Microwave Engineering Education in Australia

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***Abstract*—The emergence of Australian science/engineering is presented in its historical and socioeconomic milieu. Engineering education is then considered in tertiary educational institutions where microwave engineering is taught at the undergraduate and postgraduate levels. The Australian educational system provides education of a high standard for technicians, engineers, and scientists.While there was no indigenous microwave industry in Australia, microwave engineering has been actively pursued in academia and in several quasi-government organizations/laboratories. In fields related to microwave engineering, Australia excelled in the areas of radioastronomy and microwave landing systems. In the 1980's indigenous microwave engineering firms appeared as a result of a determined effort to augment and strengthen the Australian manufacturing base. The recent emergence of the many centers described here and the appropriate fiscal policies put in place by the present government will aid the above process. In these new thrusts, universities and quasi-government organizations are destined to play a pivotal role.**

I. Introduction

One can approach the topic, microwave engineering education in Australia, from a narrow perspective. We could, for instance, simply list current educational programs for under- and postgraduates in Australian Institutes of learning. This, however, would be a hollow and futile exercise because it will lend no particular insights as to why Australia has these programs; furthermore such an approach will not allow us to have any opinions about future developments in this field.

The approach we have taken in this paper is to adopt a broad perspective and see the emergence of Australian science and engineering within its historical and sociopolitical milieu, which is unlike any other. We then sketch the educational infrastructure in Australia and enumerate the important engineering projects which contributed to microwave education in Australia. Finally, we consider what the future holds for Australia in the field of microwave engineering from a broad perspective.

II. Historical and Socio-Economic Milieu

Australia was inhabited by its indigenous people (Aborigines) long before the European explorers discovered and colonized it. A. Phillip (1738–1814), the English naval commander, captain general of the first fleet which carried the first settlers (convicts) from Portsmouth to Sydney Cove, founded the state of New South Wales (NSW) in 1788. Federation of all Australian States took place in 1901. Figure 1 is a map of Australia and in Table I important facts and figures, drawn from [1] and [2], about the country/continent are listed.

Fig 1. Map of Australia.

TABLE I
IMPORTANT FACTS AND FIGURES [1], [2]

AREA	7,682,300 km^2 (9,362,000 km^2 for the USA)
CLIMATE	Known as 'The dry continent' [50 and 80 percent of the land has a yearly median rainfall of less than 300 and 600mm respectively].
POPULATION	17 million [1991]. 10 million Australians lived in the capital cities and the nation's capital [1986].
STATES & CAPITALS	Victoria - Melbourne New South Wales (NSW) - Sydney South Australia (SA) - Adelaide Western Australia (WA) - Perth Queensland - Brisbane Northern Territory (NT) - Darwin Tasmania - Hobart
NATIONS CAPITAL	CANBERRA

The young colony was part of the British Empire despite the long distance separating England and Australia; even after federation the links between the two countries remained. In keeping with its colonial status, Australia very early established the foreign-trade philosophy of "tonnage out/technology in" and developed a tonnage-oriented technical-economic base for national development [3]. Raw materials and agricultural products were exported to Britain and technological products were imported.

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The Council for Scientific and Industrial Research (CSIR) was established to promote Australian science and its application in 1926; it was, however, based on the British model, i.e., a centrally funded organization, and followed British research ideology which emphasized the freedom of scientists from government control. Furthermore, it was directed toward agriculture (but not agricultural technology) [3]. The fierce defense of scientific freedom by CSIR's founding Chairman, Sir David Rivett, set the organization toward excellence in the acquisition of knowledge which was deemed necessary to solve practical problems [3], [4]. There was a belief in research freedom and that undirected research excellence per se would one day spin off into positive economic growth [3].

World War II(WWII) was an event of considerable importance to all nations, including Australia. Australians found themselves isolated from Britain; the isolation, however, forced Australia to become self-sufficient and promoted secondary industry. Mellor [5] noted "at the turn of the century, only about 12% of adults were employed in secondary industry as compared with 30% in primary industry. By 1950 the proportions were almost completely reversed." The events which took place prior to the Battle of the Coral Sea forged a new and long alliance between Australia and the U.S.A.

After WWII Australia took several steps toward strengthening its manufacturing base. The development of the hydroelectric potential of the Snowy Mountains and adjacent highlands has been Australia's outstanding engineering achievement and ranks as one of the world's largest undertakings of its kind. The primary function of the power stations, which have an aggregate capacity of 3740 MW, meets peak demands for electricity in NSW, Victoria, and ACT (Australian Capital Territory) [6]. The Snowy Mountains hydroelectric scheme took 25 years to complete at a cost of about 800 million Australian dollars [6]. Other hydroelectric power generating stations were built in Tasmania, NSW, Queensland, and Western Australia [6].

CSIR which became CSIRO (Commonwealth Scientific and Industrial Research Organization) launched the National Standard Laboratory, the Division of Industrial Chemistry, divisions devoted to the processing of wool and the Radiophysics Division the charter of which was R&D in rain and cloud physics, radioastronomy, and the application of radar to air and marine navigation. Australia subsequently became world leader in these three fields [4].

Although many agencies, including the Munitions Supply Laboratory and the Division of Aeronautics, made important scientific contributions to the war effort (WW2), it was not until 1947 that defense science began to evolve as an integrated activity. From these beginnings the Defense Science and Technology Organization (DSTO), the Science and Technology arm of the Defense Department, evolved [6].

In 1923 the Research Laboratories of the PMG (Post Maser's General) Department were established. From these beginnings, the Telecom Research Laboratories emerged. The laboratories conduct R&D related to communication systems. Microwave R&D of a high standard and propagation studies which extended over several years have been undertaken; a modern antenna test range is part of the Laboratories.

In another development Australia began to accept large numbers of migrants from Europe; currently the migrants to Australia come from the U.K. and Ireland, Vietnam, Hong-Kong, New Zealand, Malaysia, Phillipines, and India [1]. The order of the listing reflects the numbers of settlers taken from each country.

The entry of the U.K. into the European Economic Community, the trade partnerships which developed between Australia and Japan and several neighboring countries, including the U.S.A., contributed toward the view that Australia's future lies with the countries situated in the Pacific Rim.

III. The Recent Past—Winds of Change [4]

In the 1970's a disturbing trend became obvious: on 1979 figures, Australia ranked 9th in the world in frequency of scientific publication, but ranked 16 in the world's patented knowledge [3]. Some of the reasons were tariffs barriers (which did not encourage efficient manufacturing processes) raised by postwar governments, lack of a coherent long-term science and technology policy by postwar governments, and the roles of multinational industries in Australia [4]. On 1984 figures 74% of Australia's exports were relatively unprocessed agricultural and mineral products [3]. Australia was again playing the role of a primary producer. The collapse of commodity prices in 1985 increased the momentum for change.

Senator J. Button, minister of Industry, Trade, and Commerce and B. Jones, as Minister of Science of the Hawke Labor Government, played leading roles in the initiation of policies aimed at augmenting Australia's manufacturing base. The latter was a well-informed minister and his book [7] dealing with the consequences of technological advance generated international interest. Initiatives of the Labor government dedicated to the strengthening of industrial research included a 150% taxation concession for R&D conducted by industry, a National Industry Extension Service and various mechanisms for the encouragement of new high technology industries. Other initiatives of the same government will be outlined in Section VI.

IV. Education

The Australian school system provides 12 years of education prior to University entry (7 years of primary and 5 years secondary education or 6 years in each, depending on the state). Full-time education is compulsory until age 15 (16 in Tasmania). At age 16 a student can choose to pursue studies at the Technical and Further Education (TAFE) System, which provides, inter alia, pre-vocational, pre-apprentiship, or matriculation courses.

4.1. Tertiary Education

Tertiary education in Australia began in the Mechanic's Schools, the Schools of Mines and in the Universities (1827–1882) [8]. Today the main educational institutions providing tertiary education in Australia are the TAFE System and the Universities. Notable exceptions are the Royal

Melbourne Institute of Technology (RMIT), university, and the Australian Defense Force Academy (ADFA), both of which have university status.

Tertiary education is essentially vocational in character, with a variety of certificate, diploma, and degree courses in a wide range of fields.

4.1.1 The TAFE System: TAFE is by far Australia's largest provider of post-secondary education. It attracts over 1 million students in courses located in over 470 sites. These comprise more than 220 colleges and in excess of 250 additional off main campus centers. These courses include adult education, apprenticeships, and courses leading to certificates and associate diplomas [9]. Reference [9] is the first edition of the Australian TAFE Directory and constitutes a snapshot of vocational education and training in Australia, as provided by TAFE in 1992.

Not all TAFE colleges provide education and training in electronics, but at least one TAFE college per capital city provides education and training for technical officers who receive an associate diploma in electronics after 2–3 years (full-time) study. These technical officers of electronics technicians undertake the organization and execution of experiments/measurements in the industry/tertiary educational centers/research centers. Within these courses microwave engineering is taught not as a separate discipline but as a topic of several systems, e.g., television, satellite communications, or broadcasting.

4.1.2 Microwave Engineering Education: Electrical engineering courses in Australian Universities are four-year courses; science courses on the other hand span over three years. Students can elect to study for a combined science-engineering degree which spans over five years.

Most university courses on electrical engineering include microwave engineering and microwave related subjects such as Maxwell's equations, guided media (waveguides and transmission lines), low noise electronics, filters and circuit theory, EM theory and antennas, and computational techniques.

Instead of copiously outlining all microwave courses in all Australian Universities we shall outline the microwave courses offered at the University of Queensland; this is because the Electrical Engineering Department of that University has a long tradition in microwave engineering and microwave related topics.

The main areas of interest are microwave and millimeter wave engineering, electromagnetics, antennas/phased arrays, and optics. At the undergraduate level a wide range of subjects are offered which are prerequisites for the above specialist areas. The students' first serious encounter with electromagnetics is in second year with Electromagnetics I which covers the fundamentals of static electricity and magnetics. In third year Electromagnetics II is studied, which considers distributed systems (transmission lines) Maxwell's equations and other wave phenomena and applications. In the same year an introductory course in microwave systems and optics is offered as an elective for intending communication specialists. This course takes up the basics of satellite and optical communication links considering such aspects as optical fiber, optical transmitters, photo diodes noise and satellite link design.

In the fourth year, students can choose advanced microwave engineering, modern antenna theory and design, or optical fiber communications as elective subjects. These subjects are specialist in nature and are taught by the academic staff as well as by invited lecturers from industry or quasi-government organizations.

All subjects are of 26 hour formal lectures plus 13 hours of tutorial and problem solving periods, giving a total student contact of 39 hours per course. Computer based assignments are given in the fourth year where the computational aspects of EM are emphasized. Other CAD packages are introduced in the undergraduate subjects: PUFF, Touchstone, Pozar: antenna design using personal computers as well as some in-house developed educational software. Hands-on laboratory experience is provided in all subjects with a practical component. Assessment is mainly by written examination with tutorial and assignments contributing to the final grade. Undergraduate final year projects (theses) are encouraged in the electromagnetics/microwave fields.

At present there are a large number of postgraduate students at the Masters' and Ph.D. level. Both degrees are by research with the Masters having a small postgraduate course requirement. The course requirement also serves as a qualifying procedure for some overseas students. An attempt is also made to place emphasis on practical work, rather than the theoretical aspects, at the Master's level. The Ph.D. degree still requires work in theoretical, practical, and simulation areas although the mix of these components varies considerably.

The topics currently offered in the postgraduate area include mobile satellite antenna systems, broadband and travelling wave microstrip antennas and arrays, quasi-optical power combining techniques, low profile antennas for reception of satellite PAY-TV programs, six-port techniques, computational electromagnetics in the spatial, time and frequency domains, frequency selective surfaces and RCS (radar cross section) reduction methodology. Some students split their time between the university and other research establishments.

Other Australian University courses are either similar in nature (except that the topics differ) or less comprehensive in the microwave engineering and related areas, content.

V. Indigenous Microwave Engineering Activity

Microwave engineering has been actively pursued within CSIRO (Divisions of Applied Physics, National Standards and Radiophysics), in DSTO (several laboratories), the Telecom Research Laboratories, and in many tertiary institutions. In the private sector, microwave engineering is undertaken at Codan Pty. Ltd., Mitec Ltd. and Interscan International. What follows are brief descriptions of indigenous projects of considerable importance which helped to sustain and promote microwave engineering, prior to the establishment of indigenous microwave industry in Australia.

5.1. Instrumental Radioastronomy

Several unique radio telescopes were conceived and realized in Australia. A detailed account of all of them will be too lengthy; we have, however, cited special radioastronomy issues where Australian instrumental radio-astronomy projects were reported in great detail [10]–[14]; not all radio telescopes operated at microwaves but the majority did. In [14] the Australia Telescope commissioned in 1988 is reported in detail. On several occasions the Rockefeller and Ford Foundations, as well as the U.S. National Science Foundation, funded or partly funded [14] the realization of Australian radio telescopes. This reflects the high standing of Australian radiostronomy and the close relationship between Australia and the U.S.A. in the scientific field.

The Parkes Radiotelescope, 64 m in diameter, was the precursor of antennas used in Deep Space Network (DSN) operated by the NASA/JPL. The Australia Telescope is a synthesis radiotelescope consisting of a compact array situated in Narrabri, NSW which can operate in conjunction with an antenna 22 m in diameter situated in Coonabarabran, N.S.W., and the Parkes Radiotelescope. The compact array consists of 6, 22-m antennas, 5 of which can be moved along a linear railtrack 3 km long. The 6th antenna is separated from the other 5 by 3 km. The orientation of the linear compact array is along east–west, and Earth rotation is used to synthesize the radio images.

5.2. INTERSCAN/TRSB—Time Reference Scanning Beam System

The advantages of operating radio landing guidance systems in the microwave frequency band have been appreciated for many years. In 1972 the International Civil Aviation Organization (ICAO) decided that a single system be chosen for international use to prevent the proliferation of non-standard systems. Five countries, U.K., Federal Republic of Germany, U.S.A., France, and Australia submitted proposals for a new guidance system. Of these the TRSB proposed by the U.S.A. used the same signal format as the Australian INTERSCAN/TRSB system developed in the CSIRO Division of Radiophysics [15], [16]. In April 1978, ICAO decided that the TRSB/INTERSCAN system would become the world standard landing aid of the future. Again the close cooperation between Australia and the U.S.A. was demonstrated.

5.3. CODAN, MITEC, and INTERSCAN

For a long time the indigenous manufacturers of microwave equipment faced a "catch 22" situation. An Australian manufacturer could not obtain government orders because he could not demonstrate a performance based on a history of his product and he did not have a product history because he did not attract any previous orders [12].

In the early 1980's the Overseas Telecommunication Corporation (OTC) took steps to rectify this situation. It committed a sum of A$4.5M to an Australian consortium comprising of Codan, Mitec, CSIRO, and University of Sydney, and the South Australian Institute of Technology (SAIT), which became the University of South Australia, to develop by mid 1987 an engineering prototype for Intelsat Business Services (IBS) roof-top satellite stations. Additionally, OTC partitioned their request for tender. This made it possible for Australian firms to bid selectively for part of a system which they could do competitively with their own design and manufacture [17]. These developments greatly aided Codan and Mitec.

Mitec had its origin at the Microwave Technology Development Center which was established in 1980 by Prof. M. Gunn at the University of Queensland. From these beginnings Mitec, which moved off the University campus has become a substantial indigenous microwave firm employing a staff of 115. In 1990 it received the Australian small business award for manufacturing excellence and is the only Australian-owned space qualified company. The major markets being addressed by Mitec are satellite and terrestrial communications systems, advanced microwave components, defense communications, and satellite projects. In the space satellite area it has designed and manufactured microwave transmission and receiving equipment for incorporation on Australia and Russian satellites. Currently it has a Ka-band (30 GHz) beacon transmitter flying on a Hughes 601 satellite purchased by OPTUS Australia.

Codan was established in 1959 with principal interests and activities related to design and manufacture of HF radio communications equipment. In the early 1980's it expanded its interests to include satellite receiver systems and subsystems operating in the Ka- and C-bands. Codan now employs some 250 people.

Interscan International continued the work started in the CSIRO Division of Radiophysics. It has now become an international firm which supplies microwave landing systems to several countries.

VI. Steps Towards Decreasing the Tyranny Imposed by Geography and the Barriers Imposed by Institutions

Australians are separated geographically by long distances. The Flying Doctor Service of Australia, established in 1928, and the Radio Schools, established in 1951, contributed greatly toward diminishing "the tyranny of distance"[1] which separated Australians living in the outback (the sparsely populated regions of Central Australia). In a similar vein scientists/engineers in Australia are separated not only by distance but also by institutional barriers; more explicitly, the scientists/engineers required to realize a product at an internationally competitive price, are scattered in academia, quasi-government organizations, and in the private sector.

In an effort to decrease the barriers imposed by distance and by the Institutions, the Australian Government created Collaborative Research Centers (CRC's), Advanced Engineering Centers (AEC's), and Space Industry Development Centers (SIDC's). In a parallel effort, Australian scientists/engineers participated in several international conferences and hosted important international conferences in microwave engineering and electromagnetics. These conferences further decreased Australia's geographic isolation.

1) CRC's [18]: Fifty-two Cooperative Research Centers between tertiary Institutions, quasi-government Departments (e.g., DSTO, CSIRO), and industry have been created in an effort to strengthen the links between industry and R&D expertise available in the country. The centers

[1] A sentence coined by the Rev. John Flynn (1880–1951).

are divided into the following categories: manufacturing technology, information and communications technology, mining and energy, agriculture and rural-based manufacturing, environment, and medical science and technology. Although there are centers for sensor signal and information processing and photonics there is no center for microwave engineering.

2) SIDC's: Recently three SIDC's have been created, the charters of which are 1) space microwave engineering; 2) signal processing; and 3) satellite navigation. The aim of the first center is to coordinate R&D expertise available within tertiary Institutions and quasi-government organizations so that strategic guidance can be given to space microwave industries.

3) AEC's: Three AEC's located in Adelaide, Melbourne, and Sydney have been approved to augment the traditional roles of engineers. The AEC's will conduct courses leading to a Master of Engineering Science degree. The prerequisite for entering these courses will be three years study of traditional engineering courses (electrical, mechanical, etc.) in any University (of acceptable standard). Upon completion of these studies the student enters an AEC for a further two years course during which he/she masters skills related to the management of resources and manpower. Additionally she/he studies and takes part in research relevant to the AEC. The charters of the AEC's located in Adelaide, Melbourne, and Sydney are information technology and telecommunications, manufacturing and engineering innovation, respectively.

4) International Conferences hosted in Australia: Australia hosted several engineering conferences in the past, but 1992 was an exceptional year: Adelaide hosted the 1992 Asia-Pacific Microwave Conference which was held in conjunction with the 5th Australian Symposium on Millimeter and submillimeter waves; Sydney, on the other hand, hosted the 1992 URSI Conference on Electromagnetics, and Tencon '92 took place in Melbourne. The conferences and the symposium attracted many overseas researchers to Australia, who in return sampled Australian research in the above fields.

VII. Discussion

From the foregoing considerations it is evident that microwave engineering cannot be seen in isolation from engineering education and from major projects and policies which stimulate manufacturing growth.

In Australia it is abundantly clear that the signal processing community enjoys considerable support and attention. It is perhaps worth dwelling on the problems related to teaching and practicing microwave engineering. Two problem areas were identified [17] in teaching microwave engineering: i) the prohibitively high cost of modern microwave test equipment; and ii) the difficulty of getting graduates to undertake demanding mathematical field theory projects. The first problem can be overcome by forming partnerships between Universities and manufacturers of microwave test equipment. The Electrical Engineering Departments of Sydney University and the University of Technology formed such a partnership with Hewlett Packard which resulted in the establishment of the Sydney Microwave Resource Design Center. The second problem is, however, inherent to the microwave field, but suitable computer software is at present available to reduce the tedium of writing and testing computer programs related to microwave fields.

Given that the centers outlined in Section 6 are in their infancy, it is hard to make any definitive comments about them except perhaps to state that the rationale upon which their emergence is based is appropriate for Australia's needs. Additionally, it is clear that Universities and quasi-government organizations will play a pivotal role in the new thrusts toward augmenting and strengthening the Australian manufacturing base.

VIII. Concluding Remarks

The emergence of Australian science/engineering was presented in its historical and socioeconomic milieu. Engineering education and microwave engineering was then considered in tertiary educational Institutions where microwave engineering is taught at the undergraduate and postgraduate levels. The Australian educational system provides education of a high standard for technicians, engineers, and scientists.

While there was no indigenous microwave industry in Australia, microwave engineering has been actively pursued in Academia and in several quasi-government organizations/laboratories. In fields related to microwave engineering, Australia excelled in the areas of radioastronomy and microwave landing systems. In the 1980's indigenous microwave engineering firms appeared as a result of a determined effort to augment and strengthen the Australian manufacturing base. The recent emergence of the many centers described in this paper and the appropriate fiscal policies put in place by the present government will aid the above process. In these new thrusts Universities and quasi-government departments are destined to play a pivotal role.

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