Microwave Engineering Education in Canada

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Abstract— **Microwave engineering education, as part of the Canadian engineering education system, is evolving in response to rapid changes in engineering practice that result from the explosion of knowledge, technological developments, national and international competition, globalization, and from pressing infrastructure renewal. The present system of Canadian engineering education is reviewed in general, and microwave engineering, in particular, is described. Issues and challenges are presented, and future developments and recommended actions are discussed.**

I. Introduction

THE Canadian engineering profession has not escaped the many challenges and problems that beset the industrialized world. In a recent report [1] the Canadian Council of Professional Engineers and the National Committee of Deans of Engineering and Applied Science have described and assessed the current system of engineering education in Canada, identified the principal issues and problems it faces, and recommended a number of actions to be undertaken by the profession, the industry, governments, and universities to ensure that Canada's present and future engineering needs are met. The findings of these two Councils, which are the most familiar with the status of engineering education in the country, have served as a basis for the general picture presented in this report. The specific aspects of microwave engineering education presented in this paper are based on the author's knowledge of the Canadian system and personal acquaintance with the majority of leading Canadian educators and researchers in electromagnetics and microwaves. They are thus described from a more subjective point of view than the general educational framework.

Since microwave engineering education is a subset of the general system, let us first look at present status of engineering education in Canada. Figure 1 shows a block diagram of the formal Canadian engineering education system as it extends from kindergarten to the doctoral level. (Informal education continues, of course, throughout the engineer's career). All these blocks are interdependent and affect both the quantity and quality of the engineers the country produces. One can essentially distinguish three levels, namely, the preuniversity level, undergraduate university level, and graduate university level, with complementary opportunities for preprofessional and professional level engineering experience. In the following, the various components of this education system will be discussed in more detail, first the preuniversity education system, and then the undergraduate and graduate levels with emphasis on electromagnetics and microwaves. Finally, issues and challenges relevant to Canadian engineering education are presented, and future developments and recommended actions are discussed.

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II. The Canadian Engineering Education System

2.1 Preuniversity Education.

Canadian students spend 12 to 13 years in the school system and then enter university-level engineering programs which require typically four or five academic years. In the province of Quebec, however, students spend 11 years in school, followed by two or three academic years in a GEGEP (Collège d'Enseignement Général Et Professionnel) before entering university. CEGEP programs are either vocationally or academically oriented, the latter being similar to the final year of high school and the first university year in other provinces. The university engineering programs in Quebec extend nominally over three and one-half to four years.

2.2. Undergraduate Engineering Education

Undergraduate engineering programs in Canadian universities are structured in a manner similar to those offered in the United States. Competition for entry into undergraduate engineering programs has led many universities to introduce enrollment limits. Students are selected on the basis of overall academic achievement with particular regard for competence in mathematics and natural sciences.

2.2.1 Accreditation of Undergraduate Engineering Programs in Canada: Curricula are constantly reviewed and revised, and a set of minimum criteria has been established by the Canadian Council of Professional Engineers (CCPE) for the purpose of professional accreditation. The CCPE was established in 1936 as the federation of the provincial and territorial authorities that license engineers and oversee the profession across Canada. In 1965 this Council established the Canadian Accreditation Board (CAB), now known as the Canadian Engineering Accreditation Board (CEAB), which has as its principal mandate to test and evaluate undergraduate engineering degree programs offered at Canadian universities and to award recognition to programs which meet the required standards. The minimum criteria for accreditation are formulated to provide graduates with an education satisfying the academic requirements for professional engineering registration throughout Canada.

An accreditation visit is undertaken at the invitation of a particular institution and with the concurrence of the association having jurisdiction. A visiting team of senior engineers

TABLE I

Institution	City	Province
University of Alberta	Edmonton	Alberta
University of British Columbia	Vancouver	British Columbia
University of Calgary	Calgary	Alberta
Carleton University	Ottawa,	Ontario
Concordia University	Montreal,	Quebec
Lakehead University	Thunder Bay	Ontario
Université Laval,	Quebec	Quebec
University of Manitoba	Winnipeg	Manitoba
McGill University	Montreal	Quebec
McMaster University	Hamilton	Ontario
Memorial University*	Saint John's	Newfoundland
University of New Brunswick	Fredericton	New Brunswick
Techn. University of Nova Scotia	Halifax	Nova Scotia
University of Ottawa*	Ottawa	Ontario
Ecole Polytechnique	Montreal	Quebec
Université du Québec à Trois-Rivières	Trois-Rivières	Quebec
Queen's University	Kinston	Ontario
University of Regina*	Regina	Saskatchewan
Royal Military College of Canada	Kingston	Ontario
Ryerson Polytechnical Institute	Toronto	Ontario
University of Saskatchewan	Saskatoon	Saskatchewan
Université de Sherbrooke*	Sherbrooke	Quebec
Simon Fraser University*	Burnaby	British Columbia
Ecole de Technologie Supérieure	Montreal	Quebec
University of Toronto	Toronto	Ontario
University of Victoria*	Victoria	British Columbia
University of Waterloo*	Waterloo	Ontario
University of Western Ontario	London	Ontario
University of Windsor	Windsor	Ontario

proceeds to consult with administrators, faculty, students, and department personnel, after having scrutinized pertinent documents and questionnaires completed by the institution beforehand. The team examines the academic and professional quality of the faculty, adequacy of laboratories, equipment, computer facilities, and more. They also evaluate the quality of the student's work and analyze the curriculum content to ensure that it meets the minimum criteria. Finally the team reports its findings to the CEAB which then makes an accreditation decision. It may grant or extend accreditation of a program for a period of up to six years, or it may deny accreditation altogether. The accreditation history of all engineering programs is published annually by the CEAB [2].

Table I shows all Canadian institutions that offer accredited undergraduate programs in electrical engineering. Most of these programs offer options with electromagnetics and microwave engineering content.

2.2.2 Criteria for Accreditation: The criteria for accreditation, as formulated by the CEAB, require not only competence in engineering, but also an understanding of the effect of engineering on society. An accredited program must therefore contain not only adequate mathematics, science, and engineering, but also develop communication skills and understanding of the environmental, cultural, economic, and social impacts of engineering. In particular, an accredited undergraduate engineering curriculum of four years duration must include the following components:

1) a minimum of one-half year of **mathematics** (matrix algebra, differential and integral calculus, differential equations, probability, statistics and numerical analysis);

2) a minimum of one-half year of **basic sciences** (physics and chemistry for electrical engineers);

3) a minimum of two years of a combination of **engineering sciences and engineering design** (both years must contain at least one half of each; this leaves one year for any combination of engineering sciences and design that may be deemed desirable);

4) a minimum of at least one-half year of **complementary studies** (humanities, social sciences, arts, management, engineering economics and communication that complement the technical content of the curriculum; course content that imparts basic language skills does not satisfy this requirement; rather, it must deal with central issues, methodologies, and thought processes of the humanities and social sciences);

5) a number of **other factors** are considered in the accreditation process, such as appropriate laboratory experience, exposure to public and worker safety and health, and exposure to engineering research and development activities. Furthermore, consideration is given to the program environment, the institutional facilities, and to the competence and engineering outlook of the faculty, their teaching load, the control, development, and administration of the program, etc.

Given the increasingly international scope of engineering activities, and in view of the growing number of exchanges of students and professionals between nations, the Canadian Engineering Accreditation Board has concluded, or is in the process of concluding, mutual recognition agreements with the homologous organizations of other countries: United States—Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET); Ireland—Institution of Engineers of Ireland; Australia—Institution of Engineers, Australia (IEAust); United Kingdom—Engineering Council of the UK; New Zealand—Institution of Professional Engineers of New Zealand. Here the CEAB ascertains equivalency and acceptability of accreditation systems in other countries, keeping in mind that engineering education worldwide is multifaceted and that there is no one formula for success.

2.2.3 A Typical Canadian Undergraduate Curriculum Leading Toward a Career in Microwave Engineering: All accredited Canadian engineering curricula and hence, a curriculum with a microwave engineering option will contain the components described above. While the timing of subjects and the emphasis on subject matters varies somewhat from institution to institution, the following may be considered as typical for most Canadian programs.

The first year: The first year consists in many institutions of a "common core" program emphasizing mathematics and basic sciences shared by all engineers. It also provides for a variety of courses that satisfy part of the complementary studies requirement. Often, it also contains a course on basic engineering design principles, problem solving, or on computer systems and programming. Topics of specific relevance for future microwave engineers, such as basic electricity and magnetism, special relatively and principles of quantum physics will most likely be covered in a general first year physics course taught by a faculty member of the physics department. Mathematics courses in the first year are usually geared toward the specific CEAB requirements for engineers and taught as service courses by the Math Department.

The second year: The second year is mostly concentrating on subjects required by all electrical engineering students. Therefore, the second year curriculum consists of compulsory courses except for those in complementary studies. The former include usually a course on electricity and magnetism taught either by the Department of Physics or by an engineering professor. In order to make this course compatible with more advanced electromagnetics and microwave courses, departments often insist that a textbook employing the MKSA system rather than the CGS system of units be used for this course. At the same time, mathematics courses dealing with vector and matrix algebra, complex functions, differential and integral equations, and numerical methods are included in the curriculum. Every institution has its own problems and solutions regarding the delicate balance between the perceived practical needs of engineering and the more fundamental approach to this material preferred by physicists and mathematicians. Given the ever accelerating explosion of knowledge and the increasing difficulty of incorporating important new subjects into the engineering curriculum, some engineering educators are asking the question whether it might be better to abandon certain courses in mathematics, physics, and chemistry and to integrate these subjects into engineering courses on an "as-needed" basis.

The third year: The third year is generally the most demanding in terms of course load and breadth of subject matter; it contains mostly compulsory courses with stronger emphasis on design and laboratory practice. Included is usually an introductory course in electromagnetic engineering in which students are exposed for the first time—and most of them for the last time—to engineering concepts involving electromagnetic fields, wave propagation, transmission lines, and antennas. The relevance and attractiveness of this course depends strongly on the degree to which the professors in charge are personally engaged in microwave and electromagnetic engineering. One of the major challenges for the teacher of such a course is to overcome the aversion of many students against the abstract formalism and the traditional-fundamental character of the subject matter, and it is at this level that many potential microwave engineers are turned either on or off. Educators who are aware of, and sensitive to, this crucial phase are increasingly including computer modeling and visualization as well as CAD software in order to complement traditional approaches, to involve the intuitive qualities of the student's minds, and to address realistic microwave problems early on. Unfortunately, many Canadian engineering faculties still lack the appropriate computer facilities and software, while at the same time, laboratory equipment is outdated or lacking altogether. In many cases, exposure to modern microwave measurements and laboratory procedures is limited to a few hands-off demonstrations using precious research equipment.

The fourth year: The fourth year is a year of specialization, and thus electromagnetics and microwave courses at that level are electives as a rule. While a forth year program reflects to a certain extent the research interests of the faculty, most optional microwave engineering curricula feature transmission lines and waveguides, microwave electronics, passive and active microwave circuit design, antennas, and basic optoelectronics. In addition, fourth year projects may be offered in the microwave area. These projects, as well as summer employment of undergraduates in a research laboratory, provide excellent opportunities for attracting gifted students into a microwave research group and motivating them to embark upon a microwave career. Computer-aided design and laboratory experience are part of fourth year microwave education in all leading universities, but the degree of exposure depends strongly on the availability of equipment, software, and the expertise of the professors.

Cooperative engineering education: A number of engineering faculties offer a cooperative program in which academic terms alternate with work terms arranged in industry or government institutions. Many students and employers find this work experience very attractive and beneficial. Cooperative programs require a well-organized infrastructure for the placement and evaluation of students and prolong the total time required to complete the Bachelor of Engineering degree. On the positive side, it can enrich considerably the practical aspect of engineering education, enhance the employment opportunities of the students, and prepare them for their future working environment. Cooperative programs are open to Canadian citizens and permanent residents only and are favored by students who intend to enter the job market after completion of their bachelor's degree.

2.3. Graduate Engineering Education

Master's and doctoral programs in microwave engineering are available in most Canadian engineering faculties. The former can be divided into two categories. The first is composed primarily of course work and provides advanced-level education in a specialized area. The second combines advanced course work with research, which provides some degree of specialization and introduction to independent scientific work. It also serves as a proving ground for subsequent doctoral studies.

Doctoral programs represent the highest level of engineering education in Canada. They also comprise graduate level course work and a doctoral thesis on original research. During the first two years of their studies, Ph.D. candidates must usually pass a qualifying comprehensive or candidacy examination (or both) before they are allowed to proceed with their thesis research.

All graduate programs are administered by a Dean of graduate studies and research, while the engineering school or department provides supervision, courses, and research facilities. To supervise master's and doctoral candidates, professors must be members of the graduate faculty or school. Membership is contingent upon demonstrated scholarship and research competence, aptitude to supervise graduate students, and ability to attract research funding, in particular peer-adjudicated research grants. It is reviewed on a regular basis (every three to five years).

In order to receive government funding, graduate programs must be approved by the provincial ministry responsible for universities. (Even though universities have the right to offer graduate programs without government funding, this is highly unlikely.) Approval depends on a positive assessment by an appointed visiting team, similar to the accreditation visits for undergraduate programs as described above.

TABLE II

Index	Mean	Standard deviation
Full time equivalent professors (FTEP), #	79	54
Full time equivalent instructors (FTEI, #	91	64
Total operating budget (excluding research funds)(TB), M$	9.0	6.7
Full time equivalent students (FTES), #	1,324	1,047
Ratios:		
Student/Professor ratio, FTES/FTEP	16.8	6.1
Student/Instructor ratio, FTES/FTEI	14.6	5.6
Total budget per student, TB/FTES, $/#	6,800	5,900
Equipment budget per student (FTES), $/#	400	620
Laboratory space per student (FTES), $/#	7.9	5.0

Graduate programs in the electromagnetic/microwave/antenna field are offered at all major Canadian universities, and are animated by leading researchers who are well known to the international microwave community. Most are active members of IEEE MTT/AP/EMC societies and URSI, and contribute regularly to their yearly symposia and *Transactions*. In the larger Canadian cities such as Ottawa, Montreal, Toronto, and Vancouver, major government and industrial research institutions provide significant additional resources for local universities in the form of adjunct appointments and external graduate lectureships, research collaboration and availability of major equipment and facilities. In return, universities offer continuing education opportunities to professionals working in these institutions by admitting them to graduate level courses and workshops. Strong interaction between universities, industry, and government laboratories is strongly encouraged by all engineering leaders.

2.4. Funding of Engineering Education in Canada

Approximately 70 percent of total operating revenue available to Canadian engineering education programs is provided by central university administrations, which in turn have received it from provincial governments, except for the Royal Military College which is under direct federal jurisdiction [3]. However, the federal government transfers funds to the provinces to cover part (about one-half) of university expenditures, but the provincial governments set the university budgets. This budget is determined according to various formulas by the different provinces, based on student enrollments or simply historical reasons. In addition, universities receive revenues from student fees (often fixed by the provincial governments), investments, research grants and contracts, gifts and endowments, and special government funding.

Table II gives some statistical indices related to Canadian engineering education, including funding levels. Statistics are based on 30 Canadian Engineering Faculties and Schools in 1990 and have been published in [4]. All dollar figures are in Canadian currency. This table shows that the average operating budget per faculty member (excluding research funds) was approximately $114 000.

Research grants represent, on the average, about 25 percent of the university operating revenues. The majority of grants (between 30 and 40 percent) come from the Natural Sciences and Engineering Research Council (NSERC), Canada's federal granting council for research in science and engineering. These grants are adjudicated by peer review. In 1988–89, NSERC's total budget was $365 million; of this, Canadian engineering faculties and schools received about $85 million. Assuming that NSERC funds between 30 and 40 percent of all research in engineering, the total engineering research budget of Canadian universities is about $250 million. This amounts to an average of $100 000 per engineering faculty member from all sources for research. Of course, research funds received by individual professors vary widely, and not every staff member holds a research grant. Special measures to foster excellence in research as well as interaction with industry are federal and provincial centers and networks of excellence, industrial research chairs, strategic and infrastructure grants, matching grants for industry contracts, and various other incentives.

On a global basis, engineering education receives approximately 2 percent of the total budget allocations for education in Canada, i.e., about $1 billion is spent on engineering education compared with total educational expenditures of $50 billion. As a result, 2.5 per 10 000 Canadians are awarded an engineering bachelors degree, compared with 2.9 per 10 000 in the United States and 6.2 per 10 000 in Japan.

III. Issues, Challenges and Recommended Actions

According to the recent report on the Future of Engineering Education in Canada [1] the current practice of engineering is shaped by six major forces:

1. knowledge explosion;
2. competition;
3. globalization
4. impact of technology;
5. environmental concerns;
6. infrastructure renewal.

While the present Canadian educational system has served the profession well in the past, it must evolve in response to these forces in order to remain adequate and, in addition, face the following three principal challenges identified in [1]:

1. accommodate an increased number of suitably prepared entrants into undergraduate programs and ultimately increased interest in graduate engineering education;
2. improve the quality of engineering education to ensure global competitiveness;
3. ensure continuing high competency of professional engineers in Canada.

In order to meet these challenges, the report [1] recommends a broad framework of action by universities, the engineering profession, industry, and government to be implemented at all levels of the educational system illustrated in Fig. 1. The most important of these actions, which are relevant to engineering education, not only in Canada but also in many other countries, are summarized below.

Actions at the preuniversity level: Improve competence of elementary and secondary teachers in science and mathematics. Increase the general awareness of teachers, students, and parents of engineering work and careers. Promote interest in engineering and project a positive and realistic

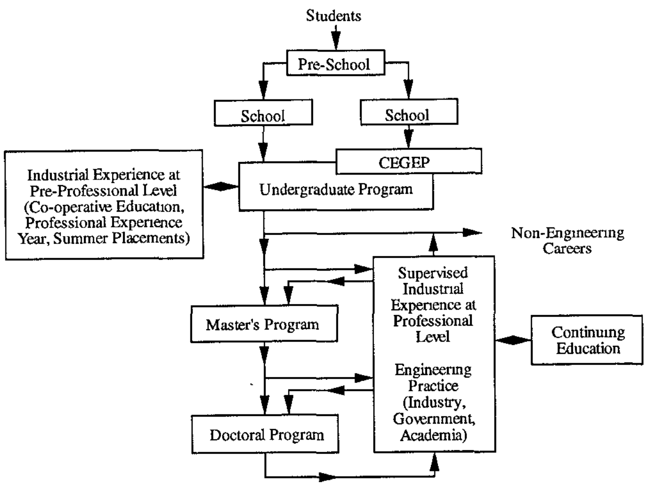

Fig. 1. Schematic diagram of the Canadian engineering education system [1].

image of engineers. Promote role models for male as well as for female engineering students.

Actions at the undergraduate level: Expand capacity of engineering programs by 20 percent by the year 2000 to satisfy increasing industry demand for engineers in Canada. Lower student-to-staff ratios by at least 10 percent. Replace and update teaching equipment to current industry standards. Preserve the broad base of engineering and avoid undue specialization at the undergraduate level. Review and restructure curricula to broaden their scope and consider increasing the total program length. Integrate mathematics and sciences into engineering courses more on an as-needed basis. Develop design and problem solving competencies, leadership, and teamwork skills. Increase opportunities for exposure to engineering practice. Develop competencies in languages and culture. Facilitate the transition from community colleges and CEGEP's to university engineering programs.

Actions at the graduate level: Take measures to allow completion of master's degrees in 16 months, and of doctoral degrees within 3 to 4 years. Facilitate entry of outstanding undergraduates directly into the doctoral program and make it easy for strong master's candidates to transfer to the doctoral program before completion of a master's thesis. Encourage engineers from industry to get involved in graduate teaching and research on a part-time basis, orient graduate work toward industrial problems, and encourage technology transfer. Create a distance education network to facilitate accessibility of specialized graduate programs, to link engineering faculties, and to avoid unnecessary duplication. Increase the range of highly specialized master's programs which could focus on particular engineering topics or combine engineering subjects with management, business, finance, law, etc. Increase funding for graduate engineering students to about 75 percent of starting industrial salaries.

Actions at the faculty/university level: Broaden the definition of scholarship to include excellence in both teaching and research. Give appropriate recognition to undergraduate teaching as well as to innovative engineering practice when making decisions on appointments, tenure, promotion, and salary. Assist young faculty members to become effective teachers. Assign balanced workloads. Create special incentive programs to encourage more young engineers and, in particular, women engineers to choose academic careers. Employ professors with industry experience, and ensure that engineering professors remain conversant with industrial practice. Increase the availability, accessibility, resources, incentives, and recognition of continuing engineering education programs.

IV. Conclusion

The present engineering education system in Canada, which has been described above, is of high quality and has served the needs of the country well. For example, Canada is a recognized world leader in telecommunication technology and engineering, and Canadian expertise in electromagnetics and microwaves is well established. However, Canada is a relatively small country in spite of its vast geographical extent. Increasing globalization and technological changes exert upon it a growing pressure to compete in many areas against much larger countries. It therefore must expand its industrial base and, hence, increase the quantity and quality of highly educated engineers. While a considerable number of established engineers, and in particular engineering professors, are "new Canadians," the increased need for professional engineers cannot be filled by immigration. On the other hand, the present educational system is unable to meet these objectives, and a number of urgent measures must be implemented so that it can satisfy the demand without undue delay. These measures were identified and recommended by the Canadian Council of Professional Engineers and the National Committee of Deans of Engineering and Applied Science. A summary of these recommendations has also been presented above. While a number of individual measures and initiatives along these lines are already being taken by a number of institutions, a more coordinated and comprehensive national effort is now under way to bring about the necessary changes and to ensure Canada's future prosperity.

References

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Wolfgang J. R. Hoefer, photograph and biography not available at the time of publication.