Jack Avins

The Essence of Engineering

by Andrew Goldstein[1]

In a recent article, respected historian of radio Hugh Aitken wistfully observed that "it takes controversies and confrontations to get an inventor into the history books."[2] Aitken's comment, unfortunately true to a large degree, is easy enough to understand. History, as the word reminds us, is a story, and dramatic stories are always the most popular.

But this tendency to focus only on the engineering stories that spill out of their technological domain into the courts of law or the corporate executive suites shortchanges the inventors whom it drives out of the limelight, and interferes with a correct understanding of the nature of technological progress. More meaningful and more revealing are the longer sagas of steady research, punctuated by regular triumphs, that characterize the bulk of engineering work. One valuable example of such story is that of a successful engineer named Jack Avins.

Avins, who worked for RCA between 1945 and 1976, patented more than fifty inventions that improved the performance of radio and television receivers. He is best remembered for leading the team that designed the first integrated circuit used in a television receiver, pointing the way for the current age when those chips are ubiquitous in television sets and other consumer electronics. Yet, before this landmark achievement, he earned the recognition and respect of the engineering world with his wide-ranging work designing radio and television circuits. Described by his colleagues as "Mr. FM," he was central to the development of two generations of circuits that each took their turn as the most popular means of detecting FM radio broadcasts. He applied that expertise to the audio circuits in television receivers, creating a reputation for himself as the master of this often overlooked side of television. He designed a system for broadcasting AM radio in stereo some twenty years before the industry ventured towards it. In the 1930s, he designed test instruments that revolutionized the radio repair business. In the 1970s, it was integrated circuits, with which he reduced whole subsystems of television sets to single modules. In between, he built a legacy of inventiveness and dedication that, augmented by his personal drive and his broad interests in matters of the intellect and the community, made an indelible impression on those who knew and worked with him. Jack Avins' career is a model study of technological innovation, and his accomplishments distinguish him as an engineer's engineer.

Beginnings

Jack Avins was born March 18 1911 in New York City, the second of four children.[3] His parents, Louis and Fannie Avins, had both emigrated from Eastern Europe to the United States as youngsters. In 1915, with their two young sons in tow, Louis and Fannie left the tumult of Manhattan, where they lived, and moved their family to a house they built themselves on the sparsely populated farmscape of Staten Island. Louis opened a hardware store, and the family settled in above it. Business prospered, and several years later, he opened a gas station across the street.

Jack grew up in an environment oriented towards craftsmanship. The men in his family, while for the most part lacking formal education, were technically inclined. Jack's uncle Nathan may have been an early influence on Jack's decision to pursue an engineering career. Making his living as an electrician, Nathan managed to put himself through Cooper Union, taking a degree in electrical engineering. After receiving his degree, he worked as an electrical engineer. Jack's older brother Samuel was also a role model. Sam worked on mechanical and electrical repairs and rebuilt car batteries at the family gas station. Jack must have found inspiration in his older brother, who managed not only to work in the family business, but at the same time attended City College, majoring in math and physics. When he graduated in 1929, the same year that Jack started college, Sam scored high on the Civil Service test for junior physicists and quickly found a job paying the impressive salary of $2,000 per year.

Complementing the technical interests of his family was Jack's parents' emphasis on education. Typical of many Jewish immigrant families of their generation, Louis and Fannie attached tremendous importance to seeing that their children were educated as fully as possible. Through their hard work and personal sacrifice, they could offer their children opportunities that had never been possible for themselves. Jack certainly lived up to his parents' expectations academically. Showing an enthusiasm for his classwork, Jack flourished in the close environment of his neighborhood's two-room schoolhouse and distinguished himself as an excellent student. His younger brother Jules, who went on to become a chemical engineer, recalled one of the first awards Jack won as a student:

> The first event that I remember was when Jack was in P.S. 11 on Staten Island. There was a Thomas Jefferson essay contest. He won it and the prize was a trip to Monticello, near Charlottesville, Virginia, on a Pullman train with all expenses paid. This was a tremendous event because nobody in the family had ever been on a train, let alone a first-class Pullman on an overnight train as far as Virginia!

In high school, Jack was on the permanent honor roll and was an elected member of the honorary scholastic society, Arista. He was also interested in sports and once enlisted his brother Jules to help him convert an empty lot near their home into a usable tennis court. The Avins brothers all had a keen interest in radio, and Jack built his own ham radio station—with both a transmitter and a receiver—and obtained his ham license. Jack and Jules had a close relationship, and the older brother coached the younger, his constant shadow, helping him to receive his own license when he was just fourteen.

Upon graduating from high school, Jack attended Columbia University, aided by a New York State Regents scholarship. Like his brother Sam, Jack double-majored in physics and mathematics. Initially he lived at home and commuted to school. Boarding the St. George ferry every morning, he would arrive on campus two hours after leaving home. After classes, he repeated the two hour commute back to Staten Island. He eventually moved to the city toward the end of his tenure.

Jack advanced through Columbia, making a record of distinction that matched what he had achieved in high school. With transcripts that boasted few grades other than A, even in the graduate-level classes with which he challenged himself, Avins had little trouble gaining admission to the Phi Beta Kappa honor society or earning an honors degree when he graduated in 1932. The year was a demanding one, however. The country was in the midst of the Great Depression and employment opportunities for young scientists were limited. Many of the important laboratories, such as AT&T's Bell Laboratories, had implemented a hiring freeze to hold down costs. They even reduced the work week for their full-time staff. Trained and experienced scientists flooded the job market, looking to fill the few positions available. Although he would return to school in 1949 to get a master's degree in Electrical Engineering from Brooklyn Polytechnic, in 1932 Avins only held a bachelor's degree and this must have further handicapped him in his search for a job.

Avins remained at Columbia as a tutor and instructor, responsible for leading recitation and laboratory sections and grading student exams. Although there are few records of his intellectual pursuits during this period, it is easy to imagine that someone with Avins' ambition pushed to involve himself in the lively electrical engineering environment of Columbia in the early thirties. Edwin Howard Armstrong, the inventor responsible for some of the most important advances in radio technology, had his laboratory there. Armstrong was legendary among radio engineers for, among other things, introducing the regenerative circuit to radio, the first successful technology to amplify faint radio waves and improve radio reception. During the early thirties, Armstrong made the fundamental inventions that permitted radio transmission using frequency modulation, a technique that cut static and noise significantly compared to the standard alternative, amplitude modulation. There is no evidence that Avins interacted with Armstrong, whose actual presence at the school was limited, but since both FM and regeneration were to figure heavily in Avins radio career, it is tempting to speculate that Armstrong was an influence.

In 1935, three years after graduating from Columbia, Avins found a job working for an outfit named John F. Rider Publisher, which published popular books and service manuals for electronic equipment. The company was owned by John F. Rider, a well-known figure in radio who broke into technical writing working with Hugo Gernsbach as "Editor of Maintenance" in Gernsbach's *Radio Craft* magazine, and its line of electronics publications included textbooks, informal tutorials written by experienced technicians, and reference works containing detailed schematics of popular electronic products. Working in Rider's laboratory, Avins had an opportunity not only to write, which he enjoyed immensely, but also to spend time testing circuits. It was here that he developed his first two inventions.

Avins and Rider worked in the lab on test and measurement instruments to improve radio diagnostics, focusing on the needs of the electronics service profession, the main audience for Rider's books. The principle tool for the radio technician at that time was the voltmeter, which servicemen could use to measure the strength of the radio signal as it passed through various stages of the radio set. The voltmeter of the late thirties had several significant limitations, however. Many models were inconvenient to use because they did not provide a direct reading of the voltage being measured; instead they required the serviceman to twist a knob on the meter while watching a small bulb called a magic eye.[4] The knob changed the meter's internal resistance, and the relation between the test circuit's voltage and the meter's resistance caused the size of the illuminated dot on the magic eye to change. When the light in the magic eye winked out—that is, when the bridge was balanced, to use the language of the serviceman—then the calibrations on the twisting knob's dial gave the test circuit's voltage.[5]

This procedure was both bothersome and tricky. The magic eye often flicked out abruptly, requiring some technique on the part of the serviceman to find just where the bridge exactly balanced. But more importantly, by relying on reduced input resistance to balance the bridge, the meter compromised its own "stiffness"—that is, it lessened its electrical isolation from the circuit being measured. With a reduced input resistance, the meter could not prevent electric current from flowing out of the circuit into the meter itself, which altered the very voltage the meter was intended to measure.

Avins and Rider together patented a voltmeter that overcame these problems. Using two triodes arranged in what was called the "long-tailed pair" configuration, the bridge in Avins' and Rider's meter balanced automatically, without operator adjustment. Their meter, which they called the VoltOhmyst, could maintain its highest possible input resistance, making it more accurate, and its results could be obtained easily, without skillful handling, by reading a needle that deflected over a graduated plate.[6]

Avins and Rider's other invention was a more complicated instrument they called the Chanalyst. This multi-faceted meter, called a "revolution in radio service," provided a comprehensive tool for diagnosing the most elusive of radio malfunctions.[7] The Chanalyst gave repair staff a potent weapon against their greatest nemesis: "intermittents," those touchy radio sets that worked erratically, malfunctioning only occasionally and apparently at random. These sets posed a formidable challenge to service professionals. Usual diagnosis techniques involved successive measurements made repeatedly at various important points in the set until eventually the problem occurred and the fault could be localized—a procedure that cost dearly in both time and frustration. The Chanalyst enabled a repair person to monitor several important conditions of a radio set's operation simultaneously and continuously. With four separate channels, the Chanalyst monitored the performance of a radio sets' radio-frequency, intermediate-frequency, and audio frequency circuits as well as its local oscillator.[8] It also provided a meter for voltage and power measurements.

Because Rider and Avins designed the Chanalyst to locate intermittent conditions, which might last for only a brief fraction of a second, the instrument needed instantaneous response. To achieve this, the pair returned to the magic eye tube indicator. Indicators that used needles over graduated scales, like the VoltOhmyst, could not offer instantaneous readings because of the inertia of the needle, which prevented the meter from reacting noticeably to quick changes, such as a temporary drop of voltage that lasted only 1/10000 of a second. Magic eye indicators, on the other hand, made such drops obvious since it was easy to see if they had shut off, even if only for an instant. The Chanalyst used four magic eyes, as well as a meter for more stable voltage and power measurements.

In order to sell the Chanalyst and the VoltOhmyst, John Rider established a manufacturing company called Service Instruments Incorporated, based in New York City. In April 1939, he hired Avins as chief engineer. Avins' employment agreement with Rider stipulated that Rider would receive the rights to any invention that Avins patented while in Rider's employ, with the two of them splitting the royalties and license fees equally.

The VoltOhmyst and the Chanalyst sold well.[9] Although veteran servicemen, interested in protecting specialized skills of their craft such as handling the sensitive magic eye voltmeters, might have turned up their nose at the convenience offered by the VoltOhmyst, the instrument was too useful for the entire profession to snub.[10] At $57.50 for the VoltOhmyst and $107.50 for the Chanalyst, Service Instruments was able to place one or both of their products on many radio service benches. Within months, Rider struck a deal with RCA, the dominant force in the American radio industry, to take over the manufacture and sale of the VoltOhmyst and the Chanalyst. In June 1939, he transferred the patent rights to RCA and became a consultant to that firm. Avins remained at Service Instruments as chief engineer.

In August 1941, with war looming ever larger, Avins enlisted in the service. He spent his first four months as an aircraft warning officer. In December, the Army promoted him from first lieutenant to captain and assigned him duty as a radar instructor with the Electronics Training Group in England.[11] Based at the Military College of Science at the Royal Army Ordinance Corps, Avins trained officers in radar theory and maintenance and after nineteen months of this duty, in June 1943, he was promoted to the rank of major and reassigned, this time to Fort Monmouth in New Jersey. There, at the Army Signal Corps headquarters, he served as the training publications officer. As chief of the radar division, he prepared and reviewed Signal Corps technical manuals and other training publications covering Signal Corps ground radar equipment. He left the military in March 1946, after earning several minor decorations and an army efficiency rating of superior.

When Avins completed his active military service, he returned to his family in Staten Island and began looking in the New York area for work as an engineer. Perhaps drawing on contacts he made while he worked with Rider, Avins arranged for an interview at RCA. Despite his impressive track record both before and during the war, he approached his job interview with trepidation. He need not have worried. RCA offered Avins a job at their Industry Service Laboratory (ISL) in Manhattan. This lab, organizationally distinct from the main research facility in Princeton, New Jersey, was an important element of RCA's overall business strategy. The ISL provided technical support for RCA's many patent licensees.

RCA, a large communications conglomerate, made a significant portion of its income from the licensing of patents. Would-be manufacturers of radio, and, of increasing importance, television receivers, often found that they were unable to produce electronic goods without using at least some of the numerous patents that RCA had either developed in-house or purchased from outside inventors. RCA had a well-established program of licensing these key patents, collecting a royalty payment from electronics manufacturers for every unit they sold that incorporated RCA inventions. Along with permission to use the patents, RCA offered its licensees free technical bulletins that disclosed the results of RCA's further research on the patents and the services of a state-of-the-art electronics research laboratory to help solve technical problems associated with the design of consumer electronics products.

The ISL expanded RCA's patent-licensing market by making the purchase of patent licenses more practical for firms that had only limited in-house resources, either intellectual or financial, for development. A typical assignment for the ISL staff might begin with a visit from a representative of one of RCA's licensees. This person would demonstrate his or her company's electronic product, or some particular circuit within, that did not perform adequately and ask the ISL engineers to uncover the problem. The lab's clients included, along with many smaller companies, well-known electronics manufacturers such as Admiral and Philco; the conspicuous exception was Zenith, which engaged a strict policy not to license RCA technology.

At ISL, Avins found a small, tightly knit group of engineers who combined their obligatory licensee support duties with more unstructured circuit design research motivated by personal curiosity. The chief engineer at the ISL was Stuart W. Seeley, widely recognized as one of the country's foremost FM circuit engineers. Avins soon struck a close working relationship with Seeley, assimilating all he could about the new radio technology called FM.

FM was still an unexplored domain at the end of the 1920s while the AM band had become an established commercial success. Although a few investigators had begun to explore the FM concept, many of their technical papers concluded with skepticism. In 1922 the influential Bell Labs scientist John Carson, for example, offered a thorough mathematical analysis demonstrating why FM could never rival AM as a system for transmitting information.[12] His analysis was not incorrect, but it did rely on several assumptions that did not continue to hold as time passed. Carson wrote in an era when AM broadcasters were struggling to squeeze as many of their 10 KHz channels onto the radio dial as they could.[13] He never imagined that FM broadcasts might use channels as wide as 200 KHz. He also failed to consider that FM broadcasting could be done in the then untouched reaches of the VHF band.[14]

By opening his eyes to both these possibilities, inventor Edwin Armstrong was able to develop a functioning FM radio system. Armstrong filed patents for key elements of his system in 1933, after many years of development and experimentation. So different were the electronics of FM radio from established AM art that Armstrong needed to invent many elements of his system from scratch. One of these elements was the *discriminator*, the section of the FM receiver that demodulates the FM carrier wave.

The discriminator played a decisive role in the overall sound quality of the FM system, so, naturally, engineers began work to improve the circuit's operation. An early success was the Foster-Seeley discriminator, first discussed in a paper published by Seeley and his partner Dudley Foster in 1937.[15] Getting a strong start through its inclusion in the first commercial FM receiver, General Electric's GM 125 which appeared in 1938, the Foster-Seeley discriminator became a mainstay in FM radio engineering.[16] It also set the stage for Seeley's next contribution, an FM demodulator he invented: the ratio detector.[17]

Trying to understand the exact nature and function of the ratio detector kept a battalion of engineers and lawyers busy during much of the late 1940s and early fifties. Seeley claimed that his circuit's unique operation simplified FM demodulation by eliminating the need for a special circuit called the *limiter,* which FM engineers placed in advance of frequency demodulators to smooth out all unwanted amplitude modulation in the FM wave. The ratio detector was self-limiting;[18] although accounts of the origin of this self-limiting have varied, all observers could agree that the difference between a ratio detector and a Foster-Seeley discriminator was slight.

Avins began working with Seeley on improving the ratio detector soon after he joined ISL. By 1947, he and Seeley co-authored a comprehensive paper which treated the circuit to a detailed analysis.[19] At almost the same time, Avins released, as sole author, an ISL bulletin on the ratio detector.[20] It is impossible to determine from the published literature precisely Avins' role in the circuit's continued development, compared with Seeley's. One might speculate that, given Avins' strengths, Seeley recruited Avins, because of his mathematical abilities, to work on improving the analysis of the ratio detector but, since the Foster-Seeley paper of the 1930s also boasted fundamental analysis and detailed mathematics, perhaps Avins added another element to the team: the experimental skills honed by his work with Rider.

The ratio detector was a centerpiece of one of the most noted and tragic legal episodes in the history of radio engineering. With Seeley's detector, along with several other FM circuits, RCA claimed to have created an original FM system that was not protected under the Armstrong FM patents of 1933.[21] In 1948, Armstrong sued RCA and NBC (the radio broadcast network which used RCA's technologies) for patent infringement. The epic court battle that followed so drained and dispirited Armstrong that six years into the proceedings, facing the prospect of another seven years of litigation before any decision would be made, he took his own life.[22]

The principle issue in the RCA-Armstrong patent suit was not whether the ratio detector (and the other FM circuits that RCA used) were duplicates of Armstrong's circuits but whether Armstrong's conception for FM was sufficiently defined to be patentable at all. Nonetheless, just as the legal proceedings began, Armstrong took the trouble to vent some of his considerable anger with RCA in an attack on the ratio detector he published as a technical paper in the *Proceedings of the Radio Club of America*.[23] In this paper, Armstrong argued that the ratio detector was not a new circuit at all, but merely a reconfiguration of an existing design, which was deliberately rearranged and confusingly described to obscure its true function. Armstrong's estate settled the legal wrangle with RCA after his death, and no conclusive judgment about the originality of the RCA circuits ever resulted, but today's electronics textbooks still offer a description of the ratio detector as a unique FM detection circuit.[24]

The ratio detector was just the beginning for Avins; under Seeley's influence, he gained expertise in all aspects of FM radio engineering. Unexpectedly, he found this training particularly well matched to RCA's research priorities of the 1950s, even though these veered sharply away from traditional radio.

In the years following World War II, RCA chairman David Sarnoff, consumed by a vision of the future of the consumer electronics industry, dedicated his company to the development of color television. After pushing RCA to the successful innovation of an entire television system during the 1930s, Sarnoff returned to television with characteristic determination after the war. Pushing other opportunities aside, he fixed on television as the mainstay for the company's future. For example, Sarnoff's reluctance to promote a technology that would rival television for space on the broadcast spectrum is one reason cited for why Sarnoff elected not to support Armstrong's FM system.[25] Of course, research on non-television projects did continue within RCA's walls—important examples include military radar systems, electronic storage systems for computers, and the electron microscope—but no observer could mistake the company's top priority. Sarnoff even promised the directors of the various television projects unlimited call on any of the company's research facilities in order to complete their missions.

RCA's "crash program" to develop its color television system, described by one weary participant as "an exhausting ordeal during which the RCA teams were probably subjected to heavier pressure than any industrial research group had ever before known in peacetime," is near legend in business and technology history.[26] The inference about a wartime research environment was appropriate; Sarnoff, who delighted in being addressed as "General" ever since he earned the honorary rank for his role in planning the communications logistics for the Allied invasion at Normandy, drove his engineers like foot soldiers on a forced march. RCA's main laboratory in Princeton, named the David Sarnoff Research Center in 1951, took lead responsibility for the high-profile portions of the project: systems and devices. The chief projects were to develop a color picture tube and design a system by which color could be included in a television signal that had been designed for black-and-white television only. As the pressure mounted, vacations were canceled and weekends interrupted. Cots began appearing on the laboratory floor.

At ISL, the color television emergency meant that the staff worked on television circuitry when not investigating issues for their clients. The lab, still under the direction of Seeley and his assistant Earl Anderson, split into two groups of approximately six engineers each. By 1950, Avins headed one of these groups, and led his staff, which included Bernard Harris and Joseph S. Horvath, in research on the processing of the incoming television signal. The other group, led by William Stoltz, focused on other aspects of television, such as the vital circuits used to synchronize the raster (the beam in the picture tube that forms the image on the glass) with the incoming signal.[27]

The television signal that is beamed through the air (or, increasingly, through a coaxial cable) is a complex melange of signals, each providing the television with different kinds of information. At its heart is the picture signal; this is the basic information that guides the television receiver in reconstructing the screen image. In addition, there is a chroma signal which supplies all the information the receiver needs in order to produce the right colors.

RCA's innovation, which ultimately placed the company in a superior position to all other television interests—CBS in particular—was to differentiate the chroma signal from the picture signal. Although they are transmitted together, the two are distinct and can be separated. This measure enabled RCA to make its color television transmissions compatible with the millions of black-and-white receivers already purchased by American households. The total signal for a color television picture can not only be received and displayed in full color by a color television, but it can also be displayed by a black-and-white television, which simply throws away the chroma portion of the signal.

The composite television signal also has the sound channel mixed in. Like the chroma signal, the sound portion is pulled out and run through its own circuitry. All of these signals nestle in an environment of multiple repeated pulses, whose steady arrival help the television receiver to keep all the activity synchronized. The prospect of developing all the different circuits to simply find and process the right parts of the signal, let alone optimizing those circuits' performance, represented a significant challenge for RCA's engineers, Avins and his staff included.

But Avins largely escaped the extraordinary incursions into his personal time endured by so many other of the RCA staff. His involvement in the push was no less consequential for his orderly work habits, however. He was one of ISL's most prolific inventors, making several significant contributions to the television circuitry art, most of which involved processing the sound portion of the television signal. This followed naturally from his interest in FM because the sound portion of the composite signal was an FM signal (although the composite signal itself was AM).

In particular, Avins invented several circuits that were useful in developing a comparatively new system for television sound, called intercarrier sound.

As indicated earlier, the sound portion of a television transmission is tucked inside a complex wave that is dominated by the picture information. The television receiver must pull out the sound at some point, process it, and direct it to the loudspeaker. In general, the processing includes three steps: amplification of the sound while it is still an FM signal; demodulation of the frequency modulation (using a ratio detector, perhaps); and final amplification of the demodulated audio-level signal. Meanwhile, the picture portion of the composite signal runs through a parallel process. There, too, the signal is amplified, demodulated (amplitude demodulated, in this case), and amplified again before being sent off to the picture tube. In the late 1940s, a scheme was proposed to handle some of the overlapping amplification action in a single stage. By delaying the point where the sound and picture were separated, the two signals were amplified together using just a single amplifier.[28] This system, called intercarrier sound, originated as a means to save money; the elimination of the duplicated amplifier meant fewer components in the receiver. But later discussion tended to focus on the system's technical merits, not its economic ones.[29]

Intercarrier sound found a dedicated advocate in Jack Avins whose interest probably stemmed from his partnership with Seeley and grew because of his appreciation of the system's elegance. In the mid-1950s, Avins worked on an improved FM detector that he intended for use in a television intercarrier sound system. These researches led him to develop an entirely new species of FM detector that was so successful, it displaced the ratio detector as the most popular type of FM demodulator. In 1955, he filed a patent application for the circuit, which came to be called a locked-oscillator quadrature grid FM detector.[30]

The quadrature grid detector achieved its superiority over earlier types of detectors through its simplicity and sensitivity. Unlike any previous FM detector, the quadrature grid detector employed feedback—that is, some of its output was rerouted to the input. In many cases, feedback of this sort, called positive feedback because the output is added to the new input, is unwanted and engineers struggle to eliminate it. In a circuit that amplifies the signal that passes through it, and then returns that amplified signal for another bout of amplification, it is easy for the signal to run out of control after just a few loops. Indeed, this is precisely what happens when microphones are held in the path of loudspeakers and a piercing squeal builds up. Feedback can be controlled, however. If the amplification of the circuit is just enough to balance the attenuation that the signal experiences as it makes its trek through the circuit, then a feedback circuit settles into a stable state. Avins harnessed this phenomenon, familiar to radio engineers since the early 1910s when Armstrong introduced his regenerative circuit to improve long-distance reception, and designed a circuit that was extraordinarily responsive to weak signals. The feedback system also permitted him to eliminate one of the several tuned circuits that were common to all FM detectors, making his circuit less expensive to build. This attribute later became more important, when electronics manufacture shifted from discrete components to integrated circuits. The quadrature detector was also effective at rejecting unwanted amplitude modulations, which was also the ratio detector's great strength.

Not all of Avins' television work involved the sound system, however; one important example was a circuit he called the noise inverter. Noise, to the electrical engineer, is an electrical disturbance that creeps in and distorts the signal the engineer is trying to preserve. A familiar example is the electrical noise that a vacuum cleaner creates when running, which causes the picture on televisions plugged into the same circuit to buzz and jump. The vacuum cleaner can always be shut off, but many sources of noise are harder to track down and even more difficult to eliminate. Indeed, the motion of the atoms that make up electronic components themselves contributes some noise to the signal. Recognizing that noise is inherent and unavoidable, engineers contrive elaborate systems to reduce it and recover from its deleterious effects. The problem, of course, is that noise does not announce itself with a calling card. Unless the signal is uniformly flat, any change in signal might easily be the signal itself, rather than a noisy distortion.

One problem that bedeviled television engineers was the effect noise had on the synchronizing pulses that frame the entire television signal. High levels of unfortunately timed noise would obscure one or more of these synchronizing pulses—much like a wild crowd whose screaming drowns out the quarterback's "hike!"—and cast the television picture into chaotic misalignment. Because noise of this type was commonplace—it might be generated by a passing car or an electric motor—engineers struggled to find an effective solution. Avins patented a circuit that tested for the presence of noise and, upon discovering it, moved in and turned it upside down.[31] With this circuit, extraneous noise that the receiver might mistake for synchronization pulses was inverted and kept below the television's threshold for attention. They slid by without accidentally triggering the receiver's synchronization circuits. The novel contribution of Avins' circuit was the inverting aspect, and it proved so useful that it became a common approach to suppressing this particular noise problem.

Avins also devised a new approach to strain the sound carrier wave from the picture signal. Before the picture signal can be processed and sent to the picture tube, the sound carrier, which is included in the composite television signal, must be removed. Isolating the sound carrier was a difficult problem in color television, however, because the sound carrier was transmitted within the composite television signal at nearly the same frequency as the chroma carrier, the portion of the signal that contained the information about the picture's color. Circuitry to remove the sound carrier that had been developed for black and white receivers proved inadequate; no one had taken the special care needed to preserve the chroma information because, of course, the monochrome signal did not include a chroma carrier. The situation left room for a wide range of compromise solutions that balanced the competing desiderata for picture quality, sound quality, and economy of design.[32]

Avins decided to design a new "trap" for the sound carrier, one that precisely targeted the audio signal while preserving undisturbed all of the valuable color information close by. He actually designed two traps: a stagger-tuned bridge trap and a bifilar-T trap. The bifilar (or two-layer) trap, suggested to him by M.D. Nelson, has been cited by Avins' colleagues as one of his most successful designs. Unlike earlier traps, which used filters and tuned circuits that attenuated the strength of the sound carrier, leaving just the picture signal behind, Avins' trap canceled the sound carrier by combining two sound signals from different places in the circuit.[33]

Some of Avins' other patents concerned television circuits as diverse as the automatic gain control, the color synchronization, signal transfer apparatus, and the sawtooth wave generator used to drive the picture tube's raster. Avins even dabbled in device development, although this was far outside his métier as a circuit engineer. Thinking he might improve the television's resolution, he conceived a picture tube that painted the picture over a greater proportion of the screen area. In existing tubes, the raster scans the same path over and over again, as if the screen were a phonograph record with a groove that the raster naturally falls into. Those grooves are close together (there are 525 of them in a full screen), but there is still an appreciable space between them. Avins imagined that if the raster moved slightly up or down with each frame, tracking a path that was just a hair offset from the path it had tracked the previous frame, the effect would be to fill in the space between the scan lines, and thus provide a smoother picture. He proposed that the space between each standard scan line be divided into some small number of sublines, perhaps ten, and that with each picture frame (there are 60 of them each second) the raster would scan a set of sublines that was one higher than the set it had previously scanned. So that instead of the raster hitting lines 1, 2 and 3 with each frame, it would hit lines 1, 2, and 3 in the first frame, but then in the second frame it would strike lines 1.1, 2.1, and 3.1 and in the following frame it would get 1.2, 2.2, and 3.2, and so forth.

Avins built a prototype and was pleased with his results, but he recognized that his picture tube lacked compatibility with existing transmission equipment. For his tube to work properly, the television camera would need to scan its images in the same gently rocking pattern. Because he knew he could not retool all the existing television infrastructure to gain this small improvement in resolution, he abandoned his idea. The decision was simultaneously typical and uncharacteristic of him. Avins was immensely practical. He saw no purpose in forcing some technical improvement that made no economic sense simply for the sake of its technical superiority. But he was also a forceful character with so supreme a confidence in his technical intuitions that he would have created difficulties for RCA had he not so often been correct. It seems clear that Avins dropped his picture tube idea because he alone concluded that it was not worth pursuing.

The balanced perspective that Avins exhibited in forgoing his picture tube research illustrates the range of insights that he brought to his work. His superiors at RCA recognized that this ability, along with the flair he showed for motivating his colleagues to meet his high standards as division leader at ISL, represented a valuable company asset. In 1956 they called on him to help establish an ISL in Zurich, Switzerland. So successful had the ISL in New York been (as well as the other ISLs which RCA maintained in Princeton, Chicago and Hollywood) that RCA decided to provide laboratory support to European licensees such as Grundig and Siemens.[34] The new Zurich facility was divided into two sections: one for research and the other for patent licensing. Avins was named lab manager of the licensing division and given official responsibility to follow up initial efforts to organize the laboratory along the lines of the one he left in New York. The licensing laboratory employed perhaps ten engineers when Avins arrived and his stewardship saw that number grow to a final complement of some thirty. His main focus was on specially developed circuitry for European broadcast standards, which differed from those in America. In addition to laboratory work, Avins spent considerable time organizing training programs and negotiating other arrangements with RCA's European partners. Fond of diplomacy, this suited Jack fine.

Not long after Avins returned from Europe in 1957, a shake-up from the outside dislodged him from his job at ISL. In 1958, RCA entered into a consent decree with the U.S. Justice Department to settle a long-standing investigation of the company's patent license policy. The government worried that RCA's licensing practices, which included compelling licensees to buy the rights to entire packages of patents, was unfair. RCA argued that its laboratories performed ground-breaking research that was essential for the entire electronics industry, and therefore the firm was within its rights to pass the cost of that activity on to the rest of the industry. Rather than proceed with expensive litigation over this dispute, which had been dragging on since the Justice Department filed its indictments in 1954, RCA agreed to abandon its rights to nearly all its existing patents. With the resulting decline in U.S. licensing revenue, RCA began to dismantle its Industrial Service Laboratory. In January 1959, Avins moved to the Sarnoff Research Center in Princeton to become manager of the research applications laboratory.

During this period, Avins had begun to think about broadcasting stereo sound. Hi-fi faddists had recently created an environment where stereo recording could catch on; stereo tapes were introduced in the 1950s and the first stereo phonograph records were released in 1957.[35] Following quickly on the heels of these developments were proposals to the FCC for stereo broadcasting. The system that ultimately won greatest public acceptance was, of course, FM stereo, endorsed by the FCC in 1961. With its broad bandwidth, FM offered the hi-fidelity that was a *sine qua non* for the enthusiasts for whom stereo mattered most. In the late '50s however, FM was still a tiny industry compared to AM. Moreover, RCA remained gripped by an animosity towards FM radio that had solidified, if not originated, with Sarnoff's dealings with Armstrong. Under these circumstances, Avins was motivated to look to the AM band for his stereo experiments.

But Avins' heart and brain were committed to FM. Almost predictably, his plan for AM stereo involved frequency modulation. He proposed a system he called "AM-FM," whereby the transmitted radio wave was modulated in a two-step process, using first FM and then AM, in order to graft onto it the two channels needed for stereo sound. He took advantage of the fact that in conventional AM, the transmitted information is placed on top of a carrier wave, which the receiving radio strips off and discards. Avins suggested making that carrier wave do double duty by not only modulating its amplitude to carry one channel of information, but also modulating its frequency as well to carry an entirely different channel. He guaranteed compatibility with existing monaural equipment by carefully selecting the content of the AM portion of the signal. Audio experiments, performed by other laboratories to support a compatible system of stereo phonograph records, had demonstrated that a signal comprised of two microphones' input, a "left plus right" signal, was aurally equivalent to the signal from a single microphone. Avins proposed using this signal, the left+right, as the AM portion of his AM-FM transmission, the one that would be picked up by existing AM radios. More complex stereo radios, which Avins would design, would be able to detect the frequency modulation that had been done to the carrier wave on which the left+right amplitude modulation rode. That signal was the signal from the "left" microphone *minus* the signal from the "right." Using a matrix of circuitry, the radio could then combine the "left plus right" with the "left minus right" to reconstruct the original signals reaching the "left" and the "right" microphones.[36]

With the support of Harry Olson, a director at the RCA Princeton Labs, Avins rigged up the transmitter for WNBC, the National Broadcast Company's radio station in New York City, to broadcast his AM-FM stereo signal for a few weeks in 1959 and then again in 1960. Positioning specially built stereo receivers at various locations throughout New York, New Jersey, and Pennsylvania, he collected data on the system's performance. After checking factors such as the quality of the stereo, its monaural compatibility, and the effect of the stereo on the strength of the signal, he concluded enthusiastically that his AM-FM system would provide effective stereo for AM stations. In late 1959, RCA petitioned the FCC to approve Avins' system for AM stereo broadcast.[37]

Nothing permanent came of RCA's AM stereo research, however, because the company's commitment to AM stereo was only luke-warm, at best, and NBC had never expressed any interest in stereo broadcasting. Given RCA's strong tradition in patent licensing, one suspects that the firm only supported Avins' work to the extent that it did in order to secure the basic patents that would emerge. If so, he didn't disappoint; the patents he earned on AM stereo are still consulted to this day. But when it became apparent that

RCA would only exert enough effort on AM stereo to protect themselves, Avins bowed out.[38] Work continued on AM stereo in the Princeton labs throughout the 1960s, but Avins was not involved.

Avins returned to AM stereo only in the early 1980s, when industry attention to the concept revived. By the late 1970s, FM had overtaken AM in listenership, its popularity spurred by a variety of technical, cultural, and economic factors. In an effort to reclaim competitiveness, AM broadcasters moved to improve the sound quality of their transmission; one direction they looked was toward stereo. Five separate and mutually incompatible AM stereo standards came before the FCC, which was expected to select one as the national system but in an unexpected move the FCC declined to favor any of the five. Embracing what they termed a free-market approach, the FCC permitted broadcasters to use any of the proposed systems, expecting that on its own, the industry would eventually settle on a *de facto* standard. The plan held peril, of course, for adventurous broadcasters and consumers who purchased equipment before any of the standards emerged as winner; if their choice of system turned out to be one of the losers, they would be out of luck. Avins fumed over what he perceived to be an abdication of responsibility on the part of the FCC. Although retired by that point, he attempted, without success, to reverse the decision with letters to politicians and newspaper editorial pages.

The AM stereo episode was not Avins' only involvement with technical standards. In fact, standards were a long-standing interest to which he devoted much attention throughout his career. Along with some of his engineers at ISL he published a paper in the 1954

Proceedings of the IRE that analyzed different sorts of distortion in television, concluding the only solution to these distortions was industry agreement on a standard type of television monitor.[39] A decade later, in 1964, he published another standards-oriented paper which evaluated the effect of a 1963 FCC order that permitted the reduction of the power of the sound signal in a UHF-channel television broadcast as compared with the power of the picture signal.[40] In this paper, which won the IEEE's Professional Group on Broadcast Television Receivers prize for best paper of 1964, Avins performed first an analytic and then an experimental investigation of the practice of television sound broadcast.[41] As an addendum to his scientific findings, he added a brief statement on the value of standards, writing, "The present permissive reduction in sound power on UHF poses a severe problem for the receiver design . . . . A single standard ratio of sound-to-picture power would eliminate this problem."

Not satisfied to simply pen the occasional advisory to his colleagues, Avins took action on standards when he was able. He was a member of the IEEE Standards Committee between 1951 and 1962, and then chairman of that same body from 1965 to 1975. He belonged to the Standards Subcommittee of the IEEE Television Receivers Committee between 1953 and 1957, even while he was chairman of the entire Receivers Committee between 1951 and 1955. Upon the inception of the IEEE Consumer Electronics Group in 1965, he was made chairman of its Standards Committee. In 1956, he served as the IEEE representative and chief delegate to the International Electrotechnical Commission. In the mid-1970s, at the end of his career with RCA, Avins focused much of his energy on drafting FM broadcasting standards.

Transitions: Entering the Solid State Era

If Avins' work following his move to Princeton seems more inchoate than that of his ISL tenure, it is because his early years at Princeton coincided with a period of drift and uncertainty within the RCA research organization. RCA research reeled in the wake of the decade-consuming drive to develop color television and, after a nerve-wracking commercial dormancy, color television finally began to emerge as a consumer product in the early 1960s. While the company eagerly collected the overdue return on its large investment, questions about what to do next quickly surfaced. Vice-President of the Princeton laboratory, James Hillier, took a conservative view that the booming color television market would level off before the end of the '60s. He struggled to align the company behind a new project that would take the place of television when that bonanza ended.[42]

At the same time, RCA faced an economic crisis with respect to its color television production. The television had become quite a complex device by the early 1960s, demanding many tubes and other components for its various subsections and production costs ran high in a number of ways. The components themselves were not only costly, but maintaining an inventory of them was a significant expense for the consumer electronics division. Furthermore, the labor costs increased as the manufacture process strained under the added work of interconnecting a larger number of components. Poor reliability was another problem that multiplied as the number of components grew. For the solution to both these problems—a new research frontier and an improvement of efficiency in television manufacture—RCA considered the new electronics technology of integrated circuits.

The integrated circuit (IC) was the apotheosis of the technological investigations into semiconductor electronics which revolutionized electrical engineering, following the invention of the transistor in late 1947.[43] Patented in 1958, the integrated circuit enabled engineers to produce entire circuits as monolithic units. Whereas conventional circuits were made up of a number of discrete components individually mounted onto a circuit board and then wired together, the integrated circuit was a single piece of semiconductor that included within its body many of the different elements of a circuit. The IC differed fundamentally from other attempts in the 1940s and fifties to miniaturize circuits because the electrical components that make up an integrated circuit were in no sense wired into place in the circuit. Rather, the components were part of the IC itself, differentiated from one another only by carefully controlling differences in the chemical structure of the IC as it was manufactured. And in the same way that the body of the IC made up the different circuit elements, so too did the IC's body serve as the wires that connected them all.[44]

The IC's development stemmed from a variety of pressures which followed from increasing transistorization of circuitry during the 1950s: a mania for circuit miniaturization, driven largely by the military, but also supported by several key consumer electronics products, such as hearing aids, radios, and watches; the high labor costs associated with component proliferation, which the military could ignore, but which firms such as RCA took quite seriously; and the quirkiness of component manufacturing, which left transistors with startlingly unpredictable properties, in particular, temperature response.[45]

Integrated circuits were still a new and primitive technology in the early 1960s, and RCA was not ideally situated to pioneer in their development. Although the source of several transistor innovations, RCA's semiconductor research was overshadowed in the 1950s by their enormous business of making and selling electron tubes, whose sales dwarfed those of semiconductors.[46] While focusing on the bigger market for tubes, RCA, like all of the established tube companies, was quickly outstripped in semiconductor electronics by nimble start-up companies.[47] Each effort RCA did make in integration proved to be a misstep. The company's semiconductor research focused on the element germanium, not silicon which allowed the formation of the oxide needed for successful ICs. In addition, RCA dedicated substantial resources investigating an Army Signal Corps research project called micromodules, which favored modular assemblies of discrete components (that interlocked much like tinkertoys) over truly integrated circuits.

Despite RCA's late start, Hillier held high hopes that integrated circuits would provide a lucrative direction for RCA's future. Apart from their use in military and consumer electronics products, the trend in ICs indicated that they might dovetail well with RCA's computer business which, though still in development, was expected to grow into a major source of profits in the 1970s. In 1963, RCA merged its semiconductor division, organized in 1955, with its electron tube division and launched a corporate initiative in integrated circuits.

The research focused primarily on digital logic circuits, which differed in nature from the circuits familiar from radio and television art (called *analog*, or *linear*, circuits) and were especially well-suited to integrated circuit technology. In particular, RCA was interested in an unproved IC technology called Metal Oxide Semiconductor (MOS), whose characteristics—slow speed, but power dissipation low enough to allow enormous concentration of circuit elements without incurring the disastrous heat build-up that poisoned any circuit's operation—matched the needs of digital logic perfectly. The semiconductor design and manufacture facility, located in Somerville, New Jersey, focused on researching this application of ICs.

Even so, RCA also considered integration for the linear circuits important to its core business of consumer electronics. The home instruments division, which manufactured the televisions and radios, was teamed with Somerville to explore the technical and commercial feasibility of using integrated circuits in its products. The project commenced with a search for a project leader. After considering people like Bernard Vonderschmitt, the director of the semiconductor research division, the laboratory management settled on Avins.

The choice was a good one. Avins had the broad experience with all aspects of television and radio circuitry to allow him to adapt to the inevitable surprises that integrated circuit implementation would bring. In retrospect, he wrote that the "circuit-design engineer is in a unique position to make the greatest contribution to the evolution and use of integrated circuits in receivers [because] the development of integrated circuits is a circuit and systems problem . . . . It appears far more efficient for the circuit-design engineer to learn the principles of integrated circuit design than it is for the device engineer to become a television receiver engineer."[48] In support of this contention, Avins noted that the complex job of interfacing even a perfect IC with the remainder of the television's circuitry was solely within the province of the circuit engineer.

Just as important, Avins possessed considerable skills outside the technical dimension that aided his leadership of the project. He was respected by the other circuit engineers and his hard-driven attitude, his excruciating standards of excellence for himself and his colleagues, and his refusal to back down from ideas he believed in all proved invaluable in surmounting the technical and bureaucratic obstacles that stood in the way of the project's success.

Avins needed to overcome the attitude of cautious skepticism that he encountered from the home instruments division in Indianapolis.[49] Staffed by a platoon of long-timers under the direction of Loren Kirkwood, Indianapolis had honed a way of making televisions that was profitable. The department, riding high on the long-awaited sales success of color television, resisted embracing the still uncertain technology of integrated circuits. The division countered Avins' proposal with legitimate questions about how much the ICs would cost and how well they would interface with the rest of the television and Jack needed to apply all of his hard-nosed diplomacy to secure Indianapolis' full cooperation. He convinced the department there to allow him to base his research in Somerville, near the company's solid-state researchers, while still being paid from the Home Instruments Division's budget.[50]

Avins then hand-picked his small team of engineers, looking for the most imaginative people he could find both inside and outside RCA. His first recruit in 1964 was Jack Craft, a gifted bench man who had begun working for RCA with no college degree. He found Craft without an assignment when the micromodules project was terminated. Next Avins obtained the service of Leo Harwood, whom he found working under Earl Sass on government projects at RCA's laboratory in Camden. Harwood, whose laid-back personality complimented Avins' own intensity, had grown bored with the military-inspired engineering style at Camden, which he characterized as expedient and lacking all regard for grace, elegance, or economy. Other engineers and technicians on the team included Steve Steckler, Erwin Whitman, Rudy Harford, Al Balaban, Bernard Yorkanis, Allen Limberg, Bernard Alexander, Mike Cow, Klaus Bahr, and Pat Griffis.

Avins and his team quickly assessed the technical and economic considerations affecting their project. The IC's cost effectiveness depended on a set of parameters that were entirely different from the ones to which they were accustomed.[51] With discrete component circuitry the cost is largely determined by the number of components. In particular, active components, such as transistors, cost the most and, obviously, the fewer transistors the engineer could get away with, the cheaper the circuit would be to manufacture. But integrated circuits presented a whole new economy. Because of the way ICs are made one does not, within certain limits, need a larger chip to put more circuit components in place. The cost of an IC was almost independent of the number of active components included on it, just as a book that has many words printed in it costs no more than one whose pages are mostly blank. Instead, what added cost to an IC was the number of external components required to interface the IC with the rest of the television's circuitry, but holding down the number of external connections promised to be a difficult job. Several common tools of the electrical engineer, such as inductors (components, often coils of wire, that store energy in magnetic fields) were not easily integrated. Circuits that required inductors had to be connected to discrete components that were located off the chip—thereby undermining the economy of the IC.

A similar situation existed with capacitors. These components, which store energy in electric fields, are (in their simplest implementation) a set of large electrically conducting plates positioned closely opposite each other with an insulator in between—almost like a pair of cymbals about to strike. Avins' engineers were able to fabricate capacitors on their integrated circuits but not at low cost. Large capacitance values took large amounts of chip area—"real estate" as the engineers called it—which made them costly. The problem was that the cost of an integrated chip, while largely independent of the number of circuit elements on board, depended very much on the size. The Somerville facility made chips in large batches, fabricating many at once on a large wafer of silicon, which they would break apart at the end into individual chips. The silicon wafers were expensive to prepare, and demanded numerous processing stages to attain the high levels of purity required. The larger each individual chip was, the fewer that could be derived from any one wafer of silicon. Consequently, larger chips were more expensive.

Inductors, capacitors, and even large resistors—components which were to radio engineers what the colors blue and orange are to seascape painters—had suddenly become too expensive to use.[52] Avins and his team understood that whatever circuits they hoped to integrate, they would have to do it without some of their most dependable tools.

This new component economy was the reason that linear ICs lagged behind their digital counterparts in the marketplace.[53] The relative ease of integrating transistors as compared with resistors, capacitors, and inductors meant that transistor-rich circuits would be the most successful ones to implement as ICs. Digital circuits, which realize their trademark on/off states with switches made of transistors, matched this profile. The ratio of transistors to passive components in digital circuits is far higher than it is in linear circuits. So strong was the bias favoring digital circuits for ICs that the trade press questioned the future of linear IC circuitry.[54] The only linear IC commercially available when Avins began in 1964 was a chip that Motorola had begun selling to hearing aid manufacturers the previous year.[55]

To beat this economy, Avins determined that his team needed to integrate a complete functional block of the television, that is, a subsystem within the television set that performed a specific job. He realized that it would not pay to integrate some portion of one of these functional blocks or some arbitrary selection of tubes spanning more than one block; to do so would require establishing interconnections between the IC and the different, off-chip components that comprised the rest of the functional blocks involved, defeating the purpose of the IC. Also, the simplifications of repair and service that the chip promised—easy location and replacement of defective parts—would have been compromised.

This last priority derived from a design philosophy that had never lost currency at RCA since the heyday of the micromodule program. RCA engineers in consumer electronics were ready to apply the lessons learned by engineers from the military division about systems engineering.[56] Avins' commitment to modularization of design, reflecting similar design trends in digital integrated circuits, was consistent with RCA thinking at the time.[57]

Avins has written, in retrospect, that with these considerations in mind, he and his group evaluated the different subsystems of the television and settled on the frequency-modulation-detection portion of the receiver as the circuit to integrate. In reality, the process was somewhat less orderly. Although the group was quickly able to rule out some of the television's subsystems, there was still a selection of circuits that were technically and economically feasible. Avins and his team began immediate work on a number of different subsystems, including, for example, the one to work with the picture (the Pix-IF subsection) and the one to control the color of the picture (the Chroma subsection.)[58] The only sections Avins ruled out were those demanding high voltage signals or high power handling. ICs could handle neither the high-voltages nor high power associated with the picture tube.

Although it was common for all of the engineers in Avins' group to work together to solve tough technical problems, for the different sections Avins divided the lead responsibility among his staff. For example, Harwood took charge of developing a chip for the chroma subsystem while

Avins, working with the close help of Jack Craft, concentrated on the FM sound system. This was the system that the Avins group finished first. Their success resulted in a chip which RCA placed in its black-and-white television receiver model KCS-153, released in the spring of 1966.

This chip was the first monolithic IC ever used in a television receiver.[59] Avins announced the advance in an article in the trade journal *Electronics,* in which he spelled out the technical details of the chip and pointed out the economies involved at each step. The chip had four functions: initial amplification to strengthen the signal; limiting, to remove any undesirable amplitude modulation; detection, to recover the audio information from the FM signal; and, lastly, audio preamplification, to ready the signal for the power amplifier that drives the loudspeaker. Together these constituted the entirety of the sound processing subsystem. The one IC replaced twenty six discrete components.

It would be a mistake to believe that the chief technical innovation around Avins' IC success was the vision to place integrated circuits within the television receiver. Although there certainly was some skepticism within RCA about the project, by 1964 there was no shortage of enthusiasm across the industry for ICs in consumer products.[60] In autumn 1965, the Admiral Corporation announced that it planned to include an integrated circuit in a color television receiver by 1967. Although guesses varied on the date when ICs would actually arrive—Zenith's J.E. Brown pegged it at three to five years down the road—the use of ICs in televisions was clearly imminent. Avins himself, when announcing his success, called the step "long-awaited."[61] To do proper credit to Avins' work, one must appreciate the details of the technical challenges that he confronted.

These were many. The team's strategy was first to develop a circuit in discrete components and then recreate it on a chip. Unfortunately, the procedure was not so straightforward. ICs were still new and the details of their use were not well established. For example, Avins hoped to use strings of diodes to supply the power for several of the transistors on his chip, a routine technique called 'biasing.' In a discrete component environment, diode biasing would be unusual. The engineer would be more likely to use resistors, which could be purchased at a far cheaper price. Avins planned to take full advantage of the relative low cost of active components however, and use diodes instead. In his discrete component prototype, Avins was able to reach into a bin he kept near his bench, pull out a handful of diodes and put them in place. When he fabricated the circuit on a chip, however, he found the diodes were not working. Although diodes, unlike inductors, had been successfully integrated on chips in the past, some unexpected production difficulties forced Avins to look for a new way to realize diodes in his particular situation.[62] Working with his team, he replaced diodes with transistors that had their base and collector shorted.[63] This solution was unimaginable with discrete component because transistors were more costly than diodes. On the integrated circuit, however, a transistor was just as easy to implement as a diode. Thus Avins' team had countered a problem raised by the special properties of the IC by exploiting another of its special properties.

Another example involved the creation of capacitors on the circuit. As indicated before, capacitors consumed great space. Avins searched for ways to obtain higher capacitance values per unit area of the chip. He achieved improvements in this area by using inexpensive transistors in an imaginative new way. Taking advantage of the fact that the IC was built up in layers, he built junction capacitors by tying the collector and emitter of a transistor together while using the transistor's base, which is at a different level, as the capacitor's other surface. Using this technique, the team was able to construct small capacitors.

All of this clever improvising to achieve difficult circuit components was not sufficient, however, to allow Avins to function as if he were working in the comfortable discrete component realm. The nature of the semiconductor material of the IC tossed one more obstacle in his path: in using ICs, Avins sacrificed control over the precise values for his circuit components.

When an engineer designs a circuit using discrete components, he or she performs the necessary calculations to specify the values for the components the engineer plans to include: 100 ohm resistors, 50 microfarad capacitors, and so forth. Before the solid-state era, this was straightforward and the manufacturers stocked millions of different kinds of resistors, capacitors, and other components, each carefully labeled and placed into bins with others of similar rating. Solid-state components made this practice more challenging. It was less easy, because of the chemistry of semiconductors, to predict the value of a semiconductor component based on its physical dimensions than it was with older components. When transistors were chipped off of a large piece of purified and prepared silicon, they might have a beta (amplification factor) of 100, or 180, or 240. It was not possible to prepare the piece of silicon to yield transistors of a precise beta. The discrete transistor manufacturers, such as Texas Instruments or Transitron, could handle this irregularity of output by simply altering their production approach. Rather than set out to make three batches of transistors of beta of 100 and six batches of beta of 175, they simply made nine batches and sorted them out into appropriate beta categories when they were finished. With large enough production facilities, things worked out statistically; engineers could still order specific transistor betas. An aura of imprecision hung over the whole process, however. The smart engineer knew not to rely too heavily on the rated values of a transistor.

This situation was exacerbated by the integrated circuit. Like transistors, ICs were cut from a large wafer of semiconductor material; thus, the values of their components eluded strict control. Unlike transistors, however, the individual components on an IC could not be measured, split apart, and saved for use in circuits where they were appropriate. When an IC rolled off the line with one of its capacitors at 100 picofarads, one of its resistors at 200K ohms, and one of its transistors with a beta of 125, Avins was stuck with that combination of values, even if the IC that followed it had its capacitor at 75 picofarads, its resistor at 112K ohms, and its transistor with a beta of 150.[64] Compounding these imprecisions, Avins faced chip-to-chip variation in how temperature changed component values. These facts forced him to adopt a design strategy that left his circuit immune to such uncertainties.

The solution was found in tracking. Avins couldn't control the value of his components values—he experienced margins of error of +/- 20% for resistors—but he did know that his resistors would *track,* that is, any two resistors on the same chip would have relatively close values.[65] If he used resistors in tandem, then he could exploit the fact that the value of the one resistor would be close (+/- 3%) to that of the other, even if he could not control the precise value of either. Avins designed circuits that relied on this particular kind of stability rather than the more conventional certainty of precise values.

In fact, Avins seized an opportunity to apply tracking to unique advantage. A nettlesome problem for solid-state engineers was the tendency of different solid-state devices, most notably transistors, to have their properties change unpredictably with changing temperature. Engineers understood that a transistor's performance depended on temperature, but the serious problem, particularly for complex circuits boasting many transistors, was that those changes were not the same for each device. Some transistors were robust in hot environments while others wilted quickly. With proper placement on the chip, however, IC components would track well with regard to temperature. So the IC offered relief from a major stumbling block of solid-state electronics. One place where Avins exploited this idea was with the biasing diodes mentioned earlier. He relied on the temperature-tracking feature of the diode in his circuit to provide thermally stable biasing for the other transistors he used in the circuit. In the discrete component world, not only would diodes have likely been too expensive for this application, but the engineer might not have been able to rely on their thermal properties being uniform.

Although Avins was not the inventor of this mode of design, he elaborated it with his work on ICs. His example influenced many IC circuit designers who followed simply by virtue of its priority. A lesser talent with circuitry, a duller mind with new ideas, might not have managed to make his circuit work in the IC *terra incognita.* Avins provided valuable precedent for a generation of engineers who were playing under new rules.

The qualities that made Avins successful at his assignment were not only his ability to work out tough solutions, but also his pioneering spirit which enabled him to turn his back on what he knew in order to try something different. For example, when designing the FM demodulator portion of his chip—the part that interprets what information is being carried on the FM signal—he ignored the familiar FM demodulator circuits, the two most popular of which he himself had developed himself, and considered using a counter demodulator, a new approach that was uniquely suited to IC implementation.

The counter demodulator is a digital approach to FM demodulation. It uses a counter to explicitly measure the frequency of an incoming wave rather than a tuned circuit that simply responds to it. By eliminating the tuned circuit, which is the heart of any ratio-detector or quadrature grid detector, Avins hoped to escape the need for an inductor, and thus a trip for the signal off the chip and into a non-integrable component. The digital approach took advantage of the strengths of the IC.

Portions of the sound subsystem were inescapably linear, but Avins did not want to pass up the opportunity to try to work digitally where he could. The IC trend was in that direction. His colleagues at the Somerville manufacturing division had more experience with digital circuits than with linear ones and the literature gave more digital examples. One other reason Avins probably considered a digital counter was the opportunity to break ground on still another generation of FM detectors. He had noted that a new generation of FM demodulator appeared every ten years: the discriminator in the mid-1930s, the ratio detector in the mid-1940s, and the quadrature grid in the mid-1950s.[66] If Avins was tickled enough by this pattern to comment on it, perhaps he was interested in preserving it.

The counter demodulator did not succeed, however. Avins found that the television needed the tuned circuit to stay oriented during channel switching. Moreover, in order to operate reliably, the counter demanded more certain values for its resistors and capacitors than the IC could deliver. It is illuminating, however, that he made the attempt. As an inventor who had done so much to develop FM demodulators that relied on inductors, Avins might easily have dismissed or even overlooked the prospect of an IC demodulator, one that would optimally be inductorless. It is to Avins credit that he rose to the challenge of this project by trying to rethink his specialty in modern terms.[67]

His adventurous foray into new turf reversed, Avins then tried to use a standard ratio detector as his demodulator, however, problems with the semiconductor environment frustrated all his attempts. He was bedeviled by the so-called parasitic capacitances that emerged as a consequence of the placement of components on the chip. He also encountered trouble balancing the values for the capacitors needed by the diodes in the ratio detector.[68] Success finally came when Avins again reevaluated the problem and designed a demodulator that relied on resistors rather than capacitors to provide load for the demodulator. Capacitors do more than just provide load, however. They also serve a critical filtering function, straining out the undesirable frequencies from the cacophony of signals that course through the circuit. Switching to a resistive load, Avins ran the risk of allowing his signal to be corrupted by stray signals. He was able to escape disaster, however, by enlisting the inherent capacitance (little valued and unintended, but nonetheless real and dependable) of his resistors and diodes. As an additional reward for his solution, Avins discovered that the resistive load helped to free his circuit from dependence on precise resistor values. Again, an IC drawback was redeemed by an IC expedient. Avins patented this innovation as an average detector.[69]

Another significant innovation in Avins' FM sound demodulator was his pioneering use of direct coupling between amplifying stages. Here, again, Avins rethought a circuitry staple to take advantage of the new IC economics. In typical sound circuits, the first thing done to the signal, even before it is demodulated, is amplification; this causes the signal to register stronger and minimizes the unwanted noise. The customary way to accomplish this is to pass the signal through one or more amplifying stages. The amplifiers are transistors (or tubes), and the links between them were generally capacitors. Avins' early models for his chip followed this pattern, but he soon grew dismayed over the cost profile of the design. He realized he could save chip real estate, and therefore money, if he could eliminate the capacitor from the link and couple the stages directly. This proved tricky to achieve, but he devised a solution by inventing a novel triad configuration of transistors which could be cascaded, one triad directly coupled to the next.[70]

Avins' IC chip was a technical triumph. The first IC to perform more than one function on a chip, it provided performance that was in every respect equal or superior to its discrete component counterparts.[71] Its design bestowed it with extraordinary flexibility, allowing Avins to promise that the chip would not only work in televisions, where the FM signal came in at a frequency of 4.5 MHz, but also in radios where it was 10.7 MHz, and in other private applications where the incoming signal might be anywhere between 455 KHz and 50 MHz.[72] Here, one size truly fit all.

This last feature, no doubt a source of great pride for Avins, mattered little for the chip's commercial fate. Somerville, the RCA division which manufactured and marketed the chip, never exerted any effort to sell it to the makers of FM radios or other radio transmission equipment. Although the chip's sound quality was good for television, it was not up to the high standards of FM radio. More importantly, the chip was expensive. Before production began, Somerville estimated that it would cost approximately $10 to manufacture each chip, compared to the subsystem of discrete components which cost just about $1.31.[73] The RCA Home Instruments Division in Indianapolis, the sole customer for the chip, informed Somerville that they were not prepared to increase the costs of their receivers just to pay the higher price for the chip. RCA, they reported, was beset by serious sales competition from Zenith and the upstart television manufacturers from Japan and could not easily afford to sacrifice price advantage. Negotiations ensued, and Somerville, under the direction of Bernard Vonderschmitt, finally agreed to sell Indianapolis the chips at competitive prices, absorbing the loss as an investment in scaling the learning curve. The industry had already witnessed rapid fall of prices for ICs in a market then dominated by digital circuits produced for the military: from $18.50 for an average chip in 1964 to $5.05 in 1966.[74] Commercial linear ICs, it was anticipated, would have to travel this same route.

Somerville's confidence proved to be well founded. Although the balance of its IC business tipped even more heavily in favor of digital circuits for computer applications during the late sixties and seventies, the division was able to manufacture some successful linear ICs as well. Not surprisingly, many of these emerged from Jack Avins' lab.

One of Avins' commercially successful chips was the CA3089 ("thirty eighty-nine"), a multi-function integrated circuit for FM radios that he announced in 1971.[75] Designed by Avins and Jack Craft, the 3089 was intended to serve as the heart of a simple, but high quality FM receiver. Requiring relatively little circuitry outside of the chip itself, and yet boasting excellent performance, particularly with regard to sensitivity, the chip became a mainstay in the car radio market. Unlike their first FM sound chip, large quantities of the 3089 reached the hands of electronics manufacturers other than RCA. Not only did Somerville sell them directly, but RCA also permitted other semiconductor manufacturers such as Motorola and National Semiconductor, to manufacture and sell the chip. In this arrangement, RCA took its royalty payment for the chip from the radio manufacturer. So ubiquitous was the 3089 that authors of engineering text books and historical articles have reprinted its schematic as an example of a model FM IC.[76]

An interesting aspect of the development of this IC involved handling the very high amplification it used to achieve its extreme sensitivity. Testing the 3089, a mandatory stage in the design of any IC, was particularly hard because of its hair-triggered response to input signals. Craft recalls that one of the important reasons that he and Avins were able to design a chip as sensitive as the 3089 in advance of other engineers was the unique test equipment they designed for it.[77] The story points out one more dimension of the ingenuity required for successful circuitry design.

Another important FM sound chip Avins worked on in the late 1960s was called the CA3065. Performing many of the same functions as his first FM sound chip, the 3065 featured some nice technical improvements which reduced the external circuitry needed to support the chip. First and foremost, with the 3065 Avins came closer to freeing himself from the scourge of the inductor. Combining two well-known circuit networks, peak detectors and differential amplifiers, he invented yet another new type of demodulator that eliminated one tuned circuit from the standard design.[78] The 3065 also offered volume control directly on the chip, supplied by the user through a knob on the television's control panel. Without this, more external circuitry would have been required, either to bring the signal back onto the chip after going off-board for volume control or to handle the final signal processing stages after volume control was carried out. These features helped to make the 3065 one of the most widely circulated ICs in history.[79]

One of the chip's most notable applications was in the RCA CTC-49, a color television receiver that RCA promoted heavily in early 1971 as a major technological breakthrough. Not the first color television to feature integrated chips, the CTC-49 nonetheless consummated in television receivers the modular design philosophy, brewing at RCA for over a decade, that Avins had embodied in his first sound chip. Representing (to the minds of its designers) "the greatest single departure from traditional circuitry and techniques in consumer electronics," the major subsystems for the CTC-49 were each self-contained on a modular board that used edge connectors to plug into sockets within the set.[80] The receiver featured six separate chips that together performed nearly every signal processing function within the receiver.

Of all the work done by his team on the ICs for this receiver, Avins was most satisfied by the CA3068, the chip that comprised the complete picture and sound intermediate frequency system. He recalled vividly the words of an engineer from Philips who in 1968 presented a paper at a professional meeting showing mathematically how unavoidable external feedback would prevent any attempts to integrate the Pix-IF system on a single chip. The problem, he said, was that the Pix-IF system inputs a high-frequency signal and then outputs that same signal amplified as much as 10,000,000 times (70dB). The output signal is so strong that it will certainly feed some signal back to the input, even though they are not purposefully connected, and cause uncontrolled oscillations. Avins laughed at the smug confidence of an engineer who worked mathematically and then didn't go to the bench to test his or her conclusions. His friends with him in the audience knew that the Avins team had already solved the feedback problem. By coupling the IF system with another subsystem of the receiver, the video detector, Avins insured that the signal output from his Pix-IF chip differed from the input signal (because the output signal was now at video frequency, unlike the IF input signal). This eliminated the potential for feedback, which only occurs when the output signal and the input signal are alike.[81]

At the end of 1971, RCA sent Avins to Japan to show off the CTC-49 and the electronic advances it represented to the company's Japanese licensees. On a grueling two-week tour, Avins visited the laboratories of Toshiba, Hitachi, Matsushita, Sanyo, Mitsubishi, Sharp, JVC, and Sony. RCA had chosen their envoy wisely; Avins' strong reputation among the Japanese earned him their respect and attention, and at each location he met with a warm reception. He typically began his visits by presenting a paper on the television set, where he referred to the technology within it as the second generation of integration in color television. Question-and-answer sessions would follow, in which his hosts would grill Avins on topics such as the history of linear IC development at RCA and a projection of future trends; the expected life cycle of the new (and old) ICs; using computer-aided-design for IC development; the present state and future prospects for MOS technology in linear ICs; and specific details about the development of the 3065.[82]

Avins returned, however, feeling that he had learned much more than those whom he had gone to teach—not about electronics, but about the comparative state of the two nations' television industries. RCA had been acutely aware of the growing presence of Japanese firms in the international television market, and lunch-time chatter among the engineers in Princeton commonly turned to those companies' successes in both sales and research.[83] But seeing the Japanese research facilities first hand was an eye-opening experience. Immediately after he returned to Princeton, he drafted a memo to M.H. Glauberman in Indianapolis, sounding the alarm bell that the United States was rapidly losing leadership in design and manufacture of color televisions. Avins observed that Japan was, to his surprise, beyond copying the Americans in circuit design.

Pointing out that Japan continued to reduce labor content of receiver manufacture through increased integration and plant automation, he called for "radical action on a wide front" for RCA.[84]

Avins waited several months but was not satisfied with the response to his memo. Not one to let a concern of his fall by the wayside, he composed another memo, this time addressed to RCA executive William Hittinger, entitled "Some Thoughts on Consumer Electronics Problems and Possible Solutions."[85] Here, he focused on what he believed were the management mistakes within RCA that allowed the company to hand its leadership role over to the Japanese. Taking his cues from Barton Kreuzer, who spoke on this subject before the IEEE Broadcast and Television Receivers Group in Chicago on December 4, and a September 1972 article in *Fortune* magazine, Avins criticized RCA's inability "to achieve the necessary teamwork among the planning, engineering, and marketing functions." He offered a detailed eleven-point plan to turn RCA's decline around that touched on nearly every aspect of the company's operation. In addition to straightforward technical recommendations, such as scaling back RCA's research on a particular circuit technology called hybrid ceramics, he ventured numerous explicit management proposals. Many of these were directed toward improving RCA's product line. For example, he suggested establishing managers with profit-center responsibility who could draw on the resources available within the large company to make a profitable "small business" and, at the same time, round out the product line and establish the desirable reality and image of broad leadership. Avins argued that only by reasserting RCA's pioneering role in the future evolution of color television could the company guarantee success for the other consumer products it planned to market, such as the Selectavision home video system, cable television, and the Home Information Center.[86] He also sought increased proving of finished products to try to hold the line on RCA's large warrantee expenses, profit sharing to attract the top engineers, limitations on the marketing departments demands (which had led to a proliferation of television models and chassis changes), and a renewed commitment to overall quality. In an explicit comparison to the Japanese approaches he observed, Avins recommended increased automation of production, augmenting the engineering staff from its present "pitifully inadequate" levels, and more generally, taking a long-term view of all business decisions.

Avins' criticisms of RCA's direction resonated with a company-wide anxiety about the RCA's slipping position in sales and research in several areas, color television in particular. In response to the negative trend, RCA launched the ColorTrak project, a new all-solid state television that was intended to establish a new standard for picture quality. Although Avins believed that RCA's problems required more than just a technological fix, he could hardly have resisted contributing to a major television research project; he took up the ColorTrak challenge.

The ColorTrak development effort, directed by William Hittinger, was a cooperative venture of the solid state division, the picture tube division, RCA laboratories, and the Consumer Electronics division that hearkened back to what was perceived as the glory days of the RCA R&D in the early 1950s. At its heart was an improved picture tube that used new phosphors to heighten the picture's contrast, particularly under bright light. The set automatically adjusted the color and brightness to optimize the picture under varying conditions of room lighting and broadcast signal quality. A wide array of other picture-enhancing features were added, many of which involved new circuitry from Avins' research group. Key contributions included a transversal filter that improved picture detail through a "sharpness" control; improved video amplifier circuitry, such as tapped delay lines to implement something like a combing function to improve the luminance (picture) signal; reduction of background noise on bright red fields, which had long been the toughest color to display smoothly; improved and enhanced filter grid delay to give better transient response; and an economical sound chip, the CA3134, which added to the on-chip functions a power amplifier which directly drove the speaker.

The Engineer Looks Outward

The ColorTrak was Avins' last major project at RCA. In 1976, he retired from the company, leaving the position of Staff Scientist in the Systems Research Laboratory, a responsibility he was given in December 1975. This milestone marked the commencement of his post-RCA years, a period marked not by a slackening of pace and decline of output, but simply by a refocusing of interests. Dividing his time between diligent efforts to improve his golf game and more cerebral pursuits, Avins did not allow his retirement to slow him down.

With his native intellectual curiosity catalyzed by concern over the acceleration of the economic developments he had begun to consider in his closing years at RCA, Avins began reading extensively in political economics. And he began to write. With the chance at hand to indulge his longstanding passion for essay composition, Avins prepared editorial pieces on a wide-ranging field of topics that he published in major U.S. newspapers and magazines.[87] Some of the issues he tackled included proposed anti-trust action against AT&T in the early 1970s, declining test scores for students, Palestinian activities in the Middle East, and several local political matters.

But the principle theme that he turned to again and again in his writing was the economic conditions and practices that were contributing to what he perceived as the sharp decline of the United States. He effectively expressed both the object and the intensity of his concern in the opening paragraph of a 1978 editorial entitled "We're Drowning—Help!"

> There is an overwhelming clear and present danger that our American way of life may not be able to survive the flood of imports reflected in our huge systematic trade imbalance, double-digit inflation, and the significant trend toward foreign ownership of our key industries, banking, and natural resources. Why has the situation gotten so badly out of control and how can we deal more effectively with it?

Other problems that he considered in this essay include unemployment, the urban crisis, and the energy crisis.

Avins faulted American leadership for the country's trouble, beginning with President Carter who, Avins charged, failed to vigorously attack America's problems as if they were (as Carter had phrased it) "the moral equivalent of war." For example, Avins saw a contradiction in the administration's stance towards energy. Although the message from Washington stressed conservation, he noticed that Secretary of the Treasury W. Michael Blumenthal and Commerce Secretary Juanita M. Kreps's solution to trade deficits with Japan and West Germany—requesting that those countries inflate their currencies to enable them to purchase more U.S. products—would entail increased energy consumption and further depletion of natural resources as U.S. industry overproduced to meet the inflated need. He also criticized the federal government's practice of tying wages in labor contracts to the cost-of-living price index because he agreed with economists who regarded this as guaranteeing an inflationary spiral.[88]

Avins was prepared to offer his own solutions to many of the problems he identified. These solutions were of a technical and policy-oriented nature, reflecting both aspects of Avins' capabilities.

A prime example of the two-pronged approach was Avins' efforts towards easing the energy crisis. Like many people at that time (and since), Avins found the United States' dependency on foreign oil particularly worrisome. He undertook to reduce it in several ways. He penned a column for *Newsweek* magazine in which he stressed conventional fuel saving strategies such as carpooling, the 55 MPH speed limit, increased use of mass transit, as well as other proposals including a $1 per gallon tax on gasoline and increased research on gasohol.[89] He also submitted in 1979 a comprehensive gas conservation program to then New Jersey Senator Bill Bradley.

In addition to these measures, Avins applied his unique inventive talents to the problem. In 1978 he took out a patent on an automobile transmission that saved gas through the use of an automatic free-wheeling mechanism.[90] His device switched the car from free-wheeling to direct drive transmission whenever the driver accelerated, and then returned the car to free-wheeling when the brake was depressed. Another idea he worked on was an invention to allow the accelerator to control the speed of the vehicle, not the speed of the engine—a response to his observation that many drivers only slightly relax pressure on gas when coasting downhill. Avins' son Larry recalls driving city streets in the prototype that Jack built in his garage. The engine stopped when the car came to rest at a traffic light, he remembers, and then started up again when Avins pressed the gas.[91]

His greatest concern, however, was the United States' surrender to Japan of leadership in several industries, including electronics and automobiles. Avins took the arguments he had made to some of his superiors at RCA—concerns about American companies realizing short-term profits through licensing of important technologies and reduction of research and development budgets—to the Op-Ed pages of numerous newspapers, just as the popular press began to see a surge in popularity of books by economists on U.S. industrial policy. He published several short pieces in a variety of places, including *The New York Times*, but made his most comprehensive case in a lengthy essay he published in the *IEEE Transactions on Consumer Electronics* in 1984.[92]

In this article, Avins lashed out at Japan for what he perceived as a hostile assault by that country on the United States consumer electronics industry. Guided by popular economist-authors such as Marvin J. Wolf, Lester Thurow, Russel Braddon, James Reston, and Robert B. Reich, Avins sounded a familiar alarm about what he saw as Japan's Ministry of International Trade and Industry (MITI) encouragement of predatory trade practices—namely, dumping and protectionism—intended to undermine the success of American companies. Alluding to the ideas found in Braddon's book *Japan Against the World 1941-2041: The 100-Year War for Supremacy,* Avins prophesied that the outcome of the trend in U.S.-Japanese trade would be the economic conquest of the United States by Japan. He foresaw the day when the United States would be "a tenant in [its] own land," where "more sophisticated, high-value-added work was systematically done in Japan, or supervised from Japan, and the more routine and pedestrian tasks parceled out to [Americans]." For Avins, the question was one of national independence.

Avins' analysis was outspokenly critical of Japan and its trade practices. Recognizing that this position exposed him to charges of "Japan-bashing," Avins considered seriously the possibility that his position was reactionary or jingoistic. As a check of his objectivity, he conscientiously debated the issue with those who were close to him; his son Larry, in particular, pressed his father about this aspect of his views. Over time, Avins succeeded in quieting his doubters. Larry came to understand that his father's criticisms about Japan were, in truth, criticisms about America, in particular of the short-sighted corporate leaders and the idealistic economists who endorsed free-trade without ever pausing to reconsider its validity in the twentieth century world. Avins strove to alert America to the threat to its own culture. He believed that America's corporations, which bore primary responsibility for the prospects of America's citizens by virtue of their position as employers, were selling out the American people and condemning the nation to a future of marginalized economic status and decrepit cultural values by chasing immediate profit. When, in his notes for a book he planned to write called "The Japanning of America," he considered "A Nation of Hucksters" as the subtitle, he was referring not to Japan, but to the U.S., projecting its sad destiny if current trends did not reverse.

Avins' 1984 article in *IEEE Transactions on Consumer Electronics* presented his account of Japan's alleged abuses not so much to indict Japan, but to initiate a critique of the free-market theory that the United States endorsed as its fundamental economic principle. He observed that free-market theory, as defined and articulated by Adam Smith and David Ricardo, was an eighteenth-century invention that had never been subject to rigorous empirical test. He claimed that the theory—dogma, he called it—was sanctified in the minds of American economic thinkers and that alternative positions were dismissed as backward and heretical. Just as Avins scoffed at engineers who relied solely on theory to inform their technical judgments, so too did he question the economists and policy-makers who counted on the unobserved, invisible hand of free-trade theory to do its job of maximizing the wealth for all trading partners. He called for America to examine the realities of twentieth-century trade and adopt, for its own preservation, an unapologetic protectionist barrier to foreign products.

Avins' son Larry recalls that his father's protectionist stance derived from his interest in protecting social freedoms that he held to be central to the American ideal. The senior Avins' observations of the path of the U.S. home electronics industry raised his suspicion about one of the cornerstones of classic free-trade theory: the principle of comparative advantage. Avins reasoned that the general application of this principle would progressively narrow the range of opportunity for young people (especially in less well-developed countries) as each economy specialized in what it was able to do best. The danger was that the pressure for each country to facilitate distribution of goods and services to its citizens as efficiently as possible tended to restrict the economic diversity that provided varied outlets for each citizen to realize his or her individual potential. In America, that meant that as the economy transformed to emphasize service functions such as marketing, American citizens would lose the opportunity to work at research, development, and manufacturing jobs. Avins argued that the benefits of economic diversity, while not measurable in terms of price, would nevertheless continue to be of inestimable value and were worth protecting. Thus he offered a humanistic slant on the old rational for protecting "infant industries" which he saw as very much a part of the American tradition.[93]

In his paper, Avins discussed several problems he noticed in free trade and then outlined his own idea for a system of international trade. He recommended that nations be permitted to buy the products of other countries, but only so far as the sale of their own products can pay for the purchases. His system prohibited the sale of national assets to support purchase of foreign consumer goods. With this simple restriction, Avins hoped to eliminate the chance of trading in a way that endangers a nation's independence.

Avins' essay was sophisticated enough to win a $300 prize as best paper presented to the IEEE Consumer Electronics Society in 1984, but it could never have solved issues as thorny as free trade and foreign competition. In the years since he published it, economic thinking on these questions has only grown more contentious. Although some American corporations continue to complain about being excluded from Japanese markets, the end of the eighties brought an abatement in popularity of the sort of "economic warfare" literature that influenced Avins. One of the writers whose ideas Avins invoked to support his attack on free market theory, Paul Krugman, has recently published articles arguing that foreign competition is a dangerous obsession distracting Americans from the true troubles with their economy.[94] It would be interesting to read Avins' response to articles such as Krugman's and to world economic development in general, but, unfortunately, this will not be possible. On June 5 1993, Jack Avins died at the age of 82. He is survived by his wife Ellen, his son Laurence, a retina surgeon, and his daughter Carol, a professor of Slavic Languages and Literature at Northwestern University.

Envoi

Over the span of his career, in which he earned fifty-five patents, Jack Avins was much recognized by his fellow engineers for the excellence of his work. In 1947, he won an RCA Laboratories Award for his work on the ratio detector. He was awarded this prestigious honor a second time in 1978, when he shared recognition with other member of the ColorTrak team for their success in bringing certain revolutionary video concepts from research to commercial product. RCA's highest award, the Sarnoff Award, went to Avins in 1971, when he was cited, along with Bernard Vonderschmitt, for excellence of a team effort and leadership in the timely development of superior integrated circuits for use in television receivers. Avins was named a Fellow of the Institute of Radio Engineers in 1957; he won the IEEE's Professional Group on Broadcast Television Receivers best paper award in 1964, the IEEE Consumer Electronics Society's best paper in 1984, for his analysis free trade, and the IEEE Consumer Electronics Society's Outstanding Contributions Award in 1976 for his exemplary work, particularly in editing and promoting standards. In 1994, he was elected to the New Jersey Inventors Congress and Hall of Fame.

APPENDIX 1

JACK AVINS' PATENTS

Patent No.	Invention	Filing Date	Issue Date
2,227,381	Electrical Testing System	5/5/38	12/31/40
2,240,635	Electron Discharge Tube System	3/18/39	5/6/41
2,291,648	Electrical Testing Method and Apparatus	2/15/39	8/4/42
2,595,441	Angle Modulated Carrier Wave Receiver	2/27/48	5/6/52
2,609,443	Keyed Automatic Gain Control	12/29/48	9/02/52
2,637,774	Keyed Noise-Clipping Circuits	12/15/50	5/5/53
2,644,082	Automatic Gain Control System	2/23/49	6/30/53
2,681,948	Noise Limiter for Television Receivers	8/24/51	6/22/54
2,685,673	High Frequency Test Probe	7/28/49	8/3/54
2,686,221	Simplified Combination Frequency Modulation and Television Receiver	11/03/49	8/10/54
2,712,568	Color Synchronization	7/23/51	7/5/55
2,717,920	Noise Cancellation Circuit	5/16/51	9/13/55
2,776,338	Variable Level Noise Clipping Circuit	12/15/50	1/1/57
2,811,580	Signal Separation System for Color Television Receiver	9/13/54	10/29/57
2,844,739	Sawtooth Current Wave Generator	7/1/53	7/22/58
2,873,314	Noise Immune Signal Processing Circuit	1/5/54	2/10/59
2,898,398	Frequency Selective Circuits	8/28/53	8/4/59
2,907,960	Signal Transfer Apparatus	4/26/54	10/6/59
2,913,579	Frequency Variation Response Circuit	10/18/55	11/17/59
3,046,335	Noise Protection Circuit for Television Receivers	11/24/59	7/24/62
3,068,475	Stereophonic Sound Signaling System	10/7/59	12/11/62
3,080,453	Stereophonic Sound Receiver System	11/13/59	3/5/63
3,103,554	Interstage Network Using Cancellation Trap as Effectively Untuned Coupling Between Resonant Circuits	10/19/55	9/10/63

APPENDIX 1

JACK AVINS' PATENTS

Patent No.	Invention	Filing Date	Issue Date
3,114,889	Desired Frequency Coupling Circuit Having Undesirable Frequency Cancellation Trap Located at Voltage Null Point for Desired Frequency	9/14/54	12/17/63
3,165,581	Keyed AGC Circuit With Means for Controlling Horizontal Sync Pulse Level of Signals Below the AGC Threshold	5/16/62	1/12/65
3,167,614	Multiplicative Stereophonic Sound Signaling System	3/16/59	1/26/65
3,319,004	Tuning Indicator System for Multiplex Radio Receivers	7/30/62	5/9/67
3,355,669	FM Detector System Suitable for Integration in a Monolithic Semiconductor Body	9/14/64	11/28/67
3,366,889	Integrated Electrical Circuit	9/14/64	1/30/68
3,383,607	Frequency Modulation Detector Circuit Suitable for Integration in a Monolithic Semiconductor Body	9/14/64	5/14/68
3,399,353	FM Counter-Type Detector Especially Suited for Integrated Circuit Fabrication	6/2/67	8/27/68
3,444,477	Automatic Frequency Control Apparatus Especially Suitable for Integrated Circuit Fabrication	3/2/67	5/13/69
3,462,694	Frequency Modulation Detector Circuit Providing Balanced Detection Over a Wide Range of Signal Levels	2/28/66	8/19/69
3,467,909	Integrated Amplifier Circuit Especially Suited for High Frequency Operation	6/29/67	9/16/69
3,495,178	Signal Translating and Angle Demodulating systems	1/24/68	2/10/70
3,512,098	Transistor Electrical Circuit with Collector Voltage Stabilization	8/28/67	5/12/70
3,519,944	Angle Modulation Discriminator-Detector Circuit	2/15/68	7/7/70

APPENDIX 1

JACK AVINS' PATENTS

Patent No.	Invention	Filing Date	Issue Date
3,531,657	Integrated circuit Amplifier Biasing Arrangement	2/29/68	9/29/70
3,564,125	Television Integrated I.F. Amplifier Circuits	3/3/69	2/16/71
3,569,740	Signal Translating System Providing Amplification and Limiting	12/27/66	3/9/71
3,577,167	Integrated Circuit Biasing Arrangements	2/29/68	5/4/71
3,614,546	Shielded Semiconductor Device	1/7/70	10/19/71
3,667,060	Balanced Angle Modulation Detector	8/26/70	5/30/72
3,673,499	Combining Tuning and Signal Strength Indicator Circuit with Signal Strength Indication Derived From Each IF Amplifying Stage	8/26/70	6/27/72
3,678,405	Amplifier-Limiter Circuit with Reduced AM to PM Conversion	8/26/70	7/18/72
3,678,406	Variable Gain Amplifier	8/26/70	7/18/72
3,679,816	Control Apparatus for a Color Television Receiver	3/29/71	7/25/72
3,697,885	Automatic Frequency Control Circuits	12/4/70	10/10/72
3,804,981	Brightness Control	11/2/72	4/16/74
3,812,289	Television Receiver Using Synchronous Video Detection	11/6/72	5/21/74
3,938,181	Automatic Luminance Channel Frequency Response Control Apparatus	10/21/74	2/10/76
3,961,361	Gain Control Arrangement Useful in a Television Signal Processing System	5/23/75	6/1/76
3,984,865	Transient Suppression in Television Video Systems	3/26/75	10/5/76
4,084,672	Automatic Control of Free Wheeling	12/24/75	4/18/78
4,577,226	Noise Reduction for FM Stereophonic Systems and Particularly Useful in Television Audio Systems	11/30/82	3/18/86

APPENDIX 2

JACK AVINS' PUBLICATIONS

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Brady, T.J. and Avins, Jack, "A Low-Cost Sound Detector for Television Receivers" *RCA ISL Bulletin* LB-1000 (October 20, 1955).

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Avins, Jack, "Sound Signal-to-Noise Ratio in Intercarrier Sound Television Receivers" *IEEE Transactions on Broadcast Television Receivers* Vol. BTR-9, no. 2 (1963): 9-17.

Avins, Jack, "Integrated Circuits in Television Receivers" *IEEE Transactions on Broadcast Television Receivers* Vol. BTR-12, no. 3 (July, 1966): 70-74.

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Avins, Jack, "Advance in Integration of Color Television Receivers" *RCA Engineer* Vol. 16, no. 5 (Feb./Mar, 1971): 32-33.

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Avins, Jack, "Economic Issues Confronting the US. Consumer Electronics Industry: An Inquiry into their Nature and Resolution" *IEEE Transactions on Consumer Electronics* Vol. CE-30, no. 2 (May, 1984): 99-107.

Avins, Jack, "Britain's Deindustrialized Fate a Portent" *New York Times* (June 19, 1986): A26.

Avins, Jack, "Value of Protection" *New York Times* (May 1, 1987): A34.

Avins, Jack, "Cost of Reagan Reign Far Exceeds Benefits" *New York Times* (January 18, 1989): A30.

Avins, Jack, "Ways to Deal with the Japanese" *Sarasota Herald Tribune* (March 29, 1989): A11.

APPENDIX 3

ORAL HISTORY INTERVIEWS

INTERVIEWEE	**INTERVIEWER**	**DATE**
Allen Limberg & Roy Christensen	*William Aspray & Andrew Goldstein*	*July, 1993*
Leo Harwood	*Andrew Goldstein*	*April 13, 1994*
Kerns Powers	*Andrew Goldstein*	*May 18, 1994*
David Holmes	*Andrew Goldstein*	*May 24, 1994*
Eugene Whitacre	*Andrew Goldstein*	*Jume 3, 1994*
Ellen & Carol Avins	*Andrew Goldstein*	*June 12, 1994*
Jack Craft	*Andrew Goldstein*	*June 15, 1994*
Larry Avins	*Andrew Goldstein*	*June 17, 1994*
Al McCovsky	*Andrew Goldstein*	*June 30, 1994*
Jules Avins	*Rebecca Hartman*	*November 30, 1994*

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[1] The author would like to acknowledge the invaluable contributions of Ellen Avins, Larry Avins, and Carol Avins, members of Jack Avins' immediate family who were all generous with their time and insight. Most of all, I would like to express my appreciation for Professor Sidney Ratner, a close friend of Jack Avins. A distinguished scholar himself, Professor Ratner first suggested that the remarkable case of Jack Avins might make an interesting subject for study and it was only through his efforts that such study became possible.

[2] Hugh Aitken, "John Stone Stone: A Memoir," *Proceedings of the Radio Club of America, Inc.* 68, no. 2 (November 1994): 63–69.

[3] Much of the biographical information presented here derives from conversations with members of Jack Avins' family (see list of interviews in Appendix 3). The author thanks Rebecca Hartman for her assistance with this portion of the paper.

[4] A popular magic eye indicator was the Radiotron type 6E5 tube.

[5] The "bridge" is nothing different than the famous Wheatstone bridge, which scientists had been using to test unknown voltages since the mid-nineteenth century.

[6] The VoltOhmyst offered 16 megaohm input resistance on the lowest six of its nine voltage ranges (which spanned 0-5 to 0-500 volts) and 160 megaohms on the highest three. Other instruments of that day could do no better than 1000 ohms per volt input resistance. For

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more technical information, see C. Orval Parker and Brian Belanger, "VTVM History: The Rider VoltOhmyst," *MAARC Newsletter* (February 1993): 8-9

[7] For the assessment of the Chanalyst's significance, see Parker and Belanger, "VTVM History," 9.

[8] It is universal practice in radios (and televisions) to use special circuits to reduce the frequency of the wave received by the antenna (the radio frequency wave) to a fixed frequency, called the intermediate frequency (IF). This permits the engineer to design most of the radio's circuitry to operate at one specific frequency, the IF, rather than any of the broad spectrum of frequencies found on the dial. After all signal processing is done, the frequency is reduced again, from the IF down to audio frequencies, the range of frequencies to which the human ear is sensitive. This audio frequency signal is the one sent to the loudspeaker. The local oscillator is crucial for these frequency reductions.

[9] Letters to Avins from his father during World War II report of quarterly royalties for Avins between $430 and $725.

[10] Industry reaction to the VoltOhmyst described by Alan Douglass in personal communication.

[11] For more information about this group, see Ruth Sadler and Lt. Col. Herbert H. Butler, "History of the Electronics Training Group in the United Kingdom," GIC Planning and Records Section, Military Personnel Branch, 1944. A typescript copy of this report was

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discovered in 1992 at the U.S. Center for Military History in Washington, DC.

[12] John Carson, "Notes on the Theory of Modulation," *Proceedings of the IRE* 10 (1922): 57-64.

[13] The size of the channels indicates how far apart on the radio dial adjacent stations may be. As channels are made smaller, the range of audio frequencies that may be carried by the radio signal is reduced. On the other hand, as channels are made larger, the number of stations that can fit on the radio dial goes down.

[14] These points are well made by David Morton in "Edwin Howard Armstrong and the History of FM Radio," *Proceedings of the Radio Club of America, Inc.* 64, no. 3 (November 1990): 171-177. The VHF band is frequencies between 30-300 MHz. Technology to use these very high frequencies did not emerge until the 1930s.

[15] D.E. Foster and S.W. Seeley, "Automatic Tuning, Simplified Circuits, and Design Practice," *Proceedings of the Institute of Radio Engineers* 25, no. 3 (March 1937): 289-313.

[16] See William O. Swinyard, "The Development of the Art of Radio Receiving from the Early 1920s to the Present," *Proceedings of the IRE* (May 1962): 793-798.

[17] Most commentators (for example, Andrew Inglis, *Behind The Tube* (Boston: Focal Press, 1990), 152, and Tom Lewis, *Empire of the Air: The Men Who*

Made Radio (New York: HarperCollins, 1991), 310) have misidentified the inventor of the ratio detector as Bell Laboratories scientist Stuart L. Seely. This is incorrect.

[18] The ratio detector was insensitive to these amplitude modulations because its output did not depend on the actual strength of the demodulated signal ('strength' is another word for amplitude here), but only on the ratio of the strengths of two different signals at two different places in the circuit.

[19] Stuart Seeley and Jack Avins, "The Ratio Detector," *RCA Review* 8 (June 1947): 201-236.

[20] Jack Avins, "The Ratio Detector," *RCA Licensee Bulletin* LB-710 (May 26, 1947). The licensee bulletins were the main organ by which RCA circulated the ISL's findings among the licensees.

[21] The other circuits include the Beers receiver. Inglis, *Behind the Tube,* 152 and Lewis, *Empire of the Air,* 310.

[22] The Armstrong-RCA legal battle is covered in great detail in a number of places, many heavily biased in Armstrong's favor. See Lawrence Lessing, *Man of High Fidelity: Edwin Howard Armstrong* (Philadelphia: J.B. Lippincott Company, 1956), or Don V. Erickson, *Armstrong's Fight for FM Broadcasting: One Man vs. Big Business and Bureaucracy* (University of Alabama Press, 1973). A more-evenhanded description is available in Inglis.

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[23] Edwin H. Armstrong, "A Study of the Operating Characteristics of the Ratio Detector and its Place in Radio History," *Proceedings of the Radio Club of America* 25, no. 3 (November 1948).

[24] See, for example, Dennis Roddy and John Coolen, *Electronic Communications,* 3rd ed. (Reston, Va.: Reston Publishing Co., 1977), 356-359. It is possible that contemporary acknowledgment of the ratio detector is due more to the historical fact that the circuit is spoken of by electronic engineers than to the circuit's originality.

[25] This reason may be secondary to his interest in pioneering the new television technology in order to replenish RCA's pool of patents as some of the older radio patents expired. See Margaret Graham, *RCA and the VideoDisc* (Cambridge: Cambridge University Press, 1986).

[26] For the full story, see George Brown, *And Part of Which I Was: Recollections of a Research Engineer* (Princeton, NJ: Angus Cupar Publishers, 1982), Inglis, *Behind the Tube,* and Graham, *RCA and the VideoDisc.* The quote is found in Graham on p. 62.

[27] The division of responsibility was described by Al McCovsky in oral history interview with the author. McCovsky stressed that the division was informal and malleable.

[28] See R.B. Dome, "Carrier Difference Reception of Television Sound," *Electronics* (Jan. 1947).

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[29] Stuart Seeley, "Design Factors for Intercarrier Television Sound," *Electronics* (July 1948): 72-75.

[30] U.S. Patent 2,913,579.

[31] See U.S. Patents 2,637,774; 2,681,948; 2,717,920; and 2,776,338.

[32] Avins spells these out in Jack Avins, "The Design of IF Amplifiers for Color Television Receivers," *IRE Transactions of the Professional Group on Broadcast Television Receivers* PGBTR-7 (July 1954): 14-25.

[33] See McCovsky interview, listed in Appendix 3.

[34] Other American electronics firms set up operations in Europe in this period to tap the valuable scientific potential that was lying underutilized in post-war Europe. See the example of Texas Instruments in Andrew Goldstein, "Finding the Right Material: Gordon Teal as Inventor and Manager," in *Sparks of Genius,* Frederick Nebeker, ed. (Piscataway, NJ: IEEE Press, 1993).

[35] See C.A. Schicke, *Revolution in Sound: A Biography of the Recording Industry* (Boston: Little, Brown, & Co., 1974), 147-155.

[36] Jack Avins, et. al., "A Compatible Stereophonic System for the AM Broadcast Band," *RCA Review* (September 1960): 299-359.

[37] Petition of Radio Corporation of America for Approval of Standards for the RCA System of Stereophonic Broadcast Stations, November 12, 1959.

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[38] Avins earned at least three U.S. patents for his system: 3,068,475; 3,080,453; and 3,167,614. The assessment of RCA's interest in AM stereo derives from a phone conversation between the author and Kerns Powers, a former colleague of Avins' who is presently consulting the Avins patents for a client.

[39] Jack Avins, B. Harris, and J.S. Horvath, "Improving the Transient Response of Television Receivers," *Proceedings of the IRE* (January 1954): 274-284.

[40] The FCC no doubt issued the directive in order to ease requirements for UHF stations, which suffered from low viewership for a variety of technical and non-technical reasons, and allow them greater freedom to broadcast their pictures at higher power. The directive was made in the same "boost-the-UHF-stations" spirit as the decision to require all TV manufacturers to include a UHF tuner on their TVs, which the FCC issued the same year.

[41] Jack Avins, "Sound Signal-to-Noise Ratio in Intercarrier Sound Television Receivers," *IEEE Transactions of the Professional Group on Broadcast Television Receivers* 9, no. 2 (1964): 9-17.

[42] See Graham, *RCA and the VideoDisc*, 85-87.

[43] General accounts of the development of solid state electronics are found in Ernest Braun and Stuart Macdonald, *Revolution in Miniature,* 2nd ed. (Cambridge: Cambridge University Press, 1982); Dirk Hanson, *The New Alchemists: Silicon Valley and the Microelectronics Revolution* (Boston: Little, Brown,

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& Co., 1982); T.R. Reid, *The Chip: How Two Americans Invented the Chip and Launched a Revolution* (New York: Simon & Schuster, 1984); among many others.

[44] This last feature is due to the planar process, contributed in 1959 by Robert Noyce who shares credit for the invention of the IC with Jack Kilby.

[45] This list derives from Braun and Macdonald, except the last item which has been all but ignored in the literature. These are causes for the origin of the IC *concept.* Braun and Macdonald argue that the IC's success in the market once invented was due to oversupply of discrete transistors in the early sixties. *Revolution in Miniature,* 87-88.

[46] For an interesting account of RCA's early transistor work, see Edward W. Herold, "The Early History of Complementary Symmetry," *Old Timer's Bulletin* (1993).

[47] See Braun & Macdonald, *Revolution in Miniature,* 61.

[48] Jack Avins, "Integrated Circuits in Television Receivers," *IEEE Transactions on BTR* T-BTR 12, no. 3 (1966): 70-74.

[49] The insights about the Consumer Electronics Division derive from oral history interviews between the author and several of Avins' partners at RCA. The representation of the home instruments divisions' stance toward innovation clearly reflects the biases held by

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Avins' side of the dispute. Others at RCA remember Indianapolis to be a dynamic and widely respected organization, responsible for more patents used in television sets than the Sarnoff Labs (see personal communication from Eugene Whitacre to author). It appears that personal judgment and perhaps also corporate politics were important factors in determining one's position on this question.

[50] For details on RCA's Somerville facility, see E.M. Troy, "Integrated-Circuit Operations at RCA Somerville—A Review," *RCA Engineer* 13, no. 1 (June–July 1967): 9-13.

[51] See Norman W. Parker, "History of Usage of Active Devices in Radio & Television Receivers (1962 to Present)," *IEEE Transactions on Consumer Electronics* CE-30, no. 2 (May 1984): 90.

[52] The top values Avins could attain were 50 picofarads for capacitors and 30,000 ohms for resistors.

[53] See Donald Christansen, "Integrated Circuits in Action: Digital IC's a Natural; Linears Loom on the Horizon," *Electronics*, October 17, 1966, 73. This trend only deepened with the introduction of MOS and CMOS ICs, which permitted the LSI and VLSI characteristic of computer chips.

[54] See Christansen, "Integrated Circuits in Action."

[55] See J. Sinclair and W. Druz, "A 'Microlithic' Hearing Aid Amplifier," *IEEE Transactions on Audio* T-12, 6 (Nov.–Dec., 1964): 118-120. A contender for the

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honor of first linear IC in a commercial product might be the chip described in Edgar Sack, "Consumer Electronics: An Important Driver of Integrated Circuit Technology," *Proceedings of the IEEE* 82, no. 4 (April 1994): 465-468. However, Sack acknowledges that this chip, designed at Westinghouse in late 1961 for use as an amplifier in a phonograph, never went into volume production.

56 See side bar by Lewis Young in Jack Avins, "It's A Television First . . . Receivers With Integrated Circuits," *Electronics,* March 21, 1966, 137-142. See also James Hillier, "New Perspectives for Consumer Electronics," speech delivered October 19, 1964 at IEEE Consumer Electronics Award Dinner.

57 Avins, "It's a Television First . . . ," 137.

58 Oral history interview with Jack Craft, June 15, 1994.

59 "Monolithic" ICs are the type considered thus far in this paper. The term refers to ICs that have their elements formed on or within a semiconductor substrate, with at least one element formed within. Other types of ICs include thin film, thick film, and hybrid.

60 See side bar by Lewis Young in Avins, "It's A Television First . . . ," 137-142, and Christiansen, "Integrated Circuits in Action."

61 Avins, "It's A Television First . . . ," 137.

62 Jack Craft, who related this story to the author, explained that the *p-n* junction would inject carriers into substrate, getting cross-coupling into adjacent devices

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on the semiconductor material, and the diode would latch up.

[63] The 'base' and 'collector' are two of the transistors three leads. The third is called the 'emitter.'

[64] To be more accurate, the IC that followed it would not have wildly different values. It was ICs cut from a different wafer that could be different. But since no production run that was anything close to economical involved just one wafer, the consequence is the same.

[65] Assuming, of course, that they were intended to have similar values. The +/- 20% figure is given by Avins in "It's A Television First . . . ," 139.

[66] He mentioned the pattern in an internal release he authored to describe his invention of the quadrature grid detector.

[67] Avins eventually did patent a counter-type detector, U.S. Patent 3,399,353.

[68] Craft interview.

[69] See U.S. Patents 3,383,607; 3,462,694; and 3,467,909.

[70] See Whitacre interview.

[71] See interview with Craft for the claim about multiple functions.

[72] The 4.5 MHz and the 10.7 MHz are, respectively, the intermediate frequencies for television intercarrier sound and FM radio.

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[73] See Whitacre interview.

[74] The figures are from P.R. Morris, *A History of the World Semiconductor Industry* (London: Peter Peregrinus, Ltd., 1990), 50.

[75] J. Avins, "Advances in FM Receiver Design," *IEEE Transactions on Broadcast Television Receivers* (1971): 164-171.

[76] Dennis Roddy and John Coolen, *Electronic Communications,* 3rd ed. (Reston, Va.: Reston Publishing Co., 1977), 360; and Irving E. Lempert, "The Development of Consumer Radio From Late 1950s to the Present," *IEEE Transactions on Consumer Electronics* CE-30, no. 2 (May 1984): 84.

[77] See Craft interview.

[78] See U.S. Patent 3,519,944.

[79] The claim is made in the Jack Craft interview, but no sales data exist to confirm it.

[80] E. Lemke and J.A. Konkel, "New Generation Color-TV Receiver," *RCA Engineer* 16, no. 5 (Feb./Mar. 1971): 3. See also L.P. Thomas, "A Modular System for Consumer Electronics," in the same issue for RCA's position on modular design.

[81] J. Avins, "Advance in Integration of Color Television Receivers," *RCA Engineer* 16, no. 5 (Feb/Mar 1971): 32-33.

[82] Some indication of the state of Japan's progress in integrating television receivers is given in Masanori

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Ogino, and Yozo Tanihara, "Introduction of Revolutional [*sic*] IC's into Color TV Receivers," *IEEE Transactions on Broadcast Television Receivers* BTR-18, no. 2 (May 1972): 91-97.

[83] A comprehensive source for information on relative market share for the leading TV manufacturers is Jonathan David Levy, "Diffusion of Technology Patterns of International Trade: The Case of Television Receivers" (Ph.D. diss., Yale University, 1981), 84-88. His figures differ, however, from those presented in Inglis, suggesting penetration of Japanese receivers in the US market occurred at a later date. Inglis' figures (*Behind the Tube),* while presented less systematically, are more consistent with the recollections of subjects interviewed for this paper. Comments that Levy makes about his sources suggest that perhaps Inglis is to be given more credence.

[84] Memo to M.H. Glauberman, 1972, in Jack Avins' personal papers.

[85] A copy of the memo, dated December 21, 1972, is found in Avins' personal papers.

[86] Selectavision was RCA's early home video playback system. Its story is told in great detail in Margaret Graham *RCA and the VideoDisc* (Cambridge: Cambridge University Press, 1986). "The Home Information Center" probably refers to plans resulting from RCA's research on Homefax, a system of transmitting textual information within the TV signal which viewers could print out on printers connected to

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their TVs that RCA explored during the late 1960s. See W.D. Houghton, "Homefax: A Consumer Information System," *RCA Engineer* 16, no. 5 (Feb./Mar. 1971): 59-63.

[87] These include *The New York Times* and *Newsweek.* See Appendix 2 for complete list of his publications.

[88] Economists such Rosenzweig of Washington University who wrote on the matter in *The New York Times* July 21, 1977.

[89] The column was written in October 1979 and appears to have gone unpublished.

[90] U.S. Patent 4,084,672.

[91] Interview with Larry.

[92] Jack Avins, "Economic Issues Confronting the U.S. Consumer Electronics Industry: An Inquiry into their Nature and Resolution," *IEEE Transactions on Consumer Electronics* CE-30, no. 2 (May 1984): 99-107.

[93] I am indebted to Larry Avins for bringing this aspect of Avins' thoughts to my attention. Indeed, the phrasing of the portion dealing with comparative advantage is his.

[94] See, for example, Paul Krugman, "Competitiveness: A Dangerous Obsession," 73, no. 2 (March/April 1994): 28-44.