


# Microwave Pioneers: Arye Rosen, “Microwaves in Medicine Was Just my Hobby”

PETER H. SIEGEL <sup>1,2,3</sup> (Life Fellow, IEEE)

(Special Series Paper)

<sup>1</sup>THz Global, La Canada, CA 91011 USA

<sup>2</sup>Department of Electrical Engineering, California Institute of Technology, Pasadena, CA 91125 USA

<sup>3</sup>NASA Jet Propulsion Laboratory, Pasadena, CA 91109 USA (e-mail: phs@caltech.edu)

**ABSTRACT** This is the fourth article in our continuing series of biographical pieces with a technical lean. The subject of this paper is Professor Arye Rosen, who – while employed full time at RCA Sarnoff Research Laboratory as an engineer and working on the side more-or-less as a “hobby” - pioneered the use of microwave angioplasty and ablation techniques in cardiology, and later influenced the use of microwaves in the treatment of benign prostatic hyperplasia (BPH). Dr. Rosen’s life story is as varied and interesting as his career path, and his contributions both to traditional microwave devices as well as microwaves in medicine will definitely inspire those of you who feel like they are pulled in more than one direction professionally. In Dr. Rosen’s case, he did “have it all,” but he worked very hard to make it happen and he took lots of chances ...as you will hear!

**INDEX TERMS** Microwave pioneers, Arye Rosen, microwaves in medicine, balloon catheter hyperthermia.

## I. INTRODUCTION

Perhaps it was the combined influences of his father, Jacob, a power engineer, and his father-in-law, Boris Tamches, who was a very prominent cardiologist in Egypt, and later in Israel, that Arye Rosen<sup>1</sup> was to become one of the few early microwave engineers to recognize, and act upon the application of microwave devices and techniques for medical problems. Arye’s parents left Poland in the early 1930’s to immigrate to Palestine, where they settled into a hard, but very satisfying life in Tel Aviv. Arye was born in 1937, and



like many of his generation who lived through both the excitement and the pain involved in the transitioning of Palestine into the State of Israel in 1948, was extremely loyal to his country, and he envisioned a career and a life that would keep him in the Middle East. He met his wife of 62 years, Daniella – who has an equally remarkable life story - in high school, where his Slavic or perhaps Hungarian features, earned him the somewhat affectionate, but historic nickname “Gingy” – the biblical King David supposedly had red hair. Arye’s dream was to attend one of the two prominent universities in Israel at the time – Hebrew University in Jerusalem (the Technion in Haifa was the other), and both he and Daniella managed to pass the entry exams just before the 1956 Arab-Israeli war broke out. Daniella was sent to the south, near Egypt, and Arye to the north. Typical of his independent nature, when Daniella was given a brief leave by the army for a home visit, Arye managed to sneak out of his barracks for a rendezvous with his girlfriend that lasted only a couple of hours. On returning to his base, where his

<sup>1</sup>This article was compiled after two wonderfully entertaining interviews with Dr. Arye Rosen – he used an iPhone no less, on March 3<sup>rd</sup> and 5<sup>th</sup>, 2021. Normally, the interviews would have been face-to-face, but Covid 19 restrictions forced their conversion into Zoom video conference sessions. Dr. Rosen was in his residence of many years in Cherry Hill, NJ where he could somewhat reasonably commute between Princeton, NJ (RCA David Sarnoff Research Center) and Philadelphia, PA (Jefferson Medical College and Drexel University) – the two cities where he spent most of his professional time. The topics quite naturally shifted from life in the early years following the foundation of the State of Israel, to embassy life in Washington DC, to the mountains of British Columbia and the Borsht Belt in New York’s Catskill region, finally ending up with the split between Princeton and Philadelphia, mimicking the divide between microwave engineering and medicine that were the *opposing* cornerstones of Dr. Rosen’s career. It was a story that kept my interest throughout, and I hope it will do the same for you!

indiscretion was uncovered, he did 35 days of hard labor as restitution – surely a sign of devotion that played a role in later winning him a spouse, but was also a hallmark of his career passion!

When they left the army, Arye's grandmother, who had a brother in Detroit, Michigan, suggested that attending college in the US might open up some desirable career opportunities while Israel was recovering from the recent and extensive conflict. Arye applied to, and was accepted at Wayne State University, and he asked Daniella if she would be willing to come with him to the US for a few years. Daniella had fortuitously been working as a stewardess for El Al (Israeli national airlines) and agreed to go, and even to supply free roundtrip tickets, if they went as a married couple – a situation which was eagerly fulfilled with consent of all parties. However, Daniella, with a specialty in languages, landed a really good position at the Israeli embassy in Washington, DC – a long way from Detroit. Taking some sound advice from the Israeli ambassador Leslie Avraham Harman<sup>2</sup>, Arye transferred from Wayne State, and in 1959 enrolled instead in nearby Howard University, on 6<sup>th</sup> Street NW in Washington DC. Howard was home to the progeny of many prominent international leaders as well as several diplomats from the Israeli embassy, and Arye felt very privileged to be there. He recalled with great fondness his first academic mentor, mathematician Elbert Cox<sup>3</sup>, who helped guide him into engineering. However, perhaps his most memorable moments in Washington, *exclusive of the embassy parties Daniella got him into*, were a trip to the White House to meet US President John F. Kennedy (*a photo from that historic occasion still hangs in his home*), and attending the famous “*I have a Dream*,” speech of civil rights leader, Reverend Martin Luther King Jr., at the Lincoln Memorial in 1963.

After graduating with an EE degree from Howard in 1963, the plan was *to use the return ticket Daniella had secured in 1959 (just joking, voc. Ed.)*, to go back to Israel and find permanent work. One of Arye's embassy contacts – where he was moonlighting in the Scientific Counselor's Office during his undergraduate years, offered him an engineering training position at General Telephone and Electric (GTE) in Chicago, which was planning to open a branch in Israel. After allowing him to complete a Master's of Science in Engineering degree at Johns Hopkins University, Baltimore, MD in 1966, for work on “Applications of the Circular Waveguide in High Quality Communications Systems” [3], GTE sent the Rosen's to Vancouver, British Columbia, Canada, where Arye worked on microwave switching and communications systems, and managed to add a professional engineering degree to his resume. In the meantime, the planned GTE branch in Israel fell through, and Arye found himself stuck in Canada. He decided to work his way back east where at least he would be a little closer to the Mediterranean! He took a job in NY State's

<sup>2</sup>Harman was the Israeli ambassador to the United States from 1959-1968 and afterwards (through 1983) became the President of the Hebrew University.

<sup>3</sup>Elbert Frank Cox was the first African American, in fact the first black person in the world, to receive the PhD in mathematics, which he worked on under William Lloyd Garrison Williams at Cornell University and received in 1925 [2]. He taught at Howard University from 1929-1965 and was head of the mathematics department from 1957-1961, while Arye Rosen was enrolled.

Catskill region at Channel Master Corporation in Ellenville, NY, where he worked for a brief time on TV roof antennas. A short stint at American Electronics Laboratories, Lansdale, PA (he had a rough time getting a security clearance and chose not to stay for a permanent position), led to a contact at RCA Laboratories in Princeton, NJ where Rosen travelled for a talk and interview in 1967. His MS work on circular waveguides landed him a job offer, and he happily moved to Philadelphia, Pennsylvania, with Daniella and the first of his two children in tow, to begin his long EE career in microwave devices.

At RCA, Arye began working on multiplier [4], [5] and oscillator [6], [7] devices and circuits [8], specifically new high performance TRAPATT (trapped plasma avalanche triggered transit) mode diodes, diode arrays, and amplifiers [9], [10], [11] for which he received a research achievement award at RCA in 1972. The TRAPATT, like the better known IMPATT (impact avalanche transit time), is an avalanche triggered mode that can provide high efficiency, high power and high frequency operation in silicon, germanium and GaAs, and held high promise for microwave power applications in the 1970's [12]. However, it requires careful design including attention to heat dissipation and breakdown considerations. By the late 1970s, Rosen had moved on to PIN diodes and circuits, again for microwave power and switching applications [13] [15].

Here we have to take a step backwards and mention that a couple of years after he arrived at RCA Laboratories, Rosen started becoming interested in possible electronics applications in medicine. His father-in-law (a cardiologist) suggested that Arye might want to study medicine, and a close colleague at RCA, Al Rose (*A. Rose and A. Rosen often mistakenly received each other's mail*), who was a television pioneer, but had just written a book on vision, suggested that Arye satisfy his new found passion for medicine by attending some classes at Jefferson Medical College in Philadelphia (originally part of Thomas Jefferson University). Arye went to his RCA supervisor, Fred Sterzer<sup>4</sup>, for permission to attend some medical classes, but was told in no uncertain terms that this was not allowed. A propos (remember the *passion*), Arye was not deterred, and he applied for and received a scholarship from Jefferson to study cardiology. Although the scholarship was half his regular salary he took a leave of absence from RCA and began medical coursework. Fortunately, Fred was sympathetic and allowed Rosen to continue part time at RCA as a consultant. After more than one year as a full time student, and with substantial medical knowledge now in hand, Rosen returned to RCA and tried to convince management there to think about, and allow some internal research on applications of their RF devices and techniques for the medical community. It was still mostly a “no-go” for RCA, although Fred became interested enough to start working on RF hyperthermia in the mid 1970s and would later leave RCA in 1987 (when it became GE) to form his own medical research company. Meanwhile, Rosen split his time between thinking about medical applications for RF and

<sup>4</sup>Fred Sterzer, a holocaust survivor from Poland, came to RCA labs in the early 1950s and later, ironically, left RCA to form his own company developing RF cancer therapies, partially as a response to his wife's illness. Near his death in 2018, he was touting pulsed heating at low RF frequencies in conjunction with chemotherapy for killing out tumor cells [16].

RF semiconductor devices for RCA. He continued to show up at Jefferson on weekends and whenever he had any spare time, and eventually earned a Master's degree in physiology in 1977 with the thesis, "Echocardiography, a Non-invasive Technique for the Detection of Heart Dysfunction." He earned his first medical patent on measuring blood perfusion using RF heating [18] in 1980 which he passed through RCA, in the hope that they would look more favorably on his pursuing a medical lean for some of his research work.

At Sarnoff, Rosen was primarily working on high power and high frequency oscillators and switches [19], and he became increasingly convinced of the value of using high resistivity silicon, as opposed to GaAs and germanium substrates, especially as the interest and applications for power and switching MMICs (millimeter-wave integrated circuits) increased. In what is considered a prescient and landmark paper in 1981 [20], Rosen and colleagues at RCA outlined their vision and work on silicon-based millimeter-wave circuits. This was followed by later papers [21], [22] that formed a solid basis for much of the groundbreaking developments that led to the revolution in high frequency silicon chips.

In the early 1980s, Rosen hooked up with Drexel University professor Peter Herczfeld, in what would become a long lasting personal and research relationship. The two began collaborating on optically activated PIN diode switching [23]–[26], but Herczfeld's interests in medical applications drew Rosen into Drexel more formally, and in the late 1980's Arye matriculated as a PhD candidate in Herczfeld's group. This time, with two more significant medical patents under his belt, and again assigned to RCA Labs, management agreed to the arrangement. The patents [27], [28], were in collaboration with Jefferson Medical School MD, Paul Walinsky, on what was to become a novel technique combining microwave heating to soften the blood vessel occlusions (amassed plaque) followed by traditional balloon angioplasty for vascular expansion. We will have more on this topic a bit later on.

By this time, the Rosen's had two children<sup>5</sup> and were living in their current house in Cherry Hill, NJ. Arye was now commuting both to RCA labs (now GE) in Princeton and to Drexel in central Philadelphia and colloquially "burning the candle at both ends." However, the medical work was extremely satisfying, and perhaps in anticipation of what was to come at GE, Rosen started up a small company with Daniella in 1989 (AMT Inc. - Advanced Medical Technologies, *as well as an affectionate sobriquet for Arlette "Maman" Tamches, Daniella's mother*) to start taking in medical grants and processing future medical patents. After considerable effort, and well past the normal age, Rosen earned his PhD from Drexel in 1993 with the dissertation, "New therapeutic approaches for the management of cardiac and vascular diseases utilizing microwave energy."

Rosen's work in cardiology, and his ideas about using microwaves to assist in angioplasty procedures and microwave ablation of tissue, took off at this point [29]–[32]. Rosen was even invited to give a keynote address at the 1989 IEEE International Microwave Symposium in Baltimore, MD, where

<sup>5</sup>Harel Rosen, who was to become a neonatologist, and would later work with Arye on several grants and projects, and Gil Rosen, who presently serves as a Special Agent at Defense Criminal Investigative Service (DCIS) [<https://www.linkedin.com/in/gil-rosen-666138181>].

he broadcast live – through a satellite communications link, and discussed a real-time, RF cardiac ablation surgical procedure on a patient at Jefferson Medical School [30]! Many additional patents were issued, this time to AMT (e.g., for a catheter with an associated RF source for irradiating the vascular tissue [33], for variations on the catheters, RF heating elements, and medical procedures [34]–[39], and even for a dental application [40]). In a truly inspired innovation triggered by Daniella's basting of a Thanksgiving turkey, the Rosen's patented [41], and then investigated experimentally on animals [42], a concept for using microwave heating to melt away fat in liposuction procedures that was much gentler than the suction techniques being deployed at the time! Most of the heating and ablation work was undertaken in the FCC ISM (industrial, science and medical) bands at 914 and 2450 MHz (see footnotes 7 and 8 in [43]). Baxter Edwards (the acquisition by Baxter International, of American Edwards in 1985), picked up on the cardiovascular application in 1988, and helped fund the development of the catheters and the accompanying microwave signal generators. These delivered more than 5W CW through silver-clad Teflon-core micro-coax. At the same time Fred Sterzer, now with his own company, MMTc, Inc., Princeton, NJ, started talking to Rosen about employing the balloon microwave angioplasty techniques for prostate disease [44]–[46], and proved that the technique (Benign Prostatic Hyperplasia - BPH) was extremely useful, especially for smaller prostates and also for opening holes up in tumors that could subsequently be injected with chemotherapy solutions. The work on microwave angioplasty and several of the other microwave medical applications that the Rosen's and their colleagues pioneered, was comprehensively summarized in 1995 in a well-received text, "New Frontiers in Medical Device Technology," [47] co-edited by Rosen's son Harel, who himself was now a full-fledged MD specializing in pediatrics and neonatal medicine. A less technical summary was published in IEEE POTENTIALS, MICROWAVES/RF magazine in 1999 [48]. As far as the microwave engineering community was concerned, microwaves in medicine was now a major topic area for the first time, and Rosen, with soon to be long-time colleague and friend André Vander Vorst from Catholic University in Belgium, edited a packed special issue of the IEEE TRANS. ON MICROWAVE THEORY AND TECHNIQUES on the medical applications of microwaves in October 1996 [49].

Back at RCA (now SRI, but still referred to as David Sarnoff Research Center), Rosen continued his mainstream job with the development of high power silicon-based solid-state devices and applications, expanding on the optically controlled PIN diodes [50]–[56], but also other devices, including some of the first MEMS switches operating at millimeter-wavelengths [57]. He also edited, with Sandia National Labs' Fred Zutavern, a book on optical switching in 1995 [58].

By 2002, the Dot Com bubble had burst, and Sarnoff began tightening its belt and laying people off. They also became very aggressive about sweeping up patents and insisted that Rosen turn over all his AMT patents! They argued that his medical work was performed while he was an RCA employee, and therefore the intellectual property could not be separated from the company's. Fred Sterzer (then in his 80s) came to the rescue with an affidavit affirming that he had specifically prevented Arye from working on his medical applications

while at RCA – a notable twist of fate! SRI settled their lawsuits with the Rosen's, but Arye had seen the writing on the wall, and with regrets after 35 years of dedicated service, left Sarnoff to take up a full time academic position at Drexel – he was already an adjunct professor there. Since he had just been elected as a National Academy of Engineering Member, he was given the prestigious title of, Academy Professor of Biomedical and Electrical Engineering in the School of Biomedical Engineering, Science and Health Systems.

At Drexel, Rosen started on a typical university track with teaching duties and graduate student supervision. He already had many connections and deep roots in the RF/medical community by this time, and was fortunate to be able to work directly with his son Harel on neonatal programs, for which he helped start (with NIH support) a non-profit research foundation for pediatrics with Drexel and St. Peter's University Hospital in New Brunswick, New Jersey. He also won (again with his son, Harel) a very competitive Gates Foundation grant to develop and commercialize a clever solar/battery powered blue LED blanket for neonatal jaundice treatment in underdeveloped countries [59], based on an idea he had patented earlier with Daniella through AMT [60].

Just before arriving at Drexel, Rosen got together with André Vander Vorst, and noted RF biomedical pioneer Maria Stuchly, at University of Victoria, British Columbia, to compose a major review article on microwave applications in medicine for the 50<sup>th</sup> Anniversary issue of the Microwave Theory and Techniques Society [61]. This invited, and widely cited manuscript, cemented Rosen's place as one of the very few “go-to” medical cross-over's within the microwave community. Rosen and Vander Vorst followed up the manuscript with a university text in 2006 (with collaborator Youji Kotsuka of Tokai University, Japan) [62], and Arye got together with his son Harel to write an overall review of the field for the newly rechristened *Journal of Infrared, Millimeter, and Terahertz Waves* special “THz for Life” issue in Dec. 2009 [63].

Rosen continued to work on old [64], [65] and new applications [66] for microwave ablation therapies and he especially became involved in neonatal issues, where he was able to spend some time with Harel and students developing RF-based pressure sensors for monitoring children with brain swelling [67], [68] or individuals with traumatic brain injuries [69], [70]. He also pursued – with almost his whole clan - the photodynamic therapy he had worked on with Daniella and Harel [71]. Especially unique is the Rosen, Rosen and Rosen author list [72]!

In 2014, Arye was offered a position at Rowan University in Glassboro, New Jersey as Associate Vice President for Biomedical Research partnerships, with the goal of trying to help bring together researchers and companies to better transition engineering ideas and devices into the medical community. This was a topic he was particularly skilled at! He finally “retired” in 2018, although he continues to consult and participate in research, as well as societal activities with his colleagues, his friends, and his family. He recently helped establish and launch the IEEE JOURNAL OF ELECTROMAGNETICS, RF AND MICROWAVES IN MEDICINE AND BIOLOGY, a lasting tribute to a pioneer in microwave medicine. When I started to become interested in THz applications in medicine back in the mid-2000s, my first consultation was with Arye, who chided, “Of course, when engineers start to get old, medical

research becomes a priority!” I can only say in response, that when Arye Rosen gets old, appreciating his lifelong “hobby” of pioneering applications of microwaves in medicine is a priority.

## SUBJECT BIO

**ARYE ROSEN** (Life Fellow, IEEE) received the B.S. degree in electrical engineering from Howard University, Washington, DC, while employed at the Embassy of Israel in the Office of the Scientific Counselor. He received the masters of science degree in engineering from Johns Hopkins University, Baltimore, MD, the M.Sc. degree in physiology from Thomas Jefferson University, Philadelphia, PA, and the Ph.D. degree in electrical engineering from Drexel University, Philadelphia, PA. Dr. Rosen was employed at RCA/David Sarnoff Research Center from 1967 to 2003, rising to the highest technical rank of Distinguished Member of Technical Staff, where he was involved in research and development of microwave and millimeter wave/THz devices and circuits, microwave optical interaction, and high power semiconductor lasers.

He has also been engaged in medical research and consulting in the utilization of energies for applications in therapeutic medicine for the past 50 years. Arye Rosen has held an appointment at Drexel University, Philadelphia, PA, as Academy Professor of Biomedical and Electrical Engineering in the School of Biomedical Engineering, Science and Health Systems, and Associate Vice Provost for Strategic Initiatives until June 2014. In October 2014, he was appointed Associate Vice President for Biomedical Research Partnerships, Rowan University, Glassboro, NJ.

Arye Rosen has authored more than 250 technical papers, co-edited two books: *High Power Optically Activated Solid-State Switches* (Norwood, MA: Artech House, 1993), and *New Frontiers in Medical Device Technology* (New York: Wiley, 1995), and co-authored a textbook titled *RF/Microwave Interaction with Biological Tissue* (New York: Wiley, 2006/2007). He holds over 60 U.S. patents in the fields of engineering and medicine. A patent issued in 2019 is assigned to Medtronic Ardian Luxembourg S.A.R.L, titled: “Microwave catheter apparatuses, systems, and methods for renal neuromodulation.”

A Member of the National Academies, National Academy of Engineering (NAE), Dr. Rosen was elected in 2002, “For contributions to microwave and laser technologies and the medical applications of these technologies.” He was involved in the early research of the utilization of ultrasound imaging for the detection and diagnosis of heart dysfunction (echocardiography), the use of Light Emitting Diodes (LEDs)/Lasers for functional Near Infrared (fNIR) Spectroscopy, and photodynamic therapy (PDT) in cancer treatment.

Dr. Rosen is a Life Fellow of IEEE, elected in 1992, “For innovation in semiconductor devices and circuits for use in microwave systems and for microwave applications to medicine,” a Fellow of the American Institute for Medical and Biological Engineering (AIMBE), a Fellow of the National Academy of Inventors (NAI), and a retired Member of the Association of Professional Engineers of the Province of British Columbia, Canada. He served as IEEE Distinguished Microwave Lecturer from 1997 to 2000, during which time he has presented his and others' work in the U.S., Japan, Europe, and the Middle East. He has been a consultant to several medical technology companies worldwide, as well as to investment trust corporations interested in funding innovative biomedical research. He is the recipient of numerous awards, including the IEEE MTT-S Microwave Career Award (May 2010), the IEEE Third Millennium Medal (January 2000) and an IEEE Microwave Application Award (June 2000). He was honored at a Special IMS 2003 Session Honoring Kiyo Tomiyasu, Martin Schneider, and Arye Rosen (*IEEE Microwave Magazine*, March 2004). He was also the recipient of a 1989 IEEE Region One Award, and a 1997 Drexel University College of Engineering, Electrical and Computer Engineering Department Distinguished Alumni Award.

## ACKNOWLEDGMENT

The author would like to thank Dr. Rosen for several very memorable personal meetings and fruitful discussions over the years. Even though we have only met individually a few times, I have treasured these brief and very positive interactions and always left more uplifted and more knowledgeable than when I arrived.

## REFERENCES

- [1] M. Howe, "Avraham Harman is dead at 77; head of university and diplomat," *New York Times*, Sec. D, p. 2, Feb. 25, 1992.
- [2] J. Houston, "Elbert Frank Cox," *Mathematical Association of America Newsletter*, Spring, p. 4, 1995. Accessed: Mar. 13, 2021. [Online]. Available: <https://www.maa.org/programs-and-communities/outreach-initiatives/summa/summa-archival-record/elbert-frank-cox>
- [3] The Johns Hopkins University, "Conferring of degrees at the close of the ninetieth academic year," Commencement booklet, Keyser Triangle, Homewood, p. 10, Jun. 14, 1966. Accessed: Mar. 13, 2021. [Online]. Available: <https://jscholarship.library.jhu.edu/bitstream/handle/1774.2/36802/commencement1966.pdf>
- [4] E. F. Belohoubek, A. Rosen, D. M. Stevenson, and A. Presser, "Hybrid integrated 10-watt CW-broad-band power source at S-band," *IEEE J. Solid State Circuits*, vol. SC-4, no. 6, pp. 360–366, 1969.
- [5] E. F. Belohoubek and A. Rosen. "Coupled microstrip-line varactor doublers," *IEEE Trans. Microw. Theory Techn.*, vol. MTT-17, no. 5, pp. 286–288, 1969.
- [6] J. F. Reynolds *et al.*, "Coupled TEM bar circuit for L-band silicon avalanche oscillators," *IEEE J. Solid State Circuits*, vol. SC-5, no. 6, pp. 346–353, 1970.
- [7] A. Rosen and J. Assour, "Silicon avalanche-diode L-band oscillator," *IEEE Trans. Microw. Theory Techn.*, vol. MTT-18, no. 11, pp. 979–981, 1970.
- [8] A. Rosen, J. J. Thomas, and J. F. Reynolds, "Improved coupled-line microstrip circuit for l and s band oscillators," *Electron. Lett.*, vol. 8, no. 5, pp. 137–137, 1972.
- [9] A. Rosen, J. F. Reynolds, S. G. Liu, and G. E. Theriault, "Wideband class-C TRAPATT amplifiers," *RCA Rev.*, vol. 33, pp. 729–736, 1972.
- [10] A. Rosen, H. Kawamoto, J. Klatskin, and E. L. Allen, Jr., "Integrated TRAPATT diode arrays," *IEEE Trans. Microw. Theory Techn.*, vol. MTT-23, no. 10, pp. 841–843, 1975.
- [11] A. Rosen, P. T. Ho, and J. B. Klatskin, "Fabrication and thermal performance of a novel TRAPATT diode structure," *IEEE Trans. Electron Devices*, vol. 24, no. 2, pp. 159–163, 1977.
- [12] B. C. de Loach, "Modes of avalanche diodes and their associated circuits," *IEEE J. Solid State Circuits*, vol. SC-4, no. 6, pp. 376–384, 1969.
- [13] A. Rosen, R. U. Martinelli, A. Schwarzmann, G. J. Brucker, and G. A. Swartz, "High-power low-loss PIN diodes for phased-array radar," *RCA Rev.*, vol. 40, pp. 22–58, 1978.
- [14] G. J. Brucker, A. Rosen, and A. Schwarzmann, "Neutron damage in PIN diode phase shifters for radar arrays," *IEEE Trans. Nucl. Sci.*, vol. 25, no. 6, pp. 1528–1533, 1978.
- [15] M. Caulton, A. Rosen, P. J. Stabile, and A. Gombar, "PIN diodes for low-frequency high-power switching applications," *IEEE Trans. Microw. Theory Techn.*, vol. 30, no. 6, pp. 875–882, 1982.
- [16] "Fred Sterzer, 1928-2018," *New York Times*, obituary, Dec. 11, 2018.
- [17] F. Sterzer, "Apparatus and method for hyperthermia treatment," U.S. Patent 4,190,053, Assignee RCA Corp, Feb. 26, 1980.
- [18] A. Rosen and W. P. Santamore, "A method for measuring blood perfusion," U.S. Patent 4,228,805, Assignee RCA Corp., Oct. 20, 1980.
- [19] A. Rosen, C. P. Wu, M. Caulton, A. Gombar, and P. Stabile, "Method of fabricating high-Q silicon varactor diodes," *Electron. Lett.*, vol. 17, no. 19, pp. 707–708, 1981.
- [20] A. Rosen *et al.*, "Silicon as a millimeter-wave monolithically integrated substrate - A new look," *RCA Rev.*, vol. 42, pp. 633–660, 1981.
- [21] A. Rosen *et al.*, "Millimeter-wave device technology," *IEEE Trans. Microw. Theory Techn.*, vol. 30, no. 1, pp. 47–55, 1982.
- [22] P. J. Stabile and A. Rosen, "Silicon technology for millimeter-wave monolithic circuits," *RCA Rev.*, vol. 45, no. 4, pp. 587–605, Dec. 1984.
- [23] P. J. Stabile, A. Rosen, and P. R. Herczfeld, "Optically controlled lateral PIN diodes and microwave control circuits," *RCA Rev.*, vol. 47, pp. 443–456, 1986.
- [24] A. Rosen, P. J. Stabile, A. M. Gombar, W. M. Janton, A. Bahasadri, and P. Herczfeld, "100 kW DC biased, all semiconductor switch using Si PIN diodes and AlGaAs 2-D laser arrays," *IEEE Photon. Techn. Lett.*, vol. 1, no. 6, pp. 132–134, 1989.
- [25] A. Rosen *et al.*, "Laser-activated pin diode switch for RF application," *IEEE Trans. Microw. Theory Techn.*, vol. 37, no. 8, pp. 1255–1257, 1989.
- [26] A. Rosen *et al.*, "Optically achieved pin diode switch utilizing a two-dimensional laser array at 808 nm as an optical source," *IEEE Trans. Electron Devices*, vol. 36, no. 2, pp. 367–374, 1989.
- [27] P. Walinsky, A. Rosen, and A. J. Greenspon, "Method and apparatus for high frequency catheter ablation," U.S. Patent 4,641,649, Assignee RCA Labs, Feb. 1987.
- [28] A. Rosen and P. Walinsky, "Percutaneous transluminal microwave catheter angioplasty," U.S. Patent 4,643,186, Assignee RCA Labs, Feb. 1987.
- [29] A. Rosen *et al.*, "Microwave balloon angioplasty," in *Proc. 19th Eur. Microw. Conf.*, 1989, pp. 913–917.
- [30] A. Rosen *et al.*, "Percutaneous transluminal microwave balloon angioplasty," *IEEE Trans. Microw. Theory Techn.*, vol. 38, no. 1, pp. 90–93, 1990.
- [31] A. Rosen *et al.*, "Treatment of intracoronary thrombus with microwave thermal balloon angioplasty," in *IEEE MTT-S Microw. Symp. Dig.*, 1992, pp. 1261–1262.
- [32] R. M. Rosenbaum, A. J. Greenspon, S. Hsu, P. Walinsky, and A. Rosen, "RF and microwave ablation for the treatment of ventricular tachycardia," in *IEEE MTT-S Int. Microw. Symp. Dig.*, 1993, pp. 1155–1158.
- [33] A. Rosen, "Catheter with distally located integrated circuit radiation generator," U.S. Patent 4,998,932, 1991.
- [34] A. Rosen and P. Walinsky, "Microwave aided balloon angioplasty with lumen measurement," U.S. Patent 5,129,396, 1992.
- [35] A. Rosen and P. Walinsky, "Microwave aided balloon angioplasty with guide filament," U.S. Patent 5,150,717, 1992.
- [36] R. M. Rosenbaum, A. J. Greenspon, S. Hsu, P. Walinsky, and A. Rosen, "RF and microwave ablation for the treatment of ventricular tachycardia," in *IEEE MTT-S Int. Microw. Symp. Dig.*, 1993, pp. 1155–1158.
- [37] A. Rosen, S. D. Edwards, R. G. Lax, H. R. Sharkey, and I. H. Lundquist, "Medical probe apparatus with laser and/or microwave monolithic integrated circuit probe," U.S. Patent 5,556,377, 1996.
- [38] P. Walinsky, A. J. Greenspon, and A. Rosen, "Cardiac ablation catheter arrangement with movable guidewire," U.S. Patent 5,716,389, 1998.
- [39] A. Rosen, S. D. Edwards, R. G. Lax, H. R. Sharkey, I. H. Lundquist, and P. Walinsky, "Medical probe apparatus with enhanced RF, resistance heating, and microwave ablation capabilities," U.S. Patent 5,720,718, 1998.
- [40] B. H. Stevens, A. Rosen, and K. W. Choi, "Dental instrument with microwave/RF radiation and method of treating a tooth," U.S. Patent 5,421,727, 1995.
- [41] D. Rosen and A. Rosen, "Method and apparatus for microwave aided liposuction," U.S. Patent 5,295,955, 1994.
- [42] A. Rosen, D. Rosen, G. A. Tuma, and L. P. Bucky, "RF/microwave-aided tumescent liposuction," *IEEE Trans. Microw. Theory Techn.*, vol. 48, no. 11, pp. 1879–1884, Nov. 2000.
- [43] P. H. Siegel, "Microwaves are everywhere: 'Ovens: From magnetrons to metamaterials,'" *IEEE J. Microwaves*, vol. 1, no. 2, pp. 523–531, Apr. 2021.
- [44] F. Sterzer, "Cathereters for treating prostate disease," U.S. Patent 5,007,437, Apr. 16, 1991.
- [45] A. Rosen and F. Sterzer, "Applications of microwave heating in medicine," in *IEEE MTT-S Int. Microw. Symp. Dig.*, pp. 1615–1618, 1994.
- [46] F. Sterzer and D. Mawwhinney, "Method employing a tissue-heating balloon catheter to produce a 'biological stent' in an orifice or vessel of a patient's body," U.S. Patent 5,992,419, Nov. 30, 1999.
- [47] A. Rosen, and H. Rosen, *New Frontiers in Medical Device Technology*. New York, NY, USA: Wiley, 1995.
- [48] H. D. Rosen and A. Rosen, "RF/microwaves [medical applications]," *IEEE Potentials*, vol. 18, no. 3, pp. 33–37, 1999.
- [49] A. Rosen and A. Vander Vorst, "Editorial: Introduction to the special issue on medical application and biological effects of RF/microwaves," *IEEE Trans. Microw. Theory Techn.*, vol. 44, no. 10, pp. 1753–1754, Oct. 1996.
- [50] A. Rosen, P. J. Stabile, and W. M. Janton, "Optically activated waveguide type phase shifter and attenuator," U.S. Patent 5,099,214, 1992.
- [51] A. Rosen *et al.*, "Investigation of active antenna arrays at 60 GHz," *IEEE Trans. Microw. Theory Techn.*, vol. 43, no. 9, pp. 2117–2125, 1995.
- [52] T. A. Yost, P. R. Herczfeld, A. Rosen, and S. Singh, "Hybrid transversal filter utilizing MMIC and optical fiber delay lines," *IEEE Microw. Guided Wave Lett.*, vol. 5, no. 9, pp. 287–289, 1995.
- [53] J. Liu, J. K. Butler, G. A. Evans, and A. Rosen, "Analysis of millimeter wave phase shifters coupled to a fixed periodic structure," *IEEE Trans. Microw. Theory Techn.*, vol. 44, no. 8, pp. 1416–1423, 1996.

- [54] W. D. Jemison *et al.*, "Hybrid fiberoptic-millimeter-wave links," *IEEE Microw. Mag.*, vol. 8, no. 1, pp. 44–52, 2000.
- [55] A. Fathy *et al.*, "Silicon based reconfigurable antennas," in *IEEE Int. Microw. Sym. Dig.*, 2001, pp. 377–380.
- [56] A. Fathy *et al.*, "Silicon-based reconfigurable antennas-concepts, analysis, implementation and feasibility," *IEEE Trans. Microw. Theory Techn.*, vol. 51, no. 6, pp. 1650–1661, 2003.
- [57] D. Bechtle, G. C. Taylor, and A. Rosen, "Microelectronic mechanical systems (MEMS) switch and method of fabrication," U.S. Patent 6,535,091, 2003.
- [58] A. Rosen and F. J. Zutavern, *High-Power Optically Activated Solid-State Switches*. Norwood, MA, USA: Artech House, 1994.
- [59] H. Rosen, A. Rosen, D. Rosen, B. Onaral, and M. Hiatt, "Use of a light emitting diode (led) array for bilirubin phototransformation," in *Proc. 27th IEEE Annu. Eng. Med. Biol. Conf.*, 2005, pp. 7266–7268.
- [60] D. Rosen and A. Rosen, "Therapeutic method and internally illuminated garment for the management of disorders treatable by phototherapy," U.S. Patent 6,045,575, Apr. 2000.
- [61] A. Rosen, M. Stuchly, and A. Vander Vorst, "Applications of RF/microwaves in medicine," *IEEE Trans. Microw. Theory Techn.*, vol. 50, no. 3, pp. 963–974, Mar. 2002.
- [62] A. Rosen, A. Vander Vorst, and Y. Kotsuka, *RF/Microwave Interaction with Biological Tissues*. Hoboken, NJ, USA: Wiley, Feb. 2006.
- [63] A. Rosen and H. D. Rosen, "The role of engineering principles in the medical utilization of electromagnetic energies from KHz to visible light-examples," *J. Infrared Millimeter THz Waves*, vol. 30, no. 12, pp. 1374–1386, 2009.
- [64] A. Rosen, A. J. Greenspon, and P. Walinsky, "Microwaves treat heart disease," *IEEE Microw. Mag.*, vol. 8, no. 1, pp. 70–75, 2007.
- [65] H. Rosen, A. Rosen, and P. Walinsky, "Microwave balloon systems in medicine," *IEEE Pulse*, vol. 1, no. 2, pp. 8–15, 2010.
- [66] G. Palma *et al.*, "Treatment of solid malignant tumors with microwave balloon ablation catheters and localized chemotherapy," *PIERS Online*, vol. 3, no. 6, pp. 924–926, 2007.
- [67] U. Kawoos, M. R. Tofighi, R. Warty, F. A. Kralick, and A. Rosen, "In-vitro and in-vivo trans-scalp evaluation of an intracranial pressure implant at 2.4 GHz," *IEEE Trans. Microw. Theory Techn.*, vol. 56, no. 10, pp. 2356–2365, 2008.
- [68] R. Warty, M. R. Tofighi, U. Kawoos, and A. Rosen, "Characterization of implantable antennas for intracranial pressure monitoring: Reflection by and transmission through a scalp phantom," *IEEE Trans. Microw. Theory Techn.*, vol. 56, no. 10, pp. 2366–2376, 2008.
- [69] X. Meng *et al.*, "Dynamic evaluation of a digital wireless intracranial pressure sensor for the assessment of traumatic brain injury in a swine model," *IEEE Trans. Microw. Theory Techn.*, vol. 61, no. 1, pp. 316–325, 2012.
- [70] U. Kawoos, X. Meng, M. R. Tofighi, and A. Rosen, "Too much pressure: Wireless intracranial pressure monitoring and its application in traumatic brain injuries," *IEEE Microw. Mag.*, vol. 16, no. 2, pp. 39–53, 2015.
- [71] G. Happawana, A. Premasiri, and A. Rosen, "Simplified light transport model for irradiation dose calculation of photodynamic therapy," *Int. J. Biomed. Eng. Technol.*, vol. 9, no. 1, pp. 25–44, 2012.
- [72] H. Rosen *et al.*, "Bilirubin phototransformation in vitro using a battery-powered, solar-charged, high-intensity blue light-emitting diode phototherapy blanket," *Int. J. Biomed. Eng. Technol.*, vol. 15, no. 1, pp. 18–28, 2014.