

FIELD TEST OF THE ARMSTRONG WIDE-BAND FREQUENCY MODULATION SYSTEM FROM THE EMPIRE STATE BUILDING, 1934 AND 1935

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Editor's Note: The following paper is written from the unique vantage point of an engineer who worked closely with Major E.H. Armstrong on the early development of frequency modulation (FM), as an aural broadcasting service. Some qualities of Howard Armstrong as an engineer, inventor and human being are disclosed, not often found in print. His system of frequency modulation was in some respects a contradiction of accepted theory in that it achieved a reduction in noise level by using a channel having greater rather than smaller bandwidth. Armstrong was inclined frequently to say that one of the difficulties in what he was doing was that people so often knew so many things that weren't so. The development of Armstrong's system of FM stimulated work on information theory which provided a better understanding of fundamental communications principles which, in turn, has guided the design of today's complex systems.

R.M.M.

Much has been written about Edwin Howard Armstrong and his four major contributions to the Radio Art. It is remarkable that nearly sixty years after his first disclosure, all four inventions are still in use. Frequency modulation as applied to aural broadcasting is in fact still developing in its service to the public. The last decade has seen an accelerating use of this method of broadcasting, with the advent of stereo and the increasing use of FM in cars providing some of the impetus. One might wonder how the Major would react to some of the sounds now heard on high-fidelity FM. The aural channel of the TV service has used FM throughout its commercial life.

Little has been recorded, however, of the first full scale FM field test conducted by Major Armstrong at the NBC transmitting plant at the Empire State Building. It was my privilege to work with this man and to benefit from the expertise which he brought to bear on problems as they arose.

The National Broadcasting Company first occupied space on the 85th floor of the newly completed but sparsely occupied Empire State Building in September, 1931. An experimental television station was constructed to conduct tests on VHF using 120 line scanning with photocells for transmission. Cathode ray tubes called kinescopes were used for picture reproduction, replacing the earlier technique in which a neon plate lamp was viewed through a scanning disc. The early kinescopes employed a willemite phosphor which



Fig. 2. Armstrong frequency modulation exciter equipment, used in the 1934-35 field tests, at the Empire State Building. The breadboard unit in the rear, just to the right of the microphone, was exhibited at a Canandaigua conference.

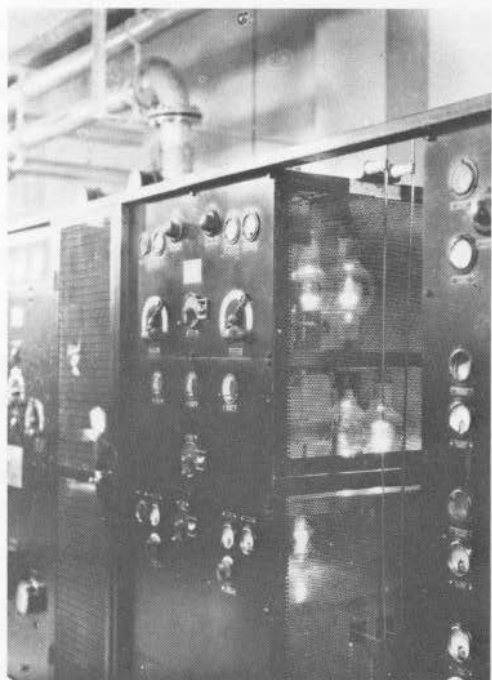


Fig. 3. Transmitter at W2XDG used in the FM field tests. This view shows the 831's in the tripler and intermediate power amplifier.

provided a picture in various shades of green. Perhaps some will recall seeing the green light in an otherwise darkened house during much of the early black and white TV era. The Empire State plant provided facilities for originating live and film picture signals with accompanying sound. The picture transmitter was licensed as W2XF to operate on 44 mc, and the aural transmitter as W2XK on 61 mc. Separate antennas were provided in the form of vertical dipoles extending above the five inch coaxial lines, and the transition from transmission line to antenna occurred at approximately ten feet above the top of the Empire State Building.

Extensive tests of this system of television transmission were conducted during 1932 and 1933. Although these tests proved the feasibility of using VHF for broadcasting, they also established that further substantial improvement in the quality of television picture transmission would be required before serious thought could be given to the development of a television broadcasting service. In the vernacular of the time, "Television was still just around the corner."

During this same period, Major Armstrong had been working on the development of wide-band frequency modulation at Columbia University. By the end of 1933 he had satisfactorily concluded initial tests of his method of wide-band FM telephony and had been issued four patents. At about this time he apparently met with David Sarnoff for the purpose of informing him of the new development, and may also have given him a demonstration at the Columbia laboratory. Probably as a result of this meeting, the NBC transmitting facility at the Empire State Building was made available to Armstrong to permit a full scale test of the new FM system.

The first visit of Major Armstrong to the Empire State Building transmitting facility is noted in a record of visitors which was maintained at that time. Under date of January 12, 1934, we find the following entry: "Mr. Beverage of RCA Communications and Major Armstrong here to discuss some experiential work which Major Armstrong expects to do here in the near future." This visit was promptly followed by another on January 19, 1934. The notation indicates that Major Armstrong was there "to get information on W2XF for experimental work he is to do on it in near future". W2XF was the visual transmitter used in the 120 line television tests.

The power amplifier for W2XF consisted of two 846 water cooled neutralized tubes operated in push-pull at approximately 5 kW input power. Measurement of radio-frequency power in this portion of the spectrum - with believable results - was still in the future. Based on the difference between the loaded and unloaded resonant current drawn by the P.A., we believed the carrier output power was approximately 2 kW. The I.P.A. and the tripler used the 831 air-cooled triode (WL-674 and FP-2 were the Westinghouse and G.E. designations of comparable tubes). The 860 screen grid tube operating as a push-pull amplifier drove the high power tripler. The overall frequency multiplication in the transmitter proper was 24 times, provided by three doublers and one tripler.

During February, 1934 the TV test transmission schedules were changed at

Armstrong's request. Network programming was applied as amplitude modulation on W2XF in place of tone or picture signals. This portion of the test was probably directed to field observations on the coverage which might be expected of this transmitter. On March 26, measurements of the band width of the radio-frequency multipliers and amplifiers as well as the band width of the antenna system were initiated by Armstrong. Observations at both the transmitting plant and at the Columbia laboratory were correlated. It is now evident that the purpose of those measurements and observations was to assure that the FM signal could pass through the transmission system without distortion. The Major had long since learned to take nothing for granted.

This meticulous approach uncovered several problems which were dealt with in due course. The antenna system offered a serious mismatch to the coaxial line, thus restricting the effective bandwidth of the antenna system. The radio-frequency stages in the transmitter were designed for maximum efficiency, since in the design application no bandwidth requirements were imposed on the driver stages. Both of these problems were effectively resolved with assistance from P.S. Carter on the matching problem and John Evans on the circuit problems.

During May, 1934, Major Armstrong had FM exciter equipment suitable for driving the low power stages of the transmitter moved into the television studio space on the 85th floor, adjacent to the transmitter. Test and adjustment of this equipment was started at once. Also in May of 1934 NBC received an experimental license which had been requested to cover experimental operation of the television picture transmitter on frequency modulation. W2XDG was assigned to operate on 40.6 and/or 41.0 mc for this purpose. A field intensity survey by RCA Victor engineers was promptly conducted at Armstrong's request.

The FM tests from W2XDG started on June 2, 1934 on 41 mc; the total time of operation during June was 49 hours. The antenna transmission line matching project was completed on June 6, and on the evening of June 20, 1934, a special demonstration of organ music was transmitted for observation by General James G. Harbord, the then-Chairman of the Board of RCA.

The FM exciter equipment as set up in the shielded TV studio was composed of a number of classical "breadboard" units. This type of construction provided adequate performance and excellent access but it obviously did not conserve space.

It should be noted here that while standards of operation and adjustment were established and maintained by the Major, the responsibility for operation in accordance with the terms of the license was in the hands of the NBC technical staff. This meant that close relations and cooperation had to, and did in fact, exist between the Major and the NBC engineers. Telephone communication was frequently employed between the point of observation, for example Harry Sadenwater's home at Haddonfield, N.J., and the transmitter plant to permit optimum interchange of information. Thus the mode of transmission or the nature of the modulating signal could be in full accord

with the Major's requirements. Similarly, when discrepancies appeared, the cause could be quickly isolated and corrections applied.

Tests continued through July with facsimile signals being added for test transmission to Haddenfield. However, trouble developed on July 30, 1934. The large insulator which supported the upper section of the center conductor of the coaxial line as well as the antenna rod for W2XDG/W2XF had failed. Initially the failure was believed to have been caused by lightning, which hit the antenna frequently. Repair of the initial failure was effected promptly by removing the antenna and replacing the insulator with an identical spare.

When the antenna rod was removed a substantial number of pit marks were discovered. These were tracks left by lightning. The fact that the two experimental TV antennas were the highest points in New York City and were frequently struck by lightning made them of much interest to K.B. McEachron of the G.E. High Voltage Laboratory at Pittsfield, Mass.

Arrangements had been made a year prior to the Armstrong tests to permit the installation of current and voltage measuring devices to gather information on lightning stroke phenomena. There were approximately 180 pock marks in the top 18 inches of the two inch diameter rod. Since the rod had been in service for three years, this suggested the occurrence of approximately 60 strokes per year. McEachron acquired the original rod and, judging from marks made in the same material in the lightning laboratory, stated that some of the strokes achieved a peak current on the order of 100,000 amperes.

A second antenna insulator failure of the same type during September led to the conclusion that the failure was caused by excessive heating due to the poor dielectric characteristics of the porcelain material at VHF. Action was then initiated to have a special insulator manufactured, and Steatite, a material having a much superior high-frequency characteristic, was specified. Since delivery of such a custom made insulator was estimated to be 6 months, RCA Communications prepared a temporary replacement made of rings of Mycalex. A coaxial line test set-up was prepared for testing these insulators at 41 mc, and as a result of this test the superiority of Mycalex over porcelain in this application was clearly demonstrated.

W2XDG was returned to service on October 10 with substantially increased radiated power, attributable to the reduction of loss in the temporary Mycalex replacement insulator. During October Armstrong commenced multiplex program tests in which two separate programs were simultaneously transmitted and successfully received at Haddonfield. These tests continued into November, 1934 with four simultaneously transmitted channels comprising program, facsimile, synchronizing for facsimile, and telegraph.

When Major Armstrong planned to make adjustments to or measurements on the performance of the FM signal generating system, he would usually phone in the morning to advise that he would arrive after lunch, meaning some time between 2 and 3 PM. After a few words of greeting and an outline of projected demonstrations, the Major would shed his jacket and frequently his shirt and tie as well, and proceed with his work in the studio. He was

sometimes unduly secretive about his objective or the nature of the problem he was trying to solve. Time meant nothing to him. The 5 PM quitting hour would come and go but Howard would continue to tinker. However, when an acceptable stopping place was reached, he would confess to the need of some nourishment and more often than not would take all hands out to dinner before turning us loose. Those were memorable occasions during which incidents in the early history of radio would be colorfully related.

We sometimes wondered about the Armstrong lunch. When Howard appeared at Empire State after lunch he was obviously full of vim, vigor, and vitality. Harry Houck recently related a story which sheds some light in this area. It seems that Tom Styles frequently accompanied the Major at lunch when the center of activity for the day was at the Columbia laboratory. One day the lunch counter which they usually frequented was closed. Tom, always eager for a good meal, induced the Major to try a nearby French restaurant. After carefully studying the exotic fare offered, Tom ordered frogs legs provinciales. When the waitress addressed the Major he ordered a cheese sandwich and a glass of milk. Tom remonstrated, saying, "Look, Howard, you always order a cheese sandwich and a glass of milk. Let's make this a little special occasion". The Major regarded Tom quizzically, passed his hand over his bald pate, and said, "Tom, you're right. We should make it a special occasion. Waitress, make that two cheese sandwiches and two glasses of milk".

During important demonstrations of the system Armstrong would arrange to have Jack Shaunessey be with us, just in case of some unforeseen problem with the FM equipment. On one occasion consternation arose when, in making a periodic routine test of the system, no signal emanated from the FM generating equipment. It was Jack who asked the 64-dollar question, "Did anyone charge the storage batteries?" A new set of batteries complete with spares and a charger assured the end of that problem.

It might be appropriate at this point to describe the receiving setup in Haddonfield, N.J. where Armstrong gave many demonstrations during these tests. Harry Sadenwater of the RCA staff, who was also a member of the Radio Club of America and a long time friend of Howard Armstrong, lived in a nicely situated home with an ample back yard in Haddonfield. This site, approximately 80 miles from the Empire State Building, was an almost ideal spot, from the Major's point of view, to demonstrate the superiority of FM over AM broadcast reception from New York.

The receiver comprised several radio cabinets containing the intermediate-frequency amplifiers, the limiters, the discriminator, and the audio amplifiers. These were preceded by a high-frequency converter consisting of a modified RCA Communications high-frequency receiver. The units were set up in the Sadenwater rumpus room in the basement, hampering the intended use of the bar for many months. The antenna was carefully chosen since it consisted of a vertically polarized half rhombic. The center was supported by a 60 foot vertical mast and the antenna was, of course, oriented toward New York. The rhombic was later supplemented by a vertical dipole mounted on the side of the house.

In order to insure our involvement and cooperation, the major entertained those responsible for the operation of the Empire State facility and ran a special demonstration for us at Harry Sadenwater's home in Haddonfield.

In December, 1934 steps were taken by NBC to re-equalize the two program circuits from Radio City to Empire State. These circuits had been equalized to 10 kc, but new equalizers were prepared to bring the response flat within 1 db from 30 cps to 14 kc. This was undoubtedly part of Armstrong's plan to establish and demonstrate FM as a very high fidelity system. Radio City, with its new studios and equipment, had uniform frequency response to at least 15 kc.

Early in 1935 activity centering on the Empire State transmitting facility grew to a crescendo. In addition to the Armstrong tests, RCA was studying propagation characteristics of the FM frequencies as well as other portions of the spectrum, and preliminary comparative tests of AM vs narrow-band FM vs wide-band FM were conducted concurrently with tests and demonstrations by the Major.

On May 7, 1935, at the annual stockholders meeting of RCA, David Sarnoff announced development of a much improved system of electronic television, and plans to start field tests in less than 15 months. This meant that conversion of the Empire State transmitting equipment would have to start very soon. It also meant that the use of the transmitter by Major Armstrong for FM tests would have to be terminated. Plans for completely rebuilding the antenna and transmitter plant were being developed under forced draft and personnel unfamiliar with the plant were being trained to operate the existing facility and make the planned modifications.

During June, July, and August of 1935 final improvements in the FM equipment were made and tested. Further demonstrations were given, with reception usually at Haddonfield. The Major was quite fond of comparing FM reception on VHF with that of the 50 kW WEAf transmitter on Long Island on a warm August afternoon when there was a nearby thunder storm. Reception of WEAf was, of course, badly marred by the heavy static, whereas the FM reception from W2XDG was crystal clear.

In October, 1935 the aural transmitter rebuilding had been in progress for more than two months and the parts for the modification of the visual transmitter were on hand. With Armstrong's reluctant permission, the FM equipment in the studio was dismantled so that the studio area could be used for some of the required construction work. Thus the FM field tests by Armstrong at the Empire State Building were terminated.

It should be apparent from the foregoing that much was learned during the course of the FM tests that is now taken for granted as an established part of the radio art. The importance of antenna impedance matching to the transmission line and of using low-loss insulators at high frequency, the necessity of designing antennas so that points of mechanical support are not at high-voltage points, to say nothing of transmitter considerations, were well learned during the FM field testing. It is interesting to note that two years later, when

the Major decided to build his own FM station at Alpine, he ordered a high-powered transmitter from RCA.

After the death of Armstrong early in 1954, it became necessary to dispose of the large collection of equipment and material which he had accumulated over the years. This included electronic gear involved in all of his inventions and developments, from his regenerative receiver and the first superheterodyne to and including the FM equipment used in his many tests and experiments. This equipment was stored at his old home in Yonkers and at Columbia University.

It fell to Armstrong's long time friend and associate, Harry Houck, to rescue this material from the junk man and oblivion. It was trucked to a large red barn in northern New Jersey, where it was stored for many years. A few pieces of breadboard equipment have been identified as those used in the Empire State tests. It is Harry Houck's intention to identify, preserve and suitably display those pieces of equipment which constitute a significant part of the Armstrong story.

I hope it is evident, but perhaps it should be stated, that I considered it an exceptional privilege to have had the opportunity to be so closely associated with Major Howard Armstrong during the development of FM, and to have had the opportunity of observing perhaps the world's greatest development engineer at work.

Photos courtesy of R.M. Morris

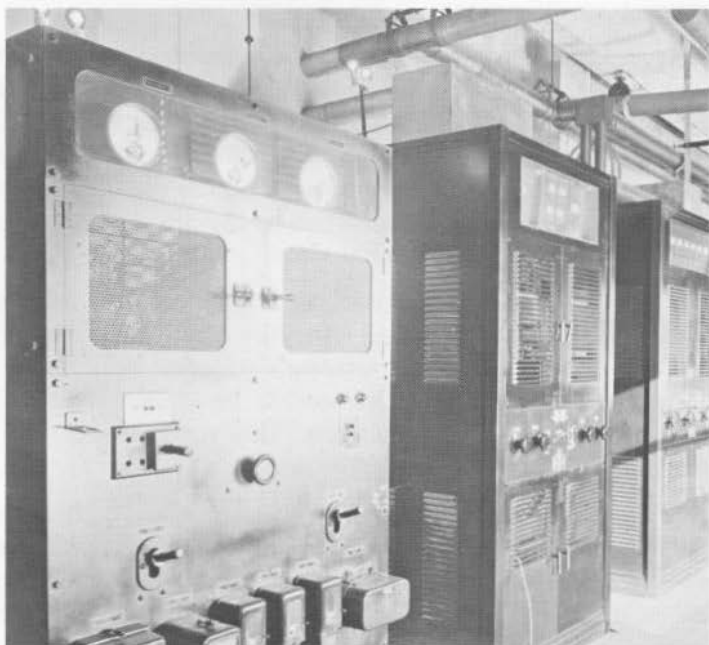


Fig. 4. NBC VHF transmitters at the Empire State Building, circa 1934.