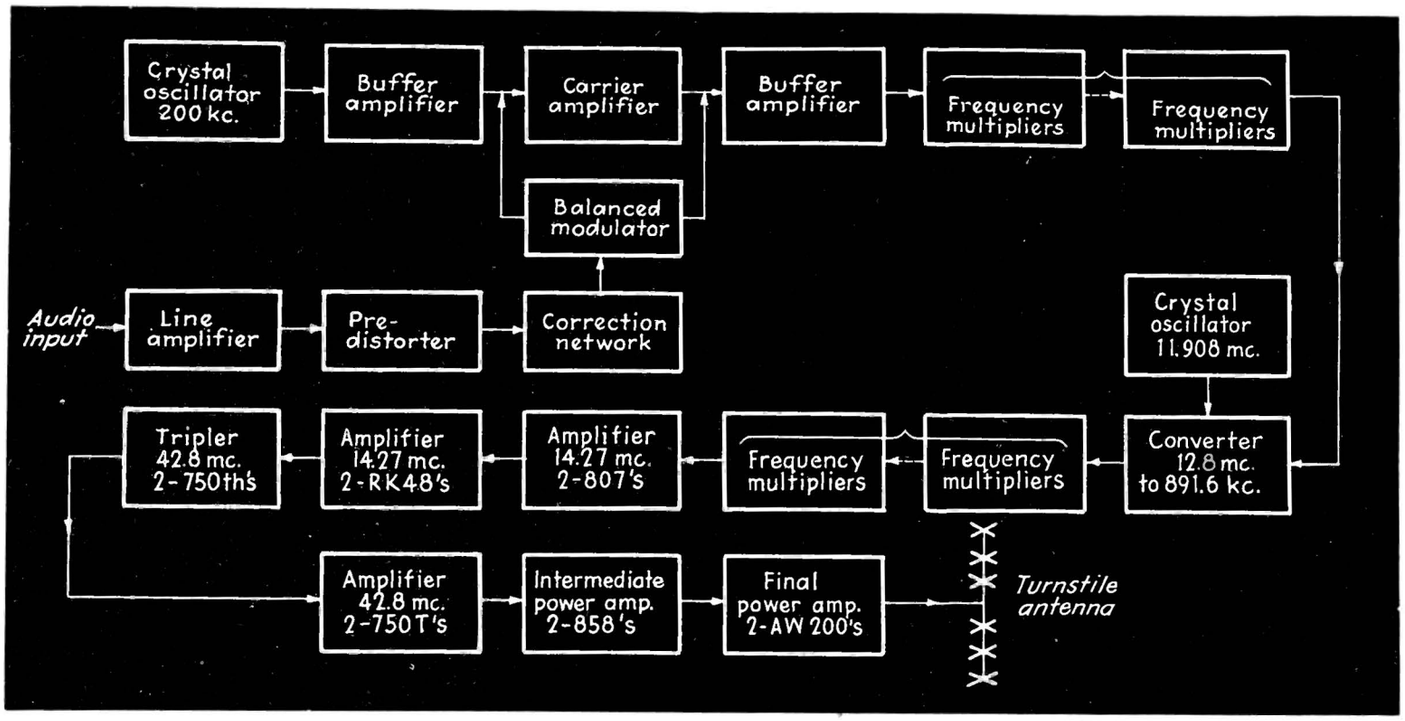


Four-hundred-foot steel tower atop Palisades supports turnstile antenna 900 feet above sea level. Radiating structure (see front cover) is supported between cross-arms at upper right

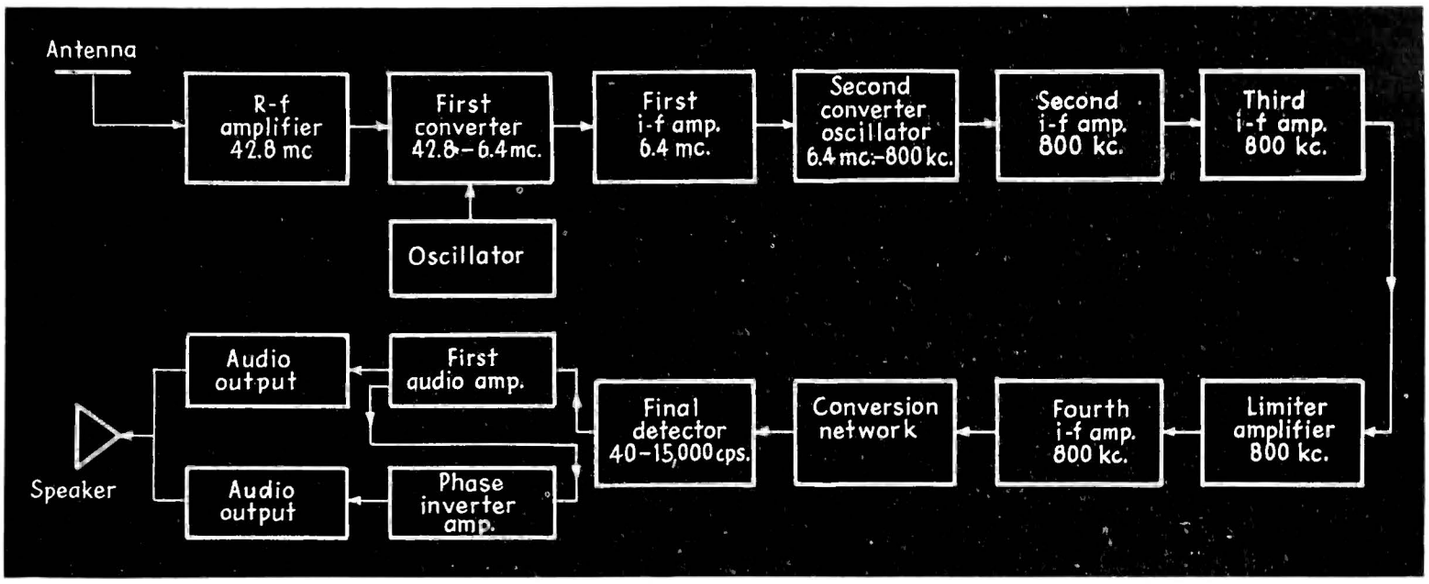
Frequency Modulation

Major Armstrong's new 40-kilowatt station at Alpine, N. J. was recently demonstrated to the editors, who report their findings herewith. Low power shown to be effective.

ON FEBRUARY 9TH, the editors of *Electronics* were given a convincing demonstration of the wide-band frequency-modulation system invented by Major E. H. Armstrong. The demonstration was made over a fifty-mile path from transmitter to receiver, on each of two frequencies, on 42.8 Mc and also on 110 Mc. The program material consisted for most part of high-fidelity vertical-cut recordings, together with a few studio presentations, involving piano music and hard-to-reproduce noise effects. The quality of the reproduction was of the highest excellence. Measurements indicate that the system is "flat" within one db from 40 to 15,000 cps, and there was nothing to gainsay the measurements so far as the ear could detect. The absence of noise in the circuit, even over the 50 mile path with the low power transmitter, was the most startling aspect of the demonstration. The background needle-hiss of the records was definitely audible, of course, but between records the circuit displayed virtually no noise at all. The effect was, in fact, as if the set had been turned off altogether. The only interfering noise was an occasional flash of ignition interference, arising from motor cars on the street directly in front of the receiver antenna. The level of this interference was low and it could not be heard except when the circuit was not modulated (in the absence of music or speech).

Behind this demonstration lies a long period of development. Previous articles in *Electronics*[1,2,3,4] have covered in detail the development of the system. Frequency modulation was considered, prior to 1935, to have little virtue and in fact was thought

[1] Frequency Modulation Advances, June 1935, page 188.
[2] Phase-frequency Modulation, November 1935, page 17.
[3] High-power Frequency Modulation, May 1936, page 25.
[4] Noise in Frequency Modulation, May 1937, page 22.
See also the brief comment in Tubes At Work, February 1939, page 36.

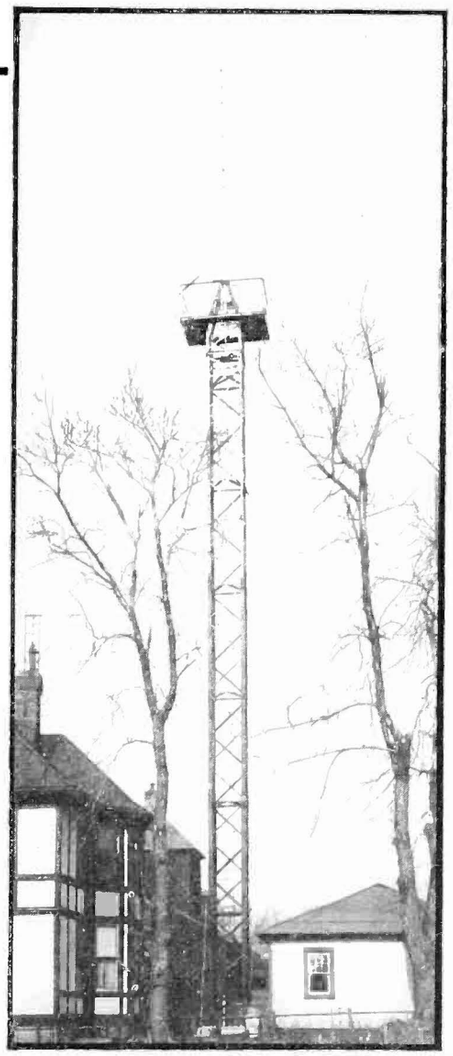


Left, block diagram of tube line-up at W2XMN transmitter, supplying 40 kw output

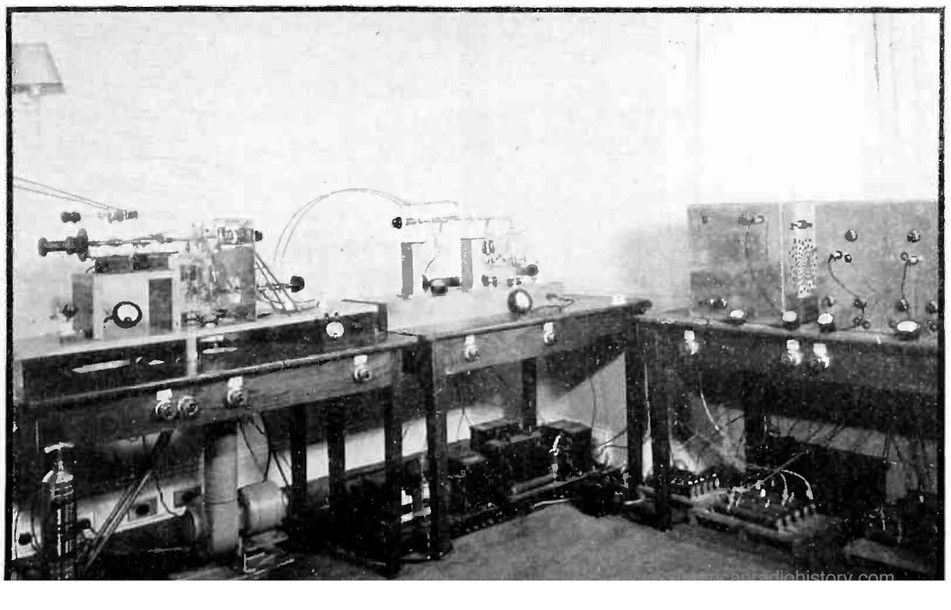
Above, diagram of high-sensitivity receiver used in demonstration

Demonstrated . . .

to have inherent distorting qualities. In 1935 Major Armstrong announced before the New York Section of the I.R.E. that he had developed a method of frequency modulation which was not only free from distortion but which possessed marked advantages in respect to the signal-to-noise ratio. The success of the system resides in the discovery that by introducing into the transmitted wave a swing greater than can exist in natural disturbances and by designing a receiver which is substantially not responsive to amplitude changes or small frequency changes, but only to the wide frequency changes of the signal, noise can be discriminated against. A high signal-to-noise ratio results. Furthermore, the wider the frequency swing used, the higher the signal relative to the noise, contrary to previous theory. In practice, the signal-to-noise ratio may be improved by a factor of 1000-to-1, relative to conventional amplitude-modulated transmission, when the noise is of the "fluctuation" type which arises in tubes and circuits. The available improvement is not so great when the noise is of the impulse variety associated with ignition systems, but the ratio is substantially bettered even in this case. Direct comparisons between amplitude-modulation and frequency-modulation transmissions on the same wavelength, cited in a previous article[3], show that an improve-



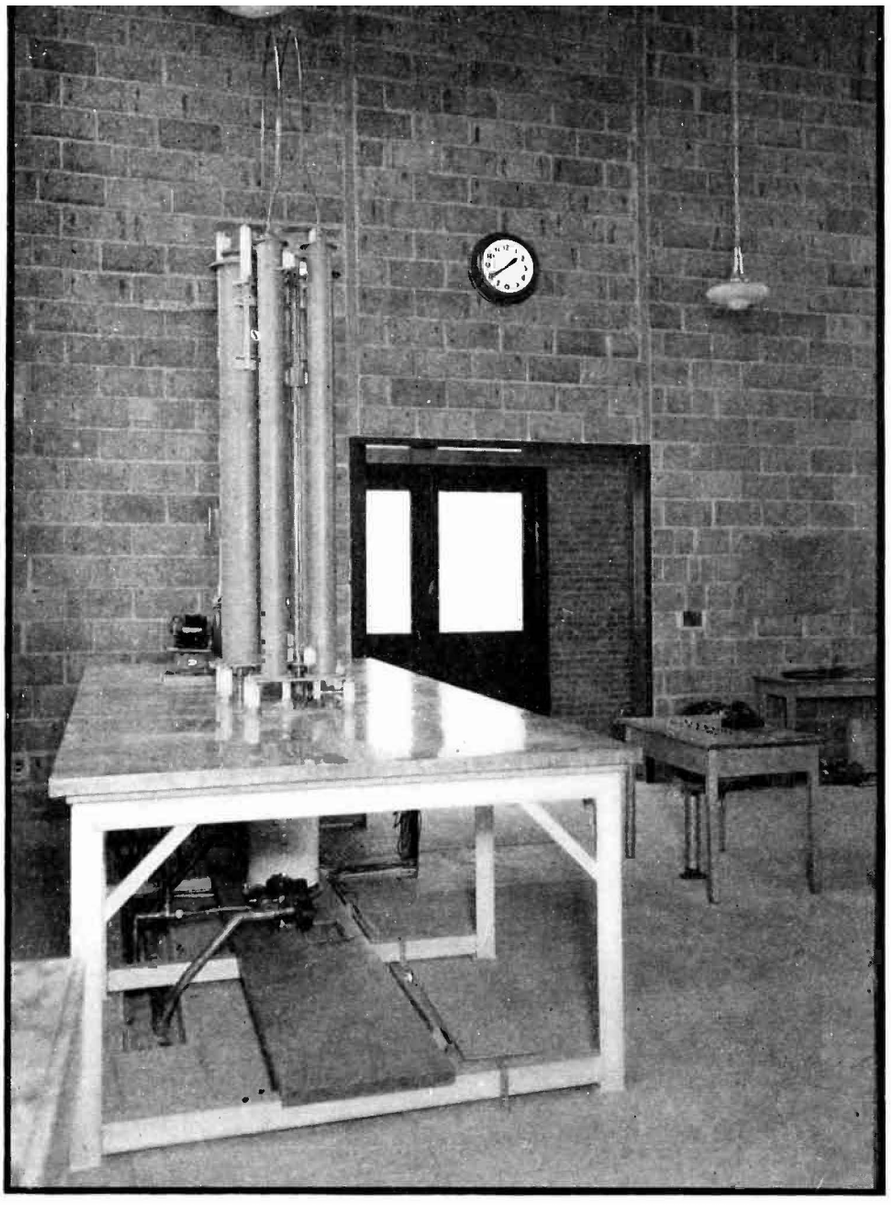
W2XCR, the 110-Mc 600-watt frequency modulation station of C. R. Runyon at Yonkers, which participated in the tests. The turnstile, above, is on a 100-foot mast



ment of 50-to-1 (35db) in the signal-to-noise voltage ratio occurs in the absence of impulse noise, and an improvement of 20-to-1 or higher in the presence of impulse noise. Comparisons with amplitude modulation on broadcast frequencies show an even greater advantage in favor of frequency modulation since the frequencies from 2000 kc to 500 kc are much more infested with atmospheric static, especially in summer.

The high-power installation in Alpine, N. J.

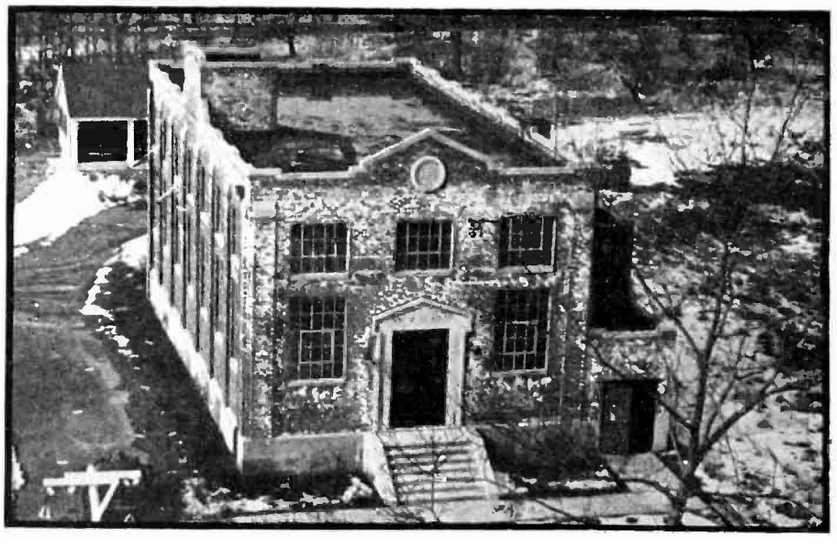
To show conclusively the advantage of his system over that of conventional broadcasting, Major Armstrong in 1936 began the construction of a frequency modulation station of a power commensurate with that of existing broadcasting stations. A permit was issued by the FCC to allow the construction of a transmitter of 40 kw output power, under the call letters W2XMN, at a site on the Palisades, in Alpine, N. J., about 10 miles north of the upper tip of Manhattan Island, New York. The construction was completed in all essentials in the summer of 1938, but the high power was not used until near the end of the year. Since then demonstrations have been given to various groups, notably to an I.R.E. section meeting at Bridgeport, Conn., some 40 miles distant. Tests were also conducted in the house of George Burghard at Westhampton, Long Island, about 70 miles distant, until this house was destroyed by the 1938 hurricane. Since then the receiving headquarters have been located at Sayville, Long Island, some 50 miles airline from the transmitter. The signals are heard at this point with substantially perfect performance, i.e. very low (actually inaudible) noise level and no fading. The transmitter has been heard consistently on a receiver located at the top of Mount Washington in New Hampshire, at an airline distance of 275 miles. At this distance, fading is experienced, but without distortion so that a-v-c action can be employed profitably.



Coaxial circuit (on table) for r-f power amplifiers at W2XMN shown during construction. The final stage develops 40 kw at 42.8 Mc

The transmitter is remarkable in that it produces by far the highest power ever developed for any purpose on the ultrahigh frequencies, whether for frequency-modulation or otherwise. At present the output power of the final stage is limited to 20 kilowatts, since at higher levels the grid seals of the amplifier tubes become hotter than is permissible. However, the full 40 kilowatts output (85 kilowatts input) has been developed for periods of a few minutes. At present special air blowers are being installed for cooling the grid seals, after which the full power of 40 kilowatts will be employed regularly. The effective signal level along the ground is increased by the use of a turnstile antenna system which has a power gain, in all directions, of at least two.

The transmitter building is located on cliffs which are approximately 500 feet above sea level. The antenna is supported on a massive 400-foot steel



The transmitter building at Alpine, which houses the 40-kilowatt station and experimental facilities

tower. The antenna proper is mounted on a vertical mast supported at the ends of two side arms on the tower. The turnstile antenna is based on the design given by G. H. Brown[5]. Unfortunately the theoretical design does not coinside exactly with the actual design, apparently due to the effect of the metal support mast. As a result it was necessary for Major Armstrong to spend many hours daily for a period of over two months suspended on a boatswain's chair while adjusting the position of the dipoles and feeder wires. At present the turnstile consists of two sets of four horizontal dipoles each, the two groups being supported from a single mast but fed separately from each end of the mast. The power gain of this arrangement, compared to a single dipole of the same dimensions, is roughly 4 times. Further adjustments are expected to raise the ratio to 5 times. The height of the cliffs plus the tower puts the antenna about 900 feet above sea level, consequently the antenna commands within its horizon virtually the entire metropolitan area for some 35 miles in all directions. However, the limit of the station's primary service area is definitely not the horizon distance. Acceptably high fields strengths are obtained in almost any location within 100 miles of the transmitter.

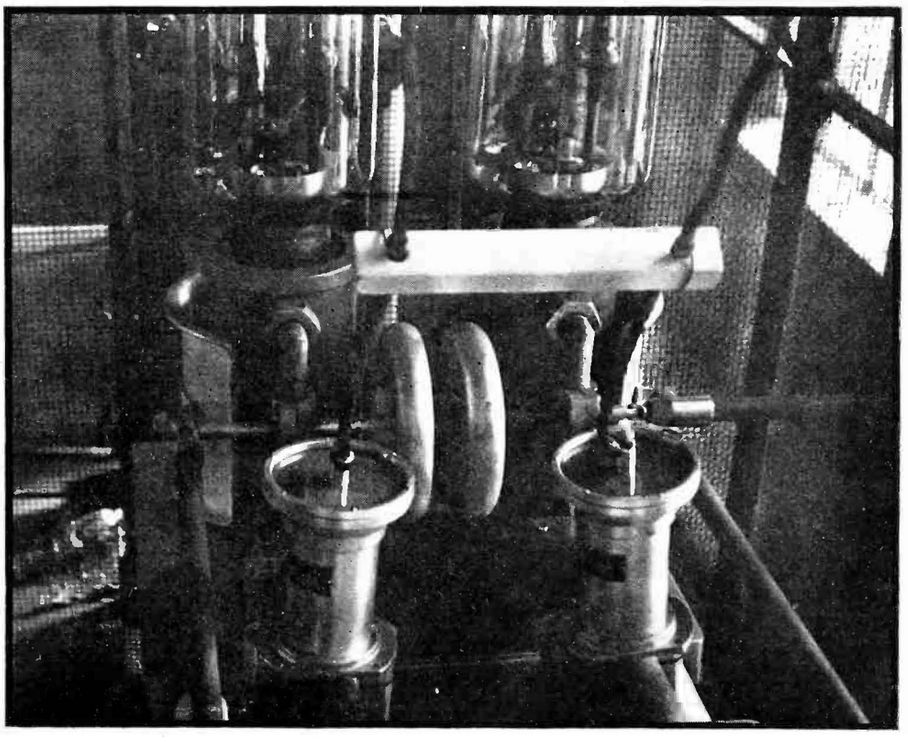
The transmitter itself is illustrated by the block diagram. The program starts in a conventional high quality telephone amplifier, and is given to a predistorter which accentuates all frequencies above 1000 cycles. The signal is then passed through a correction amplifier which introduces an amplification inversely proportional to frequency. The output of this amplifier is then used to control the phase angle of the output of a low frequency (200 kc) crystal-controlled oscillator. Subsequent frequency multiplier stages multiply the oscillator frequency, and its attendant variable phase shift, by several thousand times. The multiplied phase shift, with the amplitude inversely proportional to frequency, is equivalent to a frequency modulation, i.e. the amount of frequency deviation corresponds to the amplitude of the original program. The frequency-modulated signal is then heterodyned to a submultiple of the carrier (middle-value) frequency. Thereafter the signal is frequency-multiplied to the carrier frequency of 42.8 Mc. All this signal manipulation consumes a great number of tubes (about 50 in all) but the tubes are of small size. When the central frequency and its deviations appear at the carrier values they are at low level. Thereafter three class C amplifier stages increase the power level to the final value of 40 kw.

The input to the first of these stages uses conventional coil-and-condenser tuned circuits, but the plate circuits and all the circuits in the last two employ resonant-line circuits. The intermediate power amplifier (driver of the final stage) employs two type 858 tubes in pushpull, with four coaxial-line tuned circuits, two in the grid circuits and two in the plate circuits. The final stage employs two type AW-200 tubes, with coaxial lines in the grids and an open-wire circuit in the plates. Neutralization of the final stage is accomplished in the plate circuits. The total length of the tuned circuit in the final output is roughly 24 inches. From the output tank, an open wire balanced feeder line is used to convey the energy to the tower and thence to the two sets of dipoles in the turnstile antenna.

The efficiency of the final stage is between 45 and 50 per cent. This is remarkable performance at 42 Mc, but the explanation lies in the fact the stage acts as a class C (telegraph) amplifier. It is a characteristic of frequency modulation transmission that no variation in amplitude occurs, and consequently the class of amplifier operation is of little moment, so far as distortion is concerned. Class C is used because it is the most efficient. Furthermore the power input and output remain constant, regardless of modulation level or frequency. The result is that the carrier level of the transmitter corresponds to the peak level, rather than to one-fourth the peak level as in amplitude modulation. An antenna meter in the feeder line showed no movement whatever when the transmitter modulation was increased from zero to full level (the latter point corresponding to a frequency swing of roughly 120 kc, or 60 kc each side of the center frequency.

The three class C amplifiers are required, of course, to pass a frequency bandwidth of at least 120,000 kc (actually the sidebands extend somewhat beyond the region of frequency swing). This bandwidth constitutes a very small fraction of the carrier frequency, and for this reason no loading is required in the tuned circuits of the last three stages, since the tubes themselves introduce the

(*Continued on page* 81)



The final power stage, showing plate seals of AW-200 tubes, tank condenser and transmission line (foreground)

[5] The "Turnstile" Antenna, by G. H. Brown, *Electronics*, April 1936, page 14.

for any high voltage work up to 10,000 volts. The 879 is a high voltage half-wave rectifier with coated filament, suitable for levels up to 2500 or 3000 volts (7500 peak inverse voltage). In the Arcturus line, type 5X3 is a high voltage rectifier used for electric deflection power supply, and types 6AD5G and 6R6G are a hi-mu triode and remote cut-off pentode amplifier, respectively, intended for electric deflection amplification.

Cathode ray tubes for television purposes have been announced by four companies: DuMont Laboratories, Hygrade Sylvania, National Union and RCA. The DuMont tubes are all of the electric deflection type: Type 54–11–T, 5-inch, white screen, intensifier; Type 94–11–T, 9-inch white screen, intensifier; type 144–11–T, 14-inch white screen, no intensifier. The RCA tubes include 906-P4, 3-inch white screen, electric deflection; 1802-P4, 5-inch white screen, electric deflection; 1804-P4, 9-inch white screen, magnetic deflection; and 1803-P4, 12-inch white screen, magnetic deflection. The suffix P4 refers to phosphor number 4, a white non-sulphide material. The 1805 is a "short" five-inch tube with white screen offered by National Union. Nine-inch tubes are also manufactured by this company. Hygrade Sylvania has thus far offered cathode-ray tubes only in the smaller diameters.—D.G.F.

Frequency Modulation

(*Continued from page* 17)

necessary damping.

The station itself is arranged with the low level modulating stages inclosed in a doubly shielded room, containing a high quality phonograph turntable for both vertically- and laterally-cut recordings. The last two or three frequency-multiplying stages are outside this room, and feed the first class C amplifier. The last two amplifiers, which employ the resonant lines, are mounted on a table and completely surrounded with a wire shield. The high voltage power supply is located across the room from the final amplifier. The station, despite the large number of small tubes used, is extremely stable and simple to operate. "Cranking

up" the transmitter consists simply in lighting the filaments, starting the air blowers, and bringing up the high voltage power to the desired level. Virtually no supervision is required after the station is on the air, since there are no peaks of power. As a result rectifier arc backs are extremely rare, and the station has thus far never been forced off the air for any reason other than a momentary loss of power from the incoming 60-cycle lines. The operators do not "ride gain" in any sense, since overmodulation cannot occur, in the usual meaning, and since the peak frequency swing (corresponding to maximum audio level) can be readily adjusted to the limits allowed by the channel.

The 110-Mc Transmitter at Yonkers, N. Y.

The other transmitter used in the tests was W2XCR, at the home of C. R. Runyon of Yonkers, N. Y., who has been associated with Major Armstrong throughout the development of the system. The modulating equipment is essentially the same as that used at Alpine, but the carrier frequency is 110 Mc, and the output of the final linear amplifier is only 600 watts. This station was originally an amateur station (call W2AG) operating above 110 Mc. However, in order to transmit music after the December 1st amateur regulations went into effect, an experimental license was obtained. The antenna is a 7-element turnstile array supported on the top of a 100-foot steel tower. This tower is 700 or 800 feet below the line of sight to the receiving location at Sayville, but this circumstance appears to have little effect on the strength and quality of the reception. The antenna power gain (non-directional) is five, making an effective power of three kw.

The receivers employed (except the 110-Mc receiver) were constructed by the General Electric Company to specifications laid down by Major Armstrong. The block diagram shows the line-up. These receivers contain 15 tubes (1 rectifier, 4 audio, 10 rf), and will deliver a recognizable program with but 1 microvolt input. However, proper limiter action is obtained only with a signal of perhaps 2 to 5 microvolts, which can be obtained well beyond the horizon distance, up to 100 miles if the effective transmitter power is of the order of

three kilowatts or greater, at reasonable antenna heights.

Details of the test demonstration

The following brief resume of the impressions gained during the demonstration indicate the quality of the system as a whole. The first demonstration was at the apartment of Major Armstrong, on the east side of Manhattan Island, roughly 14 miles air line from the transmitter. The receiver was mounted in a conventional but massive console located in a room on the south side of the building and had but three controls, tuning, volume and tone. When the Alpine station came on the air, exact tuning was accomplished by listening to the noise level, since no tuning meter was provided on the set. Tuning was not at all critical, and required no readjustment, once set. The quality of the system, as previously stated, leaves nothing whatever to be desired. The background noise was, so far as the ear could detect even within a foot of the speaker, completely inaudible. The antenna used was a 6-foot length of twisted lamp cord, with the outer ends unraveled for a few feet to produce a dipole. Moving the antenna about in the room had no noticeable effect. One noticeable fact was the high audio level at which the receiver could be operated without any apparent distress to the ear. The lack of distortion and of background noise probably account for this.

One interesting comparison was made at the Alpine station, to which the editors traveled before going to Sayville. At the station, a loudspeaker was so connected that it could be switched rapidly from the ingoing audio line (from the turntable pickup amplifier) to the output of a monitor receiver which picked up the frequency-modulated signals from the output of the station. Thus a direct side-by-side comparison of the distortion and noise introduced by the frequency-modulation system could be made, relative to the original audio-frequency signal. It was literally impossible to tell the difference between the two switch positions. In response to a request for a demonstration of "over-modulation", Major Armstrong increased the audio level gradually to 15 db above normal, thus increasing the frequency swing greatly beyond its normal limits. No distortion could be noticed in the monitor

receiver until roughly 10 db above normal range was reached.

At Sayville, the results were substantially the same as in New York City, although the receiver was approximately 40 miles farther from the transmitting station. As previously mentioned, the only sources of noise were needle-hiss on the records, and very occasional ignition interference, the latter being of such low level that it could not be heard when music was being received. After several recordings were received from the Alpine station a relay was arranged whereby the 110 Mc station at Yonkers was picked up at Alpine (about one mile from Yonkers) and rebroadcast on 42.8 Mc to Sayville. As was to be expected, the results in this case were the same as when recordings originated at Alpine. However, Mr. Runyon's home at Yonkers provided a studio (actually a living room) for some piano music, and for several sound effects. The piano music was extremely good, since there was no background noise whatever. The sound effects consisted of tearing a piece of paper, lighting a match and a cigarette, pouring water from a bottle into a glass, and similar noises in which high frequencies predominate. This was the most perfect example of sound reproduction the writer has ever witnessed, no doubt due to the fact that 15,000 cps was actually reproduced. But if the slightest background noise had existed the crispness of the reproduction would have suffered. The absence of distortion was shown by the ringing of a bell and of a set of chimes. The disonant upper partials in the bell tone were correctly reproduced without "overhang" or blurring. This was a most effective demonstration of what truly high fidelity, coupled with low background noise, can mean to a sound reproduction system. The antenna used was a 6-foot partially unraveled lamp cord, tied to the curtain rods near the set.

As a final test, a 110 Mc receiver was used to receive the signals from the Yonkers location directly over the 50 mile path. A dipole and single reflector were mounted on the roof as a semi-directional receiving antenna. Despite the fact that the effective power of the 110 Mc station was 3000 watts, or roughly 1/30th of the Alpine transmitter, and that the frequency was 2½ times as high, the

110 Mc reception was virtually the equal of the 42.8 Mc case. The only difference was that a slight background hiss could be heard, but only if the audio output level of the receiver was raised to its highest point. A switch was arranged for transferring from 42.8 to 110 Mc reception, on the same program, and no difference whatever could be detected, except the almost imperceptible increase in background noise in the 110 Mc case. The test showed that a frequency modulated transmitter of moderate power (600 watts output at the final amplifier) and a simple antenna can cover a radius of 45 or 50 miles with a completely satisfactory signal. Other tests not witnessed by the editors indicate that the useful range of the low power transmitter is nearer 100 miles.

Plans are now underway to provide demonstrations of the system to interested persons, such as owners and operators of conventional broadcasting stations, during the coming summer. Studio as well as recorded programs will be made available from station WQXR, local high fidelity station in New York, as soon as telephone repeaters having a low enough noise level are installed in the line from the WQXR studio.—D.G.F.

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Patent Suits

1,231,764, F. Lowenstein; 1,403,475, H. D. Arnold; 1,465,332, same; 1,403,-932, R. H. Wilson; 1,507,016, L. de Forest; 1,507,017, same; 1,573,374, P. A. Chamberlain; 1,618,017, F. Lowenstein; 1,702,833, W. S. Lemmon, filed Mar. 16, 1934, D. C., S. D. N. Y., Doc. E 77/272. In the above case, on Sept. 28, 1938, the following patents were omitted by supplemental bill; 1,531,805, R. C. Mathes, Oscillation generator; 1,658,346, same, Amplifier circuit; 1,596,198, S. Loewe, System for generating oscillations; 1,896,780, F. B. Llewellyn, Modulating device; 1,239,852, F. K. Vreeland, Receiver of electrical impulses; 1,544,081, same, Transmitting intelligence by radiant energy; 1,811,095, H. J. Round, Thermionic amplifier and detector; Re. 18,579, Ballantine & Hull, Demodulator and method of demodulation, *R. C. A. et al. v. H. Kirschbaum* (*Luxor Radio Mfg. Co.*). Consent decree for plaintiff (notice Oct. 31, 1938).

1,251,377, A. W. Hull; 1,297,188, I. Langmuir; 1,795,214, 1,707,617, E. W. Kellogg, D. C., S. D. N. Y., Doc. E 77/273, *General Electric Co. v. H. Kirschbaum* (*Luxor Radio Mfg. Co.*).