Andrew V. Haeff: Enigma of the Tube Era and Forgotten Computing Pioneer

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Andre A. Haeff
A.V. Haeff Papers

Prolific, yet neglected inventor Andrew Vasily Haeff (1905–1990) made numerous contributions to vacuum tube art, including the traveling wave tube, the inductive-output tube, the electron-wave tube (or "double-stream" amplifier), the resistive wall tube, and many others. Haeff's contributions to computing history include his pioneering computer monitor technology, his high-speed electrostatic computer memory tube, and his early work in the display and storage of text and graphics.

Harbin to Caltech

Andrei—later Andrew or Andy—Haeff was born in Moscow on 12 January 1905 (or 30 December 1904, by the Julian Calendar in use in Russia at the time).[1] In 1920 his family fled from Russia to Harbin, in northeastern China. An important railway city not far from the Russian border, Harbin became home to a large Russian population in the wake of the 1917 Bolshevik revolution. Haeff's father, Vasili, owner of the Churin Trading Company and a venture capitalist specializing in gold mining, continued the family business from Chinese soil. Haeff completed high school at Harbin and went on to study electrical and mechanical engineering at the Russian Polytechnic Institute there, graduating in January 1928.[2] Later that year, following a successful application to the California Institute of Technology, he came to the United States. At Caltech, Haeff obtained a master's degree in electrical engineering in 1929 and a PhD in electrical engineering and physics in 1932. Caltech's director Robert A. Millikan introduced the young Haeff to Einstein as one of the institution's most promising graduate students.

The topic of Haeff's doctoral dissertation was "Ultra High Frequency Oscillators," in particular the 1,000 MHz oscillator that he had developed.[3] He was soon using this oscillator in a transmitter that he built in order to carry out UHF communications experiments involving his first major invention, the traveling wave tube (TWT) amplifier.[4] The TWT went on to become one of the most important paradigms in microwave engineering, with interest in the tube remaining strong today, especially for radar and communications applications.[5]

Haeff's younger brother, Alexei Haieff, followed him to the US in 1931. Haieff, a talented composer, soon gained a reputation in his adopted country, spending long periods with Igor Stravinsky in Hollywood. It was a favorite family anecdote that when Haieff and Stravinsky were driving back to Hollywood together through the Rocky Mountains, Stravinsky exclaimed irritably, "I despise mountains—they don't tell me anything."[6]

Andrew V. Haeff

Born: 12 January 1905, Moscow, Russia

Died: 16 November 1990, Whittier, California

Education: BS (electrical and mechanical engineering), Russian Polytechnic Institute (Harbin, China), 1928; MS (electrical engineering), California Institute of Technology, 1929; PhD (electrical engineering and physics), California Institute of Technology, 1932.

Professional Experience: RCA, vacuum tube research engineer, 1934–1941; Naval Research Laboratory, consulting physicist, 1941–1950; Hughes Electron Tube Laboratory, Hughes Aircraft Company, research director, 1950–1954; Hughes Research Laboratory, vice president and director of research, 1954–1961; Acoustica Associates, consultant, 1962; TRW, researcher, 1968–1975; Caltech and NRL, consultant, 1975.

Awards: IEEE Harry Diamond Memorial Award, 1950.

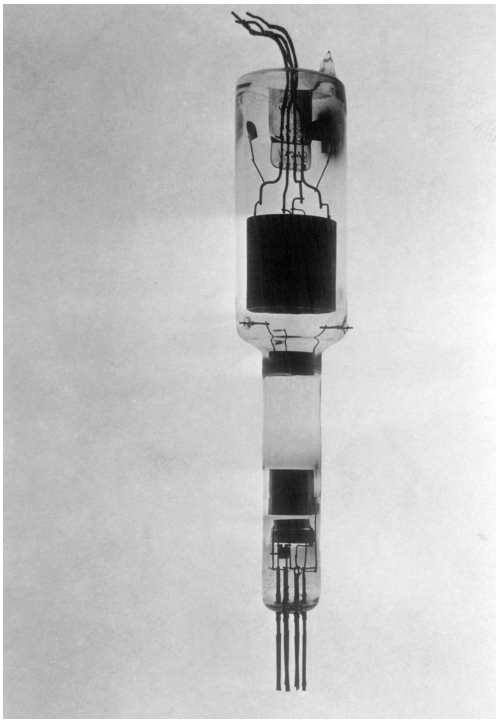

Figure 1. Prototype of Haeff's IOT (inductive output tube) in 1939. The market version of the tube was the RCA-825 Inductive-Output Amplifier.

Andrew too was highly musical, playing violin and piano from an early age and remaining musically active until almost the end of his life. At Harbin the young brothers would fill the house with music, Alexei at the piano and Andrei playing his violin inventively and with consummate style. In his teens Andrei was, like his brother, an avid composer, and dreamed of writing music to accompany Hollywood's silent movies. He even mailed a proposal from China to the Metro-Goldwyn-Mayer studios in Hollywood, but fortunately for the vacuum tube industry, nothing came of it.

Radio Corporation of America, 1934–1941

In March 1934, Haeff shifted from academia to industry, joining the Research and Engineering Department of RCA in Harrison, New Jersey. He worked on the development of small tubes ("acorn" tubes) for use in television—the RCA passion—and on UHF transmitting and receiving tubes and circuits.[7] At RCA Haeff filed a number of patents on velocity-modulated tubes and embarked on an analysis of space-charge effects in magnetically focused electron beams, an investigation that laid the foundations for much of his life's work.[8]

He also secured the foundations of his personal life, marrying Sonya in 1936. Their only child, Andre, was born in 1938. It was at RCA that Haeff made his second major contribution to tube art. He realized in 1938 that a high-velocity bunched electron beam would generate electromagnetic energy if passed through a resonant cavity and, in 1939, filed the first IOT (inductive output tube) patent, describing the density-modulation induction phenomenon and the resultant amplification of very high frequencies.[9] In this patent he called his grid-controlled tube simply an "electron discharge device," using the phrase "inductive-output tube" in his 1940 IRE article on the tube.[10] (In the summer of 1940, Haeff took the train all the way from New Jersey to Los Angeles to present his invention at the IRE Pacific convention.[11]) Employing a system of short magnetic lenses, his IOT provided power amplification over a wide band of frequencies in the UHF range. The production version of Haeff's tube was the RCA-825 Inductive-Output Amplifier (see Figure 1).[12]

Haeff's IOT was used in RCA's historic 1939 demonstration of television's potential, a large-scale experiment involving scheduled TV broadcasts to metropolitan New York, using a transmitter on top of the Empire State Building.[13] Early live programs included coverage of President Roosevelt opening the 1939 New York World's Fair. Haeff's IOT was used in the crucial repeater stations that relayed the signal beyond line-of-sight, extending the range of the experimental transmissions as far as Riverhead on Long Island, a total distance of 70 miles.[14] His IOT was "the only tube in existence in 1939 which made the television radio-relay system possible at that time," Haeff said.[15]

Soon, however, velocity-modulation tubes in the klystron family eclipsed the IOT. Forty years later, Haeff's IOT was rediscovered by Donald Preist and Merrald Shrader of Varian Associates.[16] Preist and Shrader noted that "Haeff's tube produced over 35 watts CW output at 500 MHz, a remarkable performance at the time."[17] The 1981 prototype of their improved version of Haeff's tube had a power output 1,000 times greater than the original tube.[18] Varian marketed the Preist-Shrader IOT under the trade name "klystrode" because (as Preist and Shrader observed) "between the anode and the collector, the

Haeff tube is similar to a klystron, while between the cathode and the anode, it closely resembles the tetrode."[19] In the 1980s and 1990s, the IOT rapidly took over the UHF TV market, and today Haeff's tube excels in digital TV broadcasting.

By the end of the 1930s, Haeff was totally Americanized and had virtually lost his Russian accent (very occasionally a trace of it would reappear, in moments of high stress). Millikan described him as "Russian in origin but completely American in outlook, personal appearance and bearing."[20] He was devoted to his new country. A dark, serious, thickset teddy bear of a man, Haeff was kind and friendly, but also shy. His favorite conversations were one-on-one, deep, and usually scientific. Haeff enjoyed the company of creative people, whether scientists, musicians, artists or writers. He was less fond of hidebound or dictatorial thinkers—especially the bureaucrats and administrators with whom he was increasingly forced to mix as he moved up the scientific career ladder. Ironically, he himself eventually became a top-level research administrator, a role he carried out with aplomb but did not much enjoy.

Naval Research Laboratory, 1941–1950

In 1941 the effort to develop radar was consuming ever-larger numbers of electronic engineers. Haeff entered the radar battle full time in March of that year, joining the staff of the Naval Research Laboratory (NRL) in Washington DC, with the rank of consulting physicist for the Radio Division.[15] "I felt that I could contribute considerably more if I worked directly for the Government on National Defense projects," he said.[15] Haeff played a significant role in the wartime development of radar and, in 1942, was a founder member of the legendary Vacuum Tube Development Committee (VTDC).

A glimpse of the nature and scope of Haeff's war work is provided by the flurry of patent applications that he lodged at war's end, during the period from September 1945 to February 1946. He was prolific in inventing new types of microwave signal generators and radar pulse generators, and he also contributed to radar countermeasures, inventing a sophisticated pulse-jamming system (with Franklin Harris). This rendered enemy radar equipment ineffective by transmitting interfering pulses.[21] The pulses were synchronized with, and powerful enough to obscure, the echo signals returning to the enemy receiver.

Haeff's pulse-jammer was designed for use against high-accuracy radar systems, such as shore-based fire control (gun-targeting) equipment. He spent many weeks during the early part of 1945 aboard a Navy cruiser off the California coast, testing the equipment in preparation for the planned (but preempted) invasion of Japan later that year. Of the five pulse-jammer patents that Haeff applied for in early 1946, three were withheld for security reasons until the 1970s, and his advanced design continues to be referenced in patents on jamming equipment up to the present day.

Haeff's UHF signal generators, developed at the NRL from 1943, generated radio frequency energy of known wavelength and amplitude.[22] They were used for testing and adjusting many varieties of radio equipment in the laboratory, factory, and field. The generators could deliver either continuous or pulsed output and, in pulse mode, were used principally to evaluate the performance of radar receivers and radar jammers. The Bureau of Ships and the Bureau of Aeronautics granted contracts to various manufacturers to produce signal generators according to Haeff's design (with Haeff acting as advisor to the manufacturers). Hundreds were produced for distribution to naval bases and to ships. One of the manufacturers was the fledgling Hewlett-Packard Company, situated in what is now Silicon Valley. Hewlett-Packard turned out Haeff's signal generators for the Navy and the Army, as well as for Britain and Russia. Commercial signal generators manufactured during the 1950s by RCA, General Communications, and Airadio as well as Hewlett-Packard (notably the Hewlett-Packard Model 610A), all followed Haeff's designs closely.[23] It was the Haeff signal generator, and also his radar jammer, that first put Hewlett-Packard on the industrial map.[24]

The war over, Haeff became head of the new Vacuum Tube Research Section at NRL, where in addition to directing tube research, he made his next two major contributions to the art. Pursuing his earlier study of space-charge effects, he investigated the interaction of electron streams of different velocities and discovered a new means of amplifying microwave energy.[25] Haeff called his new microwave amplifier the "electron-wave tube," now known as the double-stream amplifier. This was effectively a traveling wave tube with the helical electrode replaced by a second electron beam. Haeff conceived the basic idea in April 1946,[26] and in December of that year, he gave the first written description of the tube in a brief two-page note.[27] The concept of the double-stream amplifier had arrived, and to the proud Haeff, it looked a wonderful idea. He eventually reduced the idea to practice in May 1948.[26]

Phenomena discovered in tube research often proved to be of importance in astrophysics, and Haeff's double-stream instability was no exception. Haeff himself, in a foray into astrophysics, suggested that his double-stream effect accounted for the origin of solar radio noise, conjecturing that intermingling streams of charged particles emitted by the sun will greatly amplify an initial disturbance.[28] He also suggested that the Aurora Borealis (Northern Lights) and Aurora Australis are produced by a release of energy from streams of solar electrons that are pulled in by the Earth's magnetic field. Haeff's double-stream instability remains the subject of fundamental research today, in connection with particle accelerators and high-energy electronics, for example.

It was also during his highly productive period at the NRL that Haeff invented his "Memory Tube," the basis of his various contributions to computing history.[29] The Memory Tube stored information on a coated glass screen. Haeff had a prototype of this electrostatic tube working in June 1947[30] and, in the same month, prepared a confidential report on the tube for NRL. In this he wrote, "The signal-storage device described in this paper has many applications. It promises satisfactory solutions to such problems as … flash communications, the storage and reading of binary numbers for electronic digital computers, and many other problems."[30]

An important piece of early computer technology, the Memory Tube had its origins in Haeff's radar research. The tube would, he said, permit "simultaneous multicolour and three-dimensional presentation of radar or sonar data," moreover offering operators the advantage of "daylight viewing," and the tube could automatically generate a trace whose length was "proportional to the velocity of the target."[31] The tube was quickly declassified by NRL, and Haeff presented it at the IRE Electron Tube Conference in Syracuse, New York, on 10 June 1947.[32]

His invention aroused considerable interest. The Memory Tube was written up in *Newsweek* in September 1947 and then in *Popular Science* in May 1948.[33] "The Navy's new electronic memory tube," *Popular Science* reported, "remembers signals as long as you want it to."[34] *Newsweek* described the Memory Tube as a "long-sought memory device for the new 'electronic brain' calculating machines now being designed as successors to the Eniac," and the article echoes Haeff's view that the tube could resolve what *Newsweek* called the memory "bottleneck"—the problem of developing a fast, cheap memory capable of keeping pace with the high-speed electronic processors then under consideration.[35]

With one of the world's first electronic storage and display devices functioning in his laboratory, it is unsurprising that Haeff also became a pioneer of electronic graphics. He was probably the first to store graphics and text for a prolonged period on an electronic visual display screen, using the Memory Tube to display letters and pictures early in 1947. He also took the first historic steps toward digital graphics and text, storing letters and images on the tube's electrostatic screen in the form of discrete luminous elements (picture elements, or "pixels").

As a high-speed computer memory, Haeff's Memory Tube was eclipsed by the British Williams tube, although Haeff-type tubes did form the main high-speed memory of MIT's Whirlwind I computer. The Memory Tube had its most significant impact on computing as a display device. Hughes Products commercialized the Memory Tube, marketing versions of it called the Memotron, used for storing and displaying graphics, and the Typotron, which functioned as a text-based computer output device. Later forms of Haeff's Memory Tube were in common use as computer monitors and interactive graphics terminals until the 1980s, most notably the big screen Tektronix 4014, which many will remember as a thoroughly modern alternative to interacting with a mainframe via a paper-fed teletype.

Haeff was the first recipient of the IEEE Harry Diamond Memorial Award, presented to government servants for "outstanding technical contributions" (www.ieee.org/about/awards). The citation read, "For his contribution to the study of the interaction of electrons and radiation, and for his contribution to the storage tube art."[36] The award, bestowed in 1950, was primarily for Haeff's ground-breaking inventions, the Memory Tube and the double-stream amplifier,[37] but undoubtedly his radar signal integrating tubes, signal generators, and radar jammers also played a significant role in determining his selection for the award.

Hughes Aircraft Company, 1950–1961

The pivotal year 1950 saw Haeff leaving the NRL for the Research and Development Laboratories of the rapidly expanding Hughes Aircraft Company in Culver City, California. Owned by Howard Hughes, the flamboyant and eccentric entrepreneur, aviator, and movie producer, the company was at that time primarily under the technical leadership of Simon Ramo and Dean Wooldridge. Electronics was the main focus at Hughes and the company was hiring stellar researchers. The Hughes strategy was to take on military-oriented research problems that were sufficiently hard to deter competitors.[38] When his friend Si Ramo first broached a move to Hughes in January 1950, Haeff was initially reluctant to leave the NRL, but things changed following the outbreak of the Korean War later that year. Hughes was a leading supplier to the US forces and, by 1957, was the largest defense contractor in the United States. Haeff's new position, from November 1950, was head of the Hughes Electron Tube Laboratory, a move that cemented his transition from researcher to research director.

Haeff set up the Electron Tube Laboratory and led the Hughes research program in storage tubes. Under his direction, the Electron Tube Laboratory developed his Memory Tube and his TWT. Haeff continued to invent, especially in the field of microwave amplification, devising first his electron-stream amplifier tube (filing a patent in April 1952), and later the resistive-inductive wall amplifier, or "resistive-wall amplifier," with his Electron Tube Laboratory colleague Charles Birdsall (they filed for the first patent in October 1952).[39] The resistive-wall amplifier exploits an instability occurring when an electron beam flows close to a coated surface. The resistive-wall instability discovered by Haeff and Birdsall is now the subject of a considerable literature, especially in connection with plasma work and high-energy particle accelerators.

In 1954, Haeff's Electron Tube Laboratory was merged with other Hughes laboratories to form a single entity under Haeff's overall control, the Hughes Research Laboratories.[40] At this time Haeff was made a vice president of Hughes and designated director of research (see Figure 2). In a large, research-heavy organization such as Hughes —the company had a workforce of over 20,000 by 1955[41]—this was a superb, if demanding job.

Figure 2. Haeff in brother Alexei's Manhattan apartment in 1954.

Haeff's traveling wave interaction was core to the early maser developments ("microwave amplification by stimulated emission of radiation"). Later, his double-stream amplifier was important in the double beam cyclotron maser, essentially a double-stream amplifier in which the two electron beams travel at relativistic speeds.[42] Following the pioneering invention of the ammonia beam maser by Charles Townes at Columbia University in 1954, Haeff had a hand in setting up the maser research program at Hughes. The laser (or optical maser) was developed in Haeff's Research Laboratories by Ted Maiman in 1959, and the prototype Maiman ruby laser was built and operated in Haeff's laboratory during 1960. Haeff took color slides home to show his excited family. He himself went on to invent a number of laser devices, including an influential chemical laser apparatus in 1968. This achieved radiation amplification by siting a chemically reacting mixture next to an optical cavity.[43]

The laser opened up new horizons in military electronics. An internal memo to Haeff, written a few weeks after the ruby laser first operated, suggested researching its potential use in "communication systems, optical radars, passive detectors, … destructive weapons, … submarine detection, inertial guidance."[44] Haeff gladly harnessed his

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brilliant mind for the production of military hardware. A technologically superior force had overwhelmed the land of his birth in 1941, and from that year, he had devoted himself to the development of military and military-related technology for the defense of his adopted country.

The launch of the Russian Sputnik satellite in October 1957 triggered the lucrative space race, and in 1959, Hughes entered the field of space communications. As director of research, Haeff played a leading role in managing a research and development program that led rapidly to Hughes' Syncom, the first geosynchronous communications satellite. At Syncom's heart was a lightweight TWT developed in Haeff's laboratories. The research program midwifed by Haeff led to the first operational commercial communications satellite, the Syncom-based Early Bird (also known as Intelsat I), launched in 1965, and ultimately to Hughes' domination of communications satellite manufacture.[45]

The Later Inventions

Haeff himself left Hughes in 1961, following a period of illness and exhaustion. He bravely made the step back from director of research to researcher and inventor, working on his own and also as an independent consultant. While consulting for Acoustica Associates (a firm led by his friend and former Hughes Vice President Andrew "Rus" Russell), Haeff invented his volumetric measuring device in October 1962, the time of the Cuban missile crisis. This important and influential device used sound waves to measure the volume of fuel in missiles, rockets, and spacecraft and was able to function in a zero gravity environment.[46]

The patents began to flow faster again, a diverse cascade of inventions. Still working with the properties of sound, Haeff carried out a series of experiments in 1963 (with Cameron Knox) showing that, under certain conditions, the human ear is able to perceive high frequency ultrasound as ordinary sound.[47] In 1964, now working from his home in West Los Angeles, Haeff became fascinated with the idea of using laser beams to scan 3D objects—statues, buildings, works of art, museum treasures—and to recreate the objects virtually. He foresaw industrial, household, and military applications for his new invention, a harbinger of virtual reality that he prosaically described in his 1964 patent application as an "Apparatus for Scanning and Reproducing a Three-Dimensional Representation of an Object."[48]

In 1959, while still research director and vice president at Hughes, Haeff began to study controlled nuclear fusion. He realized that since classical nuclear fission is environmentally hazardous, somehow the clean-burning hydrogen fuel of the sun would have to be harnessed, first in the laboratory and then in a revolutionary new type of power plant. He struggled intermittently with the problem of implementing fusion, envisioning the use of a plasma containment vessel. It was not until 1968 that he made a concrete contribution, when in a sustained burst of inspiration, he invented his plasma containment device just weeks after inventing the chemical laser apparatus described earlier.[49] Haeff was by this time employed in the research laboratory of the Thompson-Ramo-Wooldridge Corporation (TRW), whose founders were the same Simon Ramo and Dean Wooldridge who, 18 years earlier, had brought Haeff to Hughes from the NRL.

Haeff stayed at TRW until 1975, when he finally retired from formal employment. He continued consulting at Caltech and NRL, and (like Einstein before him) he became increasingly engrossed with a unified theory of gravity, hoping to integrate gravitation and quantum mechanics. Haeff labored on his unified theory at home, publishing some abstracts, but the work was left unfinished. He died in Whittier, California, on 16 November 1990.

Haeff is among America's most brilliant inventors, yet his name is little known even within the electronic engineering community.

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