

# ELECTRICAL ENGINEERING HALL OF FAME

## HARRY NYQUIST

**I**N 1960, the Institute of Radio Engineers (IRE) awarded its Medal of Honor to Harry Nyquist (Fig. 1). He was cited for his “fundamental contributions to a quantitative understanding of thermal noise, data transmission, and negative feedback.” He spent most of his professional career as a Communications Research Engineer with the American Telephone and Telegraph Company (AT&T). He is remembered especially for his formulation of what became known as the “Nyquist criterion” for determining the stability of amplifiers. One of his colleagues recalled that Nyquist “had an almost uncanny ability to find the most direct and simple way to solve a problem.”

### I. EARLY LIFE AND EDUCATION

Harry Nyquist was born February 7, 1889, in Nilsby, Sweden. He came to the U.S. in 1907 where he lived in Minnesota. In 1912, he enrolled at the University of North Dakota (UND) where he studied physics under Albert H. Taylor (Fig. 2). A graduate of the University of Wisconsin, Taylor had earned his doctorate in Germany in 1909. Taylor did research on directive antennas and radio wave propagation while teaching at UND from 1909 to 1917. He went on to have a distinguished career at the Naval Research Laboratory and received the IRE Medal of Honor in 1942. Nyquist received both an undergraduate degree and a master’s degree at UND.



Fig. 1. Harry Nyquist (IEEE History Center).

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He then continued his education at Yale University where he received his doctorate in physics in 1917.

### II. RESEARCH ON TRANSMISSION THEORY

Nyquist joined the engineering staff of the AT&T Department of Development and Research in 1917. The rapid growth in the use of vacuum-tube repeater amplifiers and the advent of carrier multiplex for telephone and telegraph circuits posed challenging problems for Nyquist and his colleagues in the 1920s. He was a coinventor with Alva B. Clark and Danforth K. Gannett of a voice-frequency signaling system. They applied for a patent on the invention in November 1921, and it was issued in December 1924. Nyquist also devised a method to increase the message capacity of narrowband telegraph channels.

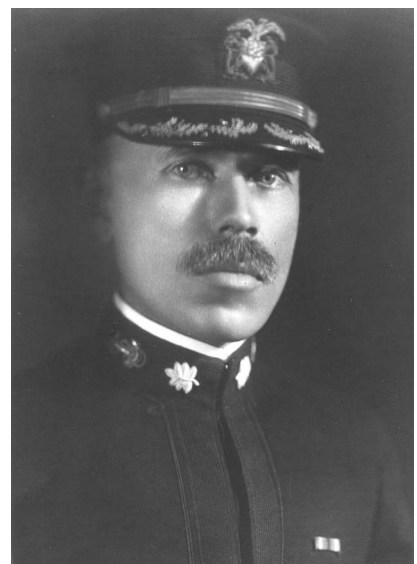
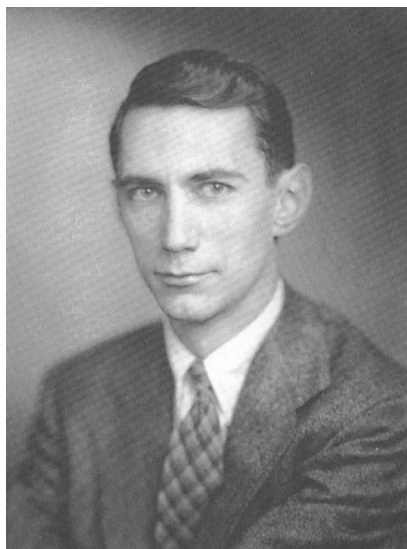


Fig. 2. Albert H. Taylor (IEEE History Center).



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

Nyquist carried out systematic theoretical studies of the behavior of digital and analog signals in closely coupled circuits and discovered the “Nyquist rate” for pulse capacity. He discussed his analysis in a paper titled “Certain factors affecting telegraph speed” published in the *Bell System Technical Journal* in April 1924. He authored two additional papers on transmission theory published in the *Transactions of the American Institute of Electrical Engineers* (AIEE) in 1928. Claude E. Shannon (Fig. 3) later credited this work by Nyquist for helping to provide a foundation for a general theory of communication. Shannon published a classic paper titled “A mathematical theory of communication” in the *Bell System Technical Journal* in July 1948.

Nyquist also investigated various sources of distortion affecting teletype and telegraph transmission. He and his colleagues carried out laboratory experiments and designed instruments suitable for use in the field to make distortion measurements. He undertook an analysis based on thermodynamic principles of thermal noise in vacuum tubes as observed by J. B. Johnson, an engineer with Western Electric. Johnson and

Nyquist published complementary papers on the topic in the *Physical Review* in 1928.

### III. NYQUIST CRITERION

The invention of negative feedback amplifiers in 1927 by Harold S. Black (Fig. 4), an engineer at the Bell Telephone Laboratories, offered the prospect of substantial improvement in the quality of long-distance telephony. However, the amplifiers were subject to instability unless design criteria to guard against “singing” could be developed. Nyquist worked out an ingenious solution to the instability problem and disclosed it in a classic paper titled “Regeneration theory” published in the *Bell System Technical Journal* in 1932. Nyquist’s paper contained the “Nyquist criterion”

specifying the conditions necessary to ensure stability in feedback circuits. He had done a general analysis of an amplifier in which the output was linked to the input by a transducer. His analysis employed complex variable theory and could be illustrated by depicting paths of integration on graphs with real and imaginary axes. He identified a critical point on the graph at which instability would occur when the magnitude of the variable was unity and the phase angle was zero. He stated that, if the critical point was outside the curve over the entire range of frequencies, “the system is stable.”

Nyquist included in his paper a number of diagrams to illustrate some of the possibilities that might be encountered. In one case, the system was stable for low values of amplification,



**Fig. 4.** Harold S. Black in his Summit home office (Courtesy of AT&T Archives and History Center).

became unstable as the gain increased, and then became stable with a still higher gain. His diagrams provided an effective bridge between abstract mathematical analysis and the graphical culture common in design engineering. One of his colleagues, who worked on circuit design, later recalled that the Nyquist criterion and the Nyquist diagrams had been “like a revelation on plates of gold.” He added that “at last we knew what we were trying to achieve.”

Experimental confirmation of the Nyquist theory was reported in an October 1934 paper by three of his AT&T colleagues, Eugene Peterson, Lawrence A. Ware, and John Kreer. Their paper was titled “Regeneration theory and experiment.” Peterson had received a doctorate from Columbia University in 1926 and had worked for AT&T since 1919. Ware had earned a doctorate at the University of Iowa in

1930 and had come to Bell Labs in 1930. Kreer had received a master’s degree at Columbia University in 1928 and came to AT&T in 1925. In their 1934 paper, they noted that the Nyquist stability criterion had been presented in a convenient form and was not restricted to any particular circuit configuration. They called attention to a “striking conclusion” by Nyquist where a given amplifier might “sing” but that either an increase or decrease in gain would cause it to stop singing. They had designed a circuit to test this prediction and had found the experimental results to be in agreement with the theory.

#### IV. LATER CAREER

Nyquist was transferred to the Bell Labs in 1934 where he worked on the problem of delay distortion in television and techniques of frequency

compression for speech transmission. He was a participant in the introduction of the so-called “vocoder” which was tested successfully in 1942 using a transatlantic radio circuit. It employed digital coding of speech signals. Nyquist became a Fellow of the AIEE in 1951 and a Fellow of the IRE in 1952. He was appointed Assistant Director of System Studies at Bell Labs in 1952.

Nyquist retired in 1954 but continued to do consulting work for government agencies and various companies. He received the Stuart Ballantine Medal from the Franklin Institute in 1960 and the Mervin J. Kelly Award from the AIEE in 1961. He later received the Founders Medal of the National Academy of Engineering in 1969. He died April 4, 1976, at age 87. ■

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