be surmounted only called forth in Bose all the endurance and all the effort which are latent in manly natures, welding them to the fullest strength of character and intensity of thought by which alone a great life-task can be accomplished. In contemplating the great career of his fellow countrymen, the young India will be stimulated to put brain and hand to fine tasks, nothing fearing. Thus will he be inspired not only to recover the noble intellectual tradition of the Indian past, but to restate these traditions in modern times and find the greatest challenge for mind and soul in achieving their vital relation with the coming age." [2]

While the above words of wisdom go back almost a hundred years, the advice is still relevant today, and it applies not only to young scientists from India, but to other parts of the world as well.

References

[1] D.L. Sengupta, T. Sarkar, and D. Sen, "Centennial of the Semiconductor Diode Detector," *Proc. IEEE*, vol. 86, no. 1, pp. 235–243 Jan. 1998.

[2] P. Geddes, *The Life and Works of Sir Jagadis C. Bose*. London: Longmans, Green & Co., 1920.

Sir Jagadis Chunder Bose: Traversing the Interdisciplinary Gap Between Physics and Biology

■ Peter H. Siegel

Sir Jagadis Chunder Bose was a prolific and inventive experimental scientist. Born in what is now Bangladesh in 1858, his scientific career spanned more than 30 years and included a degree in natural sciences from Christ College, Cambridge, and a doctorate from the University of London in 1884. He studied under the likes of Lord Rayleigh, Sir James Dewar, and the great naturalist, Francis Balfour. In 1885, under great controversy, Bose assumed a faculty post in physics at Presidency College, Calcutta, India and remained there until his retirement in 1915. In 1917, he founded the institute which still bears his name and stayed technically active well into his 70s. At first, working with his own funds and only a tin smith, he managed to assemble the most sophisticated Hertzian wave apparatus of his day, and in only ten years, his fame had spread throughout Europe. He received a knighthood in 1917; Fellowship in the Royal Society and the Austrian Academy of Sciences (including fellow members: Boltzmann, Doppler, Schrödinger, Lorentz…) in 1920 and 1928, respectively; and, in 1935, two years before his death, served as a founding Fellow of the Indian National Science Academy, India's premier scientific society. Bose is widely recognized as one of India's most influential and accomplished scientists. He earned the companion of the Order of the Indian Empire in 1903 and the companion of the prestigious Order of the Star of India in 1912.

The metal-semiconductor point-contact detector diode is perhaps Bose's most influential invention.

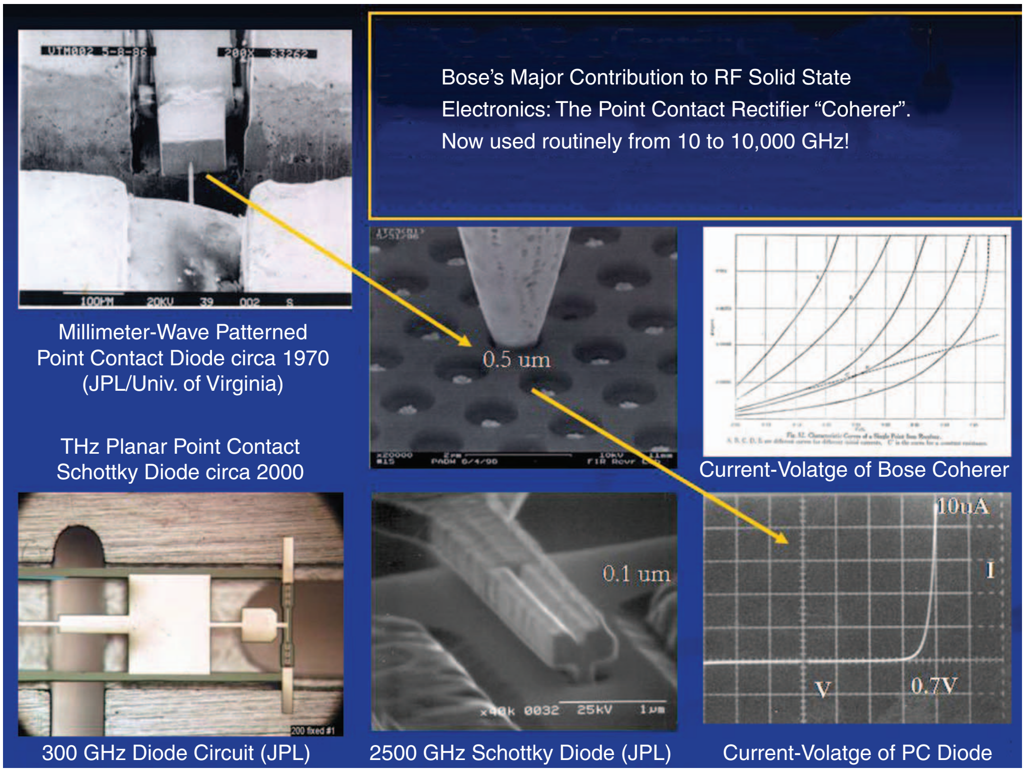
Peter H. Siegel is with the California Institute of Technology (Caltech) and the Jet Propulsion Laboratory (JPL), Pasadena, CA. He is a Fellow of the IEEE.

Digital Object Identifier 10.1109/MMM.2009.932241

Between 1895 and 1928, Bose managed to produce no less than 13 books and approximately 30 technical papers on subjects ranging from the generation, detection, and properties of high-frequency (50 GHz) EM waves to the physiology and behavior of plants. He is now widely regarded as the father of mm waves and credited with the invention or, at least, very early use and optimization of the following:

- point contact diode
- pyramidal feed horn
- the first continuous mm-wave spark gap generators
- polarization filters made from both wire and dielectric grids as well as birefringent crystals
- a method for producing circular polarization
- cavity resonators
- the first mm wave field absorbers
- the first narrow band measurements of the absorption
- scattering properties and index of refraction of solids and liquids at mm wavelengths
- the use of resonant gaps for producing variable transmission attenuators
- the grating spectrometer
- the microwave lens.

Bose also demonstrated the transmission of microwaves through walls and buildings and their detection and use for performing remote signaling at long distances in 1894 in Calcutta, only one year after Tesla showcased much lower frequency transmissions for communications applications in the United States and three years before Marconi's famous wireless demonstration at



Examples of point contact diodes used at terahertz frequencies using Bose's coherer concept.

Salisbury Plane in the United Kingdom. The metal-semiconductor point-contact detector diode is perhaps Bose's most influential invention. It formed the basis for many of his later experiments on the behavior and reaction of materials (metals and insulators) and living organisms to EM radiation. In one of his most interesting monographs, presented at the Royal Institution, London, one Friday evening in May 1901, Bose relays the results of his many experiments on the galvanic response of inorganic matter, plants, and animals to electrical, chemical, mechanical, and EM stimulation. In that discourse, he describes an artificial retina composed of galena inside a metal cavity with a small hole and lens that he says mimics the eye. He calls it a *tejometer*, *tej* being the Sanskrit word for radiation. He then describes how his tejameter responds through an attached galvanometer to EM radiation from the optical through the radio regime. He anticipates and properly uses the term *radiometer* to describe the sensitive detection mechanism. He goes even further by replacing the artificial glass lens with a water lens in an attempt to mimic a real eye and concludes that water absorbs the invisible Hertzian wave energy, exclaiming how lucky we are that the natural eye absorbs this radiation and protects us by "veiling our sense against insufferable radiance" in these "days of space-signaling by Hertzian waves" [1].

Bose was and remains a pioneer, not only in mm waves, but in his personification of the true man of science.

In my own view, one of the most interesting aspects of Bose's chosen career path was his emphasis on cross-disciplinary investigations. Educated in the natural sciences and for most of his early years a practicing applied physicist/engineer, Bose dared to cross the often rigid boundary between the physical and life sciences. Bose's early training in the medical field combined with his long-time fascination with physiology guided him into a prolific number of experiments on animals and plants, especially in their responses to the newly discovered EM waves that had been the basis of his early work. This path was by no means an easy one, nor was it well accepted. In a dramatic incident in which Bose presented some of his many experiments on the galvanic responses of plants and animal tissues to electrical and EM stimulation to an audience at the Royal Institution in London near the turn of the century, he was publicly chastised by the likes of renowned physiologist Sir John Burdon-Sanderson and two Oxford physicists in attendance, who told Bose he should not have abandoned physics for biology. Bose's papers in this area were subsequently held up by the Royal Society, and, eventually, Bose determined that he could best distribute his ideas and experiments on the unifying themes he saw linking the physical and life sciences by publishing his papers in his own books. His work in this area covers more than 2,500 pages and six volumes! He describes his experiences in trying to cross disciplinary boundaries in his dedication speech for the opening of the Bose Institute in 1917.

> "In the pursuit of my investigations I was unconsciously led into the border region of physics and physiology and was amazed to find boundary lines vanishing and points of contact emerge between the realms of the living and non-living. It was with great hope that I announced my results before the Royal Society—results demonstrated by experiments. But the physiologists present advised me, after my address, to confine myself to

physical investigations in which my success had been assured, rather than encroach on their preserve…Thus no conditions could have been more desperate than those that confronted me for the next twelve years … yet it made me stronger in my determination, that I should make the path of those who would follow me less arduous." [2]

Bose's hope for the institute that bore his name was that it would be a place where "the lines of physics, of physiology and of psychology converge and meet and here will assemble those who would seek oneness amidst the manifold." Despite the rhetorical statements to the contrary in every funding agency, there is little doubt that scientists today face similar hurdles when they try to "encroach into fields that have not been their mainstay."

To be fair, many of Bose's explanations for his observed effects due to EM radiation were later proven to be misguided. He maintained that many of the actions observed in conductors and dielectrics exposed to low-level EM fields or electrical currents were mechanical in nature and involved molecular movement due to induced stress and strain. He also believed that low-frequency vibrational motion caused systematic changes in the dc current flow in wires. This explanation led him to conclude that relaxation effects were extremely important, both in metals and other inorganic materials, and later in falsely correlating this observed response in materials with that of responses in living organisms. Bose's overriding interest in biology and medicine (he studied medicine at the University of London for a short time in 1880 before attending Cambridge and later received a doctor of science degree from that institution in 1884) pushed him towards his many controversial papers on the nature and reaction of living organisms (plants) and animal tissues to electrical stimulation, EM radiation, chemical exposure, temperature, and mechanical stress. In these experiments, Bose measured the galvanic response of plants to current pulses, poisons, heat, vibration, high-intensity light, and even mm waves. He developed his own apparatus for holding, isolating, and quantifying electrical responses, including a very unusual and early type of rotating drum recorder that used both pen and ink driven by a galvanometer needle, as well as a photographic recorder that used a mirror to deflect a strong focused light beam from the galvanometer needle onto a moving photographic film. In order to measure the impact of various stimulants on plants, and especially for his many experiments on the rate of plant growth, he developed what he termed a *crescograph* (from the Latin verb crescre, to grow). This mechanical apparatus used a clever series of levers and a clock mechanism to magnify the change in height induced through contact of the plant stem with the mechanism by some 1,000 times and record the change on a moving plate. The idea was to automatically record, more immediately, changes in plant height due to various external stimuli. Bose went on to conclude that the shortest wavelengths of RF energy he could produce, which he successfully measured to be 6 mm (50 GHz), were effective in modifying the growth rate of plants. Experiments were conducted at distances of up to 200 m. Bose found that plant growth rate was retarded whenever strong RF radiation was present but recovered when the radiation was removed. Bose also used the crescograph to examine the affect of visible light, chemical agents, and temperature on plant growth, and he tried to quantify the energy storage associated with photosynthesis. He further tried to correlate the physiological response mechanisms in plants with those of animal tissues, even concluding that variation in the conduction of current in plants is the equivalent of nerve impulse transmission in animals. Although these experiments were extremely difficult and likely fraught with systematic and random errors, they formed the basis for much of the later work on the physiological links between external stimuli and the basic chemical mechanisms that induce response in organic matter. Bose himself wrote, "The intricate mechanism of life can only be elucidated by extension of our power of investigation, often in the realm of the invisible. It is only from facts so obtained that a fully satisfactory theory can be established in regard to the diverse activities of life; it is not improbable that these will some day be ultimately traced to physico-chemical reactions" [3]. I think most engineers and biologists today would concur with J. C. Bose's vision and with his careful experimental approach to the acquisition of knowledge. Indeed, Bose was and remains a pioneer, not only in mm waves, but in his personification of the true man of science.

Bose found that plant growth rate was retarded whenever strong RF radiation was present but recovered when the radiation was removed.

Additional fun facts, quotes, general historic information, and many diagrams of the various apparatus Bose designed and constructed can be found in [4]. For a copy contact the author at *phs@caltech.edu*.

References

[1] J.C. Bose, "Discourse presented at the Royal Institution," May 1901, in *Collected Physical Papers of Sir Jagadis Chunder Bose*. London: Longmans, Green and Co., 1927, pp. 259–276.

[2] J.C. Bose, "Inaugural address in dedication of the Bose Institute, 30 Nov. 1917," in *The Life and Work of Sir Jagadis C. Bose,* P. Geddes, Ed. London: Longmans, c1920, pp. 227–241.

[3] *General Summary from Collected Physical Papers of Sir Jagadis Chunder Bose*, London: Longmans, Green and Co., 1927, pp. 374–397.

[4] P.H. Siegel, "Sir Jagadis Chunder Bose: Traversing the interdisciplinary gap between physics and biology," presented at the opening of the Bose exhibit at the National Electronics Museum, Baltimore, MD, Nov. 2008.