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L. L. JONES
VARIABLE RELAY CONDENSER
Filed March 6, 1928

1,777,410

Fig. 1.

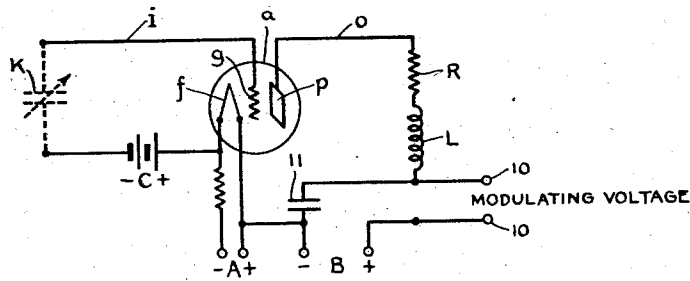


Fig. 2.

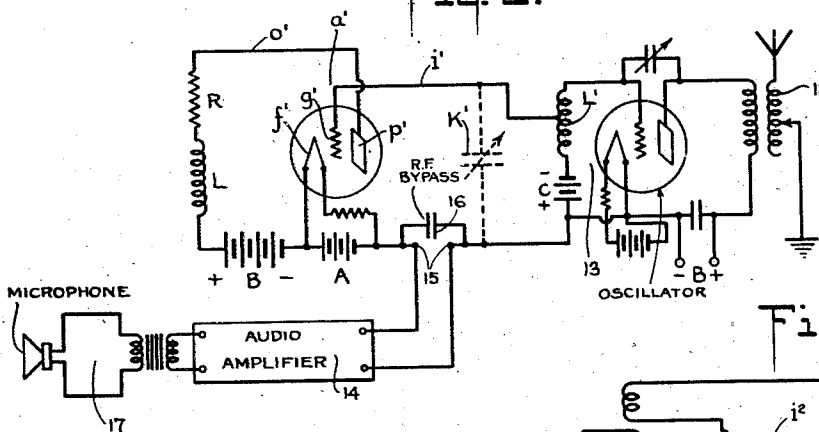


Fig. 4.

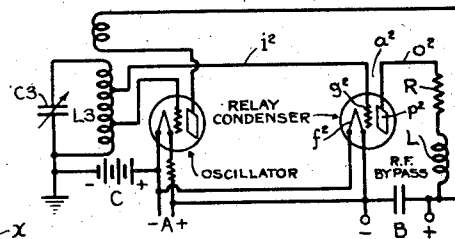
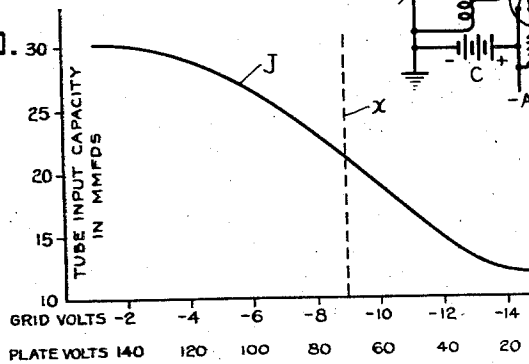


Fig. 3.



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VARIABLE RELAY CONDENSER

Application filed March 6, 1928. Serial No. 259,452.

This invention relates to a variable condenser and relates more particularly to a condenser which may be varied electrically as by a change of circuit constants, and has special reference to the provision of a variable condenser which may be varied at a high rate of speed.

In the radio art there is oftentimes required a condenser whose capacity must be varied at a rate which is so high as to preclude the possibility of using mechanical varying means or a capacity which must be varied in a predetermined way. An example of such a requirement or desideratum occurs in the frequency modulation of the carrier wave of a transmitting station, either for purposes of broadcast transmission or for purposes of secrecy sending; and for such frequency modulation it is very desirable to employ a condenser which could be varied in a predetermined way and at a high rate of speed for securing corresponding variations in frequency.

The prime object of my present invention centers about the provision of variable electrical condensers capable of being electrically varied at high speeds and in a predetermined way, and thus capable of being used, for example, in frequency modulation and for the solution of other similar problems. The invention utilizes certain inherent properties of an electron discharge relay tube; and is therefore termed by me a variable relay condenser, and by employing the principles of the present invention it is possible to secure condensers substantially free of losses, the capacities of which may be varied at any rate through a large range of values and at speeds in excess of millions of times per second.

The present application is a continuation in part of my application for Letters Patent, Serial No. 742,342, filed October 8, 1924 to "Method of and means for controlling energy feed back in electron discharge devices", Patent No. 1,713,130, May 14, 1929, the underlying principles of electron discharge tube relays upon which the present invention is based being disclosed in said application and in others of my copending applications such

as Serial No. 42,399, filed July 9, 1925 to "Electron discharge tube amplifier systems", Patent No. 1,713,131, May 14, 1929, and Serial No. 198,061, filed June 11, 1927 to "Electron discharge tube amplifier system", Patent No. 1,673,287, June 12, 1928.

To the accomplishment of the foregoing and such other objects as will hereinafter appear, my invention consists in the elements and their relation one to the other, as hereinafter more particularly described and sought to be defined in the claims, reference being had to the accompanying drawings which show the preferred embodiment of my invention, and in which:

Fig. 1 is a wiring diagrammatic view showing one form of the relay condenser of my invention,

Fig. 2 shows one of the applications of the same in the arts, the same being shown as used for obtaining frequency modulation in transmitting systems.

Fig. 3 is a graph explanatory of certain principles of the invention and the relation between constants used for certain elements of the circuits, and

Fig. 4 is a wiring diagrammatic view showing another method of applying the relay condenser of the invention.

The relay condenser of my invention is based upon the properties of the electron discharge tube relay when organized to embody the means for controlling or compensating energy feed-back therein by a feed-forward action, as described and claimed in my aforesaid copending application, Serial No. 742,342. These properties may be explained by reference to Fig. 1 of the drawings which shows one form that my present invention may take. The relay condenser, as shown in Fig. 1, comprises an electron discharge tube a having a filament cathode f , a grid g , an anode or plate p , a grid or input circuit i , and a plate or output circuit o , the output circuit having an inductive load L and a resistance R related to produce a given input capacity in said tube which defines a condenser as represented in the grid filament circuit by the phantom condenser K . This input capacity or condenser K is made va-

riable by varying an electrical characteristic of said relay, and more specifically, by modulating the energy supplied to one of the electrodes of the relay. In the form of the invention shown in Fig. 1, this is produced by a modulating voltage applied in the output circuit *o* across the terminals 10, 10 thereof, as indicated by the legend "Modulating voltage".

The electrodes of the variable relay condenser may be supplied with suitable energy characteristics or values, the filament *f* being fed from an energy supply or battery A, the plate circuit *o* being provided with a B battery supply designated as B, and the grid *g* being given a suitable negative bias as by means of the battery C, these energy sources being poled as shown in Fig. 1 of the drawings. The output circuit *o* may also be provided with a suitable radio frequency by-pass condenser 11.

As is well known, the inductance *L* in the output or plate circuit comprises a load which produces an energy feed-back through the grid plate tube capacity; and as set forth in my aforesaid copending applications, Serial Nos. 742,342 and 42,399, a predetermined value of resistance *R* in the output circuit functions for producing an energy transfer or feed-forward from the input circuit *i* to the output circuit *o* through said grid plate tube capacity and the relay action of the tube, which energy feed-forward may be made to compensate or neutralize the energy feed-back. This interrelation between the inductance load *L* and the resistance *R* produces a given augmented tube input capacity which is represented by the condenser *K*.

This resistance *R* is preferably though not necessarily inductance-free and is also preferably capacity-free so that the resistance may be kept as small as possible to minimize the decrease of plate voltage due to the voltage drop in the plate circuit, and so that a balance for all frequencies may be had. The magnitude of this resistance is generally made equal to the ratio of the filament-plate impedance to the amplification constant of the tube. Thus, with a filament-plate impedance of 10,000 ohms and an amplification constant of 10, the value of this resistance *R* should be about 1000 ohms. The values of *L* and *R* vary with the wave length range in which the condenser is used, and in the broadcast range the value of *L* is preferably such as to give the plate circuit a natural wave length less than 200 meters. The resistance should be high enough to effect the desired control, but should in practice be maintained at a minimum so as to prevent any appreciable voltage drop across the resistance, and therefore any appreciable drop or reduction in the plate voltage.

Viewed from the standpoint of the energy relations in the interlinked or coupled input

and output circuits of the tube, the insertion of the resistance *R* in the plate circuit has the effect of absorbing or abstracting energy from the grid circuit in proportion to and corresponding in variation with the energy retransfer or feed-back that takes place from the plate circuit to the grid circuit. Viewed from the standpoint of the resistance relations of the interlinked circuits the resistance *R* in the plate circuit has the effect of introducing a positive resistance in the grid or input circuit *i* which may be made to neutralize the negative resistance of the grid circuit resulting from the feed-back of energy thereto. The abstraction of energy or the energy feed-forward from the input circuit produced by the resistance in the plate circuit is 90° out of phase with the energy feed-back, but takes place in each cycle so that the energy feed-back is effectively compensated for or neutralized.

The effect of the inserted resistance in the plate circuit of producing a feed-forward of energy from the input circuit to the output circuit in opposition to the energy feed-back from the output to the input circuit may be explained on the theory that the feed-forward capacity current through the grid-plate capacity is in effect magnified or augmented by the resistance in the plate circuit due to the said resistance producing a larger than the normal voltage on the plate which is in phase with the grid voltage, and this current is in series with the inserted plate resistance, and therefore tends to abstract energy from the preceding input circuit. Thus the resistance in producing a larger in-phase voltage component has the effect of producing a larger capacity current, and more particularly a larger feed-forward capacity current moving from the grid to the plate; and this feed-forward of energy may be controlled by the size or magnitude of the resistance to nullify any part or the whole of the energy feed-back. This theory further explains the reason why the feed-forward of energy always equalizes the feed-back of energy independent of any change in the tube characteristics or constants, such equalization of the feed-forward of energy with the feed-back of energy being due to the location of the resistance in the electronic current path. Thus with the resistance located in the output circuit, an increase in the filament current, which as known produces an increase in the feed-back of energy from the output to the input circuit due to an increase of the plate potential or the electronic flow of current in the output circuit, produces a corresponding increase in the potential drop across the output resistance *R*, and hence a corresponding increase in the plate voltage which is in phase with the grid voltage, resulting in an increase of abstraction or feed-forward of

energy corresponding with the feed-back increase. Likewise, the feed-forward and feed-back of energy will be equalized independent of any variation of the plate potential or a change in the amplification constant of the tube or any changes in the grid-plate capacity of the tube resulting from replacement or substitution of tubes of different types.

action of this resistance is made to exactly compensate or neutralize for the feed-back action of the inductive load L , the input circuit i is devoid of conductance, the negative resistance component due to the feed-back being neutralized by the positive or damping resistance component, due to the feed-forward. The capacity or condenser K may therefore be obtained as a pure condenser.

The effect on producing an augmented input capacity K by thus interrelating the inductance and resistance components L and R and the consequent possibility of applying this discovery to the production of variable condensers of my present invention will also be seen by the following comparison. By inserting the inductance L in the output circuit (Armstrong) the feed-back of energy is exhibited or manifested by an increase in amplitude of the oscillation in an input circuit of the tube over what is caused by a signal in said input circuit, together with an increase in the selectivity or sharpness of tuning of such an input circuit. Correspondingly, but conversely, I have found that the introduction of substantially capacity and inductance free resistance of the magnitude aforerelated in the plate circuit causes a reduction of the amplitude of oscillation in the input circuit below that which is due to a signal acting alone, together with a reduction of the selectivity or sharpness of tuning of such an input circuit. The mechanism of operation, comparing the Armstrong feed-back and my feed-forward is, in this respect, broadly similar but opposite. In Armstrong the amplified plate voltage operates through the grid-plate capacity to feed energy back to the input circuit. With my feed-forward resistance, the amplified energy in the plate circuit operates to feed energy forward through the grid-plate capacity. There is, however, this difference in the mechanics: In the Armstrong feed-back, substantially no change in the effective grid-plate capacity takes place, and the current which flows through the grid-plate capacity, determining in part the energy feed-back, is measured by the grid-plate capacity and plate voltage. In my feed-forward system, on the other hand, the effective grid-plate capacity is variable with the amplification of the system and the amount of feed-forward resistance in the plate circuit.

It is this characteristic, therefore, of the capability of varying the input capacity K which I utilize for producing a variable relay condenser. The variation of this condenser K may therefore be obtained by varying the resistance R or any characteristic of the electrodes which would produce a variable amplification of the tube. It is desirable, however, to maintain the resistance R constant for the reason that when the feed-forward

In Fig. 1 of the drawings I show means for obtaining the variations of the condenser K by modulating the voltage in the plate circuit. This is produced by applying the modulating voltage at the terminals 10, 10 of the plate or output circuit o . The effect of such a modulating voltage in the plate circuit is shown by the graph of Fig. 3 of the drawings wherein the plate volts are plotted as abscissæ and the tube input capacities are plotted in mmfds. as ordinates. By reference to this graph it will be seen that a modulated voltage over a range of 20 to 140 volts on the plate may produce a variation in tube input capacity from between 12 to 30 mmfds. this being shown by the curve J . By suitably selecting the mean or constant plate voltage supply, such as is indicated by the dotted ordinate line x at substantially 70 volts, it is thus possible to secure variations of the input capacity K in accordance with the modulation energy supplied to the plate. I have found when the plate voltage is thus modulated that the input capacity of the condenser K may not only be made to change over the range shown in Fig. 3 of the drawings, but that such change may be effected with no perceptible deviation from the negligible input conductance.

In Fig. 2 of the drawings I show an application or use of such a variable relay condenser for securing frequency modulations in transmitter circuits, the variation of capacity being obtained by voltage variations in the grid or input circuit instead of in the plate or output circuit of the electron tube relay. In this Fig. 2 of the drawings, the transmitter having the transmitter antenna 12 is provided with an oscillator 13, also designated by the legend "Oscillator", the said oscillator having a grid circuit containing an inductance L' . The relay condenser of the invention is applied to the inductance L' for producing a variable capacity across a part or all of the inductance L' , which capacity is represented by the phantom variable condenser K produced by a condenser relay a' embodying the principles of my invention. This relay a' is provided with a grid circuit i' , a plate circuit o' , the plate circuit having the inductance and resistance components L and R related in a manner similar to that described for the corresponding parts of Fig. 1 of the drawings, the

relay a' being provided with the filament, grid and plate electrodes f' , g' and p' respectively, these electrodes being supplied by A, B and C sources of energy, similar to that heretofore described for Fig. 1 of the drawings, poled as shown in Fig. 2 of the drawings. In the form of the invention here shown, one biasing battery C is used for both the oscillator and the condenser tubes. If a higher biasing voltage is desired for the condenser tube a' , a separate biasing battery may be used therefor.

The oscillatory tube and condenser tube (a') are joined by tapping the lead connected to the grid g' along a point of the inductance L' . The inductance L' is tapped at a suitable point to obtain a proper voltage on the grid of the condenser tube a' . As shown, the inductance L' is tapped to swing the grid of the condenser tube to about one-half of the grid swing of the oscillator tube. The point at which the inductance L' is tapped also determines the capacity variations, the capacity variations obtainable increasing as the tapped point is moved from the lower part of the coil L' to the upper part thereof. It will be apparent that the voltage applied to the grid g' varies in a similar sense. If more voltage is applied to the grid g' , the grid bias and the modulating voltage for the condenser tube a' should correspondingly be increased.

The modulating energy for the system shown in Fig. 2 of the drawings is obtained by a modulation voltage supply in series with the grid circuit, as for example, by an audio amplifier 14 connected into the grid circuit of the tube a' at the terminals 15, 15, across which terminals a radio frequency by-pass condenser 16 is placed. This form of the invention has the advantage that substantially no power is required to cause the variation of the relay condenser capacity.

In the operation of the system shown in Fig. 2 of the drawings, the frequency of the oscillator 13 is caused to vary by the relay condenser represented in effect by the condenser K' which is effective across a section of the inductance L' in the input of the oscillator circuit. Although the modulating energy is derived from an audio amplifier 14 having a microphone circuit input 17, it is to be understood that any other modulating voltage, such for example as the super-audible frequency variations employed in multiplex or secrecy sending systems may also be used. In Fig. 3 of the drawings the curve J shows the variation in the capacity of the condenser K' which is obtained by a modulation of the grid voltage between minus 2 and minus 14 volts, the mean or constant value of the grid voltage being taken at about minus 9 volts. With a relay condenser of this type and where approxi-

voltage variations are desired, the normal voltage on the grid would be held at about minus 9 volts, so as to hold the normal relay condenser capacity at its approximate mid-value.

Referring now to Fig. 4 of the drawings, I show another application or use of the relay condenser of the invention wherein the condenser variations are effected by causing a variation of electron emission, as for example by varying the heater or filament current for the cathode. This method of producing the condenser variations may be applied to the stabilizing of the frequency of an oscillator against slow variations of the "A" battery voltage. In making this application, the input circuit i^2 of the relay condenser tube a^2 having the filament, grid and plate electrodes f^2 , g^2 and p^2 respectively is connected to the inductance coil L^3 of the "oscillator," as shown in Fig. 4 of the drawings, and the output circuit o^2 of the condenser tube is provided with the inductance and resistance components L and R related in a manner similar to that heretofore described. Both of the oscillator and relay condenser tubes are also supplied by the A, B and C sources of energy poled as shown in Fig. 4 of the drawings.

It has been found that most vacuum tube oscillator circuits such as shown in Fig. 4 of the drawings suffer changes in the frequency of the generated oscillations when the cathode heat is varied. Usually these changes are of a small order of magnitude, that is, 1% for normal battery voltage changes. This change is also usually an increase of generated frequency with decreasing cathode heat. The relay condenser a^2 is employed for compensating this change, and for accomplishing this the relay tube (of the thoriated tungsten filament type) is operated at relatively high temperature so that an increase of temperature results in a reduction of electron emission. By connecting the filament f^2 of the relay condenser tube a^2 in parallel with the oscillator cathode as shown in Fig. 4 of the drawings, and by arranging the relay condenser in shunt with the oscillator condenser C^3 of the oscillator, the frequency compensation desired can be effected. The variations produced in the relay condenser which are dependent upon the heater or filament current are necessarily restricted to slow variations on account of the time required to create temperature changes in the filament or cathode. Where the type of oscillator is one in which the frequency falls as the cathode temperature falls, the relay condenser may have its filament operated below the saturation point so that the emission and also the relay condenser value fall as the filament temperature falls.

The use and operation and the various ap-

5 plications of the relay condenser of my invention and the many advantages thereof will in the main be fully apparent from the above detailed description thereof. It will be further apparent that while I have shown and described my invention in the preferred form, many changes and modifications may be made in the structure disclosed without departing from the spirit of the invention, defined in the following claims.

10 I claim:

1. A variable relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, an input or grid circuit comprising the condenser, and an output or anode circuit having inductance and resistance related to produce a given capacity in said condenser, and means for varying an electrical characteristic of said relay for producing predetermined variations in the capacity of said condenser.

2. A variable relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, an input or grid circuit comprising the condenser, and an output or anode circuit having inductance and resistance related to produce for said condenser a given input capacity of substantially no conductance in said tube, and means for varying an electrical characteristic of said relay for producing predetermined variations in the capacity of said condenser.

3. A variable relay condenser comprising an electron discharge tube relay including cathode, plate, and grid electrodes, an input or grid circuit comprising the condenser, and an output or plate circuit having inductance and resistance related to produce a given augmented capacity in said condenser, said resistance having a magnitude of the order of the ratio of the plate impedance and the amplification constant of the tube, and means for varying an electrical characteristic of said relay for producing variations in the capacity of said condenser.

4. A variable relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, an input or grid circuit comprising the condenser, and an output or anode circuit having inductance and resistance related to produce a given input capacity in said condenser, and a modulating means for electrically varying at a high rate a characteristic of said relay for producing corresponding high speed variations in the capacity of said condenser.

5. A variable relay condenser comprising an electron discharge tube relay including cathode, plate, and grid electrodes, an input or grid circuit comprising the condenser, and an output or plate circuit having inductance and resistance related to produce a given augmented capacity in said condenser, and means for predeterminedly varying the grid-plate current flow through said relay

for producing variations in the capacity of said condenser.

6. A variable relay condenser comprising an electron discharge tube relay having cathode, plate and grid electrodes, a grid or input circuit comprising the condenser, and a plate or output circuit coupled to the grid circuit through the grid-plate capacity of the tube, an inductive load in said output circuit for producing an energy feedback through the grid-plate tube capacity, resistance in said output circuit for producing a predetermined energy transfer or feed-forward from the input circuit to the output circuit through said grid-plate tube capacity and through the relay action of the tube for compensating for said energy feedback, said inductive load and resistance producing a given capacity in said condenser, and means for varying an electrical characteristic of said relay for producing predetermined variations of the capacity in said condenser.

7. A variable relay condenser comprising an electron discharge tube relay having cathode, plate, and grid electrodes, a grid or input circuit comprising the condenser, and a plate or output circuit coupled to the grid circuit through the grid-plate capacity of the tube, an inductive load in said output circuit for producing an energy feedback through the grid plate tube capacity, resistance in said output circuit for producing a predetermined energy transfer or feed-forward from the input circuit to the output circuit through said grid-plate tube capacity and through the relay action of the tube for substantially neutralizing said energy feedback, said inductive load and resistance producing for said condenser a given input capacity of substantially no conductance in said tube, and a modulating means for varying at a high speed an electrical characteristic of said relay for producing predetermined high speed variations of the capacity in said condenser.

8. A variable relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, an input or grid circuit comprising the condenser, and an output or anode circuit having inductance and resistance related to produce a given capacity in said condenser over a given frequency band, and means to apply a modulation voltage between two of the electrodes of said relay for varying the capacity of said condenser.

9. A variable relay condenser comprising an electron discharge tube relay having cathode, plate, and grid electrodes, a grid or input circuit comprising the condenser, and a plate or output circuit coupled to the grid circuit through the grid plate capacity of the tube, an inductive load in said output circuit for producing an energy feedback through the grid-plate tube capacity, resistance in said output circuit for producing a predetermined

energy transfer or feed-forward from the input circuit to the output circuit through said grid-plate tube capacity and through the relay action of the tube for compensating for said energy feedback, said inductive load and resistance producing a given capacity in said condenser, and means to apply a modulation voltage between two of the electrodes of said relay to cause a variation of the capacity of said condenser.

10 10. A variable relay condenser comprising an electron discharge tube relay including cathode, plate, and grid electrodes, an input or grid circuit comprising the condenser, and an output or plate circuit having inductance and resistance related to produce a given augmented capacity in said condenser over a given frequency band, and a means for modulating the energy supplied at one of said electrodes of said relay for varying the capacity of said condenser.

25 11. A variable relay condenser comprising an electron discharge tube relay including cathode, plate, and grid electrodes, an input or grid circuit comprising the condenser, and an output or plate circuit having inductance and resistance related to produce a given capacity in said condenser over a given frequency band, means for supplying energy to one of said circuits of the relay, and a means for modulating the energy supplied to said one of the circuits for varying the capacity of said condenser.

35 12. A variable relay condenser comprising an electron discharge tube relay including cathode, plate, and grid electrodes, an input or grid circuit comprising the condenser, and an output or plate circuit having inductance and resistance related to produce a given augmented capacity in said condenser over a given frequency band, one of the circuits being supplied with a mean voltage, and means to apply a varying modulation voltage to said last mentioned circuit for varying the capacity of said condenser in a predetermined way.

50 13. An arrangement for frequency modulation comprising an oscillator circuit the oscillation frequency of which is at least partially dependent upon the capacitance of a portion of said circuit, and a variable relay condenser for determining the said capacitance, said relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, a grid circuit comprising the said condenser, and an anode circuit having inductance and resistance related to produce a given capacitance in said condenser, means for supplying energy to one of said relay circuits, and means for modulating the energy in order to vary the capacitance of said condenser and the frequency of said oscillator.

65 14. An arrangement for frequency modulation comprising an oscillator circuit the

oscillation frequency of which is at least partially dependent upon the capacitance of a portion of said circuit, and a variable relay condenser for determining the said capacitance, said relay condenser comprising an electron discharge tube relay including cathode, anode, and grid electrodes, a grid circuit comprising the said condenser, and an anode circuit having inductance and resistance related to produce a given capacitance in said condenser, and means to apply a modulation potential between two of the electrodes of said relay in order to vary the capacitance of said condenser and the frequency of said oscillator.

Signed at New York, in the county of New York and State of New York, this 3rd day of March, A. D. 1928.

LESTER L. JONES.