Remembering Jan Rajchman and the Origins of Electronic Memory

By Alexander B. Magoun

Editor's note: *This month we bring to you an article based on the Engineering and Technology History Wiki's Oral Histories collections. Since its establishment over 30 years ago, the IEEE History Center has collected the oral histories of prominent engineers. Center staff and volunteers have conducted more than 600 interviews, all of which are available on the Engineering and Technology History Wiki administered by the History Center, www.ethw.org. Scholars in a range of fields have drawn extensively on these interviews as have writers and producers of popular books, articles, exhibits, and documentaries. Some editing has been done, along with the addition of a few illustrations, to make the article mores suitable for a journal publication.*

Jan Rajchman, a pioneer of electronic and electromagnetic computer memory, discusses his work on electron multipliers, the Computron and Selectron, magnetic core memory, and transfluxors.

In 1975–1976, RCA's David Sarnoff Research Center arranged for oral histories of nine of its distinguished senior technical staff by Mark Heyer, an audiovisual consultant with a background in physics, and Albert Pinsky, its administrator of Scientific Information Services. RCA donated the recordings to the IEEE and after the History Center was formed in 1983, it had them transcribed and then posted on its website, http://ethw.org/Oral-History:RCA_Engineers. Quotations in this article without citation are from this oral history.

Jan A. Rajchman (1911–1989), a pioneer of electronic and electromagnetic computer memory, was one of those interviewed in 1975. He joined the Radio Corporation of America (RCA) in Camden, NJ, USA, in 1935 where he led a small group during World War II in attempting to build a gun-control computer in an electron tube. After the war, at RCA's Princeton Laboratories, in collaboration with John von Neumann at the nearby Institute for Advanced Study, he developed a digital RAM memory in an electron tube (Fig. 1). Independently of Jay Forrester's team at MIT and a group at IBM, he invented a practical form of magnetic core memory. He spent the next 20 years attempting to supplant this with denser forms of digital storage, up to a full-cycle holographic system in 1973. Research in matrix addressing also stimulated research and development in flat-panel displays; the Society for Information Display named an award after him in 1993. Rajchman was a Fellow of the IEEE, the American Physical Society, and the American Association for the Advancement of Science; a member of the National Academy of Engineering; and recipient of the Morris N. Liebmann Memorial Award and the Edison Medal.

I. A COSMOPOLITAN UPBRINGING

Jan Rajchman was born in London to Maria and Ludwik, a dynamic Polish bacteriologist—and future founder of UNICEF—who was doing research at the Royal Institute of Public Health and King's College. In 1918, the family returned to Warsaw where Ludwik created the National Hygiene Institute to respond to the postwar typhus epidemic. Three years later, having accepted an offer to lead the League of Nations Health Organization, he took the

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Fig. 1. ***This advertisement appeared in National Geographic in 1950 as one of J. Walter Thompson's series of ads for RCA innovations after World War II. (Courtesy David Sarnoff Library.)***

family to Geneva, Switzerland, where Jan learned French again and

> was highly interested in mathematics and physics. Also I was fortunate enough to have been in a school environment where manual dexterity was highly considered. We were taught how to actually use our hands to build various objects .... It was a sort of laboratory environment, in which I learned to build things myself. In that period, the late '20s, many boys built their own radios .... I was among them, and I built many radio receivers when I was in school, including superheterodyne receivers, which at the time were quite novel, the latest invention.[1]

Rajchman graduated from the Collège de Genève (now Collège Calvin) in 1930. After discussion with his parents and looking at the employment trials of his uncle, a skilled

[1]Oral History of J. A. Rajchman, interviewed by R. R. Merz, Oct. 26, 1970, *Computer Oral History Collection*, Archives Center, National Museum of American History, http://amhistory.si.edu/archives/AC0196_rajc701026.pdf, accessed Jun. 6, 2015.

mathematician, he decided against trying to qualify for one of the French Ecoles and enrolled at the Federal Institute of Technology in Zurich. There he mastered German, majored in electrical engineering, and received his diploma four years later. Rajchman received his Doctor of Science in 1938, also in electrical engineering.

Rajchman journeyed to the United States in 1935, "a classic immigrant," hoping to work at RCA Laboratories with Vladimir Zworykin, who had announced the successful Iconoscope electronic video camera two years earlier: "I must say I heard of Zworykin before I heard of RCA." In the wake of RCA's second year of losses during the Great Depression, however, no job was available and Rajchman attended MIT's summer school instead to improve his English. Then he received a telegram from RCA's Edward Kellogg in Camden, NJ, "who was kind enough to let me know that there was an opening . . .. I was at MIT, but he advised me not to linger, so I was in Camden the next day."

II. MULTIPLYING ELECTRONS

Initially, he worked on electron multiplier tubes, which Zworykin had also been working on to amplify the weak video signal over various forms of noise in the iconoscope.

> At that time the most interesting thing in electronics was electron optics. That was really the forte of Zworykin's lab. The multipliers had already been conceived. They were of a magnetically focused type that . . . also suffered from large dark current; in other words, when there was no light there still was a fairly large output . . .. What I really did was to make them simpler by making them electrostatic and also discover the reasons for the dark current problem and try to avoid it.[2]

On trips back to Switzerland, Rajchman obtained permission from his advisor, Paul Scherrer, to apply his work on electron multipliers to a doctoral thesis, which he defended at the end of summer 1938.[3] RCA and the successor to its specialty tube division, Burle Industries, continued to make and sell the 931 photomultiplier of the same design up to 2009; Hamamatsu Photonics continues to sell its version of the device.

III. DIGITAL COMPUTING IN A TUBE DURING WORLD WAR II

After Germany and the Soviet Union invaded Poland in September 1939, the U.S. military began examining seriously the use of electronics in modern warfare.

> [T]he Frankford Arsenal approached us because our anti-aircraft fire control was notoriously poor and the Germans at the time had a great superiority in the air. So the question was, "Could we make some computers that would direct the anti-aircraft guns in a better way than the mechanical devices existing at the time?" That's how I got into it. I was, in fact, the first man to get into it. Our first work was what we call today "analog devices" and then later I switched to digital devices . . .. mostly because it was so difficult to get the right accuracy on our devices. So during that time we made many basic concepts of . . . how to do logic, how to do read-only memories, and so forth. Perhaps the most notable thing is the read-only memory because it was an easy thing to put a label on and it was used quite widely afterwards. Many of the circuits developed at the time for logic were tube circuits, which later became the transistor circuits.

RCA's research in this area led naturally to discussions with other groups working on the same or similar problems with similar solutions. Zworykin, Rajchman, and Arthur Vance met with the Moore School group and John von Neumann and during a "long period of negotiation" the National Defense Research Committee (NRDC) invited RCA to contract for the construction of an electronic digital computer for ballistic tables. Zworykin calculated that such a device would require 20 000 vacuum tubes and the associated components and circuitry, and the mean-free path to failure would be about 10 min: "He didn't want to be involved in something as massive and unreliable as that."

> I was very sorry . . . he did decline the offer because I thought it would be rather fun to do it and we were by far the most able group, I think, in the country at the time . . .. In fact, we were asked to tell everything we knew to the Moore School, and I went to the Moore School many times . . .. It was all an atmosphere, of course, of great fervor for the war, and nobody worried about patents or priorities or anything like this.

During those discussions the prospect of an electronic, digital, general purpose computer arose.

> [T]he idea was advanced to make a matrix of wires to change the wiring, depending on the problem, and then you changed one matrix from another to change problems. Then the idea was maybe you could have some read-only memories to do that. Then gradually the idea came that maybe you could put just a plain matrix memory to do that and have a universal machine. The way I see the concept of the universal random machine of today, it was born in a very gradual way-and not by one man. [A]fter the fact . . .

[2]V. Zworykin and J. A. Rajchman, "The electrostatic electron multiplier," *Proc. IRE*, vol. 27, no. 9, pp. 558–566, 1939.

[3]J. A. Rajchman, "Le Courant Rèsiduel dans les Multiplicateurs d'Electrons Electrostatiques," Diss. Techn. Wiss. ETH Zürich, No. 1046, http://e-collection.library.ethz.ch/eserv/eth:20699/eth-20699-01.pdf, accessed Jun. 11, 2015.

people dug up the fact that [Charles] Babbage or [Countess of Lovelace] Ada . . . had the idea . . .. I mean, reality told half of it in a very gradual way and nobody read the literature in the past, which is usually the way things happen. And so, I frankly don't ascribe to such a clear-cut way that somebody invented this total program computer.

IV. DIGITAL COMPUTING IN A TUBE

For a single-purpose computer, Rajchman and Richard Snyder proposed the Computron, an electron tube designed to perform the parallel addition and multiplication of digital numbers for use in anti-aircraft fire control.[4] It was one of several promising approaches to the problem of accurately targeting enemy aircraft flying 500 km/h for small gun batteries, and Warren Weaver's Division 7, Fire Control, at the NDRC approved funding for two six-month cycles in 1942 (Fig. 2).

It was an exercise of integrated vacuum electronics you might call it today because it had, I think, a 14 × 14 array of calculating sets. It was like an integrated chip of a little calculator of today, but only it was implemented in vacuum technology. Actually, we never made a full tube, but we made a few cells of it and it did work alright.

After 12 months, Weaver admired the technical elegance of the program but declined to continue funding the Computron in the face of more immediate solutions developed at other institutions.[5]

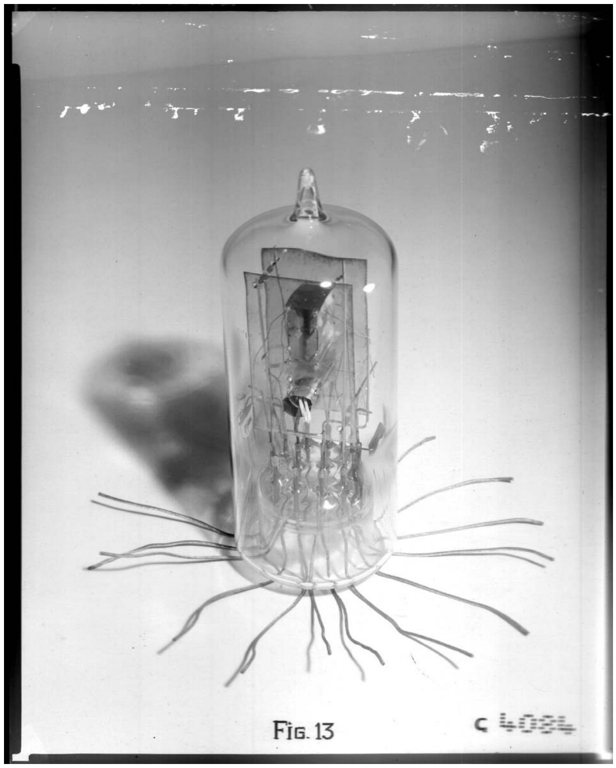

Fig. 2. ***Experimental component for digital electronic Computron fire control computer, c. 1943. (Courtesy David Sarnoff Library.)***

V. DIGITAL RAM FOR THE JOHNNIAC

In November 1945, John von Neumann met four times with Zworykin, Rajchman, and others at RCA Labs to discuss the design and construction of a digital, electronic, programmable computer at the Institute for Advanced Study (IAS) near Princeton University. "By then the ENIAC was approaching its completion, and it was obvious that the stored-program machine was the thing and the ENIAC was sort of a patched-up stored program machine because it wasn't designed that way to start with." Having declined the opportunity to contribute more substantially to the machine at the Moore School of Engineering at the University of Pennsylvania, RCA agreed to consult on what became known as the JOHNNIAC. "[T]he main difficulty with a stored-program machine of course is that you need a memory." Rajchman believed this could be resolved by techniques similar to those used on the Computron tube. The Selectron was

like a cathode-ray tube storage [Williams-Kilburn] tube, except that the selection is not by directing a beam of electrons, like an electron garden hose, to a certain place, but rather showering electrons all over the place and then excluding them in every place except the place you wish by means of grid arrangement and gating arrangement. By doing this then you have an absolute certainty of getting to where you want . . .. The fact that you have the rain of electrons available all over also means that you can use it to keep the information locked in, because you can use a mechanism of storage that depends on the fact that locally you have a bi-stable element that can sit in one way or another. So therefore you are also free from losing the information due to insulating losses.

Unlike the Williams–Kilburn tube, which was accessed via analog circuitry, the Selectron was a fully digital device.[6] Rajchman filed his first patent application and

[4]U.S. Patent 2 424 289, applied Jul. 30, 1943, www.google.com/patents/US2424289, accessed Jun. 11, 2015.

[5]RCA Computron, Final Rep. PB-40611, Report to the Services no. 57: NDRC Div. 7, Fire Control, 1943.

[6]See C. Osborne's *The Selectron*, www.rcaselectron.com/index1.html, accessed Jun. 11, 2015, for the most thorough explanation and documentation.

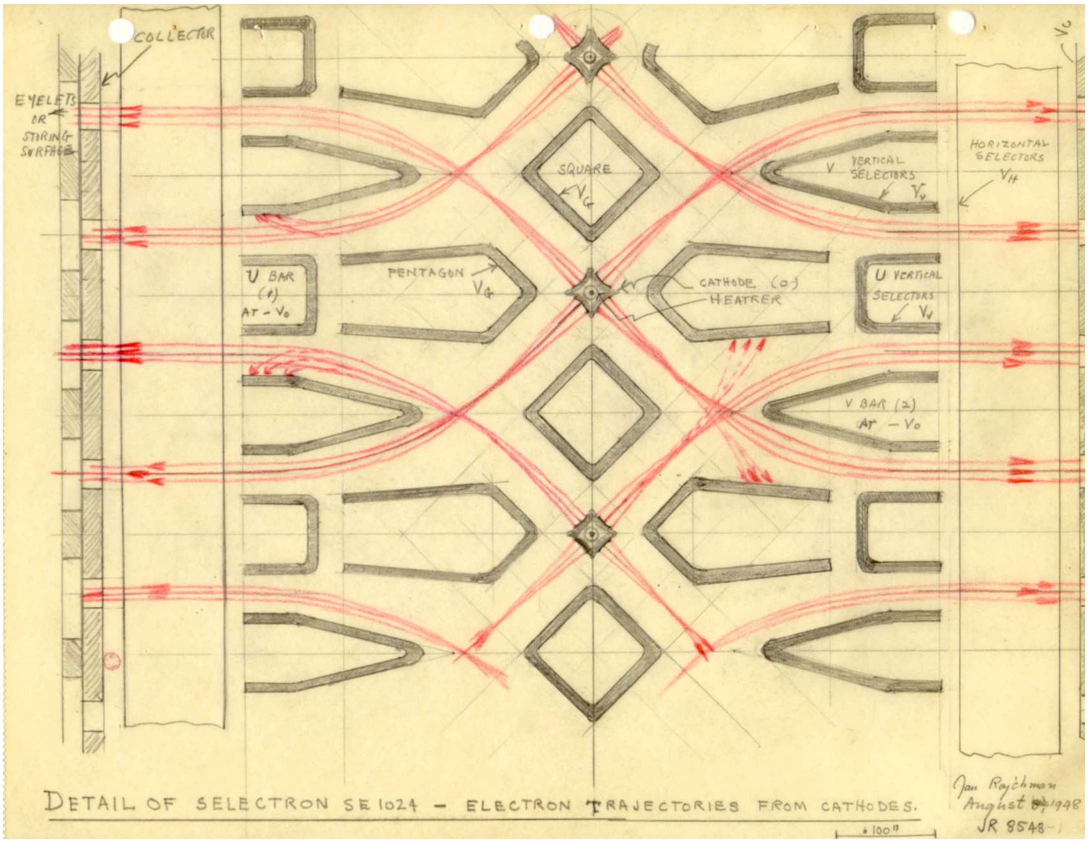

Fig. 3. ***Page from Jan Rajchman's laboratory notebook showing electron trajectories in 1024-bit Selectron RAM memory, August 1948. (Courtesy David Sarnoff Library.)***

lectured on the Selectron by summer 1946.[7] Over the next three years, however, the Selectron shrank in capacity from 4096 to 256 bits (Fig. 3).[8] It proved more difficult to fabricate in a lab setting than Rajchman anticipated since running 35 pins through the base multiplied prospects for contamination of the vacuum. RCA's industrial tube executives were reluctant to add a Selectron assembly line at the Lancaster, PA, factory. They were already wrestling with the efforts to improve UHF transmitting tubes, scale up the size and volume of monochrome cathode-ray tubes (CRTs) for television, and grapple with making the Labs' shadow-mask CRT a practical part of color television. Milt Rosenberg, who worked with Rajchman on the tube from 1947 to 1953, remembered production division heads asking

> such embarrassing questions as, "How many of these will be used?" . . . "What was the cost of the last hundred of these that you made?" And also . . ., "How did these last hundred work in the system?" Of course, our statement was that we think that there's a very large market which we can't codify, and you know, all the good things that we believe, which are religious almost in nature. I don't think that that sort of response, after several years, was well received.[9]

RCA reduced the Selectron to practice too late for von Neumann's IAS machine, but other groups building JOHNNIACs invested in the tubes, which were among the world's most expensive. RAND Corporation's JOHNNIAC used 40 of them at $800 apiece and Keith Uncapher argued frequently with RCA over the right to

[7]U.S. Patent 2 494 670, applied Apr. 26, 1946, www.google.com/patents/US2494670, visited Jun. 11, 2015; J. A. Rajchman, "The Selectron," Lecture 43, "Theory and techniques for design of electronic digital computers," Moore Schl. Eng., Univ. Pennsylvania, Aug. 23, 1946, reprinted in M. Campbell-Kelly and M. R. Williams, Eds. *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers* (Cambridge, MA: MIT Press, 1985), pp. 497–516.

[8]J. A. Rajchman, "The selective electrostatic storage tube," *RCA Rev.*, vol. XII, no. 1, pp. 53–97, Mar. 1951.

[9]Oral History of Milt Rosenberg, by R. Mapstone, Feb. 19, 1973, *Computer Oral History Collection*, no. 76, Archives Center, National Museum of American History.

return defective tubes that, because the Labs staff made them, it defined as "experimental."[10] Nonetheless Uncapher recalled that he and Bill Gunning telegrammed Rajchman to report that a Selectron RAM unit "had broken all reliability records, ran error-free—this was 10 bits, 256 words, not much of a memory by today's standards—for ten hours, but in fact it was a world's record in terms of reliability."[11] The U.S. Air Force paid $3000 each for 20 SB256 Selectrons to provide 5120 bits in a $750 000 RAM system at the Air Force Cambridge Research Center in Bedford, MA, USA.[12]

VI. THE CORE SOLUTION TO COMPUTER MEMORY

The solution to a cheaper, scalable digital memory was widely recognized among interested parties, if not easy to realize in the available materials and circuitry. Magnetic material offered the prospect of electronically controlled digital memory based on changing polarity, if one could obtain a material with a sufficiently square hysteresis curve.[13] Rajchman was one of several researchers who independently conceived of magnetic core memory (Fig. 4).

> One day I saw . . . that the Germans have virtually developed magnetic amplifiers . . .. I said, "It's obvious, you can make a thing and its square loop, so here you are." I got a hold of the materials, and we started to work on magnetic memories . . .. [I]t was fairly obvious you could do it with single cores, but that it would not be all that easy to assemble many cores. Therefore the trick would be to start making a sheet with holes and making it integrated to start with. We made a sheet and put holes in it, but when we tried that it was miserable. So . . . "Why don't we just take a few individual cores, wire them up, and see how it works, even though it's going to take us forever to assemble them." We did it just to see how it works so we would have a little idea of the system. To my great amazement it took only an afternoon for somebody to wire 256 cores. I was totally amazed that it was so trivial a task.

Fig. 4. ***Jan Rajchman holds RCA's first ferrite core memory panel, a 16 × 16 matrix using magnetic ribbons wrapped around spindles. This memory is on permanent exhibit at The College of New Jersey's Sarnoff Collection in Ewing, NJ, USA. (Courtesy David Sarnoff Library.)***

Rajchman's recollection comprises work from his first patent application in September 1950 to February 1952, when his technician wrapped molybdenum-Permalloy ribbon around tiny ceramic bobbins for RCA's first matrix. Seeking a more practical way of fabricating the cores,

> We went to . . . [Humboldt] Leverenz, and we asked him, "Could you make a material which would have a square-looking trace?" and he said, "Well, we can try." They made one in about six months, which I thought was pretty fast. Then, we made little doughnuts out of it because ferrite is like a powder. I wanted a machine that could make them very fast, and it turned out that the F. J. Stokes [Machine] Company in Philadelphia made aspirin and other pharmaceutical tablets for a lot of pharmacists. They made tablets automatically with a very small machine, but very fast. We bought one of these machines and adapted it to make doughnuts instead of pills . . .. That's how we made the cores.

Rajchman's patent application predated the filing date of MIT's Jay Forrester, who had been developing his approach to addressing cores well before Rajchman. In the interference proceeding between them, RCA's lawyers asserted that Forrester had never reduced his designs to

[10]W. H. Ware *et al.*, *RAND and the Information Evolutions: A History in Essays and Vignettes* (Santa Monica, CA: RAND Corp., 2008), p. 57. The $800 price may be missing a zero; Richard Endres of RCA Labs remembers $3000 as the unit price for the Cambridge Research Center Selectrons and the author had heard a price of $8000 from a former RCA Labs staff member during his tenure at the David Sarnoff Library in the 2000s.

[11]"An interview with Keith Uncapher," conducted by A. Norberg, Jul. 10, 1989 (Charles Babbage Institute, Minneapolis, MN), p. 4, http://conservancy.umn.edu/bitstream/handle/11299/107692/oh174ku.pdf?sequence=1&isAllowed=y, accessed Jun. 11, 2015.

[12]J. Ward, "Early transistor history at RCA: Richard Endres," pp. 3–4, http://semiconductormuseum.com/Transistors/RCA/OralHistories/Endres/Endres_Index.htm, visited Jun. 11, 2015.

[13]See E. Pugh, *Memories that Shaped an Industry: Decisions Leading to IBM System S/360* (Cambridge, MA: MIT Press, 1984), especially Ch. 2–3, for an excellent and thorough accounting of the people and groups involved in pioneering core memory.

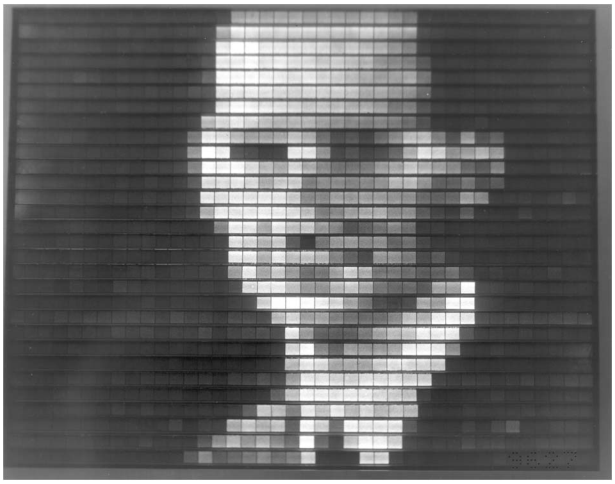

Fig. 5. *Image of Jan Rajchman on 30 × 40 pixel electroluminescent screen showing gray-scale addressing by Rajchman's transfluxors, c. 1957. (Courtesy David Sarnoff Library.)*

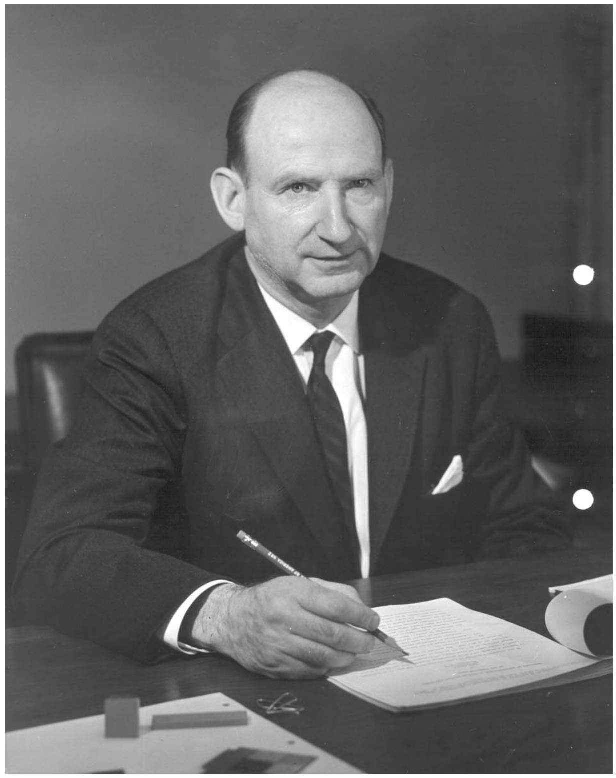

Fig. 6. *Jan A. Rajchman, director of the David Sarnoff Research Center's Computer Research Laboratory, 1965. (Courtesy David Sarnoff Library.)*

practice and that he had abandoned his invention in early 1951. After four years, the Board of Patent Interference agreed and awarded Rajchman priority on the broadest conflicting claims, those for coincident-current or -voltage selection of bistable magnetic elements with rectangular hysteresis loops.[14] Four more years of litigation between MIT, its licensing company, IBM, and RCA resulted in the world's most expensive patent license agreement, $13 000 000 from IBM to MIT. As IBM's production of cores leaped from half a billion in 1961 to 8.8 billion in 1966, even that price became a bargain.[15]

VII. FROM MEMORY TO FLAT-PANEL DISPLAYS VIA TRANSFLUXORS (FIG. 5)

As much as cores were an improvement over tube memory, Rajchman and others thought that there had to be a more efficient format.

> The idea was that an integrated approach was better than an individual approach. So, for example, we made plates with holes and asked, "How close can you put the holes?" We started to put the holes very close together. When we put the holes very close together, we found that they started to interact . . .. in ways that were very complex. That's what led to the concept of the transfluxor . . .. [W]ith two holes . . .. you could not only store "on-off" information but you could store a gradual amount. Furthermore, you could store it in a non-destructive way. A core, in order to know what it is, you have to reverse it and momentarily the information is lost . . .. But in a transfluxor the information that's around one of the holes always remains the same, and the information around the other one depends on what's on the first one, but it can be reversed indefinitely without affecting the other one. Therefore it's completely non-destructive. So, it's both non-destructive and analog and therefore provides all kinds of possibilities. For example, one possibility was to make a flat TV display, which we made at the time.[16]

VIII. MANAGEMENT AND MEMORY

In 1957, Rajchman began his rise through the managerial ranks at what was now RCA's David Sarnoff Research Center (Fig. 6). En route to becoming Staff Vice President for Data Processing and then for Information Sciences in 1971, he continued to shepherd efforts to improve the state of computer memory, through superconducting planes of

[14] Pugh, p. 86.
[15] Pugh, p. 213 and 249.

[16] J. A. Rajchman and A. W. Lo, "The Transfluxor," *Proc. IRE*, vol. 44, no. 3, pp. 321–332, 1956; J. A. Rajchman, A. W. Lo, and G. R. Briggs, "Transfluxor controlled electroluminescent display panels," *Proc. IRE*, vol. 46, no. 11, p. 1808–1824, 1958.

262 000 bits, magnetic bubbles, and holographic discs.[17] The state of the art at the dawn of personal computers, however, was exceedingly unsatisfactory in spite of the steady advances in core and disc technologies.

> [T]he memory of the computer is still something that needs great improvement. . . . which you would like to have more if you could afford it. . . . What you would really like is something in which you could store for centuries, yet have access in nanoseconds. It wouldn't cost you anything to do it . . .. However, memory is very expensive, and the fact is you still resort to mechanical motion which is like resorting to an ax in the days of electronics.

The problem was that

> There is no way of storing large amounts of information purely electronically. If you want to make transistor memories, . . . you still have to pay a tenth of a cent or so per bit; and if you want a million bits . . . you won't be able to afford it. If I want to transcend the problem beyond the point of a view of myself or even RCA . . ., finding a memory for a storage device that is a very cheap way of storing information . . . is the outstanding problem of electronics. Maybe not electronics, but some other science or technology will do it.

Rajchman recognized that as the cost of processors continued to drop, the demand for memory would continue to rise.

> [P]eople are going to improve semiconductor memories because the whole industry is going that way- and they are going to make them cheaper and bigger. That's going to become like the core memory used to be. It's going to be the yardstick that you have to beat by a big factor in order to come in.

Nonetheless, he observed, "it's very difficult to visualize that the technology of the semiconductor can be that good that you will be able to make 10 to the 12th." ■

[17] J. A. Rajchman, "Computer memories: A survey of the state of the art," *Proc. IRE*, vol. 49, no. 1, pp. 104–127, 1961; J. A. Rajchman, "Memories in present and future generations of computers," *IEEE Spectrum*, vol. 2, no. 11, pp. 60–65, 1965; J. A. Rajchman, "Promise of optical memories," *J. Appl. Phys.*, vol. 41, no. 3, pp. 1376–1383, Mar. 1970.