Establishing Standards for Measuring the Performance of Radio Receivers

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Abstract: Regularly scheduled radio broadcasting began in the United States in 1920, and just ten years later the majority of U.S. homes contained a radio. Radio engineering made great advances in this decade, particularly in the design of radio receivers. The engineering profession, notably the Institute of Radio Engineers, a predecessor society of the IEEE, made a vital contribution by devising and standardizing means of measuring the performance of radio receivers. The IRE standards, published in 1928, defined three fundamental properties of receivers—sensitivity, selectivity, and fidelity—and specified procedures for measuring them. These standands made it easier for engineers to design a system as a whole and to optimize overall performance while keeping the projected cost of a receiver at a particular level; they served the engineering community by making possible unambiguous communication; they were valuable to manufacturers for quality control; and they made it easier for purchasers to evaluate and compare radios.

Regularly scheduled radio broadcasting began in the United States in 1920, and just ten years later the majority of U.S. homes contained a radio. Not surprisingly, radio engineering made great advances in this decade. One of the most important is the subject of this paper: devising and standardizing means of measuring the performance of radio receivers.

In the early 1920s, when radio was a novelty, people often judged a radio receiver by how many stations it received and, especially, by how distant they could be. As the decade progressed, other features of radios became important to buyers: the sound quality, the lack of interference between stations, the volume of sound, the quality of the cabinet, and the portability of the set. Some of these, such as the last two, could readily be judged by the prospective purchaser, and it was straightforward to compare two radios for distance of reception or volume of sound. But the degree of interference and, especially, the sound quality of the radio receiver were more difficult to judge and seemed fairly subjective. As with other areas of subjective judgment, one could, of course, trust the experts, in this case, musicians. Indeed, several radio manufacturers boasted in advertisements that they employed musicians to perform "tone tests" to guide their engineers in the design of receivers.

By the end of the decade, however, the situation had changed. Some properties of receivers, such as the attractiveness of the cabinet, were still judged by the purchaser, but engineers had devised and agreed upon quantitative tests of the performance of radios in reproducing radio broadcasts. These tests, carried out in a carefully specified way by engineers, were objective in the sense that the results depended only upon the receiver being tested and not by whom or where the tests were performed.

This devising and agreeing upon quantitative tests of receiver performance is an interesting episode of quantification in engineering and of standardization of procedures within the community of radio engineers.

While the importance of quantification in the history of science has received a good deal of attention, quantification in engineering has not been much studied. Historians of science writing about quantification are wont to quote from a lecture Lord Kelvin gave in 1883 to the Institution of Civil Engineers: "In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and methods for practically measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind ...." This quotation, or part of it, has been used many times as an epigraph in engineering books and articles, which in itself is evidence of the importance engineers attach to quantification.

From its beginnings, radio posed new problems of measurement. New instruments were required to measure wavelength or frequency, to measure radiated power, and to measure decrement of wireless signals. Even for quantities, such as current and voltage, which had long been measured, there was a need for new instruments, partly because of the extremely low levels of current and voltage that needed to be measured. The importance of "methods for practically measuring" (Kelvin's phrase) is evidenced in one of the milestones of radio science: *The Principles of Electric Wave Telegraphy* (1906) by J.A. Fleming, inventor of the diode electron tube. A second edition, with the augmented title *The Principles of Electric Wave Telegraphy and Telephony*, appeared in 1910. In this volume, the second chapter, on "High frequency electrical measurements", fills 101 pages and begins with a section on "The essential difference between high and low frequency electrical measurements". Fleming writes, "The measurement of high frequency electric currents and potentials and other specific qualities of electric conductors and insulators ... to a considerable extent calls for the employment of special instruments and methods", and the chapter goes on to discuss such instruments and methods.

Another indication of the importance of quantification in the development of radio engineering is the attention given to it by one of the most illustrious radio engineers, Frederick Terman. He published two landmark volumes in the history of electronics: *Radio Engineering* (1932) and *Measurements in Radio Engineering* (1935). Terman explains in the preface to the latter that these are companion volumes, the one dealing with the physical principles of radio, the other with measuring equipment and techniques. The latter volume reappeared in an enlarged form in 1952 as *Electronic Measurements*.

There is an interesting passage in the preface to Fleming's *The Principles of Electric Wave Telegraphy and Telephony*: "The quantitative aspect of the subject is, however, of special importance at the present time. There comes a stage in the development of the technical applications of scientific discoveries when exact measurement is the very life and soul of further achievements, and when empirical methods and personal skill have to be replaced by careful predetermination and precise measurement."

Accepting Fleming's premise—that there is a stage of development "when exact measurement is the very life and soul of further achievement"—one might argue that, at least as far as radio receivers is concerned, this stage occurred in the years around 1930 rather than the years around 1910, when Fleming wrote these words. The early history of radio receivers is, after all, the story of qualitative improvements: Hertz's spark gap, Edouard Branly's coherer, Fleming's diode detector, H.H. Dunwoody's crystal detector, de Forest's triode detector, Reginald Fessenden's heterodyne receiver, and Edwin Howard Armstrong's regenerative receiver. These were fundamentally different designs with readily apparent differences in reception, so that precise measurement of receiver properties had little role either in the design of these receivers or in the choice of one over another. Indeed, what became the standard receiver design, Armstrong's super-heterodyne, patented in 1920, was developed by an engineer not much given to quantitative reasoning.

In 1930, however, when the superheterodyne had become the standard receiver circuit, radio manufacturers were competing by making small improvements in quality of reception and by reducing the cost of receivers. Here quantification of the relevant qualities, including the technical means to make precise measurements, was, in Fleming's words, "the very life and soul of further achievement". Requiring precise measurement was not only the performance of individual components, but also the overall performance of radio transmitters and receivers.

Work in other areas—notably telephone engineering, acoustic engineering, and phonograph engineering—was useful. For example, two devices developed by telephone engineers were valuable in testing radios: the thermophone (a frequency generator) and condenser-type microphone. Nevertheless, radio engineers, working for the government and in the private section, needed to devise their own test-and-measurement techniques.

Much of the early work in radio measurement took place at government laboratories. The U.S. Navy took an early interest in wireless and was an important contributor to radio test-and-measurement. Beginning in 1911, which was the year of the Radio Ship Act requiring many ships to carry wireless apparatus, the National Bureau of Standards (NBS) sought methods and developed instruments for measuring quantities associated with radio transmission and reception. Its first tasks were the standardization of a wavemeter and the development of a decremeter (to measure the rate of decay of the bursts of energy emitted by the transmitters of those days). In 1913 a Radio Laboratory Section of NBS was formed, and its activities increased markedly with the outbreak of war in Europe in 1914. In these years the Radio Laboratory produced what became one of the most influential books in the history of radio: NBS Circular 74, entitled *Radio Instruments and Measurements* and issued in 1918. Written under the direction of John Howard Dellinger (Chief of the Radio Laboratory), Circular 74 presented in 330 pages the theoretical basis of radio measurement as well as the instruments and methods of measurement. (Wireless Press made a clothbound version available, and in 1924 a second, revised edition was published.) Britain's counterpart to the National Bureau of Standards, the National Physical Laboratory, was another site of important work.

At least as important as the government-sponsored work, however, were the efforts of scientists and engineers employed in industry. Radio research at AT&T began more than a decade before the organization of Bell Laboratories in 1925, and General Electric supported research in radio. Other large companies that contributed to the improvement of radio test-and-measurement were Westinghouse and RCA, whose Technical and Test Department was established in 1924. Three small companies that had a large impact were General Radio Company, Hazeltine Corporation, and Radio Frequency Laboratories.

General Radio Company was unique in the 1920s in specializing in the manufacture of test instruments for the radio industry. In 1915 Melville Eastham started General Radio specifically to manufacture instruments. In the mid 1920s, as the number of radio manufacturers increased and as the importance of measurements became more and more obvious, the company grew rapidly as it introduced a wide variety of instruments. Before the end of the decade, General Radio had marketed "the first commercial vacuum-tube voltmeter to measure radio-frequency voltages, the first standard-signal generator to measure the sensitivity and selectivity of radio receivers, and the first power output meter to measure the electrical power available to drive their loudspeakers." And in the mid 1930s "came the first commercial sound-level meter to measure the fidelity of the sound produced by the loudspeaker, the first wave analyzer to measure the distortion that prevents faithful reproduction, the first radio-frequency bridge to measure the characteristics of antennas, and the famous General Radio Type 650-A Impedance Bridge, which became an industry standard for measuring components and which set the amazing longevity record ... of twenty-six years without a redesign."

The second small company that had a large impact on radio test-and-measurement was Hazeltine Corporation. Founded in 1924 by Louis Alan Hazeltine, designer of the Neutrodyne receiver, this company prospered as a licensing and consulting firm. The company always placed emphasis on quantitative testing, and several of its employees, including Harold Wheeler, Art Loughren, and L.J. Troxler, excelled in the design of test equipment. Wheeler writes, "From the beginning of the Company laboratory in Hoboken, my creative work was about evenly divided between the end product and the testing of its performance. The latter offered an opportunity for much ingenuity in the development of methods and the design of equipment for accuracy and ease of operation."

The third small company was Radio Frequency Laboratories (RFL) of Boonton, New Jersey. Like Hazeltine, RFL was a consulting and licensing company. It was formed in about 1923 by two outstanding engineers, Lewis M. Hull and Charles Stuart Ballantine, both of whom later served as president of the Institute of Radio Engineers. One of the services RFL performed for its licensees, which included such prominent companies as Stromberg-Carlson and Colonial Radio, was the quantitative testing of popular radio receivers.

Engineers from all three of these companies played a large role in the adoption of standards for the testing of radio receivers, a subject to which we now turn.

The establishment of standards for engineering practice had long been a principal activity of both the American Institute of Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE). In the 1920s standards for some of the components used by radio engineers were specified by AIEE committees, while the IRE took responsibility for specifying standard tests of the overall performance of radio receivers.

1928 was the first year the IRE published standards for testing a radio receiver. The Receiving Sets Subcommittee of the IRE Standardization Committee, which formulated these standards, included two engineers from Hazeltine Corporation, founder Alan Hazeltine and Chief Engineer William A. MacDonald. Hazeltine, who at the beginning of his career worked in the General Electric Testing Department, practiced a scientific approach to design, including laboratory experiments and measurements. MacDonald had pioneered in test-and-measurement for radio with a paper "Importance of laboratory measurements in the design of radio receivers" first presented at an IRE meeting in November 1926 and published the following year in *Proceedings of the IRE*.

In that paper MacDonald wrote, "It is obvious that an exact knowledge of the individual and over-all characteristics of a radio receiver should be accurately known, yet experience shows that many manufacturers, including some of the largest, are practically unaware of the exact performance of the apparatus they produce." MacDonald did not here consider tests of overall performance, but described 13 fundamental measurements of receiver subsystems. (The instruments required were a precision wave meter, a radio frequency oscillator, an audio frequency oscillator, and a vacuum-tube voltmeter.) Two GE engineers, who apparently took umbrage at MacDonald's statement that some of the largest manufacturers were "unaware of the exact performance of the apparatus they produce", published a description of some of the test procedures—namely, the tests of overall performance—in use at General Electric.

A paper that appeared the following year confirmed both MacDonald's claim that quantitative tests of radio receivers were sorely needed and the objection of the GE engineers that Hazeltine Corporation was not the only company developing such tests. Written by A.F. Van Dyck and E.T. Dickey of the RCA Technical and Test Department, the paper "Quantitative methods used in tests of broadcast receiving sets" described procedures in use at RCA. The authors wrote: "In radio receiving set engineering, numerous obstacles to quantitative measurement work were present which required the development of new methods and new apparatus. ... As a result of this lack of means of measurement, receiving set tests during the first twenty-five years or so of the radio art were conducted in a necessarily crude, practical way, chiefly by so-called "listening tests," wherein the receiving set was operated exactly as in actual service, and observations made by ear."

It was in that year, 1928, that the IRE published its "Standard tests of broadcast radio receivers". The members of the Receiving Sets Subcommittee—J.H. Dellinger was the chairman—did not seek a single "figure of merit" to guide purchasers of radios. Instead they sought to specify measures of three fundamental properties of receivers—sensitivity, selectivity, and fidelity—with the expectation that such measures would help engineers improve radio design and would aid radio distributors and dealers in the "selection of apparatus for specific service conditions".

Sensitivity of a receiver at a given broadcast frequency was defined as the input signal in microvolts necessary for a standard output; the sensitivity characteristic of a receiver is a graph of the sensitivity for various value of carrier frequency. Selectivity was defined as the ability of a receiver to distinguish between signals on two slightly different frequencies, and it is expressed as a curve giving the signal strength required to produce standard output for frequencies around a selected frequency. Fidelity was defined as the degree to which a system accurately reproduces at its output the audio signal which is impressed upon it. To measure fidelity at a given carrier frequency, the engineer varied the modulation frequency from 40 to 10,000 Hz while keeping the field intensity fixed and measured the ratio of output voltage at the modulation frequency of measurement to the output voltage at the modulation frequency of 400 Hz.

The Receiving Sets Subcommittee gave much attention to standardizing the procedures for these tests. A set of standard test frequencies for sampling the carrier-frequency range was specified; modulation was set at 30 percent; a "standard dummy antenna" was defined; and so on. The procedures for these tests were refined and other tests were specified in subsequent publications by the IRE Standards Committee. The Receiving Sets Subcommittee became the Technical Committee on Radio Receivers, E.T. Dickey became chairman, and a revised report on standard tests was published in 1931. The following year Harold Wheeler became chairman and considerably revised reports were published in 1933 and 1938. The tests discussed and agreed upon by these committees have, with only minor changes, remained in use to the present day.

Thus, the performance of radio receivers was quantified, and quantified in a standardized way. What difference did this make to the radio industry?

Measurement was important in the design of radios, making it easier for engineers to design the system as a whole and to optimize overall performance while keeping the projected cost of a receiver at a particular level. Measurement helped also in understanding how a subsystem worked and how its performance was related to that of other subsystems; it made clear that in some cases there are trade-offs, as with selectivity and fidelity (a receiver that is extremely selective will necessarily have poor fidelity at high audio frequencies, and, conversely, a receiver with excellent fidelity at these frequencies cannot be extremely selective).

For the engineering community as a whole, measurement made possible unambiguous communication. As A.F. Van Dyke and E.T. Dickey wrote in 1928, "It is the belief of the authors that the day is not far distant when it will be possible for radio engineers to use one universally comprehensible language in speaking of receiving set measurement and performance."

Measurement made it easier to monitor the manufacturing process, permitting such things as statistical quality control and reliability estimation. Being able to describe the output of a manufacturing process quantitatively may allow one to set production standards in order to maximize efficiency (aiming to get a high percentage of manufactured sets with acceptable performance without raising manufacturing costs greatly).

Finally, for the purchasers of radios, measurement made it easier to evaluate and compare radios. And the improvements in radio design and manufacturing meant that in the 1930s, the radio industry produced high-quality, low-cost receivers. In 1925 the average price of a radio was $85; in 1940 it had fallen to $40. In the same period, the percentage of homes with radios increased from ten to more than eighty percent, and this despite the economic hardship of the Depression.