaves as well as increasing use of computational tools and online resources, while still providing solid theoretical foundations, will certainly be seen in the microwave courses in the future.

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