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Technical Papers

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TECHNICAL PAPERS

A METHOD OF REDUCING DISTURBANCES IN RADIO SIGNALING BY A SYSTEM OF FREQUENCY MODULATION*

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Summary—*A new method of reducing the effects of all kinds of disturbances is described. The transmitting and receiving arrangements of the system, which makes use of frequency modulation, are shown in detail. The theory of the process by which noise reduction is obtained is discussed and an account is given of the practical realization of it in transmissions during the past year from the National Broadcasting Company's experimental station on the Empire State Building in New York City to Westhampton, Long Island, and Haddonfield, New Jersey. Finally, methods of multiplexing and the results obtained in these tests are reported.*

PART I

IT IS the purpose of this paper to describe some recent developments in the art of transmitting and receiving intelligence by the modulation of the frequency of the transmitted wave. It is the further purpose of the paper to describe a new method of reducing interference in radio signaling and to show how these developments may be utilized to produce a very great reduction in the effects of the various disturbances to which radio signaling is subject.

HISTORICAL

The subject of frequency modulation is a very old one. While there are some vague suggestions of an earlier date, it appears to have had its origin shortly after the invention of the Poulsen arc, when the inability to key the arc in accordance with the practice of the spark transmitter forced a new method of modulation into existence. The expedient of signaling (telegraphically) by altering the frequency of the transmitter and utilizing the selectivity of the receiver to separate the signaling wave from the idle wave led to the proposal to apply the principle to telephony. It was proposed to effect this at the transmitter by varying the wave length in accordance with the modulations of the voice, and the proposals ranged from the use of an electrostatic micro-

* Decimal classification: R400 X R430. Original manuscript received by the Institute, January 15, 1936. Presented before New York meeting, November 6, 1935.

phone associated with the oscillating circuit to the use of an inductance therein whose value could be controlled by some electromagnetic means. At the receiver it was proposed to cause the variations in frequency of the received wave to create amplitude variations by the use of mistuned receiving circuits so that as the incoming variable frequency current came closer into or receded farther from the resonant frequency of the receiver circuits, the amplitude of the currents therein would be correspondingly varied and so could be detected by the usual rectifying means. No practical success came from these proposals and amplitude modulation remained the accepted method of modulating the arc. The various arrangements which were tried will be found in the patent records of the times and subsequently in some of the leading textbooks.[1] The textbooks testify unanimously to the superiority of amplitude modulation.

Some time after the introduction of the vacuum tube oscillator attempts were again made to modulate the frequency and again the verdict of the art was rendered against the method. A new element however, had entered into the objective of the experiments. The quantitative relation between the width of the band of frequencies required in amplitude modulation and the frequency of the modulating current being now well understood, it was proposed to narrow this band by the use of frequency modulation in which the deviation of the frequency was to be held below some low limit; for example, a fraction of the highest frequency of the modulating current. By this means an economy in the use of the frequency spectrum was to be obtained. The fallacy of this was exposed by Carson[2] in 1922 in the first mathematical treatment of the problem, wherein it was shown that the width of the band required was at least double the value of the highest modulating frequency. The subject of frequency modulation seemed forever closed with Carson's final judgment, rendered after a thorough consideration of the matter, that "Consequently this method of modulation inherently distorts without any compensating advantages whatsoever."

Following Carson a number of years later the subject was again examined in a number of mathematical treatments by writers whose results concerning the width of the band which was required confirmed those arrived at by Carson, and whose conclusions, when any were expressed, were uniformly adverse to frequency modulation.

[1] Zenneck, "Lehrbuch der drahtlosen Telegraphy," (1912).
Eccles, "Wireless Telegraphy and Telephony," (1916).
Goldsmith, "Radio Telephony," (1918).

[2] "Notes on the theory of modulation," PROC. I.R.E., vol. 10, pp. 57-82; February, (1922).

In 1929 Roder[3] confirmed the results of Carson and commented adversely on the use of frequency modulation.

In 1930 van der Pol[4] treated the subject and reduced his results to an excellent form for use by the engineer. He drew no conclusions regarding the utility of the method.

In 1931, in a mathematical treatment of amplitude, phase, and frequency modulation, taking into account the practical aspect of the increase of efficiency at the transmitter which is possible when the frequency is modulated, Roder[5] concluded that the advantages gained over amplitude modulation at that point were lost in the receiver.

In 1932 Andrew[6] compared the effectiveness of receivers for frequency modulated signals with amplitude modulated ones and arrived at the conclusion that with the tuned circuit method of translating the variations in frequency into amplitude variations, the frequency modulated signal produced less than one tenth the power of one which was amplitude modulated.

While the consensus based on academic treatment of the problem is thus heavily against the use of frequency modulation it is to the field of practical application that one must go to realize the full extent of the difficulties peculiar to this type of signaling.

Problems Involved

The conditions which must be fulfilled to place a frequency modulation system upon a comparative basis with an amplitude modulated one are the following:

1. It is essential that the frequency deviation shall be about a fixed point. That is, during modulation there shall be a symmetrical change in frequency with respect to this point and over periods of time there shall be no drift from it.

2. The frequency deviation of the transmitted wave should be independent of the frequency of the modulating current and directly proportional to the amplitude of that current.

3. The receiving system must have such characteristics that it responds only to changes in frequency and that for the maximum change of frequency at the transmitter (full modulation) the selective characteristic of the system responsive to frequency changes shall be such that substantially complete modulation of the current therein will be produced.

[3] "Ueber Frequenemodulation," *Telefunken-Zeitung* no. 53, p. 48, (1929).
[4] "Frequency modulation," Proc. I.R.E., vol. 18, pp. 1194-1205; July, (1930).
[5] "Amplitude, phase, and frequency modulation," Proc. I.R.E., vol. 19, pp. 2145-2176; December, (1931).
[6] "The reception of frequency modulated radio signals;" Proc. I.R.E., vol. 20, pp. 835-840; May, (1932).

4. The amplitude of the rectified or detected current should be directly proportional to the change in frequency of the transmitted wave and independent of the rate of change thereof.

5. All the foregoing operations should be carried out by the use of aperiodic means.

The Transmitting System

An extensive experience with the various known methods of modulating the frequency convinced the writer as indeed it would anyone who has tried to work with this method of modulation at a high frequency that some new system must be evolved. During the course of this work there was evolved a method which, it is believed, is a complete solution of the transmitter problem. It consists in employing the modulating current to shift the phase of a current derived from a source of fixed phase and frequency by an amount which is directly proportional to the amplitude of the modulating current and inversely proportional to its frequency. The resulting phase shift is then put through a sufficient number of frequency multiplications to insure 100 per cent modulation for the highest frequency of the modulating current. By keeping the initial phase shift below thirty degrees substantial linearity can be obtained.

The means employed to produce the phase shift consisted of a source of fixed frequency, a balanced modulator excited by this source, and arrangements for selecting the side frequencies from the modulator output and combining them in the proper phase with an unmodulated current derived from the initial source. The phase relations which must exist where the combination of the modulated and unmodulated currents takes place are that at the moment the upper and lower side frequencies produced by the balanced modulator are in phase with each other, the phase of the current of the master oscillator frequency with which they are combined shall differ therefrom by ninety degrees.

The schematic and diagrammatic arrangements of the circuits may be visualized by reference to Figs. 1 and 2, and their operation understood from the following explanation. The master oscillator shown in these diagrams may be of the order of fifty to one hundred thousand or more cycles per second, depending upon the frequency of the modulating current. An electromotive force derived from this oscillator is applied in like phase to the grid of an amplifier and both grids of a balanced modulator. The plate circuits of the modulator tubes are made nonreactive for the frequency applied to their grids by balancing out the reactance of the transformer primaries as shown. The plate currents are therefore in phase with the electromotive force applied to the grid. The succeeding amplifier is coupled to the output transformer by a coil whose natural period is high compared to the frequency of the master oscillator and the electromotive force applied to the grid of this amplifier when the modulator tubes are unbalanced by a modulating voltage applied to the screen grids is therefore shifted in phase ninety

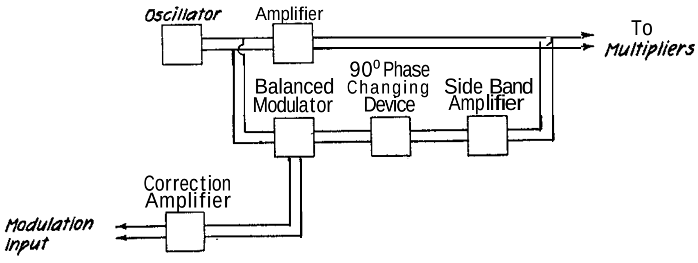


Fig. 1

degrees (or 270 degrees) with respect to the phase of the electromotive force applied to the grids of the balanced modulators. Hence it follows that the phase of the currents existing in the plate circuit of the amplifier of the output of the balanced modulator (at the peak of the modulation voltage) is either ninety degrees or 270 degrees apart from the phase of the current existing in the plate circuit of the amplifier of the

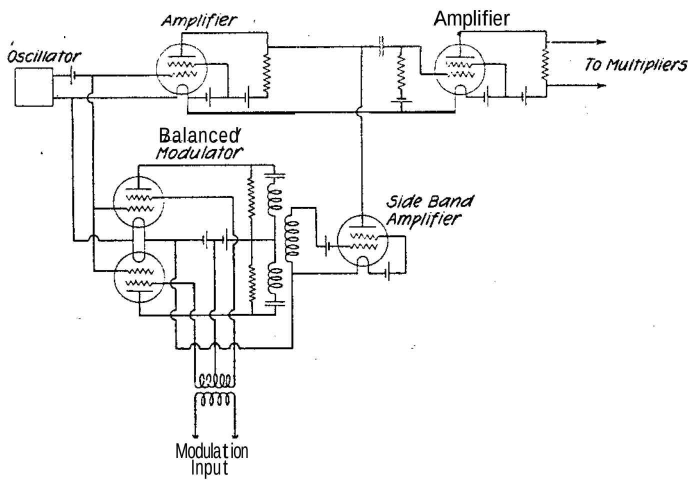


Fig. 2

unmodulated master oscillator current. Therefore the voltages which they develop across the common resistance load will be ninetv degrees apart.

The resulting effect on the phase of the voltage developed across the resistance in the plate circuits of these two amplifiers when modulation is applied, compared to the phase of the voltage which would exist there in the absence of modulation will appear from Fig. 3. It will be observed from the vector diagrams that the phase of the voltage across the common resistance load is alternately advanced and retarded by the combination of the modulated and unmodulated components and that the maximum phase shift is given by an angle whose tangent is the sum of the peak values of the two side frequencies divided by the peak value of the unmodulated component. By keeping this angle

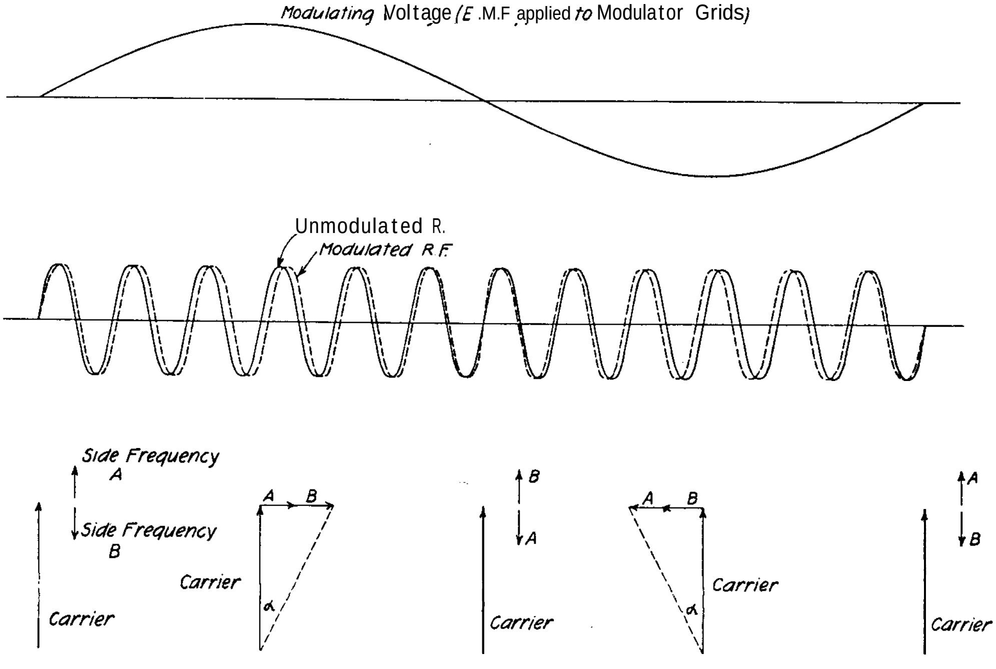


Fig. 3

sufficiently small (not greater than thirty degrees) it may be made substantially proportional to the amplitude of the two side frequencies and hence to the amplitude of the initial modulating current.[7] It will be observed that if the angle through which the phase is shifted be the same for all frequencies of modulation then the rate of increase or de-

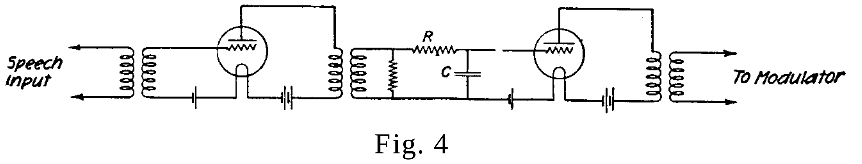


Fig. 4

crease of the angle will be proportional to the frequency of modulation and hence the deviation in frequency of the transmitted wave will be proportional to the frequency of the modulating current. In order to insure a frequency deviation which is independent of the modulation

[7] For the large angular displacements there will be an appreciable change in amplitude of the combined currents at double the frequency of the modulating current. This variation in amplitude is not of primary importance and is removed subsequently by a limiting

frequency it is necessary that, for a constant impressed modulating electromotive force, the angle through which the phase is shifted be made inversely proportional to the frequency of the modulating current. This is accomplished by making the amplification of the input amplifier inversely proportional to frequency by means of the correction network shown in Fig. 4. The network consists of a high resistance in series with a capacity whose impedence for the lowest frequency of modulation is relatively small with respect to the series resistance. The voltage developed across the capacity which excites the succeeding amplifier stage is therefore inversely proportional to frequency and hence it follows that the angle through which the current is, advanced or retarded becomes directly proportional to the amplitude of the modulating current and inversely proportional to its frequency. The resulting phase shift must be multiplied a great many times before a frequency modulated current which can be usefully employed is produced. This will be clear from an examination of the requirements of a circuit over which it is desired to transmit a frequency range from thirty to 10,000 cycles. Since the lowest frequency is limited to a phase shift of thirty degrees it follows that for 10,000 cycles the phase shift will be but 0.09 degree. The minimum phase shift for 100 per cent modulation of the transmitted wave is roughly forty-five degrees. A frequency multiplication of 500 times is required, therefore, to produce a wave which is fully modulated[8] and capable of being effectively handled by the receiver in the presence of disturbing currents.

Under ordinary conditions this multiplication of frequency can be realized without loss of linearity by a series of doublers and triplers operated at saturation provided the correct linkage circuits between the tubes are employed. Where however the wide band frequency swing which will be described subsequently in this paper is employed unexpected difficulties arise. These also will be dealt with subsequently.

From the foregoing description it will be seen that this method of obtaining frequency modulation consists in producing initially phase modulation in which the phase shift is inversely proportional to the frequency of modulation and converting the phase modulated current into a frequency modulated one by successive multiplications of the phase shift. The frequency stability, of course, is the stability attainable by a crystal controlled oscillator and the symmetry of the deviation may be made substantially perfect by compensating such asymmetrical action in the system as may occur. With the method of phase

[8] One in which the side frequencies are sufficiently large with respect to the carrier to make it possible to produce at the receiver 100 per cent modulation in amplitude, without the use of expedients which affect unfavorably the signal-to-noise ratio.

shifting shown in Fig. 2 there is an asymmetry which is of importance when the frequency of modulation is high compared to the master oscillator frequency. It occurs in the plate transformer of the balanced modulator. The plate circuits of these tubes are substantially aperiodic and consequently the amplitudes of the upper and lower side frequencies are approximately equal and from this it follows that the electromotive forces induced in the secondary are directly proportional to the values of these frequencies. Where the master oscillator frequency is 50,000 cycles and a frequency of modulation of 10,000 cycles is applied, the upper side frequency may be fifty per cent greater than the lower. This inequality may be compensated by a resistance-capacity network introduced subsequent to the point at which the combination of carrier and side frequencies is effected but prior to any point at which loss of linearity of amplitude occurs. The level in the amplifiers ahead of the compensating network must be kept sufficiently low so that the operation of the system is linear. After the side frequencies are equalized amplitude linearity ceases to be of importance.

The performance of transmitters operating on this principle has been in complete accord with expectations. While the arrangements may seem complex and require a large amount of apparatus the complexity is merely that of design, not of operation. The complete arrangement, up to the last few multiplifier stages may be carried out most effectively with receiving type tubes, these last multiplier stages consisting of power type pentodes for raising the level to that necessary to excite the usual power amplifiers.

The Receiving System

The most difficult operation in the receiving system is the translation of the changes in the frequency of the received signal into a current which is a reproduction of the original modulating current. This is particularly true in the case of the transmission of high fidelity broadcasting. It is, of course, essential that the translation be made linearly to prevent the generation of harmonics but it must also be accomplished in such a manner that the signaling current is not placed at a disadvantage with respect to the various types of disturbances to which radio reception is subject. In the particular type of translation developed for this purpose which employs the method of causing the changes in frequency to effect changes in amplitude which are then rectified by linear detectors, it is essential that for the maximum deviation of the transmitted frequency there shall be a substantial amplitude modulation of the received wave. At first sight it might appear that 100 per cent or complete modulation would be the ideal, but there are objections to approaching this limit too closely. It will, however, be clear that where the translation is such that only a few per cent amplitude modulation results from the maximum deviation of the frequency of the transmitted wave the receiver is hopelessly handicapped with respect to amplitude disturbances. This is true because even when the level of the voltage applied to the conversion system is kept constant by a current limiting device or automatic volume control there still remains those intervals wherein the incoming disturbances arrive in the proper phase to neutralize the signaling current in the detector, effecting thereby substantially complete modulation of the rectified current or the intervals wherein the disturbing currents themselves effect greater amplitude changes than the signal itself by cross modulation of its frequency.

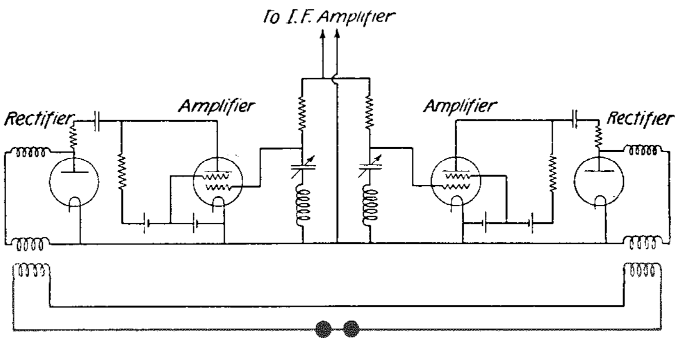


Fig. 5

An arrangement in which linear conversion can be effected without handicapping the system with respect to amplitude disturbances is illustrated diagrammatically in Fig. 5. Two branch circuits each containing resistance, capacity, and inductance in series as shown are connected to the intermediate-frequency amplifier of a superheterodyne at some suitable frequency. One capacity and inductance combination is made nonreactive for one extreme of the frequency band which the signal current traverses and the other capacity and inductance combination is made nonreactive for the other end of the band. The resistances are chosen sufficiently high to maintain the current constant over the frequency range of the band; in fact, sufficiently high to make each branch substantially aperiodic. The reactance characteristics taken across each capacity and inductance combination will be as illustrated in Fig. 6 by curves A and B. Since the resistances in series with the reactance combinations are sufficient to keep the current constant throughout the frequency band it follows that the voltages developed across each of the two combinations will be proportional to their reactances as is illustrated in curves A' and B'. The two voltages are applied respectively to the two equal aperiodic amplifiers, each of which is connected to a linear rectifier. The rectifiers are in series with equal output transformers whose secondaries are so poled that changes in the rectifier currents resulting from a change in the frequency of the received signal produce additive electromotive forces in their secondaries. Since amplifiers and rectifiers are linear the output currents will follow the amplitude variations created by the action of the capacity-inductance combinations. While the variation in reactance is not linear with respect to the change of frequency, particularly where the width of the band is a substantial percentage of the frequency at which the operation takes place, as a practical matter, by the proper choice of values together with shunts of high resistance or reactance

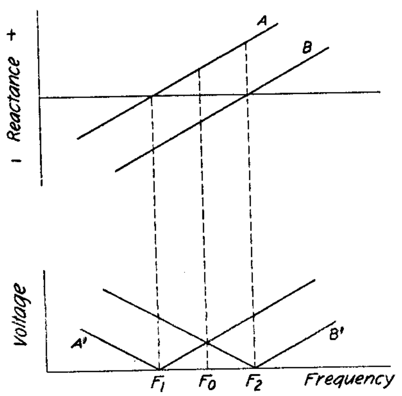


Fig. 6

these characteristics may be rendered sufficiently straight within the working range to meet the severest requirements of high fidelity broadcasting. The operation of the system is aperiodic and capable of effecting 100 per cent modulation if desired, this last depending on the separation of the two nonreactive points with respect to the frequency swing. Generally the setting of the nonreactive frequency points should be somewhat beyond the range through which the frequency is swung.

There is shown in Fig. 7 an alternative arrangement of deriving the signal from the changes in frequency of the received wave which has certain advantages of symmetry over the method just, described. In this arrangement a single capacity-inductance combination with the nonreactive point in the center of the frequency band is used and the rectifiers are polarized by a current of constant amplitude derived from the received current. In this way, by properly phasing the polarizing current, which is in effect a synchronous heterodyne, differential rectifying action can be obtained. In Fig. 7 the amplified output of the receiver is applied across the single series circuit consisting of resistance *R*, capacity *C*, and inductance *L*. The reactance of *C* and *L* are equal for the mid-frequency point of the band and the reactance curve is as illustrated in A of Fig. 8. At frequencies above the nonreactive

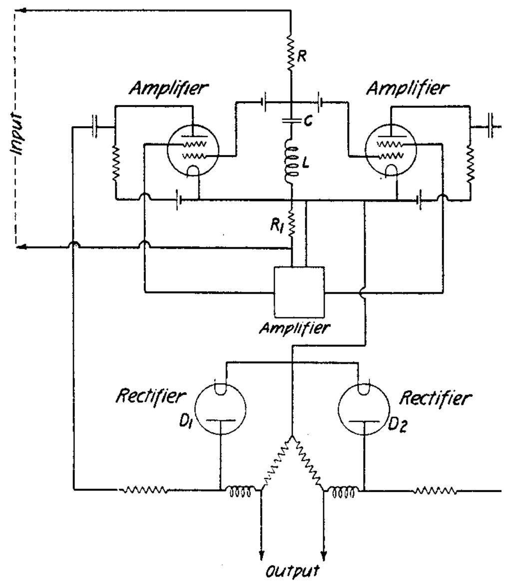


Fig. 7

point the combination acts as an inductance; at frequencies below the nonreactive point as a capacity and the phase of the voltage developed across the combination with respect to the current through it

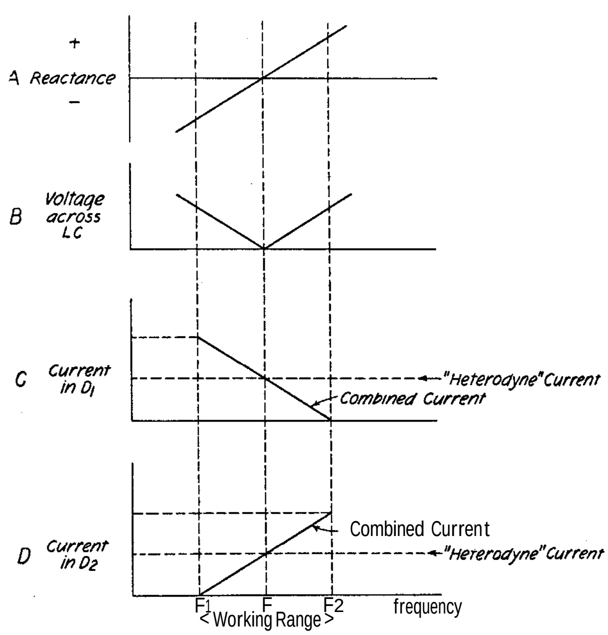


Fig. 8

differs, therefore, by 180 degrees above and below the nonreactive point. Since the current through the circuit is maintained constant over the working range by the resistance *R* and since the resistance of the capacity C and inductance L may be made very low the electromotive force developed across C and L is of the form shown in curve B. This curve likewise represents the variation in voltage with variation in frequency which is applied to the grids of the amplifiers and eventually to the two rectifiers D_1 and D_2.

The heterodyning or polarizing voltage is obtained by taking the drop across the resistance $R1$, amplifying it, changing its phase through ninety degrees and applying the amplified voltage to the screen grids of the amplifiers in opposite phase. The characteristic of this amplifying and phase changing system must be flat over the working range. Under these conditions the signaling and heterodyning voltages are exactly in phase in one rectifier and 180 degrees out of "phase in the other, and hence for a variable signaling frequency the rectifying characteristics are as shown in curves C and D the detector outputs being cumulatively combined for frequency changes. Adjustment of the relative amplitudes of the signaling and polarizing voltages in the rectifier controls the degree of amplitude modulation produced from 100 per cent down to any desired value.

PART II

With the foregoing description of the instrumentalities for transmitting and receiving frequency modulated waves it is now in order to consider the main object of the paper; the method of reducing disturbances and the practical results obtained by its use.

Method of Reducing Disturbances

The basis of the method consists in introducing into the transmitted wave a characteristic which cannot be reproduced in disturbances of natural origin and utilizing a receiving means which is substantially not responsive to the currents resulting from the ordinary types of disturbances and fully responsive only to the type of wave which has the special characteristic.

The method to be described utilizes a new principle in radio signaling the application of which furnishes an interesting conflict with one which has been a guide in the art for many years; i.e., the belief that the narrower the band of transmission the better the signal-to-noise ratio. That principle is not of general application. In the present method an opposite rule applies.

It appears that the origin of the belief that the energy of the disturbance created in a receiving system by random interference depended on the band width goes back almost to the beginning of radio. In the days of spark telegraphy it was observed that "loose coupling" of the conventional transmitter and receiver circuits produced a "sharper wave" and that interference from lightning discharges, the principle "static" of those days of insensitive and nonamplifying receivers was decreased. Further reduction in interference of this sort occurred when continuous-wave transmitters displaced the spark and when regeneration narrowed the band width of the receiving system. It was observed, however, that "excessive resonance" must not be employed either in telegraphic or more particularly in telephonic signaling or the keying and speech would become distorted. It was concluded in a qualitative way that there was a certain "selectivity" which gave the best results.

In 1925 the matter was placed on a quantitative basis by Carson[9] where in a mathematical treatment of the behavior of selective circuits when subjected to irregular and random interference (with particular reference to "static"), on the basis of certain assumptions, the proposition was established that "if the signaling system requires the transmission of the band of frequencies corresponding to the interval $\omega_2 - \omega_1$ and if the selective circuit is efficiently designed to this end, then the mean square interference current is proportional to the frequency band width $(\omega_2 - \omega_1)/2\pi$.

Hazeltine[10] pointed out that when a detector was added to such a system and a carrier of greater level than the interference currents was present, that for aural reception only those components of the interfering current lying within audible range of the carrier frequency were of importance and that Carson's theory should be supplemented by the use of a factor equal to the relative sensitivity of the ear at different frequencies.

With the discovery of shot effect and thermal agitation noises and the study of their effect on the limit of amplification quantitative relations akin to those enunciated by Carson with respect to static were found to exist.

Johnson,[11] reporting the discovery of the electromotive force due to thermal agitation and considering the problem of reducing the noise in amplifiers caused thereby, points out that for this type of disturbance the theory indicates, as in the Carson theory, that the frequency range of the system should be made no greater than is essential for the proper transmission of the applied input voltage, that where a voltage of constant frequency and amplitude is used one may go to extremes in

[9] J. R. Carson, "Selective circuits and static interference," *Bell Sys. Tech. Jour.*, vol. 4, p. 265, (1925).

[10] L. A. Hazeltine, Discussion on "The shielded neutrodyne receiver," PROC. I.R.E., vol. 14, pp. 408, 409; June, (1926).

[11] J. B. Johnson, "Thermal agitatioq of electricity in conductors, *Phys. Rev., vol.* 32, no. 1, July, (1926).

making the system selective and thereby proportionately reducing the noise, but that when the applied voltage varies in frequency or amplitude the system must have a frequency range which takes care of these variations and the presence of a certain amount of noise must be accepted.

Ballantine[12] in a classical paper discussing the random interference created in radio receivers by shot and thermal effects obtained a complete expression for the noise output.[13]

Johnson and Llewellyn,[14] in a paper dealing generally with the limits to amplification, point out that in a properly designed amplifier the limit resides in thermal agitation in the input circuit to the amplifier, that the power of the disturbance in the output of the amplifier is proportional to its frequency range and that this, the only controllable factor in the noise equation, should be no greater than is needed for the transmission of the signal. A similar conclusion is reached in the case of a detector connected to the output of a radio-frequency amplifier and supplied with a signal carrier.

It is now of interest to consider what happens in a linear detector connected to the output of a wide band amplifier which amplifies uniformly the range from 300 to 500 kilocycles. Assume that the amplification be sufficiently great to raise the voltage due to thermal agitation and shot effect to a point sufficient to produce straight-line rectification and that no signal is being received. Under these conditions the frequencies from all parts of the spectrum between 300 and 500 kilocycles beat together to contribute in the output of the detector to the rough hissing tone with which the art is familiar. The spectrum of frequencies in the rectified output runs from some very low value which is due to adjacent components throughout the range beating with one another to the high value of 200 kilocycles caused by the interferences of the extremes of the band.

It is important to note that all parts of the 300- to 500-kilocycle spectrum contribute to the production in the detector output of those frequencies with which we are particularly interested-those lying within the audible range.

[12] Stuart Ballantine, "Fluctuation noise in radio receivers," PROC. I.R.E., vol. 18, pp. 1377-1387; August, (1930).

[13] Ballantine expressed his result as follows: "In a radio receiver employing a square-law detector and with a carrier voltage impressed upon the detector, the audio-frequency noise, as measured by an instrument indicating the average value of the square of the voltage (or current), is proportional to the area under the curve representing the square of the over-all transimpedance (or of the transmission) from the radio-frequency branch in which the disturbance originates to the measuring instrument as a function of frequency and proportional to the square of the carrier voltage."

[14] J. B. Johnson and F. B. Llewellyn, "Limits to amplification," *Trans. A.I.E.E.*, vol. 53, rio. 11, November, (1934).

Assume now that an unmodulated signal carrier is received of, for example, 400 kilocycles and that its amplitude is greater than that of the disturbing currents. Under these circumstances an entirely new set of conditions arise. The presence of the 400-kilocycle current stops the rectification of the beats which occur between the various components of the spectrum within the 300- to 500-kilocycle band and forces all rectification to take place in conjunction with the 400-kilocycle carrier. Hence in the output of the rectifier there is produced a series of frequencies running from some low value up to 100 kilocycles. The lowest frequency is produced by those components of the spectrum which lie adjacent to the 400-kilocycle current, the highest by those frequencies[15,16] which lie at the extremity of the band; i.e., 300 and 500 kilocycles, respectively.

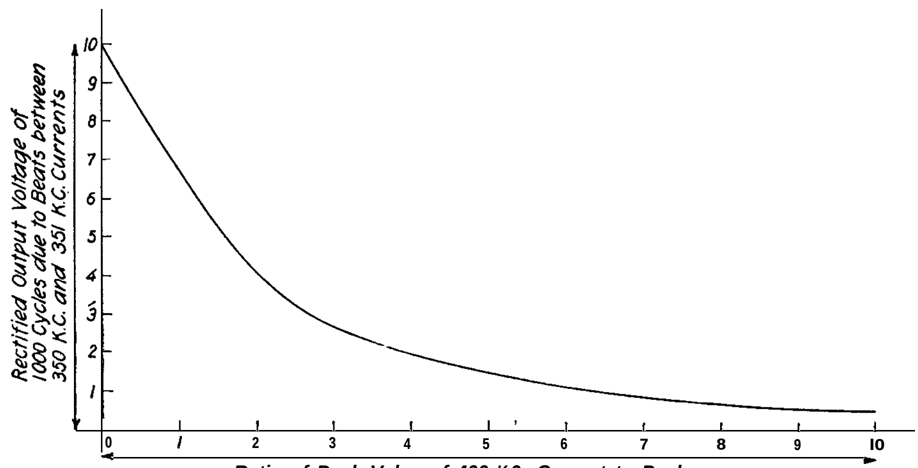


Fig. 9

The characteristics of the rectifiers and the magnitude of some of the effects involved in the above-described action may be visualized by reference to the succeeding figures. The actual demodulation of the beats occurring between adjacent frequency components by the presence of the 400-kilocycle current is shown by the characteristic of Fig. 9, which illustrates what happens to the output voltage of a rectifier produced by beating together two equal currents of 350 and 351 kilocycles, respectively, when a 400-kilocycle current is introduced in the same rectifier and its amplitude progressively increased with respect

[15] It has been pointed out by Ballantine[16] that it is improper to speak of the amplitude of a single component of definite frequency and that the proper unit is the noise per frequency interval. This is, of course, correct, but to facilitate the physical conception of what occurs in this system the liberty is taken of referring to the noise components as though they were of continuous sine wave form. The behavior of the system may be checked by actually introducing from a local generator such components.

"Fluctuation noise in radio receivers," PROC. I.R.E., vol. 18, pp. 1377-1387; August, (1930).

to the amplitude of these two currents. The characteristic was obtained with the arrangement shown in Fig. 10, in which two oscillators of 350 and 351 kilocycles produced currents of equal strength in a linear rectifier, this rectifier consisting of a diode in series with 10,000 ohms resistance. The output of the rectifier is put through a low-pass filter, a voltage divider, and an amplifier. The 400-kilocycle current is intro-

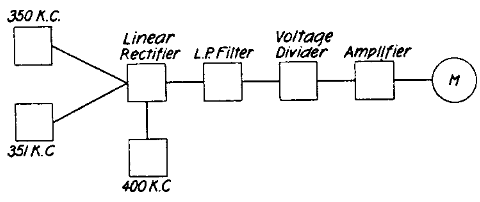


Fig. 10

duced into the rectifier without disturbing the voltage relations of the other two oscillators and the effect on the rectified output voltage observed as the 400-kilocycle current is increased. The purpose of the low-pass filter is to prevent the indicating instrument from responding to the 49- or 50-kilocycle currents produced by the interaction of the 350- and 351-kilocycle currents with the current of 400 kilocycles. The

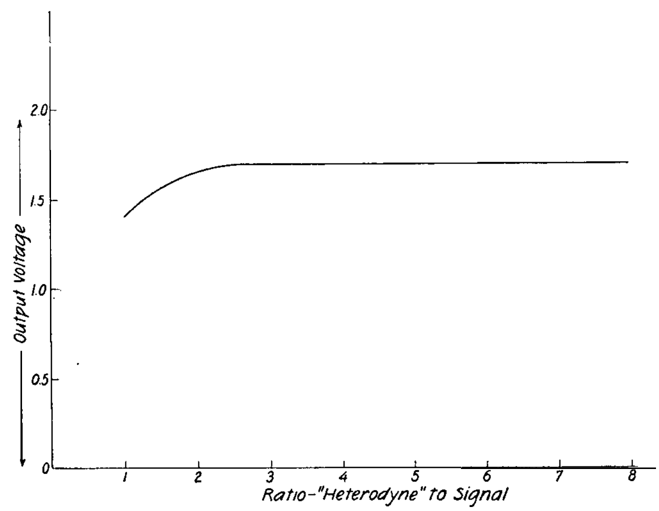


Fig. 11

linearity characteristic of the rectifier is shown in Fig. 11 where the voltage produced by the beats between a current of constant amplitude and one whose amplitude is raised from equality with, to many times the value of, the first current is plotted against the ratio of the two. The linearity of the rectifier is such that after the ratio of the current becomes two to one no further increase, in rectifier output voltage results. In fact with the levels used in these measurements when the two currents are equal there is an efficiency of rectification of only about twenty per cent less than the maximum obtained.

It is important to note here that the only frequencies in the spectrum which contribute to the production of currents of audible frequency in the detector output circuit are those lying within audible range of the signal carrier. We may assume this range as roughly from 390 to 410 kilocycles. The frequencies lying beyond these limits beat against the 400-kilocycle carrier and of course are rectified by the detector but the rectified currents which are produced are of frequencies which lie beyond the audible range and produce therefore no effect which is apparent to the ear. It follows that if the signal carrier is somewhat greater in amplitude than the disturbing currents the signal-to-noise ratio for a receiver whose band of admittance covers twice the audible range will be the same as for one whose band width is many times that value. (There are, of course, certain second order effects, but they are of such minor importance that the ear cannot detect them.) The amplitude of the disturbances in the detector output, will vary in accordance as the components of the disturbing currents come into or out of phase with the signal carrier, the rectified or detector output current increasing above and decreasing below the level of the rectified carrier current by an amount proportional to the amplitude of the components of the 300-500-kilocycle band. The reasons for the independence of the signal-to-noise ratio of the band width under the circumstances which have been described should now be apparent. In any event, it can be readily demonstrated experimentally.

It is now in order to consider what happens when a current limiting device is introduced between the output of the amplifier and the detector input. (Assume signal level still above peak noise level.) Two effects will occur. One of the effects will be to suppress in the output circuit of the limiter all components of the disturbing currents which are in phase with, or opposite in phase to, the 400-kilocycle carrier. The other effect will be to permit the passage of all components of the disturbing currents which are in quadrature with the 400-kilocycle current.

Both the above effects are brought about by a curious process which takes place in the limiter. Each component within the band creates an image lying on the opposite side of the 400-kilocycle point whose frequency difference from the 400-kilocycle current is equal to the frequency difference between that current and the original component. The relative phase of the original current in question, the 400-kilocycle current and the image current is that of phase modulation-that is, at the instant when the original component and its image are in phase with each other, the 400-kilocycle current will be in quadrature with them both and at the instant that the 400-kilocycle current is in phase with one of these two frequencies, it will be out of phase with the other.

The relation (obtained experimentally) between the amplitudes of the original current and the image is illustrated by the curve of Fig. 12,

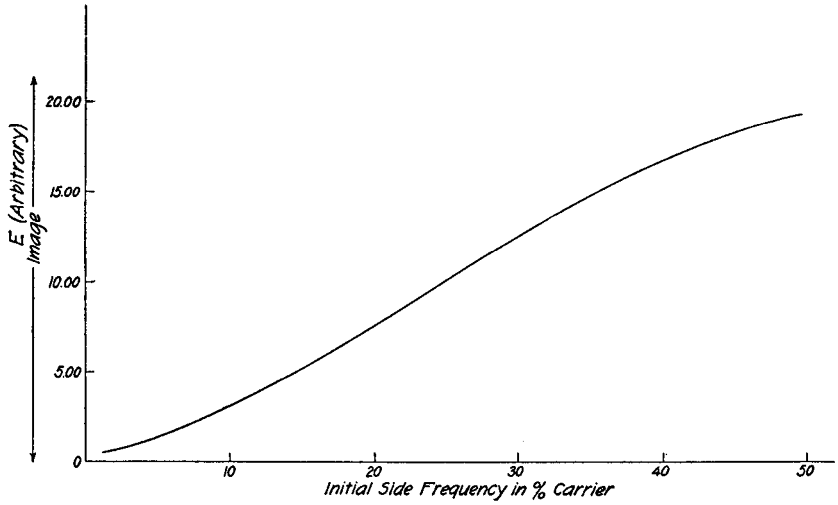


Fig. 12

which shows the relation between the amplitude of a 390-kilocycle current introduced into a limiter along with the 400-kilocycle current and the resulting 410-kilocycle image in terms of percentage amplitude of the 400-kilocycle current. It will be obvious from the curve that in the region which is of interest-that is, where the side frequencies are smaller than the mid-frequency-that the effect is substantially linear.

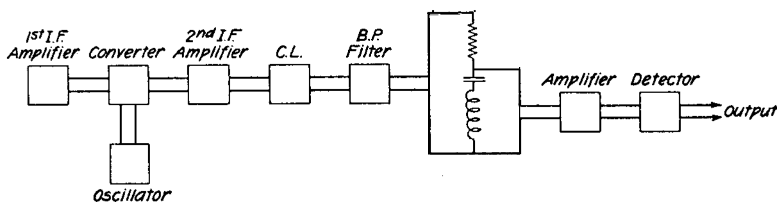


Fig. 13

With the above understanding of what takes place in the current limiter it is now in order to consider what happens when a selective system as illustrated in Fig. 13 is interposed between the limiter and the detector. (The band-pass filter is for the purpose of removing limiter harmonics.) A rough picture of what occurs may be had- by considering a single component of the interferenc spectrum. Suppose this component to be at 390 kilocycles and that by the action already explained it has created its image at 410 kilocycles. These two frequencies are equal in amplitude and so phased with respect to each other and with respect to the 400-kilocycle carrier that no amplitude change results.

Assume now that the selective system has the characteristic *MN* which as shown in Fig. 14 is designed to give complete modulation for a ten-kilocycle deviation of frequency. Since at 390 kilocycles the reactance across the capacity-inductance combination is zero and at 410 kilocycles double what it is at 400 kilocycles it follows that the 390-kilocycle component becomes equal to zero but the ratio of the 410-kilocycle component to the 400-kilocycle carrier is doubled; that

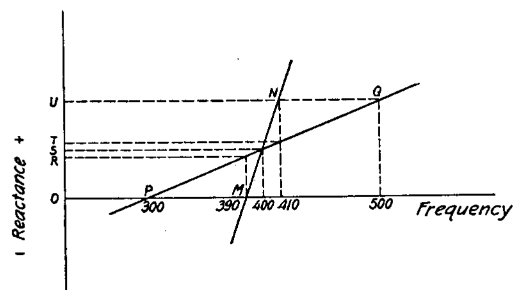


Fig. 14

is, it is twice as great as is the ratio in the circuits preceding the selective system. The change in amplitude, therefore, becomes proportional to *OU*. Therefore in combination with the 400-kilocycle carrier a variation in amplitude is produced which is substantially identical with that which would be obtained were the current limiter removed and the selective system replaced by an aperiodic coupling of such value that the same detector level were preserved.

Now consider what occurs when a selective system having the characteristic such as *PQ* and requiring a deviation of 100 kilocycles to produce full modulation is employed instead of one such as *MN*, where a ten-kilocycle deviation only is required. Assume the same conditions of interference as before. The 400-kilocycle voltage applied to the rectifier will be the same as before, but the *relative amplitudes of the 390- and 410-kilocycle voltages will only be slightly changed.* The 410-kilocycle voltage will be increased from a value which is proportional to *OS* to one which is proportional to *OT* and the 390-kilocycle voltage will be reduced from a value proportional to *OS* to one proportional to *OR*. The difference in value of the two frequencies will be proportional to the difference between *OS* and *OT* or *RT*, and the change in amplitude produced by their interaction with the 400-

kilocycle current will be likewise proportional to *RT*. The reduction in the amplitude of the disturbance as measured in the detector output by the use of a 200-kilocycle wide selective system as compared to the use of one only twenty kilocycles wide is therefore the ratio *RT/OU*. In this case it is ten per cent. The power ratio is the square of this or one per cent.

The above reasoning holds equally well if a balanced rectifying system is used where the characteristics of the selective system are as shown in Fig. 15. The output of the system insofar as voltages resulting from changes in frequency are concerned is the sum of outputs of the two sides of the balance.

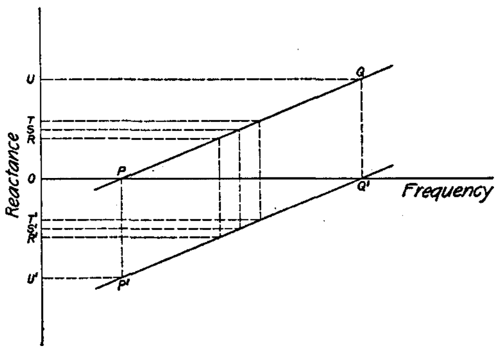


Fig. 15

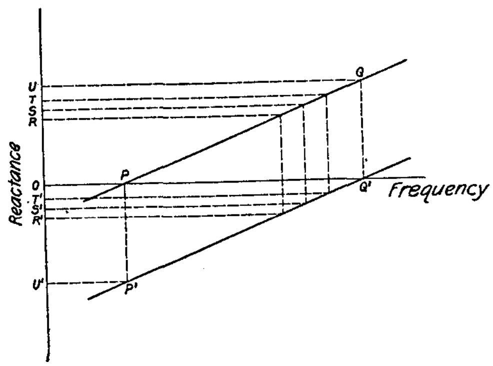


Fig. 16

It is of course clear that disturbing currents lying farther from the 400-kilocycle point than the ten-kilocycle limit will, by interaction with the 400-kilocycle current, produce larger values of rectified current than those lying within that band, *But the rectified currents produced in the detector output by those components of frequency which lie at a greater than audible frequency distance from the 400-kilocycle current will be beyond the audible range and hence will produce no disturbance which is audible.* (It is generally advisable to eliminate them from the audio amplifier by a low-pass filter to prevent some incidental rectification in the amplifier making their variations in amplitude audible.)

It remains only to consider what happens when the frequency of the 400-kilocycle current is varied in accordance with modulation at the transmitter. It is clear from Fig. 14 that when the selective system has the characteristic *MN* that a deviation of 10,000 cycles will produce complete modulation of the signal or a change in amplitude proportional to *OU*. Similarly, when the characteristic is according to the curve *PQ* it is clear that a 100,000-cycle deviation is required to produce complete modulation, which is likewise proportional to the same value *OU*. As the signal current is swung back and forth over the range of frequencies between 300 and 500 kilocycles the band of frequencies from which the audible interference is derived continually changes, the band progressively lying about ten kilocycles above and ten kilocycles below what we may call the instantaneous value of the frequency of the signal. The effect is illustrated by Fig. 16 and from this it will be seen that the amplitude of the disturbances in the output circuit of the rectifiers, which is proportional to the sum of RT and RT will be constant. This will be true where the ratio of the amplitude of the signal to the disturbing currents is sufficiently large-where this condition does not exist then there are certain other effects which modify the results, but these effects will only be of importance at the limits of the practical working range.

Comparison of Noise Ratios of Amplitude and Frequency Modulation Systems

From the foregoing description it will be clear that as between two frequency modulation systems of different band widths the signal-to-noise power ratio in the rectified output will vary directly as the square of the band width (provided the noise voltage at the current limiter is less than the signaling voltage). Thus doubling the band width produces an improvement of 4 to 1 and increasing it tenfold an improvement of 100 to 1.

The comparison of relative noise ratios of amplitude and frequency modulation systems cannot be made on so simple a basis as there are a number of new factors which enter, particularly when the comparison is viewed from the very practical aspect of how much greater power must be used with an amplitude modulated transmitter than with a frequency modulated one. If the academic comparison be made between a frequency modulated system having a deviation of ten kilocycles and an amplitude modulated one of similar band width and the same carrier level (also same fidelity), it will be found that the signal-to-noise voltage ratio as measured by a root-mean-square meter will favor the frequency modulation system by about 1.7 to 1, and that the corresponding power ratio will be about 3 to 1. This improvement is due to the fact that in the frequency modulation receiver it-is only those noise components which lie at the extremes of the band; viz., ten kilocycles away from the carrier which, by interaction with the carrier (when unmodulated) can produce the same amplitude of rectified current as will be produced by the corresponding noise component in the amplitude modulated receiver.

Those components which lie closer to the carrier than ten kilocycles will produce a smaller rectified voltage, the value of this depending on their relative distance from the carrier. Hence the distribution of energy in the rectified current will not be uniform with respect to frequency but will increase from zero at zero frequency up to a maximum at the limit of the width of the receiver, which is ten kilocycles in the present case. The root-mean-square value of the voltage under such a distribution is approximately 0.6 of the value produced with the uniform distribution of the amplitude receiver.

Similarly in comparing an amplitude modulation system arranged to receive ten-kilocycle modulations and having, of course, a band width of twenty kilocycles, with a 100-kilocycle deviation frequency

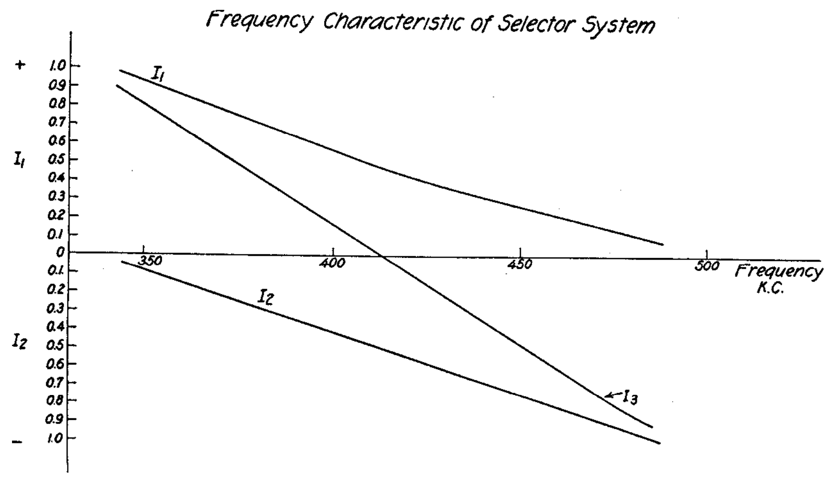


Fig. 17

modulation system (same carrier level and same fidelity) there will be an improvement in noise voltage ratio of

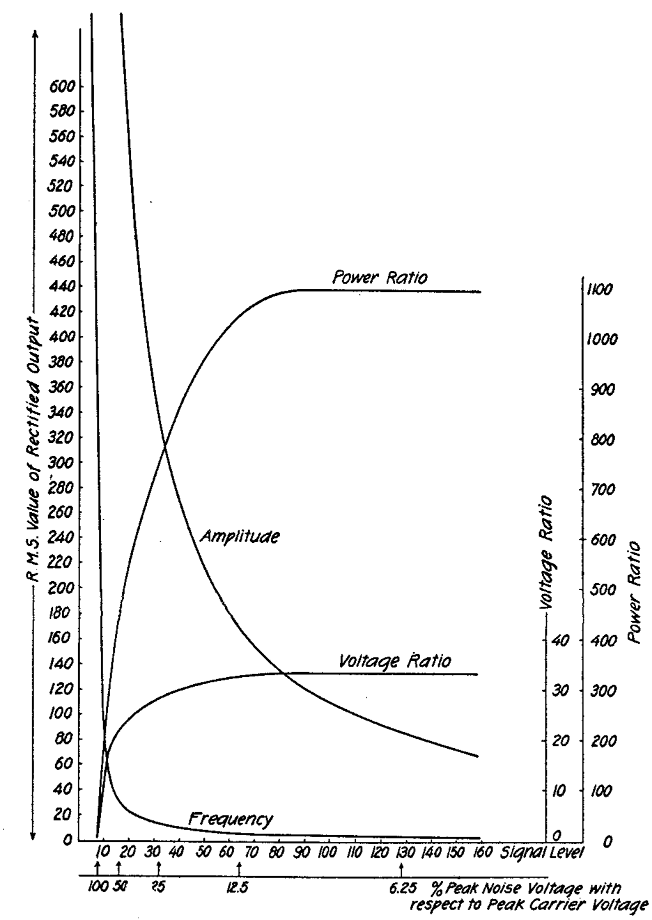
$$1.7 \times \frac{\text{deviation}}{\text{audio-frequency range}} \quad \text{or} \quad 1.7 \times \frac{100}{10} = 17.$$

The above comparisons have been made on the basis of equal carrier. The practical basis of comparison between the two is that of half carrier for the amplitude modulation and full carrier for the frequency modulation system. This results in about the equivalent amount of power being drawn from the mains by the two systems. On this basis the voltage improvement becomes thirty-four and the signal-to-noise power ratio 1156. Where the signal level is sufficiently large with respect to the noise it has been found possible to realize improvements of this order.

The relative output signal-to-noise ratios of an amplitude modulation system fifteen kilocycles wide (7.5-kilocycle modulation frequency) and a frequency modulation system 150 kilocycles wide (75-kilocycle deviation) operating on forty-one megacycles have been compared on the basis of equal fidelity and half carrier for amplitude modulation, The characteristic of the selective system for converting frequency changes to amplitude changes, which was used, is shown in Fig. 17. The variation of the output signal-to-noise ratio with respect to the corresponding radio-frequency voltage ratio is illustrated in Fig. 18. The curves show that where the radio-frequency peak voltage of the noise measured at the current limiter is less than ten per cent of the

Fig. 18

signal peak voltage then the energy of the disturbance in the rectified output will be reduced by a factor which is approximately 1100 to 1. When the peak radio-frequency noise voltage is twenty-five per cent of the signal peak voltage then the energy of the disturbance in the rectified output has been reduced to about 700 to 1, and when it is fifty per cent the reduction of the disturbance drops below 500 to 1. Finally when the noise and signal peak voltages become substantially equal the improvement drops to some very low value. While it is unfortunate, of course, that the nature of the effect is such that the amount of noise reduction becomes less as the noise level rises with respect to the signal, nevertheless this failing is not nearly so important


R.M.S. Value of Rectified Output
Power Ratio
Amplitude
Voltage Ratio
Frequency
Signal Level
% Peak Noise Voltage with respect to Peak Carrier Voltage
Voltage Ratio
Power Ratio

as it would appear. In the field of high fidelity broadcasting a signal-to-noise voltage ratio of at least 100 to 1 is required for satisfactory reception. It is just within those ranges of noise ratios which can be reduced to this low level that the system is most effective.

The arrangements employed in obtaining these characteristics and the precautions which must be observed may perhaps be of interest. As it was obviously impracticable to vary the power of a transmitter over the ranges required or to eliminate the fading factor except over short periods of time an expedient was adopted. This expedient consisted in tuning the receiver to the carrier of a distant station, determining levels and then substituting for the distant station a local signal generator, the distant station remaining shut down except as it was

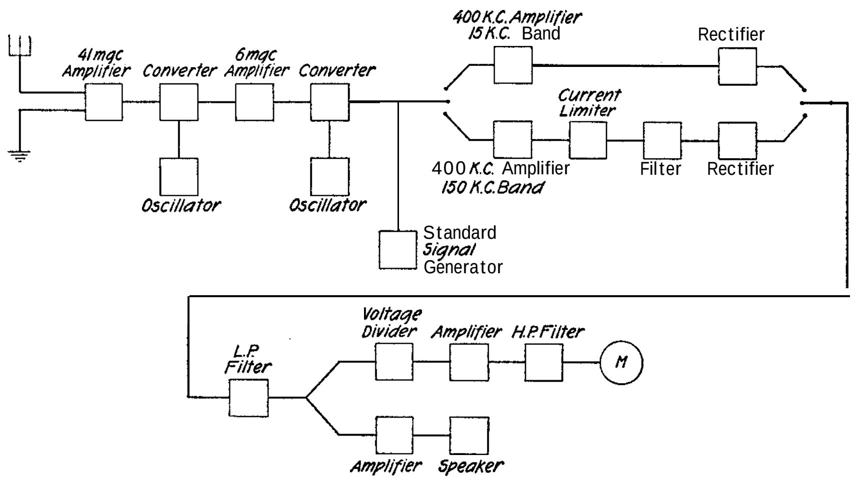


Fig. 19

called upon to check specific points on the curve. Observations were taken only when the noise was due solely to thermal agitation and shot effect.

Fig. 19 shows the arrangement of apparatus. The receiver was a two-intermediate-frequency superheterodyne with provision for using either a narrow band second intermediate amplifier with the amplitude modulation system or a wide band amplifier with the frequency modulation system. The band width of the amplitude modulation system was fifteen kilocycles or twice the modulation frequency range. The band width of the frequency modulation receiver was 150 kilocycles or twice the frequency deviation. Provision was made for shifting from one intermediate amplifier to the other without disturbing the remainder of the system, The forty-one-megacycle circuits and the first intermediate amplifier circuits were wide enough to pass the frequency swing of 150 kilocycles. Identical detection systems were used, the frequency modulation detector being preceded by a selective system for translating changes in frequency into changes in amplitude. The output circuits of the detectors were arranged to be connected alternately to a 7500-cycle low-pass filter with a voltage divider across its output. An amplifier with a flat characteristic over the audible range and a root-mean-square meter connected through a high-pass, 500-cycle filter provided the visual indication.

The standard signal was introduced into the input of the two branches of the second intermediate-frequency stage at 400 kilocycles. As long as the receiver is linear between the antenna and the point at which the standard signal is introduced it is immaterial whether the signal be of forty-one megacycles, six megacycles, or 400 kilocycles. This has been checked experimentally but 400 kilocycles was chosen on account of the greater accuracy of the signal generator on low frequencies.

The relative noise levels to be compared varied over such ranges that lack of linearity had to be guarded against and readings were made by bringing the output meter to the same point on the scale each time by adjustment of the voltage divider, and obtaining the relative voltages directly from the divider.

Two other precautions are essential. The absolute value of the noise voltage on the frequency modulation system becomes very low for high signal levels. If the voltages due to thermal agitation and shot effect are to be measured rather than those due to the power supply system the output meter must be protected by a high-pass filter of high attentuation for the frequencies produced by the power system. The cutoff point should be kept as low as possible since because of the difference in the distribution of energy in the rectified outputs of frequency and amplitude modulation receivers already referred to there is a certain error introduced by this filter which is small if the band width excluded by the filter is small but which can become appreciable if too much of the low-frequency part of the modulation frequency range be suppressed.

A second precaution is the use of a low-pass filter to cut off frequencies above the modulation range. Because of the wide band passed by the amplifiers of the frequency modulation part of the system there exists in the detector output rectified currents of frequencies up to seventy-five kilocycles. The amplitude of these higher frequencies is much greater than those lying within the audible range. The average detector output transformer will readily pass a substantial part of these superaudible frequencies which then register their effect upon the output meter although they in no way contribute to the audible disturbance.

The procedure which was followed in making the measurements we are considering consisted in tuning the receiver to the distant transmitter and adjusting the two detector levels to the same value for the respective carrier levels to be employed. This was done by cutting the carrier in half at the transmitter when the amplitude modulation detector level was being set and using full carrier for the adjustment of the frequency modulation detector. Each system was then modulated seventy-five per cent and output voltages checked against each other. If they were equal the modulation was removed and the relative noise voltages measured for the respective carrier levels. This gave the first point on the curve. The transmitter was then shut down and a local carrier introduced which gave the same level in the 400-kilocycle intermediate amplifier circuits as the half carrier distant signal. This level was directly ascertainable from the rectified detector current in the amplitude modulation system. From this point on the procedure was entirely within the control of the receiving station. The noise ratios could be compared at any signal level by adjusting the voltage introduced by the signal generator to any fraction of that of the distant signal, bringing the level in the amplitude modulation detector up to the same original value by adjustment of the amplification of the second intermediate amplifier (the frequency modulation detector stays at its point of reference because of the current limiter) and comparing the two output voltages. The level of the detector in the amplitude modulation receiver was of course set with the half carrier value of the signal generator and the output voltage measured at that level. The output voltage of the frequency modulation system was measured when twice that voltage was applied.

It is important to keep in mind just what quantities have been measured and what the curves show. The results are a comparison between the relative noise levels in the two systems (root-mean-square values) *when they are unmodulated.* In both an amplitude and in a frequency modulation receiver the noise during modulation may be greater than that obtained without modulation. In the frequency modulation receiver two principal sources may contribute to this increase, one of which is of importance only where the band for which the receiver is designed is narrow, the other of which is common to all band widths. If the total band width of the receiver is twenty kilocycles and if the deviation is, for example, ten kilocycles, then as the carrier frequency swings off to one side of the band, it approaches close to the limit of the filtering system of the receiver. Since the sides of the filter are normally much steeper than the selective system employed to convert the changes in frequency into amplitude variations and since the frequency of the signaling current will have approached to within the range of good audibility of the side of the filter a considerable increase in both audibility and amplitude of the disturbance may occur, caused by the sides of the filter acting as the translating device. This effect is obviously not of importance where a wider frequency swing is employed.

The other source of noise which may occur when the signal frequency swings over the full range is found in systems of all band widths. It was first observed on an unmodulated signal when it was noted that swinging the intermediate frequency from the mid-point to one side or the other by adjustment of the frequency of the first heterodyne produced an increase in the amplitude and a change in the character of the noise. The-effect was noted on a balanced detector system and at first it was attributed to the destruction of the amplitude balance as one detector current became greater than the other. Subsequently when it was noted that the increase in the noise was produced by the detector with the smaller current and that the effect was most pronounced when the signal level was relatively low, the explanation became apparent. As long as the signal frequency was set at the mid-point of the band its level in the detector was sufficiently large to prevent the production of audible beats between the noise components lying respectively at the two ends of the band where the reactance of the selective systems is a maximum.

When however the signal frequency moves over to one side of the band the amplitude of the voltage applied to one of the detectors progressively decreases, approaching zero as the frequency coincides with the zero reactance point of the selective system. The demodulating effect of the signaling current therefore disappears and the noise components throughout the band, particularly those at the other side of it, are therefore free to beat with each other. The noise produced is the characteristic one obtained when the high-frequency currents caused by thermal agitation and shot effect are rectified in a detector without presence of a carrier. The effect is not of any great importance on the ordinary working levels for simplex operation, although it may become so in multiplex operation. It indicates, however, that where the signal-to-noise level is low, complete modulation of the received signal by the conversion system is not desirable and that an adjustment of the degree of modulation for various relative noise levels is advantageous.

In the course of a long series of comparisons between the two systems a physiological effect of considerable importance was noted. It was observed that while a root-mean-square meter might show the same reading for two sources of noise, one derived from an amplitude modulation, and the other from a frequency modulation receiver (both of the same fidelity) that the disturbance perceived by the ear was more annoying on the amplitude modulation system. The reason for this is the difference in the distribution of the noise voltage with respect to frequency in the rectified output currents of the two systems, the distribution being substantially uniform in the amplitude system but proportional to frequency in the frequency modulation system. Hence in the latter there is a marked absence of those frequencies which lie in the range to which the ear is the most sensitive. With most observers this difference results in their appraising a disturbance produced in the speaker by an amplitude modulation system as the equivalent of one produced therein by a frequency modulation system of about 1.5 times the root-mean-square voltage although of course the factor varies considerably with the frequency range under consideration and the characteristic of the individual s aural system.

On account of this difference in distribution of energy the correct method of procedure in making the comparison is that given in the article by Ballantine,[16] but lack of facilities for such determinations made necessary the use of a root-mean-square meter for the simultaneous measurement of the entire noise frequency range. The increase in noise voltage per frequency interval with the frequency may be readily demonstrated by means of the ordinary harmonic analyzer of the type now so generally used for the measurement of distortion. Because of the extremely narrow frequency interval of these instruments it is not possible to obtain sufficient integration to produce stable meter readings and apparatus having a wider frequency interval than the crystal filter type of analyzer must be used. The observation of the action of one of these analyzers will furnish convincing proof that peak voltmeter methods must not be used in comparing the rectified output currents in frequency and amplitude modulation receivers.

All the measurements which have been heretofore discussed were taken under conditions in which the disturbing currents had their origin in either thermal agitation or shot effect, as the irregularity of atmospheric disturbances or those due to automobile ignition systems were too irregular to permit reproducible results. The curves apply generally to other types of disturbances provided the disturbing voltage is not greater than that of the signal. When that occurs a different situation exists and will be considered in detail later.

There are numerous second order effects produced, but as they are of no great importance consideration of them will not be undertaken in the present paper.

THE NEW YORK-WESTHAMPTON AND HADDONFIELD TESTS

The years of research required before field tests could even be considered were carried out in the Marcellus Hartley Research Laboratory at Columbia University. Of necessity both ends of the circuit had to be under observation simultaneously and a locally generated signal was used: The source of signal ultimately employed consisted of a standard signal generator based upon the principle of modulation already described and capable of giving 150,000 cycles swing on forty-four megacycles. The generator was also arranged to give amplitude modulated signals. Suitable switching arrangements for changing rapidly from frequency to amplitude modulation at either full or half carrier were set up and a characteristic similar to that of Fig. 18 ultimately obtained.

A complete receiving system was constructed and during the Winter of 1933-1934 a series of demonstrations were made to the executives and engineers of the Radio Corporation of America. That wholly justifiable suspicion with which all laboratory demonstrations of static eliminators should be properly regarded was relieved when C. W. Horn of the National Broadcasting Company placed at the writer s disposal a transmitter in that company s experimental station located on top of the Empire State Building in New York City. The transmitter used for the sight channel of the television system delivered about two kilowatts of power at forty-four megacycles to the antenna and it was the one selected for use. This offer of Mr. Horn s greatly facilitated the practical application of the system as it eliminated the necessity of transmitter construction in a difficult field and furnished the highly skilled assistance of R. E. Shelby and T. J. Buzalski, the active staff of the station at that time. Numerous difficulties, real and imaginary, required much careful measurement to ascertain their presence or absence and the relative importance of those actually existing. The most troublesome was due to the position of the transmitter, which is located on the eighty-fifth floor of the building and is connected by a concentric transmission line approximately 275 feet long with a vertical dipole antenna about 1250 feet above ground. Investigation of the characteristics of this link between transmitter and antenna showed it to be so poorly matched to the antenna that the resulting standing waves attained very large amplitude. The problem of termination afforded peculiar -difficulties because of the severe structural requirements of the antenna above the roof and of the transmission line below it. It was however completely solved by P. S. Carter of the R.C.A. Communications Company in a very beautiful manner, the standing waves being practically eliminated and the antenna broadened beyond all requirements of the modulating system contemplated. With the transmitter circuits no difficulty was encountered at this time. The frequency of the system was ordinarily controlled by a master oscillator operating at 1733 kilocycles which was multiplied by a series of doublers and a tripler to forty-four megacycles. The multiplier and amplifier circuits were found to be sufficiently broad for the purposes of the initial tests.

The crystal control oscillator was replaced by the output of the modulation system shown in Fig. 20 in which an initial frequency of 57.33 kilocycles was multiplied by a series of doublers up to the input frequency of the transmitter of 1733 kilocycles. It was found possible to operate this apparatus as it is shown installed in the shielded room

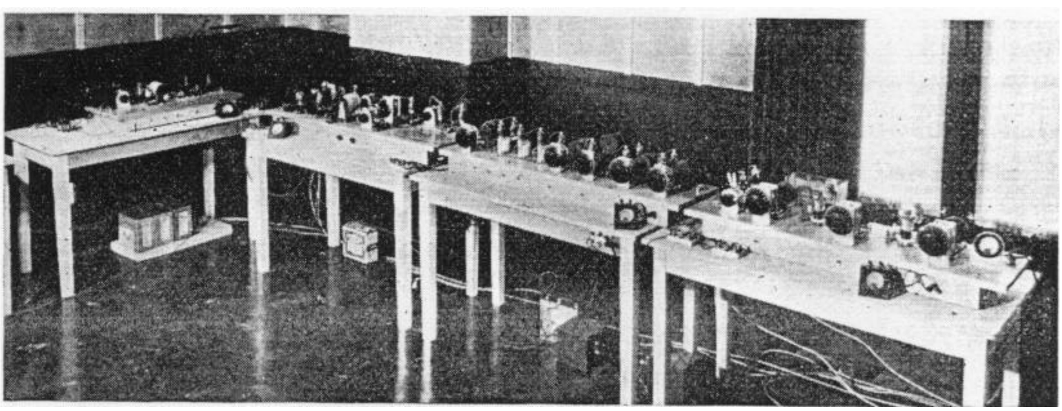


Fig. 20

of the television studio at the Empire State station as the shielding furnished ample protection against the effects of the high power stages of the transmitter located some seventy-five feet away.

The receiving site selected was at the home of George E. Burghard at Westhampton Beach, Long Island, one of the original pioneers of amateur radio, where a modern amateur station with all facilities, including those for rigging directive antennas, were at hand. Westhampton is about sixty-five miles from New York and 800 or 900 feet below line of sight.

The installation is illustrated in Figs. 21 and 22 which show both frequency and amplitude modulation receivers and some of the measuring equipment for comparing them. The frequency modulation receiver consisted of three stages of radio-frequency amplification (at forty-one megacycles) giving a gain in voltage of about 100. This frequency was heterodyned down to six megacycles where an amplification of about 2000 was available and this frequency was in turn heterodyned down to 400 kilocycles where an amplification of about 1000 could be realized. Two current limiting systems in cascade each with a separate amplifier were used. At the time the photograph was taken the first two radio-frequency stages had been discarded.

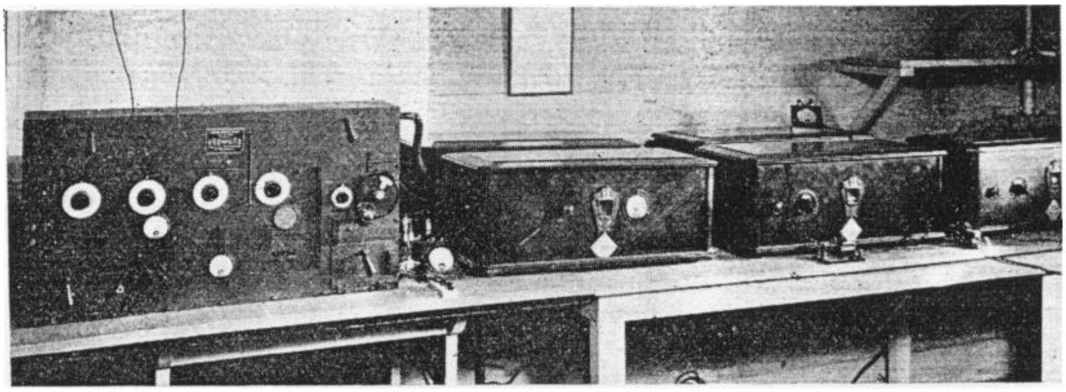


Fig. 21

The initial tests in the early part of June surpassed all expectations. Reception was perfect on any of the antennas employed, a ten-foot wire furnishing sufficient pickup to eliminate all background noises. Suc-

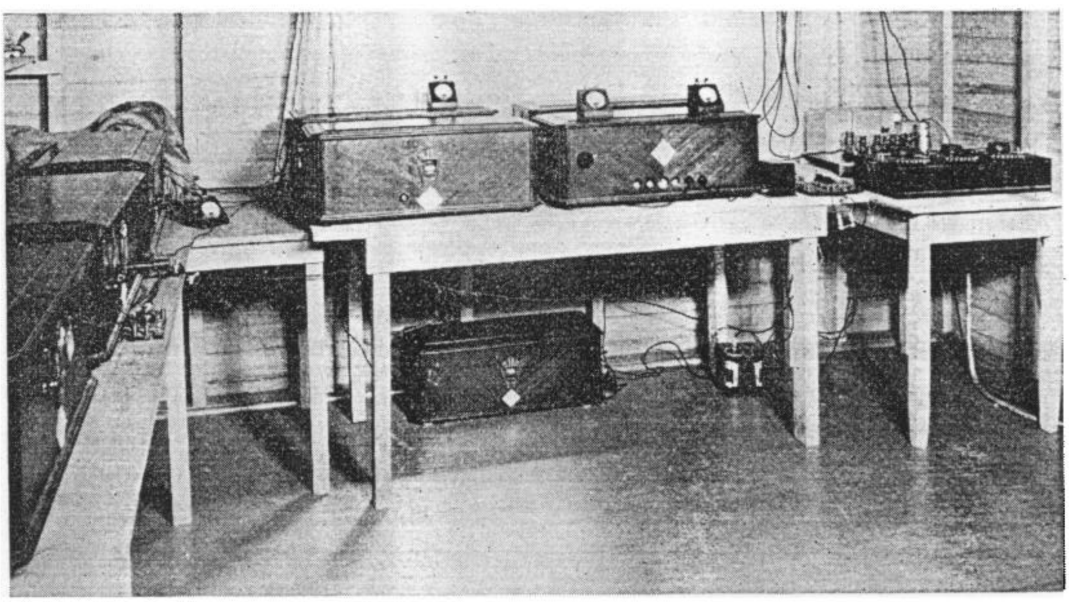


Fig. 22

cessive reductions of power at the transmitter culminated at a level subsequently determined as approximately twenty watts. This gave a signal comparable to that received from the regular New York broadcast stations (except WEAF, a fifty-kilowatt station- approximately forty miles away).

The margin of superiority of the frequency modulation system over amplitude modulation at forty-one megacycles was so great that it was at once obvious that comparisons of the two were principally of academic interest.

The real question of great engineering and economic importance was the comparison of the ultra-short-wave' frequency modulation system with the existing broadcast service and the determination of the question of whether the service area of the existing stations could not be more effectively covered than at present. The remainder of the month was devoted to such a comparison. With the Empire State transmitter operating with approximately two kilowatts in the antenna, at all times and under all conditions the service was superior to that provided by the existing fifty-kilowatt stations, this including station WEAF. During thunderstorms, unless lightning was striking within a few miles of Westhampton, no disturbance at all would appear on the system, while all programs on the regular broadcast system would be in a hopeless condition. Background noise due to thermal agitation and tube hiss were likewise much less than on the regular broadcast system.

The work at Westhampton demonstrated that in comparing this method of transmission with existing methods two classes of services and two bases of comparisons must be used. It was found that the only type of disturbarice of the slightest importance was that caused by the ignition systems of automobiles, where the peak voltage developed by the interferenqe was greater than the carrier level. In point-to-point communication this difficulty can be readily guarded against by proper location of the receiving system, and then thermal agitation and shot effect are the principal sources of disturbance; lightning, unless in the immediate vicinity, rarely producing voltages in excess of the carrier level which would normally be employed to suppress the thermal and shot effects. Under these conditions the full effect of noise suppression is realized and comparisons can be made with precision by means of the method already described in this paper. An illustration of the practical accomplishment of this occurred at Arney's Mount, the television relay point between New York and Camden of the Radio Corporation of America. This station is located about sixty miles from the Empire State Building and the top of the tower is only a few feet below line of sight. It is in an isolated spot and the noise level is almost entirely that due to the thermal and shot effects. It was noted by C. M. Burrill of the RCA Manufacturing Company who made the observations at Arney's Mount that with fifty watts in the antenna frequency modulated (produced by a pair of UX 852 tubes), a signal-to-noise ratio of the same value as the two-kilowatt amplitude modulation transmitter (eight-kilowatt peaks) was obtained.

The power amplifier and the intermediate power amplifier of the frequency modulation transmitter is shown in Fig. 23. The signal with fifty watts output would undoubtedly have had a better noise ratio than the two-kilowatt amplitude modulation system had full deviation of seventy-five kilocycles been employed, but on the occasion it was not possible to use a deviation of greater than twenty-five kilocycles. It was also observed at the same time that when the plate voltage on the power amplifier was raised to give a power of the order of 200 watts in the antenna a better signal-to-noise ratio was obtained than

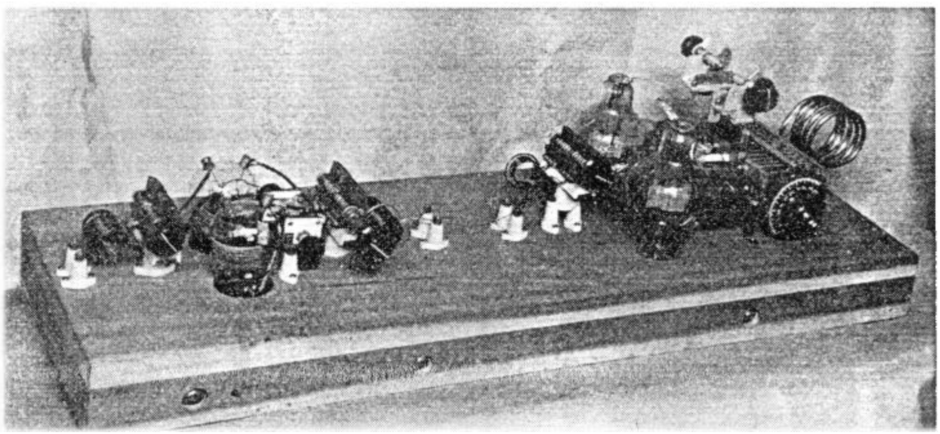


Fig. 23

that which could be produced by the two-kilowatt amplitude modulation. A casual comparison of the power amplifier stages of the frequency modulation transmitter shown in Fig. 23 with the water-cooled power amplifier and modulation stages of the Empire State transmitter is more eloquent than any curves which may be shown herein.

In the broadcast service no such choice of location is possible and a widely variable set of conditions must be met. Depending on the power at the transmitter, the elevation of the antenna, the contour of the intervening country, and the intensity of the interference there will be a certain distance at which peaks of ignition noise become greater than the carrier. The irregularity and difficulty of reproduction of these disturbances require a different method of comparison which will be hereinafter described.

As the site at Westhampton, which was on a section of the beach remote from man-made static, was obviously too favorable a site, a new one was selected in Haddonfield, New Jersey, and about the end of June the receiving apparatus was moved there and erected at the home of Harry Sadenwater. Haddonfield is located about eighty-five miles from New York in the vicinity of Camden, New Jersey, and. is over 1000 feet below line of sight of the top of the Empire State Building in New York. Although the field strength at Haddonfield was considerably below that at Westhampton Beach, good reception was obtained almost immediately, the sole source of noise heard being ignition noise

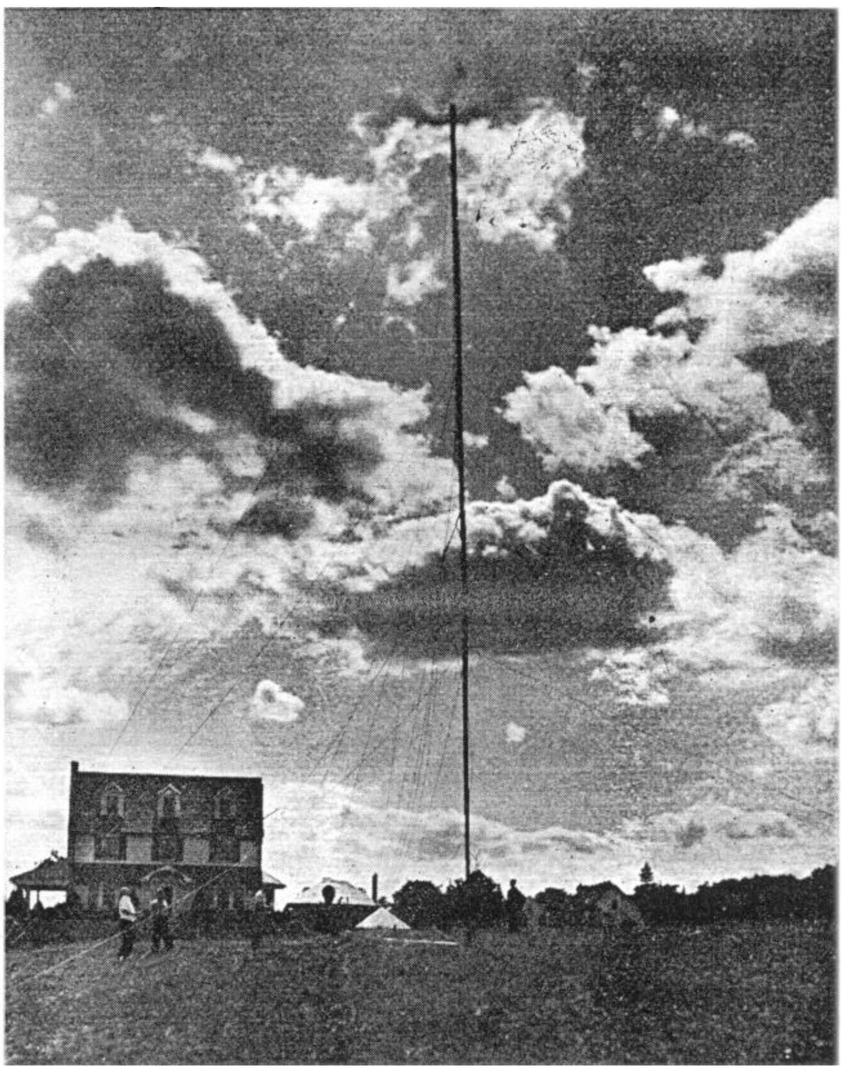


Fig. 24

from a few types of cars in the immediate vicinity of the antenna, or lightning striking within a few miles of the station. At this distance fading made its appearance for the first time, a rapid flutter varying in amplitude three- or four-to-one being frequently observable on the meters. The effect of it was not that of the selective fading so well known in present-day broadcasting. Very violent variations as indicated by the .meters occurred without a trace of distortion being heard in the speaker. During a period of over a year in which observations have been made at Haddonfield, but two short periods of fading have been observed where the signal sank to a level sufficient to bring in objectionable noise, one of these occurring prior to an insulation failure at the transmitter.

It is a curious fact that the distant fading, pronounced though it may be at times, is not so violent as that which may be encountered at a receiving station located within the city limits of New York. The effect, which appears to be caused by moving objects in the vicinity of the receiving antenna, causes fluctuations of great violence. In was apparently first observed by L. F. Jones of the RCA Manufacturing Company within a distance of half a mile of the Empire State transmitter. It occurs continually at Columbia University located about four miles from the Empire State transmitter but no injurious effect on the quality of transmission has ever been noted.

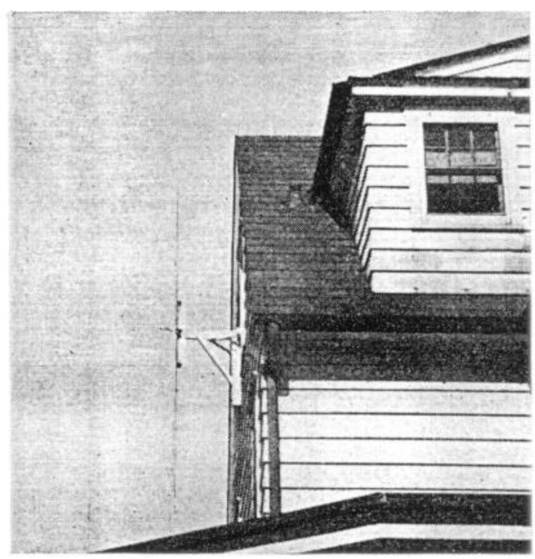


Fig. 25

While at first, because of the lower field strength at Haddonfield and the greater prevalence of ignition disturbances, the superiority over the regular broadcast service was not so marked as at Westhampton Beach, the subsequent improvements which were instituted at both transmitting and receiving ends of the circuit have more than offset the lower signal level. Some idea of their extent may be gained by comparison of the initial and final antenna structures. Fig. 24 shows the original antenna during course of erection, a sixty-five foot mast bearing in the direction of New York permitting the use of an eight-wave length sloping wire of very useful directive properties. Fig. 25

shows the final form on which the results are now much better than were originally obtained with the directional wire.

During the past summer, which was marked by thunderstorms of great severity in the vicinity of Philadelphia, it was the exception when it was agreeable or even possible to listen to the nightly programs of the regular broadcast service from the fifty-kilowatt NewYork stations. In some of the heaviest storms when lightning was striking within the immediate vicinity of the antenna, so close in fact that the lead-in was sparking to a near-by water pipe, perfectly understandable speech could be received on the frequency modulation system, although the disturbance was sufficient to cause annoyance on a musical program; but these periods seldom lasted more than fifteen minutes when the circuit would again become quiet. On numerous occasions the Empire State signal was better than that of the fifty-kilowatt Philadelphia station WCAU located at a distance of twenty miles from Haddonfield. Likewise during periods of severe selective side-band fading in the broadcast band which occurs even from station WJZ at Bound Brook, New Jersey, some sixty miles away, no signs of this difficulty would appear on the ultra-high-frequency wave.

Some of the changes which contributed to the improvement during the past year may be of interest. The introduction of the Thompson-Rose tube permitted the radio-frequency amplification required at forty-one megacycles to be accomplished with one stage and with considerable improvement of signal-to-noise ratio. It had a further interesting result. The tubes previously used for amplifying at this frequency were those developed by the Radio Corporation for the ultra-short-wave interisland communication system in the Hawaiian Islands. On account of the relatively low amplification factor of these tubes the shot effect in the plate circuit of the first tube exceeded the disturbances due to thermal agitation in the input circuit of that tube by a considerable amount. With the acorn type tube, however, the situation is reversed, the thermal noise contributing about seventy-five per cent of the rectified output voltage.

It should be noted here by those who may have occasion to make this measurement on a frequency modulation system that it cannot be made in the ordinary way by simply mis-tuning the input circuit to the first tube. To do so would remove the carrier from the current limiter and be followed by a roar of noise. The measurement must be made with a local signal of the proper strength introduced into one of the intermediate-frequency amplifiers. Under these conditions the antenna may be mis-tuned without interfering with the normal action of the limiter and the relative amounts of noise due to the two sources may readily be segregated.

Considerable trouble was caused during the early stages of the experiments by an order of the Federal Radio Commission requiring the changing of the frequency of the Empire State transmitter from forty-four to forty-one megacycles; this necessitating the realignment of the large number of interstage transformers in the modulating equipment shown in Fig. 20 and also the retermination of the antenna. It, however, led to the application of the idea inherent in superheterodyne design.

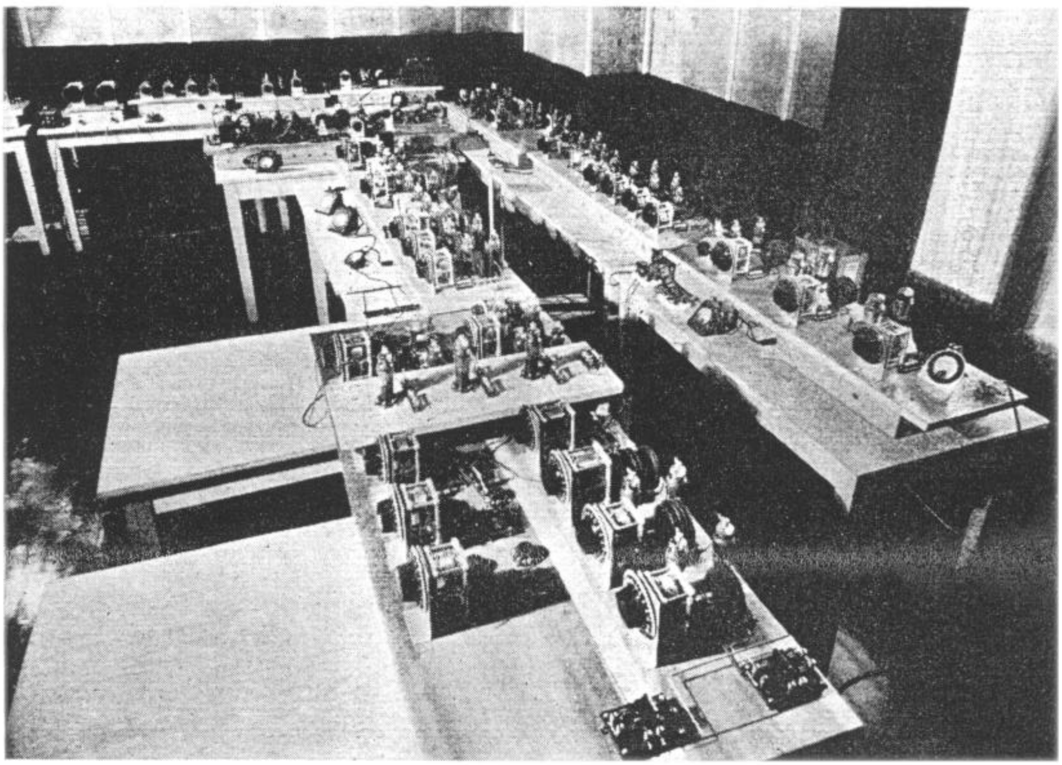


Fig. 26

While the circuits of the old modulator were temporarily modified and work carried on, a new modulation system was designed standardizing on an initial frequency of 100 kilocycles which was then multiplied by a series of doublers up to 12,800 kilocycles. By means of a local oscillator this frequency was heterodyned down to 1708 kilocycles, the new value of input frequency to the transmitter required to produce forty-one megacycles in the antenna. Any future changes in wave length can be made by merely changing the frequency of this second oscillator, The frequencies chosen were such that a deviation of 100 kilocycles could be obtained without difficulty, because of the extra number of frequency multiplications introduced. Fig. 26 shows the two modulation systems during the process of reconstruction with arrangements for making the necessary step-by-step comparisons between them.

Much attention was paid during the year to the frequency characteristic of the transmitter, which was made substantially flat from thirty to 20,000 cycles. This required careful attention to the characteristics of the doubler and amplifier circuits of the transmitter, and to John Evans of the RCA Manufacturing Company and to T. J. Buzalski I am indebted for its accomplishment. Continuous improvement of the transmitter and antenna efficiency was effected throughout the year, but of this phase of the development R. M. Morris of the National Broadcasting Company, under whose direction the work was carried on, is better qualified to speak. As the final step, the lines connecting'the transmitter with the control board of the National Broadcasting Company at Radio City, from which the test programs were usually supplied, were equalized to about 13,000 cycles, and when this had been done the quality of reception at Haddonfield was far better than that obtainable from any of the regular broadcast stations.

INTERFERENCE AND FADING

Reference has heretofore been made to the difficulty of comparing the amounts of interference produced in amplitude and frequency modulation systems by the transient type of disturbance, particularly when, as in ignition noise, the peaks are greater in amplitude than the signal carrier. The best method of comparison seems to be that of observing how much greater signal level from the standard signal generator must be introduced into the receiving system when it is arranged to receive amplitude modulation than is required for the same signal-to-noise ratio on a frequency modulated system. The experimental procedure of making such comparison is to change the connection of the speaker rapidly from one receiver to the other, simultaneously changing the level of the local generator until the two disturbances as perceived by the ear are equal. At all times, of course, the amplification in the amplitude modulation receiver is correspondingly changed as the signal generator level is varied to apply the same voltage to the amplitude as to the frequency modulation detector so that the audio-frequency signal level which will be produced by the two systems is the same. The square of the ratio of the two voltages of the signal generator gives the factor by which the carrier power of the amplitude modulated transmitter must be increased to give equal performance. While the measurement is difficult to make, the following approximations may give some idea of the magnitudes involved.

If the peak voltage of the ignition noise is twice the carrier level of the frequency modulation system, about 150 to 200 times the power must be used in the carrier of the amplitude modulation system to reduce the disturbance level to the same value. When the peak voltage is five times as great, about 35 to 40 times the power in the amplitude modulation carrier is sufficient to produce equality.[17] These observations have been checked aurally and by the oscilloscope. The results of measurements where the disturbances are due solely to the thermal and shot effects have been compared to those obtained with the method previously described and are found to check with it. The chief value of this method of measurement, however, lies in the ability to predict with certainty the signal level required to suppress all ignition noise. An experimental determination made at Haddonfield shows that a signal introduced from the local generator which produces at the current limiter ten times the voltage of the Empire State signal is sufficient to suppress the disturbance caused by the worst offender among the various cars tested. These cars were located as closely as possible to the doublet antenna shown in Fig. 25, the distance being about forty feet. The increase in field strength necessary to produce this result can be readily obtained by an increase in the transmitter power to twenty or twenty-five kilowatts and the use of a horizontally directional antenna array. An increase in the field strength of three or four to one by means of an array is within the bounds of engineering design so that the practical solution of the problem of this type of interference is certainly at hand up to distances of one hundred miles.

So also is the solution of the problem at its source. It has been determined experimentally that the introduction of 10,000 ohms (a value of resistance which is not injurious to motor performance) into the spark plug and distributor leads of the car referred to eliminates the interference with the Empire State signal.

Since active steps are now being taken by the manufacturers of motor cars to solve the more difficult general problem, the particular one of interference with sets located in the home will thus automatically disappear. The problem of eliminating the disturbance caused by an automobile ignition system in a receiving set whose antenna is a minimum of fifty feet away from the car is obviously a much simpler one than that of eliminating the interference in a receiver located in the car or in another car a few feet away.

During the course of the experimental work in the laboratory a very striking phenomenon was observed in the interference characteristics between frequency modulation systems operating within the same wave band. The immunity of a frequency modulation system from interference created by another frequency modulated transmission is of the

[17] Linear detection was used in the amplitude modulation receiver but no limiting was employed.

same order of magnitude as the immunity with regard to tube noises. This property merits the most careful study in the setting up of a broadcast system at those wave lengths at which the question of interstation interference is a major factor. It is well known that when the carriers of two amplitude modulated transmitters are sufficiently close in frequency to produce an audible beat that the service range of each of them is limited to that distance at which the field strength of the distant station becomes approximately equal to one per cent of the field strength of the local station. As a consequence of this, the service area of each station is very greatly restricted; in fact the service area of the two combined is but a small percentage of the area which is rendered useless for that frequency due to the presence thereon of the two interfering stations. With the wide band frequency modulation system, however, interference between two transmissions does not appear until the field strength of the interfering station rises to a level in the vicinity of fifty per cent of the field strength of the local one. The reason for this lies in the fact, that while the interfering signal in beating with the current of the local station under such conditions may be producing a fifty per cent change in the voltage applied to the current limiter, the system is substantially immune to such variations in amplitude. The only way in which the interfering signal can make its presence manifest is by cross modulation of the frequency of the local signal. Since, under the conditions, this cross modulation produces less than a thirty-degree phase shift and since the characteristics of the wide band receiver are such that, at least within the range of good audibility, thousands of degrees of phase shift are necessary to produce full modulation, it is clear that a thirty-degree phase shift will not produce very much of a rectified output. For example, assuming two unmodulated carriers are being received, that their amplitudes have a ratio of two to one, and that their frequencies differ by 1000 cycles, then for a system having a wide band (of the order of 150,000 cycles) the modulation produced by the interaction of the two carriers would be of the order of one per cent of that produced by full modulation of the stronger carrier. This example, however, represents perhaps the worst possible condition as during modulation of either station, with the proper type of conversion system, the aural effect of the disturbance is greatly reduced. The whole problem of interference between unmodulated carriers may, however, be entirely avoided by separating them in frequency by an amount beyond the audible range. Hence it follows that with two wide band frequency modulated transmitters occupying the same frequency band that only the small area located midway between the two wherein the field strength of one station is less than twice the field strength of the other will be rendered useless for reception of either station. This area may well be less than ten per cent of the total area. Even in this area reception may be effected as a receiving station located within it has only to erect directional aerials having a directivity of two to one to receive either station. The two-to-one ratio of field strength which has been referred to as the ratio at which interference appears is not by any means the limit but rather one which can be realized under practically all conditions. Better ratios than this have been observed, but the matter is not of any great importance since by the use of the directional antennas referred to it becomes possible to cover the sum of the areas which may be effectively covered by each station operating alone, subject only to the limitations of the noise level. The problem of the interference due to overlapping has been completely wiped out. One precaution only should be observed-the unmodulated carriers should be offset in frequency by an amount beyond the audible limit.

In the above analysis it has been assumed, of course, that the distance between stations has been selected so that the "no-mans land" between stations is not sufficiently distant from either one to be within the zone where any large amount of fading occurs. If the distance between stations is such that the signal strength varies appreciably with time then the directivity of the receiving antennas must be greater than two to one.

Difficulties and Precautions

The principles which have been described herein were successfully applied only after a long period of laboratory investigation in which a series of parasitic effects that prevented the operation of the system were isolated and suppressed. The more important of these effects, which will be of interest to those who may undertake work in this field, will be referred to briefly.

It was observed in the early work in the laboratory that it was at times impossible to secure a balance in the detector system, and that the amplitudes of the currents in the rectifiers varied in very erratic fashion as the frequency of the first heterodyne was changed. Under these conditions it was not possible to produce any appreciable noise suppression. The effect varied from day to day and the cause defied detection for a long period of time. Ultimately the presence of two side frequencies in the detector circuits was discovered, one of these frequencies lying abqve and the. other below the unmodulated intermediate frequency by an amount equal to the initial crystal frequency of the transmitter. It was then discovered that the trouble- had its origin in the transmitting system and that a current having the fundamental frequency of the crystal, (in the present case 57.33 kilocycles), passed through the first doubler circuits in such phase relation to the doubled frequency as to modulate the doubled frequency at a rate corresponding to 57.33 kilocycles per second. This modulation of frequency then passed through all the transmitter doubler stages, increasing in extent with each frequency multiplication and appearing finally in the forty-four-megacycle output as a fifty-seven-kilocycle frequency modulation of considerable magnitude. In the first doubler tank circuit of the transmitter a very slight change in the adjustment of the tuning of the circuit produced a very great change in the magnitude of this effect. A few degrees shift in the tuning of the first doubler tank condenser, so small that an almost unnoticeable change in the plate current of the doubler occurred, would increase the degree of the modulation to such extent as to make the first upper and lower side frequenciesin the forty-four-megacycle current greater than the carrier or mid-frequency current (when no audio modulation was applied). Under such conditions the proper functioning of the receiving system was impossible.

The delay in uncovering this trouble lay in the fact that it was obscured by the direct effect of harmonics from the transmitter doubler stages which had to be set up in an adjoining room and by the numerous beats which can occur in a double intermediate-frequency superheterodyne. To these effects were added an additional complication caused by the presence of harmonics in the circuits of the selective system resulting from the action of the limiter which the filtering arrangements did not entirely remove. The coincidence of one of these harmonics with the natural period of one of the inductances in the branch circuits likewise interfered with the effectiveness of the noise suppression. The causes of all these spurious effects were finally located and necessary steps, taken to eliminate them.

With the removal of these troubles a new one of a different kind came to light, and for a time it appeared that there might be a very serious fundamental limitation in the phase shifting method of generating frequency modulation currents. There was found to be in the output of the transmitter at forty-four megacycles a frequency modulation which produced a noise in the receiver similar to the usual tube hiss. The origin of it was traced to the input of the first doubler or the output of the crystal oscillator where-a small deviation of the initial frequency was produced by disturbances originating in these circuits. While the frequency shift in this stage must have been very small, yet on account of the great amount of frequency multiplication (of the order of 800 times) it became extremely annoying in the receiver; in fact for low levels of receiver noise that noise which originated in the transmitted wave was by far the worse. For a time it seemed as though the amount of frequency multiplication which could be used in the transmitter was limited by an inherent modulation of the frequency of the oscillator by disturbances arising in the tube itself. The proper proportioning of the constants of the circuits, however, reduced this type of disturbance to a point where it was no longer of importance and frequency multiplications as high as 10,000 have since been effectively used. On account of the very large amount of frequency multiplication, any troubles in these low-frequency circuits caused by noisy grid leaks, improper bypassing of power supply circuits, or reaction of one circuit upon another become very much more important than they would normally be. Difficulties of all these kinds were encountered, segregated, and eliminated.

Another source of trouble was discovered in the correction system. Because of the range in frequency required, particularly in multiplex work where thirty to 30,000 cycles was frequently used, the output voltage of the correction system at the higher frequencies became very much less than the input voltage, hence any leakage or feed-forward effect due to coupling through the power supply circuits developed a voltage across the output much higher than that required by the inverse frequency amplification factor as determined by the correction network. Hence, the frequency swing for the upper frequencies of modulation would frequently be several hundred per cent greater than it should be. Likewise, at the lower frequency end of the scale various reactions through the power supply were very troublesome. All these effects, however, were overcome and the correction system designed so that its accuracy was within a few per cent of the proper value.

From, the foregoing it might be assumed that the transmitting and receiving apparatus of this system are inherently subject to so many new troubles and complications that their operation becomes impracticable for ordinary commercial applications. Such is not the case. The difficulties are simply those of design, not of operation. Once the proper precautions are taken in the original design these difficulties never occur, except as occasioned by mechanical or electrical failure of material. During the period of over a year in which the Empire State transmitter was operated, only two failures chargeable to the modulating system occurred. Both were caused by broken connections. Even the design problems are not serious as methods are now available for detecting the presence of any one of the troubles which have been here enumerated.

These troubles were serious only when unsegregated and en masse they masked the true effects and made one wonder whether even the laws of electrical phenomena had not been temporarily suspended.

MULTIPLEX OPERATION

During the past year, two systems of multiplexing have been operated successfully between New York and Haddenfield and it has been

Fig. 27

Fig. 28

found possible to transmit simultaneously the red and blue network programs of the National Broadcasting Company, or to transmit simultaneously on the two channels the same program. This last is much the simpler thing to accomplish as the cross-talk problem is not a serious one. The importance of multiplexing in point-to-point communication services has long been recognized. In broadcasting there are several applications which, while their practical application may be long deferred, are clearly within view.

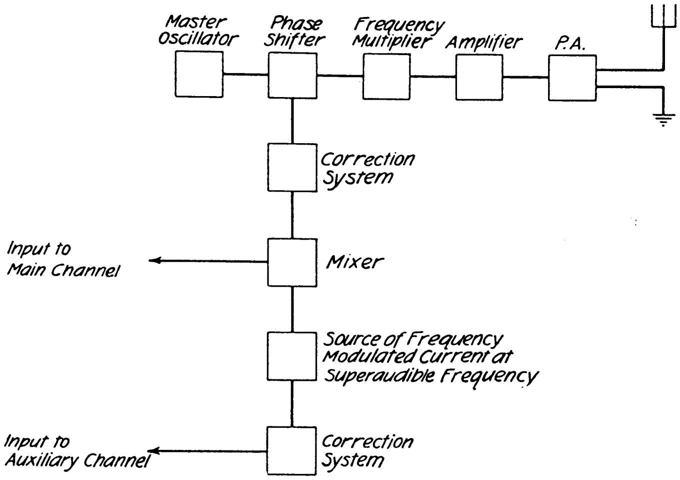

Master Oscillator
Phase Shifter
Frequency Multiplier
Amplifier
P.A.
Correction System
Input to Main Channel
Mixer
Source of Frequency Modulated Current at Superaudible Frequency
Input to Auxiliary Channel
Correction System

Fig. 27

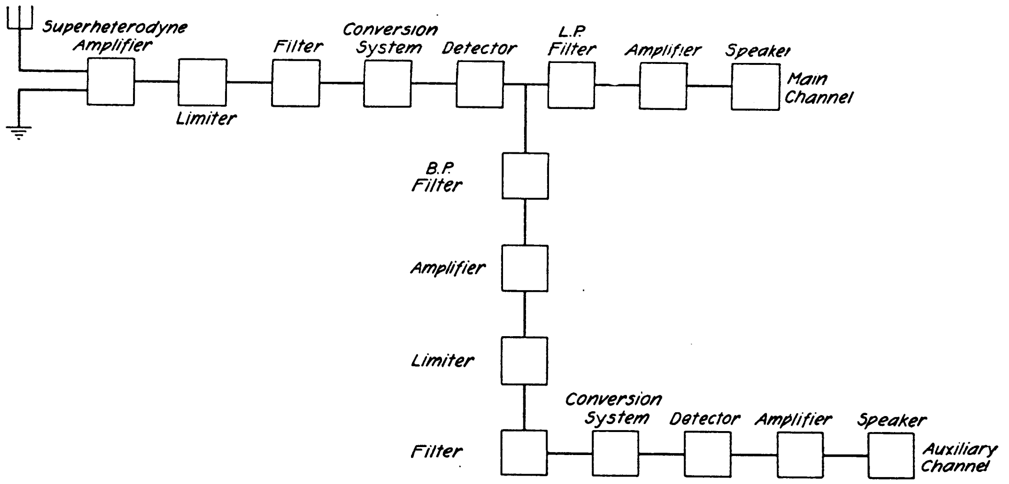

Superheterodyne Amplifier
Limiter
Filter
Conversion System
Detector
L.P. Filter
Amplifier
Speaker
Main Channel
B.P. Filter
Amplifier
Limiter
Filter
Conversion System
Detector
Amplifier
Speaker
Auxiliary Channel

Fig. 28

Two general types of multiplexing were used. In one type a current of superaudible frequency is caused to modulate the frequency of the transmitted wave. The frequency at which the transmitted wave is caused to deviate is the frequency of this current and the extent of the deviation is varied in accordance with modulation of the amplitude of the superaudible frequency current. At the receiver detection is accomplished by separating the superaudible current and its component modulations from the rectified audible frequency currents of the main channel and reproducing the original modulating current from them by a second rectification. The general outline of the system is illustrated in Figs. 27 and 28. The setting of the levels of the main and auxiliary channels must be made in this system of modulation with due regard

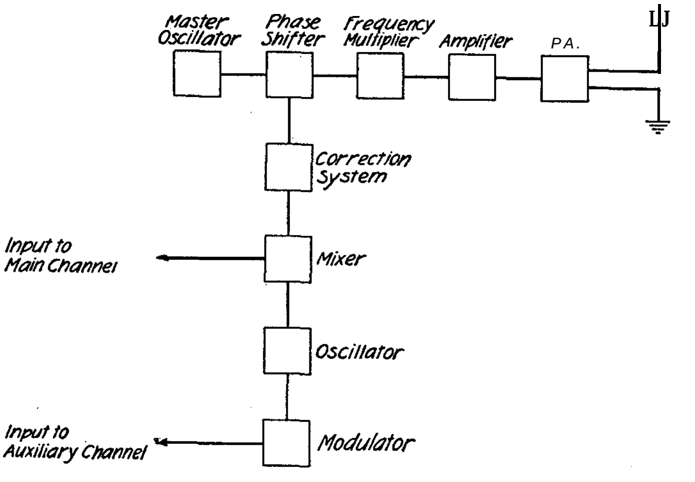


Fig. 29

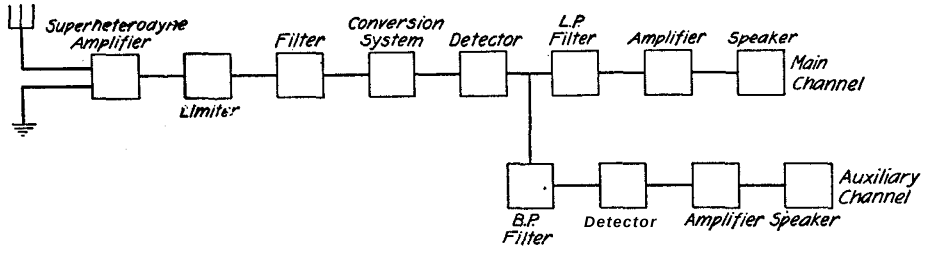


Fig. 30

to the fact that the deviation of the transmitted wave produced by the superaudible frequency current of the second channel is a variable one and changes between the limits of zero and double the unmodulated deviation.

In the second method of multiplexing a superaudible current produces a frequency modulation of the transmitted wave of constant deviation, the rate of the deviation being varied in accordance with the frequency of the superaudible current and modulation being produced by varying the frequency of this auxiliary current and thereby the rate at which the superimposed modulation of frequency of the transmitted wave changes. The operations which must be carried out at the receiver are the following: After suitable amplification, limiting, and filtering, an initial conversion and rectification produces in the output of the detector the audible frequencies of the main channel and a super-audible constant amplitude variable frequency current. This last is selected by means of a band-pass filter, passed through a second con-

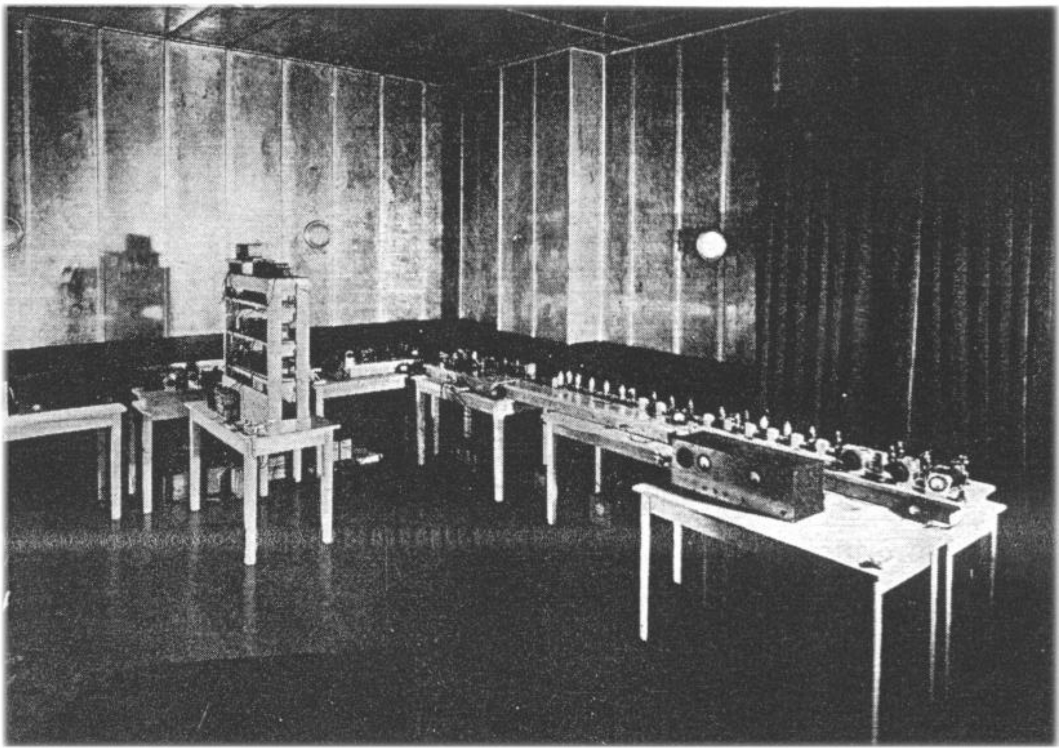


Fig. 31

version system to translate the changes in the frequency into variations of amplitude, and then rectified to recreate the initial modulating current of the auxiliary channel. The general arrangment of the system is illustrated in Figs. 29 and 30. This latter method of multiplexing has obvious advantages in the reduction of cross modulation between the channels and in the fact that the deviation of the transmitted wave produced by the second channel is constant. in extent, an advantage being gamed thereby which is somewhat. akin to that obtained by frequency, as compared to amplitude, modulation in simplex operation. The subject of the behavior of these systems with respect to interference of various sorts is quite involved and will be reserved for future treatment as it is beyond the scope of the present paper.

The final arrangement of the modulating equipment installed at the Empire State station is illustrated in Figs. 31 and 32. The main channel apparatus is shown on the five tables located on the right side of the room. The vertical rack in the left center contains three channels for transmitting facsimile by means of the amplitude modulation method of multiplexing already described. In Fig. 32, located on the four tables on the left of the room is shown the auxiliary channel of the frequency modulation type already described. The comparatively

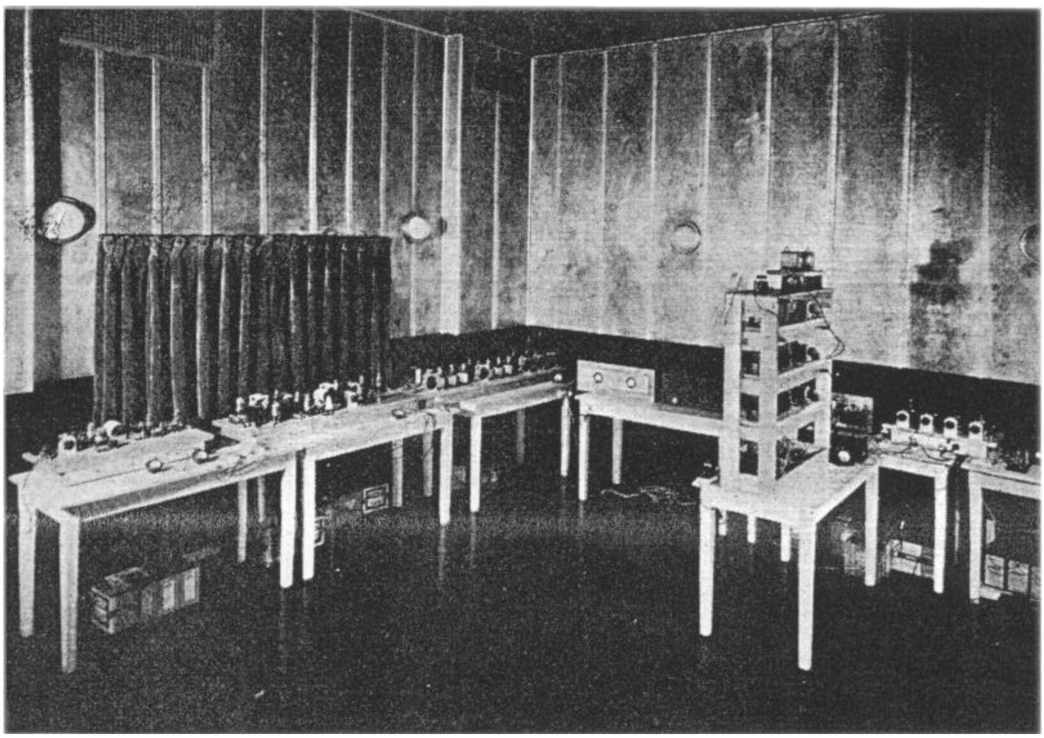


Fig. 32

low frequency of this channel was obtained by the regular method of phase shifting and frequency multiplication, the frequency multiplication being carried to a high order and the resultant frequency modulated current, heterodyned down to twenty-five kilocycles (mid-frequency). A deviation up to ten 'kilocycles was obtainable at this frequency.

The receiving apparatus located at Haddonfield is illustrated in Figs. 33 and 34. Fig. 33 shows the modified Westhampton receiver and Fig. 34 the multiplex channels of the receiver. The vertical rack to the right holds a three-channel receiver of the amplitude modulation type. The two panels in the foreground constitute the frequency modulation type of auxiliary channel.

Some of the practical results may be of interest. It was suggested by C. J. Young of the RCA Manufacturing Company that it might be possible to transmit simultaneously a facsimile service at the same time that a high quality broadcast program was being transmitted. With the assistance of Mr. Young and Maurice Artzt this was accomplished

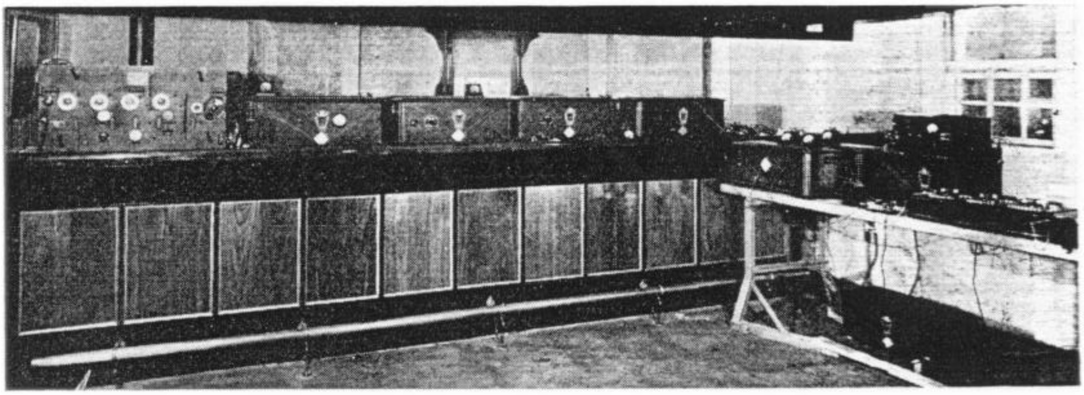


Fig. 33

over a year ago between New York and Haddonfield, New Jersey, the two services operating without interference or appreciable loss of efficiency at the distance involved. Two additional channels, a synchronizing channel for the facsimile and a telegraph channel, were also operated. The character of the transmission is illustrated in Fig.

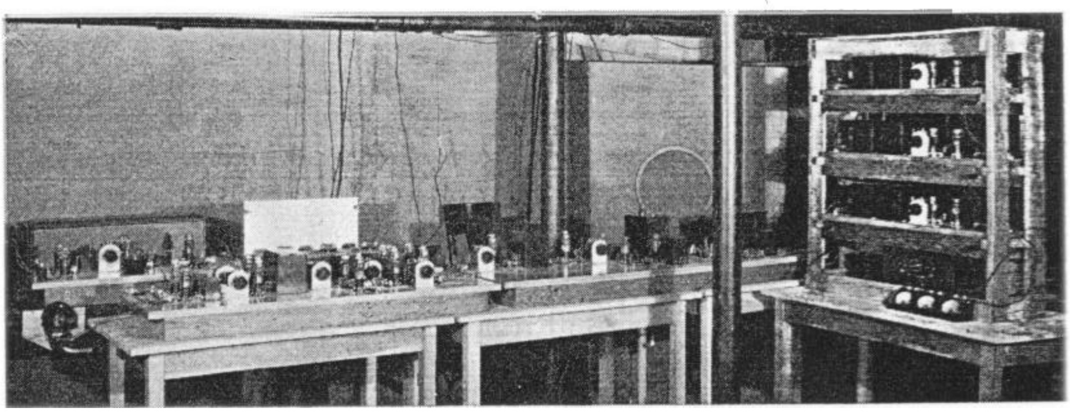


Fig. 34

35, which shows a section of the front page of the *New York Times.* This particular sheet was transmitted under considerable handicap at the transmitter as due to a failure of the antenna insulator on the forty-one-megacycle antenna it had become necessary to make use of the sixty-megacycle antenna for the forty-one-megacycle transmission. It is an interesting comment on the stability of the circuits that all four were kept in operation at the transmitter by one man, Mr. Buzalski,

New York Times.

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NEW YORK, SATURDAY, NOVEMBER 24, 1934. TWO CENTS

VANDERBILT WRIT CALLS ON CAREW TO DEFEND RULING

Definite Decision Is Sought on Habeas Corpus Action to Pave Way for Appeal.

GUARDIAN FIGHT RESUMED

Reply to Mother's Plea Asserts She Is Not Qualified to Fill Such a Position.

Mrs. Gloria Morgan Vanderbilt carried her efforts to obtain custody of her 10-year-old daughter, Gloria, to the Appellate Division yesterday, obtaining from Presiding Justice Edward R. Finch a show cause order in mandamus proceedings against Supreme Court Justice John F. Carew.

At the same time, Justice Carew's decision earlier this week, placing Gloria in custody of her aunt, Mrs. Harry Payne Whitney, for five days a week, was followed in Surrogate's Court by action bearing on the child's $2,500,000 estate. George W. Wickersham and Thomas B. Gilchrist, as co-guardians, opposed the plea of Mrs. Vanderbilt that she be made a guardian, also, of the estate.

After the show cause order had been signed by Presiding Justice Finch it was served upon Justice Carew in his chambers by Louis D. Frohlich, associate of Nathan Burkan, Mrs. Vanderbilt's counsel. The order directed the justice to show cause on Nov. 30 why he should not be required either to sustain or dismiss the writ of habeas corpus sought by Mrs. Vanderbilt in the Supreme Court case.

Clear Way for Appeal.

This was done, it was explained, to clear the way for an appeal from

SOVIET ARMY TO AID FRANCE IF INVADED, DEPUTIES ARE TOLD

Reporter of Budget Declares Russia Would Help Repel Any German Attack.

MILITARY FUNDS APPROVED

French War Minister Announces Term of Conscript Service Will Not Be Raised.

By P. J. PHILIP.

Wireless to The New York Times.

PARIS, Nov. 23.—An understanding by which Soviet Russia has offered her army to aid France in case of attack by Germany was reported in the Chamber of Deputies today by Leon Archimbaud, Reporter of the Budget.

In the course of the debate on the army appropriations, Deputy Archimbaud declared that he puts his hopes for the preservation of peace in a union of strength between France and Russia.

"Only that union," he said, "can stabilize Europe and peace. Russia has a solid, well-equipped army which she offers to us in case of conflict with Germany. It may be regrettable that twenty years after the war we should come back to the old policy of a balance of power, but it is not our fault.

"It cannot be denied that an understanding exists between the two countries."

After the debate, it was declared in government circles that the Deputy was not speaking for the Cabinet, but was only expressing his idea of what Russia would be likely to do in case of German aggression against France. It was M. Archimbaud who, in his report of

U. S. AND BRITA AS NAVY TALKS JAPAN TO DEN

PACT ASSAILED BY SAITO

Ambassador Says Tokyo Will End It No Matter What Occurs at London.

HOLDS HONOR IS AT STAKE

Tells Philadelphia Audience Ratios Show Japan Is Looked Down On as 'Spoiled Child.'

OPPOSES BUILDING RACE

Declares Tokyo Is Willing to Enter an Agreement to Guard Philippine Independence.

> Text of the address by Ambassador Saito, Page 8.

Special to The New York Times.

PHILADELPHIA, Nov. 23.—So long as a navy retains its character as a "fighting unit" instead of becoming merely a "policing force," Japan cannot give up her claim for equality in naval strength, Ambassador Hirosi Saito of Japan said here tonight in an address before the American Academy of Political

Japan's Warr In a Long C

TOKYO, Nov. 2

HULL ENC UNITY WIT

Nov. 24, 1934

Four Channel Operation

\# (1) Music from chain

(2) Synchronizing channel

(3) Facsimile signal

(4) Telegraph channel

Empire State & Haddonfield N. J. W2XDG on 41 megacycles operating on 61 megacycle antenna.

Fig. 35

who was alone in the station on that day. The combined sound and facsimile transmission has been in successful operation for about a year, practically perfect copy being obtained throughout the period of the

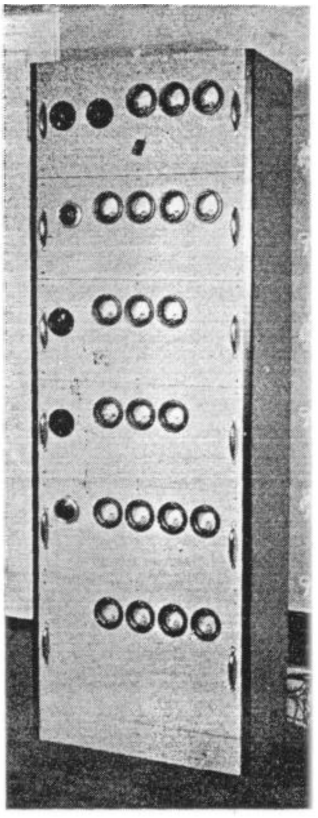

Fig. 36

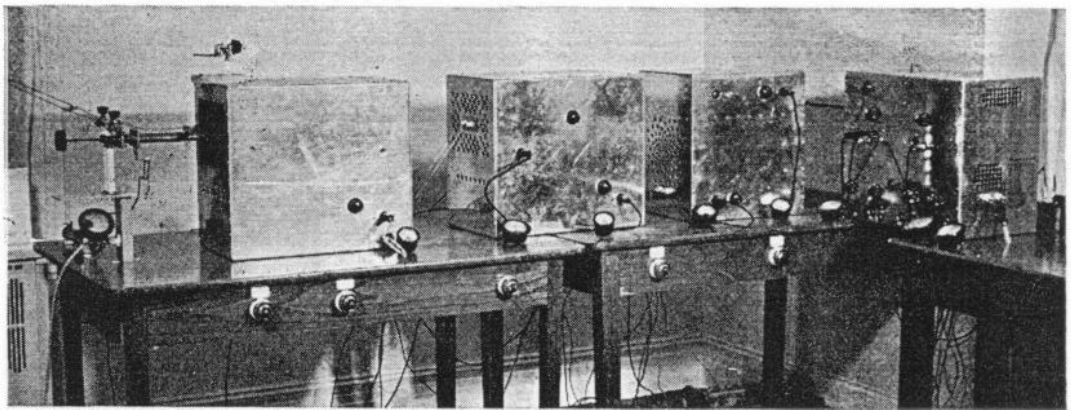

Fig. 37

severe atmospheric disturbances of the past Summer. The subject of this work and its possibilities can best be handled by Mr. Young, who is most familiar with it.

ACKNOWLEDGMENT

On account of the ramifications into which this development entered with the commencement of the field tests many men assisted in this work. To some reference has already been made.

I want to make further acknowledgment and express my indebtedness as follows:

To the staff of the National Broadcasting Company's station W2XDG for their help in the long series of field tests and the conducting of a large number of demonstrations, many of great complexity, without the occurrence of a single failure;

To Mr. Harry Sadenwater of the RCA Manufacturing Company for the facilities which made possible the Haddonfield tests and for his help with the signal-to-noise ratio measurements herein recorded;

To Mr. Wendell Carlson for the design of many of the transformers used in the modulating equipment;

To Mr. M. C. Eatsel and Mr. 0. B. Gunby of the RCA Manufacturing Company for the sound film records showing the comparison, at Haddonfield, of the Empire State transmission with that of the regular broadcast service furnished by the New York stations;

To Mr. C. R. Runyon for his development of the two-and-one-half-meter transmitters and for the solution of the many difficult problems involved in the application of these principles of modulation thereto;

To Mr. T. J. Styles and particularly to Mr. J. F. Shaughnessy, my assistants, whose help during the many years devoted to this research has been invaluable.

CONCLUSION

The conclusion is inescapable that it is technically possible to furnish a broadcast service over the primary areas of the stations of the present-day broadcast system which is very greatly superior to that now rendered by these stations. This superiority will increase as methods of dealing with ignition noise, either at its source or at the receiver, are improved.

APPENDIX

Since the work which has been reported in this paper on forty-one megacycles was completed attention has been paid to higher frequen-

On the occasion of the delivery of the paper a demonstration of transmission on 110 megacycles from Yonkers to the Engineering Societies Building in New York City was given by C. R. Runyon, who described over the circuit the transmitting apparatus which was used. A brief description of this transmitter is reproduced here.

The power delivered to the antenna was approximately 100 watts at 110 megacycles and the deviation (one half total swing) used during the demonstration was under 100 kilocycles. Fig. 36 illustrates the modulating equipment for this transmitter and the low power frequency multiplication stages. Fig. 37 shows the higher power frequency multiplier and power amplifier stages of the transmitter.

The rack shown in Fig. 36 consists of six panels. Panel number, one at the top contains the correction system. Panel number two contains the master oscillator of 100 kilocycles and the modulator circuits. Panel number three contains a pair of doublers for multiplying the l00-kilocycle frequency to 400 kilocycles and the necessary filtering means for avoiding the modulation of the currents in the succeeding doubler stages by the l00-kilocycle oscillator current. Panel number four contains the doubljng apparatus for raising the frequency to 3200 kilocycle and panel number five the multipliers for raising it to 12,800 kilocycles. Panel number five also contains a heterodyning and conversion system for beating the 12,800 kilocycles down to 2292 kilocycles. Panel number six contains a doubler for raising this to 4584 kilocycles and an amplifier for increasing the level sufficiently to drive the succeeding power stage. The output of this amplifier is fed through a transmission line to the metal box at the extreme right of Fig. 36 which contains a series of doublers and amplifiers for increasing the level and raising the frequency to 36,672 kilocycles. Adjacent to this box is a second box which contains a fifty-watt amplifier. This amplifier drives a tripler located in the third box and the tripler in turn drives the power amplifier located at the extreme left at 110 megacycles. The transmitter circuits were designed for total frequency swing of 500 kilocycles and may be effectively so operated. Because of the limitation of the receiver available at that time the demonstration was carried out with a swing of 200 kilocycles.