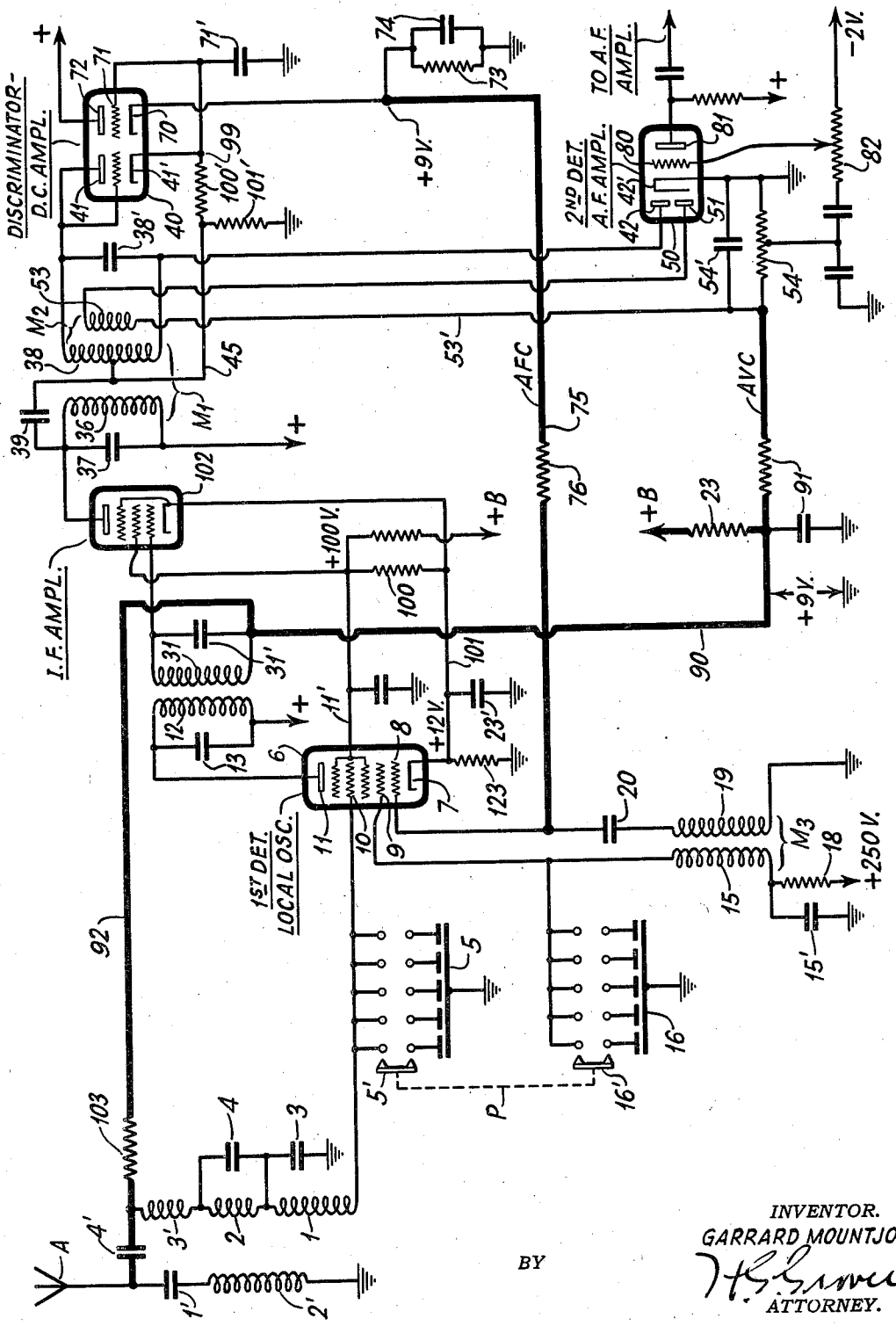
Feb. 11, 1941. G. MOUNTJOY 2,231,368

AUTOMATIC FREQUENCY CONTROL

Filed April 13, 1938



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Patented Feb. 11, 1941 2,231,368

UNITED STATES PATENT OFFICE

2,231,368

AUTOMATIC FREQUENCY CONTROL

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Application April 13, 1938, Serial No. 201,736

4 Claims. (Cl. 250—20)

My present invention relates to automatic frequency control (A. F. C.) circuits, and more particularly to an improved and highly simplified A. F. C. circuit which possesses a wide frequency control range at different settings of the tuning device.

In application Serial No. 151,794, filed July 3, 1937 by G. Mountjoy and D. E. Foster, granted Aug. 30, 1938 as U. S. P. 2,128,661, there has been disclosed an A. F. C. circuit which utilizes the I. F. amplifier as a direct current amplifier for the A. F. C. bias. The amplified bias is employed to vary the potential of the oscillator grid electrode of a pentagrid converter thereby to adjust the frequency of the oscillator tank circuit. Further experimentation and investigation has revealed that the frequency shift action on the tank circuit can be increased without increasing the number of tubes, and without interfering with normal receiver construction.

It may be stated that it is one of the main objects of my present invention to produce a greater percentage shift in tuning of the oscillator tank circuit without increasing the elements of the oscillator network.

Another important object of this invention is to permit (A. V. C.) automatic volume control action of the converter and I. F. amplifier tubes; and the A. F. C. bias being amplified by a special direct current amplifier device provided in the same tube envelope as a discriminator diode.

Another object of my invention is to provide in an A. F. C. circuit a multiple duty tube having a diode acting as a second detector and A. V. C. bias source; an amplifier section to amplify the audio output of the detector diode; and a second diode which cooperates with an independent tube to provide a frequency discriminator network.

Still another object of my invention is to provide in a multiple push button-trimmer condenser receiver an A. F. C. circuit capable of effecting satisfactory control over the oscillator tank circuit frequency; and the control circuit embodying no special tubes.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically a circuit organization whereby my invention may be carried into effect.

Referring now to the drawing, which shows a superheterodyne receiver system of compact and efficient design, there is shown a signal collector A feeding signals, which may be in the broadcast range of 500 to 1500 kc., to the signal grid 10 of the converter tube 6. The latter may be of the 6A8 type. The signal collector can be a grounded antenna circuit; a tap to a radio frequency distribution line; a loop antenna; or it can be the usual pick-up device employed in connection with automobile receivers. This particular receiver is shown employing trimmer condensers as the tuning instrumentality. Thus, numeral 1 denotes the tuning coil of the signal input circuit, one end of coil 1 being connected to signal grid 10 and the opposite end being connected to the junction of coil 2 and condenser 3. The antenna A is connected to ground through a condenser 1' and coil 2' which are in series resonance with the I. F., they provide a trap for all undesired signals of the I. F. value. The coil 2 is connected to the high potential side of condenser 1' through a path comprising coil 3' and condenser 4'. The coil 2 is shunted by a condenser 4 which resonates it to a frequency equal to the highest image frequency of the signal range. For example, with an I. F. value of 460 kc. the network 2—4 is tuned to 2420 kc. The condenser 4' is a direct current blocking condenser, while coil 3' functions to choke image frequencies with respect to harmonics of the local oscillator frequency.

The condenser 3 couples the antenna network to coil 1. The numeral 5 designates, in a purely schematic manner, a gang of trimmer condensers of different values. Those skilled in the art are fully aware of the manner of selectively connecting a desired trimmer condenser across coil 1 to tune the circuit to a desired signal carrier frequency. The numeral 5' denotes such selective means. For example, if desired, each trimmer condenser may have its associated push button for selective connection of the trimmer across the coil 1. Each trimmer, when selected, is connected between the grid end of coil 1 and ground.

The tube 6 comprises the cathode 7, and the latter is connected to ground by a resistor 123 shunted by the 0.2 mf. bypass condenser 23'. Between the plate 11 and cathode 7 there are disposed the oscillator grid electrode 8, the oscillator anode electrode 9 and the signal input grid 10. The screen grids, which surround the signal grid 10, are connected by lead 11' to the voltage reduction resistor 100; the low potential end of the latter is connected to the cathodes of tubes 6 and 102 by lead 101. The high potential end of resistor 100 is connected to a proper positive po-

tential point on the direct current voltage supply bleeder of the system.

The oscillator tank circuit comprises the coil 15 and a selected one of the gang of trimmer condensers 16. Coil 15 is connected at one end thereof to electrode 9; the other end is connected to ground through a 0.05 mf. condenser 15'. Each of the trimmer condensers 16 may be connected in shunt across coil 15; it is to be understood that the numerals 16—16' designate a gang of selectively-operable trimmers similar to the gang 5—5'. The dotted line P denotes a common actuating mechanism for concurrently selecting trimmer condensers in the signal and tank circuits which will produce the desired I. F. of 460 kc. Positive potential is applied to electrode 9 from a point (250 volts) on the supply bleeder, the resistor 18 of about 20,000 ohms connecting coil 15 to such positive point.

The oscillator grid 8 is connected to ground through a path including condenser 20, of 10 mmf., and coil 19. The latter is magnetically coupled, as at M_3, to tank coil 15. The signals and local oscillations produce I. F. energy in the resonant output circuit 13—12; the latter is tuned to the operating I. F. value. Those skilled in the art are fully aware of the action of conversion which takes place in tube 6. Briefly, the electron stream of the tube is modulated by both the signal and oscillation frequencies; "electronic" coupling is employed to produce the I. F. energy. The coil 12 is coupled to coil 31 in the input circuit of I. F. amplifier tube 102 which may be of the 6K7 type. The input circuit is resonated to the operating I. F. value by condenser 31'.

The plate of amplifier 102 is connected to a source of positive potential through coil 36; the condenser 37 tunes the latter to the operating I. F. Coil 36 is magnetically coupled, as at M_1, to the coil 38 of the discriminator input circuit. Coil 38 has its midpoint connected to the plate side of coil 36 by condenser 39. Condenser 38' resonates coil 38 to the I. F. value. The discriminator diodes are provided in two tubes 40 and 50. Tube 40 is a double triode of the 6F8 type; tube 50 may be a double diode-triode of the 6Q7 type.

The grid and plate of one triode in tube 40 are strapped together providing an anode 41 which cooperates with cathode 41' to provide a diode. Cathode 41' is connected to ground through resistors 100' and 101', each resistor having a magnitude of about 1 megohm. The junction of resistors 100' and 101' is connected to the midpoint on coil 38 by lead 45. The anode 41 is connected to one side of input circuit 38—38'; the opposite side of the input circuit is connected to the anode 42 of tube 50. The cathode 42' of the latter is grounded; hence, the resistors 100'—101' are connected in series between the cathodes 41' and 42'. Diode 42—42' provides the second rectifier of the discriminator network.

The remaining triode of tube 40 comprises the cathode 70, control grid 71 and plate 72. The cathode 70 is connected to ground through resistor 73, the latter being bypassed by the 0.1 mf. condenser 74. The grid 71 is connected to the cathode end of resistor 100', a 0.1 mf. condenser 71' bypassing the connection to ground. Plate 72 is connected to a desired positive potential point on the voltage supply bleeder. The resistor 73 is given a magnitude such that the cathode end thereof is approximately 9 volts above ground. The triode 70—71—72 provides a direct current voltage amplifier; the A. F. C. bias developed at point 99 of resistor 100' is amplified by the amplifier 70—71—72, and the variable potential across resistor 73 is applied to grid 8 of the converter tube 6 by lead 75. The latter includes a filter resistor 76, and comprises the A. F. C. connection to the oscillator section of the converter network.

The audio and A. V. C. voltages are developed by the diode 51—42' of tube 50. The anode 51 is connected to the cathode 42' through a path including link coupling coil 53, lead 53' and resistor 54. The coil 53 is of many turns, and is magnetically coupled, as at M_2, to coil 38 at the midpoint thereof. The anode end of resistor 54 is connected to cathode 42' by the I. F. bypass condenser 54'. The audio voltage across resistor 54 is impressed on the grid 80 of audio amplifier section 42'—80—81. The grid 80 is adjustably tapped, as at 82, to the load resistor 54; the usual audio potentiometer arrangement is employed in this connection. The amplified audio voltage may be transmitted to one, or more, audio amplifiers and a final reproducer.

The A. V. C. voltage is derived by connecting lead 90, including the pulsation voltage filter 91, to the anode end of resistor 54. Lead 90 is connected to the low potential end of coil 31; a second lead 92 connects lead 90 through resistor 103 to the junction of condenser 4' and coil 3'. Hence, A. V. C. bias is applied to the signal grids of the converter tube 6 and I. F. amplifier 102. Resistor 23 connects lead 90 to B+, and provides +9 volts between lead 90 and ground. Both signal grids have a minimum negative bias established by potential difference between the cathodes and grids thereof. The minimum negative bias will be −3 volts; as the carrier amplitude increases, the negative bias will increase and reduce the gain of each of tubes 6 and 102 so as to maintain the carrier amplitude substantially uniform at the detector input circuit regardless of fading effects.

The theoretical basis for the production of the A. F. C. voltage across resistors 100'—101' is explained in the following manner. The potentials at either end of coil 38, with respect to its midpoint, are 180 degrees out of phase. Hence, if the midpoint is connected to the high potential side of coil 36, one potential is realized which maximizes above the resonant frequency of the I. F. value, and a second potential is realized which maximizes below this value. If these two potentials are applied to a pair of rectifiers, such as the diodes 41—41' and 42—42', and the resulting direct current voltages are added in opposition, the sum will be equal to zero. In the type of discriminator network shown in the drawing, the primary and secondary coils 36 and 38 are so connected that two vector sum potentials of the primary and secondary voltages may be realized. When the I. F. energy departs in frequency value from the assigned operating I. F., then there is developed across resistors 100' and 101' a direct current voltage. Further description of this network is not believed necessary, since the operation of the discriminator has been fully disclosed by S. W. Seeley in application Serial No. 45,413, filed Oct. 17, 1935 granted June 21, 1938 as U. S. P. 2,131,103. The polarity of point 99 depends on the sense of frequency shift of the I. F. energy, and the potential magnitude of point 99 depends on the amount of frequency departure. Since grid 71 is connected to point 99, the cathode end of resistor 73 varies in potential according to the variation of point 99. The cathode end of resistor 73 will vary in a positive or

negative sense with respect to the predetermined +9 volts value. Hence, the grid 8 of the oscillator will vary similarly in potential with respect to its normal —3 volts bias. The +9 volts value of the cathode end of resistor 73 is chosen to correspond to correct tuning of the tank circuit 15—16 to an oscillation frequency which produces the assigned I. F. It will thus be seen that a departure of the I. F. energy from the assigned I. F. value (in this case 460 kc.) results in a variation of the oscillator grid bias. Furthermore, the variation of the latter is in a sense such that the oscillator tank frequency is adjusted to compensate for the departure.

The separate diode rectifier 51—42', arranged in tube 50, is employed so as to secure adequate selectivity even though but one stage of I. F. amplification is employed. The diode 51—42' of tube 50 has its input circuit coil 53 coupled to the coil 38, and it will be seen that the input circuit of the second detector diode is really a tertiary circuit coupled to the secondary circuit including coil 38. The coupling between coils 38 and 53 is arranged so that coil 53 is coupled only to coil 38, and not to coil 36. This is done, as schematically shown in the drawing, by coupling turns 53 close to coil 38. In this way, with the use of but a single I. F. amplifier, the selectivity preceding the audio demodulator is satisfactory.

The following explanation of the manner in which the changes in bias of oscillator grid 8 are converted to frequency changes of the oscillator tank circuit follows: The oscillator produces an oscillatory voltage across the tank circuit 15—16 which is transferred to coil 19 by mutual inductance M_3. In an oscillator the grid draws current so that there is a finite grid impedance, predominantly resistive, if the grid-cathode static capacity can be neglected. For the purposes of explaining the action this capacity will be neglected, and its effect will be shown later. The voltage across the grid coil 19 causes a current to flow through capacity 20 and the input grid resistance of grid 8 of tube 6. Capacity 20 and the grid resistance r_g of the tube rotate the phase of the current relative to the voltage in that circuit. The current flowing through r_g, therefore, has an in-phase and a quadrature component. The in-phase component serves to maintain oscillation, and the quadrature component serves to vary oscillation frequency. These two components of current flowing through r_g produce the grid voltage at oscillator frequency which, by virtue of the mutual conductance of the tube 6, produces an alternating current in the plate circuit thereof. The direction of the mutual inductance M_3 between coils 15 and 19 necessary to maintain oscillation is such that this alternating plate current produces an effect equivalent to a negative resistance and a negative capacity in shunt to the tank circuit.

The negative resistance component is responsible for the oscillation, and the negative capacity component varies the frequency to some value other than that due to the constants of the tank circuit alone. Now, when direct current voltage is applied to grid 8 of tube 6, the effect on tube 6 is to vary the mutual conductance and the grid resistance r_g. If the direct current bias on grid 8 is made more positive, the mutual conductance increases but the grid resistance decreases. The effect of these two factors being opposite, tends to maintain the oscillatory voltage substantially constant unless the bias on grid 8 is made so far positive that the oscillator ceases to function. If the direct current bias on grid 8 is made negative, the negative capacity due to the quadrature component changes. In this case r_g increases and the negative capacity in shunt to the tank circuit decreases, and the oscillatory frequency decreases.

An increase in negative capacity in shunt to a tuned circuit has the same effect on frequency as a decrease in a positive inductance in shunt to the tuned circuit. However, a negative capacity has an impedance which decreases with increasing frequency, whereas a positive inductance has an impedance which increases with increase in frequency. The frequency shift produced by a given change in negative capacity is thus greater at the high frequency end of the tuning spectrum where the tank circuit capacity is low, whereas the effect of a given change in positive inductance is a substantially constant percentage of the frequency over the tuning spectrum since the tank circuit inductance is a constant. It has been shown that making the potential of grid 8 more positive results in an increase in oscillatory frequency. If the direct current potential of grid 8 is made more negative the frequency decreases. It has been shown, also, that the effect of capacity 20 is to produce a negative capacity in shunt to the tuned circuit. If capacity 20 is replaced by an inductance the effect would be as if a negative inductance were shunted across the tuned circuit, in which case the amount of shift would be more constant over the tuning spectrum.

The tank coil and each associated trimmer condenser are made high in reactance (that is, by using a large coil and small condenser) so that the shunting effect of the anode quadrature current operates across a high impedance and produces a greater percentage shift in tuning of the oscillator tank circuit. The mutual M_3 is sufficiently great to produce vigorous oscillation and increased quadrature current. In general the mutual M_3 has this effect: increase in M_3 produces a greater increase in shift at the low frequencies than the high. Hence, M_3 may be so chosen as to obtain substantially constant shift at all frequencies of the band. As M_3 is increased by increasing the value of coil 19, the latter will tend to approach resonance at the high frequency end of the band through the action of the capacities across it, and shift at the high frequencies will be materially reduced. M_3 may be arranged to provide constant shift; or accentuated shift (with M_3 very large) at the low frequency end of the band; or accentuated shift (with M_3 small) at the high frequency end of the band.

It will be noted that the discriminator network is fundamentally similar to that described in the aforesaid Mountjoy and Foster application; however, it differs from the prior discriminator circuit in that with the discriminator tube and the demodulator tube there is secured an added function. This added function is the direct current amplification of the A. F. C. bias derived from the double diode network. Accordingly, it will be observed that A. V. C. action may be applied to the I. F. amplifier preceding the discriminator and demodulator. The direct current amplifier has a limiting action. Initially, with the correct station tuning, the amplifier provides a voltage across resistor 73 equal to the normal plate current flow under self-biasing conditions multiplied by the value of resistor 73.

With a large negative discriminator voltage applied to its grid 71, the voltage across resistor 73 becomes zero. As a positive discriminator voltage is applied to the grid 71, the drop across resistor 73 increases. However, when the self-bias is exceeded by the A. F. C. voltage the amplifier grid 71 draws grid current and shunts out the two resistors 100' and 101' which are in series with the grid, the latter elements providing the internal impedance of the discriminator output. Hence, the positive increase of the drop across resistor 73 is limited to a value very near that of resistor 73 multiplied by the zero bias current of the triode 70—71—72.

To explain the receiver operation, and specifically the functioning of the A. F. C. circuit, when an input signal is applied to antenna A, of lower frequency than is necessary to produce by beating with the oscillator frequency an I. F. of predetermined value, an I. F. signal is produced which is higher than the predetermined frequency. Signals of this higher carrier frequency are passed through the discriminator circuit and a discriminator voltage is developed across resistors 100 and 101; the voltage is negative as applied to the control grid 71 of tube 40. A decrease in cathode current in tube 40 results in a decrease in voltage across resistor 73 thus changing the bias on grid 8 of tube 6 and producing a more negative bias on grid 8. This more negative bias shifts the frequency of oscillation as previously explained, and causes a lower frequency to be produced. The lower oscillator frequency beating with the input signal produces a decrease in the I. F. signal frequency, and tends to correct for the assumed condition of I. F. signals higher than the desired I. F. With an input signal to the antenna that is higher in frequency than that necessary to produce the correct I. F. value by beating with the oscillator frequency, the reversal of the above biasing action takes place and the I. F. value is corrected. The control characteristics of the oscillator control circuit were experimentally measured on a receiver from which the schematic diagram was derived.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In a superheterodyne receiver of the type employing a local oscillator circuit, said circuit comprising a tube having at least a cathode, a control grid and an anode electrode, a tunable oscillation tank circuit connected to said anode and cathode and being reactively coupled to said grid, means for varying the direct current potential of the oscillator grid electrode, a single condenser element connected between the grid and cathode, said element being so chosen in magnitude as to reflect across said tank circuit a capacitative effect which is adapted to vary the frequency of the oscillator tank circuit in response to variations in the direct current potential of said grid, an intermediate frequency amplifier having an input circuit and an output circuit, a discriminator network having an input circuit coupled to said amplifier output circuit, said discriminator having a direct current voltage output circuit, a direct current voltage amplifier having input and output circuits, a connection between the discriminator output circuit and the input circuit of the direct current voltage amplifier, and a direct current voltage connection between the output circuit of said direct current voltage amplifier and said oscillator grid providing said varying means.

2. In combination with an electron discharge tube of the type including at least a cathode, an anode electrode and a control electrode, a resonant tank circuit connected between the cathode and one of said two electrodes of the tube, means for reactively coupling the second electrode to said tank circuit, solely a condenser external of said tube connected between said cathode and said second of the tube electrodes, said condenser having a magnitude such that it rotates the phase of the current flowing in the circuit of said second electrode with respect to the alternating voltage applied thereto thereby varying the effective reactance of said tank circuit, and means for varying the direct current potential of said second electrode thereby to control the effectiveness of said condenser.

3. In an oscillator network of the type including a tube provided with at least a cathode electrode, an anode electrode and a control electrode, a resonant tank circuit connected between the cathode and said anode electrode, purely magnetic means coupling said anode and control electrodes in such a manner as to provide an oscillatory current flow through said tank circuit, a single reactive element external of said tube connected between said cathode and control electrode, said reactive element being chosen to rotate the phase of the current flowing in the circuit of said control electrode with respect to the alternating voltage applied thereto thereby to vary the effective reactance of said tank circuit, and means for varying the direct current potential of said control electrode thereby to control the effectiveness of said reactive element.

4. In combination, a tube including at least a cathode, an anode and a control electrode, the anode including in circuit therewith a coil of relatively high inductance value, a plurality of independent condensers of different values arranged for selective shunting across the coil, means providing a magnetic coupling between said control electrode and said coil whereby oscillatory currents are caused to flow through said coil, the frequency of said currents being dependent upon the condenser in shunt with said coil, a condenser in series between the control electrode and cathode for rotating the phase of current flowing in its circuit with respect to the alternating voltage applied thereto whereby a capacitative effect is produced across said coil which is supplemental to said shunt condenser, means for varying the direct current potential of the control electrode thereby to control the value of the said effect over a desired magnitude range, and said magnetic coupling being chosen to provide a predetermined rate of variation over said range.

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