Dec. 5, 1939. G. GUANELLA 2,182,377

METHOD AND MEANS FOR TUNING ELECTRIC OSCILLATORY CIRCUITS

Filed April 14, 1938

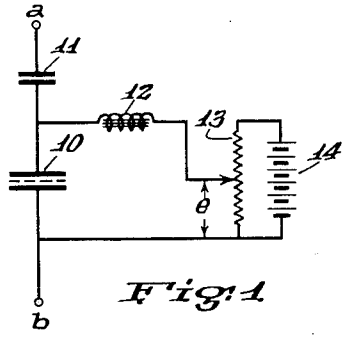


Fig. 1

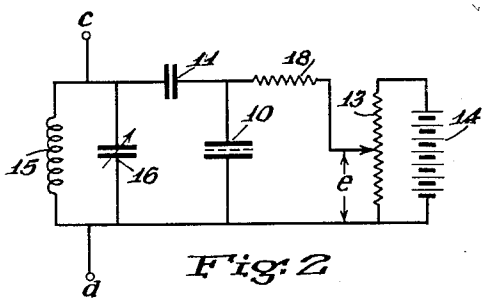


Fig. 2

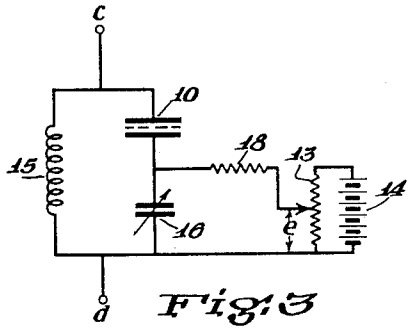


Fig. 3

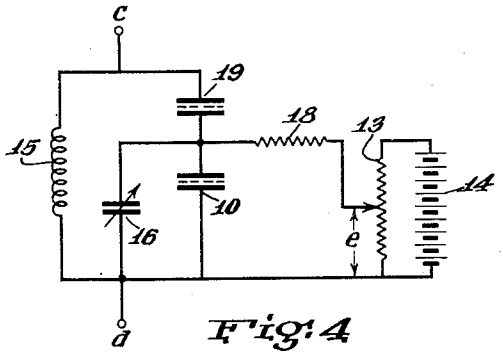


Fig. 4

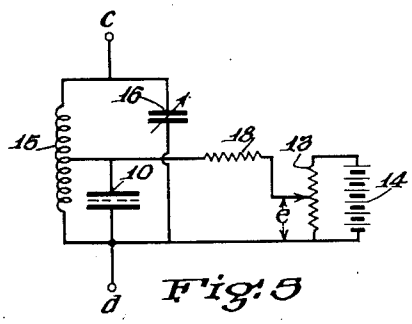


Fig. 5

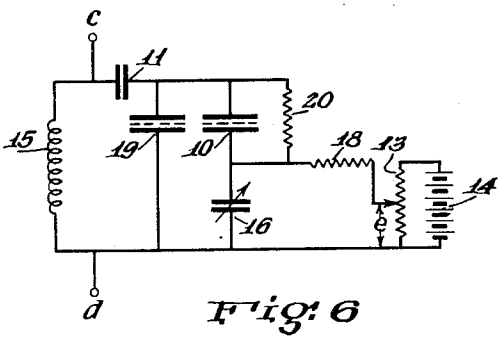


Fig. 6

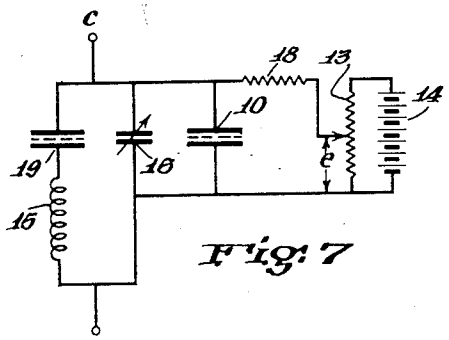


Fig. 7

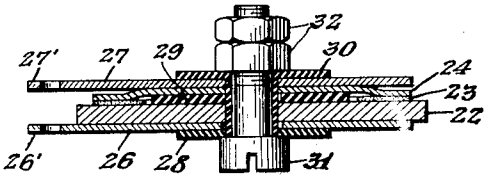


Fig. 8

INVENTOR.
Gustav Guanella

BY

ATTORNEY.

Patented Dec. 5, 1939

2,182,377

UNITED STATES PATENT OFFICE

2,182,377

METHOD AND MEANS FOR TUNING ELECTRIC OSCILLATORY CIRCUITS

Gustav Guanella, Zurich, Switzerland, assignor to Radio Patents Corporation, a corporation of New York

Application April 14, 1938, Serial No. 201,945
In Switzerland May 1, 1937

11 Claims. (Cl. 250—40)

The present invention relates to a method and means for controlling the tuning or natural frequency of an oscillatory or resonant electric circuit or network and among the objects of the invention is to effect a tuning control directly by and in accordance with an electric potential or current without requiring any mechanically moving elements.

The problem oftentimes arises in practice of controlling the tuning or natural frequency of an oscillatory circuit or resonant network such as in the case of remote control of a radio or like receiver or in automatic frequency or tuning arrangements known as A. F. C. systems serving to adjust the tuning of a resonant circuit to the frequency of a received radio signal in a receiver or to a fixed standard frequency of a control device such as a piezo electric crystal in a high frequency oscillator or transmitter.

Arrangements have already been proposed for affecting the tuning in accordance with a control potential without the employment of mechanically moving devices. Thus a tuning variation can be effected by controlling the premagnetization of an iron core inductance coil forming part of an oscillatory or resonant circuit. It has also been proposed to provide an electronic valve serving as a variable reactance element which may be controlled by adjusting a suitable biasing potential. The tuning of a resonant or oscillatory circuit may be further effected by means of voltage controlled impedances suitably connected to the circuit together with fixed auxiliary capacity or inductance elements.

All of the known processes are subject to various disadvantages. On the one hand, the tuning variations require considerable controlling energies and a substantial amount of additional apparatus resulting in increased cost while the tuning variations obtainable are in most cases insufficient for practical requirements.

By the present invention the drawbacks and disadvantages of the previous methods are substantially overcome and substantial tuning variations obtained by small controlling energies and with a minimum of auxiliary apparatus and parts required.

To this end, the invention contemplates the employment of one or more condensers having mechanically fixed electrodes, the electrical capacitance of which can be controlled by biasing potentials impressed upon the electrodes. Such potential controlled condensers employed by the invention comprise a thin blocking or boundary layer disposed between suitable electrodes in such a manner that the capacity of the condenser may be varied within the desired limits by a direct biasing potential impressed upon the electrodes.

In its general construction this type of condenser hereinafter referred to as "blocking layer" or "boundary layer" condenser comprises a metallic base forming one electrode upon which is applied a thin layer of a substance of low conductivity such as a layer of the oxide of the base metal similar to the construction of the known dry rectifiers, or a layer of selenium or an equivalent substance, said layer being firmly united or bonded to the base electrode and being in contact with a second electrode either in the form of a metallic layer sprayed or otherwise applied thereon or a separate electrode pressed into firm engagement with the blocking layer. Alternatively the second electrode may be in the form of a conducting liquid (electrolyte) serving to conduct the electric current to and from the blocking layer. Devices of this type block the electric current-flow in one direction and accordingly act as a condenser in the blocking direction. A complete satisfactory explanation of the function of these devices has not as yet been found. According to one theory accounting for various effects and results, the blocking layer acts as a dielectric similar as in a condenser of ordinary construction, however other phenomena including the capacity variations caused by an impressed biasing potential as utilized by the present invention can be better accounted for by the so-called gas film or boundary layer theory according to which a gaseous or boundary layer of molecular dimensions exists between the base metal and the blocking layer through which electrons can pass only in the direction to the metal electrode similar as in a vacuum valve. Whatever the function and theoretical operation underlying such devices, extensive experiments conducted by applicant have shown that substantial capacity variations in the current blocking direction may be effected by and in proportion to an applied direct biasing potential, which capacity variations are utilized according to the present invention to control the natural frequency or tuning characteristics of an oscillatory circuit or resonant network.

The invention will become more apparent from the following detailed description taken with reference to the accompanying drawing forming part of this specification and wherein;

Figure 1 shows a diagram of a basic circuit for producing capacity variations according to the invention,

Figure 2 shows an example for varying the tun-

ing or natural frequency of an oscillatory circuit,

Figures 3 and 4 are modifications of a circuit of the type according to Figure 2,

Figure 5 shows a combination of the circuits according to both Figures 2 and 3,

Figures 6 and 7 illustrate further modifications of the invention, and

Figure 8 shows an exemplification of a potential controlled capacity element suitable for use in connection with the invention.

Similar reference numerals identify similar parts throughout the different views of the drawing.

Referring to Figure 1, there is shown schematically by numeral 10, a boundary layer condenser of the general character described hereinabove which may be a selenium, copper oxide or any other suitable condenser and of either the dry or liquid type. This condenser in the example illustrated is connected in series with a fixed condenser 11 of standard type. The terminals *a*—*b* of the series combination of both condensers 10 and 11 may be connected in any circuit such as an oscillatory or resonant circuit wherein the capacity variations are desired. The potential controlled condenser 10 is biased in the blocking direction by a variable direct current potential supplied from a suitable source such as a battery 14 in the example illustrated in connection with a potentiometer 13 having a variable tap for impressing a variable potential *e* upon the condenser 10.

The biasing potential controlling the capacity of the condenser 10 should be applied in such a manner that the damping imposed by the direct current upon the oscillatory or tuned circuit in which the condenser 10 is connected remains within sufficiently low limits and that no short circuit is formed for the biasing potential through the oscillatory circuit or associate network. For this purpose the biasing potential *e* according to Figure 1 is applied from the potentiometer 13 through a choke coil which offers a sufficiently high impedance for the alternating currents in the associate circuits or network. This choke coil may be replaced by a high ohmic resistance as shown in the subsequent illustrations. The biasing potential applied in this manner to the potential controlled condenser 10 is blocked from the remaining portions of the associate network or circuit by the comparatively large capacity 11 in series with the condenser 10. In this manner the capacity between points *a*—*b* may be varied in proportion to the biasing potential derived from the source 14. By connecting an arrangement of this type in an oscillatory circuit the tuning or resonant characteristic of the circuit may be controlled in a simple and easy manner within predetermined limits.

Experiments have shown that the capacity of the potential controlled condenser depends to a large extent upon the frequency of the currents or potentials in the circuit in which the condenser is connected. This fact has to be considered in the design of the oscillatory circuits or network. If the tuning of the oscillatory circuit is varied by a variable condenser such as a rotary condenser within wide limits (rough tuning adjustment) the different variations effected by the potential controlled condenser (fine tuning adjustment) may be taken into account by the proper design of the shape of the plates of the rotary condenser in such a manner as to maintain substantially the same range of capacity variation for all positions of the rough tuning condenser.

Referring to Figure 2, there is shown an arrangement according to Figure 1 embodied in an oscillatory circuit. In the example shown the potential controlled condenser circuit is connected in parallel to a resonant circuit comprising an inductance coil 15 shunted by a variable condenser 16. This circuit having terminals *c*—*d* may be connected in an electrical system such as a radio receiver whereby the tuning of the circuit may be varied within predetermined limits by controlling the biasing potential supplied from the potentiometer 13. There is further shown in Figure 2 a high ohmic resistance 18 in place of a choke coil as shown in Figure 1 to block the alternating potentials in the associate circuit from the biasing potential circuit. Rough tuning is effected by varying either the inductance of the coil 15 or the capacitance of the condenser 16. In the latter case as shown in the illustration (variable condenser 16), the tuning variations for a predetermined change of the biasing potential *e* are a maximum for small values of the capacitance of the condenser 16; that is, for high tuning frequencies.

According to a further embodiment the potential controlled capacity 10 may be connected in series with the variable tuning condenser 16 such as shown in Figure 3 in which case the blocking condenser 11 may be dispensed with. In this embodiment the tuning variations corresponding to a predetermined change of the biasing or control potential *e* are a maximum for large values of the capacitance of the condenser 16; that is, for the low tuning frequencies.

In general, care should be taken that the alternating voltage impressed upon the potential controlled condenser does not exceed a certain value or amplitude if undesired non-linear distortion and reaction from the control circuit—due to a rectifying action of the condenser or other causes—are to be avoided.

In circuits with great oscillating amplitudes it is advisable for this reason to provide several potential controlled condensers in series in place of a single condenser as shown in Figure 2. In this manner the alternating voltage at each of these condensers is prevented from exceeding a predetermined maximum limit. Under circumstances it is not necessary that all the capacities are voltage controlled and only a single voltage controlled condenser may be sufficient and connected in series with one or more fixed condenser elements.

A further possibility to prevent excessive alternating potential at the potential controlled condenser consists in connecting the same across a portion of the winding of the tuning inductance such as shown in Figure 5. According to the latter the condenser 10 is placed across the lower terminal of the inductance 15 and an intermediate tap point thereof suitably chosen to prevent excess alternating current loads on the condenser.

There are further shown in Figures 4, 6 and 7 exemplifications adapted to obtain substantially equal tuning variations for both low and high frequencies. In the example shown two potential controlled condensers 10 and 19 are provided, the average capacity of the condenser 10 being large compared with the average capacity of the condenser 19. Thus for high frequencies; that is, for low values of the rough tuning condenser 16, the tuning is substantially effected by variations of the condenser 10. If, on the other hand, the

capacity of the rough adjusting condenser 16 approaches the capacity of the condenser 19 for the low frequencies the tuning will be substantially affected by the capacity variations of the condenser 19. In this manner by the proper choice and design of the condensers 16 and 19 it is possible to maintain a constant range of tuning variations for both high and low frequencies, i. e. within substantially the entire adjusting range of the rough tuning condenser. In Figure 4 which is equivalent to a combination of Figures 2 and 3 the potential controlled condenser 18 is connected in parallel to the rough tuning condenser 16 while the condenser 19 is arranged in series with both the former condensers.

In the arrangement according to Figure 6 wherein one of the potential controlled condensers 18 is in series with the rough tuning condenser 16 and the other potential controlled condenser 19 is in parallel to both the former, both potential controlled condensers are arranged in series with the biasing potential source. In order to obtain the proper potentials across each condenser, either or both may be shunted by a high ohmic resistance of suitable value such as a resistance 20 connected across the condenser 18 in the example illustrated.

Figure 7 is substantially similar to Figure 4 with the exception that the condenser 19 is arranged in series with the inductance 15, the function and operation being otherwise similar to the preceding arrangements.

From the above it is seen that by suitable combination and circuit arrangement it is possible to obtain substantially equal tuning variations for different settings of a rough adjusting tuning element such as a variable condenser arranged in an oscillatory circuit or resonant electric network. This makes arrangements of this type especially suited for use in connection with automatic frequency control (A. F. C.) systems provided in radio receivers for automatically adjusting the receiver to the frequency of a received radio signal.

The circuits shown are by way of example only and it is understood that many modifications and variations may be resorted to coming within the broader scope and spirit of the invention.

The biasing potential for varying the tuning of a resonant or oscillatory circuit according to the invention may be adjusted manually by the aid of a potentiometer as shown in the exemplifications illustrated. In the case of automatic tuning, this biasing potential is supplied by a discriminator arrangement generating a tune responsive or A. F. C. potential in accordance with any of the known methods. According to the latter as used at present in radio broadcast receivers, a direct potential is generated by the discriminator arrangement varying both as to sense and magnitude in accordance with the sense and amount of detuning of the receiver relative to a received signal frequency. If such an A. F. C. potential is applied to a potential controlled condenser suitably connected to an auxiliary circuit such as the local oscillator or tank circuit in a superheterodyne receiver, it is possible in this manner to effect an automatic tuning or frequency control of the receiver after the latter has been roughly brought into tune with the received signal frequency by means of a mechanical dial or the like. Alternatively, the arrangement according to the invention may serve for controlling or maintaining constant the frequency of an oscillator or transmitter by providing a frequency standard such as a piezo electric oscillator and controlling the tuning of an oscillatory circuit of the main oscillator by a control potential varying in accordance with the deviations of both phase and frequency of the oscillatory currents relative to the oscillations of standard frequency. In general the invention may be utilized in connection with any system wherein the frequency of an alternating or oscillating current is to be balanced or synchronized with a second frequency. Among other examples this is the case in common frequency broadcasting wherein the carrier waves transmitted from two or more stations have to be controlled and maintained in exact synchronism.

In the use of a potential controlled condenser according to the invention in a circuit or network provision should be made, as pointed out above, that the alternating load imposed upon the condenser does not exceed a permissible limit determined by the circuit and the behavior and characteristics of the condenser. For this purpose, it is desirable in most cases to provide the potential controlled tuning condenser in a special preselector circuit wherein the oscillating amplitudes have a low value and to amplify the oscillations to a desired output level. In the case of an oscillator such as the local oscillator in a superheterodyne receiver, it is advisable for this reason to arrange the potential controlled condenser in the grid circuit of an oscillator valve.

Since the tuning variations effected by a potential controlled condenser according to the invention depend to a certain extent upon the amplitude of the oscillating current it is advisable in many cases to maintain this amplitude at a constant value by special arrangements. This may be accomplished by the use of a known arrangement for automatic volume control or by the aid of amplitude limiting devices such as by temperature controlled resistances, regulating pentodes or hexodes which latter are automatically regulated to maintain a constant amplitude of the oscillating current (automatic volume control).

Referring to Figure 8, there is shown a construction of a potential controlled condenser suited for use in connection with the invention. There is shown at 22 a metal plate or disc having applied thereon a thin blocking layer 23 of any suitable material described hereinabove. Item 24 is a second electrode of resilient metal having its outer portion pressed into firm contacting engagement with the layer 23 and being insulated from the disc 22 by an insulating washer or spacer 29. Further contacting electrodes 26 and 27 having extensions or connecting lugs 26' and 27', respectively, are placed in engagement with the electrodes 22 and 23, respectively, and the entire assembly bolted together by means of a metal screw 31 having a pair of locking nuts 32 and with a pair of further insulating washers 28 and 30 interposed between the screw 31 and the contact discs 26 and 27, respectively. It is understood the construction shown is by way of example only, various modifications being possible as is obvious from the above.

Experiments have shown that with condensers of the above described type and other constructions similar to the known dry rectifiers, electrolytic rectifiers or electrolytic condensers, substantial capacity variations may be obtained by varying biasing potentials. The electrical losses of the condenser may be kept within admissible

limits by suitable design determined by experiments.

It has been found that in most cases the voltage controlled capacity variations are dependent on a blocking layer having an extremely low electrical conductivity and a thickness of less than 10^{-3} cm. According to experiments made, this blocking layer may be bounded by metallic or electrolytic conductors or semi-conductors which latter exert an influence on the capacity variations caused by the applied biasing or control potential.

By suitable choice of the semi-conducting layer it is possible to form therefrom the blocking layer of extremely low electrical conductivity. This can be obtained for instance by oxygen removal in the case of so-called oxidized semi-conductors (such as cuprous oxide, circonium dioxide, etc.) or by the addition of oxygen such as in the case of so-called reduced semi-conductors (such as zinc oxide).

The formation of the blocking layer from an adjoining semi-conducting layer is well known in the manufacture of blocking layer rectifiers. However, other processes have been proposed for the formation of the blocking layer and used successfully in the manufacture of blocking layer rectifiers. Experiments have shown that the blocking layer can also be formed by special insulating layers of sufficiently low thickness and which are bounded in a suitable manner by layers of conducting or semi-conducting material. Such artificial blocking layers may for instance consist of organic lacquers such as shellac, Bakelite, nitro-cellulose lacquer and others.

A special type of potential controlled condenser are devices known as electrolytic rectifiers or dry and wet electrolytic condensers wherein the blocking layer is produced by electrolytic formation. The variations of capacity depend to a large extent on the construction of the devices. Specially large capacity variations are obtained for instance with a tungsten anode placed in a copper nitrate electrolyte solution. Also by the employment of niobium and tantalum as anode material substantial capacity variations by biasing potential control can be effected. The time constant of the capacity variation depends on the thickness and composition of the blocking layer and adjoining electrodes and is of the order of several thousandths of a second. Apart from this rapid capacity variation a relatively slow action of the biasing potential is observed which is known as electrolytic formation depending on the forming voltage.

Although devices of the above type known as electrolytic rectifiers and electrolytic condensers may be used in certain cases without change as potential controlled condensers for the purposes of the invention, it is preferable in many cases to vary the constants and composition of such devices such as the character of fixed electrodes, the composition of the electrolyte, the forming process, etc., to differ from the usual standards and to conform with the new requirements and purpose. In many cases the direct current impedance should be as high as possible for the desired operating potentials to maintain the direct current losses at a low value. In general the direct biasing potential is applied in the blocking direction but in many cases it may be advantageous to apply a small bias in the current passing direction. Furthermore, it is possible to use devices of the above character wherein a blocking action takes place in both directions. The blocking layer and if required the adjoining conductor or semi-conductor should be chosen and constructed in such a manner that the alternating current losses of such a condenser for the operating frequency within the biasing potential range do not exceed the limits determined by the purpose and use of the condenser and that the capacity variation is large compared with the loss resistance for the desired range of operating frequencies and biasing potential.

It will be evident from the above that the invention is not limited to the specific methods and arrangement of parts disclosed and shown herein for illustration but that the novel concept and underlying principle of the invention is susceptible of numerous variations and modifications coming within the broader scope and spirit of the invention as defined in the appended claims. The specification and drawing are accordingly to be regarded in an illustrative rather than in a limiting sense.

I claim:

1. The combination with a tunable circuit, of a polarized variable condenser arranged to form an effective tuning element of said circuit, said condenser comprising a pair of electrodes and a thin intermediate layer of low conducting material arranged between said electrodes and being intimately united with at least one of said electrodes, a source of variable uni-directional potential, and means for impressing said potential upon said electrodes in the current blocking direction of said condenser.

2. The combination with an oscillatory circuit, of a polarized variable condenser arranged to form an effective tuning element of said circuit, said condenser comprising a pair of electrodes and a thin intermediate layer of low conducting material arranged between said electrodes and being intimately united with at least one of said electrodes, a source of variable uni-directional potential, means for applying said potential to said electrodes in the current blocking direction of said condenser, and further means for blocking oscillating currents in said circuit from said source of uni-directional potential.

3. The combination with a tunable circuit, of a polarized variable condenser arranged to form an effective tuning element of said circuit, said condenser comprising a pair of electrodes and a thin intermediate layer of low conducting material in contacting relation to said electrodes and having at least one surface thereof in intimate molecular contact with the adjacent electrode, a source of variable uni-directional potential, means for impressing said variable potential upon said electrodes in the current blocking direction of the condenser, and further means for preventing a short circuit of said source through said circuit.

4. The combination with a tunable electric circuit, of a pair of polarized variable condensers connected in series and parallel relation, respectively, to a tune determining element of said circuit, each of said condensers comprising a pair of electrodes and a thin intermediate layer of low conducting material in contacting relation to said electrodes, at least one surface of said intermediate layer being in intimate molecular contact with the adjacent electrode, a source of variable uni-directional potential, and means for impressing said variable potential upon said electrodes in the current blocking direction of said condensers.

5. The combination with a tunable electric cir-

cuit comprising a rough tuning element, of a pair of polarized variable fine tuning condensers connected in series and in parallel, respectively, to a tune determining element of said circuit, each of said condensers comprising a pair of electrodes and a thin layer of low conducting material in contacting relation to said electrodes, at least one surface of said intermediate layer being in intimate molecular contact with the adjacent electrode, the average capacity of one of said condensers being large compared with the average capacity of the other condenser, a source of variable uni-directional potential, and means for impressing said unidirectional potential upon said electrodes in the current blocking direction of said condensers.

6. The combination with a tunable electric circuit comprising an inductance shunted by a variable condenser for rough tuning of said circuit, of a pair of polarized fine tuning condensers, one of said polarized condensers being connected in parallel and the other polarized condenser being connected in series with said rough tuning condenser and having an average capacity which is large compared with the average capacity of said first polarized condenser, each of said polarized condensers comprising a pair of electrodes and a thin layer of low conducting material in contacting relation to said electrodes, at least one surface of said intermediate layer being in intimate molecular contact with the adjacent electrode, a source of variable uni-directional potential, and means for impressing said variable potential upon said polarized condensers in the current blocking direction.

7. The combination with an oscillatory electric circuit, of a polarized variable condenser comprising a first electrode, a thin layer of low conducting material intimately and molecularly united to said electrode, a cooperating electrode in contacting relation to said layer, said condenser being connected in said tunable circuit to form an effective tuning element of said circuit, a source of variable uni-directional potential, and means for impressing said variable potential upon said electrodes in the current blocking direction of said condenser.

8. The combination with an oscillatory electric circuit, of a polarized variable condenser comprising a first electrode, a thin layer of low conducting material molecularly united to said electrode, a cooperating armature in contacting relation to said layer, said condenser being connected in said circuit to form an effective tuning element thereof, a source of variable uni-directional potential, means for impressing said unidirectional potential upon said condenser in the current blocking direction, and further means for maintaining the oscillating potential developed across said condenser element below a predetermined limit.

9. In an arrangement as claimed in claim 8 with reference to said last means wherein said condenser is arranged so as to be subjected to a fractional portion of the alternating voltage developed in said circuit.

10. In an arrangement as claimed in claim 8 with reference to said last means wherein said condenser is connected in parallel to a portion of a tune determining impedance of said circuit.

11. In an arrangement as claimed in claim 8 with reference to said last means, wherein said condenser being connected across a portion of a tuning inductance of said circuit.

GUSTAV GUANELLA.