Early FM Radio

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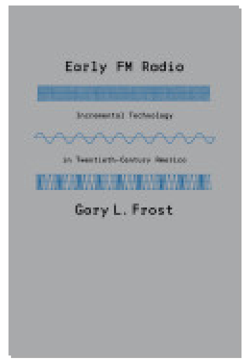

Published by Johns Hopkins University Press

Frost, L..
Early FM Radio: Incremental Technology in Twentieth-Century America.
Baltimore: Johns Hopkins University Press, 2010.
Project MUSE., https://muse.jhu.edu/.

Congestion and Frequency-Modulation Research, 1913–1933

I'm forever losing signals,
Pretty signals in the air;
They're pitched so high,
Nearly reach the sky,
Then like my dreams they fade and die,
Signals always fading,
I've tuned everywhere.
I'm forever losing signals,
Pretty signals in the air.
(sung to "I'm Forever Blowing Bubbles")

Lose M. Ezzy, 1920

We have worked intermittently for a long time on what we call "modulated frequency" which has many advantages over the present method.

Harry P. Davis, President of Westinghouse, 1931

Congestion and the Creation of the Spectrum Paradigm

For nearly twenty years after Cornelius Ehret and Valdemar Poulsen filed their patent applications in 1902, frequency-modulation radiotelephony languished in the backwaters of radio engineering as something to ponder from time to time, but ultimately dismissed as impractical or unneeded, or both. After World War I, though, more and more practitioners took up FM, thanks chiefly to the broadcasting boom that began in 1920 and the problem of congestion that followed.

Historians of radio often characterize broadcasting in the early and mid-1920s as a period of ever-worsening "congestion" and "chaos." Because the federal government lacked the authority to regulate the new industry effectively, broadcast signals began overcrowding the airwaves.[1] The number of licensed stations surged from a handful in late 1920, to 28 in January 1922, to 570 in December of the same year, prompting many observers to fear that the very success of broadcasting would soon suffocate the new medium.[2]

The rise in the number of stations only hinted at the peril radio broadcasting faced. The increased popularity of radio aggravated many old ills. Sporadic fading worsened as stations attempted to reach more distant listeners. Lightning storms frequently ruined local AM reception, and solar flares halted radio communications worldwide. Station transmitters ratcheted up in wattage, which increasingly disrupted reception, because the radiation patterns of formerly distant stations tended more often to overlap. Moreover, until the mid-1920s no station could precisely stabilize the wavelength of its carrier because changes in temperature and humidity altered the resonant frequency of an *LC*-controlled oscillator circuit.[3] In one of the most notorious cases of carrier drift, listeners in the Dearborn, Michigan, area might have found the Ford Motor Company's station anywhere between 800 and 980 kHz, a range spanning nineteen modern-day AM channels.[4] Finally, the electrification of America continuously layered on new strata of noise, originating chiefly from the sparking motors of household appliances. As one listener complained, radio was plagued by the "all too-familiar buzzes, crackles and frying occasioned by your own or your neighbor's electric razor, oil burner, kitchen mixer or vacuum cleaner."[5] In fact, anything that created sparks, including hospital X-ray machines, automobile spark plugs, and trolley cars, could spoil reception.

At first, averting congestion seemed merely a matter of allocating more wavelengths. In 1920 the Commerce Department's Bureau of Navigation, the agency to which Congress gave modest powers in 1912 to oversee American radio, declared that all broadcasting stations must use the same 30-meter wavelength. This arrangement sufficed so long as broadcasters remained small in number, low in power, and separated by adequate distances. But no law allowed the Navigation Bureau to limit the number and wattage of transmitters; as more and more stations went on the air, the agency was forced within a year to assign second, third, fourth, and fifth wavelengths. Each new allocation, though, proved increasingly less efficacious than the preceding one, and by the mid-1920s American broadcasting had indeed descended into chaos. Not until 1927 did Congress address the problem, when it created the Federal Radio Commission (FRC), a panel empowered not only to thin out the tangle of broadcast stations but also to determine the wattage, carrier frequencies, and hours of operation of those remaining on the air.

To do its work the FRC adopted a new paradigm based on the concept of the radio spectrum. The most apparent sign of this change appeared in the vocabulary of practitioners. Before and during the early years of the broadcasting boom, one spoke of a tuning to the *wavelength* of a transmitter and never to its *frequency*. The Radio Act of 1912 used the term wave length to the complete exclusion of frequency, requiring, for example, that ship stations "use two sending wave lengths, one of three hundred meters and one of six hundred meters."[6] By contrast, after 1927, one almost always spoke of the position of a transmitter's carrier wave with respect to the electromagnetic spectrum—that is, the carrier's frequency.

During the 1920s, the FRC rationalized the job of diluting congestion by using the spectrum as a one-dimensional map that graphically represented bands of radio frequencies in the same way that two-dimensional geophysical maps symbolize land. The standard AM broadcast band, the best-understood and stablest "territory" of the spectrum, extended from approximately 550,000 to 1,500,000 cps. Above that lay the ill-defined, continually upwardly shifting boundary that marked the frontier, and beyond that the "short waves" and "ultra-highs," newly discovered expanses of the spectrum where the FRC (and later the FCC) would allocate for television and other radio services. Evocative of the land-grant offices handing out acreage to American settlers during the nineteenth century, the language of the new radio landscape acquired its "pioneers," and "land rushes"—grabs for recently opened parts of the spectrum.

The spectrum paradigm not only explained interference and congestion but also helped the FRC partly solve those problems. Two stations, for example, each one restricted to a 10-kilocycle-wide channel, would not interfere with each other if the FRC assigned them carrier frequencies separated by at least 10,000 cycles per second. But a receiver designed for 10-kilocycle channels would detect stations with overlapping channels. For remedies, the FRC could choose among several, including shifting the channel assignment of one of the transmitters, reducing the power of one or both stations, or withdrawing one of the broadcasters' licenses.

Although by 1930 everyone who worked with radio took the spectrum for granted, almost no one did seven years earlier. Practitioners made do instead with analogies that implicitly compared radio to older technologies, such as the telegraph or telephone. In fact, the very invention of radio had hinged on using the right analogy. During the 1890s, a twenty-one-year-old Guglielmo Marconi invented the wireless telegraph, beating out several scientists who sought at the time a practical use for electromagnetic waves. The professionals, as historian Sungook Hong has explained, fixated on an optical analogy, which caused them to overemphasize the similarity of radiofrequency waves to light waves. This thinking prevented them from imagining that EM waves could send messages over great distances. By contrast, Marconi borrowed his analogy from overland telegraphy. His coinage of the term wireless telegraph indicates that he saw his invention as a wireless version of an older long-distance communications technology.[7]

The wireless telegraph (along with the wireless telephone) was the most common analogy used to explain radio during its first quarter century, but another deserves mention. Lee de Forest, inventor of the audion, the earliest electronic amplifying device, boasted in a 1916 magazine article that he was the first to use his invention "as a printing press." De Forest observed that the electromagnetic newspaper "has the further great advantage that it can be delivered instantly and without the nerve-racking cry of extra, in the quiet of your home, without opening the door, or even ringing your bell."[8] Others had been using a printing press analogy for electrical communications in general for decades. In 1887 Edward Bellamy described a system of wired telephone broadcasting in his utopian novel, *Looking Backward,* and reports of a "telephonic newspaper" introduced in Hungary in 1893 appeared in the United States the same year.[9] Furthermore, a Newark, New Jersey, company was transmitting a "telephone newspaper" to subscribers four years before de Forest's article about radio broadcasting.[10] After 1920, though, the radio-newspaper analogy began to fall apart because radio congestion resembled nothing in the experience of brick-and-mortar publishing.

Congestion alone forced the creation of the spectrum paradigm. When the broadcasting boom began, the federal government was still operating under the Radio Act of 1912, enacted during an age of spark gaps, coherers, damped waves, and point-to-point radiotelegraphy. Within a few years, the government's regulatory authority began to lag behind major changes in the technology, such as the mass production of electronic vacuum tubes. Those who worked with radio realized that something had to be done. In early 1922, as part of a publicity campaign to prod Congress to give the government greater regulatory powers, Secretary of Commerce Herbert Hoover invited thirteen leaders from various organizations—amateur radio clubs, the Institute of Radio Engineers, government agencies that used radio, and the radio manufacturing industry—to attend a conference about the problem, in what was to be the first of four annual meetings. Building on its tradition of public service, the Radio Club of America dispatched Howard Armstrong as the presumptive representative of ham radio operators.[11]

Delegates to these conferences sketched out several ideas that the FRC and, later, the Federal Communications Commission eventually adopted. The first group of attendees, although by no means united on every issue—amateurs, for example, feared an AT&T broadcasting monopoly—by and large agreed on the need to limit the number and power of transmitters. In April 1922 K. B. Warner, editor of *QST*, the leading American amateur radio magazine, warned that "in recent months the radio game has progressed to a point where it simply cannot wait any longer for new regulations." He reported an alarming—and accurate—rumor that "some five hundred applications for broadcasting [are] pending in the Department of Commerce." "Everybody [cannot] be wholly satisfied simply because there aren't enough wave lengths," he observed. Warner urged Congress to grant "the Department of Commerce wide discretionary powers, with the authority to issue, amend or revoke regulations and licenses." Warner also hoped that the Commerce Department would regulate "so as to be of the greatest good to the greatest number of our people."[12]

At this point the spectrum paradigm began to coalesce. Before 1922, few outside physics laboratories had even mentioned the spectrum, but the men who attended the first conference early that year used language that reflected how much they had integrated the spectrum into their thinking. Two months before hosting the first radio conference, in April 1922, Hoover struggled to find words to explain congestion, observing that the proposed regulation of radio was "rapidly becoming as vital a topic as forest preservation and protection of water power rights." The "air is full of chatter," he declared, and with only four or five wavelengths, "ordinary wireless telephonic communication . . . has clogged up this medium of communication to such an extent, that . . . some form of 'ether cops' will have to be established to regulate traffic." Hoover's reference to "wavelengths" evidenced the persistence of the old wireless telegraph analogy, and he borrowed "chatter" from amateur radio slang. But his comparison of radio with natural resources such as forests and water power reveals that he was beginning to conceive of radio in terms of a virtual landscape, similar to the one that the spectrum paradigm would map out.[13]

A year later, further shifts in language signaled a complete transformation. In March 1923 Commissioner of Navigation David B. Carson opened the second conference by asking the fifty attendees to "confine yourselves strictly to broadcasting and the allocation of wavelengths." A few days later, the assembly, after considering solutions to congestion, advised that the government abandon the practice of assigning individual wavelengths in favor of a new broadcast band from "222 meters to 545 meters, with the 'government reserve' above 600 meters opened up to take care of some of the displaced services."[14] This recommendation retained the older idiom, but the group also first invoked the spectrum paradigm explicitly by suggesting "that radio stations be assigned specific wave *frequencies* (wave lengths) within the wave *band* corresponding to the service rendered."[15] Indeed, topping the list of the conference's "more interesting and important resolutions," according to *QST*, were proposals to assign "a wave band of 10,000 cycles to each Class A broadcasting station" and to space geographically proximate stations no closer to each other than 20,000 cycles, with 50,000 cycles between distant stations. The Commerce Department speedily adopted most of these recommendations and was soon assigning stations to standardized 10-kilocycle channels.[16] This action marked when an authoritative body first embraced, albeit informally and probably unconsciously, the spectrum paradigm. The Bureau of Navigation made the conversion permanent when the agency's *Radio Service Bulletin* announced in May 1923 that it would begin publishing station frequencies, with equivalent wavelengths in parentheses. On the fifteenth of the same month, however, the *Bulletin* officially stopped listing wavelengths altogether.[17] Since the late 1920s, the FRC and later the FCC have employed the spectrum paradigm as an intellectual framework for analyzing and alleviating the problems of interference and congestion.

Eighty years ago, however, regulation offered no panacea for the ills of broadcasting. American critics, especially, protested that a system of licensing stations conflicted with traditions of free speech. Soon after Congress created the FRC in 1927, one new commissioner described his job of determining "who shall and who shall not broadcast" as "a rather appalling responsibility. The law tells us that we shall have no right of censorship over radio programs, but the physical facts of radio transmission compel what is, in effect, a censorship of the most extraordinary kind." He pointed out that broadcasting resembles in some ways the newspaper business, "but with this fundamental difference[:] there is no arbitrary limit to the number of different newspapers which may be published, whereas there is a definite limit, and a very low one, to the number of broadcasting stations which can operate simultaneously within the entire length and breadth of our country."[18] As some historians of radio regulation have observed, the first few years of the new regulatory system bogged down in controversy, when business interests with allies on the FRC and FCC muscled out most radio stations owned by nonprofit organizations.[19] Not surprisingly, because regulation alone could do only so much to solve congestion, a number of technological proposals also emerged during the 1920s and 1930s.

The Revival of FM Radiotelephony Research

Technological fixes for congestion included a motley collection of "static eliminators" and "static reducers," nonfunctional contraptions that usually originated in the workshops of freelance inventors. A few ideas worked splendidly, though, nearly all of which were inconceivable without the spectrum paradigm. Armstrong's superheterodyne circuit markedly improved receiver selectivity—the ability to tune in a single radio channel and mask adjacent ones—which in turn allowed more stations on the air.[20] George Pierce patented the crystal oscillator, which replaced traditional inductors and condensers in a resonant circuit, with a small piece of vibrating quartz, to attain far more stable carrier frequencies. This device permitted the FRC to pack stations more tightly into the broadcast spectrum.[21] AT&T engineer John R. Carson invented single-sideband modulation (SSB), which took advantage of the fact that the two sidebands in an AM channel carry redundant information. By suppressing one sideband, Carson halved the width of an amplitude-modulation channel, thereby theoretically doubling the maximum number of stations permitted on the air and halving static noise levels.[22]

Some practitioners also, for a few years, proposed a type of "narrowband" frequency modulation as a solution to congestion. The theory for the method derived from the fact that a normal amplitude-modulation signal requires a channel, a slice of radiofrequency spectrum wide enough to carry two mirror-image "sidebands." Although comprising a snarl of continuously changing audio-frequency waves that defy easy analysis, sidebands figure in a few straightforward principles for AM. First, each sideband requires a contiguous portion of spectrum, as wide as the audio-frequency bandwidth, to convey information. Thus, the channel carrying both sidebands spans *at least* twice as much spectrum as the audio bandwidth:

$$\text{AM channel width} \geq 2F_a,$$

where F_a represents the width of the audio bandwidth and of each sideband. A second principle states that widening a channel opens further the door to static noise. All this leads to a delicate balance between audio fidelity, which requires wider channels, and static noise, which tends to increase with channel width. Moreover, widening the standard channel width decreases the number of stations that can broadcast simultaneously across a fixed portion of the radiofrequency spectrum. Since the early 1920s, most engineers have accepted this matrix of trade-offs as inherent in normal AM radio practice.

A number of visionaries, though, questioned whether the same rules must apply to frequency modulation in the same way. Indeed, must the rules apply at all? Perhaps FM would sever the connections between fidelity and static and between static and the channel width. To understand how, imagine an FM transmitter that emits at any instant a single wave, not a band of mixed frequencies, as with AM. That wave's frequency "wobbles" from side to side across a small portion of the spectrum, the range of wobble proportional to the instantaneous amplitude of the modulating sound wave. Accordingly, an FM signal requires—one would hope—a channel wide enough to accommodate only the maximum extent of the wobble, called the frequency swing. Mathematically, it was simple:

$$\text{narrowband FM channel width} = 2f_m = 2hA_a,$$

where f_m is the maximum deviation from the center transmitter frequency (or half the frequency swing), A_a is the maximum audio amplitude, and h is the designer-chosen modulation index, a constant value. Because the swing varied with only the *amplitude* of the audio signal—in a constant proportion (h) selected by human designers, not by nature—then man, not nature, would determine the width of the channel. By 1923, with ever more stations jostling for channels on the spectrum, nothing would have been more propitious for broadcasting than a working system based on this theory. A designer could conceivably choose a modulation index h as small as the practical limits of electronics technology allowed, pack into the spectrum far more FM channels than the old AM method permitted, and obtain better audio fidelity to boot. Narrowing the channels would also shut out a great deal of static. At least, advocates of the theory hoped so.

The first published record of narrowband FM technology exists as a patent application filed in 1923.[23] But gossip had it that Frank Conrad, the founder of the pioneer broadcast station, KDKA, in Pittsburgh in 1920, experimented with narrowband at least as early as 1921. RCA engineer Clarence Hansell recalled eleven years later that Conrad "at one time advocated the use of frequency modulation in radio broadcasting." "Dr. Conrad," Hansell explained, "was credited with statements to the effect that frequency modulation did not produce side frequencies as in amplitude modulation and would therefore permit a great increase in the number of broadcasting stations."[24]

Conrad's claims collapsed when in February 1922 John Carson of AT&T published the first mathematical analysis of modulation in a historic article titled

"Notes on the Theory of Modulation." "A great deal of inventive thought has been devoted to the problem of narrowing the band of transmission frequencies," Carson declared in an early paragraph, adding that his article aimed "to analyze the more ingenious and plausible schemes which have been advanced to solve this problem." A page or two later he repeated this point, in a sentence remarkable for its twin coinage of the terms amplitude modulation *and* frequency modulation. "In order to eliminate the necessity of sidebands," he stated, "it has been proposed a number of times to employ an apparently radically different system of modulation which may be termed *frequency* modulation as distinguished from *amplitude* modulation, in the belief that the former system makes possible the transmission of signals by a narrower range of transmitted frequencies." "This belief is erroneous," Carson asserted, although he allowed that "the reasoning on which the supposed advantage [of narrowband FM] is based is very plausible."[25]

Carson's theoretical FM transmitter was not complex. He asked his readers to imagine a constant-frequency sinusoidal audio wave $sin(pt)$, which oscillates relatively slowly, say, at 100 cps. This modulates the frequency of a continuous-wave oscillator with a much higher carrier frequency ω_o, at perhaps 1 million cps:[26]

$$\omega = \omega_o\,[1 + h\,sin(pt)],$$

where ω is the instantaneous radio frequency emitted by an FM transmitter, ω_o is the center (unmodulated) radio frequency, h is the modulation index, and $sin(pt)$ is the hypothetical sinusoidal sound wave.

The preceding equation describes the simplest kind of frequency modulation: when a low-frequency audio wave $sin(pt)$ modulates a high-frequency carrier wave ω_o. This equation can be rearranged algebraically to clarify its meaning:

$$\omega = \omega_o + (h\omega_o)sin(pt),$$

which is equivalent to:

instantaneous frequency = center frequency + instantaneous frequency deviation

Ordinarily, this equation describes any kind of FM system, but not in Carson's article. Significantly, he restricted his analysis to systems in which the modulation index "h is small compared with unity." The purpose of this stipulation becomes clear when one observes that the maximum magnitude of $sin(pt)$ is ±1.0, and thus the maximum magnitude of the frequency deviation is $\pm h\omega_o$ (i.e., the maximum value of $h\omega_o sin\,pt = h\omega_o \times [\pm1.0] = \pm h\omega_o$). In other words, the small value that Carson assumed for *h* makes the maximum frequency deviation ($h\omega_o$), and therefore the channel width, small as well. Carson stressed that he chose a small value of *h* to conform to the premise of those who hoped narrowband FM would conserve spectrum.[27]

Following Carson's analysis in detail requires mathematical knowledge beyond the scope of this book, but understanding his conclusions in a general way does not. Contrary to the expectations of narrowband proponents, he argued, narrowband FM *does* produce sidebands; even worse, choosing a small *h* causes multiple sidebands to splay across a range of spectrum that far *exceeds* the channel width of a comparable AM signal. The term narrowband FM, therefore, refers to an impossibility. Furthermore, attempts to employ FM to narrow the channel width will actually *increase* audio distortion.

Paradoxically, although communications engineers have long regarded Carson's paper as a classic in their field, few radio engineers have suffered more unjustly at the hands of historians than John Carson. Lawrence Lessing, for instance, damns Carson's article for being "so injudicious as to draw the sweeping conclusion: 'This type of modulation inherently distorts without any compensating advantages whatever,'" asserting also that Armstrong liked to remind Carson of his "bloomer."[28] As Lessing's statement indicates, though, he and those who have followed his example have misconstrued Carson's analysis as an attack on *all* kinds of FM, something Carson clearly took pains not to do. In fact, Carson shared with Armstrong a flair for explaining clearly the gist of a highly technical argument. Even if a reader misses the fact that Carson chose a small modulation index *h* in order to evaluate only narrowband FM, she will find that Carson expressed no opinion about the feasibility of every type of FM, especially the not-yet-invented Armstrong kind.[29] Carson's critics have also explained his "mistake about FM" by implicitly caricaturing him as an out-of-touch egghead, a creature of theory, not practice.[30] This is a curious misrepresentation of Carson's career, for although he ranks among the greatest radio communications theorists of his time, few could match his practical accomplishments. In 1924, for example, the Institute of Radio Engineers awarded Carson its Morris Leibman Memorial Prize for his invention of single-sideband modulation, whose importance probably surpasses that of high-fidelity FM.[31]

Of course, the fact that Carson debunked only narrowband frequency modulation does not remove the chance that one way or another he inadvertently curbed further research in other kinds of FM, possibly by deterring practitioners who distorted his argument. Clarence Hansell, who himself often misunderstood Carson, credited "the ridicule heaped upon those who believed frequency modulation would permit reducing transmitter frequency bands" for the small number of articles about FM in the *Proceedings of the IRE* after 1922.[32] But patent records contrarily indicate that from 1922 to 1934 the number of frequency-modulation patent applications surged into the dozens, only four of which claimed to employ the narrowband method (see fig. 15 later in this chapter). The possibility that Carson discouraged research only in *narrowband* FM is more plausible, albeit admittedly harder to prove, given the small total of such patents ever issued. But blaming him for retarding the progress of frequency modulation generally is nonsensical.

FM Radiotelephony Research

Few false assumptions about frequency modulation have persisted more stubbornly than the belief that almost no one worked with the method until Armstrong invented wideband FM in 1933. Typically, assertions that John Carson's 1922 article essentially killed off FM research support this idea. Lessing declares that Armstrong "never lost an opportunity to rub it in that the investigation of frequency modulation had been fumbled."[33] But just as the traditional history of FM has twisted Carson's words, it has also completely overlooked the tremendous amount of useful work of dozens of people during the 1920s and early 1930s. In fact, approximately forty inventors filed for eighty-three patents directly and indirectly related to FM between the advent of the broadcasting boom in 1920 and the end of 1933, just before Armstrong revealed his first wideband FM system. The appendix provides a list of these patents.

The appendix requires some clarification. First, the modifying phrase FM-related in the appendix's title refers to patents that either explicitly mention the method or allude to frequency-modulation devices such as transmitters, receivers, and systems. Some patents also state that they describe only something that could be useful in frequency-modulation systems. Second, the appendix includes devices related to *phase* modulation as well. Without ignoring real differences between the two methods, this book presumes that nothing important distinguishes frequency modulation from phase modulation and that someone who has worked extensively with one of the methods has for all practical purposes worked with the other. Finally, although the appendix represents an attempt to list every FM-related invention filed before 1941, including patents with filing dates after 1940 proved impractical, because of the unmanageably large number of such inventions.

To place these inventions in context, this section provides an overview of FM research from 1913 to the mid-1930s, organized more or less according to the sources of FM-related patents, which roughly correlates with the significance of the inventions themselves: FM inventors of minor significance; the American Telephone and Telegraph Company; the Westinghouse Electric & Manufacturing Company (including its flagship broadcast station, KDKA); and RCA. Later chapters analyze in detail the work of Edwin Howard Armstrong, the inventor of "wideband" FM radio.

FM Inventions of Minor Significance

These nineteen patents comprise a wide variety of largely homegrown, sometimes eccentric, and never influential ideas. Before large corporations took up frequency-modulation research during the 1920s, nearly every FM patent in the United States was unassigned. A Grand Forks, North Dakota, man named Albert Taylor filed in 1919 an application for a simple radiotelephone patent.[34] In 1912 John Hayes Hammond Jr. applied for a patent for a dual-purpose arc oscillator system that employed FSK for radiotelegraphy and AM for radiotelephony.[35] Eighteen months later, Peter Cooper Hewitt came up with a peculiar frequency-modulated oscillator based on a heated chamber of vibrating gas or vapor.[36] Technically, Albert Van Tuyl Day filed his application for a complex vacuum-tube FM radiotelephony system in 1919, but the fact that his patent was issued thirteen years later diminishes the likelihood that the final document closely resembled his original idea.[37] Finally, in 1929 Hammond utilized frequency modulation in a communications system that transmitted light beams, not radio waves.[38]

The seven minor FM patents that their inventors assigned to companies other than Westinghouse, RCA, and AT&T before 1934 make only a slightly better impression than the unassigned inventions. General Electric and the German firm, Telefunken, accumulated two and four patents respectively. The Compagnie Générale de Télégraphie Sans Fil, of Paris, was assigned one patent, in 1931.[39] Patents from this group count individually as little more than curiosities, but they show that in Europe and America FM research did not lay dormant during the twenties.

FM Research at the American Telephone and Telegraph Company

Ten FM patents are assigned to AT&T and its subsidiary, Western Electric Company, all dated from 1920 to 1933. The Telephone Company undertook the job of making frequency modulation work with less coordination and energy than did

RCA and Westinghouse, partly because AT&T carried out its research in several locations. Also, the AT&T patents more often related to facsimile technology than to radiotelephony. By 1934 Western Electric employees had filed three radiotelephony and two facsimile applications, and AT&T engineers had applied for only one radiotelephone invention and three facsimile devices or systems. The tenth Telephone Company patent described a generic modulator circuit adaptable to the transmission of any kind of information.[40]

A combination of business and technological factors explains AT&T's relative lack of enthusiasm for FM radiotelephony. The corporation filed its last FM radiotelephony patent in 1926, the same year the firm permanently sold off its broadcast stations.[41] Furthermore, noise and fading presented much less serious challenges for *wire* telephone communications than for *wireless* radiotelephony. Finally, FM facsimile was easier to achieve than FM radiotelephony. As opposed to the real-time constraints of voice telephony, in which the reproduction of sound must occur in perfect synchronization with the source, no technical reason prevented the transmission of a still picture from taking minutes or even hours. Nonetheless, the fact that AT&T and Western Electric worked with FM at all weakens the assertion of historians of FM who have dismissed the 1920s as irrelevant.

FM Research at Westinghouse and KDKA

The first significant experiments ever with frequency-modulation radiotelephony began at Westinghouse's East Pittsburgh broadcast station, KDKA, during the early 1920s (see fig. 12 for KDKA's first FM patent). KDKA doubled as a research laboratory for Westinghouse, and the station's engineers, led by founder Frank Conrad, profitably pioneered several innovations in radio communications, most famously shortwave (frequencies above the upper limit of the standard AM broadcast band, at 1.5 megacycles) communications.[42] Only KDKA's historic local broadcasts of 1920 garnered more publicity than Conrad's trials of long-distance shortwave programs. From 1923 to 1925, listeners in the United Kingdom, South Africa, Australia, and north of the Arctic Circle could hear experimental transmissions that originated in Pittsburgh.[43] KDKA also led in the use of crystal-controlled oscillators for stabilizing transmitter carrier frequencies, which permitted more stations to broadcast with less risk of interference.[44] The station's research experience, particularly with crystal circuits, paid off during groundbreaking experiments with frequency modulation because FM demanded far steadier carrier frequencies than AM did. Westinghouse engineers also discovered that they

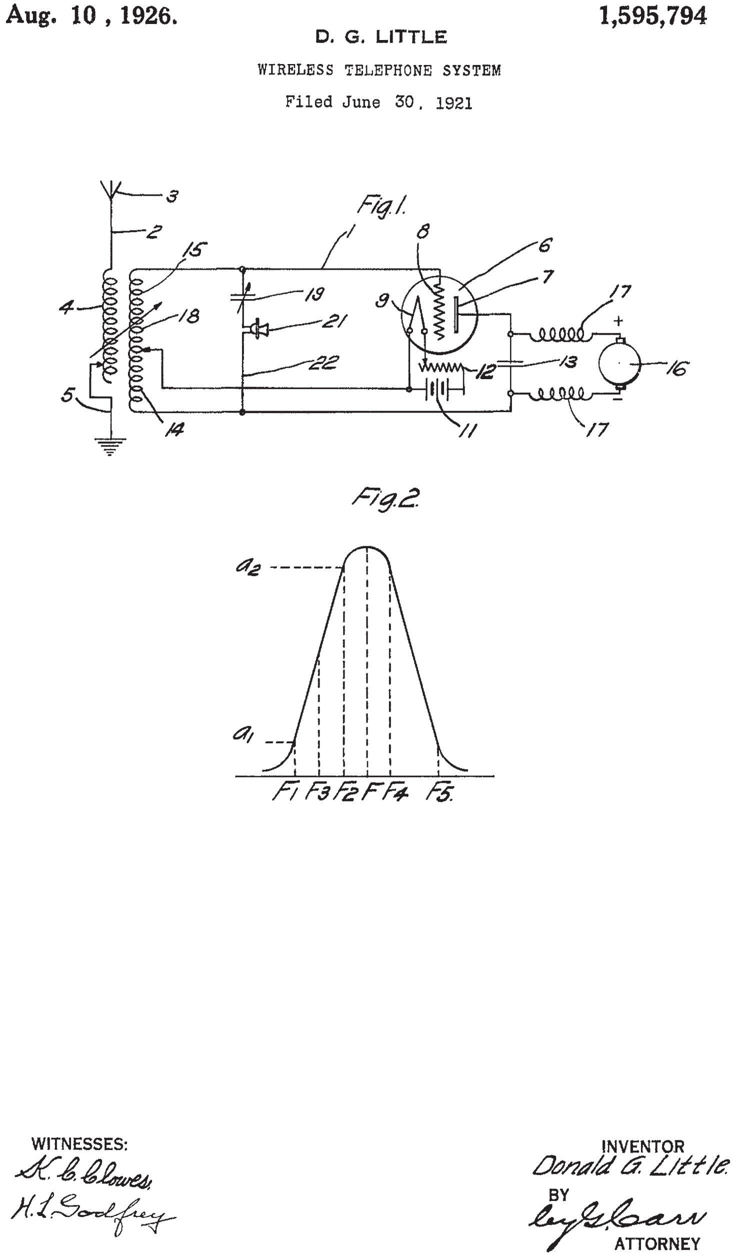

Fig. 12. KDKA's First FM Patent, 1921. Upper figure shows a simple transmitter with a condenser microphone (21). Donald G. Little, "Wireless Telephone System," U.S. Patent No. 1,595,794, application date: 30 June 1921, issue date: 10 August 1926, assigned to Westinghouse. Little was an engineer for radio station KDKA during the 1920s.

could modify their crystal oscillators to make the first nonmechanical, electronic circuit for modulating a carrier's frequency.

Notably, the several inventors who held the FM radiotelephone patents assigned to Westinghouse lived near one another. Alexander Nyman, who in the summer of 1920 filed Westinghouse's first FM patent, for an arc-based radiotelephone, resided in Wilkinsburg, Pennsylvania. Virgil Trouant, the company's most prolific FM inventor in the period before 1934, lived in the same suburb. KDKA engineer Donald Little, of nearby Edgewood, filed the first all-vacuum-tube FM invention in June 1921.[45] Little's neighbor, boss, and friend, Frank Conrad, filed the station's second FM application seven months later (fig. 13). By 1934 these men, all Westinghouse employees and residents of metropolitan Pittsburgh, had nine FM patent applications to their credit.[46] For good reason this pattern of geographic proximity among FM's early inventors persisted into the 1940s: engineers accomplished more from discussing their work with colleagues than they did when working alone.

KDKA's FM research stemmed from the station's crystal-oscillator experiments, which began about the same time. Charles W. Horn, who eventually

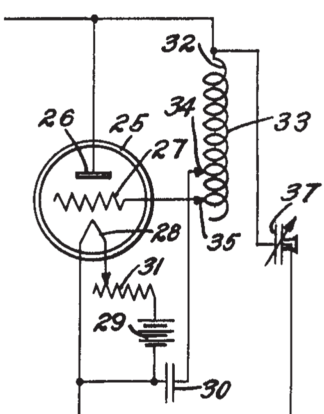

Fig. 13. Detail from Conrad FM Transmitter, 1922. Like Ehret's 1902 invention (see fig. 10), Conrad's device employed a mechanically coupled condenser microphone (37). Sound causes the capacitance of 37 to alter the electrical characteristics of a tuned *LC* circuit composed of condensers 37 and 30, and inductor 33. Consequently, the resonant frequency of the circuit varied with the amplitude of the sound. The significant improvement over Ehret's 1902 invention was Conrad's use of continuous waves and electronic amplification. Frank Conrad, "Wireless Telephone System," U.S. Patent No. 1,528,047, application date: 15 March 1922, issue date: 3 March 1925, assigned to Westinghouse.

transferred to RCA in 1929 and served as NBC's chief engineer, oversaw KDKA's engineering staff during this period. In 1939 Horn recalled that, while serving as KDKA's station manager, he and his engineers began FM experiments "soon after we first equipped KDKA with quartz crystal control" of the transmitter's main oscillator frequency.[47] Many radio stations adopted crystal-controlled oscillators for the purpose of improving frequency stability. But apparently only KDKA's engineers also noticed that an oscillator's resonant frequency shifts roughly in proportion to the voltage across its crystal, which led to the revelation that "we could vary the carrier wave frequency of the transmitter by changing voltage potentials across the crystal." Typically, an electrical audio wave was superimposed on the crystal, causing the crystal's voltage to vary, which in turn made the resonant frequency rise and fall in proportion to the instantaneous amplitude of the audio wave.[48] In fact, practitioners adopted this method as the most common means of frequency-modulating waves. Between 1926 and 1928, Westinghouse engineers filed five patent applications for inventions that used crystal-controlled frequency modulators.[49]

Examined as a group the Westinghouse patents reveal no explicit goals, but the fact that seven of nine described radiotelephone inventions suggests that the company briefly hoped to make frequency-modulation radiotelephony work in some useful way, most likely as a new kind of broadcast radio technology based on narrowband FM. Further, when Virgil Trouant filed Westinghouse's only narrowband patent in 1927, he revealed that "in one commercial embodiment of my invention, which has been in successful operation over an extended period, the . . . oscillator frequency is 970 kilocycles and the shift obtained with voice modulation is of the order of 800 cycles."[50] Indeed, KDKA often used 970 kilocycles to transmit its carrier. Trouant's description also corroborated Horn's recollection in 1939 that "we . . . were able to 'wiggle' the frequency of the [KDKA] transmitter over a range of some hundreds of cycles, the figure of 800 cycles was one of them."[51]

In 1938 the authoritative industry magazine *Broadcasting* stated that KDKA, "a number of years ago, conducted tests with frequency modulation but did not find them entirely satisfactory."[52] Several facts tell a more complicated story. A year later, Charles Horn made the broadest claims for what KDKA accomplished with frequency modulation during the 1920s. He implied, for instance, that his team discovered that FM suppresses noise before Armstrong did:

> We frequently discussed the need of some form of modulation, which was not dependent upon amplitude, in order that we might discriminate against amplitude modula-

> tion because we knew that static and noise were of that type of energy. In order to test this system, we made experiments with the receiver located in . . . the Machine Company Building at the E Pittsburgh plant, and which location was in about the noisiest place we could find due to the great amount of electrical machinery in that and neighboring buildings. I remember that the tests definitely proved that we could get a very much higher ratio of signal to noise when using the frequency modulation as against the amplitude modulation.

Horn added, "I received many complaints from listeners about their inability to hear KDKA during periods when we used frequency modulation," which "proved to me that it was true frequency modulation."[53] These claims, however, made years after Armstrong's invention of practical wideband FM, smack of wishful thinking, for only in a limited sense was Horn stating the facts. Ample evidence indicates that KDKA almost certainly made the first FM broadcasts, but no ordinary radio set could receive them. The complaints he cited proved only that listeners could not detect KDKA's transmissions. In fact, KDKA's FM technology never approached the requisite complexity that Armstrong's system achieved during the early 1930s, and no Westinghouse FM invention functioned on a practical level until the late 1930s. Most significantly, the station's engineers failed to grasp what Armstrong stumbled on years later: that static distorts the *amplitude* of a radio signal more than it distorts the *frequency*, a distinction that largely accounts for why wider FM channels make for quieter broadcasts.

That KDKA's experiments did not lead to something resembling the Armstrong system obscures their significance though, for in engineering one cannot infer worthlessness from a lack of practical success. Westinghouse's FM research did produce, in a roundabout way, useful results. The station's engineers must have learned from using 800 cps deviations what Carson taught with mathematical theory—namely, that narrowband FM did not work. Many of the rudimentary innovations KDKA's engineers devised appeared later in more sophisticated forms as components of the Armstrong system. Crystal oscillators, balanced amplifiers, frequency multipliers, limiter circuits, and high-efficiency nonlinear electronic amplifiers, for example, migrated into the material language that has characterized FM design since the 1920s. And though Virgil Trouant filed a single, poorly conceived patent application for a narrowband invention, he and other Westinghouse engineers correctly guessed that FM would eventually provide other advantages that the Armstrong system actually delivered: static reduction, resistance to fading, and greater transmitter efficiency. KDKA engineers, as one of the first groups to blaze the FM trail, made progress that seems unexceptional in a comparison that hindsight makes possible, and they pursued one dead end after another. But the hard work Westinghouse put into mapping out these dead ends later saved investigators at RCA—and Armstrong—from pursuing an uncountable number of false leads.

Knowledge of KDKA's work with FM spread, probably by word of mouth, to a handful of journalists and engineers far beyond Pittsburgh's environs. Oddly, despite evidence in the patent record that Westinghouse scarcely flirted with narrowband FM, for many years most published descriptions fixated on that mirage, suggesting that the central argument of John Carson's article had sunk less deeply into the minds of the larger community of radio practitioners than into those of the individuals who actually worked with frequency modulation. One can partly blame Westinghouse's managers for the confusion. In 1928 the firm's president, Harry P. Davis, disclosed in a speech at the Harvard Business School that KDKA had been "operating for some time with a different type of modulation called 'frequency modulation.'" He listed as one advantage the method's now well-known transmitter efficiency, which allowed the station "to eliminate three-quarters of the number of transmitting tubes that are required in the ordinary [AM] manner of transmitting. Further, the wave band is greatly sharpened and eliminates side band interference." Davis guessed correctly about the increased efficiency of FM transmitters, which unlike AM transmitters radiated constant-amplitude waves. But his use of the phrase "sharpened the wave band" and his implication that frequency modulation could achieve both spectrum conservation (by eliminating "side band interference") *and* noise reduction speaks to his ignorance of the proven futility of narrowband FM.[54]

The false myth of narrowband FM's potential also captivated a number of writers beyond Westinghouse. Mary Texanna Loomis's popular radio engineering textbook of 1928 stated that "a new kind of modulation, called 'frequency modulation,' has been used experimentally at KDKA." Like Harry Davis, Loomis hinted that FM promised spectrum conservation, declaring that "it is claimed for this [method] that stations can operate within a 10-kilocycle band." She cited FM's efficiency, too, and declared that FM stations "can also dispense with the usual [high-wattage] modulator tubes, with a reduction in power consumed."[55] KDKA's work probably also prompted Edgar Felix, an executive of the RCA-owned station WEAF in 1928 and a writer for *Radio Broadcast* magazine, to include narrowband FM among several innovations that might alleviate congestion. For FM, Felix wrote, "has been claimed the extraordinary virtue of accommodating simultaneously between one and two thousand broadcasting stations in the present band."[56] As late as 1930, similarly hopeful reports about narrowband FM appeared in Britain, where the respected magazine, *Wireless World*, published an article lamentably titled "Frequency Modulation: A Possible Cure for the Present Congestion of the Ether."[57]

That outsiders, however poorly informed, knew something of KDKA's FM work is unremarkable given the wide variety of unpublished media for the transmission of knowledge about radio technology. Much of the community of radio practitioners during the twenties exchanged information in ways that virtually ensured that word about the experiments would spread. Informality and camaraderie characterized the radio engineering profession, especially in northeastern states, where many practitioners who worked with FM lived and attended meetings of both the all-professional Institute of Radio Engineers and the "amateur at heart" radio clubs. And RCA's corporate structure, crafted to prevent Westinghouse, GE, and RCA from competing with each other, obviated any reason as to why Westinghouse engineers should not talk shop with colleagues employed by the other two companies.

The "Radio Group"

History tied the three corporations where FM research was most concentrated far more closely to each other than one might guess. David Noble describes how "the growth of the corporations, and the intensification of their control through trusts, holding companies, mergers and consolidations, and the community of interest created by intercorporate shareholding and interlocking directorates" characterized American business by the 1920s.[58] Noble's analysis makes a broad argument about corporate research in general, but it hits the mark with respect to FM radio. So does an examination of the companies that contributed most to frequency-modulation research during the twenties. Far and away the most important was the Radio Corporation of America. In 1919, with prodding by the federal government, General Electric created RCA primarily to keep American radio patents from falling into British hands. (GE itself had resulted from a merger of the Edison Electric Company and the Thomson-Houston Company in 1896.)[59] To minimize competition with its corporate owners, a contract banned RCA from manufacturing all but a small quantity of radio apparatus, but the company possessed the exclusive right to sell all of GE's radio products. RCA also acted as a clearinghouse that licensed radio patents to GE and other manufacturers on an equitable basis. Later, additional large companies that owned important radio patents joined RCA's "Radio Group" patent pool, which shielded from competition the large corporations that enrolled as members. These companies exchanged their patents and cash for RCA stock, and RCA licensed the same patents outside the Radio Group for profit.

By the time RCA began developing FM during the mid-1920s, the Radio Group had evolved into a close-knit, self-regulating syndicate. For the first few years, RCA's largest corporate shareholders included AT&T, American Marconi, the United Fruit Company, and Westinghouse.[60] Some of the group soon dropped out—most prominently AT&T, which sold off its RCA stock by mid-1923 and transferred the last of its radio stations to RCA's new network, NBC, three years later.[61] By the end of the 1920s, senior managers of only two corporate shareholders, Westinghouse and GE, dominated RCA's board of directors.

Two factors about RCA shaped FM research profoundly: first, the company operated a transoceanic point-to-point commercial service, a field no shareholder was permitted to enter; and, second, until the early 1930s, RCA, Westinghouse, and General Electric agreed not to compete with each other in the radio business.

FM Research at RCA

Despite the early lead in patents that Westinghouse built up during the early 1920s, RCA dominated FM research by the end of the decade. Engineers in the latter firm began investigating FM radiotelephony a few years after their KDKA colleagues did, but with different aims. While Westinghouse focused on making a commercial broadcast FM technology that utilized the medium frequencies of the standard AM band (500 to 1,500 kilocycles per second), RCA sought chiefly to improve the reliability of its point-to-point overseas shortwave service, which sent messages between stations separated by thousands of miles. Initially, the company's engineers evaluated FM from the standpoint of its effectiveness in solving the most critical problem of long-distance communications: fading.

Thanks to a large number of in-house memoranda by Clarence Hansell, who supervised engineering work at RCA's Riverhead, New York, laboratory during the 1920s and 1930s, we can learn a great deal about RCA's earliest FM work. In 1932 Hansell wrote that Harold O. Peterson and Harold H. Beverage had "set up and operated a simple frequency-modulation system in the Riverhead Receiving Laboratory" as early as 1924. Beginning in 1925, "the development of frequency modulated transmitting equipment suitable for high frequency experiments . . . had a regular place on the program of the Rocky Point [New York] Development Laboratory," and in 1925 RCA established experimental FM circuits between New York and stations located in Argentina and Brazil.[62] In 1927 Harold

Peterson strayed, for a short period, into the cul-de-sac of narrowband FM, when he applied for an FM radiotelephone patent, one of three assigned to RCA that year, and the only narrowband invention ever assigned to the company. "The requisite maximum wave band [i.e., the channel width] may be made as small as desired," explained his patent, which also claimed that a frequency swing "of only five hundred cycles per second . . . suffices for successful operation, even on very short wave lengths." Apparently, Peterson and his patent examiner had either not read, understood, or believed John Carson's 1922 article, for in contravention of Carson's argument, Peterson's patent also described the employment of a "frequency wobble which helps . . . avoid the use of side band frequencies, in the ordinary sense, with their attendant disadvantages."[63] (Carson, of course, had contrarily proved that narrowband FM creates innumerable side band frequencies.) In any case, FM soon after took a back seat to "other work," partly because of improvements in receiver antenna design that increased signal-to-noise ratios of AM radio signals. "Little concrete progress was made" with frequency modulation until 1929, when "interest in the problem was renewed and both the Rocky Point and the Riverhead laboratories began to follow it up more intensively."[64]

By mid-July 1929 the chief difference between the earliest patents of Westinghouse and RCA was that the latter company had filed a much greater number. RCA had accumulated some twenty-five FM patents versus Westinghouse's nine, a gap that would steadily widen until the mid-1930s. RCA's patents also claimed, more often than did Westinghouse's, to reduce the effects of fading, again a central problem for long-distance communications. But, in other ways, the two organizations did similar things; both turned out not radical designs but rather incremental improvements to FM, including circuits that Armstrong later further elaborated on and employed in his wideband system of 1933. The "limiter" circuit Clarence Hansell placed in the receivers of his August 1927 and October 1928 patents (see fig. 14 for one of the 1928 patents) to reduce the effects of fading, for example, appeared in a more sophisticated form in the Armstrong system.[65]

Patterns of FM Research

An examination of FM radiotelephone patent applications filed from 1913 through the 1930s indicates that the development of frequency-modulation radio occurred predominantly in three large corporations headquartered in the northeastern United States: RCA, Westinghouse, and, far less productively, AT&T. Aside from one-time independent inventors in Illinois, North Dakota, and the

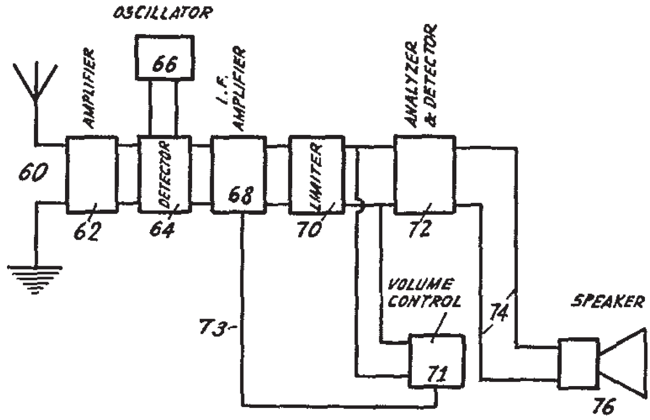

Fig. 14. Block diagram of Clarence Hansell's FM Receiver, 1928. Block diagram shows a limiter circuit, something Armstrong improved upon in his wideband FM system of 1933. Clarence W. Hansell, "Signaling," U.S. Patent No. 1,803,504, application date: 5 October 1928, issue date: 5 May 1931, assigned to RCA.

District of Columbia, and in a handful of European countries, the individuals who filed for patents lived in one of four adjacent northeastern states. New Jersey and New York together claimed more than two-thirds of the total patents; Massachusetts and Pennsylvania inventors contributed four and nine patents (5% and 11%) respectively. Where the inventors resided correlates with the location of the assignee corporations, because the largest companies that researched FM tended to employ the inventors who lived in these states.

Figure 15 and the appendix show how RCA came to dominate FM research for several years. That firm, whose engineers at the Riverhead and Rocky Point laboratories (both located less than eighty miles east of Manhattan) lived principally in the states of New York and New Jersey, acquired rights to half of the FM patents filed between 1920 and 1934 (forty-four out of eighty-three). In fact, 30 percent of all American FM patent applications before 1934 were filed by only two RCA research engineers, Murray Crosby (ten) and Clarence Hansell (fifteen), with Hansell alone holding nearly one-fifth of all FM patents filed.

Besides RCA, the other two major corporate assignees were AT&T and Westinghouse, each of which obtained the rights to ten FM patents before 1934. Nine of Westinghouse's were filed by men who lived near that firm's factory in Pittsburgh or in nearby Wilkinsburg and Edgewood. A weaker but nevertheless similar pattern existed for the ten patents assigned to the third major corporate source of FM patents, the AT&T–Bell Labs–Western Electric organization, although this

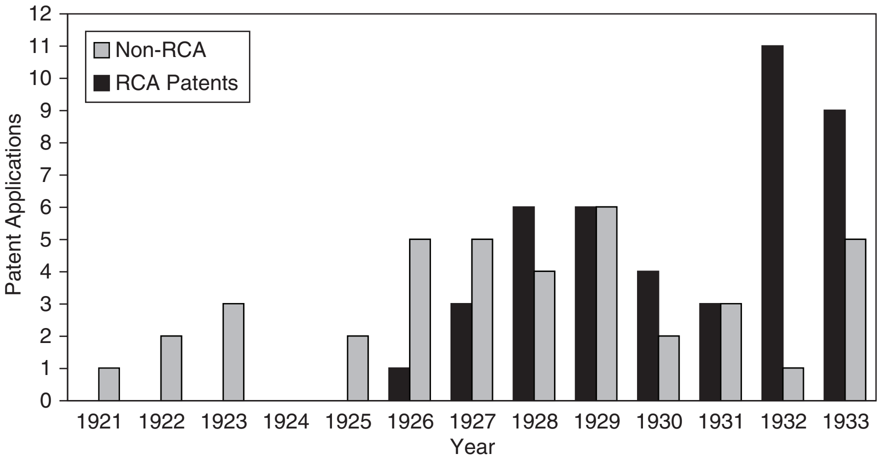

Fig. 15. FM-Related Patent Applications, 1921–1933. Darker bars = assigned to RCA; lighter bars = not assigned to RCA.

group's inventors were far more geographically dispersed among the three companies.

The chronology of RCA's patents suggests that interest in FM at RCA ebbed and flowed but, over the long run, persisted longer and remained stronger in that firm than in the other two major corporations. Figure 15 shows that RCA, which entered the field of FM later than AT&T and Westinghouse (filing in 1926 the sixth patent application of the early broadcast period), soon surpassed all other assignees combined. RCA engineers filed more than two-thirds of all FM patents in 1928, and in every year afterward through 1935 they continued to apply for at least half of the annual number of FM patents in the United States. But RCA's output occurred unevenly in three short-lived surges. The first began about 1926, peaked in 1928, and tailed off afterward. The second started in 1931 and peaked in 1932. The last surge began in 1934, shortly after Armstrong informed the firm about his wideband system. RCA's output the next year reached its peak with five patents, but in 1936 company engineers filed only one application, their last until the 1940s.

The smaller number of patents assigned to the other two major corporations makes discerning chronological patterns more difficult, but not impossible, to determine. Westinghouse accumulated nine FM inventions before 1934—only one-fifth of RCA's total—but the Pittsburgh firm began its research earlier, and sustained a continual trickle of patent applications from 1920 through 1928. Maximum output occurred during the two-year period from August 1926 through

May 1928, when five of ten Pittsburgh patents were filed. AT&T also owned ten patents, variously assigned to subsidiary firms Bell Laboratories and Western Electric (AT&T's manufacturing arm), as well as to the Telephone Company itself. All but one of these were filed in 1928 or earlier, only one before the publication of AT&T engineer John Carson's 1922 article. Even if readers widely misunderstood Carson's argument, one cannot argue that he prevented FM research from accelerating, even in his own company.

These facts support two broad generalizations about FM research before 1934. First, large organizations strongly shaped how FM radio technology evolved, confirming the argument of David Noble, who has contended that by the 1920s the age of the independent inventor had essentially ended, due partly to a concerted effort on the part of large corporations to co-opt independent research engineers and scientists. Second, the quantity of patent applications filed in the United States indicates the existence of at least a moderate level of curiosity about FM in a handful of research centers, well before Armstrong was issued his patents. True, no organization, not even the companies with the greatest interest, assigned the development of frequency modulation the highest priority. Several other fields of radio technology—antennas, vacuum tubes, linear circuits, and television—accumulated far more patents. But neither was FM an esoteric, neglected, or abandoned concept or practice during the 1920s, as Lessing would have us believe. (Indeed, the *Proceedings of the Radio Club of America* reported in 1939 that "what was probably the first public discussion of the subject was had before a meeting of the Club some fifteen years ago.")[66] All through the early broadcasting period, from 1920 through 1933, a significant number of men, many of whom were Radio Club members and engineers who knew Armstrong as a friend—corporate and independent alike—actively worked to develop practical FM technology.

During the 1920s, FM radiotelephony remained a solution searching for a problem. Because nothing more gravely challenged the future of radio during the 1920s than congestion, the mirage of narrowband FM opening up the spectrum for thousands of additional stations fascinated a few practitioners, even several years after John Carson demonstrated the method's infeasibility. FM seemed to offer other advantages as well, such as greater power efficiency. But, as the next chapter shows, it was fading, a problem of long-distance communications, that more than any other technical factor spurred FM research after 1929. Nevertheless, the work of the 1920s did not go to waste, and those who labored to make FM useful during the 1930s owed a great deal to the hits and misses of the previous decade.