PROCEEDINGS OF THE IEEE THROUGH 100 YEARS: 1940–1949

I. INTRODUCTION AND OVERVIEW

The 1940s was one of the most turbulent decades in our planet's history (Fig. 1). In the first half of the decade, with much of the globe being drawn into the most destructive conflict mankind has known, most of the industrial production of the United States, as well as many other nations, went toward wartime efforts (Fig. 2). Radio engineering was no different, and the field experienced tremendous wartime growth. While most engineering research was classified during the war itself, the vast amount of resources dedicated to research and development hastened the pace for a number of breakthroughs that would dominate the course of engineering through the rest of the decade and onwards.

During the 1940s, industrial production, in many nations, went toward wartime efforts, and while most engineering research was classified during the war itself, the vast amount of resources dedicated to research and development hastened the pace for a number of breakthroughs.

Before the United States involvement in the war, trends in radio engineering had expanded upon the landmark developments from the 1930s, the most significant of these being frequency modulation, television, and the exploration of ultrahigh frequencies. Radio receivers were getting smaller and more popular, and in May 1940, the Federal Communications Commission (FCC) had set aside 40 channels for FM broadcast stations [1]. By 1941, more than 20 FM stations were actively maintaining regular transmitting schedules [2]. Most of the work done on frequency modulation in the prewar period consisted of refinements and further detailing of existing technologies, and six of these papers appeared in the PROCEEDINGS OF THE IRE during the 1940–1941 period.

Television was another area of expansion in the early 1940s. In 1940, several experimental television broadcast stations were in operation, with an estimated 4000 receivers in use. Various demonstrations of color television were made during 1940, and the FCC would adopt the National TV Standards Committee (NTSC) standards for black and white television, authorizing the broadcast of commercial programs in 1941. While television progress was scaled back during the war, and television broadcasting was suspended, the industry experienced rapid growth in the postwar period, with the number of broadcast stations increasing from six in 1946 [3] to 16 in 1947 [4] and to 51 in 1948 [5]. Other applications of television led to developments in the fields of astronomy and electron microscopy.

After the United States entered the war in December 1941, most of radio research and manufacturing was dedicated to wartime needs. Radio manufacturing was considered vital to the war's progress and radio apparatuses for war use were produced in record numbers. Several manufacturing companies who previously had not made radios were now beginning to produce radio and other electronics. The boom in manufacturing brought in a great deal of new workers in the field, including large numbers of women, who would be employed in a wide range of positions spanning research technicians, machine attendants, and radio operators.

While nearly all of the pioneering research conducted in the period between 1942 and 1945 would remain classified until after the war, papers continued to be published on refinements for transmitters, antennas, receivers, frequency modulation, piezoelectricity, and television. Though many radio stations were shifted to wartime needs, international radio broadcasting was substantially increased. One area of research which emerged during the war is the study of radio wave propagation. While the full implications and advances were published after the war's end, a large amount of literature was published during the wartime period; seven

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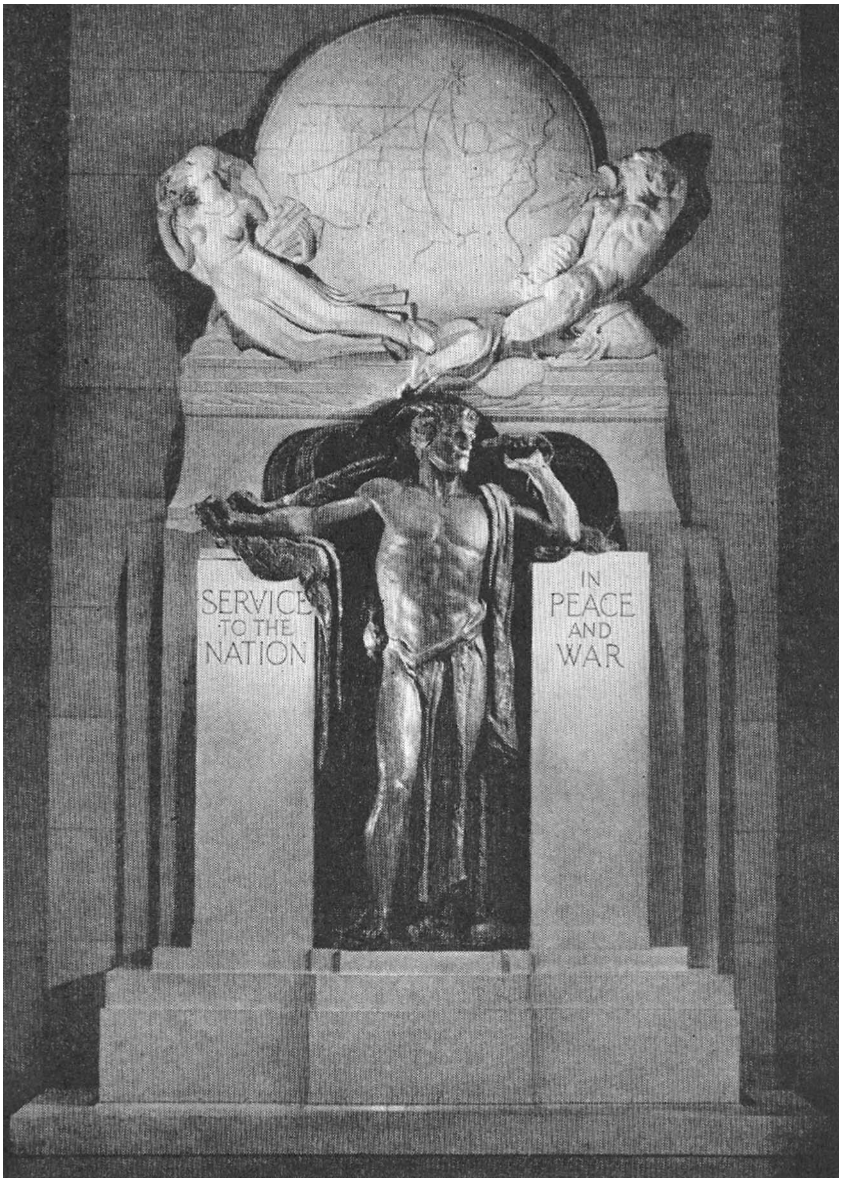

Fig. 1. ***An advertisement by Bell Telephone System. Original caption: "Following the last World War a bronze and marble group was placed in the lobby of the American Telephone and Telegraph Company building in New York..." (from Proceedings of the IRE, vol. 30, no. 1, Jan. 1942, p. xv).***

books and over 100 papers were published between 1942 and 1944 on the subject [6].

After the war's conclusion in August 1945, a great deal of the theoretical base for the pioneering research done during the war became declassified. The military applications of new techniques in radio engineering were quickly adapted to peacetime needs. Methods relating to radio navigation, or radar, would be made available in 1946, and by 1947 radio navigation would be applied on a large-scale basis for commercial airlines and shipping. Pulse methods, developed for the war for a variety of purposes, including radar, would have a great deal of practical applications. A great deal of influential literature involving pulse methods was made available in 1946, and research on pulse-code modulation would be made available in 1947 [4].

Wartime research greatly diversified the publishing activity in the Proceedings. In addition to the wartime developments in radar and pulse methods, the fields of nuclear studies and electronic computing emerged, as well as an expansion in communications theory sparked by Claude Shannon's (Fig. 3) 1948 paper "A mathematical theory of communication" [7] and his 1949 follow-up "Communication in the presence of noise" [8]. These papers introduced several key theorems as well as mathematical and geometrical representations of communication theory [9].

In addition to its technical areas experiencing rapid growth, the IRE itself also experienced a period of tremendous expansion. Membership increased from over 5000 members in 1940 [10] to approximately 25 000 in 1949 [11]. The number of papers in the Proceedings almost doubled over the course of the decade, going from 1800 papers to 3500 [11]. The number of local IRE Sections also dramatically increased after the war, going from 20 in 1937 [12] to 26 in 1942 [13] and to 48 in 1949 [14].

Reflecting the diversity of postwar research, the number of Technical Committees in the IRE also expanded, going from 12 in 1942 to 21 in 1949. Some of the new Technical Committees established in the postwar period represented the emerging fields of study which grew out of the war. These areas include computing (electronic computers), radar (navigational aids), information and communication theory (modulation systems), and nuclear science (nuclear studies).

II. RADAR

Radar was one of the biggest priorities for radio engineering during World War II. While much of the innovation in radar technologies was developed during the war at institutions like the Massachusetts Institute of Technology (MIT) Radiation Laboratory, radar began development in the late 1930s. The United States military had 580 radar sets on hand in December 1941, and the SCR-270 Army radar gave for an early warning of the attack on Pearl Harbor. After war was declared,

Fig. 2. ***An advertisement published in the Proceedings of the IRE during the war years (from Proceedings of the IRE, vol. 31, no. 1, Feb. 1943, p. xx).***

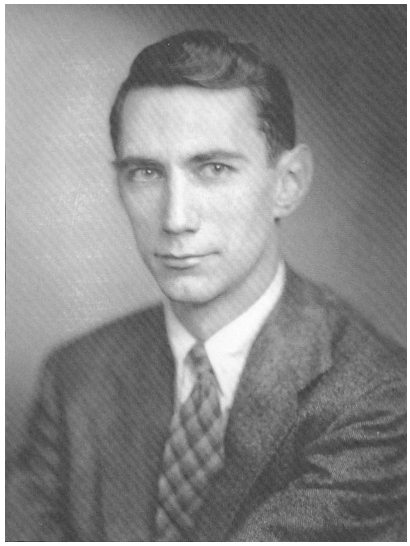

Fig. 3. ***Claude Shannon (from Claude Elwood Shannon: Collected Papers, N. J. A. Sloane and Aaron D. Wyner, Eds., IEEE Press, 1993).***

research in the field increased dramatically. Due to the strategic importance of being able to navigate, locate, and track aircraft through the use of radio waves, radar research was conducted in secrecy. Following the war's conclusion, a great deal of this work became declassified, and much radar research no longer needed to be classified. This is reflected in the pages of the PROCEEDINGS, as the Journal's first paper dealing with radar is a November 1945 article by Roger Colton of the Army Air Force, which detailed the early developments and history of radar [15]. The PROCEEDINGS would publish 17 more papers on the radar before the decade's close.

Airborne radar was primarily developed for wartime purposes, but its applications had many commercial uses in the postwar era. Lloyd Berkner, whose 1946 paper "Naval airborne radar" outlined the history and development of airborne radar technologies, identified seven primary areas of radar applications, namely search and reconnaissance, navigation and beaconry, attacking, intercepting, fire control, identification of friend or foe, and radar relay [16]. Though some of these applied only to wartime and defense applications, applications in the civil sector could easily be adopted in several of these categories. Directly tied to commercial air traffic and control, navigation and beaconry received a great deal of interest from the civil and military sectors. Ludlow Hallman of the Communication and Navigation Laboratory at Wright Field published two papers in the PROCEEDINGS outlining the theory of beaconry and its applications to air traffic control [17], as well as identifying a number of potential problems

Fig. 4. ***Harry Nyquist (IEEE History Center).***

with existing beacon and transponder systems [18]. By the end of the decade, radar was being actively used in commercial aircraft and shipping navigation systems. Other applications of radar such as exploratory surveys and mapping were being implemented as well.

Theoretical aspects of radar were also explored in the PROCEEDINGS. Noise and loss of signal were important problems to be overcome, and the PROCEEDINGS published papers on noise reduction [19], propagation of waves through various inclement weather conditions such as heavy rainfall [20] or through high altitudes like the troposphere [21]. Also explored were mathematical issues such as the theoretical limits of a minimum detectable radar signal [22], and potential applications including a proposed communication system via reflected power using principles of radar transmission [23].

III. INFORMATION THEORY

Mathematical theory as applied to broader aspects of radio transmission and communication methods experienced a great deal of expansion and study in the postwar period. While the basis for communication theory is detailed in the 1920s papers by Nyquist (Fig. 4) [24] and Hartley (Fig. 5) [25], Claude Shannon's "A mathematical theory of communication," published in 1948, expanded upon Nyquist and Hartley's base and extensively detailed mathematical and geometrical representations of communication theory related to problems involving both discrete noiseless systems and discrete channels with noise. Shannon describes all steps of the communication process, including bandwidth, coding and decoding, and reception and transmission.

Shannon's paper is considered a foundational paper in the information theory discipline [9], and immediately initiated a great deal of study [5]. Shortly after its publication, Shannon published two papers in the PROCEEDINGS related to communication theory. The first, cowritten with Bernard Oliver (Fig. 6) and John Pierce (Fig. 7) and published in the November 1948 issue, dealt with theoretical issues behind transmitting speech through pulse-code modulation methods, outlined the potentials which could be achieved with this technology, and showed how it compared to FM transmission [26]. The mathematical laws describing the expressions for the capacity of a communication system which transmits information directly applied to modulation and pulse methods. Developed in the late 1930s by Alec Reeves of the International Telephone and Telegraph for voice communications in the late 1930s, pulse-code modulation by transmitting information digitally allowed for significant reductions in noise, interference, and signal repeating without distortion. Its first practical use was the SIGSALY, a secure speech system which was used for top secret communications during World War II. Pulse-code modulation research was published extensively in the PROCEEDINGS; more than ten papers related to the subject appeared in the Journal between 1947 and 1949, and the paper by Shannon, Oliver, and Pierce was one of the most influential works in the field.

Fig. 5. ***Ralph Hartley (IEEE History Center).***

Fig. 7. ***John Pierce (IEEE History Center).***

Fig. 6. ***Bernard Oliver (IEEE History Center).***

The second paper authored by Shannon appeared in the January 1949 issue of PROCEEDINGS OF THE IRE, "Communication the presence of noise." It has been selected as a classic paper by today's PROCEEDINGS OF THE IEEE editors. "Communication the presence of noise" details a method for representing any communication system geometrically by using a modulation process which maps a signal and its messages from one function space to another [8]. "Communication the presence of noise" provided many foundational theorems and mathematical laws, including representations of channel capacity, bandwidth, noise, encoding, and the sampling theorem, which is a fundamental process for converting a signal into a numeric sequence.

These groundbreaking theories described by Shannon had applications for pulse-code modulation and radio transmission, and were applied to a wide variety of emerging fields including rapidly the expanding computer science discipline. Digital electronic computers which operated on pulse methods would be one of the most significant practical applications of abstract communication theory.

IV. ELECTRONIC COMPUTERS

The 1946 completion of the Electronic Numerical Integrator and Computer (ENIAC) at the University of Pennsylvania was a landmark event in the field of computing. Designed to primarily solve differential equations related to exterior ballistics, the ENIAC is widely considered to be the first working electronic computer [27]. An extremely large machine, the ENIAC contained over 18 000 vacuum tubes and had the ability to perform several operations including addition, subtraction, multiplication, division, square-rooting, and looking up function values [28].

As a digital computer, the ENIAC represented data by discrete digits, unlike analog computers such as differential analyzers which represent data as a continuous function of time. Digital computing promised greater accuracy; the ENIAC could handle ten significant figures, whereas a differential analyzer could handle only four or five. The implications of a machine that could operate with such accuracy and speed were extremely far reaching and led to a great deal of subsequent research.

In 1949, four large-scale electronic digital computers were completed and put into operation: Harvard's Mark III Calculator, Bell's Model VI, IBM's card-programmed electronic calculator, and Eckert-Mauchly's BINAC. The rapid growth of the field shortly after the ENIAC's announcement was also reflected in the pages of the PROCEEDINGS. The electronic computer which was designed at the Naval Ordnance Laboratory under Atanasoff introduced a number of problems in the computing field, which were dependent on a counter capable of operating at a megacycle input pulse rate. C. B. Leslie, also of the Naval Ordnance Laboratory, published a paper which described the development and construction of a modified ring or stepping-type counter that would address these issues [29].

Large-scale computing posed a number of unique challenges in regards to memory, and by 1949, a great deal of influential research had been conducted in this area. J. Presper Eckert (Fig. 8), one of the designers of the ENIAC, published with Isaac Auerbach, Robert Shaw, and C. Bradford Sheppard a paper describing the development of a mercury delay line memory system, which was capable of operating at pulse repetition rates of several megacycles per second, and thereby allowed for a significant increase in speed of electronic computing. This system would be used in the computer EDVAC [30], whose design was finalized in 1947 and which began operation in 1951 [31]. Eckert also described a dynamically regenerated memory tube, which was developed in parallel by the Eckert–Mauchly Computer Corporation and by Manchester University in the United Kingdom. These tubes would use cathode-ray tubes to store a large number of binary digits [32]. By the end of the decade, more electronic digital computers were in the process of being built than were functional.

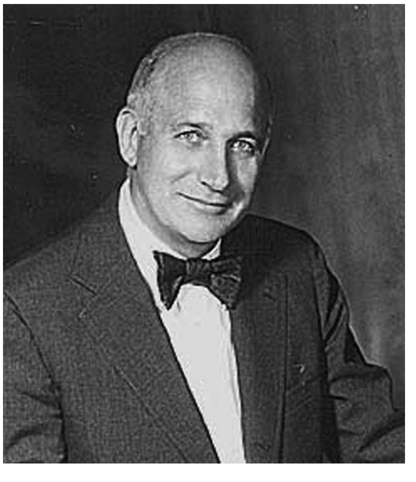

Fig. 8. ***J. Presper Eckert (IEEE History Center).***

Several publications dealt with theoretical applications of digital computers. C. F. West and J. E. DeTurk from Raytheon published a paper that described a theoretical machine which could solve problems related to scientific applications such as the study of shock waves, various applications of electromagnetic theory, and Fourier analysis and synthesis [33]. The newly emerging field of information theory was intrinsically linked to computing, and Claude Shannon presented the possibility of programming a chess game on a computer at the 1949 Symposium of Electronic Computing Machines, the first serious attempt to explore such an application [34].

In addition to the electronic computing, analog computing was explored as well. Though the first differential analyzer dated back to 1931 [35], many improvements in speed and accuracy were made during the war [36], and the field was booming by 1949 with the Westinghouse Anacom, the Northwestern University computer, and the California Institute of Technology analog computer all in operation [37]. Electronic devices and principles were integrated into analog computers; electronics could be used to generate and produce functions of the independent and dependent variables, as well as produce active linear elements and represent the nonsymmetrical terms of the matrix [38]. These methods could then be applied in the use of circuitry and tubes for multiplication, addition, function generation, and integration for an electronic differential analyzer [39].

Fig. 9. ***Haraden Pratt (IEEE History Center).***

Fig. 10. ***Arthur Van Dyck (IEEE History Center).***

V. NUCLEAR SCIENCE

Wartime development of atomic energy had a profound impact on the world, both in the destructive capabilities of the atomic bomb, and the possibilities of nuclear power. The PROCEEDINGS began publishing technical papers on the applications of radio engineering in nuclear science in December 1948, when Haraden Pratt (Fig. 9) and Arthur Van Dyck (Fig. 10), both IRE past-presidents, published an article on their experiences witnessing the tests at Bikini Island. Pratt and Van Dyck commented on the enormous destructive capabilities of the atomic bomb, its significance in warfare, and the necessity of avoiding war to prevent total destruction [40].

The PROCEEDINGS published nine technical papers on nuclear science and its relationship to radio engineering between December 1948 and the end of 1949. During this time, the IRE established the IRE Professional Group on Nuclear Science, who cosponsored a conference on Electronic Instrumentation in Nucleonics and Medicine with the American Institute of Electrical Engineers. The Atomic Energy Commission sponsored many meetings on peacetime applications of nuclear power, including instrumentation, scintillation counters, ionization chambers, and Geiger Tubes [37]. Scintillation counters in particular experienced steady progress in 1949 [41], as did Geiger Tubes [42].

The first successful Soviet nuclear test in 1949 was another significant event in the history of nuclear science. The growing tensions between the Union of Soviet Socialist Republics (USSR) and the United States in the postwar period would be greatly heightened by two superpowers now having atomic weapons. The tension between the USSR and the United States would lead to a great deal of military research during the 1950s. Further advancements in the field of computing, and the 1948 announcement of the transistor, which was first mentioned in the PROCEEDINGS in the Radio Progress section of the March 1949 issue [5], led to the miniaturization of electronics. The strategic importance of space was realized with satellite communication and the origins of the spaceflight program. These trends, which will be detailed in the next article, had a profound influence on the course of engineering of the 1950s and beyond. ■

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REFERENCES

[1] "Radio progress during 1940," *Proc. IRE*, vol. 29, no. 3, pp. 89–103, Mar. 1941.

[2] "Radio progress during 1941," *Proc. IRE*, vol. 30, no. 2, pp. 57–71, Feb. 1942.

[3] "Radio progress during 1946," *Proc. IRE*, vol. 35, no. 4, pp. 399–425, Apr. 1947.

[4] "Radio progress during 1947," *Proc. IRE*, vol. 36, no. 4, pp. 522–550, Apr. 1948.

[5] "Radio progress during 1948," *Proc. IRE*, vol. 37, no. 3, pp. 286–322, Mar. 1949.

[6] "Radio progress during 1944," *Proc. IRE*, vol. 33, no. 3, pp. 143–155, Mar. 1945.

[7] C. E. Shannon, "A mathematical theory of communication," *Bell Syst. Tech. J.*, vol. 27, pp. 379–423, Oct. 1948, 623–656.

[8] C. E. Shannon, "Communication in the presence of noise," *Proc. IRE*, vol. 37, no. 1, pp. 10–71, Jan. 1949.

[9] A. D. Wyner and S. Shamai, "Introduction to 'Communication in the Presence of Noise'," *Proc. IEEE*, vol. 86, no. 2, pp. 442–446, Feb. 1998.

[10] "Information about the Society," *Proc. IRE*, vol. 28, no. 1, Jan. 1940, DOI: 10.1109/JRPROC.1940.228814.

[11] "Information about the Society," *Proc. IRE*, vol. 37, no. 1, Jan. 1949, DOI: 10.1109/JRPROC.1949.232957.

[12] Institute of Radio Engineers, 1937 Yearbook.

[13] Institute of Radio Engineers, 1942 Yearbook.

[14] Institute of Radio Engineers, 1949 Yearbook.

[15] R. Colton, "Radar in the United States Army: History and early development at the signal corps laboratories, Fort Monmouth, N.J.," *Proc. IRE*, vol. 33, no. 11, pp. 740–753, Nov. 1945.

[16] L. Berkner, "Naval airborne radar," *Proc. IRE*, vol. 34, no. 9, pp. 671–706, Sep. 1946.

[17] R. D. Hultgren and L. B. Hallman, "The theory and application of the radar beacon," *Proc. IRE*, vol. 35, no. 7, pp. 716–730, Jul. 1947.

[18] L. B. Hallman, "Considerations in the design of a universal beacon system," *Proc. IRE*, vol. 36, no. 12, pp. 1526–1529, Dec. 1948.

[19] S. Coldman, "Some fundamental considerations concerning noise reduction and range in radar and communication," *Proc. IRE*, vol. 36, no. 5, pp. 584–594, May 1948.

[20] R. Wexler and J. Weinstein, "Rainfall intensities and attenuation of centimeter electromagnetic waves," *Proc. IRE*, vol. 36, no. 3, pp. 353–355, Mar. 1948.

[21] A. Friend, "Continuous tropospheric soundings by radar," *Proc. IRE*, vol. 36, no. 4, pp. 501–503, Apr. 1948.

[22] A. V. Haeff, "Minimum detectable radar signal and its dependence upon parameters of radar systems," *Proc. IRE*, vol. 34, no. 11, pp. 857–861, Nov. 1946.

[23] H. Stockman, "Communication by means of reflected power," *Proc. IRE*, vol. 36, no. 10, pp. 1196–1204, Oct. 1948.

[24] H. Nyquist, "Certain factors affecting telegraph speed," *Bell Syst. Tech. J.*, vol. 3, pp. 324–326, Apr. 1924.

[25] R. V. L. Hartley, "The transmission of information," *Bell Syst. Tech. J.*, vol. 3, pp. 535–564, Jul. 1928.

[26] B. M. Oliver, J. R. Pierce, and C. E. Shannon, "The philosophy of PCM," *Proc. IRE*, vol. 36, no. 11, pp. 1324–1441, Nov. 1948.

[27] A. W. Burks, "Electronic computing circuits of the ENIAC," *Proc. IRE*, vol. 35, no. 8, pp. 756–767, Aug. 1947.

[28] J. G. Brainerd and T. K. Sharpless, "The ENIAC," *Electr. Eng.*, vol. 67, pp. 163–172, Feb. 1948.

[29] C. B. Leslie, "Megacycle stepping counter," *Proc. IRE*, vol. 36, no. 8, pp. 1030–1034, Aug. 1948.

[30] I. Auerbach, J. P. Eckert, R. F. Shaw, and C. B. Sheppard, "Mercury delay line memory using a pulse rate of several megacycles," *Proc. IRE*, vol. 37, no. 8, pp. 855–861, Aug. 1949.

[31] M. R. Williams, "The origins, uses, and fate of the EDVAC," *IEEE Ann. History Comput.*, vol. 15, no. 1, pp. 22–381993.

[32] J. P. Eckert, H. Lukoff, and G. Smoliar, "A dynamically regenerated memory tube," *Proc. IRE*, vol. 37, no. 2, pp. 165, Feb. 1949, abstract of oral paper.

[33] C. F. West and J. E. DeTurk, "A digital computer for scientific applications," *Proc. IRE*, vol. 36, no. 12, pp. 1452–1460, Dec. 1948.

[34] "Institute news and radio notes," *Proc. IRE*, vol. 37, no. 2, pp. 166, Feb. 1949.

[35] V. Bush, "The differential analyzer. A new machine for solving differential equations," *J. Franklin Inst.*, vol. 212, pp. 447–488, 1931.

[36] V. Bush and S. H. Caldwell, "A new type of differential analyzer," *J. Franklin Inst.*, vol. 240, pp. 255–3251945.

[37] "Radio progress during 1949," *Proc. IRE*, vol. 38, no. 4, pp. 358–390, Apr. 1950.

[38] G. D. McCann, C. H. Wilts, and B. N. Locanthi, "Electronic techniques applied to analogue methods of computation," *Proc. IRE*, vol. 37, no. 8, pp. 954–961, Aug. 1949.

[39] A. B. MacNee, "An electronic differential analyzer," *Proc. IRE*, vol. 37, no. 11, pp. 1315–1324, Nov. 1949.

[40] H. Pratt and A. Van Dyck, "Bikini observations and their significance," *Proc. IRE*, vol. 34, no. 12, pp. 930–933, Dec. 1946.

[41] J. W. Coltman, "The scintillation counter," *Proc. IRE*, vol. 37, no. 6, pp. 671–682, Jun. 1949.

[42] H. Friedman, "Geiger counter tubes," *Proc. IRE*, vol. 37, no. 7, pp. 791–808, Jul. 1949.