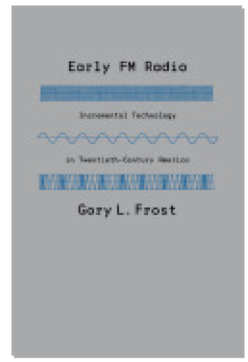
Early FM Radio

Frost, Gary L.



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RCA, Armstrong, and the Acceleration of FM Research, 1926–1933

> Major Armstrong feels that phase modulation and frequency modulation are extremely important developments and that we should keep it confidential for some time to come.
>
> *Harold Beverage, 26 February 1932*

The traditional history of FM radio implies that Edwin Howard Armstrong's revolutionary wideband FM patents caught RCA off guard. Lessing, for example, writes that "the saga [of FM radio] began shortly before Christmas, 1933, when Armstrong invited [RCA president] David Sarnoff up to the Columbia University laboratories to witness his latest wonder." Lessing says also that Armstrong offered to sell the patent rights to FM to RCA before all other firms because "R.C.A., by reason of the large royalties it had collected and the large research laboratories these had built up, was the logical company to undertake the expensive development of a new invention for the industry."[1] But the traditional history has it wrong. In fact, RCA and Armstrong both began researching frequency modulation about the same time—during the mid-1920s—and not surprisingly, because they enjoyed a collaborative relationship that made Armstrong, for all practical purposes, an RCA employee. His contractual obligation to RCA, not RCA's size, determined the "logical company" to develop wideband FM; Armstrong had no other choice.

The organizational context of the American radio industry strongly influenced the strategy of FM research before 1934 and the rate of progress in two other ways. From 1928 to 1933, RCA achieved far more with FM radio than did any other company, principally because a reorganization of the firm forced its largest corporate shareholders, Westinghouse and General Electric, to share their findings about FM with RCA engineers. Also, because RCA operated a long-distance communications service, its engineers saw fading—not static—as their chief problem. Unfortunately, the orthodox belief that a wider channel invariably passes more static noise discouraged these men from experimenting with wider frequency swings, an intellectual barrier that Armstrong would surmount in 1933 and 1934.

Armstrong's Relationship with RCA

The close relationship between RCA and Howard Armstrong grew out of Armstrong's boyhood experience as an amateur radio operator. He was born in the New York's Lower West Side neighborhood of Chelsea in 1890 to a schoolteacher mother and the American representative of the Oxford University Press. Armstrong joined the Radio Club of America, probably in 1911 or 1912, during his senior year as an electrical engineering student at Columbia University, and around the same time he made his first invention, the regenerative or "feedback" circuit. This truly revolutionary device made possible the electronic generation of radio-frequency waves, and it remains ubiquitous in electronic engineering today. When Armstrong demonstrated his invention to the American Marconi Company in December 1913, one of that firm's representatives was David Sarnoff, who soon became one of Armstrong's best friends.

America's entry into World War I advanced Armstrong's career considerably. He enlisted in the Army Signal Corps and served principally in France, where he co-invented the superheterodyne circuit, another fundamental radio invention that modern receivers still use to simplify tuning.[2] In recognition of this work, the French government decorated him with the Légion d'honneur, and the Institute of Radio Engineers awarded him its first Medal of Honor. Understandably, Armstrong took pride in his army experience, and for the rest of his life he preferred to be called "Major" Armstrong.[3]

After the war, his invention of the superheterodyne, regeneration, and a similar but never widely utilized idea called superregeneration, propelled Armstrong into the orbit of the Radio Corporation of America. In 1920 Westinghouse, one of RCA's major corporate shareholders, paid Armstrong $335,000 for the patent rights to the regeneration and superheterodyne patents.[4] This money, plus the hundreds of thousands of dollars he earned for selling additional patents, could have guaranteed his independence from corporations, but by the end of the decade, David Sarnoff, by now RCA's general manager, secured the inventor's complete loyalty with even more money. In June 1922 Sarnoff approved a payment to Armstrong of "$200,000 in cash and 60,000 shares of R.C.A. stock" for the superregeneration circuit, making the inventor, according to his biographer, Lawrence Lessing, "the largest individual stockholder in the company." The following summer, Sarnoff commissioned Armstrong and another engineer to design a home radio set, the Radiola, which "made more money for R.C.A. than any set that was to appear until 1927." For this Armstrong collected an additional 20,000 shares of stock. By the winter of 1922–23, Armstrong's holdings in RCA amounted in value to "something over $3 million," a figure that tripled by 1930. Because he had also signed an agreement promising to grant RCA first refusal on his future inventions, for all practical purposes he was a consulting engineer with only RCA as a client. Thus, for RCA to share proprietary information with Armstrong was to benefit both him and the firm.[5]

Armstrong knew during the 1920s that RCA was working on FM; indeed, that knowledge likely inspired him to pursue his own line of research. Harold Beverage, who recalled first meeting Armstrong at a Radio Club of America gathering "soon after he'd come back from France," counted the inventor as one of his "close friends" and visited Armstrong's penthouse apartment "quite often." In 1992 Beverage remembered that Armstrong first heard of RCA's frequency-modulation research during the 1920s when "a guy named Murray G. Crosby was working on all kinds of modulations [at RCA]: amplitude, phase, frequency and any other ones you can cook up. Armstrong was interested in that." And, as Beverage explained, "Armstrong was free to come to Riverhead and see what we were doing. And he did. He came out quite frequently."[6] He even got on well with the company's lawyers, once receiving a letter of thanks from an RCA attorney for volunteering to defer to RCA in a patent interference case.[7] In 1931 the company's Patent Department sent him a list of "patents [that] may prove of interest to you in connection with your work on frequency modulation."[8]

Armstrong never kept good records of his work, but ample evidence confirms that his research with frequency modulation began shortly after RCA's. In 1927 he filed a patent application for his first FM radiotelephony invention.[9] Two months later Harold Peterson, who worked closely with Beverage, filed RCA's first in-house FM application.[10] The fact that these two patents constitute half of all the narrowband patents ever issued by the United States Patent Office suggests that the men who filed them were cognizant of each other's work.

Unification, Convergence, and the Acceleration of FM Research at RCA

Historian Hugh Aitken has observed that the companies that owned RCA during the 1920s—namely, GE, Westinghouse, and AT&T—normally did not share engineering data, largely because logistical barriers discouraged the movement of notebooks and other records from one office and field laboratory to another.[11] But Aitken limits his analysis to a period that terminated around 1928, when RCA verged on a series of organizational changes that for FM radio dislodged these obstacles. Those changes were summed up in one word: "unification." Even before 1928, David Sarnoff, the general manager of RCA, and the person who most clearly envisioned the advantages of centralized research, saw waste in the uncoordinated distribution of radio manufacturing and sales functions among GE, RCA, and Westinghouse. He thus launched a campaign to consolidate all operations related to radio. The idea made sense commercially, because the three firms were already contractually barred from competing with each other in almost all aspects of the radio business. Unification would also reinvigorate frequency-modulation research.

In October 1927 representatives of Westinghouse, GE, and RCA appointed Sarnoff chair of a three-man committee to evaluate his own plan. Six months later, the panel recommended creating a new "Radio Manufacturing Corporation," with three shareholders: GE (48%), Westinghouse (32%), and RCA (20%). With this goal in mind, RCA's board of directors, many of whom also served GE and Westinghouse as top-ranking executives, approved a leveraged purchase of the Victor Talking Machine Company for nearly $70 million, a move that not only gained RCA entry into the lucrative phonograph market but also enabled the company to mass-produce radio apparatus. On 26 December 1929 the RCA Victor Company was incorporated, and on 3 January 1930 the board of directors made Sarnoff president of RCA.

Historians have characterized unification as a grave setback for Sarnoff and RCA because an ensuing federal antitrust lawsuit shut down the reorganization project during the early thirties, which ultimately led to the breakup of the Radio Group patent pool and its noncompetition agreements.[12] But unification accelerated the progress of FM radiotelephony as much as any single cause by creating a temporary intellectual pipeline though which knowledge acquired about FM flowed directly from General Electric and Westinghouse to RCA, and eventually to Howard Armstrong.

New information about FM began to arrive at RCA laboratories several months before the formal acquisition of the Victor Company. In July 1929 James Harbord, the future chairman of the board of RCA Victor, assigned C. H. Taylor, the new vice president of engineering at RCA Communications, the job of merging the research efforts of Westinghouse, GE, and RCA. "I consider this coordination of the engineers of the three companies," Harbord wrote to Taylor, "as being one of your major duties." Harbord instructed "the Westinghouse Company . . . to supply a report [to RCA] on the frequency modulation method of broadcasting done [by KDKA] at East Pittsburgh." FM, Harbord believed, represented one of the technologies "which are vital to the success of our new company." Without "coordination," the efforts of the three companies acting independently, he feared, "will lack direction, cohesion and results, besides being expensive."[13]

As the unification plan fell into place, RCA began two FM projects, both built on a foundation that Westinghouse and KDKA had already laid. The first endeavor began around 1928 or 1929, when the National Broadcasting Company (NBC), then owned by RCA, installed Westinghouse-built receivers in the network's Manhattan-skyscraper headquarters. Engineers hoped to detect transmissions from KDKA, but the experiment swiftly came to naught because the transmitters and receivers—prototypes that a team led by Frank Conrad had designed—continually drifted out of electrical alignment. After one month of tests, NBC engineer Robert Shelby reported a raft of equipment failures, and he speculated that the Westinghouse apparatus was "not properly constructed, or is not properly adjusted, or the transmitter is not properly adjusted to work with frequency modulation."[14] Soon afterward, mention of this project disappears from RCA company records.

RCA Communications' second undertaking achieved far more, thanks principally to the funneling of data about FM from GE and Westinghouse to RCA. Ironically, RCA researchers learned from reading GE's laboratory reports that General Electric had almost nothing to teach about frequency modulation. J. L. Labus, the principal author of one paper, did little but summarize information he had gleaned from the scant published technical literature about FM and from his recent visits to the RCA laboratories in Rocky Point and Riverhead. Not surprisingly, RCA's best FM theorist, Murray Crosby, found little admirable in, as he saw it, Labus's error-riddled paper. Crosby surmised that Labus's expertise was "confined to the mathematics side of the question and that his practical experience and knowledge are very meagre. He tries to cover his uncertainty with borrowed (from R.C.A.) experiences and fails in the attempt. Perhaps if he confined his writings to the mathematics he would not run into this trouble." But Crosby also pointed out several mathematical errors in the report, as well as a misinterpretation of something Labus observed during a visit to Rocky Point. Labus claimed that he had learned from RCA that a frequency shift "must not exceed 500 cycles in order to produce a quality comparable with that obtained in amplitude modulation." In fact, Crosby explained, Labus had inadvertently based his analysis on a broken transmitter. The malfunction prevented the transmitter from swinging more than 500 cps from the center frequency, and Crosby guessed that Labus had wrongly inferred that the transmitter's behavior—suggestive of narrowband FM—was normal operation.[15]

Westinghouse engineers, in spite of their inability to design a functional system, made a far more positive impression, primarily because some of the Pittsburgh engineers had begun to tease out a respectable mathematical theory to describe FM. In September 1929, a few weeks after Harbord issued his unification edict, Clarence Hansell read a report written by V. D. Landon, who at the time held the position of chief operator of KDKA.[16] Before unification, Landon had intended to submit his manuscript to the *Proceedings of the Institute of Radio Engineers,* and Hansell agreed that his new colleague's article "certainly should be published." But not immediately, he cautioned his supervisor, lest the piece motivate competitors outside the Radio Group also to take up frequency modulation. "It seems very probable," said Hansell, "that the publication of Mr. Landon's paper would advertise the possibilities of frequency modulation very widely and cause many others to work on this same development." Better, he suggested, to wait until RCAC gains a surer foothold in the area of long-distance FM. "Present indications are that this method may become an exceedingly important one," explained Hansell, adding that "we believe that no one except ourselves is following up the development of frequency modulation." Therefore, he recommended, "RCA [should] build up a very strong patent situation by intensive development before rival companies become interested in the method."[17]

One hitch prevented RCAC from fully exploiting the Westinghouse data: few engineers at Riverhead could understand Landon's analysis. To overcome this problem, the job of translating his findings, along with those of other theoretical literature, into more accessible language fell on Murray Crosby. In June 1930 he distributed a memorandum to RCA managers and engineers that explained the nuances of frequency modulation in terms that less theoretically inclined engineers could understand.[18] As a grateful Harold Beverage confessed at the time, Crosby "convincingly [cleared] up many points which were obscure to engineers, like myself," and RCA's vice president of engineering agreed that the report gave him "a clear picture of the phenomena involved" with frequency modulation.[19] Every engineer involved with FM at Riverhead and Rocky Point likely received a copy of Crosby's report, including Howard Armstrong, a frequent visitor.

Deeper theoretical knowledge, practical experience, and a surer picture of how much—and how little—Westinghouse and GE had accomplished stiffened RCA's resolve to make FM work. On 17 October 1930 Hansell asked Ralph Beal, the manager of the Pacific Division of RCAC's overseas service, to assist in a long-term FM experiment aimed at improving long-distance telephone and telegraph communications. Beal, whose responsibilities included overseeing a former Marconi Company station in Bolinas, California, located near San Francisco, expressed "a great deal of interest" in Hansell's proposal and suggested daily four-hour tests between the West and East Coasts, on shortwave frequencies of around 9, 14, and 18 megacycles.[20] Hansell agreed, and after two months of preparing prototype apparatus, the Riverhead and Rocky Point engineers were ready to begin. Hansell and Beverage assigned the job of running the California side of the trials to a junior engineer named James Conklin, who set out by automobile from New York for the West Coast at the end of January 1931. By mid-March, Conklin had installed several FM transmitters and receivers in an old storage building located at the Bolinas station, and from mid-April until September, he helped conduct the most ambitious experiments with FM to date. In the beginning no one could confidently predict success, but an optimistic Harold Beverage declared beforehand that "we have some reason to hope for a worth while improvement in . . . short wave communication."[21]

Conklin's homesickness accounts for much of what we can know about these experiments. Aside from tinkering with the equipment, he had little to relieve the tedium of recording measurements of repetitive test signals from New York and sending similar patterns back east. Moreover, his colleagues in Riverhead initially shared frustratingly little information about the results of the trials. In June he asked for permission to return to New York. Hansell turned Conklin down but shored up his morale with a lengthy explanation of what, so far, had been achieved. "[Your] inability to obtain satisfactory replies to requests for information as to what conclusions are being drawn from the tests," said Hansell, ". . . may have given you the impression that interest in the tests is somewhat lukewarm on this end of the circuit." In fact, the experiments had produced both positive and negative results, and hence "the outcome is still in doubt." Hansell also disclosed that Howard Armstrong was trying out a new receiver of his own design. "Your transmissions," Hansell assured Conklin, "have been observed on the equipment developed by Crosby at Riverhead and also on equipment developed by Major E. H. Armstrong."[22]

It is important to understand that a long-distance commercial system already in place, rather than a short-range high-fidelity broadcast service not yet imagined, shaped how RCA designed and tested FM at this stage of the technology's development. For more than a decade, the firm had been in the business of sending and receiving long-distance point-to-point radiotelegraph and radiotelephone messages. The Rocky Point and Riverhead engineers therefore hoped to adapt FM for that kind of work, primarily to reduce the effects of fading. Of merely secondary importance was the expectation that FM transmitters might cost less to build and operate. And no one at the time, including Armstrong, seriously envisaged expanding the scope of FM to encompass other uses, such as commercial broadcasting or short-range radio communications of any kind. Even more removed from consideration were dreams of what later FM pioneers called "staticless" radio or of a high-fidelity medium.

Ultimately, the Bolinas tests revealed long-distance FM to be neither a simple failure nor an unqualified success. On occasion, frequency modulation worked well, sometimes dramatically better than AM, but only during the beginning and end of daylight hours. For the remainder of a twenty-four-hour day, Hansell told Conklin, "it was obvious . . . that the quality of reproduction obtained with frequency modulation was considerably inferior to the quality obtained with amplitude modulation." FM, Hansell explained, faltered most often "when transmission conditions were such as to allow reception of several incoming rays of radiation."[23] In other words, frequency modulation fell victim to an old problem in long-distance radio communications: multipath fading. The Bolinas transmitter simultaneously radiated multiple waves that ricocheted between the ionosphere and the earth's surface from California to New York. Because each wave traveled a unique and unpredictable path, two waves that left a transmitter at the same instant might arrive out of phase because one traveled a longer path. If a pair of waves traveling from Bolinas arrived exactly 180 degrees out of phase at the receiving antenna in New York, the net effect at the receiver would be a cancellation of both waves. Sporadic multipath fading also degraded the reception of AM-modulated waves at almost all frequencies, but RCAC discovered that FM in the ultra-high frequencies was even more susceptible.

To their credit, Hansell and Crosby made no final judgment about frequency modulation in general, particularly after Armstrong dropped in on the Riverhead laboratory on 19 June 1931 to listen to transmission tests from Bolinas. He announced that while eavesdropping on their tests "in the middle of New York City" he had gained "a much more favorable impression of the possibilities of frequency modulation than had been obtained by the observations at Riverhead." Armstrong invited his colleagues to hear for themselves, and so, six days later, Clarence Hansell, Murray Crosby, and Harold Beverage motored the seventy miles from Riverhead to Columbia University "to observe the reception and to discuss plans for future tests."[24]

The evening of 25 June 1931 ranks among the most significant in the history of frequency modulation, thanks in large part to the considerable talents of Armstrong's guests. Within a few years Murray Crosby would begin writing articles and filing patents that established his reputation as one of the twentieth century's pioneering figures in the field of frequency-modulation theory. Clarence Hansell had already applied for a dozen FM patents—one fourth of all that had ever been filed—and had been issued three. Though the FM patent record of Harold Beverage would never rival Crosby's or Hansell's, he had nonetheless made a name in the field of antenna design. Further, few men, even at RCAC, had more extensive hands-on experience with frequency modulation systems than Beverage did. By comparison, Armstrong was a latecomer; despite his stellar reputation in other areas of radio engineering, he had in fact no FM patents to his credit; and one of the two he had applied for described an unworkable narrowband invention.

Crosby and Hansell already knew a little about Armstrong's setup, as Armstrong had described it to them during his recent visit. Upon arriving in New York City, Hansell "immediately observed" that reception conditions were "very much different" from those in Riverhead. (Presumably he heard local transmissions from Riverhead, and not from Bolinas, whose signals multipath distortion usually rendered inaudible on summer nights.) In the city, "inductive disturbances"—that is, manmade static—from "all sorts of electrical equipment, buses and motor cars" "almost completely drowned out" AM reception. In contrast, "the reception of frequency modulated signals was often reasonably good and in practically all cases was much better than the amplitude modulated signals." "It is safe to say," estimated Hansell, "that the signal to noise ratio for frequency modulated reception was at least 10 to 1 in voltage better than amplitude modulation." He hoped that directional antennas might alleviate the relatively poor performance of AM but admitted that on balance "it seems probable that the results obtained might be overwhelmingly in favor of frequency modulation."[25] These tentative statements made up some of the first reports of FM's most famous property today: its ability to suppress static, particularly the inductive static that originates most often in urban areas.

Commercial reality dampened Hansell's enthusiasm, though. To be sure, frequency modulation, even in its pre-high-fidelity stage of development, resisted, far better than AM, disturbances caused by static. Within five years, broadcast FM pioneers outside RCA would justifiably cite this feature when they promoted Armstrong's new "static-less radio." But RCAC's chief business was to provide point-to-point communications between distant stations, which seemingly ruled out long-distance FM because of the method's susceptibility to multipath fading. Moreover, static suppression counted less as an advantage for RCA than one might assume. Because the company preferred to locate stations on sites with minimal electrical interference, it chose locations far removed from urban areas like New York City. No one before the Bolinas tests would have thought about comparing reception in rural Riverhead with reception in the electromagnetic din of Manhattan. As Hansell put it, "in our [RCA] Communications system it is not customary to do the receiving in cities." Thus, he concluded, "prospects for the general adoption of frequency modulation . . . for long distance telephony and multiplex telegraphy are not very good."[26]

Nevertheless, what Armstrong had accomplished so fascinated his guests that they lingered until three o'clock in the morning. Armstrong's showpiece was a fifteen-foot "breadboard" bench, on which he had wired a prototype system. The transmitter impressed Crosby and Hansell with circuits that boasted greatly improved linearity and lower distortion, two properties upon which FM has always depended. Hansell and Crosby suggested modifications to match RCAC's mission of providing "good enough" radio telecommunications; they wanted to simplify the circuits somewhat without forfeiting the long-dreamed-of advantages of long-distance FM—namely, its "ability to eliminate fading" and its efficiency, that is, "the possibility of obtaining four times the transmitter power output that can be obtained with amplitude modulation without appreciably changing the cost of the transmitter." Hansell conceded that his and Crosby's proposals would allow for more noise than did Armstrong's original design, but the results would be no worse than AM delivered under optimal conditions. "Crosby and I concluded," he explained to Conklin, "that we should obtain all the advantages of frequency modulation [with our changes] except for some sacrifice in signal to noise ratio and at the same time we should obtain a quality of reproduction substantially the same as for amplitude modulation."[27]

Clarence Hansell recorded no reaction on Armstrong's part to these suggestions, but a few days later Hansell wrote to Conklin that the inventor had asked RCAC to ship his breadboarded transmitter and receiver to Bolinas. Despite his reservations about using FM for long-distance work, and about the risk of transporting a fragile prototype thousands of miles, Hansell almost approved Armstrong's request. FM had long been a sideline interest of Hansell's, and he predicted to Conklin that "the present development [of FM] will prove to be an extremely important one and may result in a great improvement in short wave telephony and multiplex telegraphy." He also began to imagine other uses besides long-range communications, adding that frequency modulation "may also be the forerunner of a solution to the problem of very short wave broadcasting, television, etc. within city areas where the induction problem is the biggest obstacle to satisfactory service."[28] This prediction did not describe exactly the high-fidelity system that Armstrong would patent eighteen months later, but it was close, and after all, Hansell's work had little to do with broadcasting. Besides, Armstrong saw the future of FM no more accurately than Hansell did.

Sizing up what RCAC had done with frequency modulation by the end of 1931 depends on one's yardstick. Hindsight tells us that the company's engineers were pursuing a futile game by attempting to perfect long-range FM radio. Moreover, the belief that a wider frequency swing let in more static especially impeded progress. In 1931 RCAC engineers were working with swings no greater than approximately 25 or 30 kilocycles, while the Armstrong wideband system of two years later employed a swing of 150 kilocycles. No one in 1931—not even Howard Armstrong—hoped, let alone predicted, that further widening the swing and shortening the distance between transmitters and receivers would bring spectacular benefits—namely the suppression of static to nearly inaudible levels, the tripling of the audio bandwidth, and the consequent improvements in audio fidelity. In fact, RCAC engineers were technologically and psychologically committed to the goal of *minimizing* the frequency swings—not below, of course, Carson's well-known theoretical limit of twice the audio bandwidth, but neither did company engineers wish to widen the swing needlessly and thus waste spectrum. Furthermore, Clarence Hansell intuited that a wider swing, which created additional sideband components, would incur greater audio distortion, especially at lower carrier frequencies and longer distances. He correctly theorized that because power distributed among sideband components over a wider channel would be spread more thinly, then weaker components would more likely risk attenuation to inaudible levels. Again, Hansell's disinclination against wider swings arose from RCAC's mission of running a long-distance service; he had little incentive to contemplate what might happen to those sidebands over short ranges.

In terms of their own goals for FM, RCAC engineers had good reason to anticipate further progress. With Armstrong's help, they had come closer than anyone before to realizing a practical technology with an audio fidelity comparable to the quietest AM system. Building on Westinghouse's work, RCAC had discovered empirically much about what FM could and could not do. Most important, the oldest dream of FM experimenters, implied in Cornelius Ehret's 1902 patent, had materialized: FM consistently resisted fading, albeit at relatively short distances. FM transmitters also demonstrably wasted less power than did AM transmitters, proving an intuitive theory first spun by Westinghouse engineers. The location of Armstrong's receiver suggested that FM could sometimes be received more clearly than AM in electromagnetically noisy environments—that is, it resisted static. Finally, they had learned where FM failed. Narrowband FM did not work at all, and the Bolinas tests indicated that multipath distortion would always plague long-distance FM.

All in all, only an institutional predisposition against experimenting with wide channels and short distances prevented RCAC from developing a commercially practical FM broadcast system, a prejudice manifested by Hansell's distaste for wider swings. But no reason existed to assume that this bias would have been permanent or that RCAC's top engineers had not the ability to devise wide-swing circuits. Even without Armstrong's help, RCA almost certainly would have achieved some kind of practical FM, though that system would likely have lacked the high-fidelity features of the Armstrong version that lay ahead.

Despite the well-founded skepticism surrounding FM's future for RCAC's long-distance work, on one occasion the technology worked fabulously for that very purpose. Eight days after Hansell, Beverage, and Crosby met in Armstrong's lab, an NBC executive in New York telephoned Ralph Beal in Bolinas to request that the California crew relay from Cleveland, Ohio, to Hawaii and the Philippines the following evening's heavyweight boxing championship fight in Cleveland between Germany's Max Schmeling and Young Stribling of Georgia. NBC routinely relayed broadcasts to Asia, accomplished with a telephone circuit linking Bolinas to an inland source like Cleveland, then with a point-to-point shortwave AM radio circuit from Bolinas to stations in Hawaii and the Philippines, which rebroadcast locally on standard AM frequencies. James Conklin, who happened to be visiting Beal during the telephone call, suggested taking advantage of the event to compare shortwave transoceanic AM with shortwave transoceanic FM—that is, to relay the telephone feed from Ohio to Bolinas, and then to the overseas stations, using separate channels for each method. Beal assented, recalling that fading and interference during the previous night had wiped out an amplitude-modulated music program beamed to Manila.

As the bout approached, Conklin and Beal realized that if FM could not carry the fight to the Philippines, nothing would, for noise on AM receivers in Manila had climbed to intolerable levels. After Conklin made a few adjustments in his equipment, for the first time FM radio began to air a complete program. What followed was a spectacle to which overseas listeners, none of whom knew about FM's role, responded enthusiastically. AM Station KGU in Honolulu reported 140 telephone calls from fans who, after Schmeling TKO'd Stribling in the fifteenth round, complimented the unusually good reception. The operator of RCAC's Manila station noted in a telegram to Conklin a low audio-frequency distortion similar to what Hansell had also observed in Armstrong's lab, but the same operator pronounced the experiment "wonderful." "MANY THANKS," he telegraphed Conklin, "FIGHT BROADCAST SURELY GREAT THING FOR ORIENT."[29] Beal marveled in his follow-up report that "I doubt very much if Manila would have received anything worth while had the X [frequency] modulation not been available. If these results are duplicated in the future," he predicted, "there can be no question as to the merits of this type of modulation for long distance work."[30] When Hansell forwarded to Armstrong a copy of the Manila operator's telegram, Armstrong, whose equipment had *not* been used, groused that it was "too bad they didn't have the right receiver."[31]

The working relationship between RCA and Armstrong was complicated. On one hand, their interests were so legally and financially intermingled as to make the firm, for all practical purposes, Armstrong's exclusive client and Armstrong almost an RCA employee. On the other hand, it would be going too far to describe Armstrong and RCAC as collaborators in the usual meaning of the word, because the company's engineers revealed far more to him about their day-to-day work than he disclosed to them about his. (This lack of reciprocation, though, never troubled RCA engineers, who gave Armstrong wide berth because he was obligated to offer RCA first refusal for his patents.) Nor can one claim, without qualification, that RCAC engineers co-invented the Armstrong system. But clearly Armstrong owed much to his friends at Riverhead, because his insider status gained for him knowledge about the successes and instructive failures of Hansell, Beverage, Crosby, Conklin, and other Riverhead engineers—knowledge he applied to his own work. As figure 16 shows, Clarence Hansell and Murray Crosby forwarded to him detailed descriptions of test results, proposed circuit changes, and other matters relating to FM.[32] Armstrong also knew that RCAC engineers filed eighteen patent applications for FM inventions during the trials, including six by Crosby, three by Hansell, and two by Conklin. He himself filed two, in January 1933, both for his wideband system, but he concealed this fact until close to their issue date in late December of the same year.

Rocky Point, New York
July 16, 1931
A-RD-1105

Major Edwin H. Armstrong
211 Central Park West
New York, New York

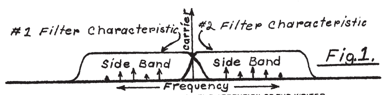
Dear Mr. Armstrong:

I believe Mr. Beverage advised you by telephone that I would send a letter outlining some of my conclusions in connection with the study of phase modulation and of equipment with which to carry it out. I have not been able to give the subject nearly as much time as it probably deserves so that my conclusions are not complete and have not been gone over thoroughly to detect errors. However, by attempting to state them to you I may be able to learn something myself and, at the same time, provoke discussion which may result in a better understanding of the problem by all of us.

First of all it appears that, if we are to obtain good quality reproduction over long distances, the number of side frequencies produced by the modulation must be kept to a minimum. To do this we must keep the phase deviation of the transmitted current to a value much less than plus and minus 90 degrees. I believe that plus and minus 45 degrees phase deviation in the final output of the transmitter should be the maximum allowed for peak values of the modulation current. This corresponds to side frequencies having a maximum voltage sum equal to the carrier and is substantially similar to 100% amplitude modulation.

Since the carrier power of a phase modulation transmitter may be made four times the power of an amplitude modulation transmitter, with equal number of tubes and about the same cost, it is evident that we will obtain approximately twice the carrier and side band currents if we use phase modulation. Since the detector efficiencies are equal in receivers correctly designed for either method, it appears that the strength of receiver output, where no limiting is used, will be four times as great for 100% phase modulation as for 100% amplitude modulation.

At the same time, if the two filters for the detectors of the phase modulation receiver have characteristics such as shown in Fig. 1, only one sideband reaches each detector. Therefore the



PLEASE ADDRESS REPLY TO THIS DEPARTMENT FOR THE ATTENTION OF THE WRITER

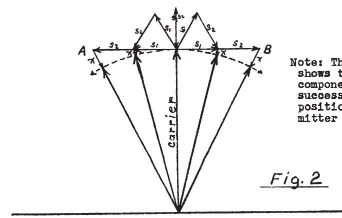
ratio of carrier to side bands in each detector is twice as great as is the case in an amplitude modulation detector. This should result in less harmonic distortion and cross modulation products from beating between side frequencies.

Another interesting observation is that, in a phase modulation receiver with the characteristics illustrated in Fig. 1, it is not necessary for the carrier to remain stronger than the combined peak value of the sidebands. The terrible distortion observed with amplitude modulation when the carrier fades below the sidebands should therefore be absent.

Although on first inspection the use of filter circuits such as those shown in Fig. 1 may seem as difficult as the reception of short wave single sideband transmission I do not believe this to be the case, because the carrier frequency is automatically fixed at the transmitter. By applying automatic control to the first beating oscillator in the receiver, operated by detector current unbalances, as you have done in your receiver, the problem of keeping the receiver adjusted should not be difficult.

On the assumption that the final phase deviation in the output of the transmitter should be kept below plus and minus 45 degrees, I have given consideration to the relative merits of the transmitter set up in your laboratory as compared with the one which I suggested to Conklin in my letter of June 27, 1931, a copy of which was sent to you.

In the output of your modulator appears the carrier, which may be as indicated in Fig. 2. To this carrier are added two side frequencies, or groups of frequencies, which may be represented as two sets of vectors, one rotating faster than the carrier and one slower. In other words, one rotates counterclockwise and one clockwise with respect to the carrier. They have a phase relative to the



Note: This figure shows the current components for 5 successive phase positions of transmitter output.

carrier which is displaced 90 degrees with respect to the phase relations obtained with amplitude modulation. Therefore, the sum of any pair, or any number of pairs of side frequencies must always be at right angles to the carrier and will lie on the line A-B (Fig. 2). The peak radio frequency output from your modulator is then equal to the vector sum of the carrier and the peak value of the sidebands. The output power from the modulator is increased by the sidebands.

As soon as the output power is made constant by limiting, the carrier is reduced and additional side frequencies are produced. These added side frequencies correspond to the addition of both amplitude and phase modulation components. Their vector sums are indicated as X in Fig. 2. It will be apparent that these undesired components are small for small phase deviations but become extremely large when 90 degree phase deviation is approached.

Since this addition of undesired frequency components is determined by the phase deviation irrespective of the carrier frequency and the deviation is multiplied by multiplying the carrier frequency, it is apparent that the phase deviation in your modulator should never be more than about plus and minus 45 degrees divided by the multiplying ratio of the frequency multipliers.

I have not been able to devise any modulator which would be free from the undesired frequencies produced by limiting without sacrificing the high power efficiency and output from a transmitter and have concluded that the only practical solution is to keep the phase deviation low. Consequently, I believe that, from the standpoint of theoretical performance at least, your modulator cannot be improved.

In considering the extent to which the relatively simple form of modulator suggested to Conklin meets the performance of your modulator, I have constructed the vector diagram shown in Fig. 3. In this diagram C_1 and C_2 represent the output from the two tubes used in the modulator, the vector sum of which gives the carrier. The relative values of C_1 and C_2 are varied differentially by the

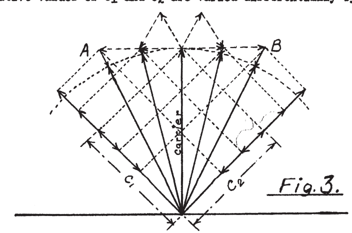


Fig. 16. Part of Hansell Letter to Armstrong about FM, 16 July 1931. Three pages of a letter written by Clarence Hansell to Howard Armstrong, discussing RCAC's FM research and development. Drawing on leftmost page indicates Hansell's theories about sidebands created by frequency modulation. The other drawings depict Hansell's vector analysis of frequency modulation. Hansell to Armstrong, 16 July 1931, box 161, AP.

Armstrong also persuaded RCA to adopt of a policy of nearly complete secrecy about frequency modulation, which explains why the company adopted the term *X modulation*. "Major Armstrong is also following your tests with considerable interest," Beverage told Conklin's replacement in California. He added that "the main reason why we do not wish to refer to the word 'modulation' and its qualifying adjective ['frequency'], is, that we do not wish to let outsiders, who may be listening in, learn what we are doing." Moreover, "Major Armstrong feels that phase modulation and frequency modulation are extremely important developments and that we should keep it confidential for some time to come for various important reasons."[33] Because of the secrecy imposed on the X modulation project, no one outside the RCA organization learned about the Manila broadcast, the most impressive feat of FM technology until 1936.

Armstrong also figured into the question of whether and how to announce publicly RCAC's FM achievements. Despite the Schmeling-Stribling broadcast, Clarence Hansell realized that the company still could produce neither marketable apparatus nor even material proof that could substantiate claims of priority should someone else file a patent interference. "Circumstances," Hansell explained to Harold Beverage on 6 January 1932, "prevent our establishing credit for the development by immediately using [frequency modulation] commercially." But he feared that his team had invested and accomplished too much to chance the "great danger that some of our competitors may take most of the credit from us by prior publication." He therefore drafted an article about the Bolinas trials that he hoped to submit to the IRE's *Proceedings*, titled "Phase and Frequency Modulation Applied to Short Wave Communications."[34]

Hansell assured his staff that the company's first FM paper would recognize the efforts of all contributors to the development of frequency modulation, particularly the "very active" role of Howard Armstrong. An early draft of the article said as much. "The tests were observed closely by Armstrong, Beverage, Crosby, Hansell and Peterson," read the introduction. "The purpose of this paper is to present their conclusions together with some of the considerations and observations upon which the conclusions were based."[35] Hansell even suggested to Harold Beverage that "since Major Armstrong took such an active part . . . you will, no doubt, wish to have him pass upon the paper, or perhaps become a joint author."[36]

Unfortunately, an unknown staff attorney—probably Harry Tunick, who headed the New York office of the RCA Patent Department—quashed the article lest it spur rival firms to accelerate their own FM research and development programs.[37] Today, an examination of the FM patents that emerged during the next several years exposes those fears as groundless. In fact, RCA had sprinted too far ahead for anyone to catch up. During the three years before Hansell's proposal, only one FM-related patent per year had been issued to non-RCA inventors, while RCA had filed thirteen in the same period.

Nearly half a decade later, after Armstrong had severed his relationship with RCA, the *Proceedings of the Institute of Radio Engineers* finally published a report, in 1936, on the New York–California trials, a dry, workmanlike piece authored solely by Murray Crosby, who altogether ignored Armstrong's participation.[38] Sadly for Crosby and his employer, this article, RCA's first about FM, failed to attract the recognition it deserved. Crosby had, after all, described in detail the first nearly practical FM system, which antedated Armstrong's by two years. Moreover, probably no one understood the mathematical theory behind frequency modulation better than Crosby did. But he fell victim to the worst possible timing; the previous month's issue of the *Proceedings* contained Armstrong's celebrated paper about *his* FM system, a relatively breezy piece that diverted a great deal of attention from Armstrong's former collaborators.[39] Today, almost every historian of FM radio cites the Armstrong article, but no one mentions Crosby's.

That Howard Armstrong stole RCAC's thunder was multiply ironic. Clarence Hansell had feared in 1932 that a competing firm would beat RCA at publishing the first major article about frequency modulation. As things turned out, no such competition existed at the time, but the fear materialized anyway because of an insider—Armstrong—whose thinking about FM owed much to RCA's research. Armstrong borrowed language from Hansell's paper, for example, when his first FM paper provided the same misinterpretation of Carson's work. (Armstrong quoted the same sentences that Hansell did in support of that misreading.)[40] Also, by suppressing publication in 1932, the RCA Patent Department gave up what would have been the best insurance against the ensuing distortions of RCAC's role in the history of FM radio's development.

How differently things might have turned out—for RCA, for Armstrong, and for the way the history of FM has been told—had Hansell's manuscript seen publication before 1934, before the Armstrong-RCA relationship soured. Hansell had written the first draft of history, the sole contemporary narrative of his company's work with FM, and the only version ever to originate within RCA that has admitted to Armstrong's involvement in the Bolinas trials. The article Clarence Hansell wanted to publish would have documented that fact, and when the time came to author competing narratives of FM's development, neither Armstrong nor the company could have ignored or even denied that collaboration as they both would attempt to do.