March 13, 1934. F. W. HOORN 1,950,406

METHOD AND APPARATUS FOR CONTROLLING ELECTRICAL WAVES

Original Filed May 7, 1929 3 Sheets-Sheet 1

FIG. 1

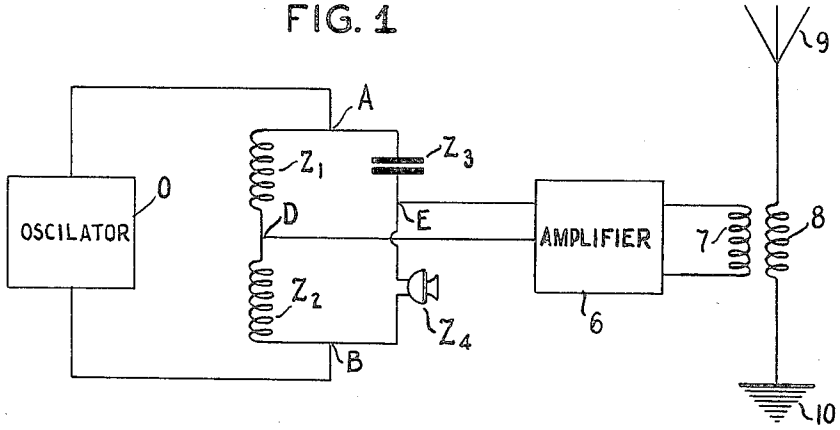


FIG. 2

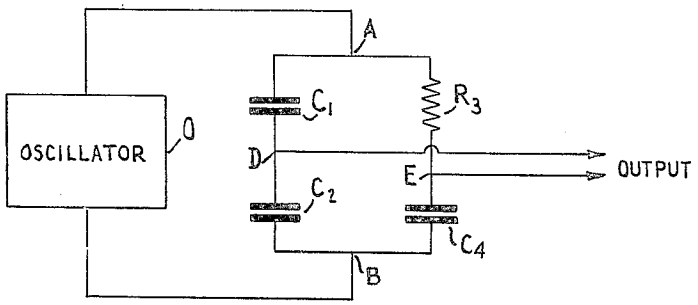
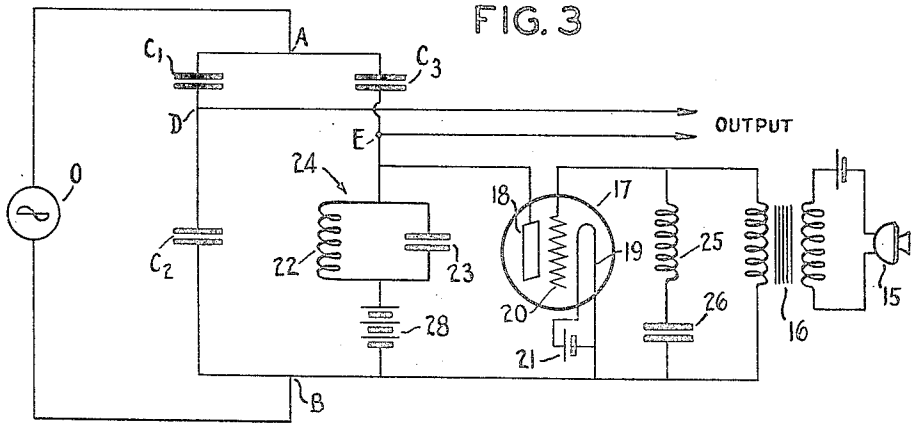


FIG. 3



INVENTOR
FREDERICK W. HOORN
BY
Clyde C. Morton
ATTORNEY

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METHOD AND APPARATUS FOR CONTROLLING ELECTRICAL WAVES

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FIG. 4

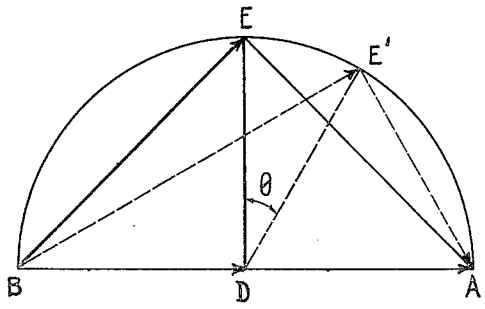


FIG. 5

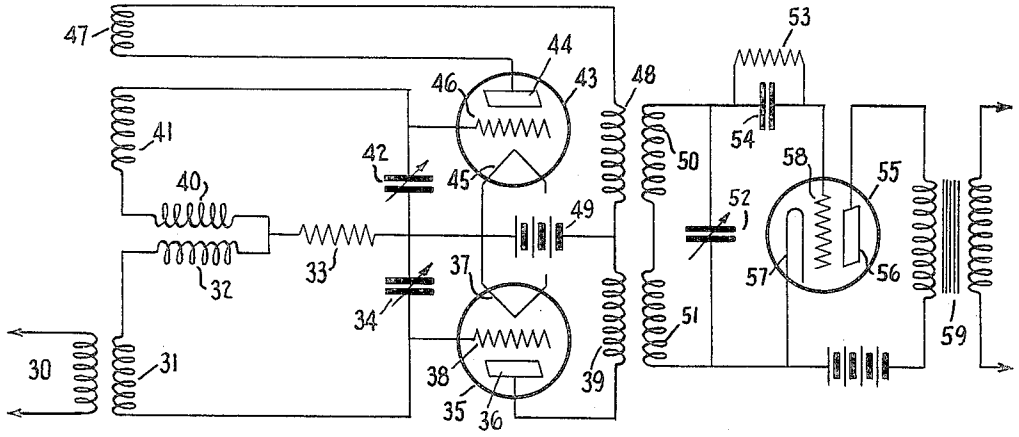
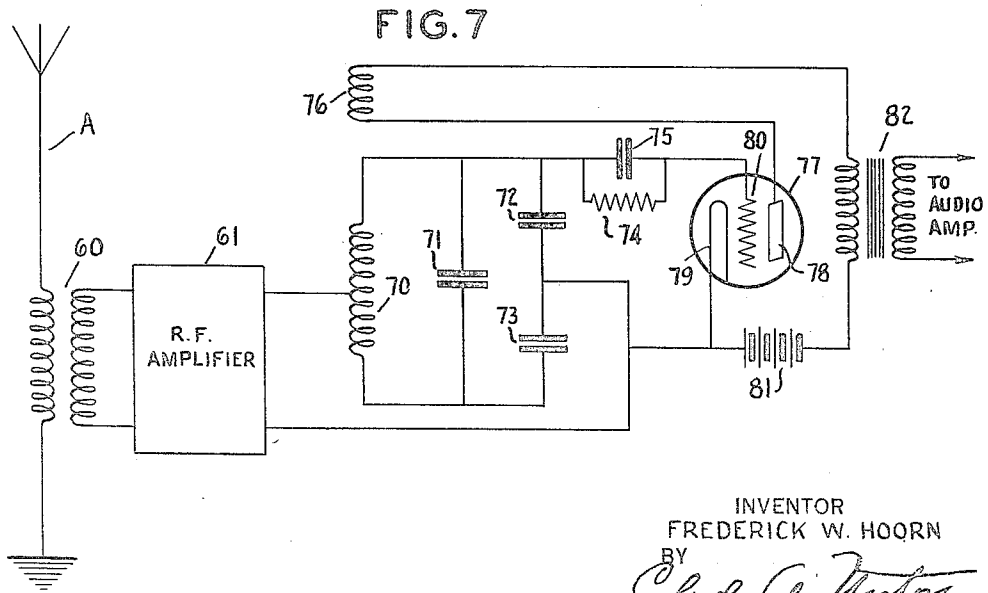


FIG. 7



INVENTOR
FREDERICK W. HOORN
BY
Clyde A. Watson
ATTORNEY

March 13, 1934. F. W. HOORN 1,950,406

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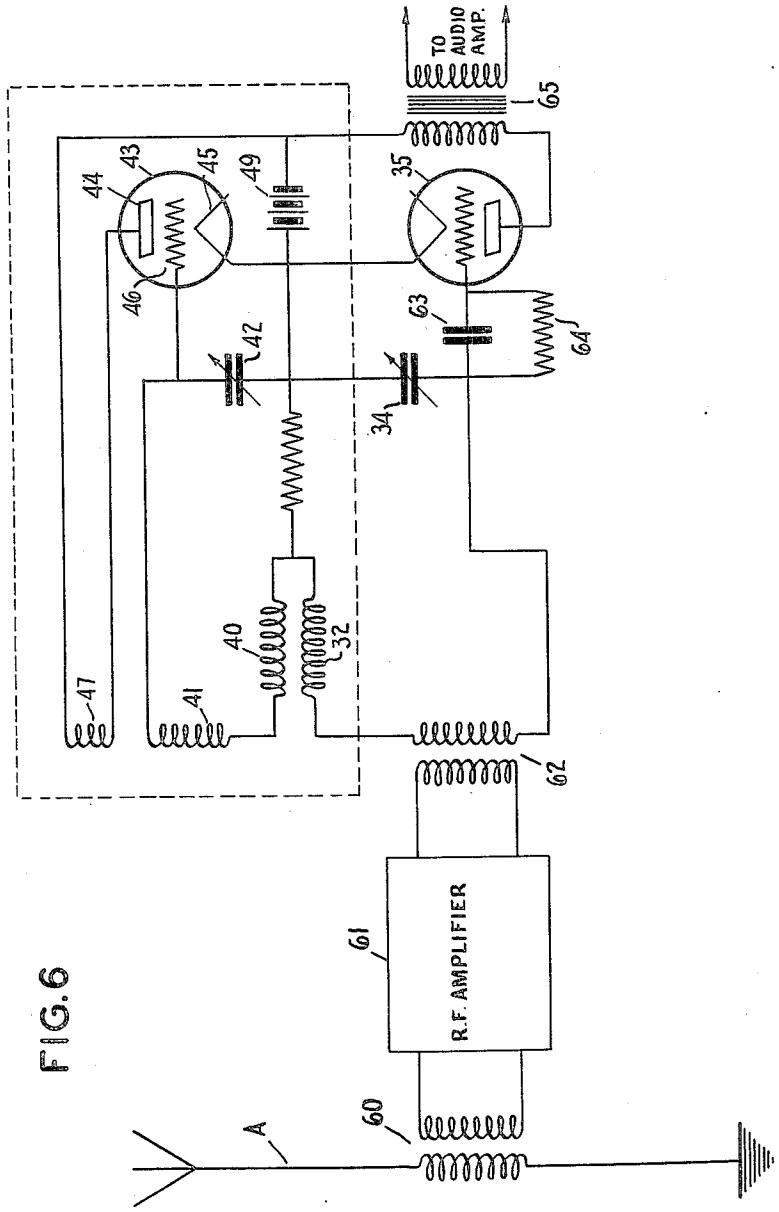


FIG. 6

INVENTOR
FREDERICK W. HOORN
BY Clyde C. Hunton
ATTORNEY

Patented Mar. 13, 1934 1,950,406

UNITED STATES PATENT OFFICE

1,950,406

METHOD AND APPARATUS FOR CONTROLLING ELECTRICAL WAVES

Frederick W. Hoorn, Washington, D. C.

Application May 7, 1929, Serial No. 361,030

7 Claims. (Cl. 179—171)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described in said application, if patented, may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

This invention relates to a method and apparatus for controlling electrical waves or currents of one range of frequency in accordance with waves or currents of another and lower range of frequency, and more particularly to the application of such control to the transmission and reception of signals by radio, carrier current and the like.

For this purpose it has heretofore been customary to modulate the high frequency currents or waves in accordance with the signals to be transmitted, such as voice currents or the like, thereby producing changes of amplitude or frequency, or both, in the high frequency or carrier wave. As is well understood, such modulation produces new waves or currents, commonly called "side bands", having a frequency range extending above and below the carrier frequency by an amount equal to the highest modulating or signal frequency. The side bands may include all frequencies lying within the limit of $fr \pm fa$, where fr is the carrier frequency and fa the highest modulating or signal frequency.

It is also understood that when it is desired to send or receive voice or music signals as modulations of higher frequency waves, a channel or band of frequencies sufficient to include the side bands must be available, that is to say, the apparatus used for transmission and reception cannot be so sharply tuned to the carrier frequency as to discriminate against side bands without distorting the signal to a greater or less extent.

Attempts have been made to diminish the width of the frequency channel required, as for example by suppressing one set of side bands, and even one set of side bands and the carrier, but to my knowledge no system has heretofore been devised which does not require the transmission of at least one set of side bands, and in music transmission this requires a band of at least five kilocycles for average good quality. In picture transmission and television the band is usually very much greater.

It is an object of the present invention to provide a method and apparatus for controlling high frequency currents in accordance with currents of lower frequency, which permits the use of a narrower frequency channel for a given signal frequency range than has heretofore been possible.

It is a further object of my invention to provide a method and apparatus for controlling high frequency currents in accordance with lower frequency signals, by shifting the phase of the high frequency currents under control of the signals while maintaining the amplitude of the carrier current substantially constant.

It is still a further object of my invention to provide a method and apparatus of the class described in which the phase shift introduced in the carrier wave shall not in any event exceed 180°, and which may be held within limits as small as may be desired, as for example 10 or 15 degrees.

It is still a further object of my invention to provide a method and apparatus of the class described in which the control of the carrier wave may be achieved without the use of the conventional modulating apparatus, and in which the width of the frequency channel required may be greatly decreased without the necessity for introducing filters, side band suppression circuits or the like.

Still other objects and advantages of my invention will be apparent from the specification.

The features of novelty which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its fundamental principles and as to its particular embodiments, will best be understood by reference to the specification and accompanying drawings, in which:

Figure 1 shows diagrammatically a simple form of radio transmitter according to my invention.

Figure 2 shows a somewhat different form of transmitting apparatus according to my invention.

Figure 3 shows still another form of transmitter according to my invention.

Figure 4 is a vector diagram illustrating the operation of my invention.

Figures 5, 6 and 7 show diagrammatically various forms of receivers according to my invention.

My invention, in its fundamental aspect, contemplates modifying the phase of the high frequency carrier wave in such a manner that the phase displacement from normal is at any instant dependent on the amplitude of the current representing the signals to be transmitted, herein termed "signal currents". This is achieved by combining a wave, the phase and amplitude of which is constant, with another of the same frequency, the phase and amplitude of which is varied under the control of the signals in such man-

ner as to produce a resultant of constant amplitude but of varying phase which may be transmitted.

Reception may be obtained from the transmitted wave by a reversal of the process, that is, by combining with the received wave another wave of the same frequency and of constant amplitude and phase, the resultant of which may be detected and will yield currents corresponding to the original signal currents to be transmitted.

Referring now more particularly to Fig. 1: 0 designates diagrammatically an oscillator capable of delivering high frequency oscillations of constant amplitude and frequency to the input points A and B of the four-element network Z_1, Z_2, Z_3 and Z_4. It will be noted that these four elements are connected in series with each other in a closed loop. The input point A is taken intermediate impedances Z_1 and Z_3, and input point B intermediate impedances Z_2 and Z_4. The output circuit is connected across points D and E, point D being located between impedances Z_1 and Z_2, and point E being located between Z_3 and Z_4.

The network as seen from the input or output terminals may therefore be regarded as being made up of two branches in parallel with each other, each branch being in turn made up of two elements in series.

Impedances Z_1 and Z_2 may be resistances, inductances, capacities, or combinations thereof, but both should be identical in magnitude and character so that the voltage drops through each due to a voltage impressed between points B and A, and are equal and in phase, whereby they may be represented by vectors E_{BD} and E_{DA} in Fig. 4, E_{BD} and E_{DA} representing the impedance drop in Z_2 and Z_1, respectively, due to the current flowing in Z_2 and Z_1, as a result of the impressed voltage.

Impedances Z_3 and Z_4 may be any suitable impedances having phase angles differing by 90°. For example Z_3 may be a reactance, such as a condenser or inductance, the resistance being kept as low as possible, and Z_4 being a resistance, the reactance of which is kept as low as possible. Either of the impedances Z_3 and Z_4 is arranged to vary in magnitude under the control of the signal currents of low frequency.

In Fig. 1, I have shown Z_3 as a condenser and Z_4 as a simple form of carbon transmitter, the resistance of which varies in accordance with sound waves impinging thereon, but other arrangements may be used, as will hereafter be more particularly explained.

Referring now to Fig. 4, since the nature of impedances Z_3 and Z_4 are so chosen that the voltage drops across them are always in quadrature, and since E_{BDA} must always equal E_{BEA} in magnitude and phase (Kirchoff's law), the conditions define the locus of two sides of a triangle, the angle between which sides is fixed and the third side of which is fixed.

It will be seen that the locus of point B is on the circumference of a semi-circle drawn about point D with a radius equal to DA, and that regardless of the location of point E in the locus, the fundamental requirements are satisfied.

From this diagram we may find the voltage drop E_{DE} which must equal the vector sum of E_{DB} and E_{BE}, which always equals E_{DA} plus E_{AE} vectorially. The vector DA of Fig. 4, represents the potential difference of constant amplitude and phase, referred to in the method claims. Although represented as a stationary vector to represent magnitude and relative phase; this is a rotating vector, in the sense that it generates by its rotation the sinusoidal potential difference E_{DA}.

The vector DA is then, further, the vector of constant length, rotating about its point of origin with uniform angular velocity, the peripheral end of which traces the semicircle BEA of Fig. 4.

Vector AE represents the potential difference L_{AE}, and is the vector referred to in the method claims, as the vector drawn from the peripheral end of vector DA, to a point on the circumference of the circle traced by vector DA in its rotation.

Vector DE is the sum of the above mentioned vectors DA and AE and necessarily remains constant in magnitude but varies in phase, as the magnitude of AE changes, and its quadrature relationship to EB is maintained. In either case, E_{DE} is represented by a vector of constant length having a phase relation which may be displaced by an angle θ, which cannot exceed 90° in either direction of shift, and hence the total shift in phase cannot exceed 180°. It will be understood that by controlling the change of impedance Z_4, that is, by operating it within certain fixed limits, the phase displacement of E_{DE} may also be kept within corresponding limits, and hence, to obtain any predetermined limit of phase shift of E_{DE}, it is only necessary to operate Z_4 in such a way that the greatest possible change of Z_4 shall be small as compared with the normal value of Z_4.

Now, it can be shown mathematically that the actual frequency transmitted according to my invention may be represented by $ft=fr\pm fz$, where fr is the basic carrier frequency and fz is the apparent frequency introduced by a phase displacement θ introduced in the carrier. If R represents the impedance of the element Z_4 which is variable, and X the impedance of the element Z_3 which is fixed, and if R is made equal to X when no sounds are falling upon the microphone, then we may write $R=r_1+r_2 \sin \omega at$, where ωa, represents the audio or other low frequency signal.

When, as already pointed out, r_2 is made small, say .10 x R, and r_1, which represents the normal value of R, is equal to X, it can be shown that under this condition

$$fz=fa\frac{r_2}{R}$$

in which

$$fz=\frac{1}{2\pi}\frac{\delta\theta}{\delta t}$$

and fa is the signal or audio frequency, and fz has a maximum value which is a small fraction of fa when $\cos \omega at$ is unity or nearly unity. The equation for transmitted frequency then becomes

$$ft=fr\pm\left(\frac{r_2}{R}\cos \omega at\right) fa$$

in which

$$\frac{r_2}{R}\left(\cos \omega at\right)$$

is always small. From this it will be seen that the amount of phase shift or phase displacement introduced by the signal currents may be held within any predetermined limit, and therefore the apparent variation in transmitted frequency may be held within any desired limit by correspondingly limiting the value of change in R.

The voltage E_{DE} may be amplified to the extent desired and transmitted in any suitable way. In Fig. 1, I have shown diagrammatically amplifier 6, the output of which supplies antenna 9,

grounded at 10, through coupling coils 7 and 8.

In Fig. 1, I have shown impedances Z_1 and Z_2 as inductances, Z_3 as a condenser and Z_4 as a variable resistance transmitter. In Fig. 2, I have shown a modified arrangement in which impedances Z_1 and Z_2 are shown as condensers C1 and C2, while Z_3 is shown as a fixed resistance R3, and Z_4 is a condenser transmitter C4. The principle of operation is the same as already described.

Referring now to Fig. 3, I have shown a still further modification in which Z_1, Z_2 and Z_3 are all condensers, while Z_4 is the plate-filament resistance of a suitable vacuum tube amplifier. In this case 15 is a transmitter of any suitable type, the output of which is supplied to the vacuum tube amplifier 17 by means of transformer or other coupling means 16.

Amplifier 17 comprises an anode 18 a cathode 19 and a control electrode 20, and as these devices are well known in the art and form per se no part of this invention, they are not described in detail.

In order to prevent the building up of any high frequency voltage on the input circuit of tube 17, a circuit consisting of inductance 25 and capacity 26, tuned to the high frequency, may be connected in shunt with the input circuit.

The output circuit may comprise a tuned circuit 24, consisting of inductance 22 and capacity 23, tuned to the high frequency, and a suitable source of plate current 28. Circuit 24 offers infinite impedance to the high frequency current, but substantially zero impedance to currents of lower frequencies, so that no audio frequency voltage can be built up between anode 18 and cathode 19 of tube 17, the plate circuit of which therefore operates as a variable resistance, varying in accordance with sounds picked up by microphone 15. To prevent the tube acting as a rectifier of the high frequency current, the potential of source 28 should be so large that the anode 18 is always positive with respect to cathode 19.

A suitable source of power 21 is shown for heating cathode 19, and it may be desirable also to employ some form of stabilization to prevent oscillation of amplifier 17 when the input and output circuits are tuned to the same frequency. This may be in the form of a resistance connected in the grid circuit, or may be some form of tube capacity neutralization, all of which are well known. It may be found in certain cases that one or both of the tuned circuits may be omitted without introducing undesirable effects.

For the purpose of deriving signal currents from the received carrier or radio frequency wave on which the signals have been impressed, as already described, it is necessary to combine with the received wave a second wave of the same prequency as the constant frequency used for transmission, which second wave has a constant amplitude and phase relation. This process is the reverse of the process described for transmission and is also represented by the vector diagram of Fig. 4, wherein, for example E_{DE} represents the received high frequency wave and E_{BD} the local wave of constant frequency amplitude and unvarying phase, which is combined, thereby producing voltage E_{BE} of varying amplitude.

Referring now more particularly to Fig. 5, I have shown one arrangement suitable for the purpose, in which 30 represents the input coil, which may be for example connected in an antenna not shown. Coil 30 is coupled to a second coil 31 connected to the control electrode 38 of vacuum tube 35 and connected also through coil 32 and resistance 33 to the cathode 37 of amplifier 35. If desired, a tuning condenser 34 may be connected between the cathode 37 and control electrode 38. The anode 36 is connected to coil 39 to the source of plate supply 49. Coil 32 is coupled to a second coil 40, and resistance 33 and coils 40 and 41 are connected in the input circuit of a second vacuum tube 43, the input circuit of which may be tuned by means of condenser 42 connected between the control electrode 46 and cathode 45. Anode 44 is connected to coil 47 for the purpose of permitting the vacuum tube 43 to generate oscillations, as is well known in the art. The output circuit of tube 43 is completed through coil 48 and the source of plate supply 49. Coils 39 and 48 are coupled to coils 51 and 50, respectively, connected in the input circuit of vacuum tube detector 55, having an anode 56, cathode 57 and control electrode 58. Coils 50 and 51 may be tuned by tuning condenser 52. Resistance 53, shunting condenser 54, may be provided for causing the tube to operate as a detector. A suitable transformer 59 may be provided in the output circuit of tube 55 for supplying the output thereof to any suitable device such, for example, as an amplifier or translating device. In the operation of this arrangement tube 35 operates as an amplifier, whereas tube 43 operates as an oscillator, both being tuned to the frequency of the incoming signal. By adjustment of condenser 42, the oscillations generated by tube 43 will be of the same frequency as the incoming oscillations impressed on tube 35, that is to say, the oscillator will fall in step with the received signal. However, this coupling, controlled by coils 32 and 40 and resistance 33, should not be made so tight that the phase of the oscillatory currents generated by tube 43 follows the phase of the incoming signals, since tube 43 supplies the oscillations of constant frequency and unvarying phase. These oscillations are supplied to the input of detector 55 by means of coils 48 and 50, while the amplified signal input is similarly supplied to the input of tube 55 by means of coils 39 and 51. The amplitude of oscillator 43 should be so adjusted that the generated oscillations are of substantially the same order of strength as the currents with which they are to be combined. But in any event, the coupling between coils 48 and 50, and 39 and 51, may be adjusted until best results are obtained. The detected currents supplied by tube 55 will then correspond to the currents delivered by the microphone or other device in Fig. 1, and may be amplified to the extent desired for the particular purpose in view.

Referring now more particularly to Fig. 6, I have shown a slightly modified arrangement in which the incoming signals are first amplified and in which tube 35 operates as a detector. In this arrangement A designates an antenna representing the primary or coupling transformer 60, the secondary of which feeds a suitable frequency amplifier 61, the output of which is fed to the input of detector 35 by means of coupling transformer 62. In this arrangement it will be noted that grid leak and condenser 64 and 63 are connected in the input circuit of tube 35 in the manner known in the art, to cause the said tube to operate as a detector; also, coils 39, 48, 50 and 51 are dispensed with and a transformer 65 or other suitable coupling device is provided for supplying the detected currents to any suitable amplifier or other translating device. In this instance the oscillator 42 is preferably enclosed in a suitable shield indicated by the dotted lines as enclosing

also certain of the elements of the circuit of tube 43 within the shield.

Referring now more particularly to Fig. 7, I have shown a slightly further modified form of apparatus in which the same tube operates as detector and oscillator. In this instance the output of radio frequency amplifier 61 is impressed between one pair of opposite points of a balanced Wheatstone bridge made up of coil 70, tuning condenser 71 and series condensers 72 and 73, while the input of tube 77 is taken off condenser 72. The anode 78 is connected through coil 76 and the primary of output transformer 82 through the source of plate current 81 to the cathode 79, while the input circuit is connected between control electrode 80 through grid leak 75 to condenser 72, the opposite side of which is connected to cathode 79. This arrangement is similar to that described in United States patent to Pressley 1,560,854, dated November 10, 1925, and permits the tube 77 to generate oscillations without such oscillations being radiated from the antenna A. In this case the locally generated oscillations are combined with the incoming signals in tube 77 and its associated circuits, and the resultant is detected by the said tube.

I claim:—

1. A method of controlling a high frequency current in accordance with signal currents of lower frequency, which comprises deriving a high frequency potential difference of substantially constant amplitude, but shifting phase, by combining a first potential difference of constant amplitude and phase with a second potential difference of varying amplitude and phase, said first potential difference being that which is being represented by a vector of constant length rotating about its point of origin with uniform angular velocity, and said second potential difference being that which is represented by a second vector drawn from the peripheral end of said first vector to a point on the circumference of the circle traced by the outer end of said first vector in its rotation.

2. A method of controlling a high frequency current in accordance with signal currents of lower frequency, which comprises deriving a high frequency potential difference of constant amplitude, but shifting phase, by combining a first potential difference of constant amplitude and phase with a second potential difference of amplitude and phase, which is varied in accordance with said signal currents of lower frequency, said first potential difference being that which is represented by a vector of constant length rotating about its point of origin with uniform angular velocity, and said second potential difference being that which is represented by a second vector drawn from the peripheral end of said first vector to a point on the circumference of the circle traced by the outer end of said first vector in its rotation.

3. A method of decreasing the frequency channel necessary to transmit signals of lower frequency as variations of higher frequency signalling waves, which comprises deriving a high frequency potential difference of constant amplitude, but shifting phase and irrespective of the relative values of the fixed and variable elements, by combining a first potential difference of constant amplitude and phase with a second potential difference of varying amplitude and phase, said first potential difference being that which is represented by a vector of constant length rotating about its point of origin with uniform angular velocity, and said second potential difference being that which is represented by a second vector drawn from the peripheral end of said first vector to a point on the circumference of the circle traced by the outer end of said first vector in its rotation, and limiting the phase shift of said second potential difference to a predetermined value corresponding to a predetermined width of high frequency signalling wave channel.

4. A method of controlling a high frequency current in accordance with signal currents of lower frequency by displacing the phase of said high frequency current while maintaining its amplitude constant, and limiting the phase displacement to a predetermined value, which comprises deriving a high frequency potential difference of substantially constant amplitude, but shifting phase and irrespective of the relative values of the fixed and variable elements, by combining a first potential difference of constant amplitude and phase with a second potential difference of varying amplitude and phase and limiting the phase of said second potential difference to a predetermined value corresponding to the predetermined value of phase shift of said high frequency current desired, said first potential difference being that which is represented by a vector of constant length rotating about its point of origin with uniform angular velocity, and said second potential difference being that which is represented by a second vector drawn from the peripheral end of said first vector to a point on the circumference of the circle traced by the outer end of said first vector in its rotation.

5. Apparatus for controlling high frequency currents in accordance with lower frequency signals, comprising in combination a network consisting of two branches connected in parallel, each of said branches comprising a pair of impedances connected in series, the impedances in one branch being identical in all respects, and the impedances in the other branch having phase angles differing by 90°, a high frequency imput circuit connected across the opposite ends of said network, and a high frequency output circuit connected between points intermediate the impedances in each branch, and means for varying the value of one of said impedances in said second branch in accordance with currents of a lower order of frequency.

6. Apparatus for producing a high frequency difference of potential, controlled in accordance with signal currents of lower frequency, comprising a network consisting of two branches connected in parallel, one of said branches comprising a pair of series connected impedances of equal value, the other branch of said network comprising a pair of series-connected impedances, one of said impedances having substantially zero resistance and the other having substantially zero reactance; a high frequency input circuit connected across the opposite ends of said network; means for impressing high frequency currents of constant frequency and amplitude upon said input circuit; means for varying the value of one of said impedances in said second branch in accordance with currents of a lower order of frequency; and a high frequency output circuit connected at points intermediate the impedances of each branch.

7. Apparatus for producing a high frequency difference of potential controlled in accordance with signal currents of lower frequency, and having a phase shift limited to a predetermined value, comprising a network consisting of two branches connected in parallel, one of said branches in-

cluding a pair of series-connected impedances of equal value, the other branch of said network comprising a pair of series-connected impedances, one of said impedances having substantially zero resistance and the other having substantially zero reactance; a high frequency input circuit connected across the opposite ends of said network; means for impressing high frequency currents of constant frequency and amplitude upon said input circuit; means for varying the impedance value of one of said impedances in said second branch within predetermined limits corresponding to the phase shift permissible in said high frequency currents; and a high frequency output circuit connected at points intermediate the impedances of each branch.

FREDERICK W. HOORN.