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Early FM Radio

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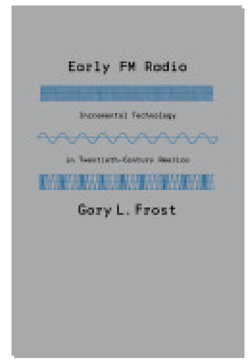

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CHAPTER FOUR

The Serendipitous Discovery of Staticless Radio, 1915–1935

> Serendipity a very expressive word. . . . You will understand it better by the derivation than by the definition. I once read a silly fairy tale called The Three Princes of Serendip: as their highnesses travelled, they were always making discoveries, by accident and sagacity, of things which they were not in quest of.
>
> *Horace Walpole, 1754*

To explain how Armstrong invented something resembling modern broadcast FM radio, I have examined how Armstrong profited both indirectly and directly from the results of thirty years of work by other men. He relied on his insider's knowledge of RCAC's research, and that firm had earlier learned much from the previous efforts of KDKA engineers and from the extensive use of Valdemar Poulsen's arc oscillator-based radiotelegraph system. In this chapter, I take a closer look at how Armstrong stumbled on what wideband FM radio actually did.

At all times, Armstrong traveled a path of invention that is best described as *serendipitous*—not in the modern dictionary meaning but in the sense that Walpole used when he coined the word in 1754. Before the issue date of the wideband FM patents, and for several years afterward, no one, not even Armstrong, completely understood the potential of what he had invented. He had based his patents on imaginative yet flawed theories of radio communication, and he therefore anticipated virtually none of the now well-known properties of modern FM radio, most notably its abilities to suppress static and reject interstation interference. To Armstrong's credit, though, he possessed the sagacious quality of intellectual adaptability, which enabled him (and others) to realize, over the course of several years, that he had invented a kind of FM far more valuable than he had intended. Moreover, when his system contradicted his expectations, he pragmatically overhauled his theoretical framework and continued to improve the technology. Certainly, this story of discovery was serendipitous in the way dictionaries define the word today—namely, as a happy accident. But the original meaning of the word fits better. In the "fairy tale" of Horace Walpole, the king of Serendip hired the best tutors for his three sons' educations. When they reached manhood, the king exiled the princes to wander the countryside, where they exercised their wits by analyzing evidence to solve a series of mysteries they happened on. Yes, luck played a part in their accomplishments, but so did cleverness. As Walpole would recognize, FM radio also resulted from a similar combination of accident *and* sagacity, not from accident alone.[1]

This chapter revises a second aspect of FM's history; namely the interaction of the evolution of FM radio technology and the competitive-cooperative relationship between Armstrong and the Radio Corporation of America. The fact that Armstrong kept much of his FM work secret from RCA adumbrated the rupture of that relationship. But shortly before or immediately after receiving his patents in December 1933, he disclosed them only to that company, which for more than a year afterward contributed considerable human and material resources for testing his system. Unfortunately, serious defects marred these tests. RCA and Armstrong designed them to investigate only the principal claim of Armstrong's patents: that FM extended the geographical range of radio waves transmitted at 30 megacycles or higher. Thus, only a small number of RCA engineers, and even fewer managers, adequately grasped what now seems like FM's obvious ability to suppress static. Furthermore, until the end of the 1930s, no one—not even Armstrong—knew about FM's capacities to reproduce high-frequency sound with superior fidelity and to resist interstation interference. Consequently, RCA engineers and managers never possessed sufficient information to make intelligent guesses about the potential of the wideband system.

The Balanced Amplifier and Frequency Modulation before 1934

At first, evaluating Armstrong's work apart from RCA during the twenties and early thirties seems especially difficult. The inventor habitually neglected to keep records of his research, confided in almost no one, and often unveiled his creations only after securing their patents. Indeed, in a rare criticism of his subject, Armstrong's biographer, Lawrence Lessing, characterized the fact that "he was secretive and stubborn in the direction of his own affairs" as his "most serious fault." Armstrong, Lessing wrote, "would never keep a regular or orderly laboratory notebook, describing his experiments as he made them, preferring to keep everything in his head until he was ready to make a full disclosure to the world." Lessing also believed that Armstrong's secretive tendencies were "so inextricably woven into his inventive nature as to have the look of fate about them."[2] In Lessing's telling, wideband FM seems the spontaneous outcome of ineffable genius.

Yet Armstrong's patents, published articles, and correspondence confirm his confession that he arrived at wideband FM only after a long period of trial and error, during which he followed "more will-o-the-wisps than I ever thought could exist."[3] By mid-1931, when Crosby, Hansell, and Beverage came to his laboratory at Columbia University to observe his latest FM receiver, he still had not yet hit on the idea of widening the frequency swing within range of his high-fidelity system of the late 1930s, 150 kilocycles. But he was well positioned to move in that direction, chiefly on account of his nearly two-decades-long, often-quixotic quest to suppress radio noise with a circuit called the balanced amplifier.

Every experienced radio designer in 1930 knew about the balanced amplifier.[4] Recognizable in schematic drawings by its characteristic symmetry, the circuit boasted two parallel mirror-image signal paths. It was normal practice to provide each path with separate input and output connections, and to combine the two signals, at either the inputs or the outputs, for the purpose of electrically adding or subtracting the signals. A crucial advantage of the balanced amplifier was its improved linearity compared to single-path circuits, something known even before the advent of vacuum tubes during World War I. In 1915 John R. Carson used balanced amplifiers in the patent that introduced single-sideband suppressed-carrier modulation (fig. 17), and ten months later another Carson patent used a balanced amplifier in "an improved detector in which distortion is largely eliminated" (fig. 18).[5] Clarence Hansell, RCAC's FM patent workhorse, similarly employed balanced amplifiers in at least eleven patents he filed before 1931.[6] Although no one seems to have understood *why* balanced amplifiers appeared to produce "cleaner" signals than single-path amplifiers, radio designers nevertheless pragmatically made the circuit part of normal practice by the mid-1920s. As for Armstrong, balanced amplifiers entered his design vocabulary during the beginning of his career. Soon after he graduated from college in 1913, he submitted an article to the *Proceedings of the Institute of Radio Engineers*, which published the piece in 1915. In it he introduced a circuit he described as a combination of "the two most effective static eliminators known; the balanced valve

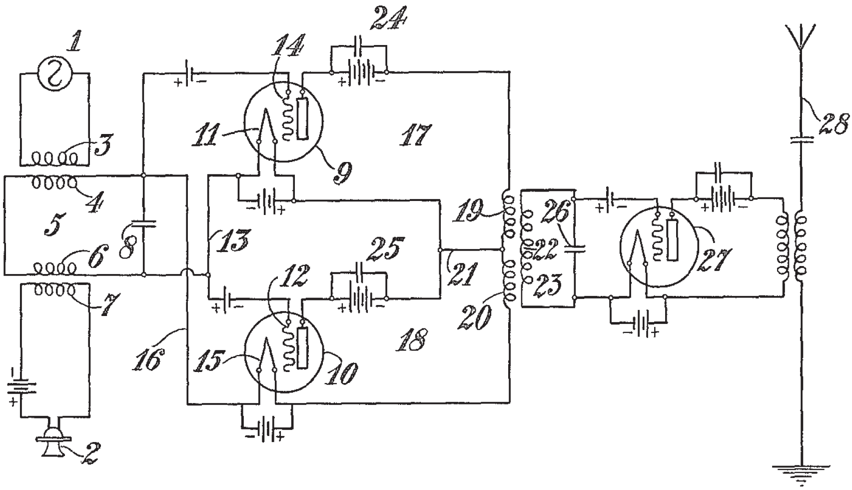

Fig. 17. Carson Single-Sideband Transmitter, with Balanced Amplifier, 1915. John R. Carson, "Method and Means for Signaling with High-Frequency Waves," U.S. Patent No. 1,449,382, application date: 1 December 1915, issue date: 27 March 1923, assigned to AT&T.

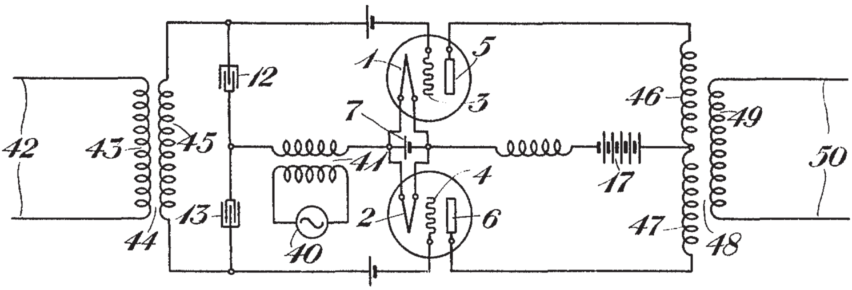

Fig. 18. Carson Balanced Amplifier, 1917. John R. Carson, "Duplex Translating-Circuits," U.S. Patent No. 1,343,307, application date: 5 September 1916, issue date: 15 June 1920, assigned to AT&T.

and the heterodyne receiver." As the symmetry visible in figure 19 shows, this circuit was a kind of balanced amplifier.[7]

Armstrong is sometimes mistakenly portrayed as a purely practical engineer, which has fostered the almost universally accepted misconception that theory had nothing to do with how he approached invention and design. In fact, he was a bold spinner of theories, many about balanced amplifier circuits. In 1914 his first published paper proposed a theoretical model describing how the au-

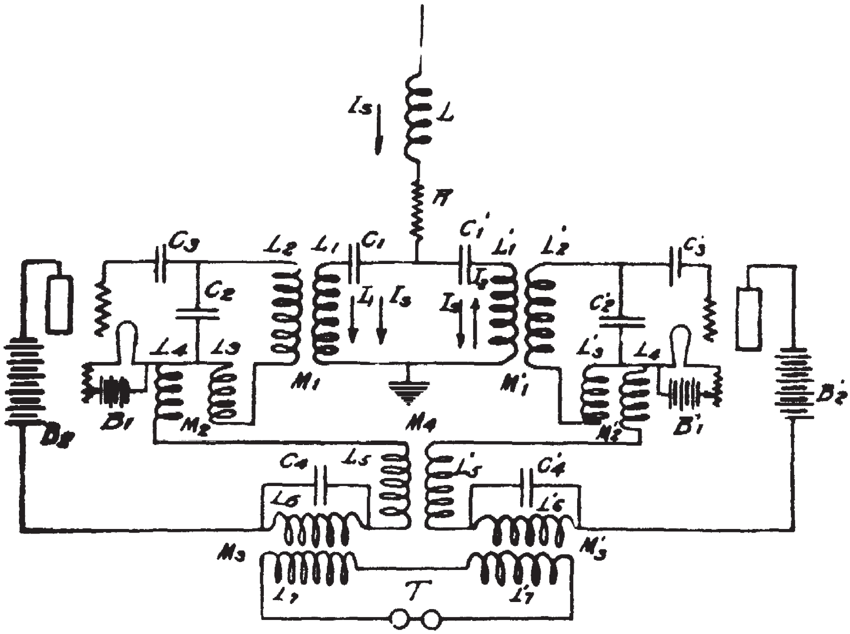

Fig. 19. Armstrong Balanced Amplifier, 1915. Balanced radiotelegraphy receiver described in Armstrong's second article, published in 1915. With "each receiver," he claimed, "it is possible to balance out the static and at the same time secure an additive response of the signals from each receiver." Edwin H. Armstrong. "Some Recent Developments in the Audion Receiver." *Proceedings of the Institute of Radio Engineers* 3 (September 1915): 215–47, reprinted in John W. Morrisey, ed., *The Legacies of Edwin Howard Armstrong* (n.p.: Radio Club of America, 1990), 67; also reprinted in *Proceedings of the IEEE* 85 (April 1997): 685–97.

dion worked, based on experiments he had carried out during his senior year at Columbia University. When the audion's inventor, Lee de Forest, ridiculed the model, Armstrong's rebuttal exposed de Forest's shaky understanding of his own invention.[8] Additional articles and patents authored by Armstrong, including his now-celebrated 1936 paper on wideband FM, also contained theories, several about the operation of balanced amplifiers. Armstrong fell short as a theorist, however, in one major respect: he never proved anything mathematically, in the style of, say John Carson or Murray Crosby, and math above the level of even high school algebra rarely appeared in his dozens of published papers. Not that Armstrong resented mathematics or mathematicians, but he tended to restrict his use of math to charts of recorded data. Perhaps his middling skills or evident incuriosity about the subject accounts for this inclination.

His overreliance on direct observation and intuition, and his underutilization of mathematics, go far in explaining his tortuous, twenty-year, and usually poorly conceived pursuit of a theory that suggested that balanced amplifiers might solve the problem of radio noise. As a college student, likely after visually inspecting paper oscillograph tapes and using his sense of hearing to compare balanced amplifiers with single-path amplifiers, he came to suspect what practitioners now share as common knowledge: that balanced amplifiers preserve fidelity better than single-path amplifiers. But no competent engineer would today claim, as did Armstrong for several years, that balanced amplifiers reduce random noises such as atmospheric static. He seems to have based this belief on a combination of hunches and wishful thinking. His 1915 paper, for instance, explained the alleged static elimination properties of the balanced valve by stating that "strays which cause serious interference [strong static-noise impulses] are of a much greater amplitude" than the signal, a fact that causes a single-path receiver to decrease its current in the output of its amplifier tube. By wiring "two complete receiving systems" in mirror fashion so that the output of one tube was subtracted from the other, he asserted, "it is possible to balance out the static and at the same time secure an additive response of the signals from each receiver." This theory rested on two precarious assumptions: that radio waves carrying static, as well as signal waves created by transmitters, always behaved (for reasons that Armstrong neglected to provide) more differently than alike in terms of the noise they caused in receivers; and that "static of large amplitude does not interact with the local frequencies [the received signal]."[9] In fact, the former assumption is sometimes true, and the static that bedevils AM radio reception today testifies to the falseness of the latter.

That the balanced amplifier captivated Armstrong's imagination is apparent also from his many patents and published articles. These reveal a line of descent from his theoretical confusion about the balanced-valve AM-detector circuit of 1915 to his low-static FM receiver of 1933 and eventually to the high-fidelity FM receiver of the late thirties. At all points Armstrong used balanced amplifiers, although he continually adjusted his explanations for how they worked, and what purpose they served. The 1915 circuit, for example, resurfaced in 1917, when he and his mentor at Columbia, Michael Pupin, invented a "Radioreceiving System Having High Selectivity" (fig. 20).[10] The two men claimed no advantage for the circuit, but in 1922 Armstrong revived his static-reduction theory for balanced amplifiers when he filed an application for a "Wave Signaling System" (fig. 21). The patent that was issued, No. 1,716,573, referred to the balanced amplifier as it was described in his 1915 audion paper (see fig. 19). Armstrong still believed in the

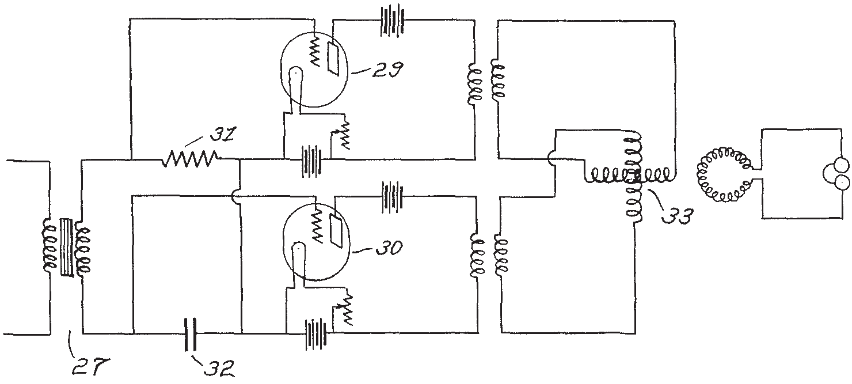

Fig. 20. Armstrong-Pupin Balanced Amplifier, 1917. Michael I. Pupin and Edwin H. Armstrong, "Radioreceiving System Having High Selectivity," U.S. Patent No. 1,416,061, application date: 18 December 1917, issue date: 16 May 1922.

static-reduction properties of balanced amplifiers, for the patent described a circuit "whereby the undesirable effects produced by atmospheric disturbances or other types of interference [i.e., static], in the course of the reception of signals, are greatly reduced." He also admitted that the 1915 circuit had "not been found to operate satisfactorily." He said this not to reject his static-reduction theory, though, but rather to explain how his new invention remedied other problems associated with the earlier circuit.[11]

The years 1927 and 1928 were the toughest during Armstrong's struggle to form a theory to explain how the balanced amplifier might suppress static. In August 1927 he filed a patent application for a low-static radiotelegraph system, and five months later he published an article about this invention in the *Proceedings of the Institute of Radio Engineers.* Again elaborating on his 1915 theory, Armstrong asserted that the energy of static noise changed significantly with respect to time but hardly at all with respect to frequency. Therefore, he concluded, more or less identical noise would inhabit two adjacent and extremely narrow channels on the spectrum at all points in time. Armstrong proposed using FSK to send and receive radiotelegraphic messages, shifting the transmitter frequency between closely spaced upper and lower channels. During transmission, one channel would contain signal + noise, and the other channel only noise—presumably noise identical to that which distorted the other channel's signal. Then he used the two sides of a balanced amplifier to detect the two channels separately. Electrically subtracting the output of one side of the amplifier from the output of the

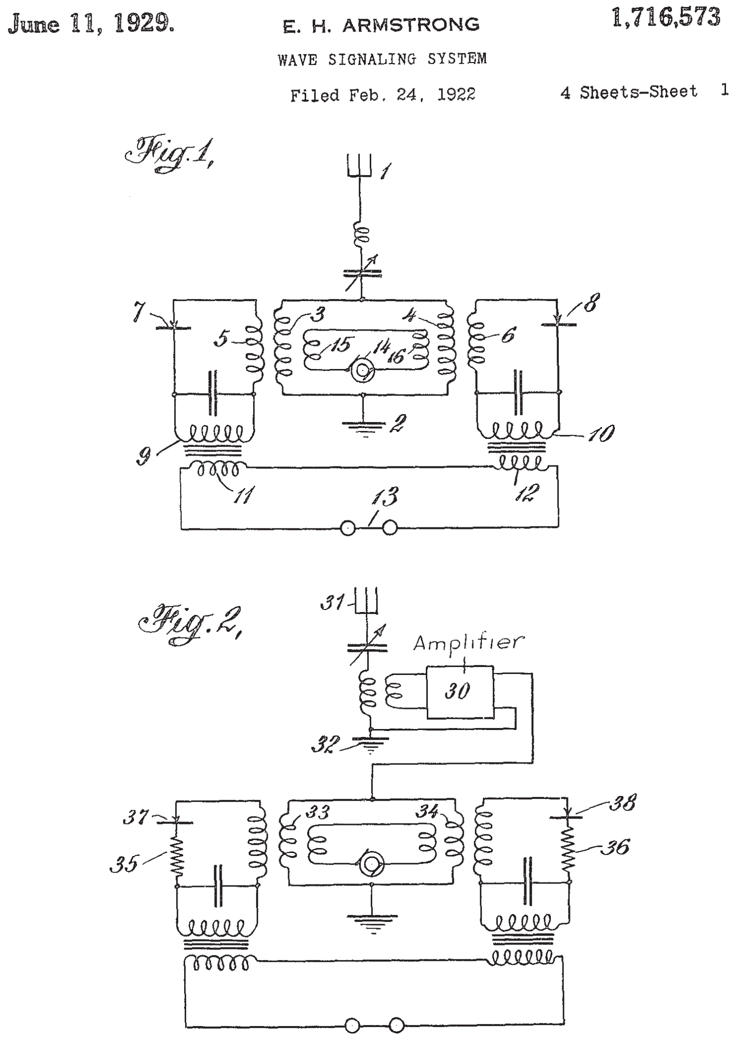

Fig. 21. Armstrong Balanced Amplifier, 1922. Edwin H. Armstrong, "Wave Signaling System," U.S. Patent No. 1,716,573, application date: 24 February 1922, issue date: 11 June 1929.

other side would cause the noise to cancel itself out (that is, signal + noise – noise = signal).[12]

This theory caught the wary eye of John Carson, who in July 1928 brilliantly cut "Armstrong's scheme" to pieces, dismissing it as merely "another arrangement which provides for high-frequency selection plus low-frequency balancing after detection." Carson proved that "no appreciable gain is to be expected from balancing arrangements" and showed that Armstrong had overstated the similarity of static noises in adjacent channels and underestimated the randomness of static in general. "In the Armstrong system," he said, "interference occurring during a spacing interval [a period of no transmission] may result in a false signal, depending on the intensity of the interference, and on uncontrollable, variable phase angles." That is, because at any point in time two channels almost always contain radically different noise, in terms of amplitude and phase, the balanced amplifier cannot cancel static simply by subtracting the noise in one channel from the noise in the other channel. "We are unavoidably forced to the conclusion," Carson declared, "that static, like the poor, will always be with us."[13] No record exists of Armstrong's immediate reaction, but he evidently accepted Carson's judgment. Save for a handful of inconsequential patents, after 1927 he ceased publishing assertions that balanced amplifiers could reduce static.

The balanced amplifier also featured prominently in Armstrong's first FM patent, a curious document that reveals him at his worst as a theorist and, ultimately, at his most serendipitous as an inventor. On one hand, "No. '447" (fig. 22) is one of only four narrowband frequency-modulation patents ever awarded by the U.S. Patent Office, all of which were filed years after John Carson debunked narrowband FM in 1922.[14] Armstrong must have known of Carson's article, by far the most widely cited of only a handful published on the subject of frequency modulation before 1935. Further, Armstrong and Carson had each authored several papers in the *Proceedings of the Institute of Radio Engineers*, published by an organization that had honored both men with the Liebman Prize for their inventions—Armstrong for regeneration, and Carson for single-sideband suppressed-carrier modulation.

At any rate, although in 1927 Armstrong did not dispute Carson's argument on mathematical grounds, he still trusted his own engineering instincts. He probably suspected for intuitive reasons that Carson's critique of narrowband FM—at least as Armstrong understood that critique—was flawed. Many years later Armstrong would implicitly acknowledge that *he*, not Carson, had been in error. But that admission came in 1935. In 1927 he still believed that narrowband FM could conserve spectrum and reduce the effects of static. "This method of modulation," he claimed in his patent, "is not subject to the usual limitations which requires [*sic*] at least 5000 cycles. The band may be made any width desired depending on the particular conditions and the distance over which it is desired to operate. This can only be determined by experiment. In general however the narrower the band the less the effect of atmospheric disturbances."[15] With good reason, Carson must have found this assertion preposterous.

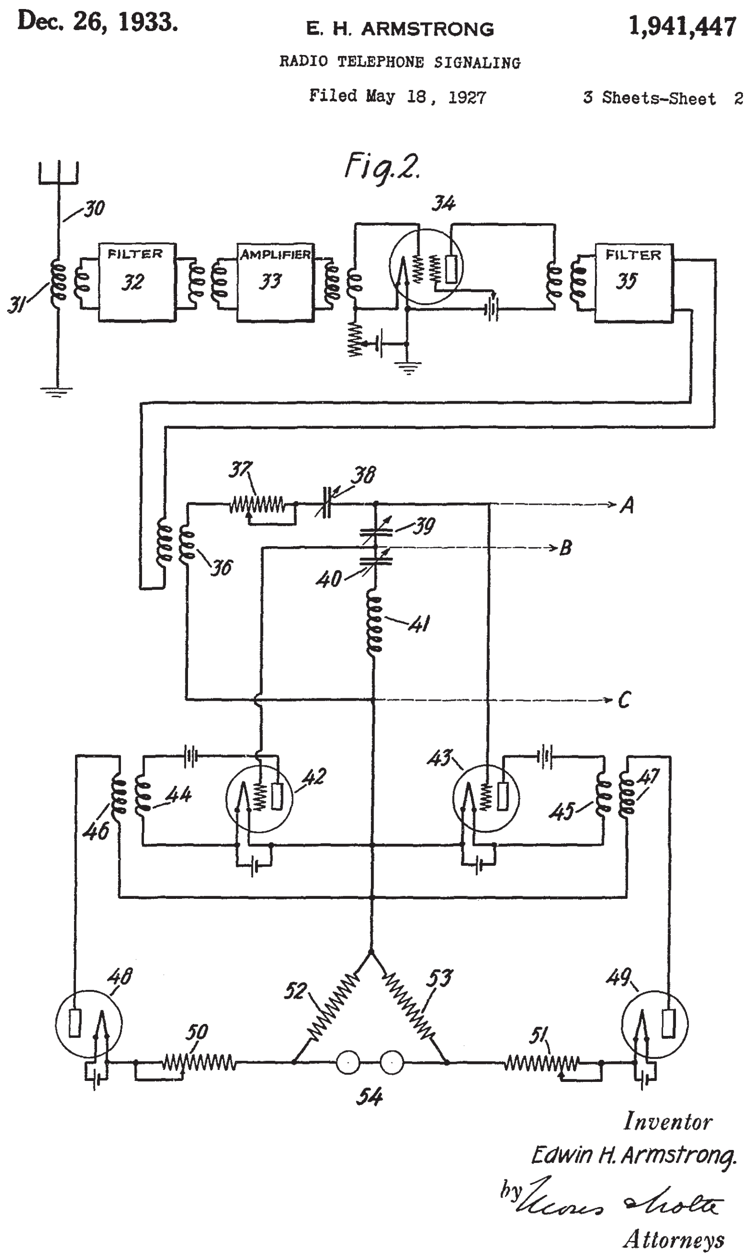

Fig. 22. Armstrong's First FM Receiver, 1927. The receiver of Armstrong's narrowband FM system. Note the balanced amplifier detector connected to the output of the filter (35). Edwin H. Armstrong, "Radio Telephone Signaling," U.S. Patent No. 1,941,447, application date: 18 May 1927, issue date: 26 December 1933.

On the other hand, No. '447 introduced a circuit Armstrong would recycle profitably a half decade later in his wideband FM system. Rather than resort to a traditional Ehret-style single-path slope detector, Armstrong instead devised a balanced-amplifier detector. One side of the amplifier was tuned to the upper frequency limit of the FM channel, the other side to the lower limit, so that the two halves worked in complementary fashion, analogous to a seesaw. Incoming radio waves at the upper radio-frequency limit caused the audio amplifier output to be driven to its negative-most amplitude. Conversely, radio waves at the lower end of the frequency swing made the audio amplifier deliver a maximally positive voltage. A radio wave with a frequency equal to the carrier's caused the audio amplifier to output a midpoint potential; usually zero volts. This design carried two advantages: first, it exhibited far greater linearity; and, second, the receiver had the potential to work over a much wider frequency swing, although Armstrong did not realize or claim this until the early 1930s.

No. '447 also marks the point at which Armstrong first began to toy with the important insight that "static, fading and like disturbances manifest themselves substantially as amplitude variations of the wave." Although he failed at the time to follow up with a crucial deduction, this statement would prove correct. Because static behaves primarily like an "amplitude variation" and not a frequency variation, an ideal frequency-modulation system, which ignores amplitude variations, resists the effects of static more effectively than an AM system does. In other words, one can minimize static distortion with two methods: either outmuscle the amplitude-distortion of the static with tremendous AM transmitter power or swamp the frequency distortion effects by maximizing the frequency swing of an FM transmitter. The former method is impractical, but in 1933 Armstrong would discover the second method and use it as the basis for low-static FM. In 1927, however, no reason existed to try extraordinarily wide swings. No practitioner had ever attempted to build a wideband system, and no theorist had considered wideband FM in the abstract. But he did believe, for at least a few months, that his *narrowband* FM receiver would resist static. Again, he cited the illusory static-reduction properties of balanced amplifiers.

Armstrong fiddled with balanced amplifiers into the early 1930s, always hoping that they would help vanquish static noise, even if they could not do so alone. His second FM patent, filed in 1930, featured an improved version of the 1927 receiver, and probably resembled the design that impressed Hansell, Crosby, and Beverage when they visited Armstrong's laboratory in late July 1931.[16] Just two months later, in September 1931, Murray Crosby filed a patent application for a similar phase-modulation receiver.[17] During the late 1930s, after Armstrong and

RCA parted ways and Armstrong sued Crosby for patent infringement, Crosby admitted that he inadvertently copied Armstrong's balanced-amplifier design during his July 1931 visit and had later failed to recall its source.[18]

Finally, on 24 January 1933, Armstrong filed applications for the two patents—Nos. 1,941,068 and 1,941,069—that laid the foundation for the high-fidelity broadcast FM radio technology that dominated the second half of the century.[19] Any radio engineer would have noticed two innovations in these documents, one largely conceptual, the other chiefly material. First, Armstrong declared the desirability of employing a "greater swing to the frequency of the transmitted wave," though he neglected to specify how much greater. His point was that widening the swing had positive benefits and was not merely a necessary expedient. Second, Armstrong permanently scrapped simpler modulation and demodulation circuits that had been recognized as normal design practice for FM technology for decades. Since 1902, all FM radiotelephony transmitters had used a variable reactance modulator, at first completely mechanical versions like Cornelius Ehret's, in which sound waves physically altered the electrical properties of reactive components such as condensers or inductors. Later, KDKA engineers introduced more sophisticated *LC*, crystal, and electronic reactance circuits that mimicked Ehret's modulator. Now, going even further, Armstrong used a balanced amplifier as a modulator. He also abandoned the reactance demodulator, introducing a circuit built around a balanced-amplifier circuit with the usual twin-signal paths, essentially a reworking of his narrowband system of 1927. But the new receiver boasted a superior linearity over far wider frequency deviations, and he used it as a "means for selecting these large swings of frequency."[20]

What Armstrong Thought He Had Invented

With a new transmitter design and a modified six-year-old receiver in hand, Armstrong had crafted a system that resembled in many ways modern broadcast FM radio. Yet, paradoxically, his patents described no such thing. Armstrong failed even to hint at two characteristics that later made FM the first high-fidelity mass medium—namely, a wider audio bandwidth that reproduced sounds far more realistically, and the ability to remove almost all static noise. Nor did he know yet that the radiation pattern of an FM transmitter was easier to regulate than that of an AM station and that frequency modulation all but erased the effects of interstation interference.[21] He did imply that his FM could convey wider bandwidths, but not in connection with audio reproduction; rather, Armstrong declared that this ability would prove useful for sending television or facsimile images.

No. 1,941,068, the more narrowly focused of the two core patents for wideband FM, straightforwardly defined the transmitter: a dual-input balanced-amplifier circuit that mixed two out-of-phase waves. Injected into one input of the amplifier was an unmodulated radio-frequency carrier; into the other input, an amplitude-modulated wave of the same frequency as the carrier but ninety degrees out of phase with the carrier. Adding the two signals electrically resulted in a composite signal at the output: an amplitude-modulated radio-frequency wave whose phase shifted in proportion to the instantaneous amplitude of the audio signal. (This technically amounted to phase modulation, but conversion to frequency modulation is a simple matter.) "Limiter" stages that followed removed the amplitude-modulated components of the wave, and subsequent "doubler" and "tripler" stages multiplied the signal frequency to the range of the transmitter frequency. These multiplier stages widened the frequency swing as well.[22]

The patent also explained that the balanced modulator worked "by aperiodic means, (that is, without the use of resonant circuits and therefore without the creation of transient oscillations therein)." By this, Armstrong meant that he had jettisoned the old reactance modulator, whose response curve conformed to that of a tuned *LC*, "periodic" circuit. Armstrong observed that *LC* circuits used this way tended, unfortunately, to "ring"—that is, to emit short-lived spontaneous, "transient" oscillations. His transmitter also used resonant circuits but not in parts of the apparatus where transients would most likely crop up.[23]

Patent No. '068 allows for little theoretical interpretation; it described only the behavior of an invention. By contrast, No. 1,641,069 staked out broad theoretical claims about radio in general and about the advantages of frequency modulation specifically. It is also laden with assertions—many of them ambiguous, unsupported, or misleading—that reveal what Armstrong *believed* he had invented. Most important, he declared that the primary objective of his invention was to "[increase] the distance of transmission which may be covered in radio signaling with very short waves."[24] That is, his system would extend the maximum geographic range of radio waves that operated at frequencies far above the standard AM broadcast band. This assertion, while largely valid, played a central role in Armstrong's failure to sell FM to RCA.

A later-discredited assumption about noise in the upper radio frequencies lay at the foundation of Armstrong's claim about FM's greater range—and his failure to anticipate FM's static reduction properties. Armstrong believed that static noise, still the bane of AM radio today, did not affect reception in certain higher-frequency ranges. "It is well known," he declared in the opening lines of '069, "that waves of the order of ten meters or lower [30 megacycles or greater] are limited in the distance of transmission by tube noise alone as *the amount of static in that part of the spectrum is negligible*."[25] This statement reflected a commonly held misconception among radio engineers during the early 1930s, when much of the spectrum above the AM broadcast band remained barely explored and poorly understood—namely, that the "ultra-high" frequencies were almost free of static. Additional experience would teach that static inhabits the ultras at comparatively low energy levels. Further, the relatively steady intensity of upper-frequency static noise (as opposed to the characteristically dynamic impulsive static of the AM broadcast band) caused engineers to suspect wrongly that static hardly existed in that region of the spectrum. Although high-frequency static does differ from AM-band static, the dissimilarities are as much qualitative as quantitative.

Armstrong coupled his belief in an almost-static-free region of the spectrum with an even more mistaken conviction that *frequency modulation can effect no reduction in static noise*, a recent version of a theory he had been continually constructing, tearing down, and rebuilding for nearly ten years. Formerly, of course, Armstrong had believed FM *could* reduce static, and his 1927 narrowband FM patent declared that he had made "an invention for eliminating the effects of fading and static."[26] But John Carson had exposed the futility of narrowband FM five years earlier. In 1930 Armstrong applied for another balanced-amplifier FM invention but stated no opinion on the question of whether FM reduces static. Now, he was pivoting 180 degrees from his original position. No. '069 wrongly asserted that static degrades the quality of FM transmissions in proportion to the channel width, just as it does with AM. "Band widths have always been kept down to as low a value as possible," he explained, "because the amount of static which is received is proportional to the width of the band."[27]

To justify this claim, he transplanted into FM theory the well-known relationship between static and channel width as it applied to AM radio: "It is the practice in designing amplitude modulated receivers," he stated, "to design the width of the selective system to be equal to twice the frequency of the modulation to be received." With FM also, he continued, "while there is no [standard] practice, the experimentation has proceeded along the same lines, the width in this case being somewhat greater than in the amplitude-modulated case in order to allow for the deviation in frequency." Armstrong went on to explain that because the bandwidth of an FM channel depends on the frequency swing, to widen the channel is to invite proportionally more static, which will degrade the signal: "These band widths have always been kept down to as low a value as possible because the amount of static which is received is proportional to the width of the band and hence after providing for the signal there is no advantage in going further." By asserting that "this applies both to amplitude and frequency modulated waves," he implied that static noise degraded wider FM channels and AM channels in the same way.[28] Ironically, the very invention whose patent contained this language later proved that Armstrong simply had it backward. Practitioners now know that broadening the channel has the opposite effect on FM compared with AM; a wider channel *reduces* static noise on the former and *increases* static noise on the latter.

If Armstrong believed in 1933 that FM per se could not reduce static noise and that widening the channel width allowed more static to distort the audio signal, what advantage did he hope to gain from a wideband system? The implicit answer to this question rested on still another misbegotten theory. Because, he asserted, negligible static exists at or above 30 megacycles, "it is well known that waves [there] . . . are limited in the distance of transmission *by tube noise alone*."[29]

Here, one must understand clearly what Armstrong meant by "tube noise"—or its synonym, "tube hiss." Tube noise was not the same as "static noise." The two were—and still are—understood to be different in terms of their origins. Sources outside the receiver, either natural ones such as lightning or man-made ones like electric motors, cause static. By contrast, the radio receiver's vacuum tubes produce the molecular- or quantum-level white noise called tube noise. As Armstrong put it, the nature of tube noise, "which is due mainly to the irregularities of the electron emission from the filaments of the vacuum tubes, is that of a spectrum, containing all frequencies."[30] This emission makes a hiss audible to human ears.[31]

Tube noise, to be sure, was a real and worsening problem in 1933. During Armstrong's youth, radios had no more than one stage of vacuum-tube amplification, sufficient to drive a low-power headset, but not enough to create especially objectionable hissing. But newer radio receivers amplified weaker signals and had to drive loudspeakers, which required more wattage than a single-stage audio amplifier could provide. Therefore, after 1920 designers began employing two or more stages of "cascaded" amplification, which fed forward the energy of an amplifier tube stage to the input of a succeeding stage. Multiplying the individual gain factors of each stage obtained the overall amplifier gain. For example, if the three stages of an amplifier boosted the input signal by gains factors of 20, 50, and 100, respectively, the overall gain was $20 \times 50 \times 100 = 100{,}000$. This design practice made for more sensitive radios, but each tube in a cascaded amplifier unfortunately amplified the accumulated noise of the preceding stages. By the third or fourth amplifier, tube noise, as Armstrong said, "manifests itself in the [speaker] by a high pitched hiss, the frequencies composing which run from some low value to above audibility."[32]

One document in Armstrong's papers demonstrates that he had tube hiss and not static in mind when he began investigating wider frequency swings for FM. On 21 July 1932 he sketched a circuit diagram of an FM receiver that closely resembled his balanced amplifier design of 1927 (see fig. 23 for the sketch and fig. 22 for a patent drawing of the 1927 receiver). At the top of the page he scrawled: "Demodulation of Tube Noise by Frequency Modulation at 7.5 meters [40 megacycles]." In the bottom right quadrant, he summarized the results of an experiment:

> Frequency swing
> 50 to 60 K.C.
> Comparison with amplitude
> modulation showed very
> many times improvement
> of hiss ratio.
> Demonstrated to C. R. Runyon Jr.
> July 20, 1932 at Hartley
> Research Laboratory.
> (signed) E. H. Armstrong
> July 21, 1932.
> (signed) C. R. Runyon Jr.
> July 21, 1932[33]

This text reveals several aspects of Armstrong's work with FM in mid-1932. First, although a "50 to 60 K.C." swing spanned a narrower slice of the spectrum than the 150-kilocycle high-fidelity broadcast FM systems of today, Armstrong was already working with frequency deviations more than twice those RCAC engineers were using. That only four weeks later Armstrong penned a draft of one of his first wideband FM inventions, No. '069, indicates that sometime during July or August 1932, he adopted for his system an even wider frequency swing.[34]

The sketch also sheds light on Armstrong's personal loyalties, foreshadowing his increasingly profound suspicions of large organizations in general and of RCA in particular. Who else knew about Armstrong's FM development? Of course, he had to admit into his circle of confidants his patent lawyers and an assistant or two. Those men needed to know about his research in order to do their own work, and professional ethics as well bound the lawyers to secrecy. But only

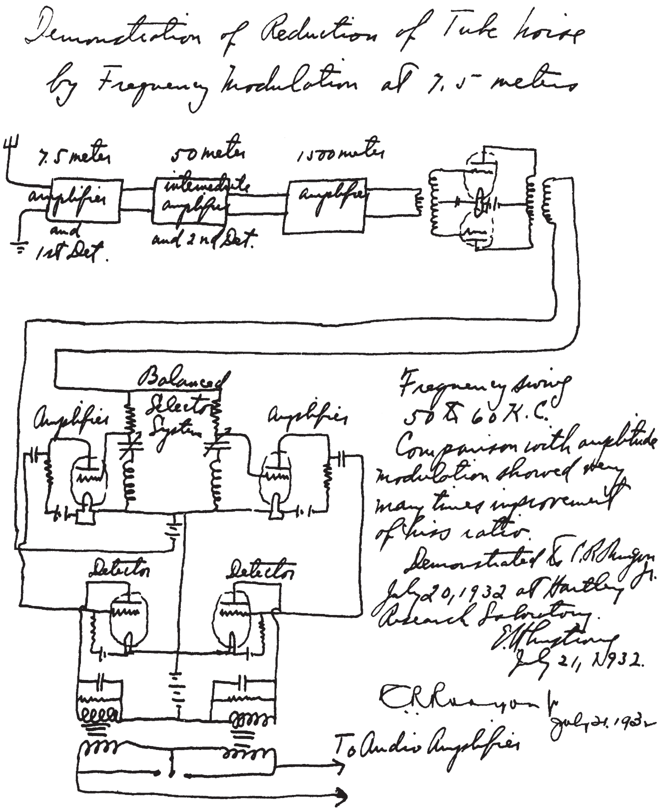

Fig. 23. Armstrong's Sketch of Wideband FM Receiver, July 1932. Edwin H. Armstrong. Memorandum. "Demonstration of Reduction of Tube Noise by Frequency Modulation at 7.5 meters," 21 July 1932, box 159, AP.

friendship can account for the signature of Carman Runyon Jr. as a witness. He and Armstrong had grown up together in the same Yonkers neighborhood, and Runyon had cofounded the Radio Club of America. In fact, Runyon had probably recruited Armstrong into that organization, where both men remained active members. Though no professional practitioner—he managed a coal delivery company for a living—only Runyon enjoyed Armstrong's implicit trust, and together the two men would stage several of the 1930's most important demonstrations of frequency modulation. By contrast, until late 1933 Armstrong confided in no RCA employee about wideband FM, not even his friends David Sarnoff and Harold Beverage, or any of the other RCAC engineers who had freely shared with him information about *their* work.

Armstrong's sketch, as well as his subsequent draft of U.S. Patent No. '069, also shows that he had both John Carson and balanced amplifiers in mind. But at this point he no longer considered the latter as a means to fight static, for Carson had taught him the uselessness of that idea. Rather, Armstrong's perception of a nonexistent clear distinction between tube hiss and static led him to believe that he had spotted a loophole in Carson's analysis, and thus he concocted still another flawed theory concerning balanced amplifiers: tube hiss, he asserted, is predictable, and static is not. He probably based this conviction on the fallacious logic that, because the sibilance of tube hiss can *seem* less random to the ear than does the crackle of static noise that plagued the AM broadcast band, then tube hiss *is* less random. Armstrong never said this explicitly, but his choice of language shows that he thought of tube hiss as "continuous" and not "irregular" or "discontinuous"—the latter two words he habitually used to describe static noise. "Electrically," he stated, tube hiss, "is practically a continuous spectrum. In this it differs from static in that static is an extremely irregular spectrum in which, because of its discontinuous character, the peaks may be commensurate with or greater than the signal before serious disturbance occurs."[35] By using the term continuous spectrum, Armstrong meant that over a span of time tube hiss generated something close to what is now called "white noise": radio waves of all frequencies at the same average amplitude, as opposed to the bursts, pops, and crashes that all too often blank out AM radio reception. In other words, tube hiss, when compared to static on AM radio, more or less *sounds* as if it lacks randomness.

This argument, which implied that a receiver could distinguish tube hiss from static, explains Armstrong's return to the balanced amplifier. He understood—correctly—that if a balanced amplifier adds two signals, one the negative of the other but otherwise identical, then the amplifier will cancel out both signals. A 100-kilocycle sine wave, for example, subtracted from an identical in-phase 100-kilocycle sine wave yields a null output. Therefore, his thinking went, subtracting the apparently "continuous" tube noise from itself will remove the noise. He had tried the same theory in 1927 to reduce static.

But Armstrong failed to comprehend that, for a balanced amplifier to work this way, the signals in both paths of the amplifier must have identical phases and amplitudes *at all points in time*. Alas, although tube hiss over the long run exhibits a more or less constant *average* amplitude over a wide spectrum, at any arbitrary *instantaneous* point in time its amplitude and phase are at least as unpredictable as garden-variety impulsive static. Indeed, tube hiss is analogous to an undisturbed blanket of snow that appears uniformly flat, but which actually comprises countless unique crystalline structures. Our sense of hearing similarly deceives us by "averaging" the sound of tube hiss so that it sounds "the same." But a modern spectrum analyzer reveals that tube hiss resembles "white" noise, the most random kind possible, and therefore the most resistant to noise-cancellation schemes.

Armstrong's ill-conceived theories sent him in a wrong direction, but ironically the same path led to the serendipitous development of modern FM radio. Because the ability to reduce tube hiss in Armstrong's system came, according to him, not from frequency modulation but rather from the balanced amplifier's properties, he probably considered using a balanced amplifier circuit to do the same thing with AM receivers as well. But he knew of two advantages FM held over AM. One was FM's demonstrated ability to resist fading. The other was his private discovery of "a very great improvement in transmission" due to wide frequency swings, which he mischaracterized as a reduction in tube noise alone.[36]

More than seventy years of hindsight reveals that Armstrong was on to something, but for the wrong reasons. However flawed his original theories behind wideband FM, he had, for the first time, hit on a reason beyond expediency for widening the frequency swing. Simply put, widen the swing, reduce the level of tube noise. And wider swings were possible only in the recently discovered expanses of the spectrum's short wave regions. But, again, he had not yet made the connection between frequency swing and static noise suppression. (That epiphany would strike him a few weeks after field tests of wideband FM began in early 1934.) Moreover, modern FM, which closely resembles Armstrong's system, *does* sound quieter—that is, less noisy—thanks to a greater frequency swing. But the inventor of wideband FM misunderstood what caused this "very great improvement in transmission" (i.e., a greater geographic range) and the reduction of noise. He believed that FM with balanced amplifier receivers reduced *only* tube hiss. And he initially interpreted the lower levels of audible and quantifiable hiss on his prototype FM receiver as confirmation of this hypothesis. Further, Armstrong's other presumption, that static virtually did not exist in the upper frequencies, was wrong as well. In fact, static noise did exist above 30 megacycles, but it resembled white noise—and tube hiss—more than it did the static crashes that polluted the AM band. A good deal of what Armstrong took for *tube*-noise reduction was probably *static*-noise reduction instead, and a wide frequency swing—not the balanced amplifiers—actually accounted for virtually all the reduction of both kinds of noise.

RCA and Armstrong's Discovery of Staticless Radio, 1934

Sometime around the issue date of his patents on 26 December 1933, Armstrong began disclosing his system to a handful of RCA employees by transmitting FM signals across his Columbia University laboratory. Precisely which outsiders witnessed the first of these presentations is uncertain. In 1939 he remembered that he selected the president of RCA for that privilege. "In December 1933," stated Armstrong, "I gave Mr. Sarnoff a demonstration of my system at Columbia University, following it up during the next two months with demonstrations to some two dozen or more of the leading engineers of the Radio Corporation and its subsidiaries."[37] No one recorded Sarnoff's impression of this event, and in any case Armstrong may have revealed his invention even earlier to Harold Beverage, who recalled (also in 1939) that "shortly before his patents issued, [Armstrong] disclosed his wide band frequency modulation [to me]."[38]

The reactions of the RCA engineers who visited Armstrong's lab in January 1934 ranged from guarded optimism to pure enthusiasm. Significantly, however, virtually no observer, including Armstrong, described hearing anything close to modern FM radio. On 3 January 1934 Murray Crosby wrote in his notebook that "Bev [Harold Beverage], Pete [Harold Peterson], Hansell and I went to New York to a demonstration by E. H. Armstrong of the system of his U.S. Patent 069." Crosby, the world's preeminent frequency-modulation theorist at the time, prudently neither endorsed nor challenged Armstrong's contention that FM decreased tube noise levels. But he did note that "by using this high [frequency] deviation and a broad band receiver," Armstrong claimed "that more noise is eliminated in the output."[39] This was a fair, even generous assessment at the time, given that no one besides Armstrong had field-tested the system. Six months later Harold Beverage held a rosier view of the same demonstration. He recalled in June that "we agreed that there was a large improvement in the signal to noise ratio in the laboratory demonstration, on the order of 15 or 20 fold."[40] Because RCA had not yet constructed equipment for quantitatively assessing the Armstrong system, though, Beverage either estimated these figures or projected them back from observations made later.

These demonstrations soon led to RCA's most direct material contribution to the development of wideband FM radio. For the better part of two years, the company would lend the inventor one of the best-equipped broadcasting test laboratories in the world. NBC had recently installed four experimental "ultra high-frequency" transmitters in the crowded upper two stories of the "newly-completed but sparsely-occupied" Empire State Building.[41] RCA constructed these stations, which operated on frequencies around 41 megacycles, primarily for the development of broadcast television, and thus named the site the "Empire State Building Television Laboratory." But the network's engineers tested other communications technologies there as well. RCA's corporate report for 1933 declared, for example, that by exploiting the "ultra high frequencies" the company "proposes to introduce the first domestic facsimile radio communication service between New York and Philadelphia." Another project was the development of "multiplex transmission," the "simultaneous sending of three different radiograms on one wave-length."[42]

Harold Beverage played a central role in obtaining a place for wideband FM in the television laboratory. For years he had been attempting without success to obtain lab space and funding to field-test RCA's earlier versions of FM. In April 1932 he wrote Charles Young, a senior engineer in RCA's recently created manufacturing arm, RCA Victor, and Charles Horn, the chief engineer of NBC (and KDKA's chief engineer until 1929), about "the possibilities of [developing] high quality broadcasting on the ultra short waves," which Beverage explained, "[applied] frequency or phase modulation to the ultra short wave transmitter." Beverage implied that FM suppressed static with balanced amplifiers. "Frequency modulation," Beverage said to Young, "can be used to very great advantage over circuits where selective fading is not a factor. . . . It has been found that frequency modulation with a properly designed receiver, will balance out a great deal of man-made interference such as automobile ignition, power noises, etc." "Major Armstrong has been working quite closely with us on this problem," he added. Why Beverage failed to secure the Television Lab for FM radio tests in 1932 is uncertain, but his statement that "Mr. Horn . . . is apparently favorable to the project if it can be financed" suggests economic, not technical reasons.[43]

Two years later, Beverage made essentially the same request, but he secured a favorable answer. On 12 January 1934 Beverage took Armstrong to the Television Laboratory "to discuss some experimental work [with FM] which Major Armstrong expects to do here in the near future."[44] Beverage sold Armstrong's new system to Horn as a noise reduction technology that demanded field-testing, "as it is always easy to be fooled by laboratory demonstrations."[45] Horn agreed, and from March until June, Armstrong and two assistants installed the first wideband FM broadcast transmitter in the Empire State Building.

It was Howard Armstrong's bad luck at this most hopeful stage of wideband FM's development to be forced to bear the greatest and unfairest personal setback of his life. The story begins in 1912, when he invented the "feed-back" or regenerative circuit. This device, his first invention, quickly became one of the most commercially important circuits in the field of electronic engineering. Even today virtually all electronic devices contain a number of feedback circuits. But in 1912, Armstrong was still a college student, and he lacked the $150 necessary to file a patent application, and so in January 1913, he resorted to paying twenty-five cents to have a sketch of his circuit notarized. Not until the following October did he scrape up the cash to file a proper application.

That nine-month delay set a tragedy in motion. Soon, Armstrong faced three patent interference claims. The courts threw out two, but that of Lee de Forest survived because de Forest documented his challenge with a laboratory notebook entry for a similar audion-based regenerative circuit, dated five months earlier than Armstrong's notarized sketch. The stakes escalated when large corporations took the side of each man. At first, AT&T, which had bought the rights to all audion-related inventions, stood in de Forest's corner, and when AT&T transferred its radio patents to RCA, the latter company, following the logic of ownership, also sided with de Forest. Armstrong found a backer in Westinghouse, which retained the rights to *his* version of regeneration.[46] But after the RCA "Radio Group" bought the rights to Westinghouse's radio patents, litigation among the corporations involved ceased.[47]

In 1931 Armstrong reopened the case, this time against de Forest personally, in hopes of winning punitive damages. By then, virtually all engineering authorities had judged the dispute as an open-and-shut case in favor of Armstrong. They pointed out that de Forest's notebook entry related only to *audio*-frequency waves in wired circuits, which aside from being electrical, had no connection to radio waves. Thus, the Institute of Radio Engineers, by awarding Armstrong its first Medal of Honor for regeneration in 1918, effectively rebuked de Forest, despite the fact that both men enjoyed considerable prestige in the organization. As the case dragged into the late 1920s, Lessing writes, "all Armstrong's amateur and professional friends, who had lived through the facts of the case, rallied to the cause, which became a leading and sulfurous topic at meetings of the Radio Club of America and the Institute of Radio Engineers."[48]

The months passed as the case worked its way up a ladder of appellate courts. Finally, on 21 May 1934, just as Armstrong was installing his FM modulator in the Empire State Building, Supreme Court Justice Benjamin Cardozo effectively ruled in favor of de Forest by affirming the decision of lower-court judges. Inexplicably, Cardozo failed to grasp that they had wrongly conflated de Forest's audio-frequency waves and Armstrong's radio-frequency waves. Exactly one week after Cardozo's decision, and two months after Armstrong began working in the NBC Television Laboratory, the humiliated inventor stepped before "nearly a thousand engineers" who had assembled for the annual meeting of the Institute of Radio Engineers. He intended to return his Medal of Honor, which he had won for regeneration, by reading a prepared statement:

> It is a long time since I have attended a gathering of the scientific and engineering world—a world in which I am at home—one in which men deal with realities and where truth is, in fact, the goal. For the past ten years I have been an exile from this world and an explorer in another—a world where men substitute words for realities and then talk about the words. Truth in that world seems merely to be the avowed object. Now I undertook to reconcile the objects of these two worlds and for a time I believed that that could be accomplished. Perhaps I still believe it—or perhaps it is all a dream.[49]

Armstrong never completed this speech. IRE president Charles Jansky Jr. (who in 1938 would establish Washington, D.C.'s first FM broadcast station) cut Armstrong off with an announcement that the institute's board of directors "hereby strongly reaffirms the original award, and similarly reaffirms the sense of what it believes to have been the original citation." Accordingly, the board of directors, "half of whose members," says Lessing, "were prominently employed by A.T. & T. and R.C.A. or their affiliated companies"—firms that had taken de Forest's side in court—refused Armstrong's offer to return his medal in dishonor.[50]

Armstrong should have taken comfort from his colleagues' expression of moral support and let the matter go. Many successful independent inventors in the early twentieth century coped with the exasperating distractions of patent litigation by leaving legal matters to their attorneys. But few patent fights in American history have drained the disputants more than the regeneration case did, and Cardozo's ruling permanently scarred Armstrong psychologically. After 1934 he continually narrowed his circle of those he trusted and for the remainder of his life cultivated a cynical worldview that profoundly influenced how he developed and promoted wideband FM radio. At first, he directed his contempt chiefly toward lawyers, who lacked, in his opinion, both the special knowledge and moral integrity necessary to evaluate technological issues. Later, as he perceived unwarranted resistance to wideband FM, he folded into his list of enemies the Federal Communications Commission, Congress, RCA, and his friend David Sarnoff. Eventually, to disagree with Armstrong about any point of radio technology was to invite having him, his allies, or his biographer impugn one's competence and character.

Even while reeling from his defeat, Armstrong persevered at the hard work of installing his system in the Empire State Building lab. On 26 March, NBC engineer Robert Shelby reported, Armstrong began calibrating "all [radio-frequency] stages and the antenna system."[51] Armstrong and the handful of RCA and NBC engineers assigned to help him had to integrate his home-built FM modulator with a 2,000-watt General Electric transmitter originally designed for television broadcasts. On one occasion, an acute electrical mismatch through a 275-foot-long coaxial cable connecting the transmitter and antenna almost wrecked the job. The cable ran along the exterior of the skyscraper, so replacing the line was out of the question, but Philip Carter, one of Armstrong's assistants, "completely solved" the problem mathematically, as Armstrong described, "in a very beautiful manner."[52] The task of mounting a bank of resistors that were designed to absorb power from the transmitter proved almost as challenging.[53] Diverting to the bank a portion of the wattage that otherwise would go to the antenna enabled Armstrong to reduce the radiated power to as little as 20 watts.

During these months, Armstrong experienced one of the most serendipitous moments in the history of radio technology. He began to realize that wideband FM radio suppressed static, a finding that squarely contradicted the language of the same system's patents. One NBC engineer later described Armstrong "as sometimes unduly secretive about his objective or the nature of the problem he was trying to solve," so perhaps predictably Armstrong never explicitly acknowledged to others his change of mind.[54] But he clearly made it, perhaps all of a sudden, but more likely after dozens of hours of tests in which he transmitted speech from the television lab to his receiver in Philosophy Hall a few miles away, and probably to Carman Runyon's home in Yonkers as well.[55]

Armstrong spread word of his discovery to RCA and NBC employees and also likely allowed some people to hear for themselves. Curiously, a lawyer first recorded in writing the new finding. Harry Tunick, who headed the RCA Patent Department's New York office, declared in May that "the essence" of the Armstrong system "resides in the reduction of noise, mainly atmospherics [i.e., static]." Armstrong, he explained,

> has made a decided advance in the art by showing that with ordinary frequency modulation systems in which the carrier is swung at the modulating frequencies over a small range corresponding, say, to the present day permitted 10 kilocycle range of frequencies, atmospherics and noise will come through. However, [Armstrong] is the first to teach the thought that by exceeding this range so that many more sidebands are required in the detector to reproduce the signal, noise components spread themselves out over this frequency spectrum in such a way as to become self-canceling.[56]

These words almost exactly conformed to Armstrong's peculiar new theory of FM. He now believed that the noise components "spread themselves out" over the channel and somehow "self-canceled." Tunick also made distortions of record that Armstrong—and later Lessing—would ultimately incorporate into what became the canonical history of FM. In fact, contrary to Tunick's (and Armstrong's) assertion, no one had attempted to design an "ordinary frequency modulation system" with a 10-kilocycle frequency swing in more than a decade. Further, Armstrong's patents decidedly did *not* "teach" that wider frequency swings accounted for FM's static noise-reduction capability. On the contrary, the patents unequivocally implied that wider swings *increased* static. But Tunick correctly said that the Armstrong system itself reduced static, a belief that he could have learned only from direct observation or discussing FM with the small number of men who were privy to Armstrong's work.

The Westhampton Beach Demonstration of 12 June 1934

As the summer of 1934 approached, Armstrong prepared to prove to a wider audience his system's fitness as a low-static, long-range radio medium. In early June he completed the transmitter's installation, and on the afternoon of the twelfth, more than half a dozen RCA engineers and managers congregated at the Westhampton Beach, Long Island, summer home of George E. Burghard to witness the first field tests of wideband FM. Burghard, a veteran ham operator, owned "a modern amateur station with all facilities," located eighty-five miles from the television lab, and eight or nine hundred feet below the line of sight of the Empire State Building.[57] He also had cofounded the Radio Club of America and, like Armstrong, had served a term as the club's president.[58]

Not everything went smoothly, but when problems cropped up, Armstrong improvised. A few days earlier, he had hauled the components of his prototype FM receiver to Burghard's home and set up the apparatus on half a dozen tables. He and Philip Carter also strung a large *V*-shaped antenna on a frame of sixty-foot-long wooden poles, an arrangement intended to maximize the signal strength. Clarence Hansell, one of the attendees, pronounced this antenna an "excellent" design, but a technical glitch almost wrecked the show. Absentmindedly, Armstrong had designed a horizontally polarized receiver antenna; that is, it was physically oriented parallel to the surface of the earth. The transmitter antenna mounted on top of the Empire State Building radiated incongruous vertically polarized waves, making for the worst possible alignment for reception. Because neither antenna could be rotated, Armstrong disconnected the large-frame antenna and hung in its place "a vertical piece of bell wire about 10 to 12 feet long, inside [Burghard's] house."[59] Although much shorter and therefore less sensitive than the original *V*-design, the makeshift aerial seemed to do the job.

Historians of FM radio have credited the Westhampton Beach demonstration with providing incontrovertible evidence of the superiority of the Armstrong system. Armstrong's biographer, Lawrence Lessing, declares that the Westhampton test, which he did not witness, proved Armstrong's FM "to be something even beyond his own expectations." Lessing also quotes an entry in George Burghard's ham radio station logbook that prophesied "an era as new and distinct in the radio art as that of regeneration [i.e., feedback]."[60] But the tests actually produced ambiguous results that concealed FM's ability to suppress static, for reasons that hindsight makes clear. Armstrong's patents maintained that an extended geographic range constituted the primary advantage of his system, so not only RCAC engineers but Armstrong as well understandably desired to determine the system's maximum range. Since then, however, it has been determined that normal reception requires a signal strength at least twice the strength of the ambient noise that exists in the channel. Listeners at the periphery of a normal-listening radiation zone typically hear surges and fading in signal strength—much like what many of those who attended the Westhampton tests reported. Thus, because no one recorded replicable quantitative data, the Westhampton Beach tests amounted to an audible inkblot test.

Not surprisingly, Armstrong proffered the most positive interpretation, one that eventually found its way into the canonical history. Two years later, in his seminal 1936 paper on wideband FM, he stated that the Westhampton tests "surpassed all expectations. Reception was perfect on any of the antennas employed, a ten-foot wire furnishing sufficient pickup to eliminate all background noises." He added that "the margin of superiority of the frequency modulation system over amplitude modulation . . . was so great that it was at once obvious that comparisons of [AM and FM] were principally of academic interest." Armstrong also described how, when the Empire State Building transmitter was reduced in power from 2,000 to 20 watts, the observers heard a "signal comparable to that received from the regular [AM] New York broadcast stations (except WEAF, a fifty-kilowatt station located approximately forty miles away)." "Under all conditions," he continued, "the service was superior to that provided by the existing fifty-kilowatt stations, this including station WEAF." "During thunderstorms," he explained, "unless lightning was striking within a few miles of Westhampton, no disturbance at all would appear on the system, while all programs on the regular broadcast system would be in a hopeless condition."[61]

Among RCA engineers at the time, however, only Harold Beverage approached this level of optimism, in a report he sent to C. H. Taylor, RCA's chief engineer. Beverage was a dubious source of reliable information, though, because a "tonsil operation" had prevented him from actually going to Westhampton. But Beverage already knew about FM's ability to reduce static because he had heard several tests of FM in Manhattan, at ranges short enough for the Armstrong system to operate under what would resemble normal conditions today. He had also discussed FM with Howard Armstrong, who "gave me copies [of his patents] and [had] demonstrated his laboratory setup to Messrs. Hansell, Peterson, Crosby, and myself" the previous January. Beverage completely accepted Armstrong's new theory that a wider swing accounted for FM's presumed suppression of static noise. There are, he told Taylor,

> inherently considerable noise reduction possibilities in the use of frequency modulation in ordinary ways on ultra short waves, as we have found by our own tests. Armstrong carries this reduction further by using a much greater swing than is ordinarily used. We have not determined accurately, just how much additional noise reduction is produced by the greater swing, but Armstrong believes it is proportional to the swing, and is probably correct in his analysis. . . . Major Armstrong said that the [Westhampton Beach] demonstration [of 12 June] was very successful and that while WEAF reception was ruined by static from local thunderstorms, the same program via the Empire State was excellent, practically free of any kind of noise.[62]

Beverage did admit that "I have not had an opportunity to talk with any of our engineers to determine their reaction. Neither do I know," he added, reflecting the absence of quantitative test results, "how much of the noise reduction may have been due to the characteristics of the ultra short wave and how much due to Major Armstrong's invention." He also acknowledged the system's "greatest drawback"—namely, "the wide frequency band required," but Beverage pointed out that "wide bands are inherently available on the high frequency end of the ultra short wave band." He concluded his letter by presciently recommending the development of FM as a commercial medium. He predicted that the Armstrong system "should be of great value in certain fields, particularly the sound entertainment field." "At least," he offered, "it is worth our while to make some investigation of the possibilities."[63]

Virtually no one else shared Beverage's and Armstrong's enthusiasm, however. A few days later, Clarence Hansell reacted tepidly, partly because his theoretical preconceptions about frequency modulation prevented him from swallowing Armstrong's new ideas. Five days after Beverage posted his memorandum to Taylor, Hansell (who received a copy of the letter) stripped the veneer from Beverage's analysis, first by reminding Beverage that he (Beverage) had not actually attended the Westhampton Beach test. "You indicate that you have not been fully informed," he stated. During the evening of the twelfth, Hansell continued, "none of the ordinary broadcast stations were usable because of lightning crashes from a thunderstorm somewhere over land to the west and north of Westhampton Beach." Furthermore, Hansell did not "remember observing any noise from lightning on the forty-one-megacycle signal from the Empire State Building even when ordinary amplitude modulation was being used." At this point the same newly outmoded theory of noise that Armstrong had used to invent wideband FM still held Hansell in its grip. He assumed that almost no static noise existed in the ultra-high frequencies. Yes, Armstrong's FM came through relatively clearly, but not, he guessed, because the system suppressed noise. Rather, Hansell insisted, "The elimination of atmospheric noises during the demonstration [of FM] was, I believe, due to the very low level of such noises on 42 [*sic*] megacycles as compared with noise on frequencies around 700 kilocycles [the standard AM broadcast band]." Moreover, widening an FM channel's frequency swing, he believed, amounted to asking for even more static; a wider deviation necessitated a greater "band width" [channel width], so double the swing, double the noise. Hansell calculated that "the noise at 7500 cycles should have increased about 10 to 1 in voltage when the transmitter wave deviated 75,000 cycles from the normal carrier value."[64]

Hansell chafed when Armstrong said (according to Hansell) that "he disagreed with AT&T engineers and others who had stated the noise output from a receiver is proportional to its selectivity band width. He said the noise was substantially independent of band width." In 1934 Armstrong's assertion—which we now know was correct—literally inverted what radio practitioners had regarded as a fundamental principle for at least ten years. Hansell especially doubted FM's ability to reduce static "where the noise is due to short peaks of very high intensity such as local lightning and inductive disturbances might produce."[65] Had Hansell listened under what today constitutes normal listening conditions, though, with a receiver placed at a short or medium distance from a far more powerful transmitter, and in an urban environment, he more likely would have realized that impulsive noises were precisely the kind that FM reduced best.

Hansell's reservations about the usefulness of FM fostered further misgivings in his mind about the strength of Armstrong's patent claims. "Armstrong has made a valuable contribution to the art of telephone transmission on frequencies above 30 megacycles," he admitted, and "his scheme will undoubtedly have wide commercial use." But the Armstrong system offered nothing new, according to Hansell, and "I am very doubtful of the validity of his patent claims covering the general principle of wide band modulation." "Probably only his specific circuit arrangements"—an allusion to Armstrong's balanced-modulator transmitter and balanced detector—"for which numerous alternatives are available, will stand up in court." Hansell buttressed this prediction by stating that RCAC engineers "used wide band frequency modulation at [RCA's] Rocky Point on Transmitter WQN, with a wave length of about 54 meters, in August 1925. The frequency modulation was applied to the transmitter continuously by the method described in my U.S. Patent 1,830,166, for reducing the effects of fading in telegraph transmission."[66]

Hansell could have cited abundant precedence for his doubts. Since the birth of broadcasting, noise-reduction schemes, virtually none of which had worked, had continually cropped up. Indeed, Armstrong himself had proposed several dead-end ideas based on the balanced amplifier, including, as mentioned earlier, a narrowband FM invention that he later recycled for the new system. Moreover, almost no evidence existed yet to back Armstrong's claims. Carefully controlled tests of wideband FM that produced quantifiable results still lay in the future, and in the absence of hard data, Hansell had little cause to alter his long-standing theoretical assumptions. After all, only a few months earlier the same assumptions had constrained Armstrong's thinking.

But Hansell also exaggerated the case against FM. Plainly, he fabricated his claim that RCAC engineers used "wide band" FM. A length of "54 meters" corresponded to a carrier frequency of approximately 5,500 kilocycles, a part of the spectrum where a 150-kilocycle frequency swing would cut an impractically wide swath. Nor did his Patent No. 1,830,166, or any other RCA patent, make a single wideband claim, as Hansell, who had filed thirteen other FM patent applications by 1934, must have known. Hansell also distorted the record when he attributed to "AT&T engineers"—an allusion to John Carson's 1922 article about modulation theory—the statement that "the noise output from a receiver is proportional to its selectivity band width." In fact, Carson's paper never mentioned wideband FM radio. Perhaps like Armstrong, Hansell misunderstood Carson's analysis.

Despite Hansell's skepticism, during the next several weeks Armstrong slowly accumulated a handful of allies within the company, principally by staging further demonstrations. These often amounted to little more than private performances, as when on 20 June he aired "a special program of organ music" for RCA's chairman, James Harbord.[67] He also found a more permanent and closer location for testing reception. A week later Armstrong drove Beverage, Hansell, and several other RCA engineers to the Haddonfield, New Jersey, home of Harry

Sadenwater to hear another demonstration of staticless FM. Sadenwater, a veteran RCA engineer and a longtime Radio Club of America member, lived near the RCA Victor factory in Camden, located fifty-six miles from the television lab. Armstrong had won him over as early as January, when, after he was "deeply impressed by the lack of audible interference from spark coil discharges [static]," Sadenwater and his wife permitted Armstrong to convert their basement bar into a more or less permanent test laboratory.[68] After hearing field tests of wideband FM for the first time in the Sadenwater home, Beverage reported that frequency modulation "was quite successful" in reducing static on the ultra-high frequencies. Even more impressive, he added, FM required a small fraction of the power of a standard broadcast station to achieve the same quality of sound. In fact, stated Beverage, AM stations in New York that radiated 50,000 watts sounded worse in Haddonfield than did the Empire State Building FM station, which used a mere 120 watts.[69] By the end of June 1934, Hansell's resistance to Armstrong FM had softened considerably. He admitted that the reception in Haddonfield of New York AM station WEAF on the evening of 25 June "was not particularly satisfactory and would not have been used for ordinary entertainment purposes," even though the weather "could have been far worse." "At the same time," he observed,

> wide band frequency modulation from the Empire State Building utilizing the same or similar NBC program was quite satisfactory and was generally free from noise and noticeable distortion. . . . It was quite evident that wide band frequency modulation transmitted from the Empire State Building on 41 megacycles with about 2 KW. power gave far more satisfactory reception at Mr. Sadenwater's house in Haddonfield than could be obtained over about the same distance from WEAF using about 50 KW. power on a frequency of 0.660 megacycles.[70]

These words marked an abrupt change of mind on Hansell's part. Less than two weeks earlier he had taken Beverage to task for saying much the same things, but now he estimated that because Armstrong's channel width could hold fifteen standard AM channels, the signal-to-noise ratio should improve proportionally.[71] This upended the theory he cited in Westhampton to justify his earlier skepticism. To be sure, Hansell remained wary about FM's commercial possibilities, and he continued to assume that operating in a nearly noise-free part of the spectrum caused the lower noise levels in the new system. But coming around to even part of Armstrong's theory so quickly speaks well for Hansell's intellectual flexibility.

Two months later, RCA further expanded the scope of its wideband FM tests.

The firm constructed two receivers, on the basis of the Armstrong patents, to assess long-distance FM. Beginning in October 1934, over a period of five months several engineers who lived in cities and towns located at least seventy miles from the Television Laboratory (chiefly in Pennsylvania and New Jersey) took this apparatus home to record reception data. Their weekly one- or two-page summary reports indicate that three central questions defined the goals of these tests:

1. How successfully does FM withstand interference of all kinds, including natural and man-made electromagnetic noises?
2. How does FM reception compare with AM with respect to noise suppression and maximum range?
3. How well does an FM signal propagate to receivers located at the extremities of reception; that is, a few miles over the horizon?

The narrowness of these questions, with their unfortunate overemphasis on "maximum range" goes far in explaining why, eventually, RCA declined to back wideband FM. RCA would typically test FM at long distances, beyond the range of normal reception, and with only a 2-kilowatt transmitter. The results of the tests added nothing to the understanding of frequency-modulation radio's most famous feature today, the ability to kill static, especially at shorter ranges, because, at the periphery of reception, signals sometimes came in strongly, at other times weakly. Moreover, no one determined any method to quantify answers to any of the central questions. Instead, observers wrote test reports in only qualitative terms. Charles Burrill, an engineer who listened to test signals in the third story of his home in Haddonfield, stated that that "during a portion of the time reception of frequency modulation was all that could be desired as regards background noise, while at other times interference which was probably quite local made reception impossible." He observed periods of fading that lasted up to an hour "nearly every day," adding that "apparently such fading is more likely at about noon or 6:00 p.m."[72] From another location "on the top of the Philadelphia Saving Fund Society Building," Burrill reported that ignition noise from automobile traffic "was so great as to make reception useless either for amplitude or frequency modulation."[73] From Milburn, New Jersey, he observed that "the noise level was very low except when an automobile was in the immediate vicinity. Consequently reception was very good with either frequency or amplitude modulation. Some of the time frequency modulation appeared to be somewhat better, but at other times there was no observable difference."[74] Though a capable engineer, Burrill's subjective observations, made at the "extremities of reception," hardly constituted replicable or easily analyzable data.

Why RCA Did Not Back Wideband FM Radio

Few articles of faith in the canonical history of FM radio resonate more with our sense of injustice than Lessing's explanation for why RCA opted not to buy the rights to Armstrong's FM patents. Lessing says that FM threatened to damage RCA's financial interests by upending the old order of AM radio. Frequency modulation, he asserts, "if allowed to develop unrestrained, posed a vast number of new radio stations, a complete reordering of radio power, a probable alignment of new networks, and the eventual overthrow of the carefully restricted AM system on which R.C.A. had grown to power."[75] Lessing also insists that RCA engineers, by and large, favored the development of FM but that they "could not overcome the weight of strategy devised by the sales, patent and legal offices to subdue" the threat of FM. Moreover, to emphasize the perfidy of RCA's managers, Lessing frames the company's neglect of FM in moral terms, as a "callous evasion of the most important new development in radio since the founding of the industry," and as an act of personal hypocrisy and betrayal on the part of RCA president David Sarnoff, who in early 1934 had "addressed a letter to [Armstrong] affectionately urging him to direct his energies toward the future of radio." RCA's subsequent refusal to develop FM, motivated by a fear of hurting the company's investments in AM, says Lessing, revealed "Sarnoff's [lack of] regard for that future."[76]

Several facts disprove Lessing's argument, though. First, it hangs on the false premise that RCA held substantial vested interests in AM broadcast radio technology. In fact, the company derived only a small percentage of its income from capital assets. In 1941 the FCC reported to Congress that, although RCA turned a profit every year since its inception, its capital investment, which "barely exceed $100,000,000," "would not be regarded as staggering" for such a large American company.[77] According to annual corporate reports, RCA earned far more income proportionally from such diverse noncapitalized sources as patent licensing, international communications, and the management of radio and recording artists. Furthermore, only a minuscule portion of RCA's total income came from the actual operation of AM radio stations. RCA owned the National Broadcasting Company, and although NBC provided programming to 111 network affiliate stations in 1935, the firm itself owned only ten outlets. Nine of these held lucrative clear-channel stations, but NBC's profits scarcely depended on the use of AM technology per se.[78] Rather, according to the FCC, NBC earned "about 90 percent" of its total revenues from 1926 to 1941 from selling air time to advertisers.[79]

Thus, neither RCA nor NBC had much to lose if FM displaced AM in American broadcasting.

Even the part of the RCA empire that relied on capital investment for income would gain little if anything by retarding the spread of FM radio. The FCC described RCA's manufacturing subsidiaries, such as RCA Victor and RCA Manufacturing, as "the largest single phase of RCA's business."[80] But the fact that the firm sold radio transmitters, receivers, and other apparatus did not translate into a motivation to preserve AM radio technology. On the contrary, the potential profit RCA stood to reap from the sales of new radio and television receivers significantly outstripped what the company might lose if it stopped making replacement parts for old AM transmitters.

Lessing's explanation also fails to account for why RCA, if it dreaded disruptions of the broadcasting industry, poured huge sums of money into developing television, on which David Sarnoff wagered RCA's future in hopes that the new technology would revolutionize American broadcasting. That RCA threw its full weight behind a technology that many hoped would make radiotelephonic broadcasting obsolete speaks to a corporate culture that welcomed, not feared, radical innovation, but only when sufficient evidence existed that convinced managers that a particular technology stood a good chance of working. If anyone in the company "opposed" wideband FM, he likely did so in the belief that Armstrong had not proved the value of his system.

Finally, the traditional explanation for RCA's inaction with FM makes sense only if RCA engineers and managers were fully aware of FM's features in 1935. But they could not have been. Armstrong himself cited only two unique advantages for his system over conventional AM systems: a greater range, which his patents mentioned and which went unproved, and a reduction of static noise, whose possibility the same patents implicitly denied. Moreover, by testing receivers so far from the underpowered Empire State Building transmitter, RCA engineers effectively obscured the desirable static-suppression properties of FM. Yes, some RCA engineers, like Beverage, Sadenwater, and Hansell, came around to suspecting or believing that wideband FM sometimes suppressed static. But these men could cite only impressionistic observations for their evidence, as no one had ever quantified the performance of the Armstrong system at ranges well short of distances where reception began to fade.

A far more plausible explanation for RCA's reluctance to buy Armstrong's patents is that company engineers and managers knew too little about wideband FM to assess accurately the potential of the Armstrong system. The flawed, nonquantified results of the long-distance field tests of 1934–35 largely account for this ignorance. Consider, for example, how poorly RCA engineers understood the relationship between transmitter wattage and reception. Armstrong later insisted that he had entreated RCA to lend him a more powerful transmitter, and if the company had complied, perhaps the static-reduction capability of FM would have become evident when the maximum range of the Empire State Building's signals extended beyond eighty miles. Rather than hearing the erratic reception that test engineers in New Jersey, Philadelphia, and Long Island continually reported, those men would have received something that resembled modern broadcast FM: essentially static-free radio, although with an audio bandwidth only marginally greater than that of AM radio. Moreover, though many RCA employees were unaware or unconvinced of FM's ability to kill static, even FM's most ardent advocates never speculated in 1935 that the Armstrong system could convey an audio bandwidth three times that of AM radio. This advantage, when coupled with low-static reception, would eventually make wideband FM the first high-fidelity mass medium by the end of the decade. But in 1935, no one knew of the feature, not even Armstrong, who in fact had not yet invented it.

The company's engineers wrote dozens of memoranda in that year reflecting these views, with none suggesting that RCA feared FM might end its AM-radio hegemony. In one typical evaluation, engineer Elmer Engstrom, who had observed several long-distance tests, stated in early 1935 that "near the transmitter the usual amplitude modulation system and the Armstrong system are both satisfactory. At intermediate distances from the transmitter, appreciable but not striking improvement is obtained with the Armstrong system. At greater distances from the transmitter but still within signal range neither system appears satisfactory in a practical sense although under some circumstances impressive gains have been noted with the Armstrong system." Engstrom did recommend that RCA develop an FM system "without excessive cost to R.C.A.," but he felt no urgency because the "Armstrong system is [merely] one application of the general principle" that "changes in the broadcast method of transmission are desirable from a technical viewpoint." RCA, he suggested, should keep involved with FM in case it becomes important. As for now, Engstrom declared, "the Armstrong patents do not appear particularly fundamental. They are unlikely sufficient to control the situation." Even if RCA were to acquire the Armstrong patents, "we could not operate without acquiring other patents held by outsiders."[81]

An even more dubious W. R. G. Baker, the chief engineer of RCA Victor, wrote to Otto S. Schairer, who headed RCA's patent department, that "while I would like to see RCA have a good patent position in this field, I can not see as yet the practical usefulness of the Armstrong system except for special services."[82] Ralph Beal stated to Schairer in May that the "predicted advantages" of FM "are its noise reduction characteristics and its ability to extend the transmitting range of ultra short wave broadcasting stations." Beal pointed out, though, that "measurements under average field conditions have not been completed but the results thus far have not shown gains altogether comparable to what may be predicted by theory."[83] A month later, Beal added that "the most important issue at this time with respect to the Armstrong system is the question of the extent to which the service area of a sound broadcasting station may be extended by its use."[84] These men were not obstructionists who feared a new technology's economic effect on the broadcast industry. Nor did they lack the imagination or heart to envisage a future high-fidelity broadcasting system. After all, many of them were working hard on developing the potentially far more disruptive technology of television. They merely had no evidence at hand that FM performed as its inventor claimed, beyond perhaps an impression that frequency modulation reduced static from time to time.

Taking FM to the Public

As RCA managers deliberated the fate of FM in the spring of 1935, Armstrong began to resent their lack of action. In April he signaled his impatience by enlisting journalists to plant the first seeds of FM radio's canonical history. Many of the most one-sided articles containing the most egregious and persistent myths about FM radio originally appeared in the newspapers of New York City. "Radio Device Ending Fading, Static Reported," proclaimed the *Herald Tribune* on 26 April. In addition to describing wideband FM in the most glowing terms, the newspaper alluded to Armstrong's fear of reliving courtroom disasters like his loss against de Forest over regeneration, by implying a lack of goodwill on the part of RCA. "Mindful of the legal arguments that may arise over a difference of a few months," the article stated, "Major Armstrong refused to say when he developed the new idea." The article asserted as well the false claim that all previous kinds of frequency modulation were narrowband FM. "The theory on which the new system works is a direct reversal of that on which engineers have previously worked to eliminate noises. The principle has been to narrow down the selective band as much as possible in order to keep down extraneous sounds, while the Armstrong system does just the opposite." Finally, Armstrong ignored the progress earlier researchers had achieved, especially at RCAC, by declaring that "the principle [of my new invention] is carried out by the use of a discarded method of modulation known as frequency modulation. . . . This method of modulation has been known for over twenty years, and the hitherto unsurmounted difficulties due to distortion and other troubles in both transmitter and receiver have caused its abandonment by all who worked with it." Armstrong did acknowledge that his Radio Club pals, Harry Sadenwater and George Burghard, had lent their homes for testing wideband FM, and that Charles Young, of RCA Victor, had experimented with multiplexed frequency modulation.[85] The *New York Times* said much the same thing, stating that FM was "nothing [Armstrong] merely stumbled upon. It is the result of long research in the laboratory at Columbia University and in the experimental station of the National Broadcasting Company atop the Empire State Building." But this nod toward the NBC lab was untypical, the *Times*' only hint that any company had assisted Armstrong in the development of FM. The newspaper also failed to mention the FM work of RCA and other companies that preceded the Empire State Building tests.[86]

Armstrong's decision to announce publicly the invention of wideband FM represented a major shift in his strategy for promoting his system. Earlier, he had consistently exalted the importance of secrecy. He told no outsider about RCA's FM research during the 1920s or about the Bolinas tests of 1931–33 and persuaded RCA employees to do the same. He concealed his own wideband FM investigations from RCA until his patents were securely in hand. He continued to shroud FM from the public for fifteen months afterward. Now, exasperated with RCA's indecisiveness, he turned to the press, partly to spur RCA to action, partly to vent his frustration.

After the initial announcements of FM appeared in the New York dailies, additional articles appeared in the papers of other cities, as well as in trade and professional magazines. In May, *Electronics* declared that "Major Armstrong seems to have solved the missing link in the battle against man-made and natural static."[87] The following month's issue said that Armstrong planned to provide a complete description of his system at the fall meeting of the New York section of the Institute of Radio Engineers. Although grumbling that Armstrong "has consistently refused to go into the details of his system," the magazine indicated that "several highly competent observers" of FM reception at Harry Sadenwater's home suggested that "no doubt . . . the system used actually does give a vastly better signal-to-noise ratio than conventional amplitude modulation methods."[88] *Communication and Broadcast Engineering* published a similar article, and many amateur radio operators first read about FM in the flagship magazine of the American Radio Relay League, *QST*, soon after Armstrong visited that organization's headquarters in New York City.[89]

For months, Armstrong's private publicity campaign elicited virtually no reaction from RCA managers. By midsummer of 1935, their taciturnity began to crack Armstrong's patience, imperiling his long-standing relationship with the company. About 1 August he staged still another demonstration in Haddonfield for two holdouts, Ralph Beal and David Sarnoff. A few days later he protested to Beal. "Mr. Sarnoff stated that his engineers wanted to make more measurements," he wrote.

> You will recall that I stated that I could not conceive how his engineers, after having been familiar with the system for over a year and a half and having witnessed numberless demonstrations, could require any further measurements to convince them of the utility of the system. As Mr. Sarnoff could not state what further tests were required, it was arranged that I meet Dr. Baker and yourself on July 29th, when you would advise me exactly what measurements were considered necessary.
>
> At this meeting neither Dr. Baker nor yourself informed me of any tests which you desired to make other than some very general statements that you wanted to find out "how far the system would work," a matter which I supposed had been thoroughly investigated during the tests of the past year and a half. Some "other tests" were referred to, but those present could furnish no information as to what they were. I therefore requested you, and you agreed to write me specifically, what further information it was that you required. To date I have received no word.
>
> In view of the fact that I have now been demonstrating [wideband FM] to the executive and engineers of the Radio Corporation under all conceivable conditions for a period of over a year and a half, may I now request you to advise me exactly what tests your engineers want to make and what the purpose of these tests may be.[90]

Armstrong neglected to state what he would do if RCA failed to heed his "request." In any case, on the same day that he composed this letter, W. R. G. Baker attempted to calm him down. "Interested groups in RCA," Baker wrote, are "making arrangements for certain tests on your system. One of the most important tests is to determine the effect of antenna height." Baker added that "we appreciate your offer to assist us in carrying on this work and would like your help in every phase of the program."[91] But this conciliatory gesture backfired. Baker's letter, the inventor shot back, "does not answer the question raised in my letter to you." Aside from the antenna height test, Armstrong continued, Baker made only "a vague reference to 'certain tests' which are to be arranged by you in connection with the 'interested groups.'" Armstrong explained that he had requested the antenna height tests more than a year earlier, even offering to install a frequency-modulation transmitter on top of Radio City, but that "this offer was not accepted." He now sharply demanded an unequivocal answer. "In view of the fact that my patents have been issued over a year and a half," he wrote, "or about 10% of their life, and the fact that throughout this time the executives and engineers have had full opportunity to apprise themselves of all phases of the situation, may I again ask you to state exactly what tests you want to have made and what the purpose of those tests may be."[92] This exchange signaled, if not the end, then certainly the beginning of the end of Armstrong's fifteen-year-old collaboration with RCA. Trials of the Armstrong system continued, but without the inventor's participation. Moreover, in October RCA began investigating the possibility of narrowing Armstrong's frequency swing, contravening the central principle of his system.[93] Inauspiciously, RCA disclosed none of this to Armstrong and a few months later he removed his FM apparatus from the Television Lab.

No one can ignore the ironies surrounding the development of modern FM radio. Its creator applied misconceived theories about frequency modulation and balanced amplifiers to invent a system that supposedly achieved little more than a reduction in tube hiss. Armstrong, in fact, implicitly denied in his patents that FM had any effect on static. Yet the same patents constituted the foundation of modern broadcast FM radio, whose static-reduction ability proved the wrongness of Armstrong's theories. Moreover, after 1936 FM would reveal additional advantages over AM, notably a wider audio bandwidth and greater resistance to interstation interference. But while the innovator who at first mistakenly denies that his brainchild does something useful might be unusual, he is hardly unique, particularly among independent inventors of complex systems. For years, Lee de Forest refused to acknowledge that the audion he patented in 1907 could amplify electrical waves, even though it is now famous as the first electronic amplifier.

What distinguishes Armstrong FM is the particular social and technological context in which it evolved as Armstrong and others uncovered the potential of the system. To understand how frequency modulation worked was not difficult in the abstract, but to make the first practical wideband system required first-rate practitioners like Armstrong or, alternatively, some of his colleagues at RCAC. Armstrong put into FM his long experience with balanced amplifiers and frequency modulation, both of which demanded far more stable circuits than AM technology commonly provided. Developing FM required as well substantial intellectual labor and material for testing. Up to a point, Armstrong provided these himself by constructing a prototype transmitter and receiver in his own laboratory and testing them over short distances. But unless he wanted to bear the far greater costs of constructing a transmitter with an elevated antenna, he would have to rely on RCA to demonstrate his chief original claim for FM: that it increased the range of ultra-high frequency transmissions. Armstrong would build such a station during the late 1930s, but only after the test facilities of RCA had enabled him to learn at little expense to himself that FM did far more than he had expected. For him to have done so earlier would have amounted to wagering illogically that his own preconceptions about FM radio were fundamentally wrongheaded.

Nor can one deny the role of extraordinary luck in the development of wideband FM. Not one person during the 1930s predicted the full range of what the system would eventually accomplish. But serendipity in the Walpolean sense of the word more aptly describes the invention and discovery of the technology's static-reduction properties. Armstrong deserves credit for possessing the knowledge and open-mindedness—the sagacity—that allowed him to recognize that he had erred and that he had happened on something more useful than what he had originally anticipated.