ARMSTRONG'S INVENTION OF NOISE-SUPPRESSING FM

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INTRODUCTION

Edwin H. Armstrong is well known as the inventor of wide-deviation or wide-band FM. His patent on this invention was granted December 26, 1933, followed soon thereafter by demonstrations of his system before engineers, papers on the subject of wideband frequency modulation (FM) and its noise suppression property, and eventually, of course, after World War II, widespread acceptance of FM by the radio industry and the public at large. The years in between were devoted to a bitter court fight between Armstrong and RCA, leading eventually to Armstrong's tragic suicide in 1954. This is well documented in the book by Lessing devoted to Armstrong's life [1]. What is not clear is precisely how and when Armstrong had the intuitive leap, his Eureka! moment, that led to this truly momentous invention. Armstrong was notorious for leaving very little documentation on his inventions. Lessing does note that Arm-strong was fully occupied with his FM work, carrying out thousands of experiments, from 1928 to 1933, but no attempt to further narrow this interval of time down or discuss how he came to develop the wide-deviation FM concept is offered [1]. We try, in this brief note, using documentation available in the Armstrong papers housed at Columbia University, to come to grips with these questions.

Edwin H. Armstrong had been experimenting for years in his laboratory at Columbia University with various methods of reducing static in radio reception [1, 2].[1] By 1927 he thought he had come up with a solution, based on many experimental studies with radio teletype transmission carried out in his laboratory. His proposal was to "cancel" static noise, thinking that atmospheric disturbances in a "crash or burst of static" are highly correlated at closely adjacent frequency bands. His paper describing the technique and including results of some of his experiments was published in the 1928 *Proceedings of the IRE* [3] and was promptly (and properly) critiqued by John R. Carson of AT&T Bell Laboratories in a paper appearing six months later in the same journal [4]. Carson, in replying to Armstrong's paper, showed, using a simple single-sinusoidal model to represent random noise (static), that noise cannot be canceled out. In setting up this model for random noise and carrying out the analysis, Carson relied on pioneering work on modeling and analyzing noise in communication systems he had been carrying out for some years before. Carson did, however, make a regrettable and now famous comment in this paper. In replying to Armstrong's error in thinking noise can be cancelled, Carson stated unequivocally

"Static, like the poor, will always be with us."

Armstrong was to demolish this unfortunate comment by Carson just a few years later with his invention of noise-reducing wide-deviation/wideband FM.

ARMSTRONG'S PATENT ON WIDEBAND FM

Armstrong's U.S. patent on his wide-band FM invention, which he had sub-mitted for patenting January 24, 1933, was granted December 26, 1933 with number 1,941,069.[2] The patent carried the simple title *Radiosignaling*. It was one of four FM patents granted to Armstrong that same day. It was the only one dealing with noise suppression, however. The others dealt with such issues as improved means of generating FM (now called the Armstrong system), the use of a limiter in FM, and FM as a way to reduce signal fading. The other patents had application dates ranging from May 18, 1927 to the same date as '069 of January 24, 1933. Armstrong, while working over the years on finding a means to reduce noise, had been heavily involved with the design of FM systems as well. Much of this work on FM systems was carried out in con-junction with RCA engineers, in his capacity as a consultant to RCA [5]. Correspondence between RCA engineers and managers over the years he worked with them indicates that Arm-strong worked closely with RCA personnel in perfecting his FM systems, and provided demonstrations for them at his Columbia laboratories [5, 6]. But these demonstrations were, until he was granted the '069 patent, of narrowband FM systems only.

The wideband FM patent '069 is quite specific on the noise suppression property of wide-deviation FM, indicating that this is the essence of the invention. The patent begins with the words "This invention relates to a method of increasing the distance of transmission which may be covered in radio signaling with very short waves. It is well known that waves of the order of ten meters or lower are limited in the distance of transmission by tube noise alone as the amount of static in that part of the spectrum is negligible." So it is clear he knows that this method of transmission will reduce tube noise,

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[1] *Armstrong himself refers to these years of experiments in the report referenced in [2]. In this 1933 report to Michael Pupin, the first such report rendered "during the 19 years… of the laboratory," as Armstrong himself noted, Armstrong comments that, in spring 1924, "I resumed work on the old problem of the elimination of atmospheric disturbances making some progress toward its solution, despite the widespread belief it was insoluble. Some of this work was [presented] in October 1927 before the IRE. Since that time I have been practically continuously engaged on the same problem… " The work referred to as presented at the 1927 IRE conference was published the next year in* Proceedings of the IRE *[3].*

[2] *The term* wideband *used here refers to the* transmission *bandwidth. Armstrong himself, as will be seen shortly, referred explicitly to the sys-tem as "wide-swing" or "wide- deviation" FM. In such a system the frequency swing is large compared to the audio bandwidth, resulting in a much wider bandwidth than would be the case for narrowband FM or AM. There has been some confusion with terminology in the literature, some authors referring, incorrectly, to such a system as "high-fidelity" FM. The fidelity of a communications system is based on its* audio *bandwidth. Wide-deviation FM with low audio bandwidth would be a low-fidelity system, whereas, conversely, an AM system with a wide enough audio bandwidth would be classified as a high-fidelity system. Wide-deviation FM, with its corresponding wide transmission bandwidth, produces noise suppression only. High-fidelity FM requires a wide-enough audio bandwidth as well. It is clear, as seen below, that Armstrong was quite aware of the distinction. In the patent claims for his invention, he simply specifies the variation in frequency should be "substantially greater in extent than the frequency range of good audibility."*

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"due mainly to the irregularities of the electron emission from the filaments of the vacuum tubes" (i.e., mainly shot noise), but, in the jargon of the day, encompassing thermal noise as well. He does not seem to be sure of its effect on static, however; hence the constraint to operate at higher frequencies at which it was thought at the time that static would be much lower. He then describes the specific invention as follows: *"I have discovered that by imparting greater swing to the frequency of the transmitted wave than can exist in the disturbances due to tube irregularities and providing means for selecting these large swings of frequency which are at the same time substantially not responsive to the lesser swings due to the tube disturbances or to the variations in amplitude due to these disturbances, that a very great improvement in transmission can be produced."*

Much work had been carried out in the 1920s on studying noise appearing in vacuum tubes. Early studies had focused on so-called shot noise, due to the discrete and random emission of the electrons giving rise to the current in vacuum tubes. Studies by J. B. John-son of Bell Laboratories had, however, recognized the fundamental nature of thermal noise as well. This type of noise was due to resistive effects in circuitry as well as so-called radiation noise introduced at a receiver antenna. The presence of these two types of noise was recognized by the telephone engineering community. Both types of noise were referred to as *fluctuation noise*. Articles appearing in a number of technical publications at the time described experiments and measurements made to understand shot-noise phenomena, for example, in great detail. The radio engineering literature, however, did not appear to reflect this activity on fluctuation noise. The focus in that literature had been on external static (i.e., atmospheric disturbances). It was not until 1930 that papers on shot and thermal noise began to appear in the radio literature. It is clear from patent '069, however, that Armstrong, at the time of the patent application in January 1933, was well aware of the properties of tube or fluctuation noise. He writes of the "irregularities of the electron emission from the filaments of the vacuum tubes." He notes the radio frequency noise current as a result "consists of irregular variations in amplitude." The patent further notes that "the limit of reception is… deter-mined by tube noise or the disturbances which arise usually in the first tube in the receiving system," this "interference manifest[ing] itself as a steady hiss in the telephones or receiver," and exhibiting "a continuous spectrum of substantially constant amplitude…."

These properties of random or fluctuation noise are precisely those described in the work in the 1920s of Carson and other investigators. The only ambiguity appearing in the patent appears to be on the differentiation made between the properties of static and fluctuation (tube) noise.

Armstrong's invention of wide-deviation/wideband FM and its ability to suppress noise, once announced, was well received by the engineering community. Very soon after being awarded patent '069, Armstrong demonstrated his wide-deviation FM system for the first time to RCA engineers [5, 7], with impressive results. (The Sadenwater letter and memo in [7] are based on Sadenwater's recollections. Beers' report, specifically recommending the construction of "two receivers for field tests to determine the merits of the Armstrong FM system," notes, on p. 33, that "the results obtained by the [early 1934] demonstration were so impressive that it was decided to investigate the merits of this system….") Armstrong's later demonstration of his system before an IRE audience on November 5, 1935, and its very positive impact on the engineers attending, has been well documented [1]. The demonstration accompanied a formal paper presented at the meeting, which was later published as Armstrong's now-classic paper "A Method of Reducing Disturbances in Radio Sig-naling by a System of Frequency Modulation" [8]. What is particularly remarkable about this paper is that Armstrong was able to analytically demonstrate the noise reduction effect of wide-deviation FM, given a carrier-to-noise threshold had been exceeded, using a vector approach. Soon there-after, M. G. Crosby of RCA, who had worked for years on FM systems, published a more mathematical paper on the noise suppression effect of FM [9], followed by papers by Hans Roder of GE [10] as well as Carson and Thornton C. Fry of Bell Labs [11]. Other papers by various investigators soon fol-lowed. It is of interest to note that through the years, even to this day, papers by various investigators have continued to be published using different techniques to explain the wide deviation FM noise suppression property. Armstrong had created quite a cottage industry on explanations for this property of widedeviation FM! (The reception of FM signals in the presence of noise is a highly nonlinear process, involving, for example, the required use of a limiter. Analysis thus does not lend itself to a tidy mathematical approach,)

WHEN AND HOW DID HE ARRIVE AT THE WIDEBAND CONCEPT?

The questions now remain, when specifically, and how, did Armstrong actually come up with the concept that widening the deviation ratio results in noise reduction? These questions are difficult to answer and may, in fact, never be answered exactly. The problem is that Armstrong never kept notes of his conceptions and the experiments based on them. All that is available are system and circuit diagrams, usually prepared for purposes of proving dates of inventions. Using the existing documentation, it does appear possible to this author, however, to establish a reason-able approximate Eureka! date for the conception of the invention. The date turns out, in this author's estimation, to be *September 1931*, fully 16 months before the patent application was made.

On what basis is this date of the invention of wide-deviation/wideband FM as a means of reducing noise made? The Armstrong papers (AP) housed in the Columbia University Rare Book Library contain much documentation concerning his conflict with RCA on his FM inventions, including the litigation he commenced against RCA in July 1948. (It was this protracted litigation that was to end with a despondent Arm-strong taking his life January 31, 1954 [1, 12].) In particular, a memo prepared for the litigation, labeled "WideSwing Patent, Information obtained by questioning Armstrong" and dated Dec. 17, 1948 [13], states, in part, "First tried multiplier in receiver to raise mid-frequency and swing from 35 kc [kHz] ± 5 kc to 140 kc ± 20 kc. No improvement because noise multiplied. Then tried multiplier at transmitter to multiply mid-frequency and swing without multi-plying noise. At 140 kc ± 15 or 20 kc first found reduction in tube noise. Six months to be sure of this. *First written description March 30, 1932*…" [Emphasis added.] (The "multiplier at transmitter" term refers to the use of what is now called the Armstrong method of generating FM.) So, if Armstrong's recollection almost 17 years after the events leading up to the wideband FM invention is assumed accurate, the

invention must have been conceived six months prior to March 30, 1932, or in September 1931. Unfortunately, the written description to which reference is made has not been located. But there is some corroborating information: There does exist a hand-drawn sketch by Armstrong made July 21, 1932 and labeled "Demonstration of Reduction of Tube Noise by FM at 7.5 meters" [14]. (This wavelength corresponds to a transmission frequency of 40 MHz.) In addition, on August 23, 1932, a month after this sketch was made, Armstrong prepared a detailed memo [15] to his patent attorneys Moses and Nolte very similar in wording and content to the wideband patent '069 submitted to the patent office five months later. Some additional corroborating facts: Armstrong had demonstrated his (narrow-band) FM system using the Armstrong method of FM generation at his Columbia laboratory to RCA personnel on June 25, 1931 [16]. The RCA engineers found his system, which incorporated a limiter in the receiver , as well as balanced detection (the latter scheme presumably carried over from his earlier work on noise cancellation), provided "a much more favorable impression of the possibilities of FM than… at Riverhead [the RCA site]" [16]. This was presumably due to Armstrong's superior electronics and design, including the limiter and balanced detection. Two months later, on August 26, 1931, in a memo from one RCA engineer to another [17], the comment is made that FM does not seem as promising as phase modulation for short-wave experiments. It does note, however, that where FM can be used, the receiver characteristics cause balancing of a large part of the noise, *"particularly from the lower audio frequencies."* [Emphasis added] It is to be noted that with lower audio frequencies used (i.e., reduced audio bandwidth), the ratio of frequency deviation to audio bandwidth increases. This effectively causes the system to behave like a wide-deviation one. Could Armstrong have gotten the idea of using wide-deviation FM to sup-press noise from these experiments? Note that these experiments occurred just prior to the suggested September 1931 Eureka! date.

SUMMARY

Using the information referenced above, the process involved in Armstrong's conception of the noise suppression property of wide-deviation FM might be summarized as follows:

1 He worked for years to try to reduce atmospheric noise, static, being picked up by radio receivers.

2 Experiments he had carried out on signals transmitted on closely-spaced carrier frequencies convinced him that noise arising at these frequencies could be can-celled out. These experiments were the basis of his 1928 IRE paper, quickly answered in the negative by John R. Carson of Bell Labs.

3 Roughly at the same time he worked on (narrowband) FM, serving as a consultant to RCA, coming up with improved FM systems.

4 In June 1931 he demonstrated a narrowband FM system incorporating both a limiter and balanced detection to RCA engineers that appeared to provide some noise improvement compared to their own FM systems.

5 An August 1931 note from one RCA engineer to another [17], referring to Armstrong's system, notes that the receiver characteristics do provide balancing of a large part of the noise, particularly at the lower audio frequencies. The presumption might then be made that Armstrong, using this observation, came up with the idea of purposely widening the FM frequency deviation.

6 September 1931: This is the presumed date of Armstrong's conception and invention of widedeviation/wideband FM.

7 Six months of work to verify the noise reduction property of wide-band FM. Reference is made, years later, to a March 30, 1932 written description of this work. This written description has not been found, however.

8. July 21, 1932: Armstrong made a hand-drawn sketch referring specifically to the noise reduction property of (wideband) FM.

9 August 29, 1932: He wrote a memo to his lawyers containing essential-ly the same wording as his wide-band FM patent.

10 January 24, 1933: Application to patent office for Armstrong's wide-band FM invention.

REFERENCES

[1] L. Lessing, *Man of High Fidelity*, J. B. Lippincott, 1956; Bantam Paperback, 1969.

[2] Report from E. H. Armstrong to M. Pupin, Apr. 3, 1933, Box 115, Armstrong papers, Rare Book Library, Columbia Univ.. These papers are hereinafter referenced as AP.

[3] E. H. Armstrong, "Methods of Reducing the Effect of Atmospheric Disturbances," *Proc. IRE*, vol. 16, no. 1, Jan. 1928, pp. 15–26.

[4] J. R. Carson, "Reduction of Atmospherics," *Proc. IRE*, vol. 16, no. 7, July 1928, pp. 966–75.

[5] G. L. Frost, *The Evolution of Frequency Modulation Radio, 1902–1940*, Ph. D. dissertation, Univ. of NC, Chapel Hill, 2004.

[6] See, for example, letter from C. W. Hansell

to J. W. Conklin, both of RCA, June 27, 1931, Box 160, AP, which describes a demonstration by Armstrong June 25, two days earlier, in which Armstrong's equipment in New York provided "a much more favorable impression of the possibilities of FM than… at Riverhead [the RCA receiver site]." Note that this demonstration used narrowband FM equipment.

[7] G. L. Beers, Report TR-251, Armstrong FM Receivers, Feb. 6, 1935, RCA Manufacturing; letter from Harry Sadenwater, RCA Victor, to Throckmorton, Mar. 16, 1938; memo from Sadenwater to Frank Wozencraft, Mar. 15, 1940, all in Box 159, AP.

[8] E. H. Armstrong, "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation," *Proc. IRE*, vol. 24, no. 5, May 1936, pp. 689–740.

[9] M. G. Crosby, "Frequency Modulation Noise Characteristics," *Proc. IRE*, vol. 25, no. 4, Apr. 1937, pp. 472–514.

[10] H. Roder, "Noise in Frequency Modulation," *Electronics*, May 1937, pp. 22–25, 60–64.

[11] J. R. Carson and T. C. Fry, "Variable Frequency Electrical Circuit Theory with Application to the Theory of Frequency Modulation," *Bell Sys. Tech. J.*, vol. 16, Oct 1937, pp. 513–40.

[12] T. Lewis, *Empire of the Air, The Men Who Made Radio*, HarperCollins, 1991.

[13] Typed memo, "Wideswing Patent, Dec. 17, 1948, Information obtained by questioning Armstrong," p. 2; Box 160, AP, Note: It is not clear who prepared this memo, but the person being quoted is clearly Armstrong.

[14] Box 159, AP; reproduced in [5, p. 220].

[15] Memo to Moses and Holte, Aug. 23, 1932, Box 245, AP. Note: The title "Specification" appears on page 3 of this memo. Each page is signed by S. Nolte and someone else, perhaps another lawyer. There is no accompanying information of any kind, however.

[16] Letter, C. W. Hansell to J. W. Conklin, RD-1105, RCA, June 27, 1931, Box 160, AP.

[17] C. W. Hansell to R. R. Beal, Aug. 26, 1931, folder labeled "Notes from Forta's original examination," Box 160, AP. [These notes appear to have been prepared during the Armstrong-RCA litigation.]

BIOGRAPHY

MISCHA SCHWARTZ [LF], the Editor of this series of History Columns, also serves as Chair of the IEEE Communication Society's History Committee. He is the Charles Batchelor Professor Emeritus of Electrical Engineering at Columbia University, New York. He is a past President of the Communications Society and a past Director of the IEEE. He is the author of 10 books and many papers on communications and signal processing, his most recent book being one on mobile wireless communications. He is a member of the U.S. National Academy of Engineering. Among his various awards are the 1983 IEEE Education Medal, the 1986 Cooper Union Gano Dunn Award for outstanding achievement in Science and Technology, the 1994 IEEE Communications Society Edwin H. Armstrong Achievement Award for outstanding contributions to Communications Technology, the 1995 New York City Mayor's Award for Excellence in Science and Technology, the 1999 Eta Kappa Nu Distinguished Member Award, and the 2003 Okawa Prize for contributions to communication theory, computer networks, and engineering education.