© by Bachrach

Major Edwin H. Armstrong

FREQUENCY MODULATION AND ITS FUTURE USES

MAJOR EDWIN H. ARMSTRONG

Prof. of Electrical Engineering, Columbia University

ONCE in a while an invention is made that overcomes so many of the problems with which an industry has been contending that its methods are quickly recognized as the right ones to follow by those who understand its technical phases. Sometimes the new invention fits nicely into the established financial structure of an industry; sometimes it does not. In the one case, the inventor is met with open arms; in the other, he probably is assured that he really has a very fine invention and that if the art were starting out afresh no doubt it would be adopted, but to replace the existing plant—even though obviously it is now obsolete—would be too staggering a thing to be considered.

History teaches that the best method inevitably forces its way into use and ultimately becomes standard. Sixty years ago the electric light and power industry started off on the wrong road in its method of distribution. It undertook to distribute electric power, using the best; in fact, it used the only practical method at the time, namely, the low-voltage direct current system. Some years later the soundness of this procedure was challenged by the high-voltage alternating current system which, surmounting all obstacles placed in its path, went forward against powerful opposition and eventually superseded the direct current system in over 90 per cent of its applications. Looking back, one can see the absolute inevitableness of this result, yet the literature during the time of transition reflects a period of most violent controversy.

A large part of the radio industry, particularly the broadcasting division, is now facing a similar transition period, for a new principle has been discovered which furnishes a solution to the problem of "static." This term includes all those disturbances which have their origin in natural causes, such as lightning storms, and all those man-made noises which have their origin in the various kinds of electrical machinery found in towns and cities, such as electric razors, refrigerators, oil-furnace motors, elevators, etc. This new principle makes use of a process known as *"frequency modulation,"* although much more than a method of modulation is involved.

SOLVES MANY PROBLEMS

The new method solves not only the noise problem but many others which are inherent in the existing system. Due to a number of reasons, present-day broadcasting can transmit and reproduce only a part of the musical range; that is, instead of transmitting the range of 30 to 15,000 cycles which is required for natural reproduction, the range of 30 to 5,000 cycles is about the limit in present practice. In addition, this restricted part of the range which is actually utilized is reproduced none too faithfully by the existing system, on account of various distortions which occur in different parts of the transmitting and receiving equipment. Because of these limitations a radio "sounds like a radio." The new method is capable of transmitting the full frequency range (30 to 15,000 cycles), with a minimum of distortion and with practically the full dynamic range (i.e., maintenance of the proper relative amplitudes of the loudest and softest notes) that is required, so that it is possible to obtain a naturalness of reproduction never before achieved; in short, a reproduction which does not sound "like a radio."

The solution of these problems alone would warrant the application of the new technical methods, even though nothing more was accomplished than the paralleling of the existing service by the new system and the gradual transfer of the listening audiences per se from the old to the new type of broadcasting. But there is another contribution which this system can make that has very great social and political significance.

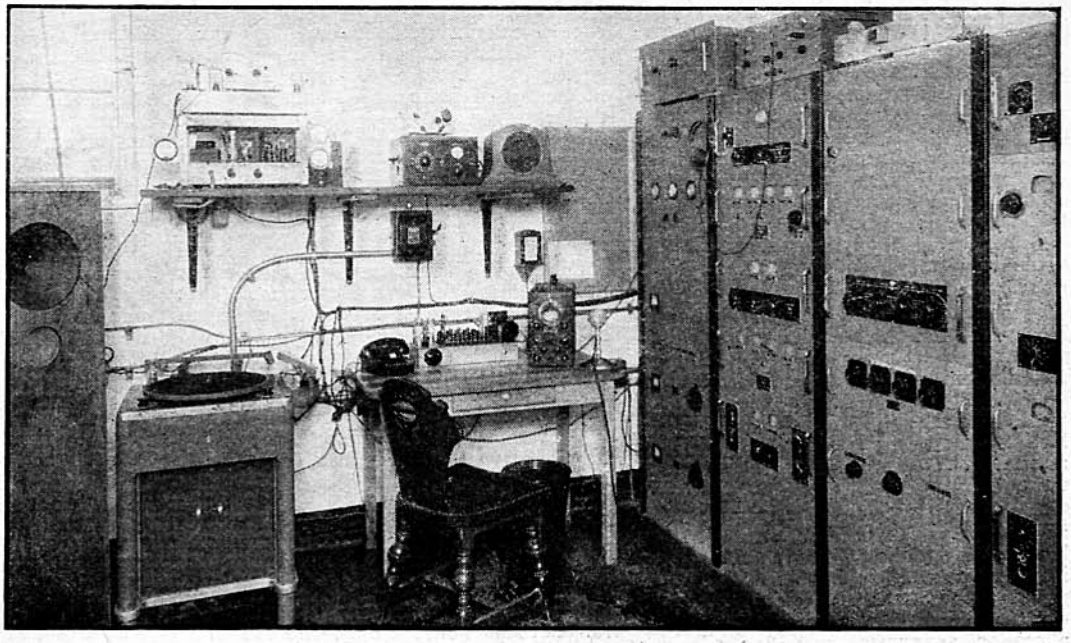
For years there has been a shortage of "wave lengths" or channel space, and the attempt to allocate equitably the inadequate facilities available has been the bane of the existence of those charged with this duty. With present methods, no permanent solution is possible; in fact, the interference situation has become worse in recent years due to increases in the number of stations operating in the United States and to the construction and operation at high power of numerous stations located beyond our southern borders.

The new system offers a solution not only to the national and international interference problem, but to the problem of giving every community one or more channels on the air so that stations particularly adapted to local needs can be set up and operated without interference. This result has come about because the system operates most effectively on wave lengths hitherto not put to use and because it has a curious immunity to interference from other frequency modulation stations, even though they may be on the same wave length channel. It becomes possible, therefore, to place stations much closer together geographically, and consequently to permit the use over and over again of the same channel within the confines of the United States. So effectively can this be done that the number of available channels may easily exceed the demand, with the factor which determines whether or not a community may have a local service resting solely upon the community's ability to support it. This alone would insure the adoption of the new system.

TRANSMITTING THE SPOKEN WORD

It is beyond the scope of this article to describe the technical processes by which these results are accomplished. They were originally described in a paper presented before the Institute of Radio Engineers in November of 1935, and to date no question has arisen as to the technical accuracy of this description or our understanding of what the new method can accomplish. But without entering into a detailed explanation of the phenomena involved, it would probably be helpful to explain some of the terms which the lay reader encounters in press and magazine articles concerning frequency modulation and to venture a sort of "curbstone" explanation of how the reduction in noise is achieved.

Radio transmission is accomplished by connecting an electrical pump (the transmitter) to a conductor known as an antenna, usually elevated above the earth, which pumps electricity into the conductor and sucks it out again hundreds of thousands or millions of times a second. Because of certain laws of nature, with which we need not concern ourselves for an understanding of the subject of this article, this process causes an exactly similar flow of electricity in conductors known as receiving antennas suitably placed within the range of the transmission, and this electric current flows up and down the receiving antenna the same number of times per second that the transmitting current flows in its antenna. The received current is weaker, of course, than the current in the transmitting antenna, being in fact a most minute replica of the current produced at the transmitting point. This weak current, however, is applied to a receiver, which amplifies it up to a strength where it may be detected and ob-



Modulator for Transmitter at Major Armstrong's famous "FM" station at Alpine, N. J. The Major personally supervised the erection of the antenna and climbed up into the lofty mast himself to check the details.

served. This constitutes radio transmission, but not communication of intelligence.

In order to transmit intelligence it is necessary to perform some operation upon the transmitted wave so that this operation may be observed at the receiver. In the case of transmission of the spoken word, the process of impressing the voice, or molding it upon the transmitted wave, is called modulation. It has been standard practice to accomplish this by *varying the strength of the current in the transmitting antenna in accordance with the fluctuations of the voice.* This may be called strength, or, technically, "amplitude" modulation. The function of the receiving equipment is to translate these modulations into voice currents so that they may be heard in a telephone receiver or loudspeaker. In this type of signaling the speed of the pump at the transmitter is not changed during modulation; the electric current flows up and down the antenna the same number of times per second, regardless of the changes in the strength of the current.

There is another form which is almost as old as *amplitude* modulation. In this form of modulation the strength of the antenna current is not varied in any way; it remains constant. But the number of times that the electric current is pumped up and down in the antenna by the transmitter is varied (speeded up and slowed down) in accordance with the fluctuations of the voice. This type of modulation is known as *"frequency modulation."* At the receiving system, where similar changes in the number of times the current flows up and down the antenna occur in consonance with those which occur at the transmitter, a somewhat different form of receiving system from the amplitude modulation system converts these changes in frequency into the voice currents that may be heard in the loudspeaker. For twenty-five years this method of modulation was considered to hold no promise of development, and it appeared to have no practical use whatsoever.

THE PROBLEM OF STATIC

Ever since its earliest days, but particularly after the invention of sensitive amplifying receivers around 1912, radio has suffered from disturbances produced by lightning storms and commonly referred to as "static." More recently, with the advent of radio broadcasting where receivers are located in metropolitan areas in the vicinity of all sorts of electrical machinery, it has also suffered from so-called man-made static. For a good many years it was believed that some form of circuit could be devised which would separate the signaling current from the currents created by these disturbances, but eventually it came to be understood that both the signaling currents and the disturbing currents were essentially the same in their nature and that very little could be done to reduce their effect except to raise the power of the transmitting station; or, in the case of man-made disturbances, to place the receiving antenna as far away as possible from the source of the noise. Subsequently it was proposed to use frequency modulation, on the theory that these disturbances were essentially amplitude modulation and hence would be rejected by a frequency modulation system; but it was found that the disturbances contained frequency changes as well as amplitude, and very little improvement resulted. However, it was observed by the writer during the course of a series of experiments that these frequency changes appeared to be limited in extent to about the same changes in frequency as were being used in the frequency modulation system. The idea presented itself, therefore, that if the frequency changes in the signaling wave could be artificially increased in extent beyond those changes which existed in the disturbing currents, and a receiving system created which was immune to the amplitude modulated part of the static—feebly responsive to its small frequency changes but fully responsive only to the wide changes in frequency of the specially modulated wave—a means could be found for differentiating between the signaling currents and the disturbances. This proposal turned out to be a sound one and improvements of one thousand to one in noise reduction can now be readily produced in practice. Not only could this advantage be obtained, but, because the system operated most effectively in the ultrahigh frequency band, a further advantage over standard broadcast methods was secured as much less static was present in the ultrahigh frequency range.[1]

OPPOSITION TO THE SYSTEM

After many years of laboratory work to put it in practical form, the system was brought to the attention of the Radio Corporation of America and was demonstrated to its executives and its engineering staff. These demonstrations began at the end of 1933 and continued for almost two years, at the end of which time the Radio Corporation declined to undertake the task of putting the system into public use. Various reasons were advanced to prove the impracticability of the system, such as its alleged inability to work beyond the horizon, the necessity of constructing new transmitting stations, and the high cost of new receivers. The proposition was also advanced that if amplitude modulation was used in the ultrahigh frequency range, substantially the same freedom from noise could be secured, as well as the same quality of reproduction. Subsequently, when the better quality of frequency modulation was demonstrated, the proposition was advanced that the public would not appreciate it and did not want it.

Still later, when a phenomenon was encountered in television transmission in large cities, which resulted in multiple images (ghosts), it was stated that frequency modulation transmission could not avoid a similar type of distortion.

The proposition was also advanced that the system was wasteful of channel space in the radio spectrum and that if ultrahigh frequencies were ever used in broadcasting the amplitude method of modulation would be more economical thereof.

The writer, disagreeing with all these conclusions, undertook the burden of introducing the invention to the public and started the construction of a high-powered station whose success or failure would take the matter out of the realm of academic discussion. As it was essential that the performance be so outstanding that any "talk down" campaign would be silenced, the station was designed to have a power ten times greater than ever before produced at ultrahigh frequency. A site was selected at Alpine, New Jersey, some seventeen miles north of New York City, and construction was started. Meanwhile an amateur station, W2AG, located in Yonkers, New York, owned and operated by C. R. Runyon, was equipped with the frequency modulation system. The performance of this station disposed of many of the bugaboos so cheerfully predicted for frequency modulation. After witnessing the demonstrations, the Yankee Network management, operators of a chain of stations throughout New England, and the owners of Station WDRC in Hartford, Connecticut, became interested and started the erection of stations in Paxton, Massachusetts, and Meriden, Connecticut. This entry into the field by two successful broadcasting interests, and the demonstrations which were carried out by the Yonkers station, stimulated a dozen or more

[1] The ultrahigh frequency range may be considered as below 10 meters (30,000 kilocycles).

enterprising broadcasters to secure construction permits and to start the erection of transmitters. The importance of the part played in this development by Mr. Runyon's station can hardly be overestimated. During the three-year period prior to the Alpine station's completion, scores of demonstrations were made to representatives from all branches of the radio industry, who were given every opportunity to examine the system's performance. No one was refused the opportunity to observe the operation under all conceivable conditions.

It was possible with very little vision to extrapolate this comparison between a 500-watt frequency modulation station and the 50,000-watt standard amplitude modulation broadcasting station, and to forecast what the service of the Alpine station would be like. There were a few enthusiastic disciples as a result of some hundreds of demonstrations.

The performance of the Alpine, Paxton, and Meriden transmitters convinced the broadcasting industry that a change was inevitable, and approximately 150 applications were filed with the Federal Communications Commission. Since the frequency allocation assignment made no adequate provision for this number of stations, in the fall of 1939 the Commission suspended the granting of experimental licenses in order to review the situation and to consider the point which had been raised by the Radio Corporation of America that the standards which were being used were not the best. After a hearing held in March of 1940 the Commission approved the standards which were then in use, removed the experimental limitation, arranged to issue commercial licenses as of January 1941, and reallocated a part of the frequency spectrum to increase several-fold the channel assignments for frequency modulation. The lower frequency part of the assignment to television, which had not fulfilled the early predictions of its readiness to furnish a public service, was rearranged. Nineteen channels had been assigned to television. Each television channel was sufficiently wide to accommodate 30 frequency modulation stations. The lower or Number 1 television channel was assigned to frequency modulation and the two lower television channels moved progressively upward, the new Number 1 occupying the old Number 2 position and the old Number 2 moving up into a space previously allocated to government use. This action by the Commission was taken in May 1940, and the art prepared to move forward.

The enthusiasm over the quietness of the reception was as expected, but the most gratifying result has been the response to the improved quality of transmission. The point had been made, and in some quarters was strongly urged, that the public would not appreciate so-called "high fidelity" reception; in fact, that it did not want it. This contention was supported by reference to the public reaction which attended the introduction of standard broadcast system receivers which had a wider range than the usual 5,000 cycles. One or two attempts had been made to create a market for receivers whose frequency range extended up to 7,000 or 8,000 cycles. It was found that these receivers did not sell well, and when they were sold the listener made rather drastic use of the tone control, which prevented the higher frequencies from being reproduced. Hence it was concluded that the public, from some impairment of its sense of aural perception, did not want the higher frequency range. Quite the reverse, however, was the case. What the average listener objected to was not the increased range of the frequencies reproduced, but the presence of certain harmonic distortions which are particularly offensive in the upper frequency ranges. These tones, together with the increased noise which always attends the extending of the frequency range, were the things which were really being rejected. When the harmonic distortions and the noise were removed from the signal by means of the frequency modulation system, the full frequency range was instantly appreciated. The reproduction then became natural. It is difficult now for one to credit that the contention was actually made that an unnatural type of reproduction was to be preferred to a natural one.

WIRE-LINE FACILITIES

At the present time only one obstacle stands in the way of a full realization of the advantages of frequency modulation throughout the country, and that is the limitation upon network operation imposed by the deficiencies of wire-line connections. These connections as at present set up are limited to the transmission of a frequency range up to 5,000 or 6,000 cycles, with a residual noise level considerably greater than that required for the full dynamic range of studio orchestral productions. This limitation does not, of course, affect the static-eliminating qualities of the system, but would reduce the quality of the transmission to that imposed by the characteristics of the wire lines. Some improvement may be expected in these characteristics, but they will probably not be set up to carry the full frequency range for a long time to come. There is, however, a relatively simple solution which is now in use in New England. By means of *radio relays*, Boston, Paxton, and Mount Washington have been successfully linked together, and within the coming year it should be possible to extend this circuit to include New York,** so that no wire-line facilities whatever will be required. No major technical difficulties are likely to be encountered.

Edwin H. Armstrong is professor of electrical engineering, Columbia University, New York City. He was associated with Professor Michael I. Pupin in research at the Marcellus Hartley Research Laboratory of Columbia University, 1914-1935; served as Captain and Major in the Signal Corps of the United States Army, 1917-1919; and is the inventor of the regenerative circuit, the superheterodyne, the superregenerative circuit, and a method of eliminating static in radio by means of frequency modulation.

While it may be possible ultimately to obtain the same technical performance by the use of the coaxial-cable method of transmission, there will be large sections of the country where it is not economically feasible to use this, and where it cannot compete with the radio relay. This is particularly true in the mountainous sections of the country. The establishment of regional networks entirely radio connected, extending throughout large sections of country of this type, is entirely practicable, and several such projects are now under way. Very rapid development in the radio relaying field may be expected.

Looking at it from the standpoint of the broadcaster, it is easy to see that the lower cost of the transmitting equipment, its economies of operation, and the possibility of the reduction of wire-line costs by the use of radio relays, are all in his favor. For the manufacturer of transmitters, and more particularly for the manufacturer of receivers, there lies a vast new market in an industry which has unquestionably reached a saturation point. Superficially, one might be led to believe that the industry would welcome a development such as this, but the fact remains that, with a few exceptions, it has not been welcomed by the large units of the industry. The burden of the development has been carried almost entirely by the smaller units. The reasons for this opposition are quite obscure, but nonetheless they are very real ones. It is important in the interest of the future progress of the radio art that at some time they should be brought out into the light of day.

PRACTICAL APPLICATIONS

In this article, the application of the frequency modulation system to the *broadcast* service has been treated. This is, of course, its major application. There are, however, applications to numerous other services, and the field is widening almost daily. At the moment, the greatest activity is in its application to the emergency services, particularly to the police service.

The largest project at the present time is that undertaken by the Connecticut State Police, who have in operation nine fixed stations and approximately two hundred mobile stations equipped for two-way operation with the fixed stations and with each other. The installation has been completely successful and the State is effectively covered.

The next largest project is in the City of Chicago, where some two hundred mobile units are in process of installation. Numerous other projects for police service and for emergency use by the power companies are being put forth, and it is doubtful whether many new installations employing amplitude modulation will be made in the future. It is, of course, needless to say that there are many important military uses; and its application in the field of aircraft appears to be a promising one.

The one important field in which progress has been inexplicably slow has been television, where its advantages, particularly on the sound channel, could be effectively utilized at once. A limited use has been made of frequency modulation for the relaying of the television sight channel.

In recent years it is only in the broadcast service where interstation interference has caused serious difficulty, and now this situation is likewise about to be cleared up. If in the future the demand for broadcast channels exceeds the facilities of the channel space now practically available, the engineering world is prepared to open up new bands in that space technically known as the ultrahigh and micro-wave region where the ratio of the unused channel space compares to that now in use as the unsettled to the settled parts of the earth. The trend of radio inevitably will be upward into the higher frequencies.—*Reprinted by permission from The Annals of The American Academy of Political & Social Science.*

**This Plan for the FM Relay Network, which includes New York City was carried out successfully during the past year. The advantages of frequency modulation transmission for relaying purposes was manifested when the programs were received without any noise or distortion, after having been relayed several times. Such noise-free, distortion-less transmission of voice and music cannot be duplicated by existing wire telephone lines.