Microwaves in the Asia–Pacific Region

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Invited Paper

***Abstract*—Infrastructure elements to produce microwave engineers and to promote microwave research and development in the Asia–Pacific region are described by active professors and researchers in this area as a multiauthor forum. The content of each description focuses mainly on the role of present-day universities, government, and industry.**

***Index Terms*—APMC, Asia–Pacific, Australia, China, government, India, industry, infrastructure, Japan, Korea, microwave, Singapore, Taiwan, Thailand, university.**

I. Introduction

INTERNATIONAL conferences are typical and very effective forums for microwave engineers worldwide to present the new results of their research and to exchange their ideas. The Asia–Pacific Microwave Conference (APMC), cooperatively sponsored by the IEEE Microwave Theory and Techniques Society (IEEE MTT-S), has been the most influential international conference on microwave engineering in the Asia–Pacific region for the past decade. It has been held in New Delhi, India (1986), Beijing, China (1988), Tokyo, Japan (1990), Adelaide, Australia (1992), Hsinchu, Taiwan (1993), Tokyo, Japan (1994), Seoul, Korea (1995), New Delhi, India (1996), Hong Kong (1997), Yokohama, Japan (1998), Singapore (1999), and Sydney, Australia (2000). Future APMC host cities, including Bangkok, Thailand, as a new member, have already been named by the APMC International Steering Committee beginning with Taipei, Taiwan, in 2001 and then ten cities up to Sydney, Australia, in 2011.

Since these conferences have been well organized by domestic institute members, local IEEE Sections and IEEE MTT-S chapter members, with the assistance of university and industry organizations, each APMC organizer should be well qualified to describe the status of microwave activities in education, government, and industry in his or her country for this TRANSACTIONS.

Approximately one page allocated for each author is hardy enough to do justice to all that is going on in microwave activities. Readers who require further information or references on a particular area of the Asia–Pacific Region are recommended to get in touch with the appropriate author by using their office e-mail addresses.

E. Yamashita

II. Microwave Infrastructure in Australia

A. Background

According to Organization for Economic Cooperation and Development (OECD) figures (1999), as a proportion of GDP, Australia is the third highest in terms of investment on machinery and equipment; however, it lags behind most countries in its investment in knowledge (Japan has a similar profile). Further, business research and development (R&D) intensity is below the OECD average and this reflects Australia's current industrial infrastructure, which is small on a world scale. The Australian R&D infrastructure is dominated by the activities in the university and government sectors, where the government funds approximately one-half of all R&D. Of this funding of about US$2 billion, approximately 50% goes to fund higher education, another 20% goes to the Commonwealth Science and Industrial Research Organization (CSIRO), a government research body, and the remainder goes to other federal agencies such as the Defence Science and Technology Organization (DSTO) or to state government agencies. Government expenditure on R&D is not spread uniformly across all fields of research. On information and communications technologies (ICT) areas, where the Australian microwave infrastructure is mainly found, R&D expenditure is only about 5% of the total.

Currently, the strongest activities in microwaves in Australia are in antennas, microwave photonics, device modeling and de-

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sign, receiver front ends, and microwave heating. More emphasis is given to the end application such as telecommunications, defence, and manufacturing than to technology areas. The bodies undertaking this work are outlined in the following sections.

B. Education

The Australian Government funds education and research in universities either directly or through grants schemes. Over 30% of universities have some microwave activity in teaching and research and eight have significant activities and/or facilities. These include the University of Queensland (antennas, microwave circuits, electromagnetics), RMIT University (antennas, microwave photonics), University of Melbourne (microwave photonics), Macquarie University (electromagnetics, device modeling), University of Technology, Sydney (antennas, electromagnetics), University of Sydney (microwave photonics, millimeter-wave imaging), University of Adelaide (integrated circuits, antennas), and the University of Wollongong (industrial uses of microwaves). Other groups with a critical mass are at James Cook University of North Queensland, Townsville (microwave aspects of superconductors), and University of New South Wales, Sydney (mobile communications). Typically, the fundamentals of fields and waves are covered in the first three years of the four-year undergraduate electrical engineering degree course and microwave topics are embedded in communications electives in the fourth year. In response to a demand for wireless engineering expertise, some universities are offering focused courses. For instance, the University of Adelaide has developed a broad Masters degree in radio-frequency engineering for DSTO and local industry.

C. Government

The two main government bodies with significant microwave expertise are CSIRO and DSTO. About 30% of CSIRO's funds come from external sources such as contract research and royalties. CSIRO has four major microwave technology activities in Sydney. These are antennas, MMIC circuit design, device fabrication, and radio astronomy. Several microwave facilities of national significance are also there, including antenna ranges and a GaAs monolithic microwave integrated circuit (MMIC) facility. CSIRO operates the national radio astronomy observatories through the Australia Telescope National Facility. Most of the specialized microwave equipment for the eight radio telescopes is developed by CSIRO, e.g., an L-band 13-beam focal-plane array for the 64-m Parkes radio telescope.

DSTO investigates, advises, and develops new equipment for Australian defence forces, and notable achievements include the Jindalee HF over-the-horizon radar. It conducts microwave research in areas related to communications, radar, electronic warfare, and imaging over the full microwave and millimeter-wave spectrum. To support these activities, DSTO has extensive facilities available for its own use. Specific technologies are often procured through research contracts with Australian universities and CSIRO.

Another arm of research in Australia is the Cooperative Research Center (CRC) Program, which commenced in 1990. Current CRCs having a significant microwave activity are the Australian Photonics CRC (microwave photonics), CRC for Satellite Systems (satellite transponders and microwave and millimeter-wave antennas and devices), and the CRC for Imaging and Signal Processing (ground probing radar).

D. Industry

Multinational companies dominate the industry sector and the few Australian companies that supply microwave equipment are export oriented. Some equipment is developed in Australia, but most is imported and used directly or modified for local conditions. Australian manufacturers include Codan (Adelaide and Brisbane), a major supplier of satellite ground station equipment, Argus (Sydney), a supplier of mobile base-station antennas and microwave landing equipment, and CEA Technologies (Canberra), a supplier of microwave radar for defence. Other Australian registered companies are part of a global company network (e.g., radio-frequency systems). As well as addressing particular markets from Australia, they provide products for the parent company. A number of small-to-medium-size companies service specialized needs for telecommunications and defence self-reliance and the largest Australian defence contractor, i.e., ADI Limited, has significant microwave system integration and test capabilities. Also, companies are developing microwave products for the mobile communications market. These include Argus, RFS, Voxson Limited (Brisbane) and Radiata (recently acquired by CISCO), which is developing 5-GHz components based on the IEEE 802.11a Standard for the wireless local-area network market.

T. S. Bird

III. Microwave Infrastructure in Mainland of China

In mainland China, almost every famous university has a Microwave Technique and/or Theory Division in the Electrical Engineering Department. Following are the main organization: The State Key Laboratory on Microwave and Digital Communications and Microwave and Antenna Division, Tsinghua University; Institute of Applied Physics and Microwave Center, University of Electronics Science and Technology; The State Key Laboratory on Antenna and Microwave, Xidian University; The State Key Laboratory on Millimeter Waves, Southeast University.

More than 20 universities include microwave groups, i.e., Peking University, University of Science and Technology of China, Beijing Institute of Technology, Tianjin University, Nanjing University of Science and Technology, Shanghai University, Beijing University of Aeronautics and Astronautics, Harbin Institute of Technology, Shanghai JiaoTong University, Xi'an Jiaotong University, Nankai University, Huazhong University of Science and Technology, East China Normal University, Northwestern Poly-Technical University, National University of Defence Technology, South China University of Technology, Nanjing University of Posts and Telecomm, etc.

In the Chinese education and academy system, Microwave Technology and Theory is the second level under electronics science and technology (first level). Every year, hundreds of Ph.D. and Master's students receive their degrees.

In mainland China, there are a lot of factories and institutes governed by the Ministry of Information Industry, Ministry of Aero- and Astro-Industry, and Chinese Academy of Science. The famous institutes include Beijing Vacuum Electronics Research Institute, Nanjing Electronic Device Institute, Heibei Semiconductor Institute, Institute of Electronics, Academia Sinica, Xi'an Institute of Space Radio Technology, Nanjing Research Institute of Electronic Technology, The Communication, Telemetry and Telecontrol Research Institute, etc.

The products cover communication systems, radar systems, measurement equipment, microwave component and subsystem, material, and others. In recent years, there appeared a lot of companies, including a joint venture with abroad company, mainly in the field of wireless communications.

The Chinese Microwave Society is an association of Chinese experts in universities and industry. It was founded 40 years ago. The Microwave Society committee has 50 director members and consists of 15 subcommittees. Its monthly publication is the *Journal of Microwaves* in Chinese (since the 1970s); the National microwave conference is held in every two years and 300–400 papers have been presented at each conference. The subcommittees organize and sponsor symposiums every two years on topics such as microwave integrated circuits, electromagnetic compatibility (EMC) and wireless communications, measurements, microwave energy applications, millimeter-wave technology, electromagnetic (EM) theory, numerical methods, etc. Every year, about 500–1000 papers are presented in a number of symposiums.

The International Conference on Microwave and Millimeter Wave Technology (ICMMT) is held every two years, organized by the China Institute of Electronics since 1998, the result of a merger of two conferences; one is the international conference on millimeter-wave technology (since 1984) and the other is the advanced microwave conference (since 1994). There is a joint meeting between the Chinese and Japanese microwave societies called the China–Japan Joint Meeting on Microwaves (CJMW). The City University of Hong Kong is also active in microwave research and served as the host of the APMC in 1997.

Z. Feng

IV. Microwave Infrastructure in India

A. Education

In India, the area of *microwaves* is generally covered under *communications*. The undergraduate curriculum in communications includes one basic course in *electromagnetic theory* at the second-year level. Additional courses covering broadly, topics such as *transmission lines, waveguides, antennas, microwave propagation, and computational electromagnetics* are generally included in the final year. Some of the Institutions also have Microwave Laboratory courses covering experiments using waveguide benches. At the postgraduate level, the curriculum leading to the Master's degree in communications generally includes two compulsory courses, i.e., *microwave theory* and a laboratory with advanced experiments on *transmission lines, waveguides, and antennas*. Provision exists for specializing in microwaves by taking elective courses such as *microwave solid-state devices, circuits including modeling, microwave integrated circuits (MICs) and MMICs, computational electromagnetics, antennas and propagation*.

Some of the leading institutions that are engaged in research and offering postgraduate programs in the microwave area are the Indian Institutes of Technology (IIT) at Delhi, Kanpur, Kharagpur, Mumbai, and Chennai, the Indian Institute of Science (IISc), the Banaras Hindu University (BHU), and some of the regional engineering colleges and universities of Delhi, Osmania, Roorkee, Jadavpur, Calcutta, Burdwan, and Gulbarga. Government-funded special M.Tech programs are offered in *microwave technology* at Delhi University, *navigational electronics* at Osmania University, *microwave tubes* at BHU, and *millimeter-wave technology* at Calcutta University. In addition, Burdwan University has a fully government-funded M.Phil degree program in *microwaves*.

B. Government Role

The Ministry of Human Resource Development (MHRD), University Grants Commission (UGC), Ministry of Information Technology (MIT), Council of Scientific and Industrial Research (CSIR), Department of Science and Technology (DST), and the Defence R&D Organization (DRDO) are the major Government agencies that have been supporting manpower training R&D in the area of microwaves. These agencies have been sponsoring projects, at various Educational Institutions and R&D laboratories. Some of the major R&D laboratories that have been receiving funding in microwaves are the Society for Applied Microwave Electronics Engineering and Research (SAMEER), the Tata Institute for Fundamental Research (TIFR), and the Central Electronics Engineering Research Institute (CEERI).

The MHRD is funding a *Quality Improvement Program* (QIP) for upgrading the expertise and improving the qualification of faculty members in degree-level engineering Institutions in the country. This QIP program is implemented and monitored by the *All India Council of Technical Education* (AICTE). Under this program, eight institutions, namely, five IITs, IISc, Roorkee University, and Jadavpur University, offer M.Tech and Ph.D. programs in the area of communication engineering including microwaves.

Funding at the universities has resulted in the growth of expert groups in several areas, namely, radar, antennas, microwave tubes, navigational electronics, EMI/EMC, and microwave and millimeter-wave integrated circuits.

Commercialization of technologies developed at the educational institutions and the R&D laboratories is supported by government agencies. Some of the key agencies include the National Research Development Council (NRDC), the Department of Scientific and Industrial Research (DSIR), and the Department of Science and Technology (DST).

C. Industry Role

A number of public- and private-sector industries are involved in the production of microwave components, antennas, and communication equipments. Some of the leading industries are Bharat Electronics Ltd. (BEL), the Indian Telephone Industries (ITI), Hindustan Aeronautics Ltd. (HAL), the Central Electronics Limited and Electronics Corporation of India

Limited. Besides having their own product line, these industries undertake production based on the know-how transferred from various R&D institutions and DRDO laboratories. HAL, ITI, and BEL have excellent infrastructure for the production of hybrid MIC subsystems/systems. For meeting the requirement of further miniaturization in the form of MMICs, a foundry named GAETEC has been set up at the national level.

For Indian Satellite Programmes, major projects in the frequency band S–Ka are carried out at the Space Application Centre and Indian Space Research Organization. These organizations also have excellent facilities for fabrication of space-qualified hybrid MICs.

Recently, several private industries have started development and production of digital radios and MMDS, LMDS systems. In view of the shortage of technical manpower, some agencies have come forward to set up fully funded R&D schools within IITs.

B. Bhat

V. Microwave Infrastructure in Japan

A. IEICE

Japanese microwave technology is conducted by the Institute of Electronics, Information and Communication Engineers (IEICE), Japan. The IEICE is the most important nodal junction for R&D work of industries, government, and academies. The IEICE is composed of four societies and one group. Each society has specialized technical groups. The technical group of microwaves in the Electronics Society conducts Japanese microwave activities with the cooperation of other relating technical groups and societies. The IEICE holds two nationwide conferences in a year and each society opens nationwide monthly technical meetings so that the microwave engineers have more than ten chances to publish their work in a year in such conferences.

The IEICE annually holds Microwave Workshops and Exhibitions (MWE). The MWE is a joint microwave event of tutorial lectures, invited papers, university activities exhibition, and industrial technical exhibition. As the MWE covers a versatile field of microwaves, from microwave fundamentals to current topics, a great number of microwave engineers get together every year. In MWE2000, the number of attendees was 5500. More than 360 companies participated in the exhibition, among which about 25% were from Japan and 75% were from the U.S. and Europe. The scale of the MWE is growing every year. Due to the themes dealt with, the MWE is also believed to play an important role for educating young engineers in universities and industries.

The APMC is a microwave international conference held every year around the Asia–Pacific countries and is cooperatively sponsored by the IEEE MTT-S. The first APMC was held in February 1986, in New Delhi, India. The APMC is consecutively held every year around Asia–Pacific countries. The IEICE sponsors APMC when it is held in Japan. Although the history of the APMC is rather young compared with the IEEE International Microwave Symposium and the European Microwave Conference, an important role of the APMC in international microwave collaboration of Asia–Pacific countries has clearly been recognized.

B. Universities

Universities are considered to have three roles, i.e., education of students, producing and sending competent youth to industries, and responsibility for fundamental research. Research in universities is based upon basic theoretical analyses. Research subjects in universities are determined substantially by the specialties of professors. As a result, the subjects are of a wide variety and there are many frontier theme-oriented researches in which industrial companies cannot be well involved. Such diversity is believed to be an underlying strength of university research.

There are not a few professors who had been working in industry, moved to a university, and now cooperate with industry. Even greater collaboration between academia and industry will be required in the future.

There are two types of universities, i.e., public and private. Public universities are financed by the government (or the local government). The financial basis of private universities is mainly tuition fees from students and is partly based on government aid. Universities also receive funds in the form of grants from the government and private companies. Such grants are provided mainly for specific study themes, but some of them are allocated directly to the professors.

C. Government

The main role of the government is to finance universities (through the Ministry of Education, Culture, Sports, Science, and Technology), to administer/regulate communications and the radio spectrum (through the Ministry of Public Management, Home Affairs, Posts and Telecommunications), and to provide basic research leadership (through the Communication Research Laboratories (CRL) of the Ministry of Public Management, Home Affairs, Posts and Telecommunications). The government budget is composed of a program of grants on selected topics for research.

The main role of the CRL is exploiting frontier frequencies and new microwave frequencies utilization and convening collaboration of nationwide organizations for R&D works in these fields. As frontier frequency exploitation, commercial application of millimeter waves is one of the major projects. The CRL expects a wide variety of applications of millimeter waves in indoor information distribution networks, local-area networks, and traffic surveillance applications. They conduct a prototype field experiment of indoor television signal distribution by means of 60 GHz, in which electronics companies get together and participate. They also find a prospective application of millimeter-waves in subscriber end lines or premises lines in optical-fiber information distribution networks.

The Intelligent Traffic System (ITS) is one of the biggest nationwide projects that may comprehensively change future traffic/transportation systems and, therefore, the government is deeply involved in this project. The CRL is responsible for realizing radio communication networks. Almost all electronics companies and communication companies join this project. Field tests are now under way.

The CRL also convenes annual international conferences relating to its mission, e.g., topical meetings on millimeter waves, microwave photonics, ITS, and photonic technology.

D. Industry

Major applications of microwaves in Japan are public communication, broadcasting, sensing, traffic control, and medical treatment. They are mainly aimed at commercial purposes. Military and defense activities of microwaves are not explicitly targeted or, at least, are a small percentage with respect to the whole volume. In recent years, versatile needs for portable wireless terminals have been significantly increased. The microwave industry has become more active due to the emergence of portable wireless technology.

Companies engaged in microwave technology are electronics companies, electronic component makers, and communication companies. Major electronic companies are involved in the overall process from semiconductor material manufacturing and MMIC design/fabrication to equipment design/assembling. Electronic component makers are rather specialized and supply their products to electronic companies for specific commercial products. Dielectric resonators, for example, widely used in wireless terminals are solely supplied by a few component companies.

Communication companies also have an all-round technical strength since microwaves are major communication media along with metallic cables and optical fibers. In recent years, however, the content of communications has been changing from simple voice information to multimedia and broad-band information. The main R&D objectives, therefore, are changing from hardware-oriented technology realization to software-oriented new-services development.

M. Akaike

VI. Microwave Infrastructure in Korea

The freshmen enrollment in the area of electrical engineering and computer science in Korean universities has increased about ten times during the last 25 years to about 23 000 in 1997 in 310 departments, while the national per capita income (NPCI) increased about 40 times from US$250 to about US$10 000 during the same period. The yearly graduates with degrees of B.S. and B.E. in electrical engineering are about 15 000, with degrees of M.S. and M.E. about 2000 and with degrees of Ph.D. about 900 in 1997. These numbers are saturated and will decrease since the population of young people has decreased.

The three leading universities in engineering and science in Korea are the Korea Advanced Institute of Science and Technology (KAIST), the Pohang Institute of Technology, and the Seoul National University. The Department of Electrical Engineering and Computer Science (EECS), KAIST has about 82 faculty members, 420 juniors and seniors, and 394 M.S. and 737 Ph.D. students, where the average ratio of electrical engineering to computer science is about 1 : 0.6. The annual expenditure of KAIST including the external contracted research per one student is about US$2400. These three universities are comparable, but the average budget of other Korean universities is about one-half of this amount. The graduate students studying the area of microwaves, optics, and EM waves are about 0.1 of EECS students.

The Brain Korea 21 Program was initiated by the Ministry of Education to promote a few Korean universities into the world-class level in the graduate education in the area of engineering and science. For the Information Technology (IT) area covering the conventional electrical engineering and computer science areas, the forementioned three universities joined by three other minor universities (Kwang-Ju Institute of Science and Technology, Kyoung-Book National University, and Korea University) were selected in 1999. Annual grant of about US$13 million is awarded to IT area of these universities for seven years, which supports the graduate students, the international cooperation, the post doctorates, the visiting professors, and the R&D activities.

The national funding for the R&D activities are through various government ministries and funding agencies such as the Korea Science and Engineering Foundation (KOSEF), etc. The annual funding for 1999 amounts about US$2.7 billion and about one-half of this funding goes to R&D activities and the other one-half is for the R&D infrastructure and national laboratories. The universities share about 22.6% of the total budget and IT, including electronics and telecommunications, shares about 31.2% of the R&D activities excluding the funding for the infrastructure and national laboratories. The total amount of R&D funding in Korea has been steadily increasing over the last five years.

Electronics industries in Korea started in the late 1960s by assembling AM radios. Until 1990, the major production of electronics industries was in the consumer goods with its production of about US$23 billion and its exports of US$15 billion, making the electronics industries the first ranking among the export industries, occupying about 25% of total exports of the year. During the 1990s, the production of memory chips, optical fibers, and its communication systems, CATV, and the successful implementation of CDMA wireless cellular phones certainly made the electronics industries leading among Korean industries in domestic production as well as in exports.

The start of the microwave industry in Korea was the production of microwave ovens in the late 1970s. Maintenance of military radars and radio communication terminals was rather limited. Civilian radio communications market was suppressed until 1990 by the government because of the communication security against North Korea. In 1996, CDMA mobile cellular telephone system began its service and three companies installed their networks nationwide. They merged into two companies and, in 2000, had approximately 27 million subscribers (out of a population of 45 million). As the subscriber market exploded, the demand for nationwide radio base-stations and relays and handsets grew greatly. This has driven the microwave industry to manufacture various components and subsystems such as antennas, power amplifiers, filters, etc. in the frequency bands of 820–900 MHz (cellular) and 1.75–1.87 GHz (PCS).

After the successful launching of CDMA cellular services, the Ministry of Telecommunication is planning to launch IMT-2000 service and selected two companies last year. It is estimated to spend about US$80 million, respectively, by

Samsung and LG in the coming two years to develop systems of WCDMA or CDMA 2000. This will again drive the markets of various microwave components, subsystems, and systems in the frequency band of 1.92–2.17 GHz. This requires over 2000 well-trained engineers for this project alone by the above two companies. If we include the funding of two selected operator companies (SK and Korea Telecom) and associated small companies, total funding would be up to approximately US$500 million.

The Electronics and Telecommunications Research Institute (ETRI) coordinates R&D activities in national telecommunications projects supported by the Ministry of Telecommunications. ETRI has laboratories of satellite communications, radio communications, semiconductors, etc. Laboratories of semiconductors develop the power MESFET, MMIC amplifiers, and pHEMPTs, etc. Radio communication laboratories developed CDMA cellular mobile systems (i.e., switch board, personal terminals, and base-stations) and will develop IMT-2000 systems with the development of its modems, components, and key technologies where they may spend about US$58 million in two years. This will drive the microwave industry further in producing more components.

Various Korean societies play an important role organizing conferences, seminars, and workshops. The institutes with societies in microwave technologies and antennas and propagation are the Institute of Electronics Engineers (IEEK), Korea, the Korea Institute of Communication Sciences (KICS), and the Korea Electromagnetic Engineering Society (KEES). Approximately 1000 members from these institutes and societies are actively participating together in IEEE MTT-S and IEEE AP-S activities and in three jointly supported domestic conferences held regularly every year, where 60–70 papers are presented in one conference.

J. W. Ra

VII. Microwave Infrastructure in Singapore

A. Education

Two universities in Singapore, namely, the National University of Singapore (NUS) and Nanyang Technological University (NTU), have comprehensive modern facilities for teaching and research activities in microwave system and device modeling, design, characterization, and fabrication and antenna and *RCS* measurement. Other tertiary institutions, which have embarked in basic training in RF and microwave engineering, include polytechnics such as the Temasek Polytechnic and Nanyang Polytechnic.

NUS and NTU have ongoing collaborative projects with Singapore Telecoms (on the effect of local weather conditions on microwave propagation); defense-related organizations (on microwave scattering, large array antenna design, T/R module design and others); Mass Rapid Transit Corporation (on EMI/EMC control between systems); Hewlett-Packard Company, Santa Rosa, CA (on error-correction strategies for network analyses and NNMS); Institute of Microelectronics (on large-signal nonlinear modeling of semiconductor devices such as GaAs FETs using a new pulsed dc and pulsed RF measurement technique); Aachen Technical University (on active device modeling).

Related research centers and laboratories include the following:

- Center for Wireless Communication (CWC), a national center for RF communication research;
- Institute of Microelectronics (IME), a national center for semiconductor microelectronics research;
- Center for Optoelectronics (COE), a faculty-based research laboratory equipped with a RIBER MBE machine and associated supporting equipment.

B. Government Role

In Singapore, the National Science and Technology Board (NSTB) is the lead government agency under the Ministry of Trade and Industry, which is providing focus and direction to the country's technopreneurship drive and spearheading the nation's technological capability development. The key role of the NSTB is to develop capability through promoting and strengthening the local technological infrastructure. This involves developing research capabilities in the research institutes and centres, universities, polytechnics, and government-funded institutions, which have economic relevance and which will lead to the commercial exploitation of technology and innovation.

In early April 2000, a US$1 billion technopreneurship Investment Fund was launched to attract more venture capital activities to Singapore. This is in addition to the US$4 billion national Science and Technology 2005 (S&T 2005) Plan officially announced in October 2000.

The S&T Plan will build on the solid foundation laid over the last ten years by the National Technology Plan (NTP 1999–1995) and the National Science and Technology Plan (NSTP 1996–2000). Those two plans have put in place a robust R&D infrastructure in Singapore. The Gross Expenditure on R&D (GERD) as a percentage of GDP registered a compound annual growth rate (CAGR) of 12% for the 1996–1999 period, exceeding the 6% increase for the 1991–1995 period. By 1999, GERD as a percentage of GDP in Singapore reached 1.84%, which is close to the band of 2%–3% of national R&D investments in developed countries. The number of research scientists and engineers (RSEs) per 10 000 in the labor force has also grown steadily at 10% annually, from 48 in 1995 to 70 in 1999. Patenting activities in Singapore-based R&D organizations have also increased, reaching a figure of 673 patents filed in 1999. A sizable number of these patents relate to microwave and RF.

C. Industry Role

In microwave and RF engineering, a number of industrial companies are currently engaged more predominantly in developmental type of work than in research. Such companies include homegrown small manufacturing enterprises, local companies, and large multinational corporations. Most academic staff and research students from the tertiary institutions are involved in collaborative research and consultancy projects with them.

There are also a number of existing collaborative postgraduate teaching programmes between academia and industry, such

as the joint M.Sc. degree in wireless communications and postgraduate diploma in electromagnetics and RF. In microelectronics wafer fabrication, a number of multinational companies have already been in operation for many years. Companies with activities in MMIC design, characterization, and fabrication are presently being actively encouraged to come to Singapore. The newly corporatized DSO National Laboratories is presently the lead agency to promote MMIC locally.

M. S. Leong

VIII. Microwave Infrastructure in Thailand

Research activities in microwaves in Thailand were started not very long ago since the background of the country is largely agricultural. In addition, human resource to conduct research in this area was quite limited.

To promote the research activity in the field of electrical engineering, faculty members in various universities have established the national conference on electrical engineering [called the Electrical Engineering Conference (EECON)] in 1978. Since then, research in electrical engineering has been continuously conducted. In the beginning, most of the papers were related to electronics, power, and computer technology. There were very few papers related to microwaves.

Research on microwaves has been more active since ten years ago. The majority comes from King Mongkut's Institute of Technology Ladkrabang (KMITL), which initially focused on telecommunication technology. Besides this national conference, there are some domestic journals such as the *Proceedings of the Thailand Engineering Journal* and journals issued by various universities.

The research groups that continuously conduct research in microwave can be categorized as follows.

Chulalongkorn University (CU), Bangkok, Thailand, has established the research group on EM-wave technology. This group pays attention to research on reconfigurable antennas, high-frequency computation techniques, near-field antenna measurement, microwave remote sensing, and numerical computation, particularly the finite-element method. There are currently two active research staffs holding doctoral degrees, two Ph.D. candidates, and about 20 M.Eng. students.

Kasetsart University (KU), Bangkok, Thailand, has a group performing investigating on finite-difference time-domain (FDTD) computation. The application of interest is to study interaction of an electromagnetic wave to the human body. One Ph.D. associate professor and some graduate students are involved in this group.

There is a group with King Mongkut's Institute of Technology North Bangkok (KMITNB), Bangkok, Thailand, which focuses on microwave circuit, measurement techniques, and antenna analysis. Three faculty members are involved, one holding a Ph.D. degree and the other two M.Eng. degrees in addition to about ten M.Eng. students.

There has been a research group on microstrip antennas in King Mongkut's University of Technology Thonburi (KMUTT), Thonburi, Thailand, of which many papers have been published. Unfortunately, the group leader passed away in 2001.

The above information is concerned with the national universities. However, there is a private university, i.e., the Mahanakorn University of Technology (MUT), Bangkok, Thailand, which is also active in research on optical/microwave and antenna. At this university, there are three Ph.D., three M.Eng. staff, five Ph.D. candidates, and about ten M.Eng. students related to microwave.

As mentioned earlier, the main contribution is from KMITL, which has a background in telecommunication technology. It has several research groups including the following.

The Mobile Communication Laboratory, which focuses on propagation of mobile communication particularly to the personnel communication system (PCT). One Ph.D. and two M.Eng. research staffs including two Ph.D. candidates and 20 M.Eng. students are involved in this laboratory.

The Satellite Communication Laboratory focuses on satellite signal propagation. Two associate professors and ten M. Eng. students are currently studying such a subject.

The Signal Transmission Laboratory has produced some papers on active antennas.

The Wireless Communication Laboratory is the last group to be mentioned. It consists of one Ph.D. and one M.Eng. There are currently five Ph.D. candidates and 13 M.Eng. students. This group divides its interest into three categories, i.e., steerable antennas, slot antennas, and antennas for mobile communication.

Most of the above research is limited to education, however, some research can be applied to support industries such as the bidirectional antenna, developed by the Wireless Communication Laboratory, Research Center for Communications and Information Technology (ReCCIT), KMITL. Over 1000 pieces of this antenna are installed on the express way to extend the separation of PCT base-stations. This is an example of linkage between laboratories and industries. It is expected that it will be exploited more in the near future.

Besides basic research in the universities, some applied research is conducted in the national laboratory and state enterprises.

The Telecommunication Technology Laboratory of National Electronics and Computer Technology (NECTEC), Bangkok, Thailand, is developing a PCT handset, adaptive antenna, and third-generation (3G) mobile phone system.

The Research Department of Telephone Organization of Thailand (TOT), Bangkok, Thailand, has developed a 400-MHz wireless local loop system.

In addition to conducting research, some facilities have been established to support research such as the Electrical and Electronics Products Testing Center (PTEC), National Electronics and Computer Technology Council (NECTEC), Bangkok, Thailand. This center not only provides testing service to electronics export industries, but supports research as well.

In order to promote research activities, the government of Thailand has provided research funds through funding bodies such as the Thailand Research Fund (TRF), the National Science and Technology Development Agency (NSTDA), the NECTEC, the National Research Council of Thailand (NRCT), and the Ministry of University Affairs (MUA). Some foundations established by industries, e.g., the Thailand Toray Science Foun-

dation (TTSF) and the Thailand Asahi Foundation (TAF), also provide research fund.

M. Krairiksh

IX. Microwave Infrastructure in Taiwan

After World War II, Taiwan was under martial law for a long time during domestic political turmoil, and radio communications were totally controlled by the government. Thus, except for some military applications, there had not been any significant activities in R&D on microwaves in the civilian sector before 1970. With the political reform and telecommunication deregulation in recent years, it is almost a miracle that Taiwan has become a major supplier of handsets for cellular phones; the penetration of mobile communications in Taiwan now stands at 70% of the population. The congestion of the radio spectrum has caused service providers to cry for a more available spectrum, thus, creating pressures on the government to come up with new technologies for higher spectral efficiency or to develop new frequency bands. This presents, in turn, a pressure, but also an opportunity for the academic community to engage in more research on microwave-related science and technologies.

Though late in coming to play a significant role, the importance of the microwave area had been well recognized and EM theory and applications have been required courses in the undergraduate programs in major universities throughout recent history. Graduate programs were first established in some universities during the period of the 1960s, offering first the M.S. degree and then the Ph.D. degree ten years later. The study of microwave engineering began at the National Taiwan University, Taipei, and the National Chiao Tung University, Hsinchu, and it has been flourishing ever since at other universities as well.

On the research front, while most of the theoretical work had been carried out in universities and many contributions to the literature in related fields had been made, the development of microwave circuits and solid-state transceiver modules began in the late 1970s at the Chung-San Institute of Science and Technology, as part of the military establishment. The circuits were mainly based on hybrid MIC technology for the frequency band from 1 to 10 GHz. In the early 1980s, the frequency moved up to the low end of the millimeter-wave band, first with the effort of building up the measurement and assembly capabilities. At about the same time, the microwave industry began to take shape, with the first commercial enterprise being Microelectronic Technology Inc. Since then, the rapid development of the industry has proven to be one of the successful stories in the country. Today, Taiwan has built up the capability for microwave devices and components such as low-noise amplifiers, power amplifiers, mixers, filters, switches, frequency sources, attenuators, phase shifters, etc. Furthermore, RF modules have been successfully developed and are being used in various applications such as ground-based and airborne radar, missiles, electronic warfare devices, communication equipment, etc.

To keep up with the expansion of the service sector, the manufacturing sector is also catching up, but it is still limited to the production of terminal equipment. The current effort in the nation is to develop the core systems of telecommunications, so that the industries will have more freedom to move into new frequency bands such as the millimeter-wave range. Currently, the commercial needs for more high-speed short-range communications have stimulated considerable interest in millimeter-wave technology; it is not only to alleviate the spectral congestion, but also to afford a larger bandwidth for high data-rate applications. Specifically, high density fixed services (HDFS) cover new wireless point-to-point and point-to-multipoint technologies ranging from fixed wireless access (FWA) to high-speed broad-band wireless systems such as local multipoint distribution service (LMDS). High-altitude platform stations (HAPS) are investigated to operate like sophisticated repeaters, relaying messages between fixed and mobile users on the ground. Finally, intelligent transportation systems (ITS) require millimeter waves for detection, tracking, and communications. All these applications are attracting considerable efforts in universities to build up the technical capability, covering the frequency range from approximately 30 to 77 GHz at present. In short, microwave science and technologies are very much alive in Taiwan and should play an increasingly important role in the country's future.

S. T. Peng

Eikichi Yamashita *(Editor)* (M'66–SM'79–F'84–LF'00) was born in Tokyo, Japan, in 1933. He received the B.S. degree from the University of Electro-Communications, Tokyo, Japan, in 1956, and the M.S. and Ph.D. degrees from the University of Illinois at Urbana-Champaign, in 1963 and 1966, respectively, all in electrical engineering.

From 1956 to 1964, he was a member of the research staff on millimeter-wave engineering at the Electrotechnical Laboratory, Ministry of International Trade and Industry of Japanese Government. While on leave (1961–1963) and from 1964 to 1966, he was with the Ultra-Microwave Research Group, University of Illinois at Urbana-Champaign. From 1966 to 1967, he was with the Antenna Laboratory, University of Illinois at Urbana-Champaign, as Research Associate. In 1967, he joined the University of Electro-Communications, as an Associate Professor, and became a Professor in 1977, the Dean of the Graduate School (199201994), and Dean of the Graduate and Undergraduate Schools (1996–1998). He retired from the University in 1998 and is currently a Professor Emeritus of the University of Electro-Communications. Since 1956, his research interests have principally concerned the device applications of EM waves such as the development of design principles for various microwave transmission lines (1956–1998), including the variational approach in the Fourier-transform domain for designing microstrip lines using computers effectively (1967), the development of pyroelectric-effect detectors for sub-millimeter waves (1963), the finding of a radiation impedance approach for the design of negative-resistance diodes with whiskers, mounted in waveguides and working as oscillators (1965), the finding of a design principle for microwave-bandwidth laser modulators using microstrip-line structures (1974–1988), the application of microwave propagation to the safety system of railroad crossings (1975), the application of group theory to the design of optical fibers having symmetrically distributed multiple cores (1985–1995), the shaping of picosecond electrical pulses using the dispersion property of microstrip lines (1991–1992), and the finding of a design principle of array antennas on multiple dielectric-layer structures for the millimeter-wave imaging system (1995).

Dr. Yamashita was an associate editor of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES (1980–1984, 1996–1997). He was chairman of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) Tokyo Chapter (1985–1986) and a member of the IEEE MTT-S AdCom (1992–1997). He was chairman of Chapter Operations Committee of the IEEE Tokyo Section (1995–1996). Since 1988, he has been actively involved with the APMC, which is cooperatively sponsored by the IEEE MTT-S, in many countries in Asia, and for holding various IEEE MTT-S meetings and workshops in the Region 10 area. In 1998, he served as chairman of the Organizing Committee of the APMC' 98, Yokohama, Japan. He was the recipient of the 2000 IEEE MTT-S Distinguished Service Award and the 2000 Electrical and Computer Engineering Distinguished Alumnus Award presented by the University of Illinois at Urbana-Champaign.

Trevor S. Bird (S'71–M'76–SM'85–F'97) received the B.App.Sc., M.App.Sc., and Ph.D. degrees from the University of Melbourne, Melbourne, Australia, in 1971, 1973 and 1977, respectively.

From 1976 to 1978, he was a Post-Doctoral Research Fellow with Queen Mary College, University of London. He then spent five years as a Lecturer in the Department of Electrical Engineering, James Cook University, North Queensland. In 1982 and 1983, he was a consultant for Plessey Radar plc, Chessington, U.K. In 1984, he joined the Commonwealth Scientific and Industrial Research Organization (CSIRO), Epping, N.S.W., Australia. He has held several positions with CSIRO and is currently a Chief Research Scientist and General Manager—Information and Communications Technologies. He has authored or co-authored numerous papers in the area of antennas, waveguides, electromagnetics, and satellite communication antennas. He holds several patents.

Dr. Bird is a Fellow of the Australian Academy of Technological and Engineering Sciences, the Institution of Engineers, Australia, the Institution of Electrical Engineers (IEE), U.K., and is an Honorary Professorial Fellow in Electronics at Macquarie University, Sydney, Australia. He was a Distinguished Lecturer for the IEEE Antennas and Propagation Society (IEEE AP-S) (1997–1999), chairman of the IEEE AP-S/IEEE Microwave Theory and Techniques (IEEE MTT-S) chapter of N.S.W., Australia (1995–1998), and chairman of the 2000 APMC. He is currently chairman of the IEEE N.S.W. Section. He is currently an associate editor for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION. He was a recipient of an IEEE Third Millennium Medal for outstanding contributions to the IEEE N.S.W. Section. In 1988, 1992, 1995, and 1996, he was the recipient of the John Madsen Medal of the Institution of Engineers, Australia, for the best paper published annually in the *Journal of Electrical and Electronic Engineering, Australia*. He was also the recipient of a 1990 CSIRO Medal for the development of an Optus-B satellite spot beam antenna and a 1998 CSIRO Medal for the Parkes multibeam antenna feed system.

Zhenghe Feng (M'95) was born in Shanghai, China, 1945. He graduated from Tsinghua University, Beijing, China, in 1970.

Since 1970, he has been with the Department of Electronics Engineering, Tsinghua University. He was a Visitin Scholar with from 1979 to 1981. He is currently the Chairman and Professor of the Department of Electronics Engineering, Tsinghua University, and Deputy Director of the State Key Laboratory on Microwave and Digital Communications. His main research fields are wireless communication, smart antennas, antennas and antenna arrays, RF, microwave integrated circuits (ICs) and microelectromechanical systems (MEMS), EM theory, and numeric method.

Prof. Feng is a member of the IEEE Beijing section, deputy chair of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) Beijing Chapter, and vice chair of the Microwave Society of China (in charge of international academic exchange).

Bharathi Bhat (SM'82) received the B.E. and M.E. degrees in electrical communication engineering from the Indian Institute of Science, Bangalore, India, in 1963 and 1965, respectively, and the M.S. and Ph.D. degrees from Harvard University, Cambridge, MA, in 1967 and 1971, respectively.

From 1971 to December 1972, she was a Post-Doctoral Research Fellow with the Division of Engineering and Applied Physics, Harvard University. In January 1973, she joined the Indian Institute of Technology (IIT), Delhi, India, as an Assistant Professor, and became a Professor in 1977. She is currently the Head of the Centre for Applied Research in Electronics, IIT. She has authored or co-authored 85 research papers, *Analysis, Design and Applications of Finlines* (Norwood, MA: Artech House, 1987), *Stripline-like Transmission Lines for Microwave Integrated Circuits* (New York: Wiley, 1989), *Microwave and Millimeter Wave Phase Shifters, Vol. I—Dielectric and Ferrite Phase Shifters; Vol. II—Semiconductor and Delay Line Phase Shifters* (Norwood, MA: Artech House, 1991), a chapter on "Materials and Technology for Microwave Integrated Circuits" in *Microwave Materials* (New Delhi, India: Narosa, 1993), *Finline CAD for DOS-Analysis and Design Software for Millimeter Wave Integrated Circuits* (New Delhi, India: New Age Int. Publishers, 1997) and *CAD of Millimeter Wave Finlines-Analysis and Design Software for Windows* (New Delhi, India: New Age Int. Publishers, 1997). She was a member of the Editorial Board of the *Journal of IETE* (1986–93) and the *Journal of Pure and Applied Physics* (1989–92).

Dr. Bhat is a Distinguished Fellow of the Institution of Electronics and Communication Engineers (IETE), a Fellow of the Indian National Academy of Engineering (INAE), and Life Member of the Indian Society for Technical Education (ISTE). She was an honorary editor of the *Journal of the Indian National Academy of Engineering* (1981–83), a member of the IETE Council (1982–85, 1988–90), the INAE Council (1987–89), the National Committee for the International Union of Radio Science (URSI) (1985–90), and the chairman of the IEEE Electron Devices Society (ED-S)/Microwave Theory and Techniques Society (IEEE MTT-S) Chapter of the IEEE India Council (1983–85). She was the recipient of several national awards for her contributions in the area of microwave and millimeter wave engineering, including the 1983 Ram Lal Wadhwa Gold Medal, the 1986 S. K. Mitra Research Award, and the 1994 First Prof. K. Sreenivasan Award, all presented by the IETE, the 1985 Vikram Sarabhai Research Award, the 1991 Top Invention Award of the National Research Development Council (NRDC), the 1994 VASVIK Award presented by the Vividhlaxi Audyogik Samshodan Vikas Kendra, the 1998 Academy Excellence Award presented by the Defence Research Development Organization, and the 1998 Suman Sharma Award from the Institution of Engineers.

Masami Akaike (S'65–M'84–SM'91–F'98) was born in Kamakura-shi, Kanagawa-ken, Japan, on October 15, 1940. He received the B.Eng., M.Eng., and Dr.Eng. Degrees in electronics engineering from the University of Tokyo, Tokyo, Japan, in 1964, 1966 and 1969, respectively.

In 1969, he joined the Musashino Electrical Communication Laboratories, NTT, Tokyo, Japan. From 1969 to 1981, he was engaged in the R&D of guided millimeter-wave transmission systems and terrestrial digital microwave systems. He was especially responsible for solid-state devices in microwave and millimeter-wave frequencies for these systems. From 1982 to 1983, he was involved with the planning and field evaluation test of ISDN systems. From 1983 to 1984, he was responsible for R&D on radio propagation characterization. From 1989 to 1992, he joined the ATR Optical and Radio Communications Research Laboratories, Kyoto, Japan, during which time he was Head of the Radio Systems Department responsible for R&D of future personal mobile communications. In April 1992, he became a Professor in the Department of Electrical Engineering, Science University of Tokyo.

Dr. Akaike has served as the vice-chair of Commission C of the International Union of Radio Science (URSI) since 1999.

Jung-Woong Ra (S'68–M'70) was born in Kwang-Ju, Korea, on February 12, 1941. He received the B.E. degree in electronics engineering from the Seoul National University, Seoul, Korea, in 1963, with the first honor graduated in the College of Engineering, and the M.S. and Ph.D. degrees in electrophysics from the Polytechnic Institute of Brooklyn, Brooklyn, NY, in 1968 and 1971, respectively.

He then joined the Korea Advanced Institute of Science and Technology, Taejon, Korea, As a Chartered Faculty Member of Electrical Engineering and is currently the Professor and Chairman of the Electrical Engineering and Computer Science Department. He developed the underground continuous wave (CW) EM wave radar to detect the fourth demilitarized zone (DMZ) tunnel in Korea, which led to the studies that obtained the quantitative cross-borehole tomogram through the use of iterative inverse scattering. He is also interested in the scattering of EM waves by a dielectric wedge.

Dr. Ra is the past president of the Institute of Electronics Engineers (IEEK), Korea, the past president of the Korean Society of Broadcast Engineers, and a past AdCom member of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S). He is the president of the Korean National Committee of the International Union of Radio Science (URSI).

Mook Seng Leong (M'75–SM'98) received the B.Sc. in engineering (with first-class honors) and Ph.D. degree in microwave engineering from the University of London, London, U.K., in 1968 and 1971, respectively.

From 1971 to 1973, he was a Post-Doctoral Research Fellow at Queen Mary College, London University, where he investigated high-efficiency microwave antennas in collaboration with Andrew Antennas, Lochgelly, Scotland, and Microwave Associates, Luton, U.K. In 1973, he joined the National University of Singapore, Singapore, and is currently a Professor and Head of the Microwave and RF Group, Electrical and Computer Engineering Department. He has authored or co-authored over 150 technical papers in international journals and has consulted extensively by statutory boards and public and private companies. He also co-authored the textbook *Spheroidal Wave Functions in Electromagnetic Theory* (New York: Wiley, 2002). His current research interests are EM wave propagation and scattering, antenna design and analysis, and EMC. He is an Editorial Board member of *Microwave and Optical Technology Letters* and *Wireless Personal Communications*.

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Monai Krairiksh (M'94) was born in Bangkok. He received the B.Eng., M.Eng., and D.Eng. degrees from the King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand, in 1981, 1984 and 1994, respectively.

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Song Tsueng Peng (M'74–SM'82–F'88), photograph and biography not available at time of publication.