In Memoriam

Tatsuo Itoh

Dr. Tatsuo Itoh passed away on 4 March 2021. He was born 5 May 1940 in Tokyo, Japan. He acquired his professional work ethic at a young age. Waking up well before dawn to help with deliveries in his father's milk business and spending the day in classes, the evening doing tutoring, and much of the time between twilight and dawn on his schoolwork, Itoh had little time for any self-indulgence. One of three brothers growing up in the Yokosuka Naval District, south of Yokohama, Japan, immediately following World War II, Itoh remembered playing with handmade toys, especially wooden trains and paper objects he fashioned himself. His parents had graduated from teachers' colleges and had been schoolteachers before the war, but his father had a difficult time getting steady work in the reconstruction years. Both parents had strong commitments to learning, and they sent him to a Jesuit high school with the best reputation for quality teaching in the district. Itoh's precollege interests included history and gymnastics as well as mathematics and physics. His life goal at the time was to attend the University of Tokyo. To be admitted required passing a very tough entry exam, which he took twice but failed both times. He blamed his failure on a lack of mathematics skills—ironic, considering that his most important contributions to electronics were to be analytic and computational.

Tatsuo Itoh, 1940–2021.

He ended up at Yokohama National University, perhaps fortuitously. Yokohama had no physics department, so Itoh chose *Jakuden* or "light electronics," which translates roughly as "electronics and radio science"—a field that would become his lifelong career. Itoh specialized in radio electronics at Yokohama and recalled a laboratory project to design and build a vacuum-tube power amplifier. He used a novel approach to control a pentode that earned him some notability within the department. As a consequence, his advisor, who had just returned from a visit to the United States, selected Itoh to work on a newly invented laser as part of his senior thesis. Itoh built up the system from scratch.

To his credit, when he finished his thesis in 1964, he had one of the first working lasers in Japan as well as his university degree. While completing his undergraduate work, Itoh was recruited by the Central Research Laboratory of Nippon Electric Company (now, NEC) in Kawasaki, Kanagawa, Japan, where he had interned earlier, characterizing phototransistors. However, instead of entering industry, he and a group of his college friends took an unusual path at the time, in that they all decided to pursue advanced degrees. Yokohama National University had just instituted a master's program, so Itoh stayed in place and again teamed up with his senior thesis advisor, K. Iijima, to work on lasers.

During one of the summer periods, he interned at Olympus Corporation, where he picked up much of his exposure to commercial optics—a field that greatly influenced his later development work. By the spring of 1966, his thesis project completed, Iijima suggested that Itoh continue his academic

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pursuits in the United States. Only one of the approximately 20 universities he applied to there was willing to accept this young Japanese student. It turned out to be the University of Illinois at Urbana-Champaign. Before leaving Japan, Itoh worked through the spring and summer, teaching at Tamagawa University in Tokyo and earned enough money to cover his airfare to the United States. He arrived in the fall of 1966 to what he described as a "rural desert," compared to the bustling environment of Tokyo. Consequently, he settled into his studies with no cultural distractions.

Fortunately, he was fairly fluent in English from his education at the Jesuit school in Japan. He began his Ph.D. research by working on the theory of confocal resonators supervised by Eikichi Yamashita and Raj Mittra.

Adopting an idea from Illinois professor Paul Coleman, Itoh also developed a technique for analyzing gratings with V-shaped grooves (echelette gratings), using physical optics and scattering analysis. This was a time of intense work, with midmorning coffee breaks at 10 p.m., not 10 a.m.! However, Itoh did have time to meet his wife of 51 years, Seiko, in an English class (she was a graduate student in sociology), and they were married in 1969, two days following the awarding of his Ph.D. degree.

After completing his dissertation, Itoh stayed on as a postdoctoral student for another two years before taking up a research appointment at the university. During this period, he began focusing his efforts much more on transmission-line analysis, which he had started during his thesis work. Between 1969 and 1976, Itoh and Mittra produced a prodigious number of highly cited papers and two book chapters. Itoh also completed work on his most highly cited contribution to the microwave field. The approach is extremely general, and, although it was first demonstrated on open microstrip lines, Itoh subsequently extended it to shielded lines and later to generalized transmission lines of all types.

At the University of Illinois, Itoh also became very close with renowned antenna engineer Yuen Tze Lo, who was teaching electromagnetics (E&M). Prof. Lo became a lifelong mentor and a companion with whom Itoh could talk about interests other than E&M, such as classical music and Chinese literature. After several years as a research associate, Itoh was anxious to enter an academic track.

However, the 1970s saw the worst decline in academic employment in decades. Growth in faculty positions had slowed from 10.7% per annum in the 1960s to only 1.3% per annum by the mid-1970s. Itoh actually saw many of his colleagues taking on extra work as taxi drivers. He applied to more than 50 institutions but, despite his impressive publication record, received only one offer—from the Stanford Research Institute (SRI) in Menlo Park, California. He moved there with his wife in 1976 and began work on C-band amplifiers for wireless microwave links. He quickly decided that the environment was not a good fit, and he again sent out applications for academic positions. The University of Kentucky was the first institution to respond positively, and Itoh left SRI in August 1977 for Lexington, Kentucky. Seiko, however, remained in the San Francisco Bay Area. At the University of Kentucky, Itoh continued his prior analytic work and explored new directions. He began what would become an extended period as a cross-country family commuter. However, he was not really happy in Kentucky as he found few colleagues and students with whom he could comfortably team up.

In the meantime, his earlier application to the University of Texas at Austin (UT Austin) had finally made its way to the top, and he was offered an associate professor slot in early 1978. He relocated to Austin in July and there began a meteoric rise to the top of his profession. Itoh's initial work at UT Austin was on millimeter-wave dielectric waveguide circuits, with support from the U.S. Army Research Office. He used a quasi-optical approach and tried to combine analysis with measurements whenever possible. He received devices (impact ionization avalanche transit-time oscillators, discrete transistors, and Gunn diodes) from Fujitsu and other companies and added his own waveguide, antenna, and passive millimeter-wave circuit elements. Using mainly Teflon and quartz, he demonstrated couplers, delay lines, filters, new types of waveguide and leaky-wave antennas, and a whole class of millimeter-wave integrated circuit elements. He also continued working on his spectral-domain transmission-line analysis technique and applied it to many new constructs. His specialization in millimeter waves filled an important niche at Austin. By 1981, he had risen to full professor, and in 1982 he graduated his first Ph.D. student, Yi-Chi Shih [1], [2], who later founded MMCOMM (now part of Honeywell International). Itoh received a chaired position at UT Austin in 1983.

Texas proved to be a very good place for Itoh. The department gave him the freedom to pursue whatever course he thought best, and he had a continuous flow of research funding from the Joint Services Electronics Program (JSEP), an extremely well-endowed, high-quality academic research program available at a select number of universities in the United States. During the period between 1983 and 1990, Itoh worked on a wide variety of microwave and millimeter-wave programs, which laid the groundwork for many techniques later adopted by terahertz designers. He contributed an amazing 48 books and book chapters, 89 journal papers (25 most cited), and 143 conference papers during this period. He also graduated 23 Ph.D. students, many of whom have gone on to prestigious academic careers of their own. Specific results that crossed over to the higher-frequency regime include his work on planar transmission lines, quasi-optical analysis techniques, quasi-optical receiver elements, and antennas.

Dr. Itoh's group at UT Austin typically had 15 students, at least one postdoctoral student, and one or

more visiting scientists. He emphasized practical approaches to problem solving and a combination of analysis and implementation. Appropriately, from 1982 to 1985, he took on the role of editor of *IEEE Transactions on Microwave Theory and Techniques*, to which he would contribute more than 230 articles over the course of his career. He was also president-elect and president of the IEEE Microwave Theory and Techniques Society (MTT-S) from 1989 to 1990 and a participant in literally dozens of university and conference organizing committees. He contributed time to many professional organizations, including the International Union of Radio Science (URSI), especially Commission D (Electronics and Photonics), to which he devoted more than 35 years of service.

In 1991, Dr. Itoh was enticed to leave UT Austin and relocate to the University of California, Los Angeles (UCLA). UCLA was particularly interested in becoming involved in JSEP, and Itoh brought this association with him. There was also a personal motivation, in that Seiko was still living in the Bay Area, and the move to Los Angeles was a big step in the right direction for reducing the family commuting distance. If anything, the move to UCLA increased Itoh's workload, and he practically lived in his office. In a typical story, he readily agreed to meet with a visiting colleague, who was to be in town for only a few days. Itoh told his visitor to meet him at his office at 11 p.m. the next evening. Puzzled, but obliging, the colleague came to UCLA at the prescribed time. Itoh arrived shortly afterward on his way back from the airport after arriving on a long flight from Europe. The two talked for three hours, and then Itoh headed back to the airport for a flight to Asia early the same morning!

Above and beyond all of the writing, teaching, student and staff supervision, and traveling, Itoh also was asked to assume the role of editor-in-chief for a new short-article journal that had been under development within the MTT-S for several years. Martin Schneider (of Bell Laboratories) was instrumental in pushing a new "letters"-style journal to capture the emerging field of submillimeter-wave technology. Schneider originally wanted the name *Microwaves-to-Light* to specifically capture the terahertz regime, but the journal ended up being titled *IEEE Microwave and Guided Wave Letters*. Itoh took over as editor-in-chief in 1990 and shepherded the new journal through its first four years (1991–1994), at which point it was publishing an average of 120 articles per year. Additionally, he was forced to divide his UCLA office in half and install a restricted access area to provide the necessary privacy protections for the submitted material.

At UCLA, Itoh focused on active antennas, influenced by Dave Rutledge's group at the California Institute of Technology. True to form, Itoh also tackled a wide range of other microwave- and millimeter-wave topics, including superconducting circuits and devices, high-speed photodetectors, new transmission-line structures and components, wireless circuits and antennas, and, of course, dozens of analytic methods papers. One design that proved to be extremely useful for high-frequency integrated circuit applications was based on the 1927 Uda technique. Itoh and his group went on to develop transitions, integrated active elements, and fully functional planar arrays. A variation of these antennas was later integrated into the first terahertz monolithic microwave integrated circuits, under a major government terahertz device and circuit development program.

Considering Itoh's mantras of speed and novelty, it is not surprising that he began to take an interest in the emerging field of photonic bandgap (PBG) engineering. Itoh started looking at 2D PBG structures composed of various planar antenna designs, frequency-selective structures, and purely magnetic surfaces. He focused on microwave applications and transmission-line-compatible components. In early 2000, Sheldon Schultz's group at UC San Diego demonstrated the first material with both negative permittivity and negative permeability. The emerging field of metamaterials had become a practical reality.

The emphasis-changing breakthrough for Itoh came in 2001, when officials at the Defense Advanced Research Projects Agency (DARPA) and the U.S. Office of Naval Research (ONR) initiated a Multidisciplinary University Research Initiative program, Scalable and Reconfigurable Metamaterials. The kickoff meeting on 5–6 June 2001 was attended by more than 40 participants from DARPA, the ONR, the university, and industry groups. The principal investigator (PI) was Xiang Zhang at UC Berkeley, with Itoh and other scientists of the highest caliber as co-PIs. Itoh and Christophe Caloz decided to deviate from the prevailing physics approach to metamaterials and develop "an engineering approach," based on a generalized transmission-line theory, with symmetric emphasis on developing practical applications.

They began by investigating these new left-handed materials in traditional waveguide configurations and quickly branched out to microstrip and other transmission-line structures, antennas, 2D components, slabs and prisms, lenses, surface plasmons, and magnetic structures. Besides their well-read text, Itoh and Caloz's most cited work on this subject is their review article [3] appearing in *IEEE Microwave Magazine* in 2004. During this period, when the focus was on left-handed transmission-line structures, Itoh did not falter in his other research areas. He continued to publish book chapters and articles on wireless applications, new types of passive antennas, active antennas, dielectric media, and even microwave engineering education. After 2004, Itoh continued to develop and apply his composite right- and left-handed analysis techniques to a wide variety of problems, including leaky-wave and resonant antennas, transmission-line and waveguide metamaterial components, filters, and other microwave circuits.

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Fellows

Rick Campbell was elevated to IEEE Fellow in 2019.

Awards

Robert Caverly received the Villanova University Faculty Research Award and the Villanova College of Engineering Alumni Teaching Excellence Award in 2020. Frederick Raab received the MTT-S Pioneer Award in 2019 for his work on high-efficiency power amplifiers. Ulrich Rohde received the IEEE Circuits and Systems Society Industrial Pioneer Award in 2019 and the IEEE Region 1 Technological Innovation Award in 2020, "For pioneering research and leadership in signal processing."

Book

- A. Grebennikov, N. O. Sokal, and M. Franco, *Switchmode RF and Microwave Power Amplifiers*, 3rd ed. Burlington, MA: Elsevier, 2020.

Patents

MTT-20 members received a total of three patents on antennas and power amplifiers.

Journal and Conference Papers

MTT-20 members published a total of 46 articles in assorted journals and conference proceedings, including the IMS, European Microwave Week, *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Journal of Microwaves*, and many others.

Professional Activities

Our members are engaged in a number of interesting and important projects. Industrial and academic R&D work (Figure 4) includes an extremely high-intercept and low-noise VHF receiver, an outphasing power amplifier, a power amplifier for wireless power transfer, a wirelessly powered UHF RFID, high-voltage gallium nitride field-effect transistors, the investigation of surface effects in pin diodes, wideband linearization, and tunable filters and matching networks for VHF and up. Our academic members are involved in teaching RF/microwave using HF/VHF/UHF components and techniques and improving online RF/microwave education.

Plans for the Next Period

Our IMS2021 Student Design Competition involves the design of a high-efficiency power amplifier for the 13.56-MHz Industry, Science, Medicine band. This was originally planned for IMS2020, as noted previously, but had to be canceled because of the COVID-19 pandemic.

Our HF/VHF/UHF session returns to the IMS in 2022. We are looking forward to seeing your papers on unique hardware and systems that operate at frequencies below 1 GHz. Topics include power amplifiers, radar, baluns, sensing systems, receivers, long range, RF heating, plasma generation, and so on. We look forward to seeing you in Denver.

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In addition to all of these technical achievements, Itoh was very active in many societies. He was a Life Fellow of IEEE and a member of the Institute of Electronics and Communication Engineers of Japan. He served in many capacities in the MTT-S, such as editor of *IEEE Transactions on Microwave Theory and Techniques* from 1983 through 1985, president of the MTT-S in 1990, and editor-in-chief of *IEEE Microwave and Guided Wave Letters* from 1991 through 1994. Itoh was elected an Honorary Life Member of the MTT-S in 1994. He served on the advisory boards and committees of a number of organizations. He was a Distinguished Microwave Lecturer on Microwave Applications of Metamaterial Structures of the MTT-S in 2004–2006. He was also elected to the National Academy of Engineers in 2003 and to the National Academy of Inventors in 2013.

Most recently, Dr. Itoh had focused his attention on applications of metamaterials to terahertz quantum-cascade lasers, for which he won the 2012 IEEE Transactions on Terahertz Science and Technology Best Paper Award [4]. He continued to apply his considerable analytic skills to solve problems in transmission lines and antennas, left and right, and to project metamaterial application into the future.

Until recently, Itoh was still teaching three classes, attending at least a half-dozen meetings and conferences, and publishing more in one year than most of us will in 10. He suggested that he would have liked to learn to play an instrument or take up a hobby, but he was really hoping for one more hot area to come along to attract his attention. All in all, he graduated 80 Ph.D. students, contributed to or wrote 48 books or book chapters, and contributed to 1,500 research publications. He is survived by his wife, Seiko, his son, Akihiro, his daughter, Eiko, and three grandchildren.

References

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