TITLE: **Microwaves—a journey in reshaping world technology**

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Abstract

The very fact of microwaves gaining a strong foothold in the domain of history of electronics for reshaping and reframing the communication system with its various applications over the century and its rapid development since the second World War finds mention in this paper. The research works and discoveries of eminent scientists like J.C.Bose (pioneer in the field of analog microwave) and the scientists following them have been brought forward in chronological sequence. The response of the world around to and in this development of microwave engineering and the effects of microwave is also discussed.

Introduction

Microwaves are a form of electromagnetic radiation with frequencies ranging from several hundred MHz to several hundred GHz and wavelengths ranging from approximately 1 to 20 centimeters. Because of their high frequencies, microwaves have the advantage of being able to carry more information than ordinary radio waves and are capable of being beamed directly from one point to another.

The research originated with its basics lying in the fundamentals of electricity and magnetism or more preferably in the connection between the two as established by Hans Christian Ørsted (1777-1851). Following this André-Marie Ampère (1775-1836) formulated the law of electromagnetism (Ampère's law) that describes mathematically the magnetic force between two circuits. In 1804 Jean-Baptiste Biot (1774-1862) showed that the terrestrial magnetic field does not vary appreciably with altitude. In 1815 Augustin-Jean Fresnel (1788-1827) became involved in optics and pioneered in establishing the wave theory of light. Beginning in 1830, Karl Friedrich Gauss (1777-1855) worked closely with Weber (1804-1891). They organized a worldwide system of stations for systematic observations of terrestrial magnetism. The most important result of their work in electromagnetism was the development, by others, of telegraphy. Michael Faraday (1791-1867), Joseph Henry (1799-

1878) Heinrich F.E. Lenz (1804-1865) are three scientists who studied and put forward the concepts of Magnetic induction. Then came in the field the legendary figure, James Clerk Maxwell with the seminal mathematical synthesis [1] of all the previous experimental work on electricity and magnetism. His main predictions were: (i) that waves of electromagnetism should exist and be able to travel in any medium, the hypothetical ether included, (ii) that their speed could be deduced form purely electrical measurements, and, (iii) that given the close aggrement between the speed of light determined in Kohlsrauch and Weber's experiment [2], and the speed predicted for Electromagnetic (EM) waves, light itself was an EM wave. Maxwell's equations predicting the existence of electromagnetic radiation propagating at the speed of light were made public in 1865; in 1888 Hertz had demonstrated generation of electromagnetic waves, and that their properties were similar to those of light [3]. Before the start of the twentieth century, many of the concepts now familiar in microwaves had been developed [4,5]: the list includes the cylindrical parabolic reflector, dielectric lens, microwave absorbers, the cavity radiator, the radiating iris and the pyramidal electromagnetic horn. Round, square and rectangular waveguides were used, with experimental development anticipating for several years Rayleigh's 1896 theoretical solution [6] for waveguide modes. Many microwave components in use were quasi-optical - a term first introduced by Oliver Lodge [7]. He showed that EM waves could be transmitted along wires, but failed to show that they propagate in free space. Righi in 1897 published a treatise on microwave optics [8]. Heinrich Rudolf Hertz (1847-1894) was successful and generated decimeter waves (wavelength of 66 cm); other post-Hertzian pre-1900 experimenters used wavelengths well into the short cm-wave region, with Bose in Calcutta [9,10] and Lebedew in Moscow [11] independently performing experiments at wavelengths as short as 5 and 6 mm. Clearly Lodge's great reputation inspired those who either had his lecture or read his book. These include not only J.C. Bose and Guglielmo Marconi (1874-1937) but also Branly, Zehnder, Popov and even Rutherford. Marconi experimented with 25 cm-waves. In 1897 using a pair of parabolic cylinder reflectors separated by four miles he succeeded in convincing the British Post Office that "wireless" telegraphy was possible.

Reducing the wavelength to 5 mm J.C. Bose came closer than anyone else had to the optical part of the electromagnetic spectrum: he had realized that shorter wavelengths were better for studying the light-like behavior of Hertzian waves. Subsequently, Bose also worked with 1 cm and 2.5 cm radiation extensively. His technical virtuosity was quite remarkable. Microwave generators, detectors, waveguides, horn antennas, lens antennas, mirrors, two-prism directional couplers, polarimeters, spectrometers, dielectrometers, recorders –all the appurtenances of today's research was known to him. He has been called the father of microwave analog optics for very good reason. Today with mobile, satellite and radar communication low frequency bands becoming overcrowded microwaves seem to be the solution.

Jagadis Chandra Bose and his research works: 100 years of MM-wave research

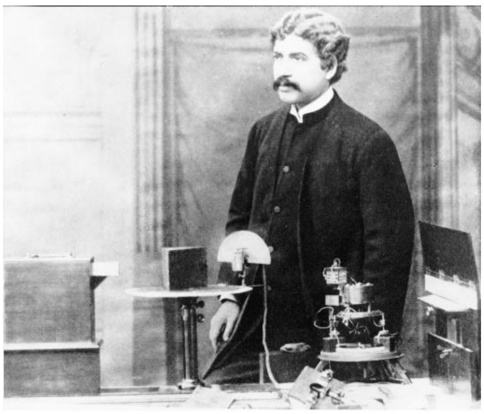

Figure 1: J.C. Bose at the Royal Institution, London, 1897. [12]

In 1954 Pearson and Brattain gave priority to J.C. Bose for the use of a semi-conducting crystal as a detector of radio waves. Sir Neville Mott, Nobel Laureate in 1977 for his own contributions to solid-state electronics, remarked "J.C. Bose was at least 60 years ahead of his time" and "In fact, he had anticipated the existence of P-type and N-type semiconductors". In 1897 Bose reported on his microwave (millimeter-wave) experiments to the Royal Institution and other societies in England [10]. The wavelengths he used ranged from 2.5 cm- 5 mm (12-60 GHz). In his presentation to the Royal Institution in January 1897

Bose speculated [see p.88 of ref.10] on the existence of electromagnetic radiation from the sun, suggesting that either the solar or the terrestrial atmosphere might be responsible for the lack of success so far in detecting such radiation - solar emission was not detected until 1942, and the 1.2 cm atmospheric water vapor absorption line was discovered during experimental radar work in 1944. The following figures show Bose’s apparatus demonstrated at the Royal Institution and the radiator used to generate 5 mm radiation.

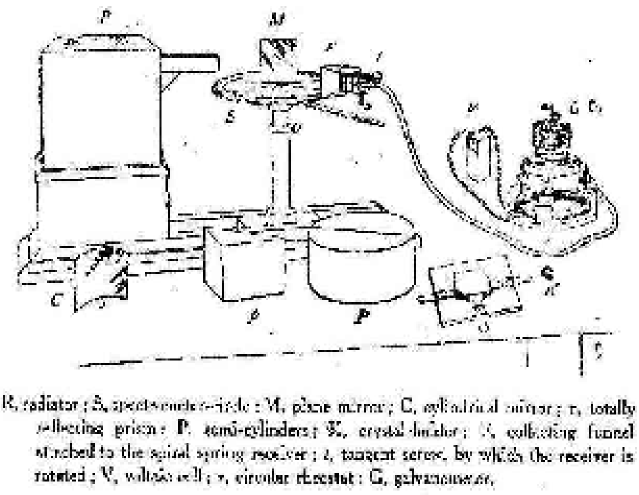

Figure 2: Bose's apparatus demonstrated to the Royal Institution in London in 1897 [10]. Note the waveguide radiator on the transmitter at left, and that the "collecting funnel" (F) is in fact a pyramidal electromagnetic horn antenna, first used by Bose.

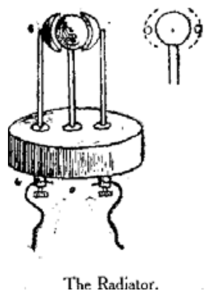

Figure 3: The radiator used by Bose to generate 5 mm waves.

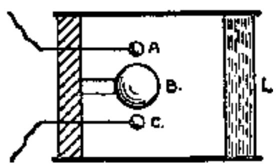

Figure 4: the arrangement with a lens *L* at the exit of the waveguide[13].

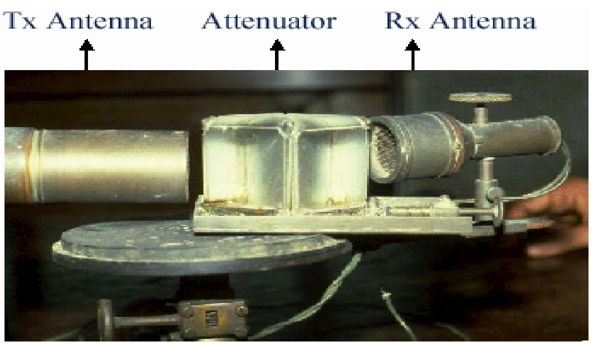

Figure 5:A complete setup showing the transmitting antenna at the left, with the receiving antenna at right. Note the adjustment screw on top of the receiving antenna, which is used to adjust the pressure of the point-contact detector (see Fig. 6). In the center is a rotating table (the "spectrometer circle" of Figure 2) on which various microwave components (prisms, lenses, grids, polarizers etc.) may be mounted for study. A dual-prism attenuator (see below) is shown in this photograph.

In dealing with short-wavelength detectors Bose experimented with the spiral-spring receiver, which has been described recently [14] as a “space-irradiated multi-contact semiconductor (using the natural oxide of the springs),”

Figure 6: Two of Bose's point contact detectors, removed from the receiving antennas.

Figure 7: A polarizer used by Bose consisted of a book (Bradshaw's Railway Timetable) with sheets of tinfoil interleaved in the pages.

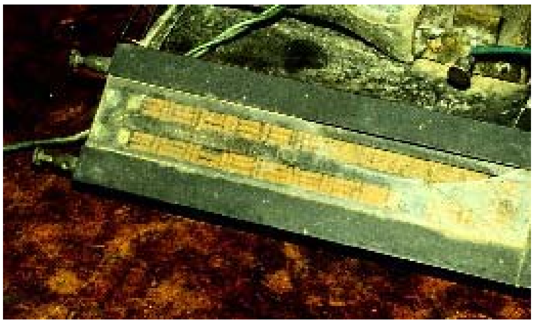

Figure 8: One of Bose's free-space radiation receivers. The springs are kept in place in their tray by a sheet of glass, seen to be partly broken in this photograph.

While the Eastern India, through the hands of Bose, was busy in transmitting the micro and millimeter-waves, the world was also engaged in trying to transmit radio waves. Marconi and Tesla's contribution in this field brought **Wireless telegraphy** and showed the signs of birth of a new system later recognized as **RADAR**.

Although it appears that Bose's demonstration of remote wireless signalling has priority over Marconi, he was the first to use a semiconductor junction to detect radio waves, and he invented various now commonplace microwave components, outside of India he is rarely given the deserved recognition.

The Nikola Tesla-Guglielmo Marconi case:

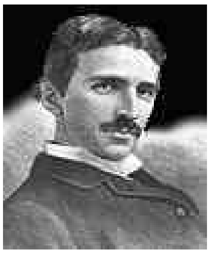

Figure 9:Tesla

Figure 10:Marconi

Despite the fact that almost every book mentions Marconi (1874-1937) as the inventor of radio, the only thing Marconi did seems to be nothing more than reproducing apparition Tesla (1856-1943) had registered years ago.

Few interesting and equally important facts:

1893: Tesla carries his first experiments with high frequency electric currents—the first demonstration of wireless communication. In his articles and lectures Tesla describes his first radio apparatus in detail.

1895: Marconi presents a radio device in London, claiming it as his invention. However, the device is the same as what Tesla had already described in his articles. Later on, Marconi will claim that he had not read Tesla's articles, despite that they were translated in many languages very quickly.

1897: First patent registered by Nikola Tesla on radio communication, Patent No. 645576.

1898: Tesla constructs the first remotely controlled boat and demonstrates it in New York. He registers this invention under Patent No. 613809.

1899: Tesla builds a large radio station in Colorado Springs, USA and starts his experiments.

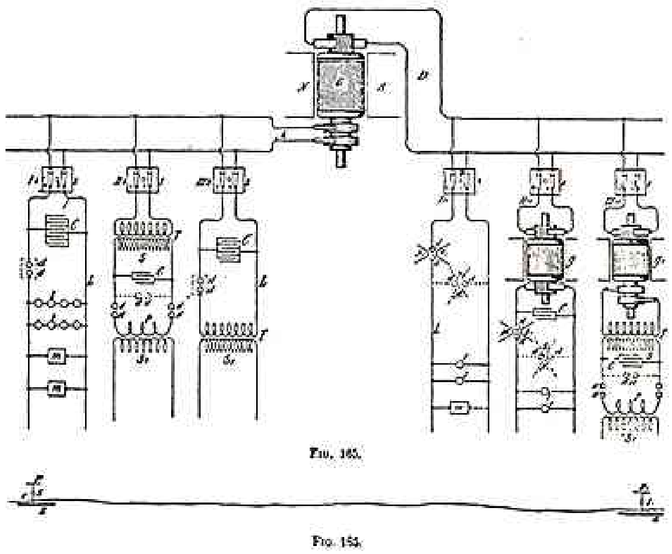

Figure 11: Tesla's drawing published in 1893, showing the first radio communication

1900: Marconi starts selling his radio apparatus. Tesla says he wants to sue him.

1901: Tesla begins the construction of a huge radio station in Wanderclyffe, near New York. This station, Tesla's biggest dream, would transmit electric signals and energy to the whole planet. It was never completed, due to lack of financial means. The same year, Marconi's great triumph was in succeeding to receive signals transmitted across the Atlantic Ocean despite the general opinion that the curvature of the Earth would limit the range of communication by electromagnetic waves. This sensational achievement was the start of the vast development of radio communication and broadcasting. The world was impressed, but did not learn that Marconi was only using Tesla's Patent No. 645576 (1897).

1917: In an article in "Electrical Experimenter" Tesla announces a system to locate metallic objects through radio signal reflection. This is the beginning of the radar.

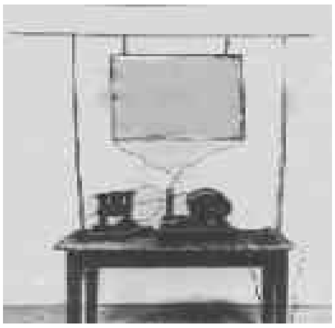

Figure 12a: This was the first transmitter built by Marconi and used by him on his estate in Italy [15].

Figure 12b: In 1907, commercial wireless service across the Atlantic began. The station at Cape Breton, Novia Scotia is shown here on opening day [15].

Despite these confusions about the true inventor of radio, in 1909 Marconi was awarded Nobel Prize for Wireless telegraphy.

A lot was happening in microwaves around the previous turn of the century. **J.A. Fleming**, who had worked with Maxwell, Marconi, and Thomas Edison, invented an "electrical valve", better known today as a **diode tube**.

Figure 13: J.A.Fleming

John Ambrose Fleming also came up with an equation that expressed the impedance characteristics of high frequency transmission lines in terms of measurable effects of electromagnetic waves. He used the Edison effect to rectify a wireless signal so that it could be indicated on a galvanometer. On 16 November 1904 he filed for a patent on what became known as the Fleming valve or Fleming diode. This was the first of the radio tubes, and it was radio that established the electronics industry. Thomas Edison's 1883 discovery of his early lamp showed a tiny anomalous electric current that flowed across a gap from the filament to a metal plate. In 1904, Fleming showed that this effect could be used as a wireless receiver.

Two years later, in 1906, Lee deForest had added a vital element, a wire grid between the filament and plate, besides his invention of an audio tube. But in the usual receiver circuit the tube did no more than detect weak signals.

Edwin Howard Armstrong (1890-1954) [16]

Figure 14: E.H. Armstrong

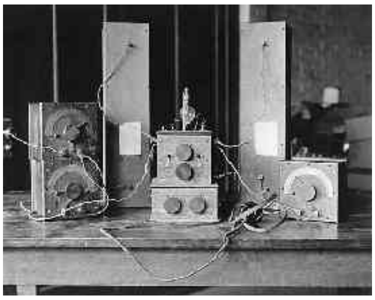

Figure 15: the 1912 feed-back (regenerative) receiver. Donated to the Smithsonian Institution.

E.H. Armstrong, electrical engineer and inventor of three of the basic electronic circuits underlying all modern radio, radar, and television, worked with every new device that came along, among them the so-called audio tube. But none of the instruments were able to amplify weak signals at the receiver, nor yet to provide stronger, more reliable power at the transmitter. In the summer of 1912 Armstrong devised a new regenerative circuit in which part of the current at the plate was fed back to the grid to strengthen incoming signals. Testing this concept in his turret room in Yonkers, he began getting distant stations so loudly that they could be heard without earphones. He later found that when feedback was pushed to a high level the tube produced rapid oscillations acting as a transmitter and putting out electromagnetic waves. Thus this single circuit yielded not only the first radio amplifier but also the key to the continuous-wave transmitter that is still at the heart of all radio operations! By the late 1920's Armstrong had decided that the only solution was to design an entirely new system, in which the carrier-wave frequency would be modulated, while its amplitude was held constant. Undeterred by current opinion, which held that this method was useless for communications, Armstrong in 1933 brought forth a wide-band frequency modulation (FM) system that in field tests gave clear reception through the most violent storms and, as a dividend, offered the highest fidelity sound yet heard in radio. But in the depressed 1930's the major radio industry was in no mood to take on a new system requiring basic changes in both transmitters and receivers. It took him until 1940 to get a permit for the first FM station, erected at his own expense, on the Hudson River Palisades at Alpine, N.J. By the late 1960's, FM was clearly established as the superior system. Nearly 2,000 FM stations spread across the United States, a majority of all radio sets sold are FM, **all microwave relay links are FM**, and FM is the accepted system in all space communications.

In the 1930's, much progress in generating high-power microwaves was achieved by invention of the magnetron and the klystron. Though A. W. Hull invented the magnetron in 1921, the practical and efficient magnetron tube gathered world interest only after Kinjiro Okabe proposed the divided anode-type magnetron in 1928.

It is interesting to note that H. Yagi and S. Uda, who are famous for their invention of Yagi-Uda Antenna, stressed a possibility of power transmission by radio waves in 1926, thereby displaying profound insight into the coming microwave tube era in Japan. The Varian brothers achieved microwave generation by the klystron in 1937 based on the first idea by the Heil brothers in Germany in 1935.

Sir Robert Alexander Watson-Watt, FRS (1892-1973) [17]

His first line of research was in meteorology where he used short-wave radio to detect the location of thunderstorms. By combining this direction finding technique with the ranging capabilities of ionosondes, he designed a system that was capable of detecting aeroplanes. He called this system Radio Detection And Ranging (RADAR). By the autumn of 1938 radar systems were in place along the south coast of Britain and by the Battle of Britain in 1940 were able to detect enemy aircraft at any time of day and in any weather conditions. Watson-Watt became scientific advisor to the Air Ministry in 1940 and in 1941 went to the United States to set up radar systems there. He was elected a Fellow of the Royal Society in 1941 and Knighted in 1942 for his role in the development of radar.

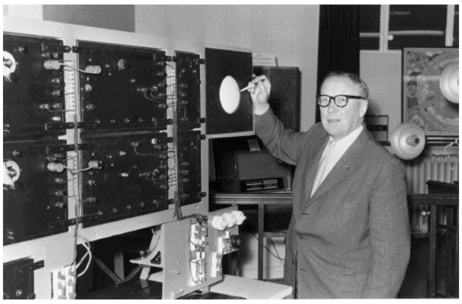

Figure 16: Sir. R. Watson-Watt with the original British Radar Apparatus made at Ditton Park in 1935.

Massachusetts Institute of Technology (MIT) & Dr. Julius Adams Stratton (1901-1994)-- Radiation Laboratory (RadLab):

Figure 17: Dr. J.A. Stratton

During the late 1920s MIT President Emeritus Dr. Stratton's MIT's Round Hill program in South Dartmouth, Massachusetts involved the propagation of short waves in radio transmissions. His studies proved to be the forerunner of later efforts to develop radar. Since airborne microwave radar had not been developed before World War II, the government of England requested assistance from the U.S. National Defense Research Committee (NDRC) to develop this capability. Fourteen months before the U.S. entered World War II, MIT's newly formed Radiation Laboratory began its investigation of microwave electronics.

Projects included physical electronics, microwave physics, electromagnetic properties of matter, and microwave communication principles. The "RadLab" designed almost half of the radar deployed in World War II, created over 100 different radar systems, and constructed $1.5 billion worth of radar. On January 1, 1946, under the sponsorship of the U.S. Office of Scientific Research and Development, RadLab's Basic Research Division continued work at MIT Under the leadership of Director Julius A. Stratton and Associate Director Albert G. Hill, it continued investigation on problems in physical electronics that involved cathodes, electronic emission, and gaseous conduction. In microwave physics, the electromagnetic properties of matter at microwave frequencies were studied. Modern techniques were applied to both physics and engineering research, and in microwave communications, engineering applications were emphasized. On July 1, 1946, the Basic Research Division was finally incorporated in to the new Research Laboratory of Electronics (**RLE**) at MIT.

RadLab's Microwave Traditions at RLE [18]

1940:When the RadLab began. Dr. Lan Jen Chu was a consultant on magnetrons, transmission lines, and wave propagation problems. As a pioneer in highly sophisticated radar antenna systems, he made contributions to modern electromagnetic theory and its applications in microwave beam tubes and antennas. Dr. Chu conceived the "Chu formulation" of electrodynamics and also discovered the small signal power theorem, the forerunner of the small signal energy principles of plasma physics.

1954: then-graduate student Hermann A. Haus worked with Professor Lan Jen Chu on this doctoral thesis, and together they developed a theory of noise fluctuations in microwave tubes. Professor Louis D. Smullin (right) and Professor Hermann A. Haus examine measurements of high-frequency noise in microwave vacuum tubes. At the Rad Lab,

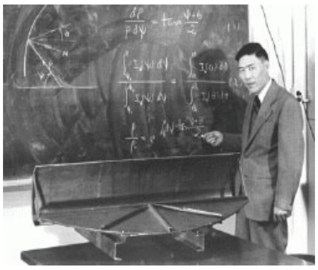

Figure 18: Prof. Lan Jen Chu (RLE file photo)

Figure 19: Hermann A. Haus (left, Photo by John F. Cook)

Figure 20: Prof. Louis D. Smullin (right, Photo by Benjamin Diver)

Professor Smullin supervised the TR and Duplexer section, and the testing of microwave tubes.

The number of systems using microwave has grown rapidly and collectively they form an important section of electronic engineering and physics. This alone may be considered as a justification for studying the history of microwave, but in addition there is an intellectual stimulation to be obtained from this subject which can be explained with mathematical rigour and leads to many useful applications as diverse as satellite communications, air traffic radar, microwave cooking, infrared remote control, laser surgery and audio compact discs. These applications by and large go on to provide the essence of microwave in **social life** of common people besides its importance in the technical field.

Advancement in technical field with its importance in social life:

Laser [19]: Spontaneous emission is proportional to the cube of the transition frequency; it is extremely small in this part of the spectrum and can be neglected compared to other important processes such as stimulated emission and absorption. The first population inversion was achieved in the ammonia molecule, which consists of nitrogen at the apex of a pyramid of three hydrogen atoms. Physical separation was accomplished in the first microwave laser (Townes, *et al.* 1954) by projecting a beam of ammonia molecules through a system of focusing electrodes, which generate a quadrupolar cylindrical electrostatic field in the direction of the beam. After the first successful operation of the microwave laser, Townes, Gordon and some other students came up with the name M.A.S.E.R.: **M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation which brought Nobel Prize to Townes, Basov and Prokhorov in 1964 for their work on both microwave and optical lasers.

Figure 22(a):

Figure 22(b):

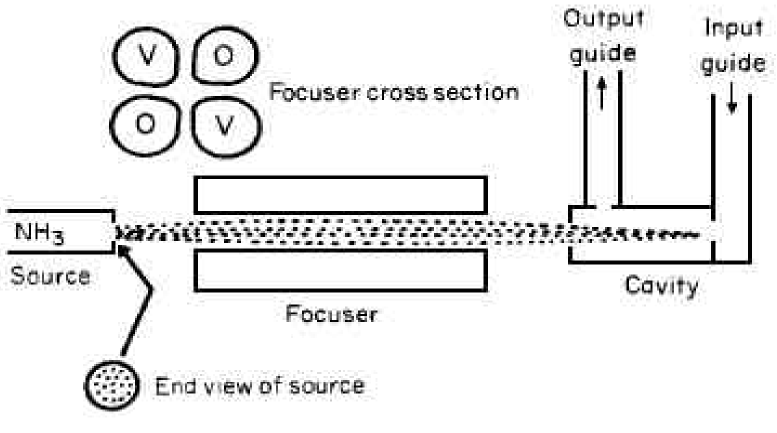

Figure 22(c):

Figure 22: (a) Charles H. Townes, (b) Arthur L. Shawlow, (c) Beam of ammonia passes through an electrostatic focuser to separate out molecules in the upper quantum state. (Townes and Shawlow, 1954).

Communication Systems: Microwaves are used extensively for communication, both in satellite television and for the transmission of long-distance telephone signals besides in radar discussed already. The receivers for microwave signals are usually disc-shaped antennae from a foot to a few feet across and are often seen installed in business locations or near private homes.

Microwave communication products can be broadly divided into three categories:

(1) Point to point connections, (2) Point to multipoint networks, (3) Spread spectrum.

Microwave communication products operate typically in the frequency range of 1-58GHz. Such products have higher bandwidth and can be operated at lower cost than wired communication links. In 1964, William C. Brown, a pioneer of practical microwave power transmission (MPT) was the first who succeeded in demonstrating a microwave-powered helicopter, using 2.45 GHz in the frequency range of 2.4 - 2.5 GHz reserved for the ISM (Industrial, Scientific and Medical) applications of radio waves. Japan carried out several MPT experiments –one is called MINIX (**M**icrowave **I**onosphere **N**onlinear **I**nteraction e**X**periment) rocket experiment (1983; the first microwave energy transmission experiment in the ionosphere in the world) and the other ISY-METS (International **S**pace **Y**ear - **M**icrowave **E**nergy **T**ransmission in **S**pace) rocket experiment (1993). The NASA/DOE concept of the Solar Power Satellite (SPS) that will generate electric power of the order of several hundreds to thousands of megawatts using photovoltaic cells of sizable area, and will transmit the generated power via a microwave beam to the receiving rectenna site was extensively developed in 1977.

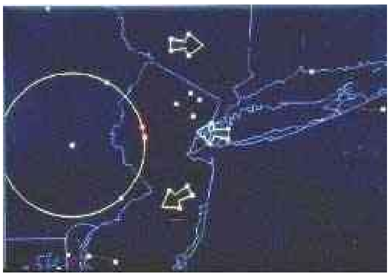
Figure 23: EMSALS in use.

Electromagnetic Simulation Applied to Landing Systems (EMSALS) is a computer simulation tool that has been used to model and analyze the growing problems of frequency congestion and electromagnetic interference at airports in ten metropolitan U.S. areas EMSALS analyzes the proposed installations of Instrument Landing Systems (ILS) and Microwave Landing Systems (MLS) by calculating and evaluating a variety of factors to determine the best frequency assignments for these systems.

Digital Microwave Consulting provides technical expertise on broadband, fixed wireless two-way system designs for high speed internet, cellular and radio architectures, employing 16 or 64 QAM (Quadrature Amplitude Modulation), QPSK (Quadrature Phase-Shift Keying), CDMA (Code Division Multiple Access) Modulations. As the television industry continues its transition from analogue to digital transmission, Microwave Radio Communications (MRC) provides broadcasters with flexibility in implementing digital video transport strategies.. Since the early 1960s, MRC has served television organizations with point-to-point microwave systems for video transport. Applications include studio-to-transmitter links (STLs), electronic-news-gathering (ENG), international outside broadcast operations, inter-city relays, satellite backhauls, and regional networks.

Cosmic Microwave Background: The New Cosmology

The Cosmic Microwave Background (CMB) is a vast curtain of energy left over from the Big Bang; it is the oldest, most distant feature of the observable universe. Since the discovery of the CMB in the mid-1960s, cosmology—the study of the origin and evolution of the universe—has experienced an explosion of activity.

Contribution of Dr. Spencer:

Figure 24: Dr. Percy Spencer with magnetron tube.

In 1929 Dr. Percy Spencer was experimenting on photoelectric vacuum tubes when one developed a small leak. Though many scientists discarded the tube Spencer, curious to know the consequences of the leak, soon discovered that the tube's photoelectric quality had increased ten times. This was a major step in the **development of the modern TV camera-tube.**

Dr. Spencer, during a radar-related research project around 1946 was testing a new vacuum tube called a magnetron when he discovered that a chocolate bar in his pocket had melted. He concluded that these were all attributable to exposure to low-density microwave energy. His experiment with other foods fed with microwave energy eventually invented what was to become the **microwave oven**. Using a microwave to cook food has its nutritional benefits.

Effects on Health:

The world of medicine uses them for sterilization, to retard tumor growth, and to treat sore muscles. However, it has many adverse effects that are now a subject of research in most of the leading nations. It has been a subject of great concern, especially for many heart patients, that stray leakage from microwave ovens could interfere with the proper operation of their cardiac pacemakers. Even common items generating RF interference like electric shavers, auto ignition systems, walkie-talkie radios, fluorescent lights, and dial telephones, diathermy, electro-surgical units, electric bed motors, elevators, personnel pagers, electric heaters and heating pads, etc. cause malfunctioning of pacemakers if they are non-shielded. The problem has been resolved, for the most part, with the development of a new-shielded pacemaker. Since microwaves, or any other type of electronic interference, cannot penetrate their stainless steel casing, the possibility of harm to people who wear these modern heart pacemakers is extremely remote. In an effort to determine the overall susceptibility of these units to electromagnetic interference, U.S. government agencies contacted all known U.S. manufacturers of cardiac pacemakers. Their findings indicate that less than 1% of all pacemakers are sensitive to electronic interference and this number is rapidly decreasing.

Figure 25: Effect on pacemaker.

If the lens of the eye were exposed to excessive heat from microwaves, its circulatory system would be unable to provide sufficient cooling, and can cause cataracts. Also, the stomach, intestines, bladder and testes are especially sensitive to thermal damage from high levels of microwaves. Research also reports a reduction in personnel efficiency, and in the ability to perform certain tasks, and even a possible link to cancer. A 1986 report on microwave oven radiation by, among others, the Food and Drug Administration, has this to say: “There have been allegations of radiation injury from microwave ovens. The injuries known to FDA, however, have been injuries that could have happened with any oven or cooking surface”[20]. Emissions from color TV sets are of the nature of X-rays, which are more serious and penetrating than low-level microwaves. However, modern circuitry improvements, combined with the stringent regulatory control of the Food and Drug Administration (FDA), have brought color TV emission levels to below that of certain natural background radiations. The **power density** of microwaves is determined by measuring the amount of energy that flows through one square centimeter (a square centimeter is about the size of an aspirin tablet) of space in one second. Western scientists believed that serious injuries could result only at levels of 100 Milliwatts per square Centimeter (mw/ cm^2) or higher. While in East European countries and, in particular, Russia, the exposure standards were being determined by a specialized research institute on occupational health. Rather than concentrating on the effects of high-intensity levels, ‘Soviet scientists were focusing their efforts on the lesser-known effects of prolonged or repeated exposure to low levels of microwaves. These effects could be seen at exposure levels at and below $10mw/cm^2$, which is the occupational safety standard in the U.S.

Conclusions:

The history of microwaves presented here has succeeded by a considerable margin in emphasizing its importance in reshaping the technology of the world, with its application to the common mass far reaching. At the very onset, the research works of J.C. Bose as mentioned, fruitfully excavated the local history on the development of microwaves. So, the century old concept of using Electromagnetic phenomenon in our day-to-day life is gradually accomplishing its goal with the growing knowledge and understanding of electromagnetic radiation by common people. As with so many modern conveniences, the benefits must be weighed against the hazards, the risks against the rewards. Sometimes this can be a delicate and a controversial balance. So, while these devices must be used at one's own risk, the application of common sense and caution will certainly minimize the risk factor in this balance. Meanwhile, the controversy and debate, the research continues.

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