Recollections of Nathan Sokal

Nathan O. (Nat) Sokal is best known for introducing the class-E high-efficiency power amplifier to the RF/microwave community. This article recalls a bit of his history along with my recollections of interactions with him while developing power amplifiers.

My Work with Nat Sokal

My interactions with Nat Sokal (Figure 1) began in the early 1970s. Both of us were working on high-efficiency RF power amplifiers and found out about each other through literature searches. This led to exchanges of papers, manuscripts, and anything else we could find about power amplifiers—which, in turn, led to our meeting one another and collaborating on a number of papers and projects.

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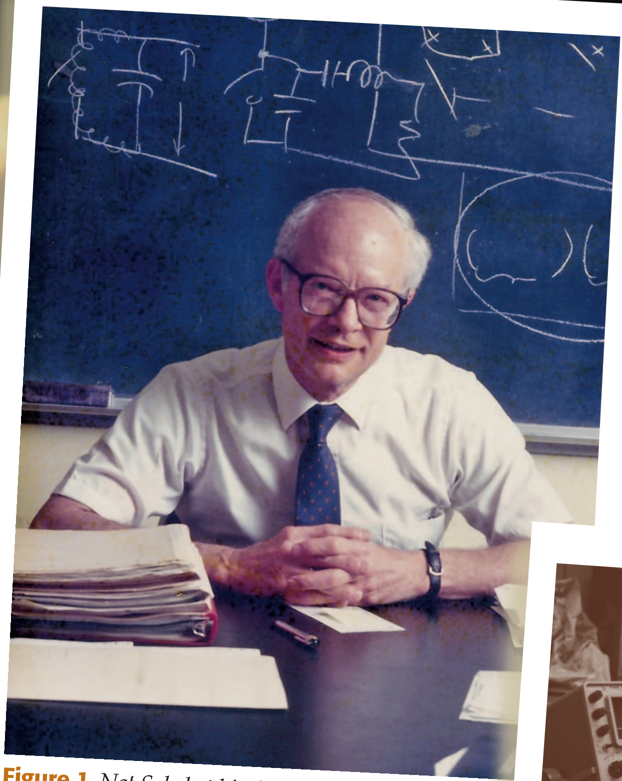

Figure 1. *Nat Sokal at his desk circa 2000. (Photo courtesy of the Sokal family.)*

Figure 2. *Nat Sokal working in the DAI lab circa 1970. (Photo courtesy of the Sokal family.)*

Frederick H. Raab

Early Years

Nat Sokal was born in Brooklyn, New York, in 1929. Five years earlier, his parents and older siblings had emigrated from a small town in Poland (now part of the Ukraine). Nat received his B.S. and M.S. degrees in electrical engineering from the Massachusetts Institute of Technology (MIT) in 1950. During his junior and senior years, he was a co-op student and worked alternate semesters for Philco Corporation (Philadelphia, Pennsylvania) on industrial projects.

Nat's wife, Zelda Kaufman Sokal, was a fellow New Yorker and a student at Radcliffe College when they met. The couple was married in 1952 and had three children: Alan Sokal (now of London, United Kingdom), Karen Sokal-Gutierrez (Piedmont, California), and Diane Sokal (Brookline, Massachusetts).

Career

Nat worked as an electronics engineer for over 60 years. At the start of his career, he helped design equipment for an atomic weapons test site on the Marshall Islands and later served with the U.S. Air Force at the MIT Lincoln Laboratory working on the U.S. air-defense system. This work was very diverse and included radar devices and systems, low-noise amplifiers, control devices, and more and ranged from components to systems to field installations.

In 1965, Nat founded Design Automation, Inc. (DAI), located on Massachusetts Avenue in Lexington, Massachusetts (Figure 2). DAI provided electronics engineering design, consulting, and design review. He sometimes described his work as "emergency fixes" and "solving unsolvable problems." This work was performed for equipment manufacturers, government agencies, and technical consulting attorneys.

Much of that work was related to high-efficiency switching-mode power conversion and power amplification at frequencies from dc to 2.5 GHz. Nat held eight patents in power electronics, including the class-E switching-mode, high-efficiency RF power amplifier. He was the author or coauthor of two books and more than 100 technical papers, mostly on high-efficiency generation of RF and dc power.

High-Efficiency Amplifiers

In the early 1970s, both Nat and I were working on high-efficiency power amplifiers. At the time, there was a good deal of interest in solid-state RF power, but not many others were concerned with efficiency. Our interest was motivated, in part, by our pursuits in amateur radio and a desire to get the most RF-output power within the legal limit on the dc-input power.

The class-D amplifier offered high efficiency. However, as frequency increased, it became difficult to synchronize the two transistors, and losses due to discharging of the collector capacitance increased. The class-F amplifier also offered high efficiency, but its multiple resonators complicated the circuit, frequencies were not easily changed, and it was not amenable to broadbanding.

A few papers suggested that single-ended amplifiers could be made fairly efficient. None, however, offered a credible theory and so did not determine actual limits or how to optimize that efficiency. Nat and his son, Alan, discovered that, with judicious choices of components, the collector voltage would drop to zero at the time the transistor turned on. This eliminated the capacitor-discharge losses of the class-D amplifier and resulted in an efficiency of 100% for an "ideal" transistor (neither on-state resistance nor voltage). The Sokals further discovered that the components could be chosen to produce a collector voltage with zero slope at the time of turn on. This rendered the amplifier somewhat insensitive to variations in its components as well as the frequency of operation.

I became aware of Nat's work through an obscure paper he presented at a conference [1]. He similarly became aware of my work after finding my Ph.D. degree dissertation. We began exchanging notes.

The Sokals' original analysis [2] included their theory for determining the required collector-shunt capacitance but also experimentally determined the net reactance in the output circuit. I had independently developed a partial theory that included the capacitance but not the output reactance. When I learned that the amplifier could be tuned to become (ideally) 100% efficient, I went to work expanding my analysis to include the output reactance.

The paper with this analysis [3] was initially rejected because one reviewer saw no use in the circuit. The reviewer also said the analysis was trivial and could be done by a "B" student in no more than five pages. Nat went to bat for me and convinced the editor to publish the paper in spite of the negative review. He also offered a side bet to the reviewer, with 2:1 odds that the analysis could not be performed in five pages.

Subsequently, we collaborated on determining effects of things like the harmonic spectrum and losses due to resistance, switching speed, on-state resistance, and so forth. We also collaborated on a couple of contracts—subcontracting parts to each other.

Using class-E in a linear amplifier requires a technique such as envelope elimination and restoration [4], which is fundamentally an open-loop system. Varying the collector voltage causes the collector capacitance to vary, and this introduces unwanted phase modulation. The use of feedback for linearizing the envelope had been developed by Bruene [5]. The Sokals added phase feedback (lock) to clean up the amplitude-to-phase conversion, thus creating the "polar loop" [6].

We watched the literature and, over time, found others who were working, or had worked, on class-E and/or similar concepts. One interesting contact we made was Anatoly Artym at the Leningrad Electrotechnical

Institute of Communications (then part of the Soviet Union). We exchanged papers and books. In the 1980s, Artym was the only Russian who would correspond with us.

In the mid-1970s, Nat put together a class-E demonstrator (Figure 3). This was a self-contained box that allowed a potential user to see class-E operation first-hand in his or her own lab. It produced 3–4 W at 30 MHz. Figure 4 shows Nat and Alan working with a demonstrator in the DAI lab. DAI later sold HB Plus, the computer program that facilitated the design of class-E amplifiers. It included not only the classic theory but also empirical adjustments.

We initially used the term *optimum* for the condition in which the collector voltage reaches zero with zero slope at the time of turn on. Nat later decided this was not appropriate. *Optimum* can refer to various different combinations of elements. It also turned out that, with nonzero on-state resistance in a field-effect transistor, the best efficiency is often obtained with a small nonzero voltage at the time of turn on. Nat decided that we should call this zero-voltage/zero-slope condition *nominal*.

Power Electronics

Nat was also heavily involved in power electronics technology, and his work at DAI included dc–dc converters. He regularly attended the Power Electronics Specialist Conference (PESC) and Applied Power Electronics Conference and presented power converter seminars all over the world.

Nat reasoned that, if the operating frequency of a dc–dc converter could be increased significantly, the sizes of its components (especially inductors) could be decreased significantly. His prototype was a 14-MHz class-E amplifier that drove a rectifier through a matching transformer. This work led to converters that operate at frequencies up to several gigahertz.

Richard Redl (Figure 5) was among the young engineers who worked for Nat at DAI (from 1978–1979 and 1984–1989), concentrating on switch-mode power supplies, multipulse ignition systems for automobiles, and power-supply control integrated circuit architectures. He recalls,

> Nat was my mentor and friend for more than forty years. I'll never forget the lessons I learned from him about how an engineer should tackle a difficult project, how to write technical papers, and how to become an active participant in the engineering community. My most productive years were spent with him at [DAI], and those years created the foundation for my subsequent professional carrier as a consultant. I'll always remember his warmth, generosity, curiosity, creativity, and openness.

Nat held eight patents in power electronics, including the class-E switching-mode, high-efficiency RF power amplifier.

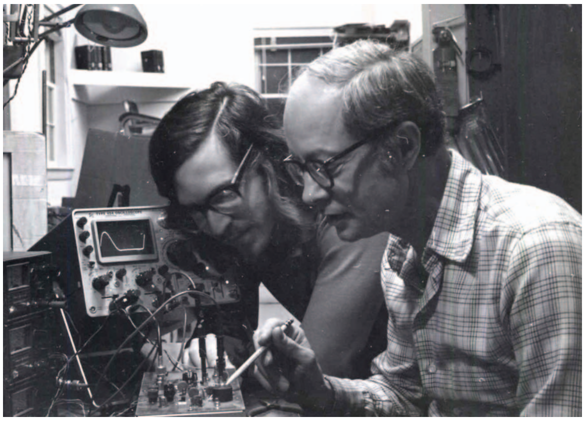

Figure 4. *Nat and Alan Sokal working with a demonstrator circa 1974. (Photo courtesy of the author.)*

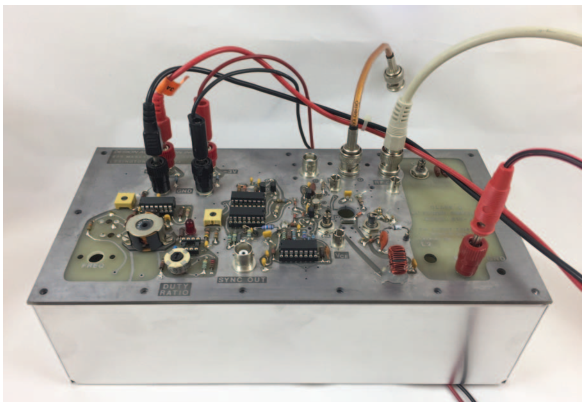

Figure 3. *Nat Sokal's class-E demonstrator. (Photo courtesy of Arturo Mediano.)*

Figure 5. *Richard Redl (left) and Nat Sokal enjoying a meeting at PESC. (Photo courtesy of Richard Redl.)*

Figure 6. *Speakers at the IMS2000 HF/VHF/UHF session. Nat Sokal is third from the left. (Photo courtesy Arturo Mediano.)*

MTT-S and Other Activities

Nat was a frequent presenter at RF Expo conferences. After the 1997 formation of the HF/VHF/UHF technical committee within the IEEE Microwave Theory and Techniques Society (MTT-S), he was also a frequent presenter at the IEEE MTT-S International Microwave Symposium (IMS) (Figure 6).

Nat presented workshops on high-efficiency amplifiers at several of IMS meetings. These were always filled to (and over) capacity. He also participated in the MTT-S Speakers' Bureau and was a contributor to the MTT-S's 50th anniversary paper on RF power amplifiers [7]. He presented long and short versions of his tutorial course "RF Power Amplifiers, Classes A–S: How the Circuits Operate, How to Design Them, and When to Use Each" to both industry and academia.

Figure 7. *2007 MTT-S President J. Stevenson Kenney (right) presenting Nat Sokal (left) with the MTT-S Pioneer Award at IMS2007. (Photo courtesy of Edward C. Niehenke.)*

Nat Sokal was always happy to help students with work in this area. An example is Ukrainian graduate student Anya Rudiakova, who attended IMS2000 in Boston, Massachusetts, under a U.S. Civilian Research and Development Foundation grant. Nat made local arrangements for her, including finding reasonably priced housing and obtaining subway tickets. Nat also served as an outside member of the Ph.D. degree committees for a number of graduate students and sometimes traveled to attend their theses defenses. For example, Nat helped Arturo Mediano (coauthor "Class-E Amplifiers at MF, HF, and VHF" on page 42 this issue) find a thesis topic.

Nat (amateur call sign "WA1HQC") was a technical adviser to the American Radio Relay League in the area of RF power amplification and dc power conversion. He was also a member of honorary professional societies Eta Kappa Nu, Sigma Xi, and the Electromagnetics Academy.

Nat was elevated to IEEE Fellow in 1989. At IMS2007 in Hawaii, the MTT-S presented him with the Pioneer Award "in recognition of a major, lasting contribution of the development of the class-E high-efficiency switching-mode RF power amplifier" (Figure 7). In 2011, the Polytechnic University of Madrid (Spain) awarded him an honorary doctoral degree (*Doctor Honors Causa*) for inventing and developing the class-E high-efficiency switching-mode RF power amplifier. His acceptance speech (see page 22 in this issue) outlines how he and Alan developed the class-E amplifier.

Other Activities

Throughout his life, Nat enjoyed nature and outdoor activities—hiking, skiing, bicycling, and canoeing—with

The Sokal Family Recalls…

We all have good memories of special times with our dad, as well as my mother's memories of being married to an "engineer": traveling all over the world, enjoying the various cultures, and getting to know the many members of the IEEE community and their wives.

When Alan looks back, he finds it incredible that he spent so much time as a teenager hanging out with his dad, working on his ham radio project and developing the class-E amplifier. He had a very special relationship with his father.

Diane learned to solder when she was around ten years old, as Dad thought this was an important skill to know. She soldered her sculpture creations in the evenings, while Dad soldered his circuit boards. This may have led her into her professional career as an architect and to her taking an "engineer's approach to life."

Our father was extremely proud to be an electronics engineer and loved his work. He believed that most people work to live, but he "lived to work." As children, we remember him jumping on his bicycle every day and joyfully riding off to his lab. Being a practical and thrifty man, he used that same bicycle from his early 20s into his 70s. He would faithfully return at 6:00 p.m. for dinner with his family and then, after dinner, use the kitchen table to spread out his work. Papers with drawings and equations kept him busy well into the evening.

Dad was an engineer's engineer, planning and organizing not just in his work environment but in everything he did. He was an environmentalist before it became popular—always using the backside of already-used paper, reusing envelopes for mailings, fixing anything he could rather than sending it to the trash. An example was a light fixture in Diane's dining room that blinked off intermittently: Dad determined that oxidation of the aluminum was the culprit and, after abrasion, the lamp worked fine His approach to life was the Massachusetts Institute of Technology's motto, "*Mens et Manus*" ("mind and hand"). His children remember that and more, in that he also had—in addition to his knowledge—heart and caring.

He loved to advise other engineers in any part of the world, offering his guidance and helping them solve their technical problems. After he bought a computer, he would sit for hours reading and responding to every e-mail. On family vacations, he would pack a whole suitcase full of professional journals to read through (a practice that Karen herself has taken up). He was also a practical man who would fix an electronic gadget that was on the "fritz" at home.

The crowning glory of Dad's career was receiving the honorary doctorate degree in Madrid in 2011. He was beaming with happiness, telling the story of his invention of the high-efficiency class-E power amplifier, surrounded by "all of those engineers," young and old. It was only then that we realized how productive he had been, publishing 130 papers and having eight patents to his credit. He was very clearly a "high-efficiency engineer."

—Karen Sokal-Gutierrez and Diane Sokal

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his family and friends. His children recall how, on weekend adventures in the woods, their father taught them how to identify the local trees, flowers, rocks, and birds. Nat and Zelda enjoyed ballroom dancing—especially the waltz, swing, and rumba—and traveling together to Europe, Asia, Latin America, and Australia. (See "The Sokal Family Recalls… .")

Retirement and Passing

Nat closed the DAI office in Lexington but continued to work from home through his through his 70s. In 2010, he and Zelda moved to Lasell Village, a retirement community in Newton, Massachusetts. At that time, he gave me some of his lab and amateur radio equipment. But, even while at the retirement community, Nat continued to provide consulting on a limited basis.

Nathan O. Sokal died on 8 May 2016 at the age of 87. He is survived by his wife, three children, and six grandchildren.

Acknowledgment

Some of the material used here was derived from the obituary at mtt.org.

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