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Focus Session: Thursday, 9 June at 8:00 a.m. in Rooms 316–317. Attendees are advised to check the room assignments upon arrival as they could have changed.

India: RF and Microwave Engineering

Madhukar V. Pitke

Microwaves were under investigation by physicists closely associated with studies of electromagnetic waves in India towards the end of the 19th century, much before microwaves became commonplace. In 1897, J.C. Bose (not related Amar G. Bose of acoustics fame) described to the Royal Institution in London his research carried out in millimeter wavelengths at Calcutta (now Kolkata). He used waveguides, horn antennas, dielectric lenses, various polarizers, and even semiconductors at frequencies as high as 60 GHz. Much of his original equipment is still in existence, now at the Bose Institute in Kolkata. Since then, there have been several research groups in Indian universities carrying out research in what we may now call "wireless."

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microwaves and wireless in India. This was intensified further by the availability of very inexpensive surplus equipment that became available after the end of the war. It was around this time that universities and colleges introduced courses in microwaves and microwave engineering. There was considerable research with excellent contributions in the field of radio communication, propagation, and ionospherics.

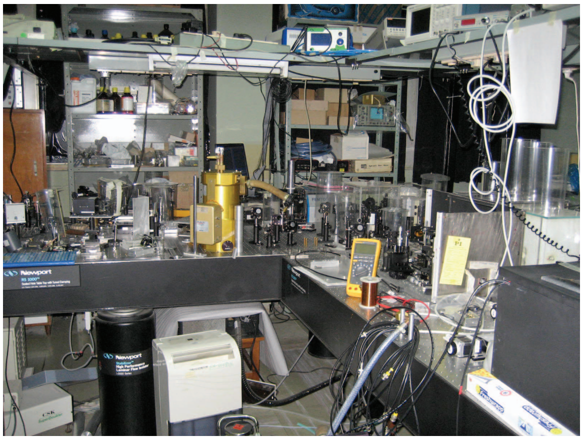

Figure 1. *The ultrafast laser lab for generation of signals at terahertz frequencies at the Tata Institute of Fundamental Research. The setup includes laser, optical path, generator, sample chamber, detection optics, and associated electronics. (Photo reprinted with permission from Prof. A.S. Vengurlekar.)*

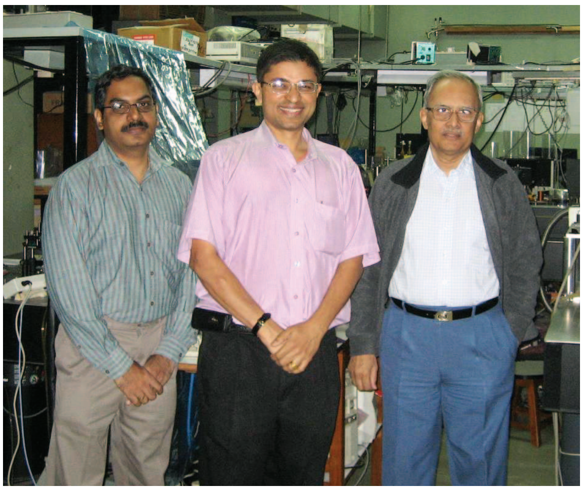

Figure 2. *Researchers A.V. Gopal, S.S. Prabhu, and Prof A.S. Vengurlekar from the Tata Institute of Fundamental Research. (Photo reprinted with permission from Prof. A.S. Vengurlekar.)*

Although long-distance radio communication, for example the wireless link between England and India, was set up in 1933, deployment of microwave equipment commenced much later, some time in the 1950s, as point-to-point links in mountainous terrain. A major transformation began with large-scale application of digital technology, semiconductor components, and computer systems in the late 1960s. This was followed by the introduction of digital microwave systems in the 1970s. Current microwave engineering activities in India could be classified into four broad groups: education and research, radars and military electronics, satellites and space research, and communications.

Education and Research

In the field of education, training and research, a number of universities, Indian Institutes of Technology (IITs), and several research and development centers provide excellent facilities. For example, graduates of the IIT in Kharagpur, the Institute of Radiophysics and Electronics in Kolkata, and the Indian Institute of Science in Bangalore have contributed immensely to the overall growth of communications in India. So have the government colleges like the College of Engineering at Guindy in Madras (now a University in Chennai) and the College of Engineering in Poona (now Pune). The Society for Microwave Electronics and Engineering and Research (SAMEER) is a research and development laboratory fully dedicated to microwave engineering. A spin-off of the Tata Institute of Fundamental Research (TIFR), it has, over the years, developed linear accelerators for medical applications, a variety of antennas, microwave components, radars, and radar instrumentation. It has set up a national facility for RF/EMC measurements. TIFR has also initiated an important research program in terahertz technology, shown in Figures 1 and 2. Its efforts include developing efficient sources and detectors for a range of sensing and imaging applications. Applications in communications are under exploration.

The rapid growth of the communications industry during the past several years appears to have had a depressing effect on microwave engineering education. Basic education in electronics has become less attractive. Mathematics and physics are being neglected by science students. This has affected studies in microwaves and RF, which have been an integral part of physics and electrical engineering curricula for a long time. Around the 1960s, optical communications experienced rapid growth. As a result, microwaves and RF began fading out of electrical engineering. This resulted in India gradually losing much of its talent in RF and wireless to the United States and Europe. When there was a renaissance of wireless in the 1980s, with the advent of cellular services, this loss of talent made it difficult for India to capture new, emerging opportunities for product, technology, and application development. This appears to have affected India's ability to master new techniques and technologies. A decline in the annual number of IEEE Fellows from India is probably an indication of this situation. Fortunately, now there are signs of improvement. Government departments are providing significant funds for undertaking engineering projects in a large number of colleges. This has benefited lesser-known colleges from rural areas, also. With the emergence of new institutions having strong associations with leading universities of the world and the return of experienced faculty from the West, the availability of highly skilled manpower is expected to improve significantly.

It may be interesting to note that there are several Indian companies that provide good laboratory equipment and components for practical training in microwave engineering. There are kits dealing with waveguides, klystrons, Gunn diode oscillators, PIN modulators, satellite communications, microwave optics, X-band minibenches, antennas, power meters, global positioning systems (GPSs), radar principles, Doppler radar, etc. These companies provide high-quality equipment to dozens of colleges and universities. They also supply more advanced and customized equipment to centers and laboratories engaged in building large radar and satellite communication systems. As an example, ASTRA Microwaves, led by an eminent microwave engineer, designs, develops, and manufactures subsystems used in defense, space, meteorology, and telecom.

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Radar and Military Electronics

The most important applications of microwave technology are in the field of military electronics. Defense organizations in India are engaged in developing, manufacturing, and deploying a wide range of advanced radar systems. Some examples are briefly described here. The battlefield surveillance radar (BFSR), shown in Figure 3 is a man-portable, lightweight, battery-operated, surveillance radar. Weighing around 30 kg, it can be carried and operated by two- or three-person teams. It is a fully coherent pulsed Doppler radar, operating with a 10% duty cycle and 5 W peak power. The low-peak power provides the radar a low probability of intercept, making it difficult to detect by enemy sensors. The radar operates over 21 channels in the J band (10–18/20 GHz). It can be operated in all weather conditions and during day and night. The radar array consists of J-band transmit, receive, and processing modules within the single-array block. The signal processor is a single on-board field programmable logic array (FPGA)-based chip, which has been tailored for very low power consumption. The antenna array is made up of a microstrip patch array. Another example is the three-dimensional (3-D) Central Acquisition Radar (CAR). It is a 3-D radar developed by the Indian Defense Research Development Organization for use with Akash surface-to-air missiles. The 3-D CAR was developed as part of a program to develop a family of mobile, S-Band (2-4 GHz) 3-D radars.

Swordfish is an Indian long-range tracking radar specifically developed to counter ballistic missile threats. It will be a part of India's ballistic missile program. It was first tested in March 2009. The main aim of the test was to validate the capabilities of the indigenously developed Swordfish long-range tracking radar. Another product, the Bharat Electronics Limited (BEL) Weapon Locating Radar (WLR), is a mobile-artillery-locating phased-array radar developed by India. This counter-battery radar is designed to detect and track incoming

Figure 3. *Battlefield surveillance radar designed to detect human infiltration. (Photo used with permission from Arun K. Vishwakarma, contact: saltoro@gmail.com.)*

The Chandrayaan I has adopted a bipropellant system to carry it from the elliptical transfer orbits through the lunar transfer orbit and, finally, in the designated 100-km lunar polar orbit.

artillery and rocket fire to determine the point of origin for counter-battery fire.

Other microwave-based systems have been developed for the Indian missile program. The Indian missile program has reached a state of maturity that allows the country to field systems and products that cover the entire spectrum of land, air, and sea platforms in face of overwhelming odds and active technology-denial regimes imposed upon it by other countries. The Integrated Guided Missile Development Program (IGMDP) started in the early 1980s for the development of a family of strategic and tactical guided missiles, including the Prithvi and Agni, shown in Figure 4. As for tactical guided- missile systems, Defense Research and Development Organization (DRDO) has developed short-range surface-to-air missiles Akash, Trishul, and the anti-tank guided missile Nag. With the many new systems under development, missiles such as the satellite launched ballistic missile (SLBM), supersonic cruise missile BrahMos, etc., the DRDO is aiming for technology leadership in this area. There are, however, technology challenges in certain key areas like seekers, which need a national thrust.

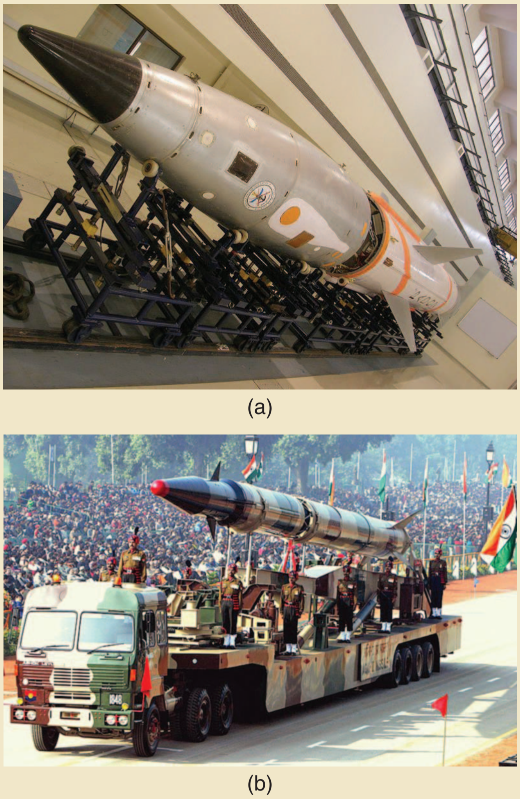

Figure 4. *The Integrated Guided Missile Development Program, started in the early 1980s, developed a family of strategic and tactical guided missiles, including the (a) Prithvi (photo reprinted with permission from Ajai Shukla, Broadsword blog, hosted at ajaishukla.blogspot.com) and (b) Agni (photo reprinted with permission from Antônio Milena/Agência Brasil).*

The defense department has made some excellent contributions is the area of microwave semiconductor devices. Some examples are 94 GHz single pole single throw (SPST) switches, micro electro mechanical systems (MEMS) devices, PIN diodes, Gunn devices, microwave integrated circuits up to 18 GHz, GaAs metal semiconductor field effect transistor (MESFETS), high-power devices for electronic warfare and radar, microwave ferrite devices, etc. A Gallium Arsenide Enabling Technology Center (GAETEC) was set up in 1996 in Hyderabad. GAETEC is a vertically integrated GaAs foundry comprising design, wafer fabrication and assembly, and testing and reliability evaluation facilities. It runs facilities for 0.7 and 0.5 micron MESFET technologies.

Satellites and Space Research

The Indian Space Research Organization (ISRO) is another government department involved in the application of advanced communication technology in a number of its ambitious projects and programs. One example is the Chandrayaan 1. This multifunction minisynthetic-aperture radar will include an altimeter, scatterometer, and radiometer, and will operate at 2.5 GHz. This instrument will probe the

Figure 5. *The 32-m Indian Deep Space Network antenna with the Moon in the background. (Reprinted with permission from* Current Science*, vol. 96, no. 4, pp. 486–490, 2009.)*

permanently shadowed areas near lunar poles to look for the signature of water-based ice mixed within the top meter of the lunar surface material. The spacecraft will be powered by single-sided solar array to generate 700 W and 36 A-hour lithium-ion batteries for eclipse operations. The Chandrayaan 1 has adopted a bipropellant system to carry it from the elliptical transfer orbits through the lunar transfer orbit and, finally, in the designated 100-km lunar polar orbit. The bipropellant system will also be used for orbit and attitude maintenance in lunar orbit. Communication will be in the S-band. The scientific payload data will be stored in two solid-state recorders and subsequently played back and down-linked in X-band (8–12 GHz) through a 20 MHz bandwidth by a steerable antenna pointing at the Indian Deep Space Network (IDSN) center near Bangalore. The IDSN consists of 18-m and 32-m antennae that are established at the IDSN campus, Byalalu, Bangalore (Figure 5). S-Band network stations will be used to support the mission during launch and early orbit phase (LEOP) that includes Earth transfer orbit (ETO) up to a range of about 100,000 km. An 18-m dish antenna is configured for mission operations and payload data collection. This antenna is capable of S-Band uplink (2 kW) and both X-Band and S-Band downlink. This system has the provision to receive two downlink carriers in S-Band and one carrier in X-Band using both right circular polarization (RCP) and left circular polarization (LCP) simultaneously, whereas, the uplink is either RCP or LCP. The system will have a receiving system figure of merit, antenna gain /system noise temperature, G/T, of 30/39.5 dB/K (45° elevation, clear sky) for S/X-Band.

EDUSAT or GSAT-3 was launched in 2004 by the ISRO. EDUSAT is the first Indian satellite built exclusively to serve the educational sector. It is mainly intended to meet the demand for an interactive satellite-based distance education system for the country. It carries five Ku-band (12–18 GHz) transponders providing spot beams, one Ku-band transponder providing a national beam, and six extended C-band (4–8 GHz) transponders providing national coverage beams.

In a stage of advanced development is the GPS Aided Geo Augmented Navigation (GAGAN), for GPS and navigation applications. The aim is to improve GPS accuracy from 30 m to 6 m, for continuity and availability for civil aviation applications. The program intends to maintain interoperability between GAGAN and other regional augmentations to GPS for global navigation.

Communications

Direct-to-the-home (DTH) TV broadcast service is also a major user of microwave technology (Ku band). Last year, the number of subscriptions stood at an impressive 23.5 million. With a growth rate of 18% per month, India has become one of the largest users of DTH in the world. Several low-cost solutions have been devised, beginning with cheap C-band antennas for satellite TV reception in the 1980s. This initiative has helped small companies develop very-low-cost antenna dishes and cable assemblies for mass deployment in the most remote parts of India.

Interest in microwave engineering received a boost from the rapid expansion of the wireless industry and the large development projects undertaken by the government.

Various projects and services have opened up vast opportunities for the microwave components and subassembly industry in India. A number of companies have emerged that develop, manufacture, and

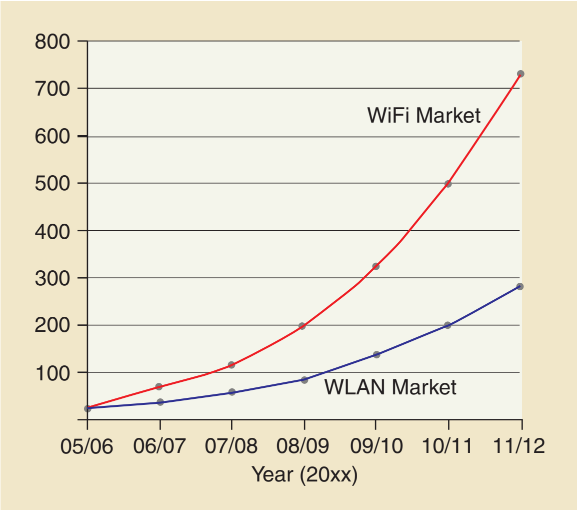

Figure 6. *The growth of telecom services in India, subscribers in millions.*

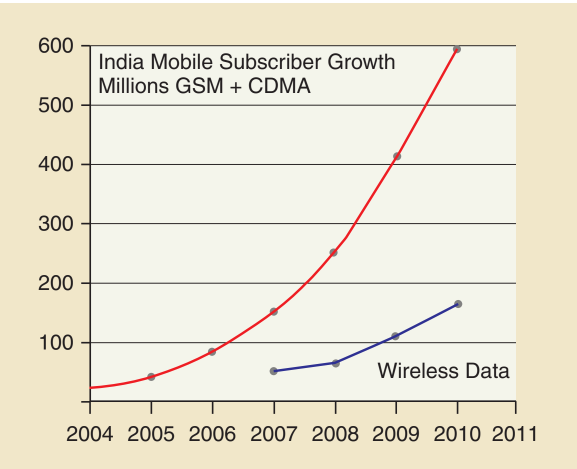

Figure 7. *Growth in the number of wireless subscribers in India, in millions.*

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supply a variety of products for major equipment companies in India and around the world. With the large-scale deployment of WiFi, WiMax, and RFID solutions, microwave communication has become ubiquitous in India, as shown in Figure 6. This has opened up enormous possibilities of new applications and innovations driven by local needs and environment. With the massive expansion of the mobile network, as shown in Figure 7, there are now more than 700 million cell phones in India. Considerable work is still required to deal with the problems of multiple local languages, communication via symbols, pictures, and patterns, speech processing, automated translations, etc. In fact, the cell phone has become an important transaction device even for the less educated poor. They are indeed coming up with novel solutions and applications which engineers never thought of.

Several unusual applications have been devised using combinations of voice, music, images, and SMS messaging, moving across the barriers of languages and scripts. Music and multimedia clips are routinely used in place of call signaling tones. Clever use of SMS helps in minimizing cost of these devices. We will see the next boom with the arrival of low-cost Kindle-type devices that are currently on the horizon and are perhaps more appropriate for India.

Rising prosperity and consumer demand in India drives a major expansion of the infrastructure. Expansion and modernization of the vast rail and road network is one of the important and critical needs. The automobile industry is witnessing a new boom. All these require new communication, control, and networking devices with innovative microwave-based technologies and solutions. Urgent steps are required to meet this challenge. The IEEE, with its exceptional leadership in microwave technology could play a major role here.

Interest in microwave engineering received a boost from the rapid expansion of the wireless industry and the large development projects undertaken by the government. There are new demands resulting from security and safety issues. The city of Mumbai needs to strengthen its surveillance and security network urgently to deal with threats from air, land, and sea. With the vast somewhat chaotic and disorganized population, the problem needs special solutions. Attention is now getting focused on promises generated by millimeter waves, terahertz frequencies, and medical imaging. Tethered balloons are also being considered.

There are new applications like home networks that are also expected to grow into big businesses. All of these activities are now supported by the generous funds that are made available by the government for advanced systems and technology development. This will help academics venture into new, unexplored territories. With large unserved demand, India's rural areas provide a good base for experimentation. It is probably the best place to explore and evaluate new ideas and developments such as those in coding, modulation, adaptive antennas, software radios, and cognitive networks, especially for spectrum conservation and management.

Of current interest is an application where microwave communication can play a critical role is the rural broadband for multiple services, up to 100 Mb/s. There are large rural areas without basic broadband services that are so critical for rapid development. Hundreds of millions of lines are required to cover all parts of India. Very-low-cost WiFi /WiMax-based solutions are being developed for this purpose, integrating conventional telephony, cellular, and IP networks (on the lines of 4G cellular communications). Although these are successful on smaller, pilot networks, large-scale deployment is still awaited. This is an outstanding opportunity for the microwave engineer to come up with some unique, innovative solutions.

Conclusion

There is an upsurge of activity in research, education and technology development. This has created a severe shortage of well-trained engineers with a good background in RF and wireless techniques. Fortunately, India now has a vast network of engineering colleges that generate thousands of well-trained electronic engineers. With additional coaching, some of these will become excellent RF engineers for the industry. In addition to this, many engineers with experience of working on advanced projects and looking for career enhancement and more challenging work are also available. The situation is thus quite favorable for undertaking major research and industrial activity. Under these circumstances, India is possibly one of the very few countries where major projects for wireless and microwave development requiring hundreds of high-quality engineers and scientists can be undertaken. New policies and an upgraded environment and facilities will help in harnessing this vast potential.