Dec. 19, 1939. M. L. DULL 2,183,905

PHASE MODULATION TRANSMITTER

Filed March 1, 1933 3 Sheets-Sheet 1

Fig. 1.

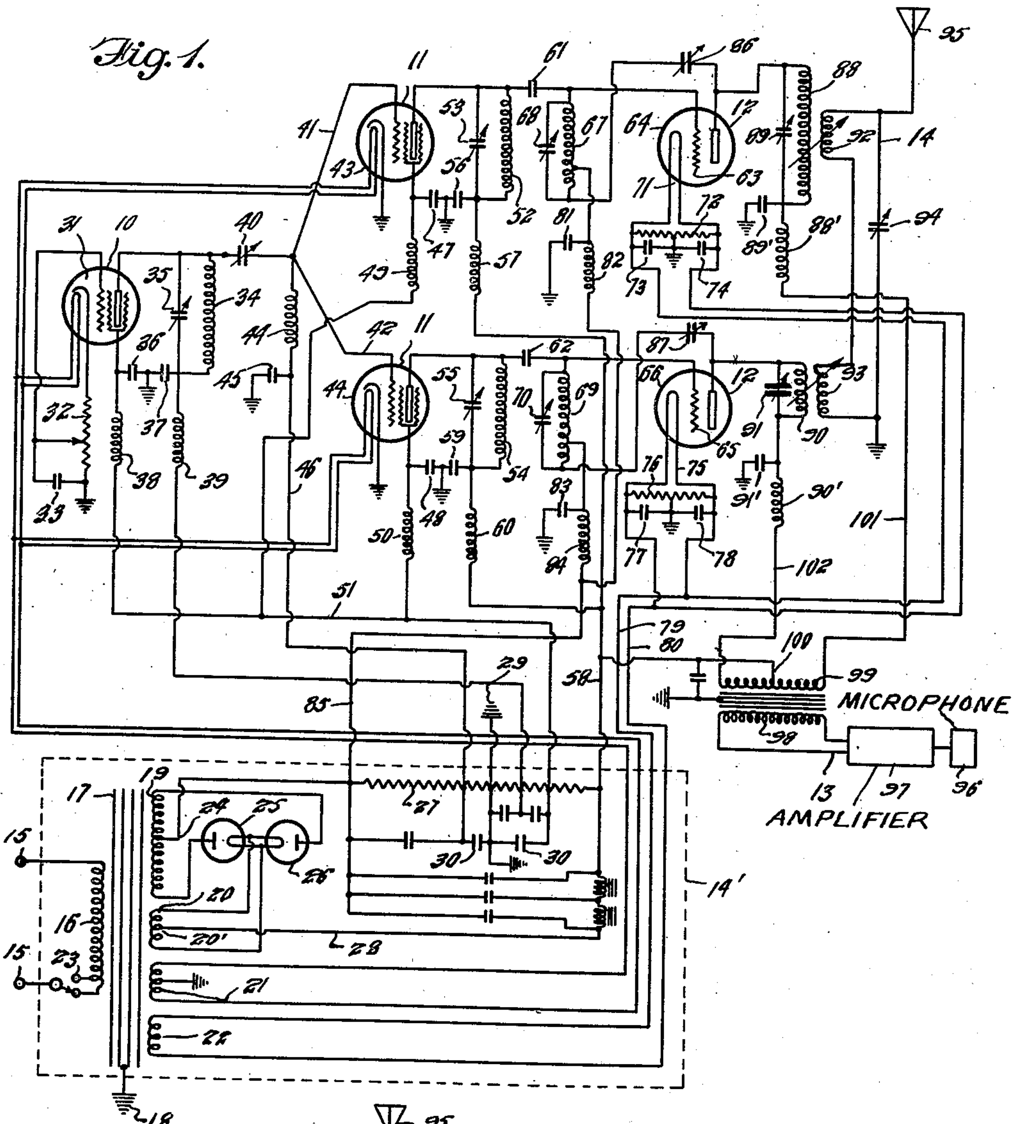
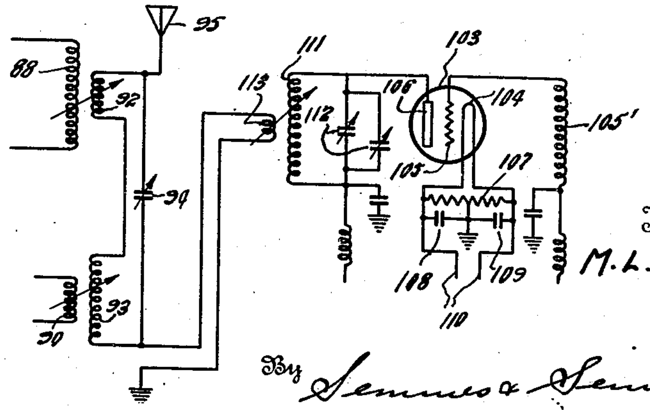


Fig. 2.



Inventor

M. L. DULL

By Semmes & Semmes

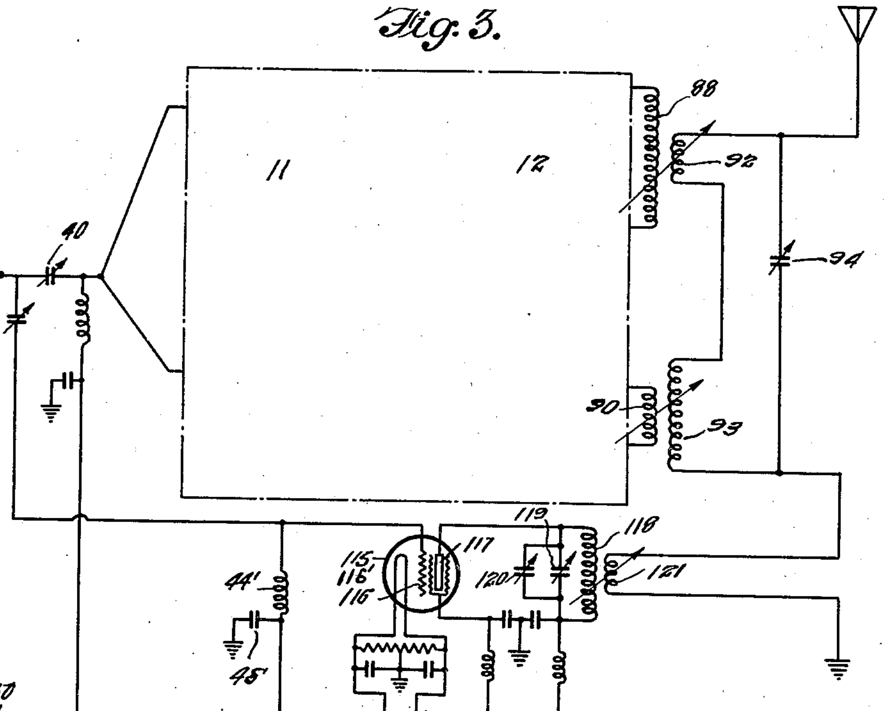
Attorneys

Dec. 19, 1939. M. L. DULL 2,183,905

PHASE MODULATION TRANSMITTER

Filed March 1, 1933 3 Sheets-Sheet 2

Fig. 3.



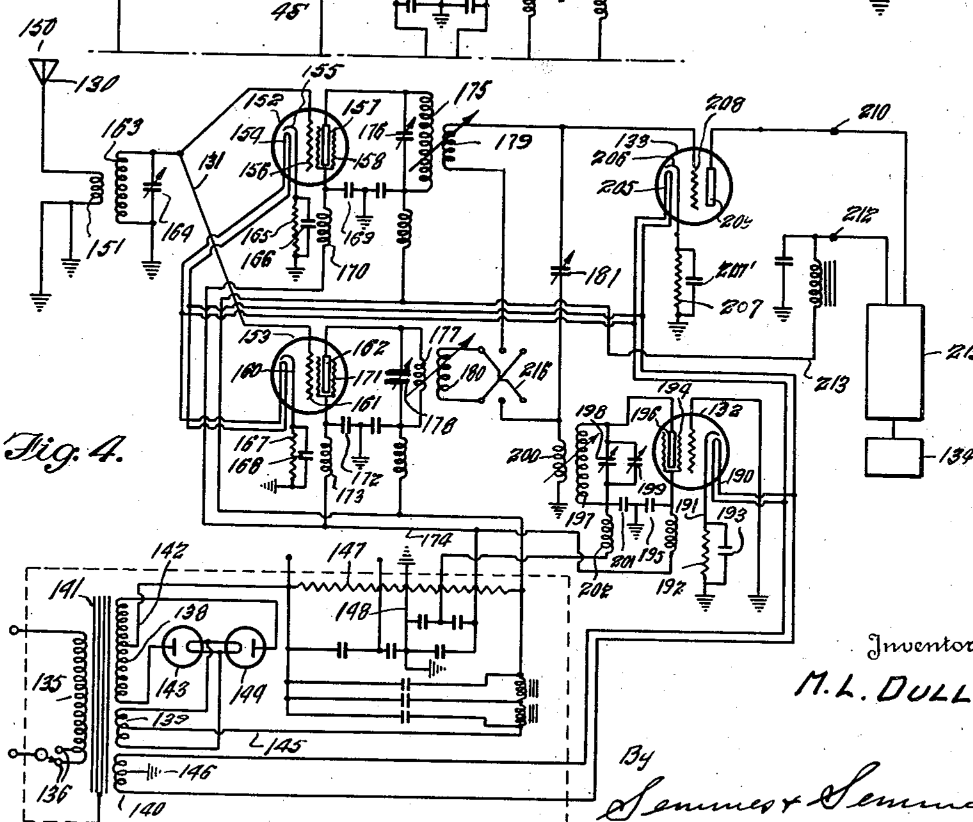


Fig. 4.

Inventor

M. L. DULL

By Semmes & Semmes

Attorneys

Dec. 19, 1939. M. L. DULL 2,183,905

PHASE MODULATION TRANSMITTER

Filed March 1, 1933 3 Sheets-Sheet 3

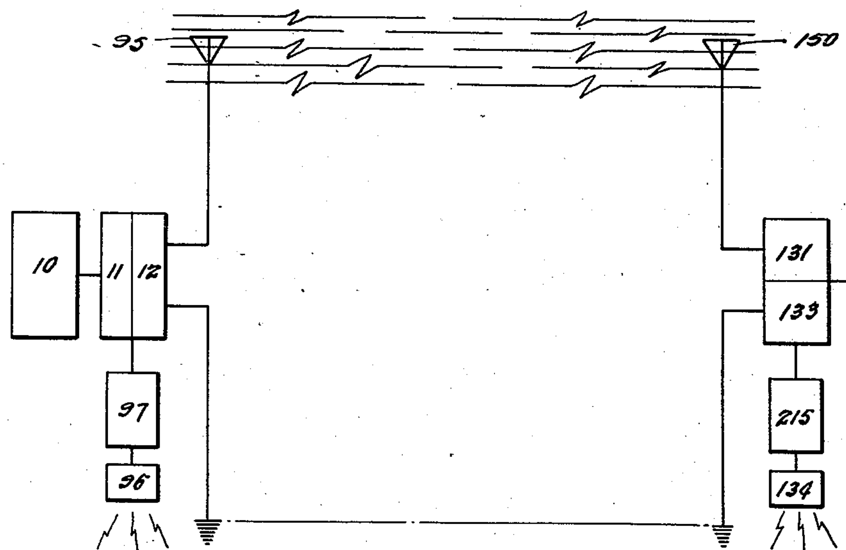


Fig. 5.

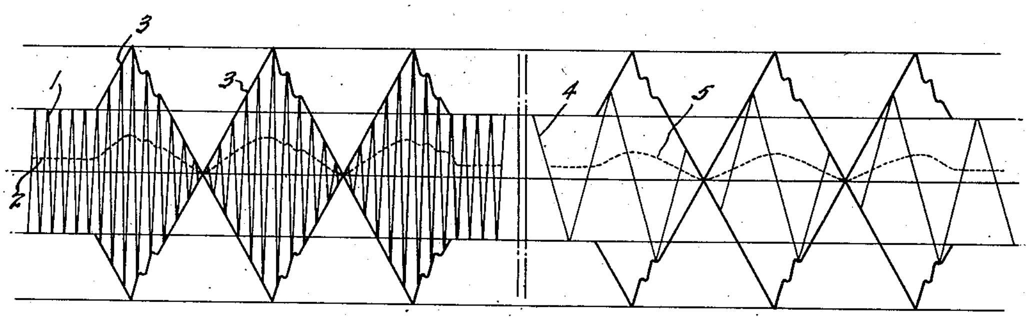


Fig. 6.

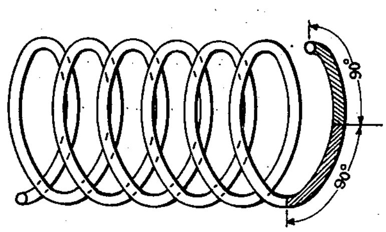


Fig. 7.

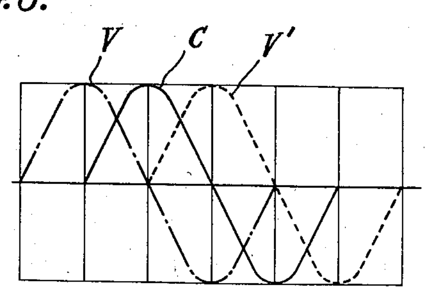


Fig. 8.

Inventor

M. L. DULL

By Semmes & Semmes

Attorneys

Patented Dec. 19, 1939

2,183,905

UNITED STATES PATENT OFFICE

2,183,905

PHASE MODULATION TRANSMITTER

Marshall Lytton Dull, Catonsville, Md., assignor to Dull Radio Laboratories, Inc., Baltimore, Md., a corporation of Maryland

Application March 1, 1933, Serial No. 659,231

3 Claims. (Cl. 250—17)

This invention relates to intelligence transmission and reception, and more particularly has reference to a phase modulation system and transmitter in accordance with factors desired to be transmitted and received or utilized at some distant point.

As will appear more fully, the present system has an extremely wide field of use. However, since the fundamental principles of the concept can well be explained by an embodiment in radio transmission and reception, and since this field includes the essentials of facsimile transmission and remote control, this particular embodiment will be chosen for illustration.

A major object of the present invention therefore is to overcome the disadvantages of amplitude modulation.

Another object is to provide a novel system of modulation.

Another object is to devise a system of modulation which increases the utility of the radio broadcasting spectrum.

A further object is to provide a novel system of radio transmission and reception.

Yet another object is to provide a new system of transmitting and receiving intelligence utilizing electro-magnetic waves as the carrier or transmitting medium.

Yet another object is to provide a novel method of remote actuation or control.

In order to more clearly explain the principles of the invention, a physical embodiment in a radio transmitting and receiving system is shown in the accompanying drawings, of which:

Fig. 1 is a circuit diagram of one type of transmitter.

Fig. 2 is a modification of the circuit shown in Fig. 1.

Fig. 3 is a further modification of a transmitter made in accordance with the present invention.

Fig. 4 is an electrical diagram of a receiver.

Fig. 5 is a schematic representation of the units comprising the complete radio system.

Fig. 6 is a graphic illustration of the type of modulation which represents prior practice.

Figs. 7 and 8 are graphic illustrations of the essential operation of the present system.

Phase displacements are utilized in the present system to effect modulation. In Fig. 8 is shown the effect of capacitance in dot-dash line, and of inductance in dotted line. It will immediately be appreciated that in the new system the modulating effects are impressed directly on the transmitting vehicle, in radio the "carrier" wave, and in a mechanical analogy may take the form of a lateral displacement of one of the phase components. This sharply differentiates from the prior art method where the modulating effects in wave form are, in a sense, superimposed on the carrier and a new resultant wave form of accentuated differential amplitude obtained. Thus with the older method the so-called modulated carrier is not in effect a carrier but a new wave or, at the least, a markedly modified carrier. With the new system the so termed carrier is in truth a carrier, for it retains its identity of frequency and amplitude even after the modulation effects have been impressed. The present system then presents all the advantages of transmission on a carrier of substantially fixed or constant amplitude and the obvious advantages of a receiving system designed to be responsive to a transmitted wave of varying phase.

The essential differences between amplitude type of modulation and the new system of phase relationship may be more readily comprehended by a study of the mechanical analogy depicted in Fig. 7. Whereas in the amplitude modulation system, as shown in Fig. 6, the modulation frequency may be considered as superimposed on the carrier to give a new resultant wave form—the operation of the new system may be considered as comprising a helix. During modulation the dimensions of the helix remain unaltered and the modulating effects are caused by a shift or reciprocation of a factor up to ninety degrees on each side of a center point on half a turn. If the helix is now considered as a sign wave, it will be seen that the effective modulation may be construed as a shifting of the modulating factor to a predetermined degree on opposite sides of the half wave. In other words, the modulating factor may be considered as a linear reciprocation or oscillation on a curvilinear locus, where the curvilinear locus is the energy wave form and the oscillating or reciprocating factor is one of the phase components.

As will be explained more fully, a number of the components of the phase of the carrier energy may be utilized to effect modulation. In order to clearly explain the system a preferred modification involving the utilization of voltage phase angle will be described.

In the operation of the improved system the equivalent of one hundred percent modulation is represented by a condition in which the voltage phase angle of the carrier, at the transmitter, is caused to lead by a varying degree up to 90° the unmodulated angle for one peak half wave of the modulating frequency, and then to lag to the same degree the other half of the unmodulated phase angle for the opposite peak half wave.

For receiving the specially modulated carrier, the incoming energy is mixed with an alternating current energy having the same frequency and strength as that used in transmission but differing from the latter in having a mean or constant voltage phase angle. This latter or local oscillation is unmodulated. The conditions are so controlled that the reaction between the transmitted energy, having a variable voltage phase angle, and the local energy of a mean or intermediate voltage phase angle, produces the exact form and character of the modulation energy used at the transmitter. At this point it will be appreciated that since thermionic tubes are voltage operated devices, they are immediately available in carrying out this system of modulation.

The receiver may be provided, as the exigencies of the particular case demand or require, with any desired number of amplification stages and the energy of the reception unit may be utilized either directly or may be transmuted into any other desired form or type of energy to operate mechanical, electrical or hydraulic control. Manifestly such control may be made either optional or automatic.

The transmitting circuit, as shown in Fig. 1, comprises essentially a stage 10 for generating radio frequency oscillations (or the other oscillations utilized as a carrier), the isolating stage 11 and the effective phase control stage 12. The phase control stage 12 is associated with a stage 13 through which the intelligence is made to act on the phase control stage.

The output is coupled to a radiator, such as the antenna circuit 14.

The isolation stage 11 and the phase control stage 12 are shown as comprising in effect dual units. These are thus designed because of these stages performing a dual function.

The isolating stage 11 serves to segregate the generator stage 10 from the control stage 12 and functions to prevent undesired reactions of the phase control circuit on the generator circuit, such for example as changing or varying the load taken from the generator stage and fed through the system. This circuit or stage 11 additionally functions to prevent undesired reactions within the phase control circuit 12, such as would occur if the input grids of the tubes in stage 12 were common to one circuit.

Similarly the phase control circuit 12 subserves a dual function. In the first place, it modifies the phase characteristics of the alternating energy from the output of the generator stage, in accordance with the input energy from the intelligence source 13. In the second place it serves to pass on the frequencies from the generator stage with unvarying output amplitude and frequency.

It will be seen from an inspection of Fig. 1 that the tubes comprehended within the different stages are fed from a power supply 14.

The power supply may comprise a power line 15 connected to transformer 17 at primary 16. This winding has a voltage adjusting tap 23. The core of the transformer is grounded at 18. The transformer is provided with a plurality of secondaries 19, 20, 21 and 22. Secondary 19 supplies high voltage to the rectifying and filament system, consisting of rectifying tubes 25 and 26; and filament heating winding 20; tap 20′ and lead 28. Tap 24 of secondary 19 is the negative terminal connecting to voltage dividing resistor 27. Tap 20′ of secondary 20 is the positive terminal connecting to lead 28. Secondary 20, as above noted, supplies heater current to the rectifying tubes. Secondaries 21 and 22 supply heater current to the tubes in the radio frequency portion of the transmitter.

In the preferred modification, at some point near midway the voltage divider-resistor 27 is connected to the common ground 29 and to the intermediate filter condensers 30. It will be seen that since the cathodes of the tubes in the transmitter proper are at common ground potential, points between the ground point of the voltage divider and the positive end may be used to give varying degrees of positive potential. Similarly from the same grounded cathode condition, points between the grounded point of the voltage divider and the negative end may be used to give varying degrees of negative potential.

It is to be clearly understood that since modulation is here secured by a control of the phase characteristics, the radio frequency generated by the oscillator is entirely a point of reference in the radio system to which the transmitter will operate. The radio frequency generator may comprise a thermionic tube 31 and is preferably of the indirectly heated cathode, screen grid type. This is provided with a cathode and a heating element for the cathode.

As shown, the cathode or electron emitting element is connected to the common ground through the potentiometer resistance 32. The moving arm of the potentiometer, by-passed to the common ground by condenser 33, is connected to the control grid of the tube. The purpose of this arrangement is to establish an independent and variable source of grid bias so that the electronic flow to the screen and hence the screen and plate current drawn by the tube may be controlled.

In the tube shown in the illustration the screen carries a higher potential value than the plate and is thus operated on the dynatron or secondary emission principle. The frequency of oscillation of the tube is governed by the resonant period of the oscillating circuit connected to the plate and comprises the inductance 34 and variable condenser 35. The low side of this circuit, as well as that of the screen, is bypassed to the common ground by the condensers 36 and 37 and is additionally filtered by choke coils 38 and 39. The output of the oscillator is taken off from the high side of the plate circuit by the variable condenser 40. The utilization of a variable condenser at this point allows for a variation of the excitation to the subsequent tubes in the system.

The output of the oscillation generator stage 10 is connected through the variable condenser 40 to the isolating circuit 11. It will be noted at this point that this circuit branches out in the form of a Y. This is advisable since from this point on to the antenna the circuit is in dual form. This dual form has been found at the present time best suited to perform the dual function incident to the isolation circuit 11 and the phase control circuit 12. The output of the oscillation generator is therefore connected through the variable condenser 40 and leads 41 and 42 respectively to the control grids of thermionic tubes 43 and 44. These tubes, similarly to the tube employed in the first stage, are of the indirectly heated cathode screen grid type, although manifestly other specific types may be employed.

This isolation circuit, therefore, insures a stability of frequency output from stage 10 and also insures the proper functioning of the units in the phase control circuit.

The cathodes of the tubes in stage 11 are directly connected to the common ground as shown. The control grids, as noted, are connected to the center point of the Y connection. This center point is also connected with the aperiodic choke coil 44. This choke coil allows the control grids to follow the excitation of the frequency source 10 and at the same time to be under the stabilizing control of a constant value of negative potential. The low end of the choke coil 44 is bypassed to ground by the condenser 45. This low end is also connected, as previously described, to the correct degree of negative potential at the power supply, through the lead 46.

The screens of tubes 43 and 44 are bypassed to ground by condensers 47 and 48 respectively and are additionally filtered by choke coils 49 and 50. The low end of these choke coils go to a common connection, lead 51, and through this are supplied with the proper degree of positive potential from the power supply.

The plate of tube 43 is connected to the C/L circuit including the inductance 52 and the capacity 53. Similarly the plate of tube 44 is connected to the C/L circuit, including the inductance 54 and variable capacity 55. The low end of circuit 52—53 is bypassed to the common ground by condenser 56 and is additionally filtered by choke coil 57. The low end of choke coil 57 is connected by lead 58 to the correct degree of positive potential in the power pack. Similarly circuit 54—55 is bypassed, through condenser 59, to the common ground and is additionally filtered by choke coil 60. Choke coil 60 connects with lead 58 and thus the plate of tube 44 is supplied with the correct degree of positive potential from the power supply.

The plate circuits of tubes 43 and 44 are connected through the coupling condensers 61 and 62 to the control elements, i. e., the grids, of the tubes in the phase control unit. Thus coupling condenser 61 is directly connected with the grid 63 of the tube 64, while coupling condenser 62 is directly connected with the control grid 65 of thermionic tube 66.

The grids of tubes 64 and 66 are each connected to special C/L circuits. Thus grid 63 is connected to the circuit including inductance 67 and variable capacity 68. Similarly grid 65 is directly connected to the circuit including inductance 69 and variable capacity 70.

It will thus be seen that the C/L circuits 52—53 and 54—55, associated with the tubes 43 and 44, and the C/L circuits 67—68 and 69—70 connected in the grids of the phase control unit, form an interstage coupling between the isolating stage 11 and the phase control stage 12. The constants of these circuits are so chosen as to insure energy input from stage 10 to the control grids of stage 12 with undisturbed phase characteristics. The circuit is so designed that the energy from the oscillator stage is fed to the control elements of the modulation stage with unchanged and undistorted phase. With the type of interstage coupling shown, this can in most circumstances be secured by having the constants of the several C/L circuits of the same value.

Like the isolating stage, the phase control stage comprises in effect a dual circuit. The two tubes employed in this circuit are disclosed as of the directly heated cathode type. The tube 64 is provided with a cathode 71 which is connected to the grounding and filtering network comprised by resistor 72 and the condensers 73 and 74. The function of the resistor is to permit the connection of the electrical center of the filament to the common ground. The condensers function to offer a short path to the common ground for the radio frequency energy operating within the circuit and secondly to stop or block this energy from following the cathode wires to the power supply. This is to insure the stability in previous portions of the transmitter circuit which operate at a lower level of radio frequency energy. The cathode and the associated connections of tube 66 are identical with those of tube 64. Thus the cathode 75 is connected to the grounding and filtering network including resistor 76 and condensers 77 and 78. The heating current for cathodes 74 and 75 is obtained from the power supply through leads 79 and 80.

It will be noted that the low point of inductance 67, which is bypassed through the tap to the common ground by the bypass condenser 81, is additionally filtered by choke coil 82. Similarly that point on inductance 69 is bypassed to ground through condenser 83 and additional filtering is secured through choke coil 84. The low end of coils 82 and 84 are connected common to lead 85 and are supplied through this lead, from the power supply, with the correct degree of negative potential.

The tapping arrangement on inductances 67 and 69 is an important feature of the present embodiment. This is desirable in order that a source of radio frequency potential, opposite in instantaneous polarity to that introduced on the control grids, may be available and by the use of condensers 86 and 87 this energy may be fed to the plates. Condensers 86 and 87 are properly adjusted so as to completely neutralize the effects of the inter-electrode capacities between the control grid and plate of tubes 64 and 66. It will be understood that the necessity for neutralization of the inter-electrode capacity is in a sense inherent in the triode tube.

The plate of tube 64 is directly connected with the C/L circuit comprising inductance 88 and variable capacitance 89. Similarly the plate of tube 66 is connected with the circuit including the inductance 90 and associated variable capacitance 91.

Thus, as shown, circuit 88—89 has a preponderance of inductance and is, therefore, inductive in effect, that is to say it functions to cause the voltage in that circuit to lead the current. Circuit 90—91, on the other hand, contains a preponderance of capacity and is capacitative in effect, and hence will cause the voltage to lag the current. It is to be clearly understood that the energy from the oscillator stage 10 is fed through the isolating circuit with its phase characteristics unchanged. Assuming this energy fed into the tubes of the control stage 12 to be of the reference or standard voltage phase angle, it will be seen that the circuits 88—89 and 90—91 operate conjointly and sequentially to shift the voltage phase angle of the energy to lead and lag positions. Thus these two circuits cause the voltage phase angle to shift or reciprocate with respect to the main or medial phase angle established at the oscillator stage.

Circuits 88—89 and 90—91 are associated or coupled to a radiator which functions to transmit or radiate energy with the modified phase angle. In order to eliminate undesired shifting or distortion of the phase angle, in the antenna proper, the antenna circuit is designed so as to have a negligible reactance.

At this point it will be appreciated that if devices are associated with the output circuits of tubes 64 and 66, which modify the phase angle shift proportionately to the intelligence input energy in the devices, a definite means of modulating the radiated signal in accordance with this input energy is available. The inductances 88 and 90 of tubes 64 and 66 respectively are coupled to individual secondary sections 92 and 93. These two inductances or secondary sections are directly connected together. Across the extremities of the circuit thus formed is connected the capacitance 94. The circuit is completed with the radiator or antenna 95. The capacitance is so adjusted as to cause the antenna circuit to resonate at the frequency which is desired to be utilized and which is generated at oscillator 10. This antenna circuit is adjusted to have as low a reactance as is practically possible. In other words the capacity to inductance ratio in this circuit is so adjusted as to cause the voltage phase angle to equal and coincide with the current phase angle.

In this transmitter when no microphonic currents are utilized the signal emanating from the antenna is a pure radio frequency wave, the voltage phase and current phase angle of which coincide, giving it a unity power factor. All factors of the wave, namely frequency, energy phase angle, wave form and amplitude, remain fixed under this unmodulated condition. When, however, modulation is imposed the voltage phase angle is made to vary, the angle first leading and then lagging the medial phase angle. It will be noted also that the power factor of the energy likewise varies as it is governed by the instantaneous voltage and current phase angle.

When the present structure is used for radio broadcasting, a source of variable or modulated energy is provided. This source may be a microphone 96. In lieu of a microphone, of course, any device which is electrically responsive proportionately to variations in the factor to be transmitted may be employed. Thus variations in sound, light, temperature, pressure and so forth may be made to act upon the element 96 to cause a variable electrical response therein. Energy from the element 96 is fed through an appropriate amplification stage or stages 97 and the output from this stage is connected to the primary 98 of a special transformer. The secondary 99 of the transformer is center tapped at 100. This center tap of the secondary is connected to the positive end of the standing plate voltage supplied by the power supply. The two ends or extremities of the secondary connect to the plate circuits of the tubes 64 and 66 through the leads 101 and 102 respectively. This transformer connection, as shown, is made to the low sides of the plate circuits of the dual phase control tubes. These two tubes, that is to say the two halves of the control circuit, are thus operated under class C operation in which modulation by plate voltage variation is secured. In other words, the tubes 64 and 66 are so operated that their output is purely a function of the square of the plate voltage. The low sides of the plate circuits of tubes 64 and 66 are by-passed to the common ground by condensers 89' and 91' and additionally filtered by choke coils 88' and 90' respectively, thus preventing feed back of radio frequency energy through leads 101 and 102, to the microphone circuit.

It will thus be seen that the output of the units of the phase control system, specifically the tubes 64 and 66, independently present a substantially linear variation with the square of the plate voltage. The plate voltage is represented by a standing D. C. voltage with the positive at the plate and the negative at the cathode or filament. In series with this is introduced an alternating or pulsating voltage, thus increasing or decreasing the effective operating plate voltage. The plate voltage therefore is constant when the system is unmodulated, but varies with modulation.

It will now be appreciated that when the element 96 is actuated one end of the secondary will have a positive polarity in respect of this center tap and at the same time instant the other end will have a negative polarity. Hence at any given instant one of the tubes in the control stage 12 will have an increased plate voltage when its section of the secondary 99 has a positive polarity. The output of this tube will, therefore, increase. This increase will be substantially linear following the ratio of the square of the sum of the standing plus the peak voltage established at a given instant between the extremity of the secondary and the center tap to the square of the standing plate voltage. The other half of the control circuit at this same instant is subjected to negative polarity and will have a corresponding decrease in plate voltage. The voltage from either extremity of the special transformer to the center tap will be the same at any given instant but will differ only in polarity.

As the amplitude of the output of one half of the control unit, say tube 64, is increased by the introduction of positive potential from the transformer, the amplitude of the output of the other half of the circuit, tube 66, is decreased less absolute amount by the simultaneous introduction of an equal amount of negative potential from the same transformer. Thus, paradoxically, while true amplitude modulation is in fact utilized in each half of the circuit (i. e., in each tube), the correlation and interaction of the tubes and the differential reactance circuits is such as to completely nullify or eliminate the amplitude effects in the final output.

It is thus evident that amplitude variations as such are not utilized in this modification of the invention. It is to be noted, however, that the differentially reactive circuits 88—89 and 90—91 are associated with the tubes 64 and 66 respectively. The maximum relative load, passing through tubes 64 and 66, following the microphonic variations, reciprocates from one-half of the control circuit to the other and is alternately reacted upon by the positive and negative reactance of the differential circuits. There is thus imposed on the output energy a shift or displacement of the voltage phase angle corresponding to the microphonic input, while nevertheless maintaining the frequency of the original or carrier energy at a substantially constant value so far as the modulation factor is concerned.

This will be seen to be true in view of the fact that the carrier energy is impressed on each the grid of tube 64 and tube 66 in exactly the same frequency amplitude and phase as this energy is generated in tube 31. Such energy therefore, up to its introduction on grids 63 and 65, is maintained at a constant value under all conditions. As explained, the microphonic or modulating effect operates upon the output energy from these last tubes, i. e., tubes 64 and 66. The differential reactance circuits 88—89 and 90—91 then operate upon the energies from tubes 64 and 66 so as to modify the voltage inverse current phase angle positions, these positions being a function of or controlled by the modulating or microphonic circuit. The energy as thus modulated is then fed immediately and directly to the antenna, without any further interaction in thermionic devices and is thus radiated. It will thus be seen that the voltage inverse current energy and the current inverse voltage energy are mixed directly in the output circuit. There can thus be no change in frequency in the energy radiated from the antenna.

The alternating energy of substantially constant frequency and amplitude but of varying voltage phase angle is transferred to the secondary or antenna circuit, in the manner described. Since this secondary circuit is so designed as to have substantially negligible reactance, that is to say negligible effect upon the microphonically displaced phase angle, the carrier wave is radiated as energy of substantially constant frequency and amplitude but with a modulated voltage phase angle.

It will be appreciated that within the scope of the invention there are a wide number of variations permissible. A typical example of one of these is shown in Fig. 2. This illustrates a modification of the secondary or antenna circuit and is designed to subserve a number of functions. In the first place it serves to make the operation of the transmitter more flexible. Its operation is quite analogous to that of a fly-wheel operating to lock the medial voltage phase angle of the secondary or antenna circuit at the fixed predetermined value. In one form the circuit may comprise a self controlled oscillator 103 provided with the filament grid and plate elements 104, 105 and 106 respectively. The tube may take the form of a directly heated cathode and is shown as of the same type as tube 64 and 66. The cathode may be connected to a grounding and filtering network including the resistor 107 and the condensers 108 and 109. Heating current is supplied to the filament through the leads 110 which may be suitably connected to the power supply. The plate is connected in C/L circuit with the inductance 111 and variable condenser or condensers 112. The inductance 111 forms a primary of a variable inductive coupling to the secondary circuit, the secondary of which is formed by the coil 113. This type of circuit is a self controlled oscillator, the frequencies of the oscillations of which are a function of the resonant frequency of the inductance capacity circuit 111—112. The frequency control circuit is so designed and/or adjusted as to have the same medial voltage phase angle as the energy fed through the system from the frequency generating stage 10. The reference or medial phase angle of this circuit is the same as that of the energy fed to the grids of tubes 64 and 66.

It will be understood that although this circuit is shown as a self controlled oscillating circuit of the so-called TNT variety utilizing an aperiodic grid circuit 105′, it may well take the form of any suitable externally controlled oscillator.

It will be appreciated from the description of the apparatus in Fig. 2 that it operates to fix or stabilize the medial voltage phase angle of the antenna circuit proper. Since the oscillator 103 has the inductance 111 and capacitance 112 so adjusted as to establish its C/L ratio in conformity to the C/L ratio of circuit 34—35, it will function to establish this exact medial voltage phase angle of the energy in the antenna circuit proper. In a mechanical sense then it tends to pull the medial phase voltage angle of the antenna circuit into step with its own medial voltage phase angle and to lock the former in its desired value.

Since the circuit 111—112 may be adjusted to any practically desired value, the tube may be operated at a frequency different from the resonant frequency of the secondary or antenna circuit. In such circumstances it will react with the antenna circuit to produce a beat frequency. By reacting on the main energy passing through the transmitter sysem with a signal, and in such circumstances as to shift the voltage phase angle of the frequency in accordance with the signal, a new type of secret signalling system is thus provided. Such a signal, comprising a variable or shifting voltage phase angle of a heterodyned transmitted wave may be received only by a receiving system designed with particular reference to the transmitter and corresponding precisely with it in the major functioning principles. By proper adjustment of the circuit 111—112 various other modified reactions on the energy in the antenna circuit may be obtained.

The improved results secured with the structure shown in Fig. 2 may be achieved with other, and specifically different, arrangements, such as shown in Fig. 3. This is illustrated to disclose the utilization of an amplifier type of circuit in lieu of the oscillator type shown in Fig. 2.

The amplifier tube 115 is shown as of the screen grid, directly heated cathode type. The filament 116′ is suitably connected to a source of heating current and like the filament of tube 103 is provided with an effective grounding and filtering arrangement. The grid 116 is capacitively coupled to the main oscillator circuit 10 and is stabilized by the correct degree of negative potential being introduced through choke coil 44′, the low side of which is bypassed to the common ground by condenser 45′. The plate 117 is connected to a circuit comprising the inductance 118 and parallel variable condensers 119 and 120. This C/L circuit, like circuit 111—112, in the preferred operation is so chosen as to constants and is so adjusted as to positively establish a medial or reference phase angle in exact conformity with the phase angle of the energy transferred from the oscillator circuit 10 through the coupling condenser 40 to the main control circuit.

The inductance 118 forms a primary of a variable inductive coupling to the secondary circuit, the secondary of which is formed by the coil 121.

The tube 115 is shown as excited directly from the frequency source of the transmitter.

Like the circuit shown in Fig. 2 the circuit of Fig. 3 may be adjusted to produce any desired beat note, a harmonic or submultiple of the frequency of the output energy from circuit 10.

It will be understood by those skilled in the art that the fly-wheel circuits of Figs. 2 and 3 may be associated with the antenna circuit in a number of ways. The connections shown are merely for the purpose of illustrating the fact that the fly-wheel circuit is operated either to effectively stabilize the antenna in respect of its medial voltage phase angle or modify the antenna energy to effect secret signalling, or other purposes.

The transmitting circuit shown in Fig. 1, together with the antenna circuit modification shown in Figs. 2 and 3, is given merely to illustrate the major concept here involved, that is to accomplish modulation by varying the phase characteristics of an energy of constant amplitude and frequency in order to obtain a modulated signal.

Thus in lieu of the method inhering in Fig. 1 the voltage phase angle may be controlled in accordance with modulating currents by varying the capacitance-inductance ratio by varying the capacitance inversely with the inductance, or vice versa, in one circuit, the resonant period remaining the same. Again, the voltage phase angle modulation may be accomplished by varying the voltage phase angle of the resonant frequency of a piezo electric crystal or a magneto-striction element, such as a mass of a particular nickel alloy.

Also this voltage phase modulation may be achieved by microphonically varying the capacity associated with an aperiodic circuit; similarly this same result may be accomplished in this type of circuit by varying the inductance.

Thus the new type of modulation may be effected by varying the voltage phase angle output from a dual circuit composed of two reacting aperiodic circuits, in one of which inductance and in the other of which capacitance predominates. Modulated output may be obtained in this type by first allowing one circuit to represent most of the output, and then alternately allowing the other to represent the major output.

When factors other than the voltage phase angle are utilized as the effective modulating means, it will be understood that the receiver is designed to be actuated by or responsive to one or more of these three variable factors in the transmitted signal.

In the embodiment chosen for illustration the receiving circuit, shown in Fig. 4 is designed to be actuated by variations in the voltage phase angle. But as noted above, such receiver may readily be adapted to be responsive to the other two variable phase characteristics.

In its essentials the receiver comprises means to receive the transmitted signals, means for coupling the signal receiving means to a special demodulator circuit, means to supply a constituent reacting with the received signal, means for isolating the reacting demodulating operation from the output connection, and an element or elements in the output connection which is proportionately responsive to the effective modulating energy input. The receiver is also provided with a power supply for supplying the power requirements of the operative elements of the receiver.

As shown in Fig. 4 the receiver proper comprises the antenna circuit designated generally by the numeral 130, the coupling and demodulating stage 131, which corresponds in general function to the control stage 12 of the transmitter, the reacting circuit 132 which serves primarily to balance out or neutralize the received frequencies, thus leaving the stage 133 to be operated by the shifting voltage phase angle, or other phase characteristics chosen and which actuates the signal responsive element 134.

The receiver is provided with a power supply entirely comparable to the similar unit in the transmitter. This is connected to a source of power which is usually a sixty cycle A. C. current. The power line is connected to a transformer primary 135. This has such a copper to iron ratio as to effectively operate on the alternating energy available. The primary is provided with taps 136 so as to adjust varying line voltages. The secondary comprises a number of different sections 138, 139 and 140. The core 141 is connected, as shown, to common ground so as to minimize the effects of radio frequency energy flowing from the secondary to the primary and thence to the line and also the energy flowing from the line to the secondary through the primary.

Secondary 138, which is designed to supply the high voltage, is center tapped at 142. The extremities of this winding each connect to a plate of a half wave rectifier, two of such tubes 143 and 144 being employed to secure full wave rectification. The center tap lead 142 forms the negative pole of the rectifier output.

The secondary section 139 provides the heating current for the filaments of the rectifier tubes. This secondary is likewise center tapped by lead 145 and the tap forms the positive pole of the rectifier output. The third section 140 provides the heating current for the tubes in the receiver. This is center tapped and grounded, as shown at 146.

Like the transmitter power supply, the negative pole of the rectifier system is connected, through lead 142, to the negative end of the voltage dividing resistor 147, the negative end of the filter condensers, the negative end of the stabilizing condenser. The positive pole is connected through lead 145 to the positive end of the first filter condenser, first filter reactor, thence through this reactor to the positive end of the second filter condenser to the second filter reactor, then to the positive end of the third filter condenser, the positive end of the voltage dividing resistor, and finally to the point in the receiver proper requiring the highest positive potential. Since these parts have been fully described in Fig. 1, the numerals are here omitted to simplify the drawings.

Some point near midway on the voltage divider resistor is connected through lead 148 to common ground and to the intermediate filter condensers. It will be observed that points between this ground point of the voltage divider and the positive end may be utilized to obtain varying degrees of positive potential. Similarly points between the ground point of the divider and the negative end may be used to give varying degrees of negative potential. The power supply is thus adapted to fulfill all the power requirements of the system.

The antenna system which receives the transmitted waves may comprise any suitable aerial 150. This is connected to the inductance coil 151 and thence to ground. Preferably the leakage resistance between the antenna and the return path should be as high as possible so as to insure efficient operation.

The circuit 131 is a dual circuit. This comprises the thermionic tubes 152 and 153. This circuit is designated as the amplitude filter demodulator circuit since in its operation the transmitted carrier frequency is nullified or eliminated, leaving only the effective modulation directly in its pure form.

The tubes 152 and 153 are preferably, though not necessarily, of the indirectly heated cathode screen grid type. Tube 152 is provided with a heater 154, a cathode or electron emitting element 155, a grid 156, plate 157 and screen grid 158. Tube 153 may be of identical construction, having a cathode 160, grid 161 and plate 162. The grids 156 and 161 are each connected directly to the high end of a CL circuit composed of the inductance 163 and the capacitance 164. The inductance 163 serves as the secondary of the aerial circuit, being coupled to the primary 151. The circuit 163—164 is so designed and/or adjusted as to have a reference or medial voltage phase angle equal to or coinciding with the medial voltage phase angle in the transmitter and to have negligible reactance. The low end of circuit 163—164 is connected to ground and the high end, as noted, to the grids in the demodulating circuit.

The cathode 155 is connected to common ground through the resistance 165 and is bypassed to ground through the condenser 166. Similarly the cathode 160 is connected to ground through resistance 167 and bypassed to ground through condenser 168. The function of these resistances is to allow the plate current IR drop to impose the optimum positive change on the cathodes in respect to the common ground. In this manner, since the control grid circuits return to common ground, the grids will have a charge of the correct sign and value, with respect to the cathode. The condensers 166 and 168 establish a short path for the alternating signal energy between the common ground and the cathodes.

The screen 158 is bypassed to common ground through the condenser 169. This screen is additionally filtered by choke coil 170. Similarly screen 171 of tube 153 is bypassed to common ground by condenser 172 and is further filtered by choke 173. The low end of choke coils 170 and 173 have a common connection to lead 174 and through this are connected to the power supply so as to receive the proper degree of positive potential.

The plate circuits of tubes 152 and 153, so to speak, are functional counterparts of the plate circuits of tubes 64 and 66 of the phase control dual circuit. Thus, plate 157 is connected to a circuit including inductance 175 and variable capacitance 176. Plate 162, of tube 153, is likewise connected in a circuit including inductance 177 and variable capacitance 178. The plate circuit of tube 152, as will be seen, contains a preponderance of inductance while plate circuit of tube 153 contains a preponderance of capacitance. The two circuits, are designed to present a certain voltage phase angle. In the circuit of predominant inductance, the voltage phase angle will lead that found in the standard or medial voltage phase angle circuits. In the circuit of predominant capacitance, the voltage phase angle will lag that found in the standard C/L circuit.

These two differential reactance circuits are coupled to individual secondaries, inductance 175 of tube 152 being coupled to the secondary coil 179 and inductance 177 being coupled to secondary coil 180. The secondaries 179 and 180 are adapted to be connected together and in the circuit thus formed is the capacitance 181. The capacity 181 is so adjusted that the circuit will resonate at the frequency of the signal being received. The ratio of inductance to capacity in circuit 179—180—181 is fixed and is so established as to cause the voltage phase angle to equal and coincide with the current phase angle, or in other words to have unity power factor.

Circuits 175—176 and 177—178 are grounded and filtered in the same manner as the corresponding circuits connected to tubes 64 and 66 of the transmitter.

Associated with the demodulator circuit just described is the generator stage 132. In the preferred embodiment this performs two major functions. First it generates and introduces into the demodulator circuit oscillations of the exact character as those generated at the transmitter and due to the reaction the carrier frequencies, as such, are nullified or eliminated. In the second place, due to its operation, it serves to establish a fixed medial voltage phase angle in the receiver which serves as the point of reference for the shiftable voltage phase angle of the signal as fed to the voltage responsive coupling tube 133.

The generator stage comprises the tube 132 which preferably is of the indirectly heated cathode screen grid type of tube. This has a cathode heater 190 suitably connected to the filament heating secondary 140. The cathode 191 is grounded through resistance 192 and is bypassed to ground through condenser 193. The screen 194 is bypassed to common ground through the condenser 195 and the low end is connected through the filtering choke coil to lead 174. Through this lead the screen is supplied with the correct degree of positive potential.

The purpose of the cathode resistance 192 is to cause the cathode to have an optimum positive charge in respect to the common ground, and in this way, since the control grid connects directly to common ground, the control grid has the correct sign and value of charge in respect to the cathode.

The plate 196 is connected to a flexible C/L circuit comprising the inductance coil 197 and the adjustable condensers 198 and 199. The coil 197 is coupled to the variable coupling coil 200 in the output secondary circuit of the demodulator. The low end of circuit 197—198 is bypassed to the common ground through the condenser 201 and is additionally filtered by choke coil 202. The low end of the choke is connected to the power supply so as to provide for the correct degree of positive potential.

The variable coupling between the generator stage and the demodulating stage not only allows for the introduction of energy of constant amplitude and frequency but also of adjustable voltage and current phase angle into the low end of the secondary circuit of the demodulator. Also this coupling allows that portion of the signal energy that is in coil 200 of the secondary circuit (under the proper adjustment of condensers 198 and 199) to pull the frequency of the generator circuit into step or synchronism with the signal frequency. It is to be noted that the inertia of circuit 197—198 does not allow the voltage phase angle to vary with that of the incoming signal. Thus the generator circuit becomes a reacting circuit, the reaction being effective between the high end of the secondary circuit 179—200 and the common ground.

A coupling device which is a voltage operative unit is connected to the high side of the secondary circuit of the demodulator. The coupling tube is provided with an indirectly heated cathode. The heater 205 is connected to the power supply and the cathode 206 is connected to common ground through resistance 207 and is bypassed to ground through condenser 207′, the functions of which have already been described. The grid 208 is directly connected to the high side of the secondary circuit 179—180. Plate 209 connects the output post or terminal 210. The other output terminal 212 is connected to the power supply through an isolation filter and line 213. The purpose of this isolation filter is to allow the modulation frequencies to remain, in their pure form, free of any disturbances that might be introduced through line 213 from the associated equipment and power supply. Output posts 210 and 212 contain the modulation frequencies in their pure form and may be utilized from then on in any desired manner.

In sound reception, modulation frequency amplifying stage or stages 215 may be employed. Associated with the output is the responsive device 134. This is representative of any type of instrument or apparatus that the modulation frequencies are intended to affect.

The coaction of the several units of the receiver will now be appreciated. The reactor circuit is so adjusted that the oscillations generated therein are in synchronism with the signal frequency fed to the demodulation circuit, but are substantially 180° out of phase with the signal frequency. From this the interaction of the reactor stage and the demodulating stage will be appreciated. Since one frequency is reacting with a like frequency, the incoming signal frequency is thus nullified or eliminated and the grid of the final coupling tube 133 is subjected only to static voltage fluctuations corresponding to the voltage phase angle variations.

It will be clear that the only factor that can alter the plate current of the coupling tube is a change in the relation between the voltage phase angles of the local reactor and the incoming signal. Since the voltage phase angle of the local reacting energy is established at a fixed value, it follows that the plate current of tube 133 follows only the variations in the voltage phase angle of the incoming signal. The plate current, therefore, accurately corresponds to the modulating effects impressed at the transmitter. When these are audio frequency modulating effects and the responsive device 134 is a loud speaker, or similar audio responsive unit, the musical notes are reproduced in precise faithfulness and full clarity.

It is particularly to be observed that the amplitude filter demodulator is, so to speak, of dual construction. The plates of the two tubes are connected to C/L circuits of differential reactance. It will be seen that each half of this dual circuit will be more responsive to a particular voltage phase angle in the received signal, hence the voltage phase angle modulated signal cannot affect the two halves of the circuit to the same extent at the same instant. However, all other characteristics of the received energy, not having this variable component, will be cancelled out since they will affect each half to the same extent at the same instant. This is so because the secondary circuit is interconnected in such a way that like values of energy introduced at the same instant, from the two halves of the preceding circuit, will oppose each other and hence cancel out. It will be observed that if amplitude modulated signals are introduced into the system they will likewise be nullified and cancelled because of the special nullifying action of the dual circuit on this particular type of energy. Since static is one form of amplitude modulated energy and since amplitude energy is nullified, this novel receiver is in truth an amplitude filter.

Again, it is known that the reaction between two substantially constant amplitude alternating energies will simultaneously alter the amplitude of each of these two energies. The amplitude modulation thus effected directly follows the heterodyne beat, or difference between the frequencies. Heterodyne or beats between two or more sources of alternating energy effect a condition of amplitude modulation on each source of energy. Thus heterodyne frequency is energy in an amplitude modulated form. The new circuit, as noted, filters out or nullifies all such amplified modulated energy.

To more clearly illustrate this special function of the dual demodulator circuit, it is so designed as to permit the effects of amplitude modulation to feed through the system. As shown in Fig. 4, in the secondary circuit 179—180 of the demodulator is connected the polarity reversing switch 216. In the normal or usual operation the inductances 179 and 180 are connected together in such a manner that like values of energy introduced into the secondary from the two halves of the preceding circuit, at the same instant, will mutually oppose, and since they are equal they will nullify each other. However, by connecting one of the coils 179 or 180 into the secondary circuit in the opposite polarity, it will be seen that such energies will not oppose but will amplify each other. It has actually been demonstrated that a receiver, constructed according to the circuit of Fig. 4, can be made responsive to the usual amplitude modulated signals, by proper operation of switch 216, and that furthermore amplitude modulations from a nearby high power station can completely be eliminated while, nevertheless, phase modulated signals are received in full clarity.

In view of this it will readily be apparent that the improved receiver may be adapted as a dual functioning device, receiving not only special phase modulated signals but also the typical or usual amplitude modulated signals. The duality may likewise be extended to the complete system, that is to say to the transmitter as well as the receiver. Thus within the scope of the invention one source of intelligence may be utilized to effect the amplitude of the transmitted signal, to secure amplitude modulation, and simultaneously another source of intelligence may be used to effect voltage phase angle modulation. The two sources of intelligence may be isolated in one receiver of the proper design or may be received in two receivers, one of which is responsive to the amplitude modulated signal and the other to the phase modulated signal.

This type of dual operation lends itself very readily to secret signalling. It is understood however that the preferred form of commercial utilization of the phase principle involves the use of the special type of transmitter and receiver described inasmuch as when operating with this novel system the disadvantages of amplitude modulation discussed hereinbefore are eliminated.

The reactance circuits 175—176 and 177—178 have been described as of a differential reactance, one of the circuits being inductive in reactance and the other capacitative. These have been described as of fixed or established value, that is to say their constants are unaffected by the modulations in the system for any given operation. It will be readily understood, however, that in the receiver, by the proper utilization of adjusting mechanism, such as gang control systems, these two circuits may be varied in their absolute values so as to tune the receiver to carrier waves of different frequency.

It is to be understood, therefore, that the appended claims are to be limited, in interpretation, only by the prior art and within the comprehensive scope of the invention as defined herein.

I claim:

1. In an apparatus for implanting intelligence

on an electrical wave energy of predetermined amplitude and frequency comprising branch circuits connected in parallel to a source of carrier waves, means for amplifying the energy in each branch, means for implanting intelligence differentially on the amplitude characteristic of the energy in each branch, transformers having a reactive primary connected in each branch, the reactance in the primary of one transformer being equal in extent and of opposite sign to that of the other, means for coupling the secondaries of the two inversely reactive transformers to a common series circuit from which the energy is radiated.

2. In a phase modulating apparatus, means for generating an electrical energy wave, branch circuits through which the energy is directed, a capacitative reactive transformer in one branch and an inductive transformer in the other branch, said transformers having their secondaries connected in series, means to cause differential amplitude modulations within the branches in accordance with superimposed intelligence energy and means to radiate the energy from the secondary circuit of the transformer, the transformers being so adjusted that there shall be radiated a wave of substantially constant amplitude with wave variations therein corresponding to the superimposed intelligence.

3. Means for impressing phase modulations at signal frequency on carrier frequency oscillations including, a pair of thermionic tubes having their input electrodes energized by said carrier frequency oscillations, means for varying the impedance of said tubes in phase opposition at signal frequency, and tuned circuits connected with the output electrodes of said tubes for relatively shifting the phase of the oscillations repeated in said tubes.

MARSHALL LYTTON DULL.