Terahertz Pioneer: Derek Humphery Martin

"The Mesh That Helped Ensnare the Cosmic Microwave Background"

Peter H. Siegel, *Fellow, IEEE*

DEREK HUMPHERY MARTIN[1] is a soft spoken and unpretentious physicist who chose to spend his professional career on smaller individual research efforts, rather than on large flamboyant projects. However, his instruments and his measurement techniques have crept into almost all of those major programs, and they have enabled some of the THz regime's most outstanding achievements.

Derek was born in the seaside resort town of Eastbourne in East Sussex, on the south coast of England, in 1929. Alec Martin, Derek's father, was a butcher. While Derek was attending middle school, Alec was serving in the U.K.'s homeland medical corps, an ironic act of fate that does not escape without a bit of sardonic comment. One of four children, Derek started out wanting to be an architect. That distinction ended up going to his younger brother, however, and Derek would end up in physics, although his enthusiasm for engineering served him well, and never waivered.

During the war years, the Martin family were all forced to evacuate their home town. Derek was relocated, with his school group, inland to Hertfordshire, north of London. He seemed to have impressed his school teachers with his abilities in math and science, and when he returned to Eastbourne three years later, at age 16, he was locked into studying physics. He recalls an unsteady time in the U.K. schools right after the war, when he had six physics teachers within a two-year period. He confessed that many of these had a poorer understanding of the subject than the pupils they were assigned to teach. By 1947, he had entered college, although his hopes for Cambridge University had been replaced by University of Nottingham, due to his less than comprehensive high school training. Nottingham was not without its notables however, and Leslie F. Bates[2] was then the department

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chair. Derek's doctoral thesis, perhaps unsurprisingly working with Bates [1]–[3], was on ferromagnetic colloidal domains in crystals (specifically Si:Fe [4], [5]). Martin received his Ph.D. degree from Nottingham in 1954.

One of the hot physics topics of the day was superconductivity, and Dr. Martin was excited to get a position as a lecturer at Queen Mary College[3] (QMC), in East London, immediately after completing his degree at Nottingham. One of the QMC notables at the time was Gwyn Owain Jones,[4] Head of the Physics department, who was setting up a growing low temperature solid-state physics group. Jones had put together a large compressor made from a motorcycle engine that was driven in reverse to act as a compressor. Each of the researchers had to provide their own helium liquefier however, to work off the central compressor. Martin's first project was to build a liquefier and a test Dewar for performing his superconducting experiments.

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The author is with the Department of Electrical Engineering, California Institute of Technology, Pasadena, CA 91125 USA (e-mail: phs@caltech.edu).

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[1]I travelled to the rural community of Pershore in Worcestershire, mid-west England, on March 7/8, 2015, to meet Professor Derek Martin at the home of his daughter, Elizabeth Martin Baker, and son-in-law, Adrian Baker. There, on a typically changeable day in early spring, we discussed a career encompassing 40 plus years at Queen Mary College, many old friends and colleagues, and the challenges of doing experimental physics on a limited budget. A more congenial gentleman, and a more welcoming family would be hard to find. Incidentally, Derek would love to hear from old friends and colleagues. He can best be reached through his son, Richard, at: richard.martin@mbda-systems.com, or his daughter, Liz, at: the_hob@icloud.com.

[2]Leslie Fleetwood Bates was a student of Lord Rutherford's and a noted expert in magnetism. He is best known for his classic text (sixth edition published in 1961), *Modern Magnetism*, Cambridge University Press, c. 1939. He passed away January 25, 1978.

[3]Queen Mary College became part of University of London in 1915 and merged with Westfield College, St. Bartholomew's Hospital Medical College and London Hospital Medical College in 1995. It was renamed Queen Mary University of London in 2013 (www.qmuol.ac.uk).

[4]G. O. Jones was a pioneer in low temperature physics and was awarded the Order of the British Empire for his work in 1978. He died in 2006. (http://en.wikipedia.org/wiki/Gwyn_Jones_%28physicist%29).

One can only imagine the configuration of this Rube-Goldberg contraption at QMC, with groups of custom designed and hand-assembled liquefiers splitting off the 2-cycle engine.[5] The helium generation process included working with liquid oxygen and liquid hydrogen as well—a literal rocket engine ready to go off in the lab at any moment! Derek insouciantly repeated an incident wherein he was working on the Dewar platform while his thumb happened to be positioned over the liquefier bellows as it was spewing out liquid air. When he finally looked up and saw that his thumb was completely white, and very numb, his first thought was regret for getting frostbite without even the thrill of skiing. Luckily some chafing on his free hand and some tender loving care of the appendage, left no lasting scars.

Once a supply of liquid helium (admittedly a limited one) was collected (maximum of 100 ml), a variety of superconducting solid-state measurements could be performed. Martin was very interested in long wavelength (millimeter-wave) spectroscopy—a very new field in the late 1950's.[6] He believed that resonances in cold solids and liquids would show up at these wavelengths because of their energy equivalence to kT (4.2 K≅0.36 meV≅87.5 GHz). Probing bulk crystals and cold metallic films (as well as low pressure gases) was an emerging field. Grating spectrometers were in common use – although they were hand scribed (up to 250 lines/inch) and quite course in their resolution (0.15 cm^{-1} or 4.5 GHz typical), but let's not get too far ahead just yet…

RF sources for the spectral measurements generally consisted of very hot black bodies (glow bars) or mercury discharge lamps (hot plasmas), which have quite low energy in the millimeter-wave bands ($<$ 1 part in 10^8 typically). Detector technology at QMC was just as primitive as the liquefier, and the most sensitive far-infrared detectors at the time were Golay cells, which had a detection limit of around 10^{-10} W in 1 s in the 1 mm wavelength range [6]. The Golay cell also had a very slow response (on the order of tenths of a second), making any fine resolution measurements take a very long time. The combination of the low source power and limited detector sensitivity made it impossible to resolve the narrow, and often closely spaced, absorption lines from known rotational states of lightweight gases, especially given the limitations of the grating spectrometer. Both microwave and near-IR spectroscopists had available resolution of 1 part in 10^6 at the time, whereas millimeter and submillimeter-wave spectrometers were limited to approximately 1 part in 100.

In the 1940's, D. H. Andrews and colleagues at The Johns Hopkins University, Baltimore, MD, USA, developed an infrared detector based on the change in resistance of a tantalum wire as it crossed from the superconducting to normal metal state [7]. Despite its potential, applications of the new detector element were limited because of the difficulty of amplifying the signals without adding significant noise. At QMC, Martin and student David Bloor (later Professor at Durham University, U.K.) tried resurrecting Andrews' superconducting *transition-edge* bolometer using evaporated tin on small (2 $\times$ 3 mm), ultrathin (3 μm) mica substrates. They suspended the mica on fine nylon threads (10 μm diameter), and then coated the nylon and the edges of the tin with evaporated lead. The lead is superconducting below 7 K and the tin is operated at its superconducting transition temperature of 3.7 K. Adding a low impedance Wheatstone bridge circuit and cold amplifier, and chopping the signal at 10 Hz, they realized the first functional superconducting transition edge bolometer for spectroscopic use in the far-IR.

With a sensitivity more than 100 times greater than the best Golay cells of the day, and a voltage responsivity above 300 V/W at 1 mm wavelength [6], [8], Martin's cryogenic spectrometer (with many incremental improvements) would be used for a wide variety of gas and solid-phase measurements [9]–[18] over the next several years. Martin himself, was interested in working on superconductors, but other researchers had already taken up many of the fundamental spectroscopic studies on these materials (in particular, American physicist Michael Tinkham at the University of California, Berkeley, USA, and after 1966, at Harvard University, Cambridge, MA, USA). Instead, much of the experimental work at QMC went into studying ferromagnetic materials and vibrational modes in crystal lattices. Despite the early success of the tin/lead superconducting bolometer, they were soon replaced by InSb hot-electron detectors, which had higher reliability, and response times in the MHz region. It would take another 15 years before Paul Richards and John Clarke would improve this faster transition-edge sensor (TES) and make it available for widespread spectroscopy use, and especially for cosmic microwave background applications [19].

1965/1966 was an exciting period for Martin. He crossed the Atlantic and the American frontier to spend time at University of California, Berkeley. In addition to the focus on spectroscopy (Charles Townes came to Berkeley in 1967), there was a very strong emphasis on superconducting devices and applications (Michael Tinkham was still there—he left for Harvard in 1966, and Paul Richards had just come in from Bell Laboratories). Martin was in with excellent company. He had just started a major text on magnetism [20], for which he spent many months in the library,[7] and he edited and released a very popular text on submillimeter waves [21] in 1967. The trip would prove to be successful in a very different way as well. It cemented the bonds between Martin and Paul Richards, who would soon become the spigot from which poured news of the benefits and applications of the Martin–Puplett polarizing interferometer!

Eddie Puplett was a talented, but somewhat overlooked junior workshop technician when he was taken into Derek Martin's research team at QMC. He proved to be an apt tinkerer as well as a capable analyst (Martin helped Puplett eventually achieve an

[5]This and other interesting make-shift parts, including filter grids made from metal coated nylon stockings, and a low thermal path loss mechanical link from a cold mirror to an ambient temperature screw-driven carriage made from the shaft of an arrow, were part of the "do-it-yourself" culture of many university laboratories in the U.K. after World War II, when research funding was scarce (Richard Martin, private communication, February 2015).

[6]Note that Townes and Schawlow's classic text, "*Microwave Spectroscopy*," McGraw Hill (ISBN 10 0-486-1623-1) was published in 1955.

[7]I found out during my interview that this 450+ page text was hand-typed—on 5 carbons—by Martin's beloved wife of 62 years, Joyce, whom Derek met when he was 17, and married when he was 22. Sadly, Joyce passed away in 2013, after an extended illness.

M.Sc. degree in data processing). Fourier transform spectrometers (FTS) for the far-infrared had been in limited use since the days of H. Alastair Gebbie [22], [23] in the early 1960's. By 1964, Paul Richards had substituted a Michelson interferometer for the usual grating spectrometer to significantly improve the resolution [24], [19, p. 343] (left column). Martin was also struggling with the FTS for broadband measurements of crystals. One of the limitations with the Michelson system was the beam splitter, which was generally formed from a single thin dielectric film (typically Mylar) or a lamellar (layered) structure at the center of the beam path. This limited the bandwidth, especially at the longer wavelengths. More critical however, was the fact that the classic Michelson, with a single physical input and single physical output port (2-port), was really a 4-port device. The signal could enter from both the assigned input as well as from the output port. As the mirror for generating the spatial interferogram was translated, it caused modulation of the thermal background coming from the output arm, as well as the desired signal coming from the input, and this tended to mask the desired interferometric response.

Martin cleverly realized that by dividing the signal beam through a series of polarizing elements, rather than employing a single total power beam splitter, he could create an interferometer with 4 fully accessible physical ports. This not only removed the unwanted background modulation (the second signal port could be terminated in a cold load), but also increased the operational bandwidth, especially at the longer wavelengths [25]–[27].

Metallic wire grids had been used as polarizing elements in the microwave regime since the days of Heinrich Hertz [28] and in fact, had been employed in the THz region as early as 1911 [29], [30].[8] As it turned out, Martin was already quite adept at fabricating submillimeter-wave components from items at hand [6], so he and Puplett were able to develop a simple method of forming very large (30 cm) sheets of close spaced parallel metal stripes by scraping (with Emery cloth) the aluminum coating off metallized Mylar sheets while the sheets were stretched around a cylinder and spun on a lathe using a very fine screw-cutting pitch [25, Appendix B]. Later the grids were made lithographically on various millimeter-wave transparent substrates, or were formed with free standing wires by wrapping the wires around a thick open frame, gluing down the wires on the front face, and cutting off the wires laying across the back face [29, p. 120].

The polarizing Michelson interferometer that Martin invented, and that Eddie Puplett helped fabricate and test, was immediately recognized by Paul Richards as an enabling advancement for the spectroscopy measurements he was then heavily involved with at Berkeley [24], as well as the pioneering cosmic microwave background experiments he was beginning to work on [19, p. 343]. According to Martin, Richards was instrumental in spreading the word about the new FTS innovation, and it was Richards who coined the acronym MP interferometer—which can be interpreted as either the Michelson Polarizing interferometer, which Martin preferred, or the Martin-Puplett interferometer, the name that ultimately stuck!

Martin had an opportunity to describe the MP interferometer in great detail in a full book chapter in 1982 [27], which was widely read. By then there were already many variations of the instrument in use, including applications in basic spectroscopy, plasma diagnostics, heterodyne radiometry (local oscillator duplexing), sky temperature measurements, recording optical transfer functions, refractive index measurements, and more. However the application that Martin is most proud of, is the use of the MP interferometer for measurements on the cosmic microwave background (CMB). Richards and his group at Berkeley used the MP instrument as part of their spectrophotometer on their pioneering stratospheric balloon measurements of the CMB black body curve in the late 1970's and 1980's [31]–[34]. Another version of the MP interferometer was then used on the NASA COBE (Cosmic Background Explorer) satellite's FIRAS instrument (Far Infra-Red Absolute Spectrophotometer), launched in November 1989, to record the now very famous near-perfect 2.7K blackbody CMB curve that appeared in 1990 [35], [36]. In consideration of his contribution, Martin received a phone call shortly before 3 o'clock in the morning, on the night before the public announcement of the CMB data by the COBE team.[9] He was given a preview of the first 9 minutes worth of data—which later earned FIRAS Principal Investigator and COBE project scientist, John Mather, the 2006 Nobel Prize in Physics.

While all the excitement over the quest for more complete and accurate CMB measurements was going on, Derek Martin was continuing to develop and employ his new far-IR spectral instrumentation on various compounds [37]–[43]. He also worked on precision blackbody loads [44] and submillimeter-wave sources [45], [46]. He became personally involved in broad bandwidth measurements in the Earth's atmosphere (stratospheric chemistry) when he teamed up with Bruno Carli of the Institute of Applied Physics at the National Research Council, Florence, Italy. Carli was developing and deploying balloon and aircraft instruments for measuring submillimeter-wave spectral line emissions in the stratosphere, mainly for ozone and Earth environmental science applications [47], [48] and he had interest in a space-borne instrument [49], [50]. Carli's precision instrument was a high resolution MP interferometer. Martin also pursued exploratory work on the CMB [51]–[53], and even took a team out to the stratospheric balloon launching facility at Palestine, TX, USA, for a flight using an MP interferometer. Unfortunately, he had to cancel the mission at the eleventh hour due to technical difficulties with the instrumentation [54]. No other major balloon flight or major space experiment opportunity for the UK team ever materialized.

In the late 1970s, Martin started to get very interested in the problems associated with long wavelength optical elements—especially the design of complex beam forming systems that had to perform well outside the limits of geometric optics. He was one of the first to realize that the Gaussian

[8]Henri du Bois and Heinrich Rubens, physicists at University of Berlin, worked from the mid-IR out to 314 μm (954 GHz) on quasi-optical devices, infrared and submillimeter wave transmission and phenomena, and bolometric detectors around the turn of the 20th Century. Both men were originally from The Netherlands.

[9]We know this because Derek afterwards phoned his son Richard, waking him up at 3 AM, with the exciting news!

mode theory published in the 1960s by Kogelnik and Li [55] for laser systems, could be applied to optical systems in the millimeter- and submillimeter-wave regimes. After releasing his paper with James Lesurf [56], which introduced the concept of quasi-optics to the millimeter-wave RF community, Martin started up a short-course which became quite popular for individuals working in the microwave industry. Later, Paul Goldsmith[10] expanded upon, and popularized Martin's methods, in his classic chapter [57] (and later full text [58]) on quasi-optical analysis and applications in the Kenneth J. Button book series, *Infrared and Millimeter Waves*. Coincidentally, Martin's comprehensive article on the MP interferometer [27] appears in the same volume (#6) as Goldsmith's quasi-optics paper.

While still within the university system, Martin became involved with a start-up company, QMC Instruments, to help commercialize and distribute the submillimeter-wave spectrometer and detector technology and the RF components that had been developed and used at Queen Mary College. The early tin/lead transition edge bolometers were not reliable enough for commercial application, and they were replaced by indium antimonide devices in the QMC Instruments product line. QMC Instruments also supplied grids, high efficiency feed horns and other components, to the defense industry, the plasma diagnostics community, especially the Joint European Torus (JET) in Oxfordshire, U.K., and the Princeton Plasma Physics Laboratories in Princeton, NJ, USA. There was also a strong involvement in the astrophysics community, especially detector deployment for cosmic background studies and laboratory spectrometers. Custom deliveries included:[11] “a real-time 6-port polarization analyzer providing all four Stokes parameters with a bandwidth of hundreds of kilohertz (kHz) in W-band, a scale-model radar system for dual-polarized monostatic RCS assessment at convenient laser lines between 300–1500 GHz, interferometers for materials characterization (solid, liquid, and gaseous) between 30 and 1000 GHz, and another large-scale version for the determination of the extinction coefficient of battlefield smoke, again from 30 to 1000 GHz integrated across a 7 m diameter detonation chamber.” One of the more intriguing products was a “bat” detector that used a stretched metallized Mylar film as an ultrasonic detector/microphone and a frequency translation circuit—reminiscent of the Golay cell. This might be the one and only millimeter-wave detector spin-off application in zoology! There were also close collaborations at QMC Instruments with the National Physical Laboratory, mainly through Jim Birch [59], [60], and with Terry Parker, then at Westfield College (now recently retired from University of Essex).

Richard Wylde arrived at Queen Mary College from Cambridge in 1980, and received his Ph.D. degree under Martin in 1985. He worked closely with Martin for the next 15 years, taking over QMC Instruments from the University, and eventually moving it to Cardiff, Wales, U.K., where it continues as a thriving high-tech company supplying a range of THz detector and quasi-optical components and custom instruments [61].

Martin continued to develop quasi-optical analysis and design techniques and detector systems, and applied them to large scale antennas [62]–[64], feed horns [65] and lenses [66], [67], complete optical systems [68], and large arrays [69]. He also worked on absolute power measurements [70], new forms of the MP interferometer [71], [72], and most recently, high frequency circulators and isolators [73], [74].

Throughout his career, Martin focused considerable energy on supporting scientific research at the college, and within the greater U.K. At Queen Mary College, he helped establish a new physics building in the 1960s and spent many years as the Head of Department, and then Dean of the Faculty of Science. He also served as a member and chair of the Astronomy subcommittee of the U.K. Science Research Council (SRC) throughout the 1970s, a post from which he helped advocate for, and ultimately fund, several large U.K. submillimeter-wave radio telescope facilities as well as the U.K. participation in the extremely successful NASA IRAS (infrared astronomy satellite) mission. From 1973 to 1983, Martin was editor of the prestigious bimonthly journal *Advances in Physics* (current impact factor of 18!), and from 1984 to 1994, he served as Honorary general secretary for the U.K.'s Institute of Physics (IOP). He retired from QMC at age 65 in 1994 and became an Honorary Fellow of the College in 1996.

At the conclusion of our discussions, I asked Professor Martin about his frequent brushes with “big science” but his ultimate decision to focus his energies on much more localized projects. He responded (my paraphrasing) that, “Working alone and with low funding is a choice. Sometimes, if you are lucky, you can still have a big impact. The satisfaction comes from developing something which can serve as the means for doing great things—even if those larger achievements are accomplished by others.” I think this is a good place to leave off, and a good message to leave off with. Derek Martin has certainly provided the means for many great achievements in THz.

[10]Paul Goldsmith is a noted radio astronomer, formerly at University of Massachusetts, Amherst, MA, USA, Cornell University, Ithaca, NY, USA, and now NASA Jet Propulsion Laboratory, Pasadena, CA, USA. He was an original founder of Millitech Corporation, the first U.S. company to supply THz components, and we hope to have him in one of our later THz Pioneer series articles.

[11]This information comes as a direct quote from a note I received from Richard Martin, Derek's son, who worked at QMC Instruments from 1982 to 1988.

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Derek Humphery Martin received the B.Sc. and Ph.D. degrees in physics from the University of Nottingham, Nottingham, U.K., in 1950 and 1954, respectively.

He arrived at Queen Mary College (now Queen Mary University of London) in 1954, became a Lecturer in 1958, a Reader in 1963, and a full Professor in 1967. He led the Department of Physics from 1970 until his retirement in 1994, and also served as Dean of the Faculty of Science and a University Senator from 1980 to 1987. He retired as an Emeritus Professor of physics in 1994 and was elected an Honorary Fellow of the College in 1996. His research involvements have included experimental studies of collective excitations in solids, of the Earth's atmosphere and of the cosmic microwave background, and in thermonuclear plasma diagnostics, all using terahertz electromagnetic waves. He is credited with the development of the first superconducting transition edge bolometer for far-infrared use, the Martin-Puplett interferometer, which was an enabling instrument for the measurement of the 2.7 K cosmic microwave background on the NASA Cosmic Background Explorer satellite, and the application of Gaussian mode analysis to long wave optical systems. He currently resides in Pershore, U.K.

Professor Martin was the Editor of *Advances in Physics* from 1973 to 1983 and then served for ten years (1984–1994) as Honorary secretary for the Institute of Physics. He is a Fellow of the Institute of Physics, and the recipient of the 1983 Metrology Award of the U.K. National Physical Laboratory, and the 1992 Kenneth J. Button Prize for his inception of polarization interferometry.