

ELECTRICAL ENGINEERING HALL OF FAME

HAROLD S. BLACK

In 1981, the National Inventors Hall of Fame inducted the engineer inventor, Harold S. Black (Fig. 1), in recognition of his invention of negative feedback amplifiers. He spent most of his professional career at the Bell Telephone Laboratories and received 62 U.S. patents as well as patents in several other countries. In 1957, Mervin J. Kelly (Fig. 2), the Bell Labs President at the time, stated that “although many of Harold’s inventions have made great impact, that of the negative feedback amplifier is indeed the most outstanding.” Kelly continued that the invention “easily ranks coordinate with de Forest’s invention of the audion as one of the two inventions of broadest scope and significance in electronics and communications of the past 50 years.”

Harold S. Black was born April 14, 1898 in Leominster, MA. He graduated in electrical engineering from the Worcester Polytechnic Institute (WPI) in 1921. He later recalled that the engineering curriculum had “included surveying, hydraulics engineering, pattern making, drop forge, and machine shop, in addition to physics, chemistry, and mathematics.”

In July 1921, Black accepted a job offer from the Western Electric Company, a subsidiary of the American Telephone and Telegraph Company (AT&T). After completing a 12-week training program, he joined the Systems Engineering Department in New York City. His initial assignment was to work on ways to improve the performance of the repeater amplifiers in a newly introduced three-channel telephone system called the Type C system.



Fig. 1. Harold S. Black in his Summit home office (courtesy of AT&T Archives and History Center).

In 1981, the National Inventors Hall of Fame inducted the engineer inventor, Harold S. Black, of Bell Telephone Laboratories, into its ranks, in recognition of his invention of negative feedback amplifiers. He received a total of 62 U.S. patents during his professional career.

The push-pull vacuum-tube amplifiers used tended to produce unacceptable harmonic distortion when connected in tandem.

Black spent several years attempting to improve the linearity and stability of repeater amplifiers. He undertook a systematic review of relevant publications and inhouse reports in the company’s files. He designed and tested numerous amplifier circuits and prepared graphs showing the requirements of amplifiers as a function of the number of channels and the distance. He received a patent in 1928 on a so-called “feedforward amplifier” which employed complicated biconjugate networks to isolate and cancel distortion produced by the vacuum tubes. The technique proved fairly successful in laboratory tests. However, it required frequent adjustment of filament current and plate voltage and was not introduced commercially.

According to Black, it was on August 2, 1927 that “the concept of



Fig. 2. Mervin J. Kelly (courtesy of the IEEE History Center).

the negative feedback amplifier came to me in a flash while I was crossing the Hudson River on the Lackawanna Ferry, on my way to work.” He immediately sketched a block diagram and equations for an amplifier with feedback on a blank page of his newspaper. He had it witnessed and signed by a colleague when he arrived at the laboratory. He designed an experimental three-stage repeater amplifier with negative feedback which served to validate his concept. He also developed circuits to match the input and output impedances of an amplifier to a transmission line or cable. In late December 1927, one of Black’s feedback amplifiers achieved a distortion reduction of about 100 000 to 1 with a frequency range extending from 4 to 45 kHz. He later recalled that this result had been “more than sufficient to do the job I had undertaken six years earlier.”

In January 1928, AT&T began development of a nine-channel carrier system for transcontinental telephony. It was to be the first major application of Black’s feedback amplifier. It was designed to utilize repeater amplifiers at 25-mile intervals. Field tests of the system were conducted in the vicinity of Morristown, NJ, beginning in 1930. By connecting 68 pairs of cable conductors in series, the engineers were able to simulate speech transmission over a total distance of more than 7000 miles with 306 repeaters in each direction. Black recalled years later that “the speech quality was excellent even though the total attenuation in each direction was about 12 000 dB.”

In January 1934, a classic paper by Black titled “Stabilized feedback amplifiers,” was published in *Electrical Engineering*, a periodical of the American Institute of Electrical Engineers (AIEE). He stated that recent improvements in vacuum tubes and circuits had made it possible “to secure any desired amplification of the electrical waves used in the communication field.” He continued that the use of negative feedback



Fig. 3. Harry Nyquist (courtesy of the IEEE History Center).

enabled “extraordinary improvement in constancy of amplification and freedom from non-linearity.” He pointed out that feedback provided “other advantages including reduced delay and delay distortion, reduced noise disturbance from the power supply circuits and various other features best appreciated by practical designers of amplifiers.” He included circuit diagrams, equations, and graphs to illustrate application of the feedback principle.

A patent application on Black’s feedback invention was submitted in August 1928, but it was not issued until December 1937. He attributed the unusual delay to the fact “that the concept was so contrary to established beliefs that the Patent Office initially did not believe it would work.” He also mentioned that it had required a long negotiation process in order to resolve issues related to the exceptional length and number of claims in the application. As finally issued, the patent included 42 pages of text, 9 pages of 126 claims, and 33 pages of figures. According to Black, the extraordinary length was due to the invention being “in a new field whose principle was not understood.” He had already anticipated that the principle “could be carried over and applied by

analogy to the synthesis and analysis of other kinds of amplifiers, to all kinds of control systems—mechanical, acoustical, chemical, hydraulic, or whatever.”

Black’s feedback theory was extended by his Bell Labs colleague, Harry Nyquist (Fig. 3), who was born in Sweden in 1889 and came to the United States in 1907. He joined the Bell Company in 1917 after earning a doctorate in physics from Yale University. He authored an influential paper titled “Regeneration theory” published in the *Bell System Technical Journal* in 1932. The paper contained what became known as the “Nyquist criterion” which specified the conditions necessary to ensure stability in feedback circuits. He also introduced “Nyquist diagrams” which facilitated visualization of the phenomena discussed.

Black was elected a Fellow of the AIEE in 1941 and received the John Price Wetherill Medal from the Franklin Institute the same year. During World War II, he contributed to the theory and application of pulse-code modulation. In 1948, he was elected a Fellow of the Institute of Radio Engineers (IRE). He was cited “for his work on negative feedback amplifiers and for his application of pulse techniques to radio communication systems.”



Fig. 4. Harold Black as a young man (courtesy of AT&T Archives and History Center).

His book titled *Modulation Theory* was published in 1953.

Black received the Lamme Medal from the AIEE in 1957 in recognition of “his many outstanding contributions to telecommunication and allied electronic arts.” At the time, Mervin Kelly asserted that “without Black’s invention, the present long-distance telephone and television networks which cover our entire country and the transoceanic telephone cables

would not exist.” He added that “the entire explosive extension of the area of control, both electrical and mechanical, grew out of an understanding of the feedback principle.”

Black (Fig. 4) retired from the Bell Labs in 1963. He served as a Principal Research Scientist with the General Precision Company in Little Falls, NJ, from 1963 to 1966 when he became an independent communications consultant. He received the Robert H.

Goddard Award from WPI in 1981, the same year as his induction into the National Inventors Hall of Fame. He did some preliminary work on an autobiography with the tentative title *Before the Ferry Docked*. However, it remained unfinished when he died December 11, 1983 at age 85. ■

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