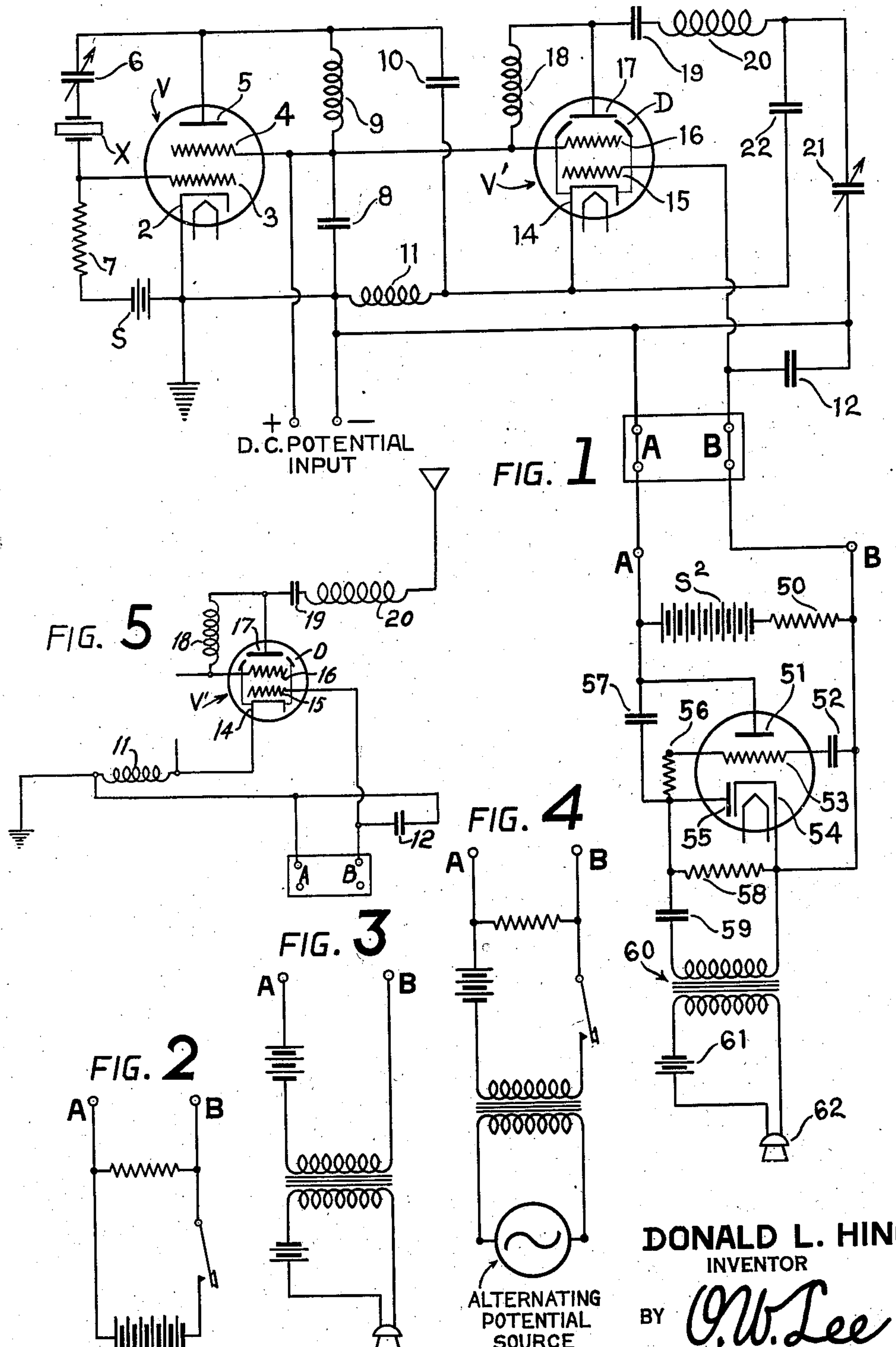
Feb. 19, 1946. D. L. HINGS 2,395,049

RADIO SIGNALING SYSTEM

Filed Sept. 29, 1941 3 Sheets-Sheet 1



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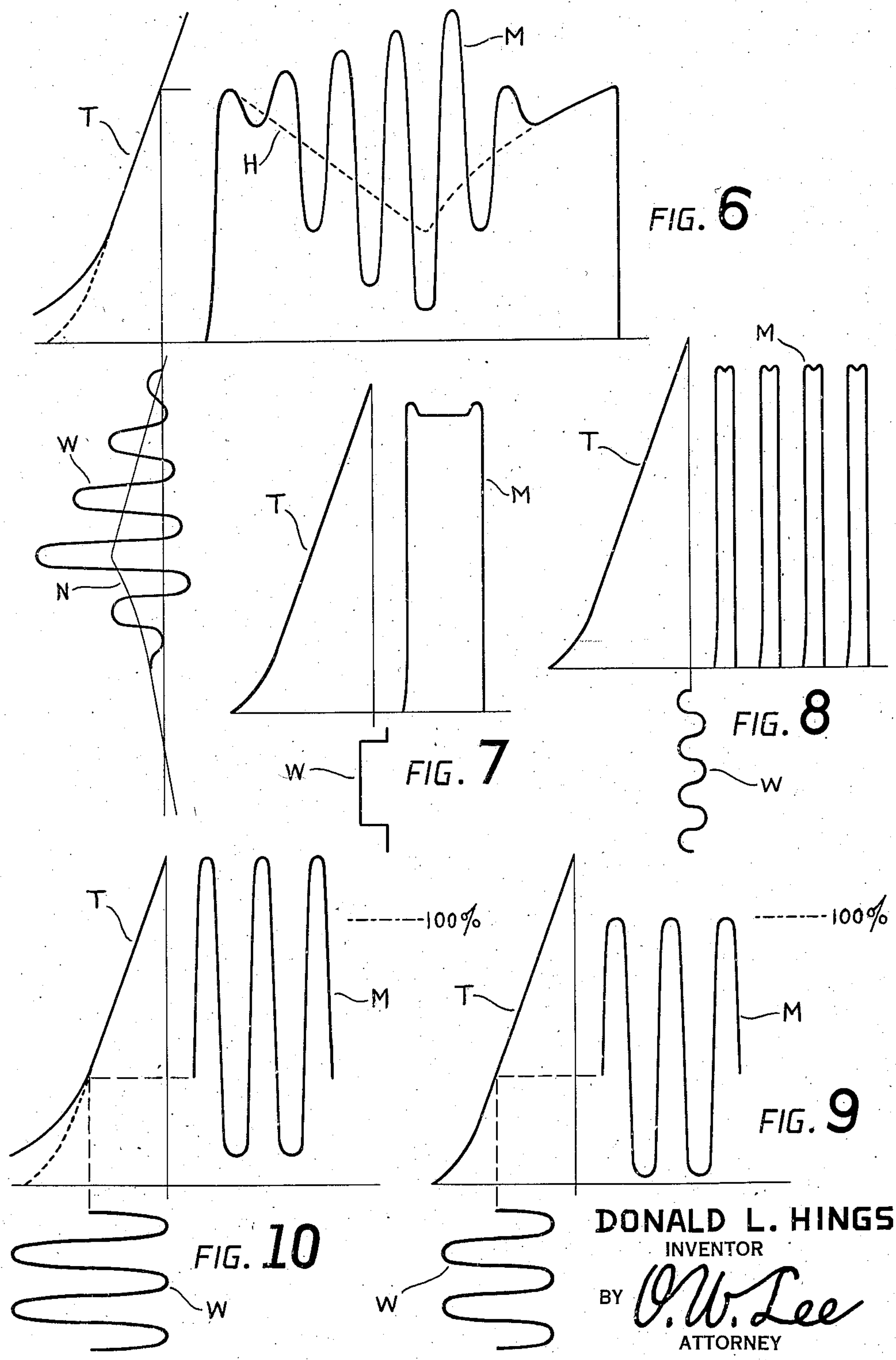

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

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FIG. 11

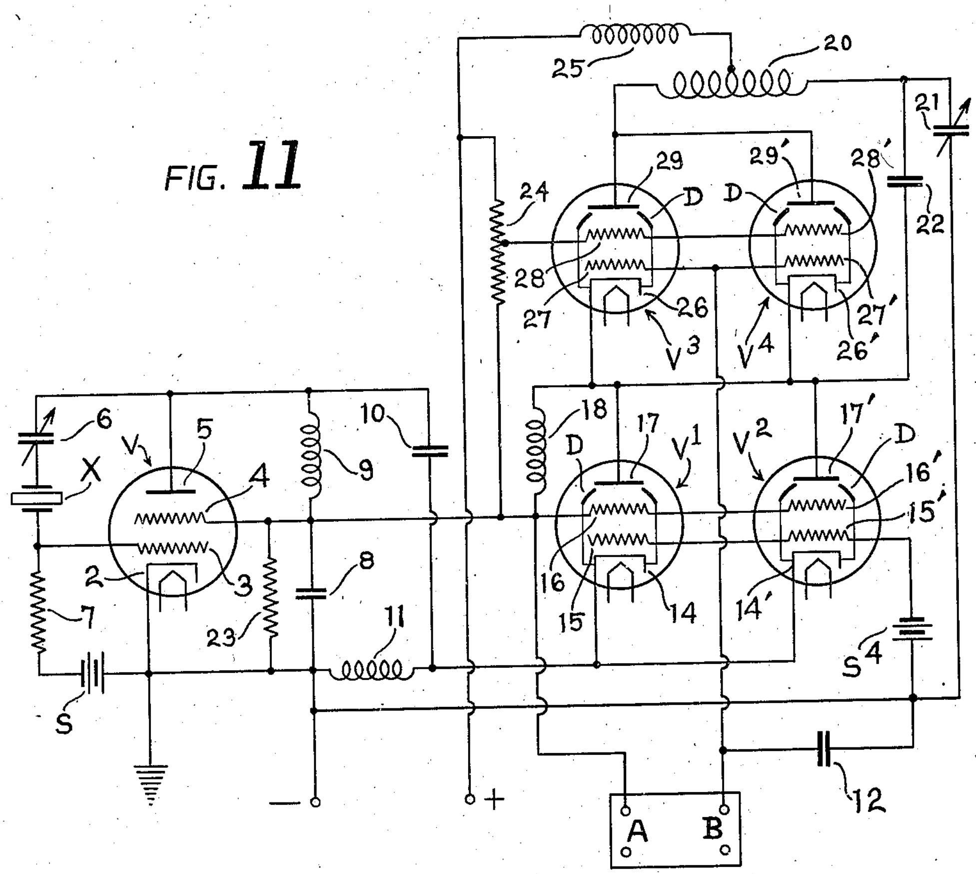
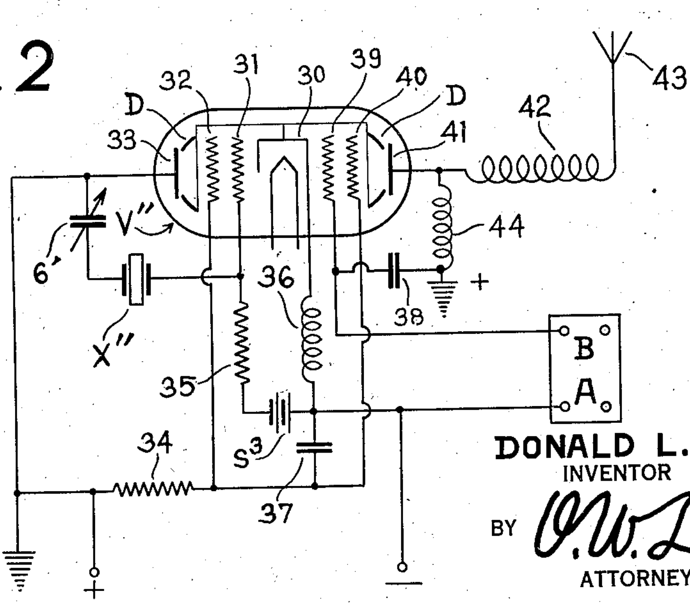


FIG. 12



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Patented Feb. 19, 1946 2,395,049

UNITED STATES PATENT OFFICE

2,395,049

RADIO SIGNALING SYSTEM

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Application September 29, 1941, Serial No. 412,708
In Canada October 7, 1940

12 Claims. (Cl. 250—17)

The present invention relates to certain new and useful improvements in a radio signaling system and is particularly directed to a carrier wave system wherein the amplitudes and the oscillator generation periods of the carrier wave are controlled directly by the modulating input to the control circuit of the amplifier which is made dynamically a part of the oscillator circuit, and vice versa.

The invention provides an improved control system to modulate the amplitudes of high frequencies by low frequencies, and affords a fast operating control system to automatically start and stop the carrier wave generator, and also affords voice control of the duration of the transmission periods.

My improved carrier wave system embodies a constant frequency oscillator which is rendered operative and inoperative by the operation of an amplifier which not only serves as the modulator and the amplifier, but also automatically starts and stops the radio frequency in the oscillator circuit, thereby eliminating the necessity for mechanical switches or relays commonly used for this purpose. I also eliminate the necessity for either a tuned circuit or else a radio frequency transformer in the oscillator circuit, and also eliminate the need of the intermediate amplifier stage commonly used as a buffer in the prior art practices of control grid modulation. I also eliminate the necessity of shielding the oscillator from the amplifier.

The constant frequency oscillator includes a piezo electric crystal, and the invention automatically controls the oscillator feedback potentials and excludes excessive currents from the piezo electric crystal, thereby maintaining the oscillator output in direct relation with the control grid modulation requirements, as is in contradistinction to the inverse relation which exists in the prior art practice of control grid modulation.

In the prior art of control grid modulation of a carrier wave, it is the conventional practice to shunt connect the carrier wave input of the amplifier with an interstage resonant circuit which is tuned to the carrier wave or some harmonic thereof, and to employ a high frequency reactor as a bypass between this tuned circuit and zero potential or ground. This practice requires tuning adjustments to be made whenever the frequency of the carrier wave is altered. None of these prior art practices are necessary with the present invention. It is also unnecessary to resort to the prior art practice of employing a radio frequency transformer as a coupling between the oscillator and the amplifier.

In the prior art practice of control grid modulation, the output resonant circuit has no influence on the input to the amplifier, because the screen grid shields or isolates the input circuit from the output circuit. To enable the input to drive the output, the prior art supplies the necessary resonance energy from an inductive circuit coupled between the oscillator and the amplifier; and the resonance energy necessary to drive each additional amplifier is also supplied by an inductive coupling between amplifiers.

The present invention departs from this prior art practice and converts the amplifier into a coupling so that the resonance energy necessary to drive the amplifier, is derived from the resonant oscillatory output circuit, instead of from an inductive input circuit such as employed by the prior art.

In the present invention, the input electrodes are reversed in relation to the prior art practices of control grid modulation and carrier wave amplifier input. According to my invention, the carrier wave input from the oscillator is applied to the cathode of the amplifier, and the modulating input is applied to the control grid of the amplifier, and this control grid is maintained at a constant potential irrespective of the carrier wave frequency, and there is relatively low impedance between the cathode and anode of the amplifier, so that the electron flow acts as a coupling between the resonant oscillatory output circuit and the oscillator. The modulation is accomplished by varying the impedance of this coupling or amplifier tube. That is to say that the potential changes occurring in the low frequency modulating input to the control grid of the amplifier will alter the impedance of this coupling, thus altering the reactance between the resonant oscillatory output circuit and the oscillator, thus altering the feedback in the oscillator circuit and thereby controlling the output of the oscillator, and also affording a fast operating automatic starting and stopping of the generation periods of the carrier wave.

In this manner, the invention provides a simplified control system which requires but a single resonant circuit, and affords various degrees of amplitude modulation which may be either linear modulation, or else with variable modulation factors. Voice control of the starting and stopping of the generation periods of the carrier wave is provided with a minimum of equipment heretofore not considered possible.

For interrupted continuous wave communications, the variations of the coupling of the invention, automatically interrupts the carrier wave, at an audio frequency rate, to thereby produce the intended tone train, which may be keyed from a remote distance without the necessity of a keying relay; and due to this coupling, the carrier wave is suppressed when the key is open, thereby affording the advantage of break-in operation, whenever occasion requires. For continuous wave communications, there is also provided the advantage of keying from a remote distance without the necessity of a keying relay, and the advantage of break-in operation whenever occasion requires. In either instance, there is afforded a high speed keying with exceptional clarity of the make and break tones.

The accompanying drawings diagrammatically illustrate the nature and principle of my invention.

Fig. 1 is a diagram of the preferred form in which the invention has been reduced to practice and is now in extensive use.

Figures 2, 3, and 4, show various control input circuits that may be used in operating my invention.

Fig. 2 shows a simple keying circuit, which may be employed when it is desired to operate my invention for keying carrier waves to produce space and marker impulses of continuous waves.

Fig. 3 shows a well known circuit for operating my invention for modulation from a microphone.

Fig. 4 shows a well known circuit which may be employed when it is desired to operate my invention for keying interrupted continuous waves.

Fig. 5 shows a fragmentary view of Fig. 1, with an antenna connected to the output of the amplifier.

Figures 6, 7, 8, 9 and 10, show several charts of waves produced by the present invention. All charts indicate the transfer characteristics of the control tube and show the control potentials and their effect on the carrier wave amplitudes.

Fig. 11 shows an arrangement of amplifier tubes connected in cascade to the showing of Fig. 1.

Fig. 12 is a diagram of a single cathode embodiment of the invention.

The invention embodies a single resonant circuit which is the resonant oscillatory output from the amplifier which is here shown as a beam type tetrode utilized as a coupling between the resonant oscillatory output circuit and the oscillator circuit. This beam tube is utilized as a control grid modulator and amplifier, and the carrier wave input from the oscillator is applied directly to the cathode of this beam tube which has its control grid bypassed to ground for radio frequency and its screen grid at relatively constant potential. This prevents the amplifier from becoming regenerative and objectionably functioning as an oscillator, and also provides for the carrier wave potentials in the resonant oscillatory output circuit to effectively control the oscillator circuit, so that the carrier wave input to the amplifier is in direct relation to the modulation requirements, and the output of the amplifier is thereby increased on the positive peak modulation. This provides an exceptionally efficient control grid modulation and also provides for resonant reactance between the output of one amplifier and the input of a succeeding amplifier without the necessity of intervening resonant circuits which are essential in the prior art of control grid modulation in order to enable the first amplifier to successfully excite a second amplifier.

If a triod is used in this manner the reactance of the anode electronically affects the control grid and causes degeneration which impairs the sensitivity of the input. If a conventional tetrode is used in this manner, the screen grid functions as a shield and buffer electrode and absorbs the electronic changes, thereby defeating effective reactance to the cathode. Likewise, the conventional pentode presents the same inaptitudes to a greater extent when used in this manner. In the present invention, an entirely different function and greatly increased efficiency is obtained by using a beam type tetrode as an amplifier and control grid modulator, with the carrier wave input to the cathode and with the control grid bypassed to ground for radio frequency and with the screen grid at relatively constant potential.

In this manner, the virtual cathode effect of the beam tetrode is utilized to afford an efficient resonant reactance between the output circuit of the amplifier and the cathode input thereof, whereby the resonant reactance energy necessary for operation of the amplifier is derived from the resonant oscillatory output circuit of the amplifier rather than from a resonant circuit preceding the input to the amplifier. It should also be noted that by applying the carrier wave input to the cathode instead of the control grid, alters the phase angle 180 degrees between the amplifier output and the oscillator from what it would be if the carrier wave input were applied to the grid, with the result that the amplifier input is in direct phase relation to the feedback requirements of the oscillator. The amplification and the coupling action of the tube are governed by the modulating voltages supplied to the control grid, and the coupling action directly affects the cathode emission current which reacts in phase with and at the frequency of the carrier wave generator, to control the feedback thereof and alter the carrier wave output in direct relation to the modulation requirements. This performance affords various improved results which are not afforded by the prior art of control grid modulation wherein the carrier wave input is to the control grid of the modulator.

Fig. 1 diagrammatically illustrates the invention in the preferred form which has been reduced to practice and widely used. As here shown, two thermionic tubes are employed, V' is in the control circuit and V is in the oscillator circuit. I have shown V' as a beam tetrode, as that is the best form readily available for the purpose of my invention. The variable low capacity reactor **6** couples the anode **5** to one holder of the piezo crystal X, which has its opposite holder connected to the control grid **3**. The negative potential is fed to this control grid through the resistor **7** which is interposed between this grid and the negative side of the biasing source S which has its positive side connected to the cathode **2** which is connected to zero potential or ground. The biasing potential is here shown as a battery, but the well known cathode bias may be employed. The positive potential to the anode **5** is fed through the high frequency choke coil **9**. The screen grids **4** and **16** have a common connection to the positive potential, and are bypassed to the zero potential or ground, by the low frequency reactor **8**.

The high frequency reactor **10** couples the anode **5** to the cathode **14**, and the high frequency choke coil **11** connects the cathode **14** to the input terminal A and to the zero potential or ground which is common to the two tubes. The input terminal B is connected to the control grid 15 which is bypassed to zero potential or ground by the high frequency reactor 12, thus making the anode to cathode return circuit of the oscillator tube V dynamically a part of the control circuit, and also making the modulating and amplifying tube V′ dynamically a part of the oscillator circuit. This amplifying tube V′ has beam electrodes as indicated at D.

The positive potential to the anode 17 is fed through the non-resonant choke coil 18. The high frequency reactor 19 couples the anode 17 with the inductance 20 when an open oscillatory circuit is employed, otherwise this reactor 19 may be omitted as it is only for the purpose of potential isolation and safety, and is not essential for normal function.

A series resonant circuit may be provided by interposing the variable low capacity reactor 21 between the end of inductance 20 and the zero potential or ground. A low capacity reactor 22 may be connected between the inductance 20 and cathode 14 for the purpose of neutralizing the inter-electrode capacity of the modulator tube V′, as is necessary for good linear modulation, but in some instances this reactor 22 may be omitted when variable modulation factors are desired instead of good linear modulation.

The reactors 21 and 22 may both be omitted and an open oscillatory circuit employed, in which case the antenna 13 as shown in Figure 5, is attached by a switch 1 to the inductance 20 which becomes a part thereof, as distinguished from the series resonant circuit in which the inductance 20 is coupled to any suitable output circuit in whatever mode may appear advisable. It will be noted that the invention does not employ the shunt resonant output circuit commonly used in the prior art.

From the foreging disclosure, it will be seen that the reactor 10, cathode 14, control grid 15 and reactor 12 form a return circuit between the anode 5 and cathode 2 of the oscillator, thereby making the cathode 14 and control grid 15 of the amplifier, dynamically a part of the oscillator circuit. The high frequency reactor 12 bypasses the control grid 15 to ground and prevents changes in the cathode potential from altering the potential of this control grid. Thus the cathode emission current alternates in phase with and at the frequency of the crystal X. The inductance 20 is excited by the anode 17 at the frequency of the crystal X thus amplifying the high frequency wave. The cathode input impedance is high with relation to ground, and the anode output impedance is relatively low with relation to grid or ground, but the cathode to anode impedance is low.

This cathode to anode impedance of the amplifier is varied by the modulating input supplied to the control grid 15, and the potential changes produced in the oscillatory output circuit alter the dynamic potentials on the anode 17 with respect to the relatively constant potential on the screen grid 16 and thus there is established a coupling action which governs the cathode emission current of the amplifier V′, so as to provide a closely linked relationship between the oscillatory output circuit and the oscillator circuit, so that the carrier wave potentials in the oscillatory output circuit directly affect the feedback in the oscillator circuit and thereby control the output of the oscillator in direct relation to the modulation requirements.

Due to this coupling, the oscillatory output circuit also supplies the cathode 14 with the resonant reactance energy which is essentially necessary for operation of the amplifier V′. Furthermore, this coupling conveys power from the oscillator V directly to the oscillatory output circuit, thereby enabling the entire output of the oscillator V to be utilized and also affording a greater efficiency of the amplifier V′.

It will be seen that this described coupling would be impossible if the carrier wave input was applied to the control grid 15 instead of to the cathode 14. That is to say that if the carrier wave input was applied to the control grid 15, then the previously described coupling between the resonant oscillatory output circuit and the oscillator circuit would not exist, because such input to the control grid would make the cathode a part of the return circuit of the amplifier output, in contradistinction to the present invention wherein the cathode 14 is excluded from the return circuit of the amplifier output, and made the carrier wave input of the amplifier, for the reason that the coupling action is always directly included in the cathode circuit rather than in the control grid circuit in which the grid is merely an operating electrode and not a conducting electrode as is the cathode.

Operation

The invention affords an exceptionally efficient modulation over a wide range of amplitudes without the necessity of any form of inductive coupling between the oscillator and the amplifier. Changes in the modulating potentials supplied to the control grid 15 alter the dynamic impedance of the beam tetrode V′ and consequently alter the coupling which controls the cathode emission current thereof, to thereby alter the feedback to the crystal, so as to produce amplitude modulation of the oscillator output and also modulate the output of the amplifier, in direct accord with the variations of the modulating requirements.

The resonant oscillatory output circuit potentials form the basis of the coupling, and these potentials react upon the anode 17 and increase the dynamic potentials thereon, with respect to the relatively constant potential on the screen grid 16, thereby establishing the coupling between the anode 17 and the cathode 14 to thereby afford an increased amplification of the oscillator output and consequently an increased amplification of the output of the resonant oscillatory output circuit. That is to say that the potential differences between the anode 17 and the screen grid 16 dynamically controls the vertual cathode effect of the beam tetrode V′ so that the coupling alters the cathode emission current of this amplifier in direct accord with the resonant frequency of the oscillatory output circuit, so as to thereby increase the output of the oscillator circuit within which this amplifier cathode 14 is dynamically included, as was hereinbefore explained.

At each negative cycle of the modulating potentials on the control grid 15, the impedance between the cathode 14 and anode 17 increases accordingly, thereby reducing the output of the resonant oscillatory circuit and thus decreasing the effect of the coupling between the anode 17 and cathode 14 and consequently decreasing the feedback to the crystal, thereby reducing the output from the oscillator in accordance with the negative modulation requirements. When the coupling is at minimum, the oscillations of the crystal are then sustained by the normal feedback from the oscillator circuit.

At each positive cycle of the modulating potentials on the control grid 15, the impedance between the cathode 14 and anode 17 is thereby reduced, and the output of the amplifier increases accordingly, which results in increased coupling action between the anode 17 and the cathode 14, thereby increasing the feedback to the crystal and thus increasing the output of the oscillator. This increased output of the oscillator increases the output of the amplifier in accordance with the positive modulation requirements. Thus it will be seen that this coupling provides a self-regulatory modulation which would be impossible with either an inductive coupling or a capacitive coupling.

The reactor 6 limits the feedback to the crystal, and whenever the mean potential of the modulating input becomes sufficiently positive to render the resonant oscillatory output circuit out of resonance with the frequency of the crystal, this out of resonance reactance will then oppose the existing feedback and promptly stop the crystal from oscillating. The maximum amplification of the carrier wave occurs just prior to the suppression of the oscillations and also at the initial input which starts the oscillator, thus assuring a fast operating control to start and stop the carrier wave generation.

The tube V' serves the fourfold purpose of an amplifier, a modulator, a coupling, and a direct control for starting and stopping the oscillator generation periods of the carrier wave, and all of these functions are dependent upon the cathode emission current which is controlled by the modulating potentials supplied to the control grid 15.

It will be noted that the invention employs either an open oscillatory output circuit or else a series resonant output circuit, either of which afford a high reactance potential, which would not be obtained with a shunt resonant output circuit such as conventionally used in the prior art of control grid modulation. It should also be noted that with either the open oscillatory output circuit or the series resonant output circuit, there is no need for a return circuit or bypass to ground, such as would be required with a shunt resonant output circuit.

When the described open oscillatory output circuit is employed, it has the effect of a half wave antenna connected directly to the anode 17, and there is high impedance between this anode 17 and ground, thereby affording exceptional efficiency without resort to a tuned input circuit such as used in the prior art. With this open oscillatory output circuit, the resonant period can be readily altered by merely altering the length of the antenna, as for instance by reeling or unreeling the antenna wire according to requirements. Whenever occasion necessitates changing the wave length, it is a simple matter to substitute a crystal of the required frequency and then alter the antenna length accordingly. This adaptability is of paramount importance in aircraft radio where cruising range sometimes gives rise to extreme conditions which would otherwise render operation exceedingly difficult or perhaps impossible. When for any reason, it is desired to alternately employ several crystals of different frequencies, it is a simple matter to quickly substitute one crystal for another and reel the antenna to correspond with the wave length afforded by the crystal, there being no problem of a tuned circuit between the oscillator and the amplifier, nor any shunt tuned circuit with antenna coupling, nor any output tank circuit.

The invention may be operated in various modes with various control input circuits such as shown in Figures 2, 3, 4, and 5. The various performances of the carrier wave control are diagrammatically illustrated in Figures 6, 7, 8, 9 and 10, each of which show the control grid input voltage characteristics, with relation to the plate or output voltage characteristics. Each diagram indicates the transfer characteristics of the control tube V' and shows the control potentials and their effect on the amplitudes of the carrier wave. For convenience of illustration, only one side band is shown in each instance.

Voice control

For voice control of the starting and stopping of the carrier wave generator, it is necessary to provide both the audio wave and a rectified D. C. potential or variable bias derived from the audio wave. For this purpose I employ a microphone and transformer, together with a thermionic rectifier and D. C. amplifier as shown in Fig. 1. As here shown, the primary winding of the transformer 60 is connected in series with the battery 61 and the microphone 62. One end of the secondary winding of the transformer 60 is connected to the cathode 54 which is common to the terminal B. The low frequency reactor 59 couples the opposite end of this secondary winding to the diode plate 55 which is connected to the cathode 54 by the biasing resistor 58. The low frequency reactor 57 couples this diode plate 55 to the anode 51 which is common to the terminal A. The grid 53 is bypassed to the cathode 54 by the low frequency reactor 52, and this grid is also connected to the diode plate 55 by the grid resistor 56. The voltage dropping resistor 50 connects the cathode terminal B to the anode battery S^2 which is connected to the terminal A.

When sound waves activate the microphone, the D. C. current from the battery 61 is pulsated to excite the transformer 60. The resulting alternating potentials from the secondary winding of the transformer 60 are applied to the cathode 54 which is common to the terminal B, and also applied to the diode 55 through the reactor 59, and imposed on the terminal A through the reactor 57, thus producing the modulating potentials.

The potential changes on the diode 55 are rectified and the resulting current flowing between the cathode 54 and diode 55 produces a voltage drop across the resistor 58, thus making the diode 55 more negative in relation to the cathode 54. The grid 53 likewise becomes negative through the resistor 56, thus the normal current flow between the cathode 54 and the anode 51 is reduced by this increased negative grid bias, and the resulting decreased anode current reduces the normal voltage drop across resistor 50 and this reduction affords an increased potential from the battery S^2 at the terminals A and B which provide the bias source for the control tube V'. That is to say that the potential changes on the diode plate 55 produce an increased negative bias at the terminals A and B.

The grid 53 is bypassed by the reactor 52 so that no modulation is produced by this bias control tube. The relative bias to rectified current is controlled by the value of resistor 58, and the bias return period is controlled by the value of resistor 56 and the capacity of the reactor 52.

It will be seen that the voice control circuit of Fig. 1 can be employed to produce both the audio wave and a rectified D. C. potential derived from the audio wave. This D. C. potential, controls the starting and stopping periods of the oscillator or carrier wave generator and thus provides automatic control of the duration of the transmission periods, solely by the voice of the sender. When these modulating waves are imposed on the control grid 15 of the amplifier V', the negative bias is also imposed thereon, whereby the carrier wave generator V is rendered active and a modulated carrier wave then exists in the resonant oscillatory output circuit. When there are no modulating waves, the oscillator is inactive and the carrier waves are suppressed. The amplitudes of the modulating input and the component bias inherent thereto effectually governs the oscillator generation periods, and also controls the carrier wave level and the amplitudes of carrier wave modulation. In this manner, the modulation of the carrier wave varies from low percentage linear modulation to a high percentage modulation with extended positive peaks, depending upon the amplitude of the modulating waves and accompanying variable bias on the control grid 15.

For voice control of the operating periods of the carrier wave and its amplitude modulation, the voice control input circuit of Fig. 1 is employed with either an open oscillatory circuit or with a series resonant circuit which may be either with or without neutralization of the interelectrode capacity, as circumstances suggest and necessity requires.

Fig. 6 shows the performance with a series resonant circuit and without interelectrode neutralization, when the modulating waves are supplied by the voice control input circuit shown in Fig. 1, and illustrates over-modulation devoid of side band interference. The curve T indicates the transfer characteristics of the tube V' when affected by interelectrode capacity, which causes it to deviate from the normal curve indicated by the dotted line. The sine wave W indicates the variable input amplitude, and the line N indicates the corresponding variations of negative bias. The sine curve M indicates the varying amplitudes of modulation of one side band, and the dotted line H indicates the mean carrier wave amplitude which is self regulating in accordance with the modulation percentage. As here shown, the oscillator generation period starts when the negative bias is imposed upon the control grid and continues until the control input definitely ceases and the negative bias impulses are no longer supplied. Thus the carried wave generation period is started and stopped by voice control.

It will be noted that the transfer characteristic of the tube is varied from the normal transfer characteristic, thereby precluding the over modulated carrier wave from reaching zero or cut-off on the negative modulation peaks. This prevents side band interference which would otherwise occur from over modulation, and makes possible an over modulation far in excess of one hundred per cent and without the carrier wave reaching cut-off. This is of particular advantage in the transmission of weak signals which require excessive modulation to render them intelligible.

It will be seen that with the simple portable equipment of my invention I accomplish results which would otherwise require considerable equipment.

When low percentage modulation with good fidelity is desired, the interelectrode capacity may be neutralized by the reactor 22 and the voice control input circuit of Fig. 1 employed for voice control of the oscillator generation periods. This function is sufficiently similar to the showing in Fig. 6 that further illustration is deemed unnecessary.

Linear modulation

For linear modulation, the control input circuit of Fig. 3 may be employed with the described series resonant circuit, and for maximum linearity of modulation, the interelectrode capacity of the control tube V' should be neutralized by inverse feedback through the reactor 22 so as to prevent distortion of the normal transfer characteristics. This performance is illustrated in Fig. 9 which shows 100% modulation.

In Fig. 9, the curve T indicates the normal transfer characteristics of the control tube, the sine wave W indicates the modulating input wave, and the sine wave M illustrates 100% modulation of the carrier wave. This showing need not be further explained, and it is shown principally for comparison with the over modulation of Fig. 10.

High percentage modulation

For variable modulation factors in high percentage modulation, the input circuit of Fig. 3 is used with a series resonant circuit, but without the reactor 22. That is to say, linearity of the modulated wave form is sacrificed for greater positive peak output relative to the unmodulated carrier wave. This performance is illustrated in Fig. 10.

In Fig. 10, the sine wave W indicates the modulating input wave; and the transfer characteristics of the control tube are indicated by the curve T until it deviates from the true curve shown by the dotted line. This deviation is due to the interelectrode capacity and prevents the output carrier wave from reaching cut-off or zero on the negative modulation peaks, thereby preventing the sideband interference which would otherwise occur from over-modulation.

It will be noted that the positive peaks extend above the 100% modulation level which is indicated by the dot and dash line, and that the negative peaks do not reach zero or cut-off. Thus it will be seen that the invention provides high percentage modulation with extended positive peaks, and without resorting to the various expedients commonly employed in the prior art practices of control grid modulation. The resulting modulated carrier wave M is convenient for point to point radio telephone communication where the equipment is subject to occasional heavy modulation, or a wide range to input amplitudes.

The results of Fig. 10 can also be obtained with an open oscillatory circuit, and in instances where there is occasion to change the frequency of the carrier wave, it is only necessary to substitute a different crystal of the required frequency and to alter the antenna accordingly. This is of paramount advantage in aircraft radio where cruising range may give rise to necessity for extreme changes in the carrier wave frequency and where time would not permit of extensive alterations being made to convert the equipment from one frequency to another. This adaptability is due to the described coupling action and the half wave antenna effect which is afforded by the open oscillatory circuit.

Continuous wave

For continuous wave code transmission, the input circuit of Fig. 2 is employed either with an open oscillatory circuit or with a series resonant circuit and either with or without the neutralizing reactor 22. This provides thermionic keying of the carrier wave generator or oscillator and affords considerably faster operation than direct keying of the carrier wave generator. That is to say that the invention provides a keying speed comparable to that of the well known bias keying of the amplifier, and also affords the advantage of break-in operation which unfortunately is absent in bias keying of the amplifier, unless resort is had to elaborate shielding of the oscillator circuit which is entirely unnecessary in the present invention. It should be mentioned that the use of the neutralizing reactor 22 makes it possible to more accurately control the feedback through the reactor 6 and thereby provide a more critical definition of the make and break, and in this way further enhance the speed of keying.

Fig. 7 shows the effect on the carrier wave when the control potential or bias is varied relative to zero by the input circuit of Fig. 2. The carrier wave is non-existent until the key is pressed, whereupon the negative potential to the control grid 15 of the tube V′ starts the oscillator and maintains the generation of the carrier wave until the key is again opened, whereupon the oscillator stops and the carrier wave ceases. A single pulse is indicated as illustrative of a marker wave in continuous wave communications.

It will be noted that the greatest amplitude occurs at the make and break of the marker wave. This affords exceptionally well defined demarcations of the pulses and clarity of perception which is of paramount importance in high speed keying. This variation of amplitude within each pulse is obtained by operating the negative bias slightly in excess of the requirements for actuation of the oscillator, and this slight excess then slightly retards the output of the amplifier until the negaive bias swings back after the break to terminate the pulse with a rise in amplitude. Due to the thermionic actuation of the oscillator, the keying can be done from a remote distance without the necessity of a keying relay.

Interrupted continuous waves

For interrupted continuous wave code transmission, the input circuit of Fig. 4 is employed, and for this exceptionally high speed function it is advisable to employ a series resonant circuit with the neutralizing reactor 22. The tube V′ affords a thermionic control which automatically interrupts the carrier wave at an audio frequency rate to produce the intended tone train.

Fig. 8 shows the effect on the carrier wave when an audio frequency wave produced by the circuit shown in Fig. 4 varies the control potentials relative to zero bias. The carrier wave is alternately released and suppressed in accordance with the audio input wave, so as to produce a series of the illustrated pulses of the carrier wave. These pulses may be keyed in groups for code transmission of the interrupted continuous wave variety, and since the oscillator is suppressed when the key is open, there is also afforded the advantage of break-in operation whenever occasion requires. Due to the thermionic actuation of the oscillator, the keying can be done from a remote distance without the necessity of a keying relay.

Single cathode embodiment

In Fig. 12 there is shown by way of example, a diagram which is explanatory of the fundamental principle of my invention. As here shown, there is enclosed within the tube V″, a single cathode positioned between two anodes, and with a pair of grids intervening between each anode and the single cathode, and beam electrodes are provided as indicated at D.

In contradistinction to the showing in Fig. 1 the grounding is reversed in Fig. 12 so as to operate with a single cathode. In this instance the ground is positive and is directly connected to the anode 33. The variable low capacity reactor 6′ couples this anode 33 to one holder of the piezo crystal X″ which has its opposite holder connected to the grids 31. The negative potential is fed to this grid 31 through the resistance 35 which is interposed between this grid and the negative side of the biasing source S^3 which has its positive side connected to the single cathode 30. The high frequency reactor 38 bypasses the control grid 39 to the positive ground, and this control grid is connected to the input terminal B. The screen grids 32 and 40 have a common connection which is bypassed to the cathode 30 by the low frequency reactor 37 and also connected to the positive ground, preferably by the resistor 34.

The negative potential is fed to the single cathode 30 through the high frequency choke coil 36. The anode 41 is connected to the positive ground by the high frequency choke coil 44 and also connected to the inductance 42 which together with the illustrated antenna 43 constitutes the open oscillatory circuit.

In this single cathode embodiment, the anode 33, reactor 6′, crystal X″, grid 31 and cathode 30 form a high frequency oscillator circuit wherein the anode is at ground potential, and therefore the cathode potential alternates relative to the constant zero potential and in accordance with the frequency of the oscillations of the crystal X″. This single cathode is therefore the output of the oscillator and also the input of the amplifier which embodies this single cathode 30, the control grid 39, the screen grid 40 and anode 41. The high frequency reactor 38 bypasses the control grid 39 to ground and prevents changes in the cathode potential from altering the potential of this control grid 39, thus the potential of the control grid 39 is maintained at zero, while the potential of the cathode alternates at the frequency of the crystal X″. The inductance 42 is excited by the anode 41 at the frequency of the crystal X″, thus amplifying the high frequency wave.

The alternating and bias control potentials between the cathode and the control grid 39 are supplied through the terminals A and B by any selected control input circuit as before explained in the discussion of Fig. 1.

Operation

The operation of this single cathode embodiment is the same as set forth under this caption in describing Fig. 1. The various performances of the carrier wave control are essentially the same as previously described in the discussion of the embodiment shown in Fig. 1 and are diagrammatically illustrated in Figures 6, 7, 8, 9 and 10. It will be readily understood that the illustrated open oscillatory circuit can readily be converted into a series resonant circuit as previously explained under Fig. 1, and either with or without interelectrode neutralization.

Multistage amplification

The amplitude of the previously described carrier waves can be further amplified by the arrangement shown in Fig. 11 which shows an arrangement of amplifier tubes connected in cascade to the showing of Fig. 1.

In Fig. 11 the first amplifier stage consists of two tubes V^1 and V^2 with all electrodes connected in parallel. The anodes **17—17'** are directly connected to the cathodes **26—26'** of the tubes V^3—V^4 which constitute the final amplifier stage. These amplifier tubes have beam electrodes as indicated at D. The screen grids **28—28'** are connected to the source of positive potential through the potential reducing resistor **24**. The anodes **29—29''** are directly connected to the series resonant inductance **20**. The positive potential is fed to the anodes **29—29'** through choke coil **25** which is connected to the center of the inductance **20** to avoid being affected by high frequency voltage. The series resonating reactor **21** is connected between zero potential and the inductance **20** and the antenna **13** is attached by a switch **1** to the inductance **20**. The control input from the terminal A is fed to the cathodes **26—26'** through the choke coil **18**. The capacity of the cathodes **26—26'** and anodes **29—29'** is neutralized by the inverse feedback through reactor **22**, and the control input from B is connected to the control grids **27—27'** so as to make this final amplifier stage the controlled input amplifier and thus make it unnecessary to neutralize the interelectrode capacity of the first amplifier stage. These control grids **27—27'** are bypassed to ground by the high frequency reactor **12**, and the bias battery S^4 is connected between ground and the control grids **15—15'**.

The positive potential to the choke coils **9** and **18** is fed through the potential reducing resistor **24**; and the negative potential to the cathodes **26—26'** is fed through the choke coil **18** from the potential reducing resistor **23**.

The potential reducing resistors **23** and **24** are used to divide the D. C. potentials to the correct values for the different tubes. The high frequency choke coil **25** performs the same function at the choke coil **18** of Fig. 1.

There is here shown a series fed series resonant circuit instead of the shunt fed series resonant circuit in Fig. 1; both are equally effective, but the series fed circuit eliminates any need for the reactor **19** shown in Fig. 1. However, a shunt tuned resonant circuit is not satisfactory for the purpose of thermionic reactance, because the reactance potentials are relatively low.

The tubes V^3 and V^4 are each rated at a much higher power than that of each of the tubes V^1 and V^2 so as to provide the intended power amplification.

It will be seen that the tubes V^1—V^2 and V^3—V^4 are connected in parallel and the groups in series. This series parallel arrangement of the four tubes provides approximately the same overall dynamic impedance between the oscillator and the series resonant output circuit as existed in the tube V' of Fig. 1; and the described arrangement makes it possible to pyramid the amplification to many times that which would be afforded by Fig. 1 and without any appreciable increase in the dynamic impedance.

Each of these amplifiers V^1, V^2, V^3 and V^4 provide a coupling, and the resonant reactance necessary to operate each of the amplifiers is supplied from the resonant oscillatory output circuit, and thus there is provided multistage amplification without any necessity for interstage circuits. These couplings enable the first amplifier stage to convey its power to the final amplifier stage and therefore the total power is not merely the output of the final amplifier stage, but is almost the sum total of both amplifier stages. That is to say, that in the absence of the coupling, the first amplifier stage would merely operate the final amplifier stage without conveying the primary amplification on to the final amplifier stage. Also, these couplings convey power from the oscillator V directly through each of the amplifiers, thereby utilizing the entire output of the oscillator.

The described parallel arrangement is for the purpose of overcoming the loss which would otherwise occur from the dynamic impedance which exists in the tubes now in general use, and it will be readily understood that when suitable amplifier tubes are available with sufficiently low dynamic impedance, that each of these pairs of parallel tubes may be replaced by a single tube and the two stages connected in series, so that the results of Fig. 11 can be accomplished with this lesser amount of equipment.

It is readily conceivable to design a single tube to replace tubes V^1—V^2—V^3—V^4 in Fig. 11, and thus make possible large amplifications of any wave-form without coupling equipment, thereby resulting in a minimum of distortions as well as a minimum of equipment.

It should be mentioned that the screen grid **4** can be omitted from any of the Figures 1, or 11, as it is not absolutely essential to successful operation. It should also be mentioned that Fig. 1 and Fig. 11 are operatable within a restricted range without this reactor **6** which is preferentially included to enhance the range of utilization by selectively controlling the feedback according to conditions of operation, so as to assure efficient stopping of the crystal oscillations. This intended purpose requires that the reactor **6** be of very low capacity, say less than 150 mmfd. as distinguished from the higher capacity reactors which are conventionally used for the purpose of isolation.

The reactors **8** and **37** have been described as low frequency reactors because that affords the most efficient operation; however, a suitable high frequency reactor will give satisfactory operation in either of these instances.

It should also be mentioned that in Fig. 1 when the inductance **20** is provided with an antenna, then the variable low capacity reactor **21** may be connected to the anode side of the inductance **20** so as to equalize the antenna capacity to ground. This provides a greater carrier voltage on the antenna than at the anode **17** and affords a stronger signal on a relatively short antenna. With the reactor **21** thus connected to the anode **17**, the neutralizing reactor **22** can also be used, provided that the antenna is less than a quarter wave length, otherwise the neutralizing reactor **22** is omitted.

It should also be mentioned that a current regulating resistor can be interposed between the screen grid **16** and the choke coil **18**, so as to provide a constant current on the screen grid **16**. When this is done, the function is essentially the same as hereinbefore described, and would be similarly stated except that the term current would be used instead of the term potential, which is the language hereinbefore employed. This current regulating resistor is not essentially necessary for successful operation, and highly efficient coupling can be obtained without it, however there are instances where it can be used to advantage.

It should also be mentioned that throughout the specification, the grid 16 has been termed a "screen grid" in accordance with the conventional language of the art; however, in the present invention, the grid 16 does not really function as a screen grid, but rather as a transmission electrode, which due to its precise linear alignment with the control grid, affords an adequate flow of electrons from the cathode to the anode and enables the potential changes which are produced on the anode by the reactance in the resonant oscillatory output circuit, to thereby create the coupling action within the amplifier and thus control the cathode emission current thereof. Thus it will be seen that in the present invention the grid 16 does not perform its usual function which is to shield or screen the oscillator circuit from the resonant oscillatory output circuit, but rather this grid 16 has decidedly the opposite effect and is of real importance in converting the beam tetrode into a coupling.

It is well known that a piezo electric crystal is the equivalent of an inductance and a capacitor shunted by a resistance, and therefore it is intended that this well known equivalent may be used in the present invention instead of the piezo electric crystal which has been mentioned in the specification merely for the convenience of description.

In the present disclosure I claim as my invention:

1. Apparatus for producing a signal modulated carrier frequency, comprising a space discharge device having at least an anode, a cathode and a control electrode, a source of carrier frequency for exciting the cathode with respect to a point of reference potential, a load circuit including a series resonant circuit connected to the anode of said discharge device and energized by current appearing between said anode and said point, and means for applying modulating potentials to the control electrode of said discharge device.

2. Apparatus for producing a signal modulated carrier frequency, comprising a space discharge device having at least an anode, a cathode and a control electrode, a source of carrier frequency for exciting the cathode with respect to a point of reference potential, a load circuit including a series resonant circuit connected to the anode of said discharge device and energized by current appearing between said anode and said point, said series resonant circuit including an antenna having a distributed inductance and capacitance with respect to said point, and means for applying modulating potentials to the control electrode of said discharge device.

3. A radio frequency system comprising an impedance, a space discharge tube including an electron discharge path, a series resonant circuit having two terminals and consisting of an inductor in series with a capacitor, means to effectively correct in series the impedance, electron discharge path and series resonant circuit, means to supply energy across the impedance at the frequency to which the series circuit is resonant, and means to connect a load between the junction of the inductor and capacitor and a terminal of the series resonant circuit.

4. A radio frequency circuit comprising, in combination, an oscillator tube having at least a cathode, an anode and a control element, a piezo-electric crystal included in a regenerative circuit connected between said anode and said control element, an amplifier tube having at least a cathode, an anode and a control element, radio frequency connecting means including an aperiodic circuit for connecting the anode of the oscillator tube in the cathode of said amplifier tube, means for connecting the cathode of the oscillator tube to a point of reference potential, a load circuit including a series resonant circuit connected to the anode of the amplifier tube and energized by current appearing between the anode of the amplifier tube and the said point, and means for applying modulating potentials to the control electrode of said amplifier tube.

5. Apparatus for producing a signal modulated carrier frequency, comprising a space discharge device having at least an anode, a cathode element and a control element, means for connecting one of said elements to a point of reference potential, a source of radio frequency for energizing the other of said elements and thereby exciting the said anode at radio frequency potential with respect to said point, a load circuit including a series resonant circuit connected to said anode and energized by current appearing between the said anode and said point, and means for applying modulating potentials to one of said elements of said discharge device.

6. Apparatus for producing a signal modulated carrier frequency, comprising a space discharge device having at least an anode, a cathode element and a control element, means for connecting one of said elements to a point of reference potential, a source of radio frequency for energizing the other of said elements and thereby exciting the said anode at radio frequency potential with respect to said point, a load circuit including a series resonant circuit connected to said anode and said point, and means for applying modulating potentials to one of said elements of said discharge device, said space discharge device having high mutual conductance and low plate resistance.

7. A radio frequency circuit comprising, in combination, a source of radio frequency oscillation including an oscillator tube and a piezo-electric crystal for controlling the frequency of the oscillations, a space discharge device having at least an anode, a cathode and control electrode, said source exciting said cathode of the discharge device with respect to a point of reference potential, a load circuit including a series resonant circuit connected to said anode of said discharge device and energized by current appearing between the said anode and the point of reference potential, means for applying a predetermined bias voltage on the control electrode of the discharge device to substantially control the amplitude of the energy fed to said discharge device by said source of radio frequency oscillation, and means for changing the bias voltage for controlling oscillations of said crystal and for applying modulating potentials to said control electrode.

8. A radio frequency circuit comprising, in combination, an oscillator tube having at least a cathode, an anode and a control element, a piezo-electric crystal included in a regenerative circuit connected between said anode and said control element, an amplifier tube having at least a cathode, an anode and a control element, radio frequencies connecting means for connecting the an-

ode of the oscillator tube to the cathode of said amplifier tube, means for connecting the cathode of the oscillator tube to a point of reference potential, a load circuit including a series resonant circuit connected to the anode of the amplifier tube and energized by current appearing between the anode of the amplifier tube and the said point, means for applying a predetermined bias voltage on the control electrode of said amplifier tube to prevent oscillations appearing in said oscillator tube, and means for changing the bias voltage for starting oscillation and for applying modulating potentials to said control electrode.

9. A radio frequency circuit comprising, in combination, a space discharge device having at least an anode, a cathode and control means, a source of carrier frequency for exciting the cathode with respect to a point of reference potential, a load circuit including a series resonant circuit connected to said anode and energized by current appearing between the said anode and said point, means for applying a predetermined bias voltage on the control means, means for adjusting the series resonant circuit at substantially resonance for said predetermined bias voltage, and means for rendering the bias voltage more negative and applying modulating potentials to said control means, thereby modulating into and out of resonance whereby control of the amplitude of the current in the series resonant circuit is obtained.

10. A radio frequency system comprising, in combination, an oscillator circuit including at least an anode electrode and a cathode electrode operating as space discharge means, means for connecting the anode to a point of reference potential, means for exciting the cathode at radio frequency potential above said point, an amplifier circuit including at least a cathode element, an anode element and a control element operating as space discharge means, radio frequency connecting means for connecting the cathode of the oscillator circuit to the cathode of said amplifier circuit, a load circuit including a series resonant circuit connected to the anode of the amplifier circuit and energized by current appearing between the anode of the amplifier circuit and the said point, and means for applying modulating potentials to the control element of said amplifier circuit.

11. A radio frequency system comprising, in combination, a space discharge device having at least a first anode, a second anode, a cathode common to both said anodes, a first control grid operating between the first anode and the cathode and a second grid operating between the second anode and the cathode, said first anode and said first grid in combination with said cathode operating as an oscillator, said second anode and said second grid in combination with said cathode operating as an amplifier, said first anode being connected to a point of reference potential, a load circuit including a series resonont circuit connected to the second anode and energized by current appearing between said second anode and said point, and means for applying modulating potentials to the second grid.

12. A radio frequency system comprising, in combination, a first space discharge device having at least an anode, a cathode and a control electrode, a source of carrier frequency for exciting the cathode with respect to a point of reference potential, means for applying a biasing voltage to the control electrode, a second space discharge device having at least an anode, a cathode and a control electrode, means for connecting the cathode of the second space discharge device to the anode of the first discharge device, a load circuit including a series resonant circuit connected to the anode of the second space discharge device and energized by current appearing between the anode of the second space discharge device and said point, and means for applying modulating potentials to the control electrode of the second space discharge device.

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