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GEORGE WASHINGTON PIERCE

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A Biographical Memoir by

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GEORGE WASHINGTON PIERCE, physicist, engineer, teacher, and inventor, died in retirement at his summer home in Franklin, New Hampshire, on August 25, 1956. He was born on January 11, 1872, on a farm in Webberville, Texas, a small rural community in Travis County just east of the state capital at Austin. His mother was Mary Gill Pierce, the second wife of George W. Pierce (senior), a farmer, cattleman, and butcher. He had one older half-brother, James Byron Pierce, and a younger brother, Ben Colvin Pierce. The latter was named, after a common custom of that day, for the notorious gambler and one-time marshal of Austin, Ben Thompson—a singular coincidence, since George himself was to occupy the chair of physics at Harvard endowed by the earlier and in some ways equally notorious Benjamin Thompson who later became Count Rumford.

Growing up on a farm often cultivates the traits of self-reliance and ingenuity, but it can also be a rugged discipline, especially under the semi-frontier conditions that prevailed during the reconstruction period in central Texas. It did not take long for Pierce to acquire a cordial dislike for farm chores, and he often remarked in later years that the frustrations of hauling water for thirsty mules from a deep well with a leaky pail provided a powerful incentive for pursuing higher education elsewhere.

Pierce began his studies in the local one-room school, where he soon discovered that it was possible to do his own assignments and at the same time to absorb the more advanced studies being taught at the front of the room to the older children. His academic horizons were broadened a little when his family moved to the neighboring town of Taylor, and his initiative and keen intelligence promptly gained him his first academic kudos, the inaugural award of a thin triangular gold medal for high honors in the fifth grade of the newly established public school in Taylor.

Pierce became an avid reader, encouraged in this perhaps by the discovery that he could avoid some farm chores by pleading preoccupation with homework. He managed to pick up a working knowledge of Spanish from itinerant Mexican laborers, and he later reported of his early schooling that he "liked especially English, mathematics, and history; and disliked nothing." As a result, and because he had "bootlegged" the study of algebra on his own, he was given advanced-standing credit in English, mathematics, physics, and chemistry when he entered the seven-year-old University of Texas in 1890 at the age of eighteen. Two fellow students of that time still living in Austin remember him as a brilliant and advanced student, and his work in physics and mathematics was sufficiently outstanding to gain him exemption from many final examinations and to earn him the B.Sc. degree in three years. In fact, there is reason to think that his teachers may have had trouble at times in keeping one jump ahead of him, and he probably remembered this in later years when he enjoyed pretending that his own students were outdistancing him. His physics professor, Dr. Alexander Macfarlane, chose him as a research assistant during his senior year, and their work led to Pierce's first publication, a joint paper with Macfarlane that appeared in the first volume of the *Physical Review* in 1893. An extension of this work during the following year earned him his master's degree and formed the subject matter of his first solo publication.

Hard times were widespread in the middle 1890s and the world was not then crying out for young physicists. After leaving the University of Texas in 1894, Pierce spent four years earning a precarious living by tutoring, doing odd jobs, "assisting an oculist in investigations of the eye," and by teaching science in the Austin High School (1895), mathematics and modern languages in Hargrove College (Ardmore, Indian Territory, 1895–96), and natural sciences in the Dallas High School (1896–97). He also worked for nearly a year in the clerk's office of the Bastrop County Court, where he acquired a knack with legal phraseology and a feeling for due process that served him well in later years; and he took advantage of the opportunity afforded during the summer of 1897 to collaborate with Professor E. F. Northrup, briefly attached to the University of Texas, in "Some Observations on the Dielectric Strength of Oils" and in "Some Experiments in Induction with Currents of High Frequency at Long Distances." In a footnote to the latter joint publication, Northrup remarked that a statement by Professor J. Trowbridge of Harvard suggested a further experiment that might be made "with an instrument of the character described"; from which it may be inferred that Northrup's advice is likely to have been influential in steering Pierce toward Harvard. In any case, the most significant by-product of this four-year period of latency seems to have been the conviction it gave Pierce that his real love was scientific research and that a career in this field would have to be pursued elsewhere.

Pierce had an inexhaustible supply of salty anecdotes and apocryphal tales which were the constant delight of his associates. One of the most often repeated of these was the story he told of how he happened to come to Harvard in 1898 instead of going to the University of Chicago. His meager resources included no allowance for train fare, so he made his way to the railroad junction at St. Louis by working as chief wrangler on a cattle train. There he discovered that the only train for Chicago on which he could work his way during the next few days was a sheep train, whereas a cattle train was leaving at once for the east coast. For one raised in the Texas cattle country this was a simple choice, and Harvard gained a new and eager scientist.

Nothing is lost from the foregoing tale if it be confessed that

Pierce had already applied to Harvard in the spring of 1898 for scholarship aid, and that the Whiting Fellowship had been awarded to him for study in the Physics Department for the academic year 1898–1899. Miscellaneous odd jobs augmented this modest support, and one of them revealed the characteristic Pierce touch. A group of Cuban students arrived for the Harvard Summer School and asked for a guide to help them see the beauties of New England. Pierce applied for the job and went to President Eliot for an interview. When asked for his qualifications, he replied that he could speak Spanish and that he was experienced in loading cattle on trains. He got the job.

The challenge Pierce was seeking was generously provided by his adviser, Professor John Trowbridge, and by such other Harvard "greats" as Wallace Clement Sabine, Edwin H. Hall, B. O. Peirce, and W. E. Byerly. He picked up another master's degree in 1899, and took his Ph.D. in 1900 with a thesis topic of his own choosing: "The Application of the Radio-Micrometer to the Measurement of Short Electric Waves." Professor Trowbridge took a dim view at the outset of his selection of this research problem, but the three publications that grew out of the work soon convinced him that Pierce had good judgment as well as high ability.

The award to Pierce of a John Tyndall Scholarship for 1900–1901 enabled him to spend his first post-doctoral year abroad, most of it in Leipzig working with Boltzmann. Once again his targets were of his own choosing, and out of this work came the material for two articles on the indices of refraction and the phenomena of double refraction for electric waves, topics he investigated with the aid of an improved form of the radio-micrometer he had devised two years earlier for his doctoral research. His nontechnical visits to Berlin and other parts of Germany, and a holiday bicycling junket to Italy, strengthened his command of European languages and heightened his interest in Germanic literature, as was evidenced by his choice of subject matter for the avocational poetry he wrote at this time—and was courageous enough to preserve.

In 1901–1902 Pierce was back at Harvard as an assistant in physics, starting his climb up the academic ladder. He was appointed instructor in 1902, assistant professor in 1907, and Professor of Physics in 1917; and in 1921 he succeeded E. H. Hall to become the seventh Rumford Professor of Physics. He was given in 1935 the additional title of Gordon McKay Professor of Communication Engineering, which thereby further enhanced the academic dignity of a technical subject he had a large share in creating. He served also as the Director of the Cruft Memorial High Tension Electrical Laboratory from the completion of its construction in 1914, and as Chairman of the Division of Physical Sciences from 1927, until his retirement as Professor Emeritus in 1940.

Pierce's curiosity about the behavior of electric waves had by no means been satisfied by his doctoral research and his studies abroad, and the growing technical interest in "wireless" telegraphy drew him like a magnet toward this field. Our present sophistication concerning electric circuitry makes it difficult to appreciate the primitive state of knowledge about resonance and the tuning relations in coupled circuits which prevailed during the first decade of this century. Pierce made a frontal attack on these problems and published between 1904 and 1907 a definitive series of five papers dealing with both theoretical and experimental aspects of "Resonance in Wireless Telegraph Circuits."

Another essential element of a "wireless" receiver was the detector, and Pierce's interest shifted to this aspect of the communications problem after General H. H. C. Dunwoody, USA (ret.), had announced in 1906 that the contact between a metal and polycrystalline silicon carbide (carborundum) would function as such a detector. Many other minerals were soon found to exhibit similar behavior, so Pierce designated them all as *crystal rectifiers* and "began a series of experiments to determine, if possible, the nature of the phenomenon." Interest in these devices fell off sharply a few years later as De Forest's three-electrode "oscillation detector" began to take over the role of detection as well as that of amplification in wireless receivers. As a result, the lucid phenomenological analysis of the behavior of crystal rectifiers that Pierce set forth in a series of five papers published betwen 1907 and 1912 remained almost unchallenged until the resurgence of interest in this class of semiconductors during and after the Second World War.

As an incidental by-product of these studies, Pierce made the first electroacoustical sound-level meter in 1908 by associating one of his molybdenite crystal rectifiers with a telephone receiver operated reversibly as a microphone. This instrument allowed him to make the first quantitative experimental study of the distribution of sound energy in a reverberant room, and to confirm thereby some of W. C. Sabine's conjectures and qualitative observations on this aspect of architectural acoustics.

As his studies of the general behavior of rectifiers progressed, Pierce was led to consider the possibility of exploiting the characteristics of electrical conduction in gases for the detection of electric waves. His experiments in this field soon guided him to the invention in 1913–1914 of a three-electrode mercury-vapor-discharge tube in which electrons were freed by ion bombardment at the surface of a pool of mercury at the bottom of the tube, whence they could fly through a grid toward a positive plate at the upper end of the tube. Under some conditions the potential of the grid would control the magnitude of this electron current, yielding amplification; under other conditions the grid would provide off-on control of the discharge current. In basic principle, therefore, this device behaved very much like the "thyratron" developed later by A. W. Hull of the General Electric Company, except that Pierce drew his electrons from a mercury pool, whereas Hull boiled them out of the surface of a hot cathode.

Pierce found that the characteristic mercury-vapor-discharge glow which concentrated near the anode in his three-electrode discharge tube would vary in brightness with the potential of the grid. In one of his five patents dealing with these tubes, Pierce showed how this effect could be exploited by using the signal from an antenna to control the grid potential and by concentrating the light from the glow into a narrow line on a strip of moving film, thus creating a photographic record of the amplitude of the control signal. More than two decades later the Western Electric Company, by this time the holder of a license under Pierce's mercury-tube patents, was called on to defend itself in a Canadian court against an infringement suit addressed to their variable-density method of recording sound on motion-picture film. Western Electric's defenders resurrected Pierce's 1913 apparatus, which had been carefully preserved intact on a top shelf in his laboratory, connected it up with a modern microphone and amplifier, and proceeded to demonstrate to the court that a variable-density sound track could indeed be recorded on film as set forth in Pierce's patent specification. When news of this outcome reached Pierce, his reaction was characteristic. "I have just discovered that I invented the talking movies," he announced to his colleagues with evident satisfaction, and then added with a chuckle, ". . . more than twenty years ago."

While still largely preoccupied with his work on the mercury-vapor-discharge tube, Pierce collaborated with Professor Arthur E. Kennelly in 1912 on some measurements of the electrical impedance of telephone receivers. In a splendid manifestation of serendipity, these measurements led by happy accident to the discovery of the important concept of motional impedance. In making their measurements, one of the experimenters would balance the impedance bridge while the other tended the signal source, a not very reliable Vreeland oscillator located in a nearby room. Quite by chance one of them would habitually lay the receiver on its side on the laboratory bench while adjusting the bridge. The other always turned it face down, thereby altering the acoustic loading on the diaphragm, its motion, and hence the electrical impedance. It is easy to understand how alarmed they were when their measurements showed a complete lack of agreement at all frequencies in the neighborhood of resonance. In the course of pursuing the source of this discrepancy, they finally decided to abandon the careful nursing of the signal source and *watch* each other balance the bridge, whereupon the difference in their procedures was at once apparent. Kennelly and Pierce both appreciated the physical significance of the effect immediately, and each independently worked out a substantially complete theoretical analysis of the phenomenon within a few hours.

In July, 1917, just after the United States entered the First World War, Pierce was granted leave to join the company of physicists assembling at the Naval Experimental Station in New London, Connecticut, for a study of ways and means to "do something" about the mounting losses due to enemy submarines. Such a gathering of physicists and engineers for common attack on a military problem can now be regarded as a precursor of the massive mobilization of civilian scientists behind the military effort of the Second World War.

The major effort at the New London "Station" was devoted to the perfection of devices for listening to the underwater sounds generated by a submarine's engines or its propellers. One group concentrated on passive all-acoustical systems; another, with which Pierce allied himself, concerned itself with electroacoustical systems using two or more underwater sound receivers, or hydrophones, attached to the ship or towed behind it. The advantages of such "multispot" systems were manifold: more sound energy could be intercepted, leading to greater sensitivity; and directional discrimination could be enhanced in much the same way that any listener's ability to locate the direction from which a sound is coming would be increased if his two ears were separated by several feet instead of by just the width of his head! In combining the signals from several hydrophones, however, it was necessary to introduce compensation for the differences in the time of arrival of the signals at each hydrophone location; and the devices for inserting the appropriate and controllable amount of delay in each signal path were called "compensators." Pierce made major contributions to this technology by inventing a new type of electric delay network (using mutual inductance) for which the time delay was essentially independent of the frequency. What was equally important, he brought to bear on the practical problems of building these devices his background of experience, his ingenuity, and his flair for inciting others to constructive action. Always a master of the pithy remark and the adroit hyperbole, Pierce epitomized his concern with these practical problems by remarking years later, "We almost lost the war on account of dirty switch contacts and poor B-batteries."

After the war Pierce made his new constant-delay network the subject of a research paper and a patent application. In 1920–1921 he made further capital of his war-time research experience by beginning to offer for the first time in any university a graduate course in underwater sound signalling; and, for almost the entire interval between the two World Wars, the Navy would send to him each year a delegation of officers for postgraduate training in this field and in the other areas of electrical communication in which he had made Harvard an academic pioneer.

Pierce had begun to lay the foundation for leadership in this field almost as soon as he returned from his year of study abroad in 1901. In his first year of service as an instructor he introduced a new half-year course titled "Radiation." Two years later the catalog listed him for a "research" course in the field of "Radiation and Electromagnetic Waves," and the following year he introduced another pioneer course in "Electric Waves and their Application to Wireless Telegraphy." Six years later, in 1911–1912, he inaugurated still another new course in this field, designated as "Electric Oscillations and Electric Waves." To appreciate how far in the van this instruction was it is only necessary to recall that Marconi's classic experiment in trans-Atlantic "wireless" transmission was only ten years old in 1911–1912, and that the sinking of the *Republic* in 1909 and of the *Titanic* in 1912 had just furnished tragic proof that the safety of ships at sea required continuous "wireless" surveillance.

Pierce consolidated these academic beachheads by publishing two timely textbooks, each containing much that was new when it appeared. The first, *Principles of Wireless Telegraphy* (1910), was based on the course he had been teaching for five years and summarized his research publications on tuned circuits and detectors. He gave the second, *Electric Oscillations and Electric Waves,* the same title as that of his later course, and its appearance in 1919 gave him the opportunity to make immediately available some of the results of his research on electric networks at the New London Experimental Station.

Pierce always regarded the position of Cruft Laboratory, midway between the Physics Department in the Jefferson Physical Laboratory and the School of Enginering in Pierce Hall, as more than a geographic accident. He maintained steadfastly that "Cruft" should be supported financially and sponsored academically by both the Department of Physics and the School of Engineering, and he guarded each of these bonds of affiliation with equal zeal. Of course, this tactical position inevitably supplied a basis for Pierce's dry comment: "The physicists call us engineers and the engineers call us physicists." Under his guidance, however, and with the stout support of Professor E. L. Chaffee, his colleague for thirty years, the term "Cruft Laboratory" came to signify not just a building but a whole scheme of applied science education based on vigorous liaison between pure physics and engineering practice. Chaffee's research interests complemented Pierce's, and their classes attracted students from near and far and gave training to two generations of leaders in the communications industry.

The 1920s can be called Pierce's "oscillator period." Two of his most important contributions were made during the middle half of this decade: the quartz-crystal "Pierce oscillator" in 1923 and the magnetostriction oscillator in 1927. Each produced one or more major publications and a portfolio of patents; each supplied the medium or the motivation for a family of doctoral theses; and together they shaped the remainder of Pierce's career.

The story of the "Pierce oscillator" is characteristic and revealing. The piezoelectric effect had been discovered as early as 1881, but it lay almost totally neglected until 1917, when Langevin began to exploit this property of quartz as the active principle of a transducer for underwater sounds. Professor W. G. Cady of Wesleyan University took up the study of these piezoelectric vibrators as soon as he heard of Langevin's work, and his experiments were chiefly responsible for opening up the field of frequency control by means of coupled electromechanical resonators. While working with a quartz crystal connected in the circuit of a self-excited vacuum-tube oscillator, Cady discovered in 1922 that the frequency of self-oscillation could be stabilized over a narrow range by the vibrations induced in the crystal.

Cady published his findings promptly, and demonstrated and described his crystal-stabilized oscillator circuits to many colleagues and friends, among them Professor Pierce. No argument was needed to convince Pierce of the technological importance of this development and he set about at once to repeat Cady's experiments. Within a few months he had invented three improved and greatly simplified forms of the crystal oscillator; circuits which differed from Cady's in that a *two*-terminal crystal would control uniquely the frequency of oscillation in a *single*-tube circuit. Each of the new circuits combined the virtues of simplicity and reliability: it would not oscillate at all unless the crystal was in the circuit, and then it would oscillate only at the resonance frequency of the crystal. As a consequence of these virtues, the "Pierce oscillator" came into almost universal use, and it has continued to dominate for more than thirty years the fields of frequency standardization and precision frequency control in radio transmitters and receivers.

Magnetostriction had been known and studied for more than forty years before piezoelectricity was discovered but, except for a handful of visionary proposals set forth in patent specifications, no practical use had been made of it before Pierce took up its study in 1926. Pierce took it as virtually a personal challenge when he found in a paper published that year the observation that "as far as can now be made out, no important application of the fact of magnetostriction . . . or of effects closely related to magnetostriction, has yet been made," and with his background of experience with crystal oscillators it did not take him very long to get a self-excited magnetostriction oscillator going. Two coils surrounded a nickel rod: one in the output circuit to excite the rod's vibration, and one in the input circuit to sense the vibration and complete the feedback path. The correct polarity for the coil connections was discovered by making a mistake, Pierce said later. The connections that were wrong for exciting self-oscillation in an ordinary vacuum-tube oscillator turned out to be right when the back-coupling was furnished by the resonant vibration of the magnetostriction rod.

Magnetostriction vibrators, like quartz crystals, are "stiff" driving elements characterized by large forces but small displacements. This is just what is needed, however, to generate sounds in a relatively incompressible liquid medium such as water, and the emergence of magnetostriction in the interval between the two World Wars was timely. Pierce kept his longtime friend and fishing companion, Dr. H. C. Hayes of the Naval Research Laboratory, fully informed of his experiments, and magnetostriction was soon being exploited to energize sound projectors for underwater echo ranging. As a result, when the United States entered the Second World War, nearly all the antisubmarine vessels of the U. S. Navy were fitted with echo-ranging equipment using magnetostriction-driven sound projectors.

With typical ingenuity Pierce found many other new applications for magnetostriction. He used it to excite longitudinal vibrations in a nickel wire and to pick the signals off the wire after transmission over moderate distances, in a modern "carrier" version of the "lover's telegraph"; and he used the same principle to make a new kind of multi-receiver "compensator" that was functionally similar to those he had worked with in 1918. In another modification, using resonant rods for coupling instead of a wire, H. H. Hall developed with Pierce's guidance a linear-phase-shift narrow-band filter that was uniquely useful for the harmonic analysis of musical sounds of short duration.

While developing directional receivers for airborne or waterborne sounds, Pierce discovered that the transverse vibrations of a thick metal plate immersed in a fluid could produce sharply directional radiation in the fluid, and that even such a thick metal plate could be relatively transparent to high-frequency sound when the trace velocity of the incident sound wavefront matched the propagation speed of the transverse wave in the plate, a "coincidence" effect whose relevance to sound transmission through building partitions has only recently been appreciated. He combined magnetostrictive and non-magnetostrictive metals into bimetallic strips to make "bender" elements, and one of his doctoral candidates explored the use of such a vibrator as a phonograph pickup. He also contrived a novel form of large-diaphragm loudspeaker by attaching a magnetostrictive drive rod to the underside of a large lecture table. Surprisingly good reproduction was afforded by this arrangement, as Pierce demonstrated spectacularly on one occasion by climbing up on the table and remarking to a startled colloquium audience, "See, you can even stand on the diaphragm of this loudspeaker without interfering with its operation!"

The fine flair for showmanship exemplified by this incident was indirectly responsible for the trend of Pierce's activity during the last dozen years of his experimental career. He had once described what he called "the interesting moment" in the development of his crystal oscillator as follows: "Suspecting that the system was oscillating with frequencies above audibility a sheet of cardboard held in the hand was moved toward the crystal. A telephone in the circuit then gave out an audible note. This was due to the Doppler effect. The crystal was radiating sound of frequency too high to hear; the cardboard reflected the sound. On account of the motion of the cardboard the reflected sound had a different pitch from the emitted sound and hence produced a beat note . . . (which) on account of the rectifying effect of the vacuum tube was audible." This experiment not only demonstrated that the crystal was oscillating but was also a pioneer venture in making such high-frequency sounds audible, and it remained one of Pierce's favorite demonstrations. During the following fifteen years he made a series of progressively improved "supersonic" (now called ultrasonic) receivers for "translating" high-frequency sounds into the audible part of the spectrum; and with these receivers available to him, the ultrasonic sounds of nature had no defenses left against his curiosity.

It had been known since 1908 that flying bats would bump into obstacles if their ears were covered but not if the covering was shifted to their eyes. In 1937, D. R. Griffin, now Professor of Zoology in Harvard, appealed to Pierce for help in exploring whether bats could hear and emit sounds at frequencies above the human hearing range. They soon proved that bats did emit ultrasonic squeaks and chirps at frequencies as high as 40 to 50 kilocycles per second. That the bats also listened, in sonar fashion, to the echoes of their own signals and used these echoes for obstacle avoidance was also proved three years later by Griffin and Galambos in one of Pierce's basement laboratory rooms; and Griffin's continuing studies now show that these clever little flying mammals have anticipated many of our most sophisticated electronic techniques of echo-location.

A similar question had often been asked, but never answered, as to whether stridulating insects, such as grasshoppers and crickets, might not also emit superaudible sounds. Even without the challenge of this question it was perhaps inevitable that Pierce should have directed the sound-gathering horn of his frequency-translating receiver toward the crickets whose songs had lulled him to sleep at night during his summers in New Hampshire. He was soon able to show that these insects did emit high-frequency sounds, that the emissions were usually modulated at a relatively low frequency, and that the modulated ultrasonic bursts were sounded in typical rhythmic pulse-code patterns. He modified his apparatus to yield permanent records of these rhythms and devised an ingenious process of sound recording and rerecording with a speed differential which, in effect, slowed down the modulation enough to let each cycle be counted. In this way he proved that each modulation cycle corresponds to the passage of one tooth of the insect's "file" over its "scraper," and his records established that the frequencies and the pulse-code pattern of each insect's chirps are sufficiently characteristic to qualify as a means of identifying the species acoustically.

These studies occupied "the large part of a happy decade," and supplied the material for his last book, *The Songs of Insects* (1948). "The casual reader may be interested," Pierce wrote in its Introduction, "to inquire how the efforts of a specialist in physics and communication engineering become directed to the study of insects. The answer might be that anyone who is ignorant has the obligation to seek enlightenment." There was, of course, a more specific reason in the fact that Pierce's background of research on the generation, propagation, and reception of high-frequency sounds qualified him uniquely for the pursuit of this enlightenment.

There was a wide disparity between the financial straits in which Pierce found himself when he arrived in Cambridge to begin graduate study and the secure financial position he subsequently achieved, largely with the proceeds from his patents. It is safe to say he did not care very much how large his fortune was so long as he had enough for comfortable living. He built an attractive home on Berkeley Place in Cambridge in 1914, and followed this in 1932 with a simple one for summer living in Franklin, New Hampshire, to which he annexed in 1936 a small laboratory to serve as a base for his insect studies. After his retirement in 1940, he built a large and comfortable winter home in St. Petersburg, Florida. He was always generous to the students who worked under him, many of whom were as needy as he had been at their age. This help usually took the form of employing them on very generous terms to assist him in his own research. In some cases these men were named as coauthors of the resulting papers; in others he encouraged them to publish independently, as Dr. Macfarlane had encouraged him to do at the beginning of his career.

An early episode revealed Pierce's pragmatic approach to financial problems. During negotiations for the purchase of his mercury-vapor-discharge tube patents, the prospective buyer cautiously inquired what price Pierce had in mind. He replied without hesitation, naming an exact figure of so many dollars and so many cents. Since this price was substantially less than the buyer had been prepared to pay, an agreement was soon reached. When questioned later as to why he had named such an odd figure, Pierce replied that this was just the amount of the unpaid balance of the loan with which he had built his house in Cambridge, and that he was now out of debt! Later on, with a chuckle that always left his listener wondering whether he was serious or not, he would volunteer a formula which reduced the problem of investment to a similar basis of stark simplicity: "Put half of any surplus money you have into American Telephone and Telegraph Company stock," he would say, "and the other half into savings banks; then if the price of A. T. & T. goes down, you'll have money in the bank to buy more of it." His abiding faith in this corporation was based partly on his deep respect for the excellence of its research and partly on his personal connections with the men in it, many of whom had been trained in the Cruft Laboratory. It can be doubted whether he followed his own investment dictum slavishly, but it did carry him safely and profitably through the financial crisis of 1929.

The sequence of events relating to the "patent phase" of Pierce's career was fortunate. The first thirteen of his fifty-three patents came before his "oscillator period" and all were salable. They yielded enough to assure him the comfortable living he sought and to give him a feeling of financial adequacy in undertaking the defense of his basic patents on the crystal and magnetostriction oscillators and on the other applications he found for piezoelectricity and magnetostriction. His early patents had not been seriously contested, but he soon found himself deeply involved in defending his "crystal" patents. For a lone college professor to lock horns in a patent interference contest with the American Telephone and Telegraph Company was a little like matching David against Goliath; but David won his match and so did Pierce, eventually, after twelve years of litigation.

The same A. T. & T.-owned patent that Pierce ran into had been cited earlier in interference with Professor Cady's application for a patent on his pioneer crystal-stabilized oscillator. Pierce always believed that Cady was entitled to his basic claims, and even after he won his own interference suit he refused to adopt any of the claims that had been derived from Cady's disclosures. He had urged Cady to defend these claims, even offering to underwrite the services of his own patent attorney, Mr. David Rines. Neither Cady nor Rines would accept this arrangement, however; and the latter generously insisted then, as he did later, on the privilege of helping impecunious academics protect their rights without regard for compensation. Cady soon tired of fighting it out even on this line and elected to sell his pending reissue applications for a modest sum that can be judged with hindsight to have been a fraction of their potential worth. On the other hand, although Pierce did not relish the litigation he encountered, he did not shrink from it when he felt that his just rights were being challenged. He never said it in so many words but the record clearly indicates that "it wasn't the money, it was the principle of the thing" that moved him. Except for the major contest mentioned above and one other "major" interference action, most of his litigation consisted of interferences relating to minor features of the crystal oscillator which Pierce felt obliged to defend for the protection of his licensees. He was victorious in most of these contests, but once his rights had been established he granted licenses liberally.

Due process followed a more equivocal course in connection with Pierce's magnetostriction patents. One of the principal users of magnetostriction in underwater-sound equipment manufactured for the U. S. Navy declined to take a license under Pierce's patents, and his suit for infringement was balked by the refusal of the Navy to reveal either in court or *in camera* the technical details of equipment still subject to military security classification. Pierce was deeply disappointed by this official reluctance of the Navy to acknowledge the use of his magnetostriction patents, and while he made his apparatus and notebooks freely available to other scientists engaged in anti-submarine research during the Second World War, he chose to continue his own research on insects and to avoid further involvement in war research. Soon after the war ended, the legal impasse was broken by a substantial settlement out of court.

Outside of Harvard, Pierce was honored in various ways. He was elected to the American Academy of Arts and Sciences in 1907, and to the National Academy of Sciences in 1920. He served as the President of the Institute of Radio Engineers for two terms, in 1918 and 1919, and became the eleventh recipient of their Medal of Honor in 1929. The Franklin Institute awarded him the Franklin Medal in 1943 with the citation: "In recognition of his outstanding inventions, his theoretical and experimental contributions in the field of electrical communication, and his inspiring influence as a teacher." He was also made a fellow of various professional societies and, although he seldom traveled to out-of-town meetings after 1920, his office was a mecca for returning students and former associates, whose affectionate homage was the honor he cherished most.

Pierce had a certain shyness about his private affairs which made him keep the past to himself. In spite of his early liking for history, he said more than once that there was no interest in things of long ago; they were of no further use. In his active life it was the present and the immediate future that were exciting and full of promise. He was an excellent talker about scientific or academic matters, with a fund of good stories, many of which dated back to his Texas days. His facility in writing, and the breadth of his reading, helped him produce a small bound volume of commemorative and other poems and speeches which have a vivacity and wit that reminds one of Oliver Wendell Holmes. This collection begins with a few poems he had contributed to the *University of Texas Magazine*. He continued to add to it for more than fifty years, including specimens in Latin, French, and German, and he was always ready to decorate a festive occasion with timely verse.

Pierce was married in 1904 to Florence Goodwin of Saxonville, Massachusetts, and they enjoyed forty-one happy years together. Although they had no children, they took great pleasure in the children of others, especially those of their neighbors, Cornelia and Walter Cannon (distinguished physiologist of the Harvard Medical School). The Cannons had a summer property in Franklin, New Hampshire, on part of which they invited the Pierces to build a summer cottage and later a small laboratory.

On one occasion, when the Pierces were taking off for a European tour in a sabbatical year, Mrs. Cannon warned Pierce that he might be bored and gave him a painting outfit. With no training but with much enthusiasm he proceeded to turn out portraits, landscapes, and more abstract subjects, one after the other, and for a while painting was his favorite hobby. The walls of his office were soon covered with portraits of friends, colorful katydids and grasshoppers, and symbolic pictures of electric waves leaping across oceans. His favorite, however, was a handsome rendition of Tenniel's version of Lewis Carroll's Dodo bird, with a superposed quotation that revealed its strong appeal to his instinct for experimentation. " 'Why,' said the Dodo, 'the best way to explain it is to do it.' " He refused to acknowledge any difficulty or handicap in painting, but he made no claims, either, except for the evolution of another Pierce-like oversimplified formula. "Paint two pictures," he would say, "and then you can use first one and then the other as a guide in making improvements."

The death of Florence Pierce in 1945 left "G. W.," as he was affectionately known to colleagues and students alike, quite alone, with no children, no close relatives, and declining strength. He was fortunate in having good neighbors, however, who had long been friends of the Pierces. One of them was Helen Russell, of Sanbornton, New Hampshire, who proved to be a helpful and congenial companion. They were married in 1946, and Pierce continued to enjoy his annual pilgrimages between his home bases in Florida, Cambridge, and New Hampshire. He had experienced one minor "cerebral accident" in 1945, and a series of these recurred in 1956, from the last of which he did not recover.

The writers of this memoir have been forced to draw on many miscellaneous sources for information about Pierce's life, since what he himself left was inadequate. We have searched our own memories and those of his many colleagues and friends; and if there are more than the usual number of whimsical anecdotes scattered through this account, it is because they best reflect the gay spirit that is the most vivid recollection we all have of this colorful man. We are especially grateful in this connection to Mrs. Helen Pierce and Mrs. Walter Cannon. We have drawn freely on the material used in preparing the Minute on his Life and Services which was spread on the records of the Harvard faculty, and on the more detailed accounts published elsewhere [1] about the antisubmarine work at New London in 1917–18 and the patent litigation relating to the "Pierce oscillator." We are also indebted to Professor Robert B. Watson, now of the University of Texas, for pursuing Texas data for us; to Mr. David Rines for much useful information about Pierce's patent activities; and to the Franklin Institute for permission to use material from the biographical memoir submitted by the committee which prepared Pierce's nomination for the Franklin Medal award. His informal acceptance speech on the occasion of that award appears as the last entry in the appended tabulation of his publications.

[1] H. C. Hayes, "Detection of Submarines," *Proceedings of the American Philosophical Society,* 59(1920):1–47 and 371–404; and F. V. Hunt, *Electroacoustics* (Cambridge, Harvard University Press, and New York, John Wiley & Sons, Inc., 1954), pp. 53–57.

KEY TO ABBREVIATIONS

Amer. J. Sci. = American Journal of Science
Elec. World = Electrical World
J. Acoust. Soc. Amer. = Journal of the Acoustical Society of America
J. Franklin Inst. = Journal of the Franklin Institute
J. Mam. = Journal of Mammalogy
Phil. Mag. = Philosophical Magazine
Phys. Rev. = Physical Review
Phys. Zeits. = Physikalische Zeitschrift
Proc. Amer. Acad. Arts Sci. = Proceedings of the American Academy of Arts and Sciences
Proc. Inst. Radio Engrs. = Proceedings of the Institute of Radio Engineers

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UNITED STATES PATENTS

The disclosures published in these U.S. Patents were also covered by many foreign patents, none of which, however, anticipated the dates of the corresponding U.S. Patents.

TUNING APPARATUS AND CRYSTAL RECTIFIERS

Item	Patent No.	Issue Date	Filing Date	Title
1.	879,409	February 18, 1908	March 16, 1906	Wireless Telegraphy
	[Receiving system with "inductive connection," variable primary, variable secondary, and detector.]			
2.	923,699	June 1, 1909	October 17, 1906	Wireless Telegraphy
	[Improved tuning apparatus.]			

Item	Patent No.	Issue Date	Filing Date	Title
3.	879,061	February 11, 1908	January 11, 1907	Rectifier for Alternating Currents
	["An electrical measuring instrument comprising a unilaterally conductive solid . . ." (carborundum).]			
4.	879,062	February 11, 1908	April 5, 1907	Rectifier and Detector
	[Use of "conducting oxid of titanium" (anatase).]			
5.	879,117	February 11, 1908	April 5, 1907	Rectifier and Detector
	[Use of silver-tellurium.]			
6.	923,700	June 1, 1909	February 20, 1907	Rectifier
	["In rectifying apparatus, . . . an asymmetrically conductive solid . . . to rectify and distort the alternating current. . . ."]			

(Items 1–6 were assigned at issuance to the Massachusetts Wireless Equipment Company but were assigned back to Pierce on April 10, 1913.)

MERCURY-VAPOR TUBE

Item	Patent No.	Issue Date	Filing Date	Title
7.	1,112,655	October 6, 1914	August 5, 1913	Apparatus for Receiving or Relaying Electric Signals
8.	1,112,549	October 6, 1914	November 26, 1913	Apparatus for Amplifying or Detecting Electrical Variations
	[Figure 2 shows arrangement for variable-density photographic recording of variable light from the glow at the anode.]			
9.	1,087,180	February 17, 1914	November 26, 1913	Apparatus for Amplifying or Detecting Electrical Variations
	[Mercury-vapor tube with keep-alive circuit and a grid.]			
10.	1,127,371	February 2, 1915	March 11, 1914	Apparatus for Amplifying or Detecting Electrical Variations
	[Improvement on Items 8 and 9 adapted for quicker recovery.]			
11.	1,450,749	April 3, 1923	March 11, 1914	Apparatus for and Method of Controlling Electric Currents
	[Describes thyratron-like behavior. "From the nature of the gaseous conductor . . . it is much easier (by grid control) to start . . . than it is to stop the flow of current when once established."]			

(Items 7–11 were assigned on April 17, 1917, to Peter Cooper Hewitt.)

COMPENSATORS AND DELAY LINES

Item	Patent No.	Issue Date	Filing Date	Title
12.	1,682,712	August 28, 1928	June 25, 1919	Electric Compensator

[Developed at the Naval Experimental Station, New London. Made intensity maximum occur at same adjustment that yielded receiver compensation for binaural centering.]

Item	Patent No.	Issue Date	Filing Date	Title
13.	1,576,459	March 9, 1926	December 24, 1921	Electric Retardation Line

[Delay line with mutual inductance between the series-connected coils. Filing date delayed by postwar negotiation for release.]

(Item 12 was assigned on April 24, 1922, and Item 13 on November 18, 1922, both to the Submarine Signal Company.)

CRYSTAL OSCILLATOR AND PIEZOELECTRIC APPLICATIONS

Item	Patent No.	Issue Date	Filing Date	Title
14.	2,133,642	October 18, 1938	February 25, 1924 Renewed April 18, 1930	Electrical System

[The "parent" crystal-oscillator case. With the additions due to interferences and other causes, it ended up with 106 claims.]

Item	Patent No.	Issue Date	Filing Date	Title
15.	1,789,496	January 20, 1931	[February 25, 1924] January 18, 1928	Electrical System

[A division of Item 14. Addressed generally to the production of constant-frequency beats in transmitter-and-receiver systems by "electromechanical vibrators."]

Item	Patent No.	Issue Date	Filing Date	Title
16.	2,133,643	October 18, 1938	March 29, 1926	Electrical System and Apparatus

[Continuation-in-part of Item 14. Addressed to crystal holders and supports and other features. With additions from interferences and other causes, 120 claims.]

Item	Patent No.	Issue Date	Filing Date	Title
17.	2,112,863	April 5, 1938	January 5, 1928 Renewed February 27, 1935	Electrical System

[A continuation-in-part of Item 14. A "Pierce Oscillator" with choice of two natural frequencies (different modes of vibration) by electrical switching.]

Item	Patent No.	Issue Date	Filing Date	Title
18.	2,133,645	October 18, 1938	January 14, 1928	Electrical System

[Continuation-in-part of Item 14. Self-oscillating detector in radio receiver, with crystal control of self-oscillation or local oscillator frequency.]

Item	Patent No.	Issue Date	Filing Date	Title
19.	2,133,646	October 18, 1938	April 9, 1930	Electrical System

[Continuation-in-part of Item 14. Oscillatory systems controlled by electromechanical vibrators; crystal frequency followed by frequency multipliers or harmonic selectors to yield stabilized high frequency in a transmitter.]

Item	Patent No.	Issue Date	Filing Date	Title
20.	2,133,648	October 18, 1938	July 10, 1931	Electrical System
	[Continuation-in-part of Item 14. Thickness vibrator; orientation of crystal "cuts"; variable impedance for adjustment of crystal frequency and other purposes.]			
21.	2,266,070	December 16, 1941	[March 29, 1926] September 28, 1938	Electromechanical Vibrator Apparatus
	[A division of Item 16. More on crystal holders, including an evacuated housing or its equivalent.]			
22.	2,133,647	October 18, 1938	June 25, 1931	Electromechanical Vibrator
	[Continuation-in-part of Items 14 and 16. Still more on crystal supports and holders.]			
23.	2,133,644	October 18, 1938	January 9, 1928	Electrical System
	[More oscillator claims, extending Item 14; a receiving system.]			
24.	1,962,155	June 12, 1934	April 23, 1928	Vibratory System and Apparatus
	[Receiving system for modulated carrier; crystal with microphone attached, conductivity of which varies in accordance with deformation.]			

MAGNETOSTRICTION OSCILLATOR AND APPLICATIONS

Item	Patent No.	Issue Date	Filing Date	Title
25.	1,750,124 RE 19,461	March 11, 1930 February 12, 1935	January 3, 1927 June 26, 1931	Vibratory System and Method
	[The "parent" case for magnetostriction.]			
26.	2,014,410	September 17, 1935	[January 3, 1927] July 20, 1928	Electromagnetostrictive Vibrator
	[A division of Item 25. Multiple-tube drive of diaphragm for radiating sound in water; segmented diaphragm.]			
27.	2,014,412	September 17, 1935	[July 20, 1928] November 19, 1930	Magnetostrictive Transmitter
	[A division of Items 25 and 26. Small core-to-diaphragm area ratio; spatial distribution of the core means "to facilitate piston-wise cophasing of the parts of the diaphragm."]			
28.	2,014,411	September 17, 1935	[November 19, 1930] August 2, 1933	Apparatus for Electromagnetostrictive Transmission and Reception
	[A division of Item 27 and continuation-in-part of Item 25. Multiply-driven diaphragm; reversible use as receiver.]			
29.	1,882,396	October 11, 1932	March 23, 1928	Magnetostrictive Transformer
	[Coupling from one coil to another via magnetostrictive rod.]			

Item	Patent No.	Issue Date	Filing Date	Title
30.	1,882,393	October 11, 1932	[March 23, 1928] August 9, 1932	Magnetostrictive Vibrator
	[A division of Item 29 and continuation-in-part of Item 25. Interchangeable rod vibrators; adjustable weights for frequency adjustment.]			
31.	1,882,394	October 11, 1932	[March 23, 1928] August 22, 1932	Magnetostrictive Vibrator
	[Another division of Item 29. Details of rod mounting.]			
32.	1,843,299	February 2, 1932	[June 28, 1927] April 23, 1928	Motor-Generator Set
	[A division of Appl. Serial No. 202,086, filed June 28, 1927, and later abandoned. Speed of motor controlled by using changing impedance of coil surrounding rod for frequency discrimination.]			
33.	1,962,154	June 12, 1934	April 23, 1928	Magnetostrictive Vibrator
	[Magnetostrictive vibrator with variable-resistance (carbon) microphone attached to generate signal for self-oscillation. Magnetostriction analog of Item 24.]			
34.	1,882,395	October 11, 1932	April 23, 1928	Frequency Indicator
	[Magnetostriction frequency-determining body.]			
35.	1,882,397	October 11, 1932	August 17, 1928	Magnetostrictive Vibrator
	[Composite vibrators, beaded rods, bimetallic strips, split tubes.]			
36.	1,882,398	October 11, 1932	[August 17, 1928] May 9, 1930	Magnetostrictive Vibrator
	[A division of Item 35. Composite vibrator made of concentric shells.]			
37.	1,882,399	October 11, 1932	[August 17, 1928] May 9, 1930	Magnetostrictive Vibrator
	[Another division of Item 35. Reed-type frequency meter with plurality of vibrators of different frequencies attached to common base.]			
38.	1,882,401	October 11, 1932	August 17, 1928	Loudspeaker
	[A continuation-in-part of Item 25. The "lecture-table" loudspeaker: Claim 4. "A loudspeaker comprising a magnetostrictive core weighted at one end and secured at its other end to a diaphragm."]			
39.	1,889,153	November 29, 1932	[August 17, 1928] February 26, 1931	Acoustic Electric Energy Converter
	[A division of Item 38. Magnetostrictive bimetallic strip driving a diaphragm.]			
40.	1,882,400	October 11, 1932	March 4, 1931	Vibratory Device
	[Magnetostrictive bimetallic strip used as phonograph pickup. S. A. Buckingham, coinventor, assignor to G. W. Pierce.]			

Item	Patent No.	Issue Date	Filing Date	Title
41.	2,063,950	December 15, 1936	December 4, 1931	Apparatus for Transmission and Reception
42.	2,063,951	December 15, 1936	[December 4, 1931] July 19, 1935	Apparatus for Transmission and Reception
	[A division of Item 41.]			
43.	2,063,952	December 15, 1936	[December 4, 1931] July 19, 1935	Apparatus for Transmission and Reception
	[Another division of Item 41.]			

(Items 41–43 were issued to Pierce's assistant, Raymond L. Steinberger, assignor to Pierce. They are addressed to the tube-and-plate type of transducer with diaphragm deeply slotted, both radially and annularly, to achieve in-phase vibration.)

Item	Patent No.	Issue Date	Filing Date	Title
44.	2,063,944	December 15, 1936	February 9, 1932	Direction, Transmission, and Reception Method and System
	[Basic case on the "coincidence" effect.]			
45.	2,063,946	December 15, 1936	February 9, 1932	Sound Communication System
	[Sound transmission on a modulated ultrasonic carrier; transmission via longitudinal waves in a wire using modulated carrier; one form of compensator.]			
46.	2,063,949	December 15, 1936	February 11, 1932	Magnetostrictive Vibrator
	[Tubular vibrator with exciting winding inside the tube; coil housing of magnetostrictive material provides shielding and return flux path for solenoidal winding.]			
47.	1,997,599	April 16, 1935	July 19, 1932	Electric Filter
	[Improvement on Item 29. Coils carefully decoupled and shielded except for coupling through magnetostriction of vibratile core.]			
48.	2,031,789	February 25, 1936	August 9, 1932	Acoustic Electric Energy Converter
	[Loudspeaker diaphragm driver with one end of drive rod fixed; permanent magnet polarization.]			
49.	2,044,807	June 23, 1936	June 30, 1933	Transducer
	[Conical and other tapered couplers for transferring sound energy from medium to magnetostrictive wire. Issued to Pierce's assistant, Atherton Noyes, Jr., assignor to Pierce.]			
50.	2,063,948	December 15, 1936	June 30, 1933	Compensator and Method
	[Improvement over Item 52. Use of cone receivers, pantograph and linear guides to move pickup coils appropriate distances. Coinventor, Atherton Noyes, Jr., assignor to Pierce.]			

Item	Patent No.	Issue Date	Filing Date	Title
51.	2,063,945	December 15, 1936	August 2, 1933	Diaphragm and Method
	["Coincidence" effect diaphragm made unidirectional by absorbing vibration at one end of plate.]			
52.	2,063,947	December 15, 1936	August 8, 1933	Compensator
	[Multi-unit receivers, wire transmission, damping of reflected wave by elastomer wrapping distributed along end of wire.]			
53.	2,014,413	September 17, 1935	May 11, 1935	Magnetostrictive Receiver
	[Continuation-in-part of Item 25. Frequency-discriminating sound receiver, plurality of tuned magnetostrictive bodies, tuned electrical circuits.]			