

May 20, 1924.

1,494,908

R. A. HEISING.

AMPLIFICATION OF MODULATED WAVES

Filed Feb. 23, 1923

2 Sheets-Sheet 1

Fig. 1

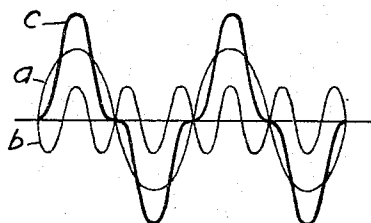


Fig. 2a

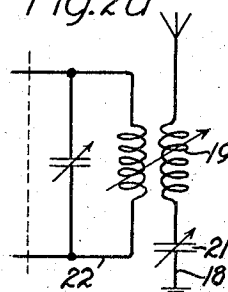


Fig. 2

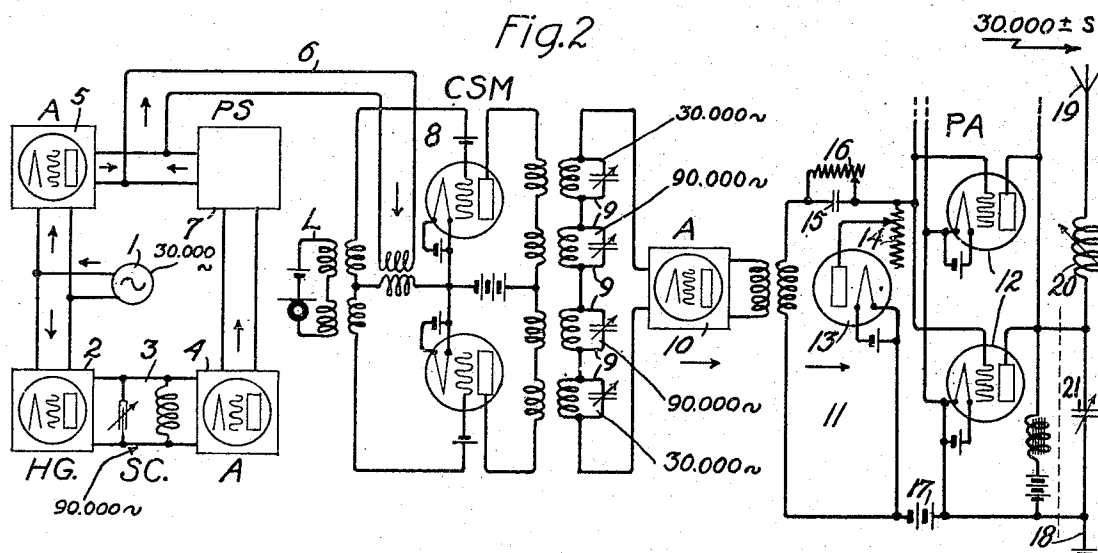


Fig. 3

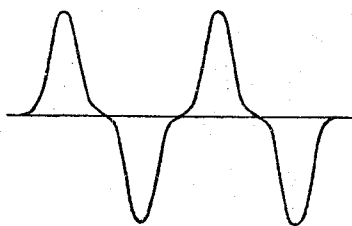
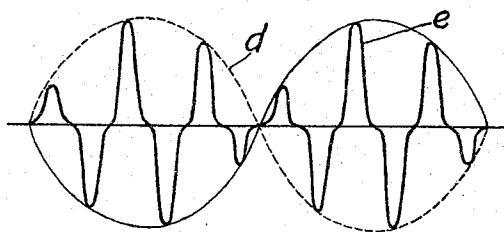


Fig. 4



Inventor:
Raymond A. Heising
by E. W. Griggs Att'y

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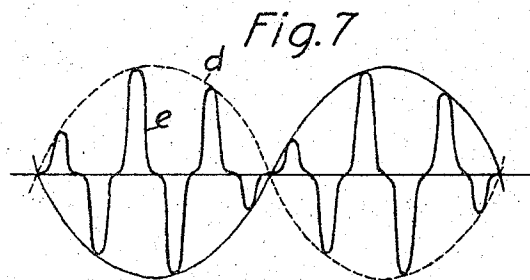
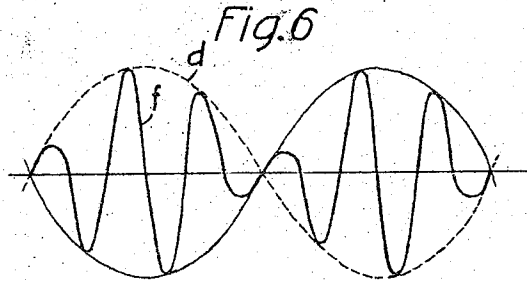
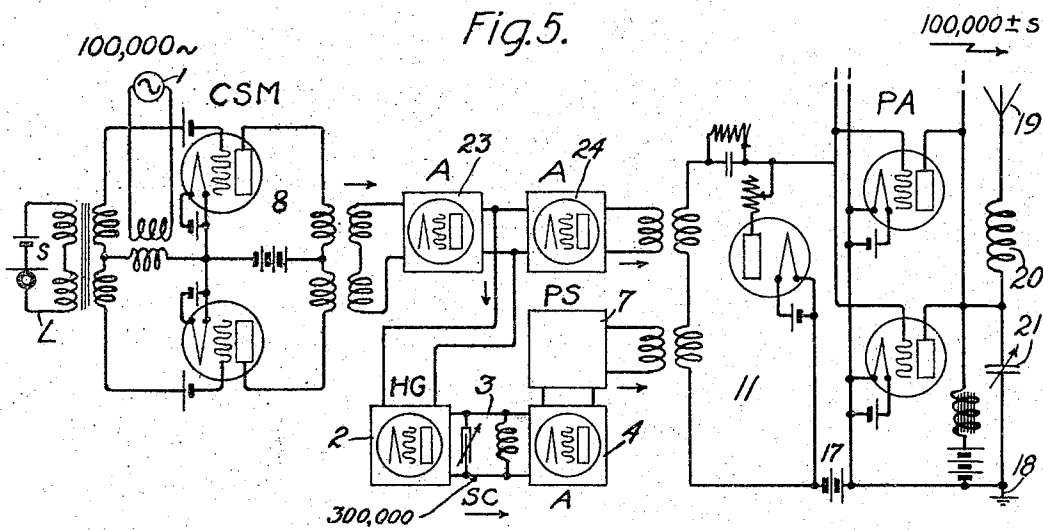
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AMPLIFICATION OF MODULATED WAVES

Filed Feb. 23, 1923

2 Sheets-Sheet 2



Inventor:
Raymond A. Heising
by E. W. Briggs Atty

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.

AMPLIFICATION OF MODULATED WAVES.

Application filed February 23, 1923. Serial No. 620,626.

To all whom it may concern:

Be it known that I, RAYMOND A. HEISING, a citizen of the United States of America, residing at Millburn, in the county of Essex and State of New Jersey, have invented certain new and useful Improvements in Amplification of Modulated Waves, of which the following is a full, clear, concise, and exact description.

This invention relates to improvements in amplifying systems. It particularly relates to methods of and means for amplifying modulated carrier waves, and is especially adapted for use in systems for amplifying a modulated carrier wave from which the unmodulated component of carrier frequency has been suppressed.

An object of the invention is to provide for greater efficiency in the use of electrical energy in amplifying systems and especially in the last or high power stage of amplification of a radio transmitter system wherein the power supplied to the amplifier to be converted into high frequency wave energy for radiation is large. A saving of power which would be relatively unimportant in a small station of one-half to one kilowatt output and which would not justify expending the cost of the apparatus necessary to effect the economies herein described, becomes of considerable consequence when the power output is large, for example, of the order of 100 kilowatts and upward.

A further object is to provide for more efficient radio transmission by means of modulated carrier waves having the unmodulated component of carrier frequency suppressed.

A system embodying the invention as herein described includes a source of carrier waves; a device for deriving from the source a triple frequency component, amplifying this component and combining it with waves from the original source to produce a peaked wave; a carrier suppression modulating device for modulating the peaked wave thus produced in accordance with a low frequency wave; a voltage step-up or low power amplifier for the modulated wave; and a vacuum tube power amplifier having a grid so negatively polarized that the amplifier is actuated only by the peak portion of each cycle of the modulated peaked wave. Each of the elements thus described may

assume a wide variety of physical forms of which those herein described are typical.

Although the invention is more particularly described in connection with radio transmission systems, the principles involved may be applied in any amplifying system wherein the use of the invention is found to be desirable. The novel features which are believed to be characteristic of the invention are pointed out with particularity in the claims appended hereto. The invention itself, however, both as to the details of its organization and its mode of operation will be better understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 is a diagram illustrating the components of the peaked carrier waves employed in a preferred form of the invention. Fig. 2 is a circuit diagram of a radio transmitter of high power embodying one form of the invention adapted for efficient amplification of waves to be radiated; Fig. 2^A shows a modified form of output circuit for the power amplifier; Figs. 3 and 4 are diagrams illustrating the wave form of the carrier frequency waves present in the circuit arrangement of Fig. 2 before and after modulation, respectively, Fig. 4 showing the form of wave applied to the power amplifier for amplification in accordance with the invention; Fig. 5 is a circuit arrangement illustrating a modified form of the invention as applied in a radio transmitter; and Figs. 6 and 7 are diagrams indicating the wave form of the modulated carrier waves present in the system of Fig. 5 after they are modulated, but before and after they are modified for high efficiency amplification respectively.

In this specification the symbols adjacent to certain vacuum tube elements are employed with significations as follows: A indicates an amplifier; HG indicates a harmonic generator; CSM indicates a carrier suppression modulator; PA indicates a power amplifier; SC indicates a selective circuit; and PS indicates a phase shifter.

The diagrams used herein to illustrate alternating current wave forms are merely illustrative and for this reason are not to be considered as drawn to exact scale, or with mathematical exactitude. Furthermore, the various diagrams do not purport to indicate either the amplitude or frequency

relations between modulating and carrier frequencies on the same scale. The ratio between carrier and modulated frequencies is always selected in view of practical considerations and the use to which the system is to be put. The expression "pure modulated wave" is used herein to define a modulated alternating current wave from which the unmodulated component of carrier frequency has been entirely or almost entirely suppressed and in which either one or both side frequencies remain.

As has been previously proposed, greater efficiency in amplification by vacuum discharge devices can be secured by employing vacuum tubes in circuits operating in accordance with the method known as "shock excitation" or impulse excitation. The advantages of this method can be promoted by the method now about to be described which consists in producing and utilizing a peaked carrier wave as distinguished from a sinusoidal carrier wave. For example, a sine wave of a given frequency to which a triple frequency component has been added gives the peaked form of wave herein proposed to be used.

Thus in Fig. 1, the curve *a* represents a sine wave and *b* the triple frequency thereof. Curve *c* indicates the peaked resultant of a superimposition of the two waves, assuming a proper phase relation as shown. A problem involved in this invention of which some of the possible solutions are herein indicated, is to produce a modulated wave which has as a carrier wave a wave of the form of the unmodulated wave *c*.

For producing such a wave the arrangement of Fig. 2 may be used. A triode oscillator or other source 1 furnishes sinusoidal carrier waves of any desired frequency, for example, 30,000 cycles. These waves are supplied to a harmonic generator 2, a device well known in the art, which produces a series of multiple frequencies including a triple frequency component. The triple frequency component is selected by any suitable type of selective circuit 3 conveniently illustrated as a simple tuned circuit. The selected triple frequency component is amplified to any desired extent by a thermionic amplifier 4. The amplified triple frequency component and wave energy from the source 1, amplified if desired by an amplifier 5, are both impressed upon a circuit 6. A phase shifter 7, a device well known in the art, is adjusted to change the phase of the triple frequency component, if any change is necessary, so that it has the phase relation with respect to the fundamental indicated by the phase relation between the waves *a* and *b* (Fig. 1). The waves in the circuit 6 constitute the carrier wave of the wave form *c* (Fig. 1) to be modulated in accordance with a speech or

signaling wave derived, for example, from the microphone or low frequency circuit *L*. For telegraph transmission the circuit *L* may comprise a source of low frequency waves of constant amplitude and a key for interrupting them in accordance with a code. The speech frequency waves and the waves of peaked wave form in the circuit 6 are applied to a carrier suppression modulator 8. The carrier suppression modulator is an electrical instrumentality of construction and mode of operation well known in the art, being described in the Journal of the A. I. E. E. Vol. 40, April 1921, No. 4, page 301. In the output circuit of the modulator 8 will be present modulated waves based on a carrier frequency of 30,000 cycles with the unmodulated component of carrier frequency suppressed and a component of 90,000 cycles similarly modulated with the unmodulated component of carrier frequency suppressed.

The unmodulated wave supplied through the circuit 6 to the modulator 8 have the wave form indicated in Fig. 3. The modulated waves in the output circuit of the modulating device 8 have the wave form indicated in Fig. 4.

In order to select and transmit these waves to a power amplifying device 11 they are applied to tuned or selective circuits 9 connected to the input circuit of a low power or voltage amplifier 10. The circuits 9 may be as sharply or flatly tuned as may be necessary. In order not to unbalance the output circuit of the device 8, the tuned circuits of 30,000 and 90,000 cycle carrier frequency are arranged in duplicate so that each half of the output circuit of the device 8 will be coupled to a similar combination. The waves from the amplifier 10 are then supplied to the input circuit of the power amplifier 11 which consists of any desired number of vacuum tubes 12 connected in parallel, or a single tube of sufficient power capacity. Connected across the input circuit of the tubes 12 is a vacuum tube rectifier 13 in shunt to a variable and preferably high resistance 14. The anode of the rectifier is connected to the grids of the tubes 12. A capacity 15 shunted by a variable and preferably high resistance 16 is arranged in series in the grid-filament circuit of the tubes 12. The arrangement and operation of parts 13, 14, 15 and 16 are described in detail and claimed in applicant's application, Serial No. 609,932, filed December 30, 1922. A variable or adjustable battery 17 serves to polarize the grids. Although the present invention is advantageously operated in connection with the elements 13, 14, 15 and 16 in accordance with the method described in application Serial No. 609,932 referred to above, it is contemplated that the present

invention may be operated without the use of the invention of that application, for which purpose the resistances 14 and 16 may be adjusted to small or zero value and the battery 17 adjusted to any value desired. The function and operation of the elements 13, 14, 15, and 16 is briefly as follows: The battery 17 is first adjusted to or at about the point where space current begins to flow in the amplifier tubes 12. Incoming high frequency waves from the amplifier 10 then have their energy partially rectified and cause the grid potential of the tubes 12 to fall to a still more negative value. When the waves become of smaller amplitude the charge on the grid caused by the rectified currents will leak off through resistance 16. The grid thus assumes a high negative potential when large waves are amplified and a smaller negative potential when smaller waves are amplified. This increases the average efficiency. Resistances 14 and 16, capacity 15, and source 17 may be made variable or of fixed values suitably predetermined. The plate and filament connections of the tubes 12 may be coupled or connected in any suitable manner to the output or load circuit. The load circuit 18 comprises a radiating aerial 19 tuned by inductance 20 and capacity 21 to the fundamental carrier frequency, that is, 30,000 cycles per second. For most efficient results the circuit 18 should be sharply tuned.

In Fig. 2^A the output circuit of the amplifying tubes 12 is connected to a tuned circuit 22, which being closed, may be more sharply tuned to the fundamental carrier frequency. The circuit 22 is coupled as desired, but preferably loosely, to the radiating circuit 18 tuned as before by inductance 19 and capacity 21.

The antenna, when properly tuned, is a circuit of such high impedance to the triple frequency component that little energy in this frequency is radiated even though some of it is impressed upon the antenna circuit.

The wave e of peaked wave form (Fig. 4), indicating a pure modulated wave modulated in accordance with the signal wave d , is impressed upon the input circuit of the power amplifier 11. The operation of the system up to this point is clear from the drawing and the preceding description. The manner in which the amplifier 11 functions is now to be considered. The grid polarizing source 17 is so adjusted that space current just begins to flow in the power amplifier when no waves are applied to the input circuit. When waves of peaked wave form, as illustrated in Fig. 3, are applied, a portion of the input energy is rectified by the rectifier 13 thereby making the grids of the tubes 12 more negative as the applied waves become larger. Each positive peak causes an impulse of current

substantially proportional to the amplitude of the peak to flow in the plate circuit. It should be remembered that the mean grid potential about which the grid oscillates is not a constant quantity. Waves of large amplitude applied to the grid circuit are partly rectified to make the grid more negative but the excess negative charge leaks off when the incoming wave ceases or decreases in amplitude. If the modulating wave form is sinusoidal the mean grid potential wave form is cycloidal and it is about this cycloidal axis that the grid potential is varied by the incoming waves.

The successive impulses of current in the tuned output circuit of the amplifier 11 set up a wave of the fundamental carrier wave frequency because the impulses recur at the fundamental frequency. Consider now that the wave applied to the input circuit is of the modulated form indicated by the curve e in Fig. 4. The wave in the output circuit has the form of a modulated carrier wave with the unmodulated component of carrier frequency suppressed because the several impulses occur at such frequency as to excite the tuned output circuit in a manner to cause a pure modulated wave to be set up therein. The carrier frequency of this wave is of the fundamental frequency of generator 1, that is, 30,000 cycles per second and is radiated to transmit the message to a distant station.

In the circuit of Fig. 2, as described; the method is first to produce a carrier wave including a triple frequency component and then modulate it.

However, the invention may be carried out by producing a carrier wave, modulating it and thereafter adding the third harmonic, amplifying it to a suitable amplitude, and amplifying at high efficiency the resultant wave of peak wave form. A circuit for doing this is shown in Fig. 5 wherein a carrier wave from the source 1 is modulated in accordance with speech by waves from the circuit 7, the modulation being performed by the carrier suppression modulator 8. After amplification in the amplifier 23, the resultant pure modulated wave is impressed upon a divided path, one branch of which proceeds through the amplifier 24 to the power amplifier 11. The other branch passes to the harmonic generator 2, to the output of which is connected a suitable selective circuit 3. In the present instance the generator 1 produces a carrier frequency of 100,000 cycles per second and the circuit 3 is consequently tuned to 300,000 cycles per second to select the triple frequency modulated component. The selected triple frequency modulated component passes through the amplifier 4 and the phase shifter 7 to be combined with the fundamental in the input circuit of the power amplifier 11. The con-

struction and arrangement of the power amplifier in Fig. 5 is the same as in Fig. 2.

In Fig. 6 the curve *f* represents the pure modulated wave and the curve *d* the wave form of the modulating wave. The curve *f* represents the form of the wave produced by the carrier suppression modulator 8 in Fig. 5. In Fig. 7, *d*, as before, represents the wave form of the modulating wave and curve *e* represents the pure modulated carrier wave having a component of triple frequency. The wave *e* is that which is impressed upon the input circuit of the power amplifier 11 in Fig. 5, and since its form is generally the same as that of the form of the wave *e* of Fig. 4, it follows that the operation of the power amplifier of Fig. 5 will be the same as described in connection with Figs. 2 and 4. In practice the wave form of the modulated carrier wave will not be strictly the same as that produced by the arrangement of Fig. 2, but it will be sufficiently near approximation to produce the same general results.

This invention is not limited in application to radio transmission, but may be applied in transmission over conductive circuits in which case the antenna circuit in Fig. 2^A will be replaced by a conductive circuit or line.

Having described the characteristic features and mode of operation of certain embodiments of the invention, the novel features believed to be inherent therein are set forth in the appended claims.

What is claimed is:

1. The method of producing a carrier wave of desired peaked wave form, which comprises producing from a given wave a multiple frequency component, deriving from said component a wave of the same frequency as said component and of desired amplitude, and combining the wave of desired amplitude with a wave of frequency the same as the frequency of the given wave to produce the desired carrier wave of desired peaked wave form.

2. The method which comprises varying a carrier wave in accordance with a modulating wave, deriving from the resultant wave an odd multiple frequency, amplifying the odd multiple frequency, and combining the amplified wave with the wave of the original frequency.

3. The method which comprises producing from an alternating current a current of triple frequency, separating the current of triple frequency from other alternating currents, combining the separated current with current of the original alternating current frequency, and utilizing the combined current in a signaling channel.

4. The method of obtaining a wave of peaked wave form which comprises producing from a current wave a wave of distorted

wave form, selecting from the wave of distorted wave form a component comprising chiefly energy of odd multiple frequency, amplifying the selected component, and recombining the component and the original wave.

5. The method of transmission which comprises modulating a carrier wave consisting of a wave of given frequency and a triple frequency component and impressing the resultant wave on an amplifying device.

6. The method which comprises producing a wave consisting of a pure modulated wave of a given frequency with its triple frequency component, and impressing the resultant wave on an amplifying device comprising a vacuum tube amplifier adjusted to normally negligible space current.

7. The method which comprises utilizing a repeater to derive from a modulated wave having a triple frequency component of large energy a modulated wave of which the energy is chiefly in side frequencies based upon the fundamental frequency.

8. In an amplifying system, means for increasing efficiency of amplification comprising a source of energy of a given frequency to be amplified, a non-regenerative amplifier for performing the amplification, a circuit upon which the amplified energy is to be impressed, and means for impressing upon the input circuit of said amplifier a wave consisting of a component of a given frequency and an odd multiple thereof.

9. A system comprising a source of waves to be modulated, a carrier suppression modulator supplied by said source, a harmonic generator for producing an odd multiple frequency component from the modulated waves, selective means for selecting the odd multiple frequency component, means for combining energy of the selected component with energy of the frequency impressed upon said harmonic generator, and a repeating device having an input circuit supplied by the combined waves thus produced in combination with means whereby only the peaks of the waves supplied to said repeater are effective to cause space current to flow in the output circuit thereof.

10. The method which comprises impressing a signaling wave and a carrier wave upon a repeating device adapted to modulate and suppress the carrier, the carrier wave comprising a fundamental and a multiple frequency component.

11. A transmitting system comprising a source of carrier waves, a harmonic generator for producing an odd multiple frequency component, a phase shifter for shifting the phase of the component thus produced, means for combining the component of shifted phase with energy of the carrier frequency, means for modulating the wave thus produced in accordance with signaling

waves or impulses, and an amplifier for repeating to a transmission circuit the modulated waves thus produced.

12. In a signaling system, an amplifying device including a cathode an anode and a grid, a circuit connecting the grid and the cathode, means for polarizing the grid negatively with respect to the cathode, means for supplying a variable amplitude wave of peaked wave form to said grid-cathode circuit, means associated with said grid-cathode circuit to vary the polarization of said grid in accordance with the amplitude variations of the supplied waves, and an output circuit for transmitting the resultant waves.

13. In a signaling system, a repeating device having an input circuit and an output circuit, a rectifier connected across the input circuit, a circuit tuned to a given frequency connected to the output circuit, and means for supplying to the input circuit an alternating current wave having a component of frequency approximately an odd multiple of the frequency to which the tuned circuit is tuned.

14. The method which comprises producing a wave having a plurality of frequency components, modulating said wave with another wave, and suppressing the resulting unmodulated components.

15. An arrangement for producing a wave having one component which is a multiple frequency of another component in combination with a balanced modulator and a source of modulating waves and means for supplying said first mentioned wave and said modulating waves to said modulator in such a manner as to suppress the unmodulated components of the first mentioned wave.

16. The method of efficiently amplifying a modulated wave which comprises impressing said wave upon the input circuit of a thermionic amplifier and simultaneously impressing on said circuit a second wave of a multiple frequency of the modulated wave.

In witness whereof I hereunto subscribe my name this 16th day of February, A. D. 1923.

RAYMOND A. HEISING.