Oct. 9, 1928.

1,687,245

R. A. HEISING

AMPLIFYING

Filed Dec. 30, 1922

Fig. 1

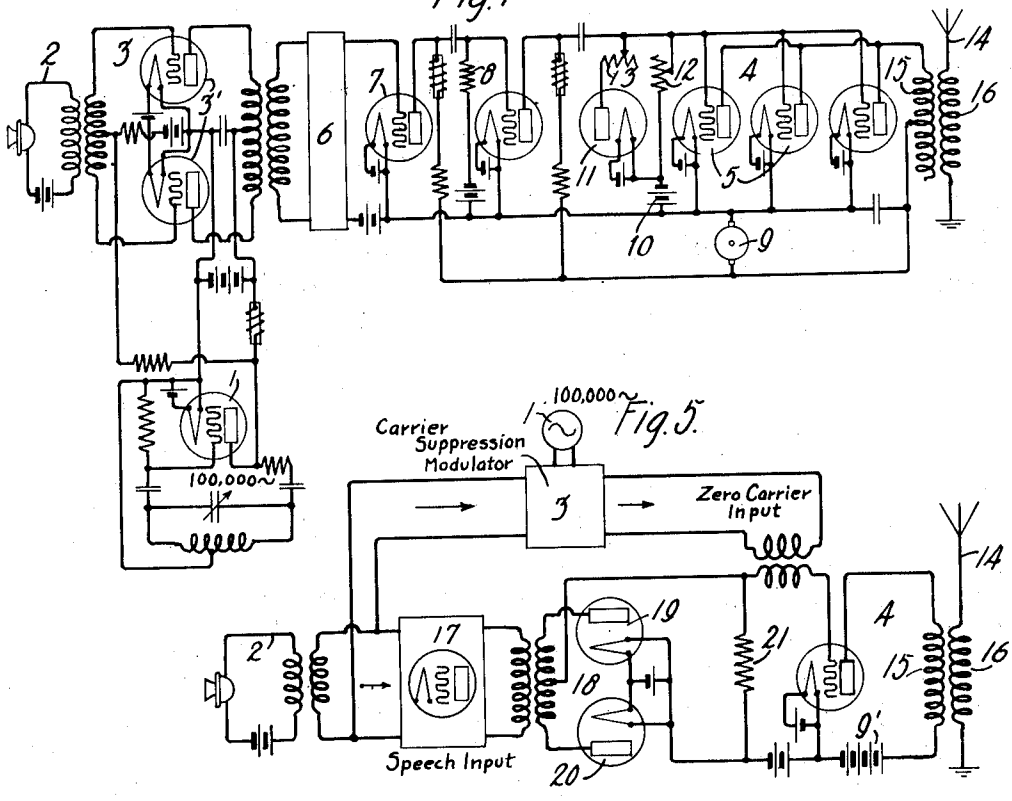


Fig. 5.

Fig. 2

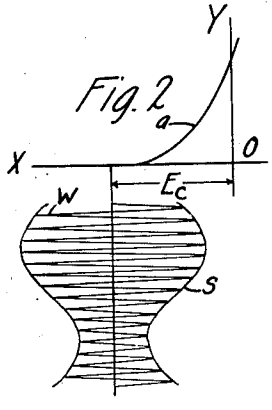


Fig. 3.

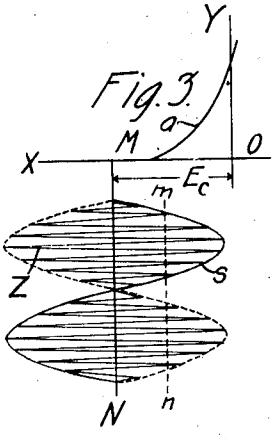
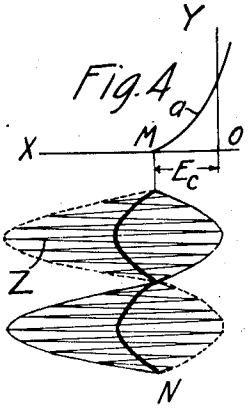


Fig. 4.



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UNITED STATES PATENT OFFICE.

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AMPLIFYING.

Application filed December 30, 1922. Serial No. 609,932.

This invention relates to the amplification of modulated waves and more particularly to the amplification of modulated high frequency waves for radio transmission.

It is well known how high frequency waves may be modulated in accordance with speech or other signals to produce a modulated wave from which the unmodulated carrier component is suppressed or how the unmodulated carrier component may be suppressed after modulation. Such a modulated wave with the unmodulated component of carrier frequency suppressed is often referred to as a "pure modulated wave." Oftentimes, for one reason or another, one of the side bands or side frequencies resulting from modulation is also suppressed, and the remaining wave is then referred to as a single side frequency without unmodulated carrier. In the present specification, any modulated wave from which the unmodulated carrier frequency component has been entirely or largely suppressed will be referred to as a "zero carrier modulated wave" or "zero carrier wave." This definition is intended to include a wave wherein both side frequencies are present or wherein only one side frequency is present.

A difficulty present in amplifier systems in general and especially important in amplifier systems for amplifying considerable power, as in radio transmission, is the inefficiency of vacuum tubes when used as amplifiers. For efficiency a high negative voltage must be impressed upon the grid and considerable distortion occurs. In a system heretofore devised and used by applicant, this difficulty is surmounted by operating the tube at such a point on its characteristic as to amplify the modulated portion only of an incompletely modulated wave.

In order to use vacuum tube amplifiers of high efficiency for amplifying "zero carrier" waves, other difficulties which arise must be overcome. These difficulties and the method of surmounting them will be discussed hereinafter.

One system described herein for exemplifying the invention consists of an arrangement in which zero carrier modulated waves are supplied to a space discharge amplifier of the usual type having an anode-cathode output circuit and a grid-cathode input circuit. The grid is adjusted to a negative potential such that space current just begins to flow when no waves to be amplified are applied to the input circuit. A rectifier is connected across the input circuit in such a manner that the application of waves to be amplified to the input circuit causes the grid to become more negative as the amplitude of the applied waves becomes larger. The system operates without appreciable loss of the signaling frequency components by which the carrier wave is modulated and is highly efficient.

In another system, current of the modulating wave form is rectified and applied to the input circuit of the power amplifier to cause the grid potential thereof to become more negative as the amplitude of the applied waves becomes larger and vice versa, to cause the grid potential to become less negative as the amplitude of the applied waves becomes smaller.

It is an object of this invention to amplify zero carrier waves by vacuum tube amplifier systems working at high efficiency. In this specification, the expression "high efficiency" is used to describe the condition of operation in which the ratio of the energy of the desired wave form produced in the output circuit to the total energy supplied to the amplifier system is high.

The novel features believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to organization and method of operation, together with further objects and advantages thereof will best be understood from the following detailed description taken in connection with the accompanying drawings wherein Fig. 1 is a circuit diagram of a system for amplifying zero carrier waves with high efficiency; Fig. 2 is a diagram illustrating high efficiency amplification of ordinary modulated waves by a vacuum tube amplifier system; Fig. 3 is a diagram illustrating the inapplicability of the method illustrated in Fig. 2 to zero carrier modulated waves; Fig. 4 is a diagram indicating the mode of operation by which the amplifier system illustrated in Fig. 1 overcomes the disadvantages indicated by the diagram of Fig. 3; and Fig. 5 illustrates a modified form of system for amplifying zero carrier modulated waves.

In Fig. 2, the curve *a* represents the grid-

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voltage-plate-current characteristic of a vacuum tube amplifier in which grid voltages are plotted along the axis OX and plate currents are plotted along the axis OY. The value of E_c represents the normal negative grid voltage to be used when the amplifier functions to amplify an incompletely modulated high frequency wave represented by the curve *w*, this wave being modulated in accordance with a speech frequency wave *s*. When the wave *w* is applied to the input circuit of the amplifier the grid voltage will at times during each high frequency cycle become of such value that space current will flow in the output circuit. This will result in the production in the output circuit of a substantially completely modulated high frequency wave of slightly distorted wave form. For radio transmission the distortion introduced is a disadvantage, but not such a disadvantage as to overcome the advantage inherent in this method of amplification.

A consideration of the wave form of the high frequency modulated wave applied to the grid circuit in accordance with Fig. 2 as compared with the wave form of a zero carrier modulated wave indicates at once that the method of Fig. 2 is inapplicable for the amplification of zero carrier modulated waves, inasmuch as the wave form of the latter is such that the envelope of the high frequency wave which represents the wave form of modulating wave is constantly descending to and crossing and recrossing the zero axis. Thus in Fig. 3 the curve *z* represents a zero carrier modulated wave consisting of both side bands and *s* represents the modulating wave. It appears at once that any system of amplifying in which only the higher peaks of the wave *z* are amplified will result in a loss of important signaling components. Thus, for example, it would not be desirable to amplify only those portions of the wave indicated as lying to the right of the dotted line *mn*. Furthermore, if all portions of the wave lying to the right of the central axis MN are amplified, the system will be inefficient from the standpoint of power consumption.

Consider now the mode of operation indicated in Fig. 4. In this case the normal negative grid voltage E_c is adjusted to that point where space current just begins to flow instead of being set well below the point at which space current begins to flow as in the case of Fig. 2. This results in good amplification of those portions of the zero carrier modulated wave of small amplitude. If now the negative grid voltage is caused to become considerably more negative during those portions of the speech frequency cycle when the zero carrier wave is of large amplitude, efficiency of operation and absence of signal destroying distortion will both result. In order to accomplish this, the negative grid voltage E_c is caused to vary in accordance with the heavy curve MN as indicated in Fig. 4. The wave form of the curve MN suggests at once that it is periodic and that its fundamental frequency is twice that of the signaling wave *s*. It is therefore contemplated that any method of operation or means for performing such method whereby the grid voltage of an amplifier for amplifying a zero carrier wave is caused to pass through variations at double the modulation frequency of the modulating wave is an embodiment of the present invention. It also appears that the principles of the invention are applicable in amplifying any modulated wave of which the amplitude at times approaches zero, i. e. complete modulation.

Among the possible arrangements functioning in accordance with the diagram of Fig. 4, is the circuit arrangement indicated in Fig. 1, which will now be described.

In Fig. 1, the tube 1 and its associated circuit arrangements comprise an oscillation generator which may generate any desired frequency of carrier wave. By way of illustration, it may be assumed that the frequency produced by the oscillation generator 1 is 100,000 cycles per second. The microphone circuit 2 typifies any desired source of modulating waves, oscillations, or impulses in accordance with which the oscillations produced by the generator 1 are to be modulated. The vacuum tubes 3′ and their associated circuit arrangements constitute a modulator 3 of the well-known carrier suppression type. The function of the modulator is to modulate the waves from the generator 1 in accordance with waves from the source 2 and largely suppress the unmodulated carrier component. The operation of the modulating system 3 is fully described in U. S. patent to Carson No. 1,343,306 granted June 15, 1920.

Before being applied to the power amplifying system 4, indicated as consisting of a number of vacuum tubes 5 connected in parallel, the zero carrier waves produced by the modulating system may be separated from any interfering waves by means of a selective circuit arrangement 6, and increased in energy in one or more stages of amplification by means of vacuum tube amplifiers 7 and 8. The amplifiers 7 and 8 are of a conventional type well known in the art and need not detailed description. The selective circuit 6 preferably consists of a band pass filter of the type described in U. S. patent to Campbell No. 1,227,113, granted May 22, 1917. The filter 6 may pass a range of frequencies consisting of the lower side band, that is, for example, from 98,000 to 99,800 cycles per second; or the upper side band, that is, from 100,200 to 102,000 cycles per second; or it may pass both side bands, that is, from 98,000 to 102,000 cycles per second.

In the present instance, we will assume that both side bands are transmitted by the filter 6 and that the unmodulated carrier component is wholly suppressed by the modulator 3 inasmuch as the wave form thereby resulting is that indicated by the curve *z* in Figs. 3 and 4. The curve *z* in Fig. 4 represents the same modulated wave as the curve *z* in Fig. 3 but in the case of Fig. 4 the zero axis of the wave *z* is curved instead of being straight as in Fig. 3.

It is in the power amplifying system 4 that large amounts of power are dissipated, this power being supplied from the space current source 9. The power consumption in the amplifiers 7 and 8 is too small to necessitate the application of the invention to their input circuits. In accordance with the present invention, the battery 10 should be adjusted to or at about the point where space current flows in the amplifier tubes 5. A rectifier 11, preferably in the form of an evacuated tube having a cathode and an anode, is connected across between the grids and the filaments of the tubes 5 so that incoming waves will be partially rectified in a manner tending to make the grid more negative. The greater the amplitude of the waves, the more negative the grids will become. Hence, when waves of large amplitude are being amplified, the efficiency is correspondingly high and when waves of small amplitude are being amplified the tubes work only on the lower part of their characteristic and but little energy is dissipated. See paper "Modulation in radio telephony", Proc. I. R. E. August 1921, Appendix. It is preferred to include the battery 10 in series with a high resistance 12, and to shunt the rectifier 11 around the resistance 12. Another resistance 13 is preferably included in circuit with the rectifier to determine the potential applied to the rectifier. The resistances 12 and 13 should be varied both with respect to each other and the other constants of the system until a desired operating condition is obtained.

The operation of the system is indicated in Fig. 4 and has been described above. The grid potential of the tubes 5 is set at the value at which space current just begins to flow. Incoming high frequency waves then have some of their current rectified in the rectifier 11 and cause the grid potential of the tubes 5 to fall to a still more negative value. During those parts of the modulating wave cycle when the high frequency waves are of small amplitude the negative charge on the grid caused by the rectified current will leak off through the resistance 12. The curve MN (Fig. 4) represents the variation of grid potential. The negative potential of the grid thus rises and falls in such a manner that when large waves are amplified, the grid is at such a high negative potential as to create an efficient operating condition. When small waves are amplified, only a small amount of power is needed, hence the average efficiency over a complete low frequency cycle remains fairly high. Whatever distortion is introduced does not result in loss of essential elements of the voice wave. The high power waves in the output circuit are transferred to the antenna circuit 14 by means of the coupling between the coils 15 and 16.

The grid of the power amplifier tubes is automatically caused to vary in potential at a frequency twice the frequency of the modulating wave. This mode of operation comprises one of the important features of the present invention. It may be accomplished in different ways with varying forms of apparatus. The arrangement herein illustrated is one of the arrangements, but by no means the only arrangement which may be devised for carrying out this method.

Thus, in the circuit of Fig. 5, a portion of the modulating wave energy is utilized to control the grid potential of the power amplifier. Modulating waves are applied from the microphone circuit 2 to the modulator 3 which is supplied from source 1 with a carrier wave to be modulated. The resultant zero carrier modulated waves are applied to the input circuit of a power amplifier system 4. Some of the speech frequency energy from the circuit 2 is amplified by the amplifier 17 and applied to a double rectifier system 18 consisting of two hot filament evacuated tubes 19 and 20. The tubes 19 and 20 rectify the alternate half waves of the alternating current of speech frequency supplied by the amplifier 17 and thus cause the grids of the power tubes of the system 4 to vary in potential in accordance with the curve MN of Fig. 4. The resistance 21 serves as an impedance element across which the electromotive force resulting from the rectified current is applied to the grid circuit of the tubes 4.

The novel features which are believed to be inherent in the invention are defined in the appended claims.

What is claimed is:

1. The method of repeating at high efficiency, as regards power consumption, a modulated wave by means of a space discharge repeater having a control element, which comprises supplying to the control element a negative voltage of such a value as to just allow the repetition of waves of small amplitude and automatically increasing this negative voltage in a ratio proportional to the magnitude of the waves when waves of large amplitude are to be repeated.

2. The method of repeating a zero carrier modulated wave comprising a carrier wave modulated in accordance with a lower frequency wave,—the unmodulated component

being largely suppressed,—by means of a space discharge device having a grid or control element which comprises varying the polarizing potential of the grid periodically at a frequency twice the frequency of the lower frequency wave.

3. The method of repeating a wave of a given frequency having amplitude variations in accordance with a modulating wave of a given frequency by means of a space discharge device having a grid or control element which comprises varying the potential of the grid periodically at a frequency twice the frequency of the modulating wave.

4. The method of repeating a high frequency wave of variable amplitude by means of a space discharge device which comprises rectifying a portion of the high frequency wave energy by means of a device other than the space discharge device and applying to the space discharge device a potential difference resulting from the rectification to control the repetition of the high frequency waves by the space discharge device.

5. The method of high frequency wave amplification by a discharge device amplifier containing a control element which comprises applying a portion of the high frequency energy which is to be repeated to a rectifier and applying to the control element of the amplifier a resultant negative voltage which varies periodically at a frequency twice that of the high frequency wave.

6. A vacuum tube repeater having input electrodes, a rectifier connected between said electrodes, a resistance in series with said rectifier, and a high resistance connected between said electrodes in parallel to said rectifier which supplies rectified current thereto for applying a varying potential between said electrodes.

7. In combination a vacuum tube repeater for repeating only impulses of a zero carrier wave of one polarity, a rectfiier in shunt thereto for varying the grid potential of said repeater at a frequency double the frequency of the modulating wave, and a resistance in series with said rectifier.

8. The method of amplifying a wave having components of fixed and variable frequencies by means of a space discharge device having an anode cathode and control electrode or grid which comprises varying the grid polarizing potential as a function of the amplitude of one of the wave components.

9. A vacuum tube repeater having grid, filament and plate electrodes, an input circuit including said grid and filament electrodes, means for impressing waves to be repeated on said grid and filament, a high resistance in series with a source of electromotive force connected across said input circuit, and, in shunt to said resistance, a rectifier controlled by said waves whereby a varying biasing potential is applied to said grid.

In witness whereof, I hereunto subscribe my name this 28th day of December, A. D. 1922.

RAYMOND A. HEISING.