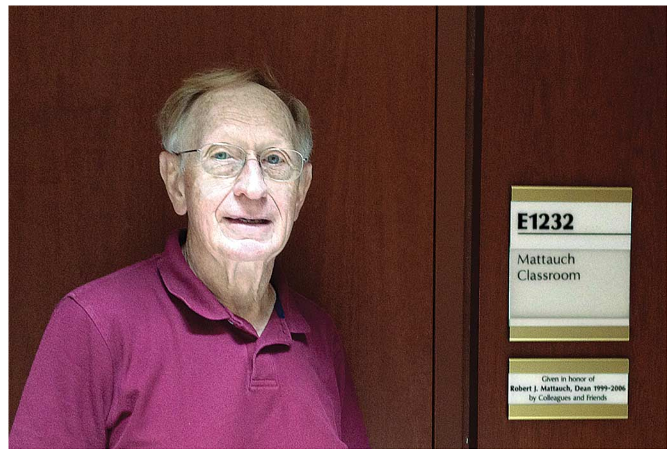
Terahertz Pioneer: Robert J. Mattauch

"Two Terminals Will Suffice"

Peter H. Siegel, *Fellow, IEEE*

ROBERT J. Mattauch[1] did not intend to spend a large part of his technical career on the development of a device as deceptively simple as a Schottky barrier diode.[2] However, that turned out to be case, and it was perhaps one of the best things to ever happen to the THz sensor community. From astronomers and physicists, to spectroscopists and chemists, almost no one who devoted their time towards making precise measurements in the submillimeter wavelength range failed to contact Bob Mattauch at the University of Virginia, Charlottesville, to ask for his latest batch of detector diodes. In fact, those of you who were fortunate enough to be present at the Thursday Plenary session of the 39th International Conference on Infrared, Millimeter, and Terahertz Waves in Tucson, AZ, USA, this past September 18th, 2014, would have heard several appeals, and even an offer of significant money from Berkeley spectroscopist, Richard J. Saykally [4], to anyone who could deliver a batch of University of Virginia whisker contacted THz Schottky barrier diodes to his laboratory!

The western Pennsylvania steel town of Monaca, along the Ohio River, included the family home of Henry Mattauch, a small town barber with a passion for leadership. At 13, Bob, an only child, began apprenticing in the family business, but he hated it. He spent most of his free time with a neighbor, Louis King, a civil engineer for the railroad who loved to tinker. King let Bob work in his basement and garage labs, and taught him calculus and lots about mechanical and electronic engineering (vacuum tubes). Bob recollects one project where he and King constructed an indoor Foucault pendulum that hung down two stories from the attic, through the house and into the basement—much to the chagrin of Mrs. King! So strong was King's influence that, despite his father's hope for carrying on the family business, Bob applied to and got accepted to the Carnegie Institute of Technology (now, Carnegie Mellon University), Pittsburgh, PA, USA, in 1958. At Carnegie, Bob started to get interested in electronics, and specifically in the new and expanding field of solid-state. Arthur G. Milnes[3] ignited Mattauch's interest in semiconductors, and Department Chair, Everard Williams, suggested he continue in the field as a graduate student. He enrolled at North Carolina State University, Raleigh, NC, USA, as a Ford Fellow in 1962.



ROBERT J. MATTAUCH

Mattauch's thesis adviser, R.W. Lade, encouraged his dissertation in semiconductors, and Bob published his first papers [5] (significantly on diodes [6], [7]!) on radiation damage in MOS (metal-oxide-semiconductor) devices between 1965–1967.

Before graduating from NC State in 1966, Mattauch was offered a position at George Westinghouse Research laboratory, near Pittsburgh, Pennsylvania at $17,000/year. However, he really wanted to start up a semiconductor lab of his own, and he wanted to teach. He turned down Westinghouse for an academic appointment at the University of Virginia, Charlottesville (UVa), where he received a salary of $8800/yr and a laboratory start-up package of $4000 (for those of you who might get a bit jealous, this start-up package amounts to only $28,500 in today's dollars—less than the cost of a single semiconductor analyzer!).

Mattauch's childhood tinkering experiences with King, now became a true asset. He had to build practically everything

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[1]The interview that resulted in this article was conducted on a beautiful sunny day at the end of August, at the home of Robert J. Mattauch, just outside the city of Richmond, VA, USA. As we wiled away the time talking about days gone by, and people we knew in common, I remember thinking about my first meeting with this gentle and caring person, who always seemed so willing to help when called upon. Working on devices that enabled circuits, that enabled instruments, that ultimately enabled science progress, always seemed to me to be the most difficult role to have. Bob Mattauch, however, never saw it that way. Thank goodness for that!

[2]The Schottky barrier diode is named after German physicist Walter H. Schottky, who analyzed the metal–vacuum barrier (Schottky–Nordheim) and later the metal-semiconductor rectifier junction, e.g., [1]. An early form of the point contact metal–semiconductor rectifier (based on iron and iron oxide) was independently invented and utilized by Sir Jagadis Chunder Bose and patented in 1904. It was commonly known as the Bose– Coherer [2]. See also [3].

[3]Arthur Milnes was a noted educator and professor at Carnegie with a specialty in semiconductors. His text, with D. L. Feucht, *Heterojunctions and Metal–Semiconductor Junctions* (Academic Press, c. 1972), is one of the most cited in the early days of the field.

he needed from scratch, including his lab space (he was seen tearing down walls and doing framing and sheetrock work every weekend). At the end of his first year at UVa, he took a summer position at NASA's Langley Research Center in Hampton, Virginia where he worked with Chris Gross, now a lifetime friend. Besides access to some state-of-the-art instruments, he managed to stumble onto their surplus equipment hangar. That fall, thanks to a large pick-up truck, the UVa semiconductor research laboratory was born!

Mattauch had to fight upstream to get semiconductors into the electrical engineering department at UVa. At the time it was considered a physics discipline. By reaching out to physics, chemistry, and materials science faculty colleagues (something which he would do successfully again and again throughout his career), he was able to begin to pull in students, and he began working on semiconductor theory and devices [8]–[12].

The breakthrough moment came in 1969, when Sandy Weinreb, then Director of the National Radio Astronomy Observatory's (NRAO) Central Development Laboratory in Charlottesville, VA, USA (now at California Institute of Technology, Pasadena, CA, USA), came over to the lab at UVa's Thornton Hall and asked Mattauch what he knew about GaAs Schottky diodes. NRAO had recently completed the 36-ft diameter millimeter-wave radio dish at Kitt Peak National Observatory in Tucson, AZ. Astronomers were extremely anxious to open up the millimeter-wave spectrum for new star and interstellar molecular line observations, and low-noise receiver technology was extremely limited by a lack of high frequency heterodyne detectors.

A recent advancement by Young and Irvin at Bell Telephone Laboratories. Murray Hill, NJ, USA [13] had opened up the field with the realization of the first photofabricated "honeycomb" diode, wherein the long used, but hopelessly unreliably performing "cat-whisker" point contact was replaced by an array of tiny (low parasitic capacitance) prefabricated metal–semiconductor junctions with well-defined areas and protected epitaxially grown interfaces. Research groups at Bell Telephone Laboratories, Holmdel, NJ, USA [14], Aerospace Corporation, El Segundo, CA, USA[15] and MIT's Lincoln Laboratory [16], amongst others, were trying to take advantage of this new development to produce higher frequency, better performing millimeter-wave sources and detectors (see, for example, [17, Ch. 1]). There was even a short-lived, but very influential millimeter-wave component company, Advanced Technology Corporation (ADTEC), Timonium, MD, USA (started by a group that included Richard J. Bauer, Marvin Cohn, John M. Cotton, John Dozier, and Larry Dickens [18]–[20]), that sold components up to, and sometimes exceeding 100 GHz (mixers, multipliers, detectors, etc.).

Weinreb offered Mattauch a contract from NRAO if he would agree to produce diodes for use by NRAO, especially at Kitt Peak. The contract was a juicy one for Mattauch—$50,000 (more than 10 times his start up package). Mattauch's first move, after reading all the technical papers he could find on high frequency diodes, was a visit to John Cotton at ADTEC to learn everything he could about fabricating GaAs Schottky diodes. As it turned out ADTEC was shutting down and selling off its assets. NRAO swooped in and bought much of ADTEC's fabrication equipment and as much of the component stock as they could get. This included an oxide furnace, metal deposition systems, mask aligner, mounting jigs, wafers, and lots of electronic test equipment. Mattauch drove to Maryland with a flat-bed truck and brought back everything he could get his hands on. He had no clean room space at UVa, so he bought two laminar flow benches that he and his first graduate student, Tom Viola[4], wanted to build into their second floor lab. It turned out they did not fit up the staircase or in the freight elevator and had to be lifted into the lab by removing the windows when no one was looking! He also bought floor tiles, which he and Viola glued down themselves, and vacuum, gas and fluid handling systems which he plumbed in with help from some of his more mechanically inclined students.

After visiting with Cotton at ADTEC, Burrus at Bell, and others, Mattauch was convinced that reproducing a few wafers worth of Schottky honeycomb diodes for NRAO would be a piece of cake. He began with small ($< 1 \times 1$ cm) pieces of the GaAs epitaxial wafers he had gotten from ADTEC. Using the lithography process he had learned from Cotton, he tried making the smallest diameter diodes he could ($\approx$8 micron) with the suggested electroplated gold-on-GaAs contact.

Nothing worked! The Kodak KMER resist wouldn't stick, there were problems with the oxide deposition, the pattern resolution wasn't high enough, the electroplated ohmic contacts peeled away and the gold anodes diffused into the GaAs resulting in "soft" contacts (rounded turn-on knees). Even the humidity in Charlottesville was against him—adversely affecting the lithography. Mattauch sought advice from everyone and anyone he thought could help. At one point, after switching to a Shipley resist recommended by Burrus, Mattauch realized that his exposure lamp wasn't putting out enough UV radiation to properly expose the photoresist films. He "borrowed" one of the new mercury vapor lamp bulbs from the ornamental Jeffersonian-style streetlight outside the engineering building, cut a hole in the surrounding UV absorbing glass casing, and installed it in his home-made mask exposure system. Adding a mechanical shutter, a relay, and a kitchen timer, he completed the setup—which served for several generations of students! Finally after more than a year of effort, he and his students, especially Tom Viola, produced their first working diode in October 1970. It had 8 micron diameter anodes and used one of the last 3 remaining ADTEC epitaxially processed wafers. It proved to be a superior mixer diode in the frequency range below 50 GHz.

Mattauch now had to decrease the anode diameter and improve the current–voltage curve (sharpen up the Schottky turn on knee) in order to increase performance (conversion efficiency and responsivity) and to move up in frequency. He and Viola, replaced the electroplated gold anodes in the ADTEC process with a platinum contact to the GaAs and an overlay of soft gold to contain the spring loaded whisker contact wire. This elimi-

[4]Thomas J. Viola, Jr. was one of Mattauch's first Ph.D. students and was instrumental in helping stabilize a successful diode fabrication process as well as developing a well cited diode noise theory. After leaving UVa, Tom went on to Hewlett Packard. He is now on his second career as a fiction writer. You can find a dedication in his second novel of *The Gumshoe Chronicles 1921* that reads: "To Robert J. Mattauch: my mentor, life-long inspirational guide and friend, who has mastered the art of teaching."

nated the gold migration into the depletion region and greatly improved the diode on-off switching properties. Smaller diameter anodes required a contact whisker with a much smaller tip. He and a valued lab assistant, and lifelong friend, Gordon Green[5] developed a process for pointing and spring loading the micron diameter wires [21]. Mattauch and graduate student, Joe Kamps, also developed a better oxide deposition process and increased the resolution of the photolithography by changing photoresists and customizing the chemistry and exposure processes [22].

Mattauch and Viola then began working on diode theory to try and further improve performance [23], [24]. Sandy Weinreb was testing Mattauch's diodes and was beginning to get some competitive noise results when they were measured against other devices [25]. By 1972, well-known mixer designer and theorist, Tony Kerr [26], [27] had joined Weinreb at the NRAO Central Development Laboratory, and together they began analyzing, testing and trying to optimize Schottky barrier diodes for use as low-noise mixers in radiometer receiver front ends. Weinreb and Kerr's classic results on cooling of mixers to reduce thermal noise [28], had Mattauch's new smaller 5-micron diameter diodes outperforming all competitors at 85 GHz.

Sandy Weinreb now started telling all of his astronomer colleagues about the new devices, and Mattauch began to get visitors from all parts of the globe. Kerr wanted to push higher in frequency—above 100 GHz, and this required both higher resolution (smaller anodes) and new epitaxial material properties. It also required greater care in all steps of the diode fabrication process to eliminate both macroscopic and microscopic defects in the junctions (stress, granularity, doping profile deviations, excess carrier resistance, parasitic capacitance, etc.). The last of the ADTEC wafers were used up, and Mattauch was searching for alternative sources of epitaxially grown GaAs. He tried at least a dozen potential suppliers, eventually settling on Monsanto Electronic Materials Company, St. Charles County, Missouri (now SunEdison, Belmont, CA, USA), which seemed to produce the better devices.

By 1975, the 100 GHz barrier was broken, and Kerr reported record performance for mixers employing Mattauch diodes at W-band (75–110 GHz) [29] and higher frequencies [30]. At this point, with Sandy Weinreb's blessing, Mattauch was distributing diodes to receiver development groups and spectroscopists around the world. Sandy stated to me (of the NRAO support Mattauch had received in 1970), "it was the best $50,000 I ever spent." So many individuals were now asking Mattauch for devices, that when Sandy came by one day to ask for a few more diodes from a particularly favored batch, Bob had to tell him there weren't any left. They had all been given out to colleagues at other observatories. Sandy's priority on the diode distribution list took several steps upwards after this!

My own interactions with Bob Mattauch began in 1976 when I was working on a new open structure mixer concept [31] as a graduate student in Tony Kerr's recently established millimeter-wave receiver lab at the Goddard Institute for Space Studies in NYC, NY. After the planar antenna and metallized quartz-based circuit structures were completed, I was told to take one of the near microscopic specks sitting in a gel pak in the desiccator, solder it down onto a small gold tab on the circuit, and then contact one of the invisible dots on the surface of the "speck" with a near invisible tungsten wire, which in turn had to be moved into position within 2 microns (x, y, and z), by a crude micrometer! After half a dozen "specks" hit the floor before ever getting to the solder tab, Tony calmly let me know that the accumulated diode chips distributed around my lab bench were worth several times my yearly stipend! A broom, a dustpan, and several hours on my knees, and I had retrieved all but one of Mattauch's Schottky diodes. The mixer circuit worked however, so my stipend was saved.

Mattauch and his students continued to improve upon the diode fabrication process [32], [33], as well as making some headway with the theory [34], [35]. Getting high quality epitaxial material was still a big problem and Mattauch tried many sources. In the end he got his best material from later colleague, and longtime friend, Hadis Morkoç,[6] who he had met at Cornell in 1973. Back then Morkoç came to the University of Virginia on frequent trips, and he helped Mattauch set up a liquid phase epitaxy process for the GaAs diodes. Morkoç went on to Varian Associates, Palo Alto, California and then to University of Illinois, Urbana-Champaign, before joining Mattauch at Virginia Commonwealth University in 1997. Wherever he was, he helped Mattauch with his devices by supplying him with high quality epitaxially grown GaAs wafers.

In the late 1970's, both astronomical and spectroscopic receivers employing GaAs Schottky diodes were reaching well into the submillimeter-wave regime [36]–[38]. Other groups were now making and distributing THz diodes [39], [40], notably Gerry Wrixon at University College Cork, Ireland (later the founder and Chairman of Farran Technology, Ballincork and President of the College). However, Mattauch's diodes were being used almost exclusively by everyone working in the millimeter-wave receiver field. An exciting application opportunity opened up in the early 1980's when JPL's Joe Waters, Margaret Frerking, Bill Wilson, and Peter Zimmermann, approached Mattauch and asked him to provide devices for a proposed Earth sounding space instrument to measure chlorine and ozone in the stratosphere, as part of the campaign to understand the root causes and global impact of the ozone depletion that had been triggered and attributed to CFC production [41]. Mattauch's devices—space qualified and all—finally made it into orbit in 1991 with the launch of the Upper Atmospheric Research Satellite Microwave Limb Sounder (UARS-MLS) [42]. They also appeared in Aerojet's 183 GHz heterodyne water vapor receivers on the U.S. Defense Meteorological Satellite Program's (DMSP) Special Sensor Microwave Water Vapor Profiler (SSM/T-2) sounder [43] in the same year [44].

Meanwhile, back on Earth, Schottky diode sources based on harmonic generation through the depletion region non-linear

[5]Gordon Green worked with Bob Mattauch as a lab assistant and microfabrication assembler (and lifelong friend) for all of the time Mattauch ran the lab at UVa. It was Gordon who kept NRAO at bay, by helping to maintain their supply of whisker-contacted components (mixers and multipliers) while Sandy Weinreb waited for new devices to be developed and delivered by Mattauch and his team.

[6]Hadis Morkoç joined Virginia Commonwealth University in 1997, soon after Bob Mattauch's appointment as Dean. He has had a stellar career in materials science and is one of the most cited researchers in the world in this field.

junction capacitance and non-linear forward conductance, were beginning to improve dramatically as new circuits and analysis techniques began to emerge [45]–[47], and [17, Ch. 6]. Mattauch's diodes, with slightly different design parameters, were deployed with equal success to their detector counterparts, as frequency generators. They made their way into frequency doublers and triplers to serve as local oscillator sources for heterodyne systems throughout the radio astronomy and spectroscopy communities. They also started to appear in sideband generators, direct detectors and harmonic mixers.

As the whisker-contacted Schottky diodes began to be widely distributed, and were used more and more in remote (balloon, aircraft, mountain top observatories, in cryostats etc.) and sometimes inaccessible locations (as in space), it was clear that a more robust form of detector was desired. However, despite many attempts, no "potted", "packaged" or "planar" lithographed version of the point-contact diode structure had been proven to be competitive in terms of achievable sensitivity. Mattauch and his students had been thinking about structures that could reproduce the low parasitic point-contact geometry, yet be fabricated in a mass produced lithographic process. In 1985, lab associate Bill Bishop and Mattauch came up with a geometry and a lithography technique that allowed the whisker-contact to be planarized into a free hanging metal air bridge (air on all sides) by using a last step surface channel etching technique to remove the GaAs substrate below the metal contact finger [47], [48]. Graduate student Kathleen McKinney helped with the fabrication. The technique was difficult, but it worked [49]–[52], and it set the framework for all modern high frequency (above 100 GHz) planar Schottky diodes, including those used on the next generation stratospheric ozone sounder [53]–[55] at 240 and 640 GHz, and the devices now routinely fabricated and used in all of the components made by Virginia Diodes, Inc. (VDI).

Tom Crowe, founder and President of Virginia Diodes Inc., Charlottesville, VA, USA, had arrived at Mattauch's lab in the early 1980s, and was completing his thesis on high frequency Schottky diodes by the time the planar diode concept was introduced. Tom's contributions to the Semiconductor Device Lab cannot be understated. He and Mattauch not only contributed significantly to the analysis, design and realization of Schottky diodes that could reach well into the THz regime [56]–[60], but they expanded UVa's fabrication and distribution of devices to literally dozens of research groups around the world. For the first time heterodyne detectors with near ideal noise and loss performance were being realized at frequencies exceeding 2.5 THz [61], [62]. The first all-solid-state heterodyne receiver above 1 THz was realized with UVa devices [63]. The first THz heterodyne receiver in space owes its heritage to the Mattauch lab [64], [65]. As mentioned at the start of this article, there are still research groups who would like to have Mattauch (now VDI) Schottky diodes from this era.

In his last major technical role, Mattauch, and Ph.D. student, Arthur Lichtenberger, joined Tony Kerr (now back at NRAO), noted superconducting device theorist Marc Feldman (then at UVa), mixer designer Shing-Kuo Pan, and others in Charlottesville, to expand the receiver element work to include the new superconducting–insulating–superconducting (SIS) devices [66] that had largely replaced Schottky barrier diode receivers in most astronomical observatories by this time [67]–[71]. The SIS device work that Mattauch started up at UVa, continues to this day, through Lichtenberger, as NRAO focuses on delivering a large number of receivers for the telescopes comprising ALMA [72], [73].

In 1987, Mattauch decided to use his considerable leadership and social skills to try his hand at departmental politics. He took on the role of Chair of Electrical Engineering and immediately began recruiting significant figures to the department. He ended up replacing six tenure track faculty members, and attracting a large number of renowned figures to UVa. The seriousness and fervor with which he took on these activities took a toll on his time that he felt he could not breach. He very graciously and humbly turned over control of the Semiconductor Device Laboratory to his former student, now EE staff member, Tom Crowe. The rest of the story concerning the SDL you likely already know. Tom has very successfully taken the semiconductor device lab that everyone in the THz research community looked to for high frequency diodes, and created a company that has, at least in my opinion, has done as much for the THz community as any other commercial entity.

As for Bob Mattauch, he continued on as department chair at University of Virginia until 1995, and then took up a completely new challenge, as the Chair of a yet-to-be established Electrical Engineering school at Virginia Commonwealth University (VCU) in nearby Richmond, Virginia. In this position he was responsible for building the Electrical Engineering program, defining computer engineering, automation and communication systems, and microelectronics, as areas of specialization. He began hiring faculty members (including Hadis Morkoç), constructing a curriculum, building the necessary program computational, instrumentation, and staff infrastructure, attracting and selecting highly qualified students, designing the electrical engineering and microelectronics clean-room portions of what was to be the new School of Engineering's first building, and enhancing visibility of the program and of the school.

In 1999, Mattauch was appointed Dean of the School of Engineering and in that position he has overseen the graduation of the school's founding class, the approval of the school's graduate program by the State Council on Higher Education of Virginia, the school's first accreditation visit resulting in full accreditation (NGR) for all eligible programs, the approval of a new computer engineering program, the installation of the engineering honor society, Tau Beta Pi, along with the institution of graduate distance education. He also is responsible for raising the funds and seeing the completion of two entirely new engineering buildings which were completed in 2001 and 2007.

When I visited Bob for the interview that comprises this article, I was taken on a tour of the VCU Engineering facilities where we met many former colleagues, and now close friends of Dean Mattauch. However what struck me the most, and what I believe was always the true core of this man's motivation and determination, was his love of teaching, as exemplified by the VCU classroom that bears his name, and which appears in the picture at the beginning of this article. Whenever I had the pleasure of being able to hear a technical talk by Robert J. Mattauch, I always felt I was in a classroom with him [74], hearing, learning, feeling, the outreach that he has always had for students, and the respect he has shown for the profession of "teacher."

Nothing could be a more appropriate tribute to Bob Mattauch than the dedication that Tom Viola has placed in his trilogy of three novels, the Gumshoe Chronicles [75]:

"*To Robert J. Mattauch: my mentor, life-long inspirational guide and friend, who has mastered the art of teaching*".

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Robert J. Mattauch joined the Department of Electrical Engineering of the University of Virginia, Charlottesville, VA, USA, in September of 1966. He immediately founded UVa's Semiconductor Device Laboratory establishing, for the first time in Virginia, a microelectronics program at a university. He and his graduate students began research on millimeter wave semiconductor devices for radio astronomy applications in 1969. In 1971, their work yielded devices which were known internationally to exhibit the highest sensitivity in the millimeter wave range (100 GHz). By 1973, devices resulting from this research were used exclusively in the vast majority of radio telescopes around the world. In 1976, Mattauch and his graduate students began work on devices designed for detection of chlorine monoxide, the compound responsible for the disassociation of ozone molecules, and were a part of the JPL led research team to perform the first bench-mark measurement of the concentration of chlorine monoxide, ClO, in the stratosphere. Semiconductor devices from his research have been used in all NASA measurements of indication of stratospheric ozone layer depletion to the time of this resume. Until 1980, Mattauch was the only faculty member in the semiconductor device area and consequently taught all undergraduate and graduate courses. He supervised a team of as many as eight graduate students, and served as principal investigator on as many as nine research grants/contracts at one time. In his time at UVa, Mattauch served as thesis and technical advisor to over 50 M.S. and Ph.D. students.

Dr. Mattauch served as chairman of the Department of Electrical Engineering at the University of Virginia beginning in 1987. Under his leadership, the Department hired 13 of its 19 tenure/tenure-track faculty members in highly specified research areas in a time of very limited resources. In addition, he guided the Department through a complete restructuring of its undergraduate curriculum which resulted in the awarding of an accreditation rating of 6V, the highest achievable, by the Accreditation Board for Engineering and Technology.

In 1993, Dr. Mattauch took up a position as Chair of Electrical Engineering for a yet-to-be formed school at Virginia Commonwealth University. In 1996 he accepted the official position of Commonwealth Professor and Chair of the newly formed School of Engineering. In this position he was responsible for building the Electrical Engineering Program which included, defining computer engineering, automation and communication systems, and microelectronics as areas of specialization, hiring excellent faculty, constructing a curriculum, building the necessary program computational, instrumentation, and secretarial infrastructure, attracting and selecting highly qualified students, designing the electrical engineering and microelectronics clean-room portions of the new School of Engineering building, and enhancing the visibility of the program and the school.In January 1998, Dr. Mattauch was named Associate Dean for Administration with the charge of mentoring fellow chairs in formation of their respective programs and advising both chairs and the Dean on all faculty and staff hiring.

Dr. Mattauch's career has been one of total devotion to excellence in teaching at all levels. In this context he has interacted with in excess of 7000 students. He has been awarded the Western Electric Fund Award of the American Society of Engineering Education for excellence in teaching of engineering students, the T. Holmes MacDonald Award of Eta Kappa Nu, as an Outstanding Electrical Engineering Educator for 1975, and was elected to the membership grade of Fellow of his professional society, the Institute of Electrical and Electronics Engineers, IEEE, "for contributions to the development of low-noise millimeter-wave diode technology."

Dr. Mattauch's hobbies are swimming, traveling with his wife, playing with his grandchildren, reading (favorite authors are Ferrol Sams, Dick Francis, Garrison Keillor, and Orson Scott Card), and playing bagpipes.