May 14, 1929. R. A. HEISING 1,712,993

SIGNALING SYSTEM

Original Filed Aug. 14, 1916 2 Sheets-Sheet 1

Fig. 1.

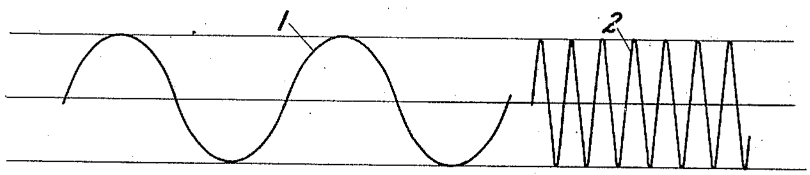

Fig. 2.

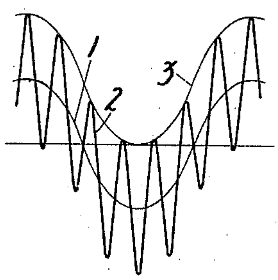

Fig. 3.

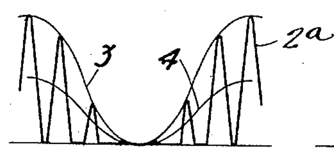

Fig. 4

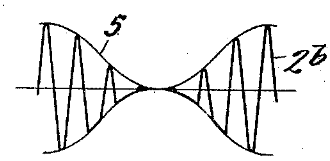

Fig. 9.

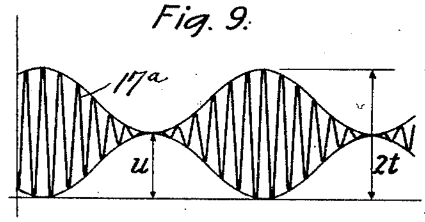

Fig. 5.

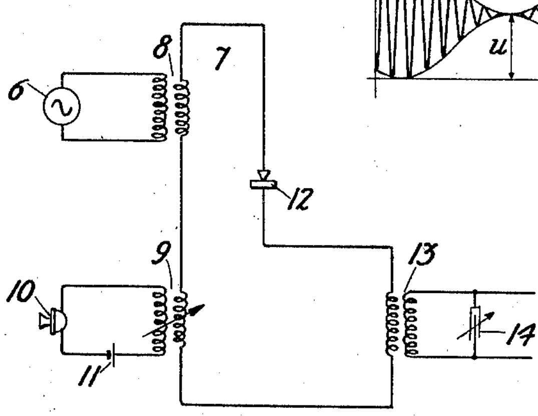

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Fig. 6.

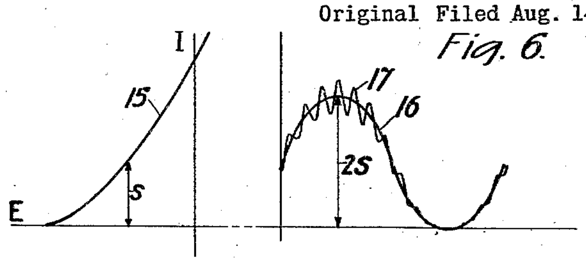


Fig. 10.

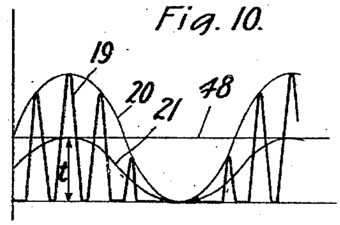


Fig. 7.

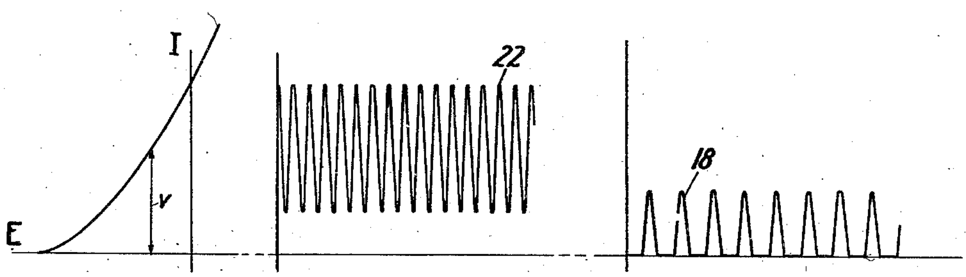
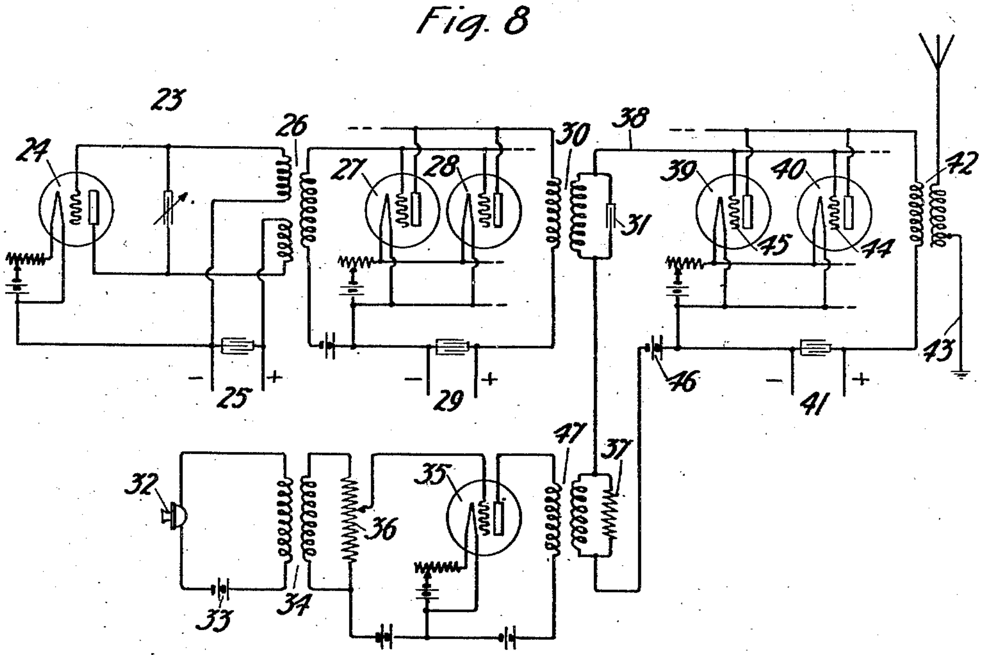


Fig. 8



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Patented May 14, 1929. **1,712,993**

UNITED STATES PATENT OFFICE.

RAYMOND A. HEISING, OF MILLBURN, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

SIGNALING SYSTEM.

Application filed August 14, 1916, Serial No. 114,777. Renewed October 17, 1923.

This invention relates to a signaling system in which high frequency oscillations are modulated in accordance with the form of a message wave to be transmitted, and has for its object to provide a method of producing modulated high frequency oscillations and to provide a method and means for reducing the power lost in a modulating system in which the efficiency and capacity are correspondingly increased.

This object is accomplished by employing low frequency signal oscillations and high frequency oscillations of substantially the same amplitudes and by impressing both of these on a unilaterally conducting device which suppresses negative portions of the resulting oscillations. The unsuppressed high frequency pulsations vary in amplitude substantially in accordance with the form of the message wave. Consequently the unsuppressed high frequency pulsations supply a suitably modulated wave which may be transmitted.

For a better understanding of the invention and its advantages, reference may be made to the drawings, in which:

Figs. 1–4 show various forms of curves illustrating the method of modulation employed in the operation of this invention.

Fig. 5 indicates diagrammatically a modulating system which operates in accordance with the method outlined in Figs. 1 to 4 inclusive.

Figs. 6 and 7 show characteristic curves of vacuum tube modulators used in a different system and in the present system.

Fig. 8 illustrates another species of modulating system which operates in accordance with the method outlined in Figs. 1 to 4 inclusive.

Fig. 9 shows a curve representing instantaneous values of the space current in the modulator tube of a different system.

Fig. 10 shows a curve representing the instantaneous values of the space current in the modulator tube used in applicant's signaling system.

In Fig. 1 the high frequency oscillations 2 represent the carrier waves which are to be modulated. The sinusoidal low frequency oscillations 1 are of the same amplitude as the carrier oscillations. When these oscillations are combined the resultant oscillations assume the form shown in Fig. 2 in which the envelope 3 of the high frequency oscillations is of the same form as the signal oscillations 1. If these two sets of oscillations have the same amplitudes as shown, the envelope 3 will touch at its lowest points the horizontal axis. This relation of the amplitudes of signaling and carrier currents enables complete modulation.

If the modulation were incomplete, the lowest point of the high frequency envelope would be spaced above the horizontal axis. In the latter case, if a line were drawn tangent to the high frequency envelope at its lowest point and parallel to the horizontal axis, these two parallel lines woud include therebetween an unmodulated high frequency portion.

In the present case, however, the high frequency envelope touches the horizontal axis so that the parallel lines are superposed. The space between these lines, representing the unmodulated high frequency component, is zero, which leads to the definition of the modulation as being complete.

Assuming now that the combined oscillations as shown in Fig. 2 are rectified and that the portions below the axis are suppressed in the process of rectification, the rectified high frequency oscillations will have the form shown in Fig. 3 in which the envelope 3 still corresponds to the form of the signal oscillations. The average values of the high frequency amplitudes in Fig. 3 are of the form shown by curve 4. The high frequency pulses 2^a of Fig. 3 may be considered as made up of two components, one of which is the pulsating unidirectional current represented by curve 4 in Fig. 3, and the other of which is the alternating current represented by curve 2^b in Fig. 4. The first component is of a relatively low frequency, and the induction of transformer 13 is so small for this low frequency that little of the energy of this component is transmitted. The high frequency alternating component is however readily transmitted. The envelope 5 of the high frequency alternating component will not accurately correspond to the form of the signal oscillations. The oscillations 2^b in Fig. 4 may, however, be considered as composed of a set of carrier oscillations in which the amplitudes vary strictly in accordance with the signal oscillations, and another set of carrier oscillations having amplitudes that vary in accordance with harmonics of the signal oscillations. As these harmonics may be tuned out, there remains for transmission suitably modulated carrier oscillations.

Fig. 5 discloses one way in which the high frequency may be modulated. In this figure high frequency carrier oscillations may be generated in any suitable manner by the generator 6 coupled to the circuit 7 by the transformer 8. Signal oscillations are also impressed on the circuit 7 through transformer 9 by means of transmitter 10 and battery 11. The transformer 9 provides a means of varying the coupling between the circuit 7 and the circuit including the transmitter whereby the signal oscillations may be adjusted to have the same amplitude as the carrier oscillations supplied by generator 6. While the effect of a transformer in coupling the circuit of a variable resistance to a high frequency circuit is ordinarily to modulate the current flowing in the high frequency circuit, this effect is disregarded in the explanation of the theory of this modulating system. If, for example, the distributed capacity of the secondary winding of transformer 9 be sufficient, the high frequency oscillations will in effect be carried by a capacity path in shunt to the transformer winding. Any modulation of the high frequency current by the action of the varying currents in the primary winding of transformer 9 must be caused by the change in effective inductive impedance of the secondary winding to high frequency current. Since, however, in the case where the secondary winding has sufficient distributed capacity between the adjacent elements of the winding itself to offer a high frequency path, the windings may be considered to be shunted by a condenser it will be apparent that the inductive impedance of the secondary winding of transformer 9 will have little effect upon the high frequency current which traverses the unvarying distributed capacity path. Consequently, a change in the inductive impedance of the secondary winding of the transformer will not affect the amplitude of the high frequency current. In such case the modulation effect just described will actually be negligible. The combined signal and carrier oscillations in circuit 7 are rectified by rectifier 12, and impressed by means of transformer 13 on a circuit 14 tuned to the carrier oscillation frequency. This circuit serves to suppress the harmonics resulting from the rectification as described in connection with Fig. 4.

Fig. 8 discloses a system in which the rectifier 12 of Fig. 5 may be replaced by a thermionic device of the audion type having a constantly active source of electrons such as a heated filament. The system in Fig. 8 is similar in some respects to that disclosed in the U. S. application of Van der Bijl for high frequency signaling, Serial No. 46,643, filed August 21, 1915, which has now become Patent No. 1,350,752, granted August 24, 1920.

In the Van der Bijl system, the characteristic curve showing the relation between the input voltage and the output current must be a curved one so that the high frequency amplification will change in accordance with the variations in the low frequency wave form. This is shown in Fig. 6, in which 15 is the curve showing the relation between the input voltage and the output current for a tube of the type employed in the Van der Bijl system. The space current normally has a value S which is, however, reduced to zero by the maximum negative value of the signal oscillations. The amplitude of the signal oscillations is large compared to that of the high frequency oscillations which, after modulation, vary in amplitude as shown by curve 17. The distance from curve 17 to the horizontal axis give the instantaneous value of the space current. Curve 16 represents the average values of the instantaneous space current, and it will be seen that the maximum value of an ordinate of curve 16 is 2S, double the amplitude of the signal oscillation component which may also be represented by curve 16 if the horizontal axis is considered as moved upward by the amount S.

In this invention, however, it is desirable that the modulator characteristic curve be straight to give a constant amplification. A thermionic device having a straight characteristic is one having a constant ratio between the space or output current and the electromotive force applied to the grid-filament or input circuit for a range of values of the space current and the input electromotive force. Such a relationship if plotted for a series of values of input electromotive force would be represented by a straight line. In general a conducting device may be said to have a straight characteristic when the ratio of its output current to its input electromotive force remains constant as the input electromotive force varies. A modulator with a curved characteristic may be used, but in this case there will be a distortion of the high frequency envelope due to the variable amplification.

This invention provides for using high and low frequency oscillations of substantially the same amplitudes, and the grid potential is so adjusted that the space current of the vacuum tube is zero when neither high nor low frequency oscillations are impressed. In this case if the high frequency oscillations alone were impressed on the modulator input circuit, the output circuit of the modulator would contain high frequency half waves as shown at 18, Fig. 7, for the space current varies from zero to a maximum then to zero but cannot reverse since the modulator is a unilateral conductor. If both high and low frequency oscillations are impressed on the modulator input circuit, its output circuit will contain high frequency pulsations 19 (Fig. 10) having, not constant amplitude as 18 but amplitudes varying in accordance with the form of the low frequency oscillations. The envelope 20 of oscillations 19 corresponds to curve 3 in Fig. 3. And as explained in connection with Figs. 3 and 4, the high frequency pulsations 19 contain as a component part properly modulated oscillations which may be transmitted.

For the purpose of comparing the relative direct current components necessary in the Van der Bijl and in the present system to effect a given modulation, it will be considered that the feeble oscillations 17 in the output circuit of the Van der Bijl modulator have been amplified to the same amplitude $2t$ of Fig. 9 as that of the oscillations 19 produced by the present system. If desired there may be used as amplifiers the vacuum tubes of the audion type disclosed in the patent to Arnold No. 1,129,942, March 2, 1915, for "gaseous repeater in circuits of low impedance." The oscillations 17 as amplified will then have the form shown by curve 17^a in Fig. 9, which indicates that the space current in the amplifier output circuit normally has a value u and will vary in accordance with the variations in the high frequency amplitude.

The high frequency oscillations in Fig. 9 are disposed about an axis distant u from the horizontal reference axis, in other words, the high frequency oscillations may be considered as having a direct current component of the steady value u.

According to the present invention, however, it was shown in Fig. 10 that high frequency oscillations 19 of amplitude $2t$ are obtained with a pulsating direct current component of maximum value t. The steady value u of the direct current component in Fig. 9 is the same as the maximum value of the pulsating component 21 in Fig. 10, so that line 48 (Fig. 10) represents the steady direct current component in the Van der Bijl system while curve 21 (Fig. 10) shows the pulsating direct current component in the system according to the present invention. By inspection it is seen that the area between the curve 21 and the horizontal reference axis is one half of the area between line 48 and that axis. In either case, the direct current component represents power wasted in the modulator or vacuum tube. For the same maximum high frequency output, the average power lost is only about one fourth the average power lost in the Van der Bijl system.

At times only the high frequency oscillations are impressed on the modulator and amplifier, and the present system has an advantage as to economy of operation in this case also. For in the Van der Bijl system, as shown in Fig. 7, the normal value V of the amplifier space current is alternately increased and decreased by high frequency waves as shown by curve 22. The distance from curve 22 to the horizontal axis gives the instantaneous values of the space current. In the present system, however, the space current is normally zero and only the alternate half waves of the high frequency would be effective to increase the space current so that the latter would have a zero value for one half of the time. The high frequency space current pulsations produced in the present system in this case are illustrated by curve 18 (Fig. 7). If neither high nor low frequency oscillations are impressed, the curve 18 coincides with the horizontal axis and the space current is automatically reduced to zero, but under these conditions in the Van der Bijl system, the space current would have the value V.

Since the capacity of a modulator is limited by its heating due to current passing therethrough, the present system provides for increasing the efficiency and capacity of a modulator by reducing the modulator current necessary to produce the desired modulation and by reducing the current used when only the high frequency oscillations are impressed. This feature of increased efficiency resulting from reduction of the current flow in the tube, particularly when only the high frequency oscillations are impressed on it, is broadly claimed in my application Serial No. 352,814, filed January 20, 1920.

A system in which a modulator of the audion type is used under the improved conditions is disclosed in Fig. 8 in which the high frequency oscillations are produced by a suitable generator 23 which is similar to the one disclosed in the U. S. application of Ralph V. L. Hartley for oscillation generators, June 1, 1915, Serial No. 31,476, which has now become Patent No. 1,356,763, granted Oct. 26, 1920. The generator shown comprises a three-element vacuum tube 24 supplied with current from a suitable source 25 and which supplies high frequency oscillations through transformer 26 to amplifiers 27 and 28. These amplifiers are connected in parallel and each comprises a three-element vacuum tube. For a discussion of the operation of the vacuum tubes as amplifiers, reference may be made to the patent to Arnold No. 1,129,942 supra. A suitable source of direct current 29 supplies the current in the amplifier output circuit which is coupled by means of transformer 30 to the condenser 31 which provides a local circuit for the high frequency oscillations.

The low frequency oscillations are amplified in a similar manner. The transmitter 32 causes low frequency variations in the current supplied by battery 33 to transformer 34. The low frequency potential applied to the amplifier 35 may be adjusted by including a suitable amount of resistance 36 in the secondary circuit of transformer 34. The amplifier 35 is similar to the amplifiers 27 and 28. The output circuit of amplifier 35 is coupled through transformer 47 to resistance 37 which provides a local circuit for the amplified low frequency oscillations. The discussion of the modulating action upon the carrier current of the transformer 9 of Fig. 5 coupling the circuit of the high frequency current to the variable impedance signaling circuit applies equally well to transformer 47.

The condenser 31 and the resistance 37 as sources of the amplified high and low frequencies, respectively, are serially connected in the input circuit 38 of the asymmetrically conducting modulators 39 and 40. These modulators are connected in parallel and each comprises a three-element vacuum tube with the usual filament or electron-emitting cathode, grid and auxiliary electrode. The space current supplied by a suitable source 41 is made zero when neither high nor low frequency oscillations are impressed by properly selecting the value of the potential of battery 46 applied to the grids 44 and 45. The output circuit of the modulators 39 and 40 is coupled by means of transformer 42 to a conductor or antenna 43 tuned to the carrier oscillation frequency by means of which the harmonics resulting from the rectification are suppressed.

An equalization of the amplitudes of the carrier and signal oscillations is obtained by adjusting resistance 36 to impress a suitable low frequency potential on the amplifier 35. The amplified high and low frequency oscillations of substantially equal amplitudes are then impressed by means of condenser 31 and resistance 37 on the input circuit of the modulators. The grid potential relative to the cathode is given such a negative value by means of battery 46 that the space current automatically drops to zero when neither high nor low frequency oscillations are impressed. Under these conditions, when the high and low frequencies are impressed on the modulators, their output circuit contains high frequency oscillations which vary in amplitude substantially in accordance with the form of the message wave. The modulated wave is then transmitted by means of the antenna 43 or other suitable sending conductor.

What is claimed is:

1. The method of modulating which comprises variably repeating the half cycles of high frequency oscillations of one polarity only.

2. The method of modulation which comprises repeating the half cycles of high frequency oscillations of one polarity only and varying the amplitude of the repeated half cycles in accordance with a signal.

3. The method of modulation which consists in superposing high frequency and speech frequency oscillations and in completely suppressing substantial portions of half waves of one polarity of said oscillations.

4. In a signaling system wherein messages are transmitted by the agency of high frequency carrier oscillations modulated in accordance with low frequency signal oscillations, the method of modulation which consists in simultaneously impressing the carrier and signal oscillations on a circuit capable of transmitting only impulses of one polarity.

5. The method of modulating high frequency oscillations in accordance with low frequency signal oscillations which consists in completely suppressing substantial portions of half waves of one polarity of superposed high and low frequency oscillations of substantially equal amplitudes.

6. In a speech transmission system, a modulator comprising a constantly active source of electrons, a conducting electrode member, means to establish a difference of potential between said source and said electrode member, means for normally preventing the passage of an electron stream from said source to said electrode and means for simultaneously impressing high frequency waves and speech current oscillations upon said modulator.

7. A modulating system comprising a source of high frequency oscillations, a source of low frequency signal oscillations, and a circuit for transmitting unidirectional current including means comprising a device capable of transmitting only impulses of one polarity of impressed energy for modulating said high frequency oscillations in accordance with said signal oscillations.

8. In a system of radio communication, means for generating high frequency oscillations, a source of low frequency signal oscillations, a circuit for superposing said oscillations, and a circuit adapted to transmit unidirectional current including means which is non-responsive to substantial portions of impulses of one polarity of said superposed high and low frequency oscillations.

9. In a system of radio communication, means for generating high frequency oscillations, a source of low frequency signal oscillations, means for superposing said oscillations, and a thermionic device adjusted to

be non-responsive to negative half cycles of said superposed high and low frequency oscillations.

10. In a system of radio communication, means for generating high frequency oscillations, means for amplifying said oscillations, a source of low frequency signal oscillations, means for amplifying said signal oscillations, a circuit for superposing said amplified oscillations, and means non-responsive to half cycles of one polarity of said superposed amplified high and low frequency oscillations.

11. In a system of radio communication, means for generating high frequency oscillations, means for amplifying said oscillations, a source of low frequency signal oscillations, means for amplifying said signal oscillations, a circuit for superposing said amplified oscillations, and a thermionic device having a discontinuous characteristic upon which said superposed amplified high and low frequency oscillations are impressed in such a manner as to operate over the point of discontinuity.

12. In a system of radio communication, a generator of high frequency oscillations, an amplifier therefor, a source of low frequency signal oscillations, an amplifier for said signal oscillations, a thermionic device capable of transmitting only impulses of one polarity of impressed waves having an input circuit and an output circuit, a circuit for serially impressing the amplified high and signal oscillations upon the input circuit of said thermionic device, and a sending conductor associated with the output circuit of said device.

13. In a system of radio communication, a thermionic device having an input circuit and an output circuit, a source of space current for the output circuit thereof, a source of carrier oscillations and a source of signal oscillations, means for impressing said carrier oscillations and said signal oscillations upon said input circuit, means independent of said source of signal oscillations for automatically reducing the space current substantially to zero when said carrier and signal oscillations are of substantially zero amplitude, and a translating circuit associated with the output circuit of said device.

14. In a system of radio communication, a thermionic device having an input circuit and an output circuit, a source of space current for the output circuit thereof, a source of high frequency carrier oscillations and a source of signal oscillations, means for simultaneously impressing said carrier oscillations and said signal oscillations upon the input circuit of said device, a source of potential for automatically reducing the space current substantially to zero when said carrier and signal oscillations are substantially of zero amplitude, and a translating circuit associated with the output circuit of said device.

15. In a system of radio communication, a thermionic device having an input circuit comprising an electron-emitting cathode and an auxiliary electrode, a generator of high frequency oscillations and a source of low frequency oscillations, means for simultaneously impressing said carrier oscillations and said signal oscillations upon the input circuit of said device, a source of space current for the output circuit of said device, a source of potential for said auxiliary electrode for automatically reducing the space current substantially to zero when said high and low frequency oscillations have substantially zero amplitude, and a translating circuit associated with the output circuit of said device.

16. A modulator comprising a rectifier substantially suppressing impulses of one polarity of the impressed energy.

17. A modulator comprising a translating device having a straight line characteristic representing the relation between the electromotive force impressed upon said modulator and the resulting output current delivered thereby.

18. A modulator comprising a rectifying translating device having a straight line characteristic representing the relation between the electromotive force impressed upon said modulator and the resulting output current delivered thereby.

19. The method of modulation which comprises subjecting high frequency oscillations and signal oscillations to the action of a device having a discontinuous operating characteristic in such a manner as to operate in part upon the discontinuous portion of the characteristic.

20. In combination, a source of waves of carrier frequency, a modulator other than said source capable of repeating impulses of one polarity only of the impressed energy, a low frequency low power current source, and means for impressing waves from both of said sources upon said modulator comprising amplifying means for said low frequency current.

21. An electron discharge device having a thermionically active cathode, an anode, and a control element, a space current circuit connecting said cathode and anode including a source of current so directed as to render the cathode negative with respect to the anode, a circuit connecting said cathode and control element and including a permanently connected source of electromotive force so directed and of such value as to prevent flow of space current in said space current circuit when acting alone in said input circuit and means simultaneously impressing high frequency waves to be modulated and lower frequency modulating waves upon

the circuit connecting said cathode and said control element.

22. The method of modulating which comprises completely suppressing substantial portions of half waves of one polarity of a carrier wave and varying the amplitude of the unsuppressed portions in accordance with a modulating wave.

23. The method of modulating by means of a device having a characteristic with a sharp break or discontinuity which comprises superposing carrier and modulating oscillations upon said device and so adjusting said device as to operate over a substantial range on each side of the break or discontinuity.

24. A method of operating a thermionic amplifier having a cathode, an anode, a control electrode, input and output circuits and a source of current in said output circuit, which method consists in applying a fixed negative potential to said control electrode of a magnitude such that the output of the amplifier is reduced substantially to zero, impressing a series of high frequency impulses to said control electrode and varying the base line potential of said control electrode such that the positive half of the high frequency impulses will travel along a greater portion of the upwardly inclined characteristic curve of the amplifier and thus liberate oscillatory energy in the output circuit of the amplifier.

In witness whereof, I hereunto subscribe my name this 12th day of August, A. D. 1916.

RAYMOND A. HEISING.