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AUTOMATIC FREQUENCY CONTROL FOR OSCILLATION SYSTEMS

Filed Jan. 25, 1936

2 Sheets-Sheet 1

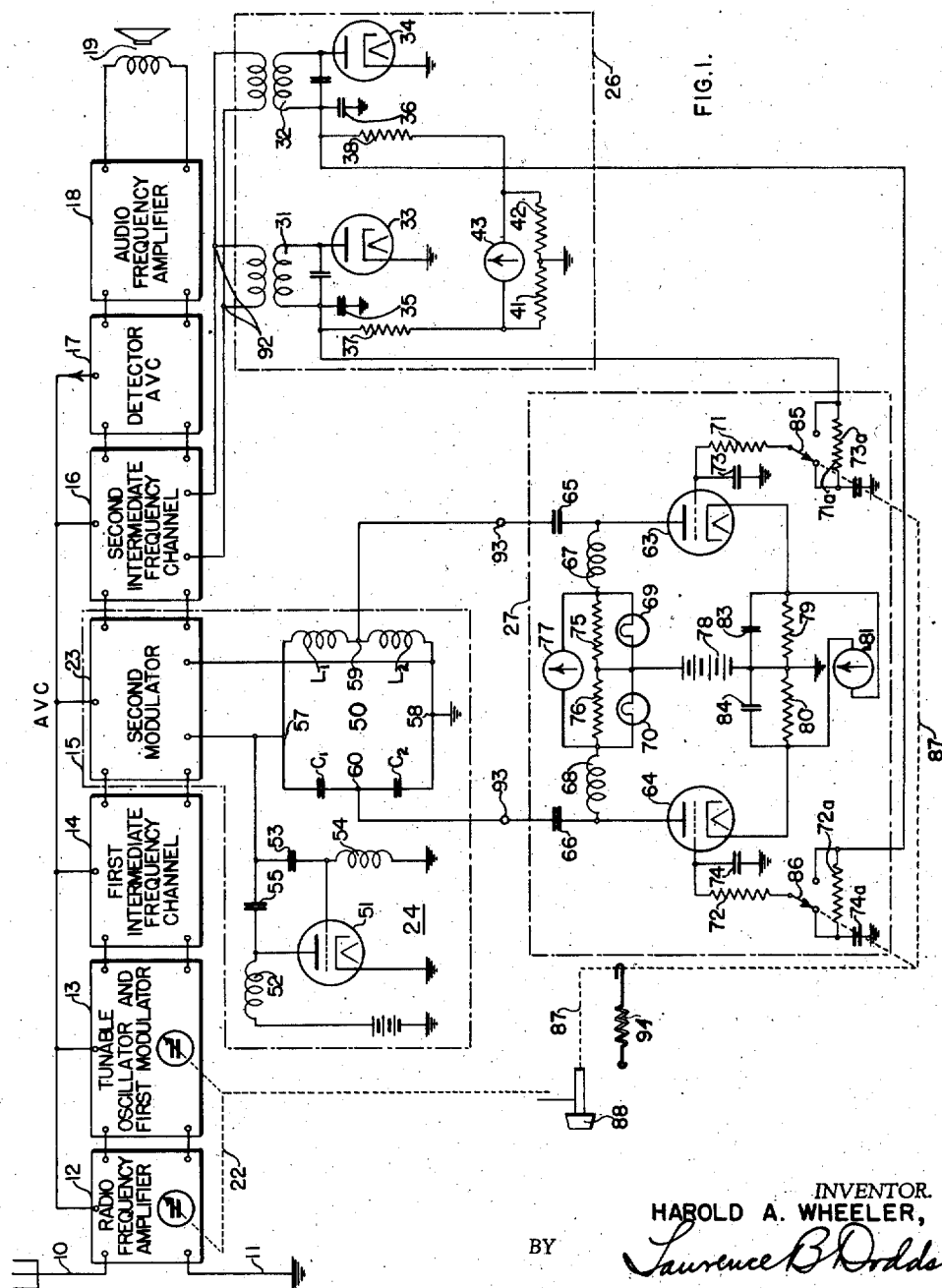


FIG. 1.

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2 Sheets-Sheet 2

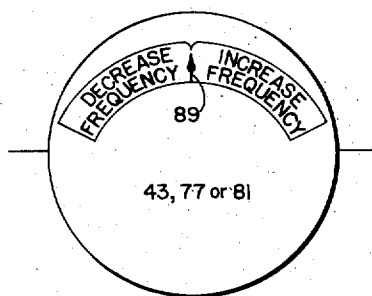


FIG. 2.

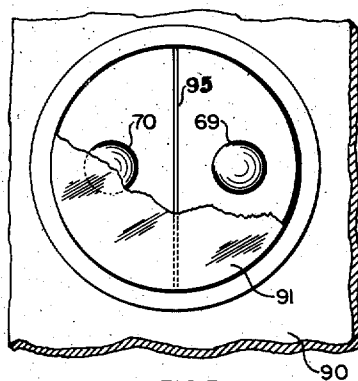


FIG. 3.

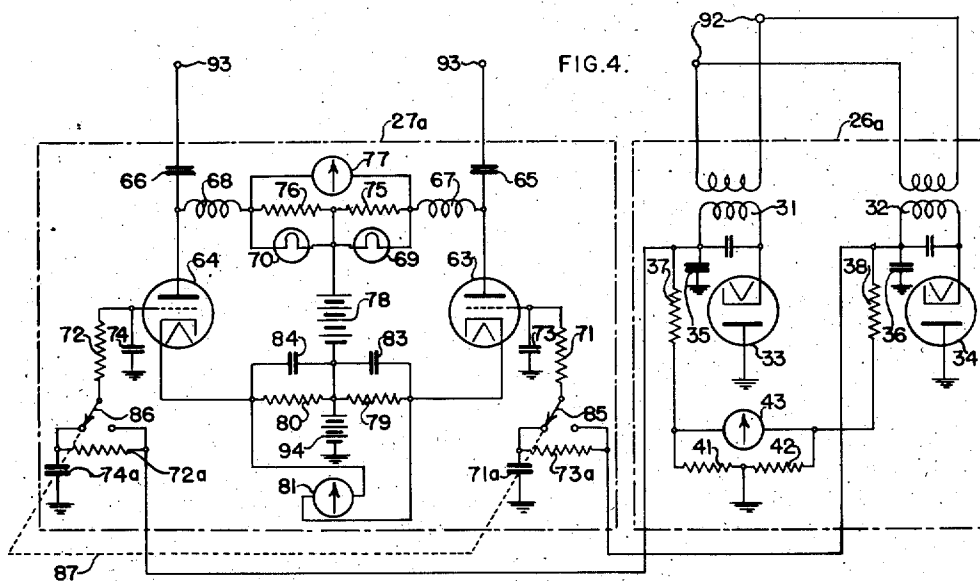


FIG. 4.

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AUTOMATIC FREQUENCY CONTROL FOR
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Application January 25, 1936, Serial No. 60,802

29 Claims. (Cl. 250—20)

This invention relates to the regulation of the resonant frequency of a tuned or tunable system and, while it is of general application, it is particularly suitable to the control of the frequency of a local oscillator of a superheterodyne receiver so as to obtain and/or maintain the carrier frequency in an intermediate-frequency channel thereof substantially at the center frequency, or at least at the normal operating frequency, of such channel. This application is a continuation-in-part of my copending application Serial No. 46,493, filed October 24, 1935.

As is well understood, the intermediate-frequency channel of a superheterodyne receiver is a channel passing a given fixed intermediate frequency and at least one of its symmetrically related side bands of modulation. As is also well understood, reception with the greatest selectivity and fidelity of which such a receiver is capable is usually obtained, other things being equal, when the frequency of the intermediate-frequency carrier wave produced by the receiver is located at the center or normal operating frequency of the intermediate-frequency channel. In common practice, however, the relationship just described often does not obtain because of the fact that the oscillations actually produced by the local oscillator of such a receiver drift relative to the frequency which the oscillator is intended to produce. This drift is particularly noticeable during each initial period of operation of the receiver in which the various elements in the receiver are heating up to their steady operating temperatures. Other factors, such as variations in the supply voltage, also contribute to oscillator drift. Oscillator drift is frequently of such magnitude as not only seriously to impair the fidelity of reception of a given signal but also to cause the complete fading out of such signal. Returning of the receiver is generally required in either instance.

A second cause for the deviation of the intermediate-frequency carrier wave from the center or normal operating frequency of the intermediate-frequency channel resides in the fact that the receiver may be inaccurately tuned to the frequency of the received signal. As a result, the tunable local oscillator of such receiver produces oscillations of a frequency different from that which it produces when the receiver is tuned precisely to the frequency of the received signal.

Each of these two factors becomes of increasing importance as the signal frequencies are higher in the frequency spectrum. Thus, the same percentage of frequency deviation incidental to

either factor produces an actual frequency deviation at 10 megacycles which is ten times greater than that produced at 1 megacycle.

It is an object of this invention, therefore, to provide a simple and effective automatic control of the resonant frequency of a tuned circuit and, more particularly, of a local oscillator of a superheterodyne receiver.

More specifically, it is an object of the invention to provide an automatic frequency control for a local oscillator of a superheterodyne receiver effective to maintain the frequency of the intermediate-frequency carrier wave substantially at the center or normal operating frequency of the intermediate-frequency channel.

It is another object of the invention to provide an automatic frequency control of the type described which has one or more of the following characteristics: uniform effectiveness throughout the tunable range of the receiver; equal effectiveness in compensating for tendencies of the intermediate-frequency carrier wave to deviate either above or below the center or normal operating frequency of the intermediate-frequency channel; independence from variations in amplitude of the intermediate-frequency carrier wave; and independence from the carrier wave of the desired signal during periods of severe fading thereof.

A further object of the invention is the provision in such an automatic frequency control system of means for indicating the sense, or, alternatively, both the sense and relative amount, by which the frequency subject to control tends to deviate from the desired normal frequency, or, more specifically, by which the frequency of the carrier wave in the intermediate-frequency channel tends to deviate from the center or normal operating frequency thereof. With such a feature embodied in a radio receiver, the user of the receiver may readjust its tuning to insure the maximum fidelity of reception and the maximum margin of automatic frequency control.

Other objects of the invention will become apparent from a consideration of the following specification taken in conjunction with the accompanying drawings and the appended claims.

The invention contemplates a tuned circuit, preferably electrically symmetrical with respect to its output connections and including at least four impedance elements arranged in two parallel arms, each arm consisting of two serially-related impedance elements, at least two of such impedance elements, one in each arm, being re-

active and of opposite type, together with means individual to an impedance in each arm for adjusting in the same sense the effective inductance and capacitance values in the tuned circuit of the reactive elements of opposite type, thereby controlling the resonant frequency of the tuned circuit. Such control may be effected automatically by impressing a control voltage of such frequency, of a frequency related thereto in a predetermined manner, or of a controlling frequency, upon two control elements the responses of which vary in opposite senses as the control voltage deviates from its normal frequency. A pair of independent similar control circuits are connected, respectively, from the control elements to the two arms of the tuned circuit, each control circuit including the adjusting means individual to the associated arm and varying the effective value of the circuit reactance in such arm in accordance with the variation of the response of the associated control element. The relative proportioning and disposition of the various elements and circuits is such as to cause the effective values of the circuit reactances of the two arms to vary in the same sense with variations in the frequency, and in the opposite sense with variations in the amplitude, of the control voltage.

More specifically, when the invention is applied to a superheterodyne receiver, the tuned circuit comprises the oscillation circuit of a local oscillator, and the control is effected in response to deviations of the intermediate-frequency carrier wave from the center or normal operating frequency of the intermediate-frequency channel. Such control may be effected by two auxiliary circuits sharply tuned respectively above and below the center or normal operating frequency of such channel and coupled thereto. The outputs of the auxiliary circuits are utilized to adjust the effectiveness of the frequency-determining reactance elements of the oscillation circuit. In the embodiment illustrated hereinafter, the outputs of the auxiliary circuits are rectified and applied as bias voltages to the grids of vacuum tubes effectively shunting the respective reactance elements.

In accordance with a preferred embodiment of the invention, the local oscillator to which automatic frequency control is applied is the second, or fixed frequency, oscillator of a double superheterodyne receiver, the frequency of the oscillator being controlled by the second intermediate-frequency carrier wave. With such an arrangement, the automatic frequency control is of uniform effectiveness regardless of the frequency to which the receiver is tuned.

In accordance with another feature of the invention, the automatic frequency control is provided with a relatively long time constant so that it remains effective independently of the carrier wave of the desired signal during short periods of severe fading thereof. Moreover, this insures that the automatic frequency control, during a period of severe fading of the desired signal, does not attach itself to an undesired signal. Further, in certain cases, the time constant of the automatic frequency control is subject to adjustment by the user of a receiver, or automatically in accordance with the tuning thereof, so that the time constant is small during initial tuning of the receiver to a desired signal and thereafter increases to its higher value during normal reception.

In accordance with still another feature of the invention, there is provided in connection with

the automatic frequency control means effective to indicate the tendency of the wave subject to such control to deviate above or below its normal frequency. In certain applications of the invention, as in a radio receiver, the indicating means preferably indicates not only the sense of such deviation tendencies, as above, but also the degree or relative extent of such tendencies, inasmuch as the degree of such deviation tendencies is of assistance in gauging the amount of adjustment required to retune the receiver. With the particular automatic frequency control described herein, indication of the sense and the degree of frequency deviations is conveniently obtained by connecting a zero-center voltmeter across two series-connected resistances, the currents in which are in opposition and individually controlled by the responses in the two sharply resonant circuits.

In the drawings, Fig. 1 is a circuit diagram, partly schematic, illustrating an embodiment of the invention as incorporated in a superheterodyne receiver; Fig. 2 is a schematic diagram of one type of indicating device represented in Fig. 1; Fig. 3 is an outline of another type of indicating device represented in Fig. 1; and Fig. 4 is a circuit diagram of a modified form of the control apparatus of the present invention shown in Fig. 1.

Referring now to Fig. 1 of the drawings, the superheterodyne receiver there shown comprises a tunable radio-frequency channel 12 connected to the antenna 10 and ground 11. The radio-frequency channel 12 may or may not include amplifying means, as desired. Connected in cascade with the radio-frequency channel 12 are a first frequency changer 13, a first intermediate-frequency channel 14, a second frequency changer 15, a second intermediate-frequency channel 16, a detector and automatic gain control source 17, an audio-frequency amplifier 18, and a sound reproducer 19. All this apparatus may be of conventional design. The first frequency changer 13 is tunable and comprises a tunable oscillator and first modulator, the tunable oscillator being tuned conjointly with the tuning of the radio-frequency channel 12 by a unicontrol mechanism indicated by the dotted line 22. The second frequency changer 15 is non-tunable and comprises a second modulator 23 and a non-tunable oscillator 24 the output frequency of which is subject to control within limits as described hereinafter. A "tunable" frequency changer or oscillator, as used herein, is defined as one which is normally operable over a substantial range of frequency directly in response to adjustment by the user. An "untunable" frequency changer or oscillator, as used herein, is defined as one which is normally operable at a frequency that is fixed in so far as any direct control of the frequencies by the user is concerned, but may nevertheless be adjustable within relatively narrow limits for the purpose of regulating the frequency output thereof. Either or both of the intermediate-frequency channels may include amplifying means. Preferably, however, second intermediate-frequency channel 16 is provided with amplifying means and is, as described hereinafter, more selective than the first intermediate-frequency channel. The automatic amplification control bias potential, indicated as A. V. C., may be applied to one or more of the radio-frequency channel 12, the modulator of the first frequency changer 13, the first intermediate-frequency channel 14, the second modulator 23, and the sec-

ond intermediate-frequency channel 16, as desired.

Considering first the operation of the receiver as thus far described, the desired received signal is selected (and also, in some instances, amplified) in radio-frequency channel 12 and converted by the first frequency changer 13 into a signal-modulated first intermediate frequency. The signal, as thus converted, is selected (and also, in some instances, amplified) in the first intermediate-frequency channel 14, converted by the second frequency changer 15 into a signal-modulated second intermediate frequency, selected (and also, in many instances, amplified) in the second intermediate-frequency channel 16, converted by detector 17 into the audio frequencies of modulation, amplified in the audio-frequency amplifier 18, and reproduced by the sound reproducer 19. The amplification of the received signal is subject to automatic control by the A. V. C. bias potentials, according to the manner well understood in the art.

In order to maintain the second intermediate-carrier frequency of the above described system at the center or normal operating frequency of the second intermediate-frequency channel 16, there is connected to such second intermediate-frequency channel a frequency responsive device 26 which, in turn, is connected to a frequency control apparatus 27 arranged to control, within limits, the frequency of the non-tunable oscillator 24.

The frequency responsive device 26 includes two tuned circuits 31 and 32 suitably energized from the second intermediate-frequency channel 16. The two tuned circuits 31 and 32 are sharply tuned, respectively, to frequencies below and above the normal operating frequency, in this instance the center frequency, of the second intermediate-frequency channel and are connected, respectively, to rectifiers 33 and 34, preferably of the diode vacuum tube type. The load circuits of the rectifiers 33 and 34 comprise the parallel connected condensers and resistors 35, 37 and 38, respectively, preferably grounded at the rectifier cathodes, as shown.

If desired, additional resistors 41 and 42 may be provided in series with resistors 37 and 38, respectively, and a zero-center voltmeter 43 connected thereacross.

The non-tunable oscillator 24 may be of any of certain conventional types. One preferred arrangement, however, is that illustrated, in which the oscillation circuit 50 is effectively connected in the grid-cathode circuit of a vacuum tube 51, with the anode-cathode circuit containing an inductance 52 by which the anode circuit is tuned to a frequency above the resonant frequency of oscillation circuit 50. The oscillator is provided with a grid choke 54 and coupling condenser 53, and with a feed-back coupling condenser 55 between the anode and grid circuits. Preferably, grid choke 54 is of such proportions as to tune the oscillator 24, other than the oscillation circuit 50, broadly to the resonant frequency of oscillation circuit 50. In this manner the capacitive susceptance of condenser 53 and its associated elements is compensated, and the oscillator 24, excluding the oscillation circuit 50, becomes a pure negative resistance. In this connection it should be observed that any other form of substantially pure negative resistance, such as a dynatron, may alternatively be utilized in the oscillator 24 in connection with the oscillation circuit 50.

The oscillation circuit of the non-tunable

oscillator 24 comprises not less than four impedance elements, of which at least two, in opposite arms of the circuit, between the output connections 57, 58 thereof, are reactance elements of opposite type. In the arrangement shown, the oscillation circuit 50 comprises four reactance elements, two of one type in one arm and two of the other type in the other arm. At the normal resonant frequency of the oscillation circuit, each of two reactance elements of opposite type and in opposite arms of the oscillation circuit has a reactance which is not greater than a minor fraction of the total reactance in the corresponding leg of the oscillation circuit and, preferably, which is equal in magnitude to the reactance of the corresponding element of the opposite type. Specifically, the oscillation circuit 50 comprises two serially-related inductances L_1 , L_2 and two serially-related condensers C_1 , C_2 connected in parallel effectively between the grid and the grounded cathode of vacuum tube 51. Inductance L_2 is a minor fraction of the total oscillation circuit inductance and, at the normal resonant frequency of oscillation circuit 50, the capacitive reactance of condenser C_2 is substantially equal to the inductive reactance of inductance L_2 .

The oscillation circuit 50 is thus electrically symmetrical with respect to the output connections 57, 58, which are points of maximum voltage difference. The term "electrically symmetrical", as applied to a tuned circuit, is used herein to describe a tuned circuit in which the impedances in the two parallel paths between the points of reference have, at the natural resonant frequency of the circuit, substantially equal values and opposite phase angles. In addition, the impedances of oscillation circuit 50 are so proportioned and arranged that point 59 (the junction of L_1 , L_2) is a point in one arm of the circuit which electrically corresponds with the point 60 (the junction of C_1 , C_2) in the other arm of the circuit. The term "electrically corresponding points" in the respective arms of a tuned circuit, as used herein, is defined as two points to which the impedances from a junction of the two arms have, at the natural resonant frequency of the circuit, substantially equal values and opposite phase angles.

In order to control the frequency of the oscillator 24 by means of the frequency responsive device 26, there is provided the frequency control apparatus 27 comprising a vacuum tube 63, effectively shunted across inductance L_2 through a blocking condenser 65, and a vacuum tube 64, effectively shunted across condenser C_2 through blocking condenser 66. A source of operating voltage, such as a battery 78, for the tubes 63 and 64 is connected to their anode circuits through choke coils 67 and 68, respectively. The grids of the tubes 63 and 64 are connected to the appropriate terminals of resistors 37 and 38, respectively, and are thus biased with voltages varying with the responses of the sharply tuned circuits 31 and 32, respectively. The grid circuits of tubes 63 and 64 may be provided with filter sections 71, 73, and 72, 74, respectively, each comprising a blocking resistor and by-pass condenser.

In certain cases, filter sections 71a, 73a and 72a, 74a, in addition to and associated with filter sections 71, 73 and 72, 74, respectively, may be provided in the grid circuits of the tubes 63 and 64 so that for each grid circuit the two corresponding filter sections are in cascade, together

with two switches 85 and 86 by means of which the additional filter sections, normally effective, may be short-circuited and thus rendered ineffective. Switches 85 and 86 are preferably operated conjointly by unicontrol mechanism indicated by the dotted line 87. Also, the unicontrol tuning mechanism 22 is preferably interlocked with the unicontrol mechanism 87 so that, whenever the receiver is tuned, the switches 85 and 86 are actuated to render the additional filter sections ineffective. This interlock is schematically indicated by an arrangement in which the tuning knob 88 must be pushed inwardly against the action of a spring 94 to engage the tuning unicontrol mechanism 22, the inward motion of the knob actuating switches 85 and 86 through unicontrol mechanism 87. Other interlocking arrangements may, of course, be employed; for example, switches 85 and 86 may be actuated by the user's hand in proximity to or touching a tuning knob directly connected to the tuning unicontrol mechanism 22.

If desired, series-connected resistors 75 and 76 may be connected in the anode circuits of tubes 63 and 64, between high-frequency chokes 67 and 68, respectively, with source 78 connected to the junction of such resistors and with a zero-center direct-current meter 77 connected across the terminals thereof. Alternatively, series-connected resistors 79 and 80 may be connected in the cathode circuits of tubes 63 and 64, between the cathodes of such tubes, with the junction of the resistors grounded and with a zero-center direct-current meter 81 connected across the terminals thereof. In this latter case, resistors 79 and 80 are preferably by-passed by condensers 83 and 84, respectively. Also, if desired, indicating lamps 69 and 70 may be connected in place of, or in shunt or series with, resistors 75 and 76, respectively.

In considering the operation of the above-described automatic frequency control system, it is first assumed that the radio-frequency channel 12 is tuned precisely to the frequency of the desired signal, that the tunable oscillator of the first frequency changer 13 is tuned precisely to, and is producing oscillations precisely of, such a frequency that the frequency of the first intermediate-frequency carrier wave is located at the center frequency of the first intermediate-frequency channel 14, and that the non-tunable oscillator 24 is producing oscillations of such a frequency that the frequency of the second intermediate-frequency carrier wave is located at the center frequency of the second intermediate-frequency channel 16. To simplify the description of the basic operation of this receiver, the functioning of the previously mentioned optional provisions will, for the moment, be neglected.

Under the conditions thus assumed, the frequency of the second intermediate-frequency carrier wave is as much below the resonant frequency of the sharply tuned circuit 32 as it is above the resonant frequency of the sharply tuned circuit 31. The responses of these tuned circuits are thus equal in magnitude, with the result that equal voltages appear across resistors 37 and 38 and equal negative bias potentials are applied to the control grids of vacuum tubes 63 and 64. Under these conditions, the resistances of the shunts across L_2 and C_2 are equal, the net inductive reactance in the oscillation circuit 50 due to the shunted inductance L_2 is equal to the net capacitive reactance in the oscillation circuit due to the shunted condenser C_2 , the oscillator 24

is operating at its normal frequency, and the second intermediate carrier frequency is exactly at the center frequency of the channel 16.

Assume now that, as a result of any of the foregoing causes, the carrier frequency in the second intermediate-frequency channel 16 tends to deviate from the center thereof; for example, the oscillator frequency of the frequency changer 13 may drift below its correct value for the particular setting of the receiver. To an extent equal to such drift, the frequency of the first intermediate-frequency carrier wave falls below the center frequency of the channel 14, assuming that the frequency of the tunable oscillator is above the frequency of the received signal. To an equal extent, the frequency of the second intermediate-frequency carrier wave tends to fall below the center frequency of the channel 16, assuming that the frequency of the non-tunable oscillator 24 is below the frequency of the second intermediate-frequency carrier wave.

As the frequency of the second intermediate-frequency carrier wave becomes nearer to the resonance frequency of tuned circuit 31 and further from the resonance frequency of tuned circuit 32, the responses of the two circuits become unbalanced correspondingly and unequal negative potentials are developed across resistors 37 and 38. The negative bias potentials applied to the control grids of vacuum tubes 63 and 64 are similarly unbalanced, that applied to the control grid of tube 63 assuming the larger negative value. The resistance of the shunt across L_2 becomes, therefore, greater, and the resistance of the shunt across C_2 becomes less, than their respective resistances under the conditions initially assumed. As a consequence, the effective inductance of L_1 and L_2 in series and the effective capacitance of C_1 and C_2 in series are both increased, and, likewise, the effective inductance and the effective capacitance of the oscillation circuit 50 are correspondingly increased. Oscillator 24 thus operates at a correspondingly decreased frequency. By suitable choice of circuit constants this decrease in frequency of the non-tunable oscillator 24 may be made very nearly to approximate and compensate for the decrease in frequency of the second intermediate-frequency carrier wave which, in the absence of the compensating action of this invention, would occur as a result of the assumed drift of the tunable oscillator. As a result, the second intermediate-frequency carrier wave is maintained very nearly exactly at the center frequency of channel 16. Obviously, in case the frequency of the second intermediate-frequency carrier wave should increase above the center frequency of channel 16, the system would operate in a similar manner but reverse sense.

It will be apparent that, in the event the frequency deviation of the carrier wave in channel 16 is produced by drifting of the non-tunable oscillator 24, or by mistuning of the receiver, or any other cause, the frequency responsive device 26 and the frequency control apparatus 27 will be effective to compensate for such deviation in a similar manner. The final result of this control of the frequency of the non-tunable oscillator 24 is that the second intermediate-frequency carrier wave is maintained very nearly at its normal frequency, i. e., the center frequency of the second intermediate-frequency channel, regardless of all frequency disturbing causes.

In selecting the time constants of the filter sections 71, 73 and 72, 74 (neglecting the addi-

tional filter sections), consideration should preferably be given to the circumstances under which the receiver is used. If the receiver is used for the reception of signals the carrier waves of which are subject to severe fading, the time constants of these two filter sections are preferably equal and sufficiently great to prevent the biases on tubes 63 and 64 from changing materially during a period of fading in which the desired carrier wave becomes too weak to operate the automatic frequency control. In such cases, the time constants may be of the order of 10 to 30 seconds, although the exact value may best be determined by operating conditions. If the receiver is used for the reception of signals the carrier waves of which are not subject to severe fading, the time constants of these two filters may be equal and fairly small, such as of the order of one second or less. If, in such case, the receiver is provided with automatic amplification control (A. V. C.), the time constant of the automatic frequency control (provided by the time constants of the filter sections) is preferably greater—at least double—the time constant of the automatic amplification control. A common time constant for A. V. C. being of the order of one-twentieth of a second, the time constant of the automatic frequency control may, when the signal carrier wave is not subject to severe fading, be of the order of one-tenth to one-fifth of a second.

When the time constant of the automatic frequency control is small, the control tends to assist the tuning of the receiver to a desired signal by compensating for inaccurate tuning by the user thereof. When the time constant of the automatic frequency control is large, it is highly desirable that the user initially tune the receiver to the desired signal with accuracy, thus assuring the user full benefit of the automatic frequency control during the continued reception of such signal.

In certain cases, provision may be made by which the time constant of the automatic frequency control is subject to adjustment by the user of the receiver. In such cases, for example, the initial tuning of the receiver to a desired signal may be made utilizing a small time constant in the automatic frequency control, with subsequent reception of such signal utilizing a large time constant in the automatic frequency control. This provision is embodied in the previously mentioned additional filter sections 71a, 73a and 72a, 74a and the equipment related thereto. The switches 85 and 86 are normally in the positions illustrated and render the additional filter sections effective, thereby imparting a large time constant to the automatic frequency control. Preliminary to tuning the receiver by the tuning knob 88, the user automatically causes switches 85 and 86 to be actuated to render the additional filter sections ineffective, thereby reducing the time constant of the automatic frequency control to a smaller value. During the tuning of the receiver the additional filter sections are maintained ineffective and they resume their effectiveness only when the user ceases to tune the receiver.

It is to be noted that, inasmuch as the carrier wave in the first intermediate-frequency channel 14 is not maintained at a fixed frequency, the filter of channel 14 is preferably rather broadly or non-critically selective so that there may be no substantial attenuation therein of the carrier wave and its side bands of modulation as

the frequency of such carrier wave deviates somewhat from the center frequency of channel 14. In contrast, the filter of channel 16 may be, and preferably is, very selective or critical, since the frequency of the carrier wave therein is maintained nearly constant. If desired, channel 16 may be provided with any well-known arrangement providing variable selectivity.

It is also to be noted that the automatic frequency control of the second intermediate-frequency carrier wave as described above is independent of its amplitude. Thus, if the amplitude of the carrier wave increases or decreases from a given value, the negative bias potentials applied to the control grids of tubes 63 and 64 are varied simultaneously in the same sense and to a similar extent, and the effective inductance of L_2 and the effective capacitance of C_2 are correspondingly varied but in opposite senses. The resulting changes in the effective reactances of the arms of the oscillation circuit are thus equal and opposite and the resonant frequency of oscillation circuit 50, therefore, is substantially unchanged.

In accordance with a feature of the invention, the automatic frequency control circuits may be designed to operate either more or less critically, as desired. More particularly, three different classes or types of operation may be obtained, which may be indicated as Classes A, B and C by analogy to the well-known Class A, B and C amplification. In Class A operation, for the control elements upon which the control voltages are impressed, initial bias voltages are provided which are substantially less than the value required to cut off the plate currents of the respective tubes, and the variable control biases are of such magnitude and polarity that the resultant grid bias is at all times less than the cut-off value. Here, therefore, the operation of the frequency control is critical and responds to all variations in the control voltages from their normal values. In Class B operation, an initial negative biasing voltage is utilized which is approximately that required to cut off the plate current; and in Class C operation an initial negative biasing voltage is employed which is substantially greater than the cut-off value. The incremental or control biasing voltages in these last two instances are applied positively to the control elements so as to reduce the resultant grid bias to values less than the cut-off value. In Class B operation, the initial bias voltage is such that the effect of a small incremental or control voltage is much less than in Class A. In Class C operation, the initial bias voltage is excessive, so that the incremental or control voltages are quite ineffective except when they exceed a predetermined value. Hence, the Class B and Class C types of operation are less critical than Class A operation, to the respective extents of the excess of initial biasing voltages employed.

It will be apparent that the embodiment of the invention shown in Fig. 1 may be considered as effecting Class A operation, in accordance with the meaning of this term as hereinabove defined. In Fig. 4 there is illustrated a modified form of the control apparatus of the invention whereby either Class B or C operation may be obtained. Excepting for the differences hereinafter specifically described, the circuits shown in Fig. 4 are identical with the corresponding circuits of Fig. 1. Corresponding parts are given the same reference numerals in the two figures and the detailed description of such parts is not repeated.

While, in Fig. 4, only the frequency responsive device 26a and the frequency control apparatus 27a, which correspond to the device 26 and apparatus 27, respectively, are shown, it will be understood that these circuits are adapted to be included in a receiver in substantially the same manner as the corresponding circuits of Fig. 1. Thus, the leads from the second intermediate-frequency channel 16 will be connected to the frequency responsive device by way of the connections 92 and the leads from the oscillation circuit 59 will be connected to the frequency control apparatus by way of the connections 93, these connections being indicated in both figures.

In the modified form of the invention, a biasing battery 94 is provided in the common lead of the cathode circuits of the tubes 63 and 64 and, as shown in the drawings, may be connected between ground and the junction of the resistors 79 and 80. This battery serves to apply a substantially fixed initial biasing voltage, above the relatively small initial bias voltage developed across the resistors 79 and 80 by the space currents of the tubes 63 and 64, respectively, as in the embodiment of Fig. 1. The voltage supplied by the battery 94 may be made sufficient to cut off nearly or completely the plate currents of the tubes 63 and 64. With this condition, it is necessary that the incremental or control bias voltages supplied by the frequency responsive device 26a be applied to the control grids of the tubes 63 and 64 in a positive sense in order that the resultant negative bias voltage applied to each tube be reduced from the cut-off value. For this purpose, two further changes are made in the circuit of Fig. 4 over that of Fig. 1. The circuit connections to each of the rectifiers 33 and 34 are reversed. The bias connections between the device 26a and the apparatus 27a are then interchanged so that the rectifier 33, in this embodiment, controls the tube 64 and the rectifier 34 controls the tube 63.

These modifications result in substantially the same frequency controlling action as described with reference to Fig. 1, but, instead of obtaining Class A control, as above defined, either Class B or Class C control may be obtained. That is, this embodiment has the additional advantage of less critical operating conditions. More particularly, the frequency control will not be effective on weak signals, as for instance signals which are too weak to operate the automatic volume control; there will be less response to small accidental frequency variations and the constants of the control circuits need not be critically proportioned. If the initial bias voltages on the tubes 63 and 64 are made approximately that required to cut off the plate current, Class B operation will be obtained, while if the initial bias voltage is substantially greater than that required to cut off the plate current, still less critical, or Class C, operation is obtained.

An inherent characteristic of the arrangements above described is that the frequency control is substantially unaffected by voltage fluctuations, such as those of the source supplying operating voltages for the frequency controlling tubes 63 and 64. This condition obtains because such voltage fluctuations are applied similarly to both tubes and tend to cause substantially equal and opposite effects on the frequency of the oscillator. A particular advantage of this property of the circuit resides in the fact that it is not sensitive to hum ripple components on the power voltages and, likewise, is not sensitive to audio-frequency

coupling through the direct-current circuits. The former would be evidenced by hum in the receiver output when the receiver was slightly detuned, so as to convert any hum modulation to modulation of the carrier. The latter would be evidenced as "motor boating" when the receiver was slightly detuned on either side. Both of these effects would be highly detrimental if they were not obviated, as above described, by the present invention.

Considering now the previously mentioned optional provisions, one or more of such provisions are preferably utilized to provide indicating means to aid in accurate tuning of a receiver incorporating automatic frequency control. Although precision tuning is not necessary in order to obtain satisfactory reception with such a receiver, it is sometimes advantageous and aids in obtaining the highest quality reception possible and in avoiding loss or impairment of the received signal during the operation of the receiver.

Illustrative of such optional indicating means is the meter 43, shown in greater detail in Fig. 2, together with its associated resistors 41 and 42. The direction and extent of the deflection of pointer 38 of such meter from its zero-center position is dependent upon the algebraic sum of the voltages across the two resistors 41 and 42. These voltages are severally dependent upon the magnitudes of currents rectified by the respective tubes 33 and 34, which, in turn, are dependent upon the magnitudes of the responses of the respective tuned circuits 31 and 32. When the frequency of the second intermediate-frequency carrier wave is at the center frequency of the channel 16, the responses of tuned circuits 31 and 32 are equal in magnitude, so that the voltages across resistors 41 and 42 are equal and opposite and the pointer 38 remains at its zero-center position, as illustrated in Figs. 1 and 2. When the frequency of the second intermediate-frequency carrier wave tends to deviate from the center frequency of the channel 16, the voltages across resistors 41 and 42 become unbalanced in sense and extent corresponding to such frequency deviation, which deviation is indicated by the device 43. As the receiver is retuned to bring the frequency of the second intermediate-frequency carrier wave to the center frequency of the channel 16, independently of the automatic frequency control, the voltages across resistors 41 and 42 are rebalanced so that the pointer 38 gradually returns to its zero-center position.

Each of the indicating means comprising zero-center meter 77 and resistors 75 and 76, and that comprising zero-center meter 81 and the resistors 79 and 80, is similar in principle and operation to the indicating means comprising meter 43 and resistors 41 and 42, the only difference residing in the fact that the currents flowing in the resistors of the former two indicating means are the space currents of the tubes 63 and 64 instead of the currents rectified by the tubes 33 and 34. Inasmuch as the space currents of tubes 63 and 64 are generally of greater magnitude than the currents rectified by the tubes 33 and 34, it may be desirable in many cases to utilize either of the indicating means 77 or 81 in preference to the indicating means 43. High-frequency currents from oscillation circuit 50 are prevented from passing through resistances 75 and 76 by means of the chokes 67 and 68, and are shunted around resistances 79 and 80 by means of the condensers 83 and 84.

An alternative form of indicating means to aid

in tuning the receiver accurately to the frequency of the desired signal wave comprises the two indicating lamps 69 and 70, connected across resistors 75 and 76, respectively. When the frequency of the second intermediate-frequency carrier wave is located at the center frequency of the channel 16, the voltage across the two lamps are equal in magnitude, with the result that they operate with equal brilliance. When the frequency of the second intermediate-frequency carrier wave tends to deviate from the center frequency of the channel 16, the voltages across the lamps become unbalanced in sense and to an extent corresponding to such deviation, which is indicated by the relative brilliance of the lamps.

A simple and convenient arrangement for enabling the brilliance of the lamps 69 and 70 to be compared is illustrated in Fig. 3. A suitable opaque panel 90, such as the panel of the receiver, is provided with a translucent window 91, behind which are mounted the two lamps 69 and 70 preferably with a light screen 95 extending therebetween.

It is to be understood that the indicating means comprising lamps 69 and 70 may be employed in lieu of any of the indicating means which include meters 43, 77 or 81. Each of the illustrated indicating means indicates both the extent and the sense of the frequency deviation. If desired, however, suitable indicating means, indicating only the sense of the frequency deviations of the second intermediate-frequency carrier wave, may be substituted for any or all of the indicating means, where such are satisfactory. It will be apparent that the indicating means herein described may be used with receivers in which automatic frequency control is obtained by apparatus or methods other than herein described.

It is to be noted that, while tubes 63 and 64 of the frequency control apparatus 27 are shown and described as having their space paths effectively shunted, respectively, across inductance L_2 and capacitance C_2 , in certain cases tubes 63 and 64 may be associated with the two reactance arms of the oscillation circuit 50 in other manners. The basic characteristic of such association is that the effective value of each of the two reactance arms is subject to individual control by the tube associated therewith.

Attention is directed to the fact that, although the oscillator in the superheterodyne receiver which is controlled by device 26 and frequency control apparatus 27 is preferably a non-tunable oscillator, such as the second oscillator of a triple detection superheterodyne, any other oscillator of a superheterodyne receiver may be so controlled, including the tunable oscillator. Thus, automatic frequency control of the tunable oscillator of a double detection superheterodyne receiver may be employed if the resulting sacrifice in the uniformity of effectiveness in the automatic frequency control throughout the tunable range of the receiver is not objectionable.

While the invention has been described in connection with a superheterodyne receiver and as concerned with maintaining an intermediate-frequency carrier wave in such a receiver at a constant frequency, the invention is of more general application and is directed broadly to controlling and/or varying the resonant frequency of a tuned system without physical alteration of the reactance elements, per se, of such a system.

While I have described what I at present con-

sider the preferred embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from my invention, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What is claimed is:

1. The method of selective reception of signal-modulated carrier waves which includes: selectively tuning to any desired one of a plurality of modulated signal waves; generating and combining therewith a wave of approximately constant but incidentally variable frequency separation from the carrier frequency thereof to produce a modulated carrier wave of first intermediate frequency; broadly selecting the carrier wave of first intermediate frequency corresponding to said desired signal wave to permit normal deviations in the frequency of said carrier wave without substantial attenuation of the modulation frequencies thereof; generating and combining with said selected first intermediate-frequency carrier wave a second wave of substantially constant frequency to produce a modulated carrier wave of second intermediate frequency; modifying the frequency of said second generated wave within a range of a small per cent of its mean value in accordance with, and responsive to, predetermined deviations of the carrier frequency of said second intermediate-frequency wave from its normal frequency to restore it thereto; sharply selecting the carrier wave of second intermediate frequency corresponding to said desired signal wave; and thereafter converting and utilizing said modulated carrier wave of second intermediate frequency.

2. A tunable radio receiver comprising; a tunable first frequency changer for converting a selected signal wave into a first modulated intermediate-frequency carrier wave of approximately constant frequency; broadly selective means for selecting said first intermediate-frequency carrier wave while permitting normal deviations in the frequency thereof without substantial attenuation of the modulation frequencies thereof; an untunable second frequency changer for converting said selected first intermediate-frequency carrier wave into a second modulated intermediate-frequency carrier wave subject to minor deviations from a given normal frequency; means responsive to said deviations of said second intermediate-frequency carrier wave for modifying the tuning of said second frequency changer to restore the frequency of said second intermediate-frequency carrier wave to said given frequency; sharply selective means for selecting said second intermediate-frequency carrier wave; and means for converting and utilizing said selected second modulated intermediate-frequency carrier wave.

3. A tunable superheterodyne receiver comprising; a tunable frequency changer for converting a selected signal wave into a first modulated intermediate-frequency carrier wave of approximately constant frequency; a first intermediate-frequency channel for broadly selecting said first intermediate-frequency carrier wave while permitting normal deviations in the frequency thereof without substantial attenuation of the modulation frequencies thereof; an untunable second frequency changer for converting said selected first intermediate-frequency carrier wave into a second modulated intermediate-frequency carrier wave subject to minor deviations from a given normal frequency; a second

intermediate-frequency channel for sharply selecting and amplifying said carrier waves of second intermediate frequency, said second channel having a center frequency equal to said normal frequency; a device responsive to deviations in frequency of said second intermediate-frequency carrier wave from said center frequency; and means controlled by said device for controlling the frequency of said untunable frequency changer to maintain the frequency of said second intermediate-frequency carrier wave at said center frequency.

4. In a tuned circuit having an inductive arm and a capacitive arm effectively in parallel, means for controlling the resonant frequency of such circuit comprising a pair of conductive paths individually effectively connected, respectively, across at least a portion of said inductive arm and across at least a portion of said capacitive arm, and means for adjusting the resistances of said paths in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

5. In combination; a tuned circuit comprising two arms effectively in parallel each including at least two impedance elements, said arms including, respectively, reactance elements of opposite type; and means for controlling the resonant frequency of said circuit without varying the physical values of any of said elements, comprising a pair of conductive paths individually effectively connected, respectively, across a reactance element of one of said arms and across a reactance element of the other of said arms, and means for adjusting the resistances of said paths to like extent but in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

6. In combination; a tuned circuit comprising two arms each including a plural and equal number of impedance elements of which at least two are reactance elements of opposite type, one in each of said arms, said impedance elements being proportioned and disposed so that said circuit is electrically symmetrical with respect to its points of maximum voltage difference; and means for controlling the resonant frequency of said circuit without varying the physical values of any of said impedance elements, comprising a conductive path connected in shunt with a portion of each of said arms including one of said reactance elements, corresponding terminals of said paths being electrically corresponding points of said arms, and means for adjusting the resistances of said paths in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

7. In combination; a tuned circuit containing at least two inductance and at least two capacitance elements disposed and proportioned so that said circuit is electrically symmetrical with respect to its points of maximum voltage difference, across which points the output of said circuit is derived; and means for controlling the resonant frequency of said circuit, comprising, two vacuum tubes having their space paths effectively connected respectively across only one inductance element and only one capacitance element of said resonant circuit, corresponding terminals of said one inductance and said one capacitance elements being electrically corresponding points of said arms, and means for controlling the conductance of said tubes in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

8. In combination; a tuned circuit comprising in parallel, two serially-connected inductance elements and two serially-connected capacitance elements; and means for controlling the resonant frequency of such circuit without varying the actual physical value of any of said elements, comprising two variable resistance paths, one effectively connected across one of said inductance elements and the other effectively connected across one of said capacitance elements, said paths normally having substantially the same resistance, and means for varying the resistances of said paths in opposite senses but to substantially like extents to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

9. In combination; a tuned circuit comprising in parallel, two serially-connected inductance elements of substantially different inductance and two serially-connected capacitance elements of substantially different capacitance, the inductance element of smaller inductance and the capacitance element of larger capacitance being disposed in corresponding portions of the two parallel arms; and means for controlling the resonant frequency of such circuit without varying the actual physical value of any of said elements, comprising two conductive paths individually connected across said inductance element of smaller inductance and said capacitance element of larger capacitance, and means for adjusting the resistances of said paths in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

10. In combination; a tuned circuit having two terminals of which one is effectively grounded, and containing, in parallel between said terminals, two series-connected inductance elements and two series-connected capacitance elements, the inductance and capacitance elements with one terminal thereof effectively grounded each having at the normal resonant frequency of said circuit a reactance which is substantially equal in magnitude to the reactance of the other and which is a minor fraction of the total reactance of like kind in said circuit; and means for controlling the resonant frequency of said circuit, comprising, two vacuum tubes having their space paths effectively connected respectively across said inductance element and said capacitance element that have one terminal thereof effectively grounded, and means for controlling the conductances of said tubes in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

11. In combination, a tuned circuit having inductive and capacitive arms, and means for varying the resonant frequency thereof over a relatively small fraction of its normal resonant frequency in response to relatively small variations in frequency of a control wave from a given frequency and substantially independently of the amplitude of such control wave, comprising; two control elements energized with said control wave, the responses of said elements varying in opposite senses over said relatively small frequency variations of said control wave; and a pair of control means individually responsive to said control elements and individually cooperating with the arms of said tuned circuit to vary the effective circuit values of said two arms in the same sense with frequency, and in opposite senses with amplitude, of said control wave.

12. In combination, a tuned circuit having two

arms including not less than four impedance elements of which at least two are reactance elements of opposite type disposed in the respective arms of said circuit, and means for varying the resonant frequency of said tuned circuit in response to relatively small variations of a control wave from a given frequency and substantially independently of the amplitude of such control wave, comprising; two control elements energized with said control wave, the responses of said elements varying in opposite senses over said relatively small frequency variation of said control wave; and a pair of independent similar control circuits connected respectively from said control elements to the inductive and capacitive reactance arms of said tuned circuit, each of said control circuits including a bias controlled vacuum tube having at least three electrodes of which two are effectively connected across said reactance element of the associated arm and including means for deriving a bias voltage the magnitude of which varies in accordance with the response of the associated control element, and for applying said derived bias voltage to the associated vacuum tube, said control circuit means and said bias deriving and applying means being relatively proportioned to vary the effective circuit values of the two reactance arms of said tuned circuit in the same sense with frequency, and in opposite senses with amplitude, of said control wave.

13. In combination with a tuned circuit having inductance and capacitance elements and normally resonant at a predetermined frequency, means for controlling the resonant frequency of such circuit without varying the physical values of any of said elements, comprising: conductive paths effectively in shunt respectively to an inductance element and a capacitance element of said circuit; a pair of auxiliary tuned circuits; means for energizing said auxiliary tuned circuits with a frequency having a fixed relation to the resonant frequency of said tuned circuit, said auxiliary tuned circuits being sharply resonant, respectively, at frequencies just above and just below the normal value of said related frequency; and means for controlling in the same sense both the effective capacitance and the effective inductance in said tuned circuit in accordance with the responses of said auxiliary tuned circuits.

14. In combination with a tuned circuit having inductance and capacitance elements and normally resonant at a predetermined frequency, means for controlling the resonant frequency of said circuit without varying the physical values of any of said elements, comprising: two vacuum tubes, each with a control grid, having their space paths effectively in shunt respectively to an inductance element and a capacitance element of said circuit; a pair of auxiliary tuned circuits; means for energizing said auxiliary tuned circuits with a frequency having a fixed relation to the resonant frequency of said tuned circuit, said auxiliary tuned circuits being sharply resonant, respectively, at frequencies just above and just below the normal value of said related frequency; means for deriving rectified bias potentials varying in accordance with the responses of said auxiliary tuned circuits; and means for applying said potentials to the control grids of said tubes with the same polarity whereby both the effective capacitance and effective inductance of said tuned circuit are varied in the same sense.

15. In combination, an oscillation generator including a frequency-determining circuit having an inductive arm and a capacitive arm effectively

in parallel, and means for controlling the oscillation frequency thereof comprising: a pair of conductive paths individually connected, respectively, across at least a portion of said inductive arm and across at least a portion of said capacitive arm of said circuit; and means dependent on the oscillation frequency of said generator for controlling the resistances of said paths in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit.

16. In combination, an oscillation generator including a frequency-determining circuit containing inductive and capacitive arms, and means for controlling the oscillation frequency thereof, comprising: conductive paths individually effectively connected in shunt with an inductance element and a capacitance element of said circuit; and means responsive to the frequency of the output of said oscillation generator for varying the conductances of said paths in substantially equal amounts but in opposite senses and responsive to the magnitude of the output of said oscillation generator for varying the conductances of said shunts in substantially equal amounts but in the same sense, whereby only variations in the frequency of the output of said oscillation generator influence the frequency produced by said oscillation generator.

17. In a frequency-changing system in which a first selected input frequency and a second selected input frequency are arranged to produce a third frequency bearing a predetermined relation to said two input frequencies, and in which the second input frequency is derived from an oscillation generator having inductance and capacitance elements in a frequency-determining circuit therefor; means for maintaining said third frequency at a predetermined frequency notwithstanding incidental minor variations in frequency of either or both of said input frequencies from their respective selected frequencies, comprising; two control elements energized with the output of said system, the responses of said control elements varying in opposite senses with variation of said output from said predetermined frequency; and means for controlling in the same sense the effective capacitance in the frequency-determining circuit in accordance with the response of one of said control elements and the effective inductance in said frequency-determining circuit in accordance with the responses of the other of said control elements.

18. A tunable radio receiver comprising; a tunable first frequency changer for converting a selected signal wave into a first modulated intermediate-frequency carrier wave of approximately constant frequency; an untunable second frequency changer for converting said first intermediate-frequency carrier wave into a second modulated intermediate-frequency carrier wave subject to minor deviations from a given normal frequency, said second frequency changer including an oscillation generator having a frequency-determining circuit having an inductive arm and a capacitive arm effectively in parallel; a pair of conductive paths individually effectively connected, respectively, across at least a portion of said inductive arm and across at least a portion of said capacitive arm; means responsive to said deviations of said second intermediate-frequency carrier wave for adjusting the resistances of said paths in opposite senses to alter simultaneously in the same sense the effective inductance and capacitance of said circuit so

as to modify the action of said second frequency changer to restore the frequency of said second intermediate-frequency carrier wave to said given frequency; and means for converting and utilizing said second modulated intermediate-frequency carrier wave.

19. In a superheterodyne radio receiver: tunable means for selecting a desired signal wave subject to severe fading and converting it to an intermediate-frequency carrier wave subject to minor deviations from a given normal frequency; a critically selective intermediate-frequency filter whose pass band includes said given normal frequency; a device responsive to deviations in frequency of said intermediate-frequency carrier wave from said given normal frequency; means controlled by said device for controlling said converting means to compensate for said deviations and thereby cause said carrier wave to equal said normal frequency; means responsive to said control means indicating the sense of the control exercised thereby; time-delay means in said control means affecting both said control means and said indicating means and of sufficient magnitude to continue the control exercised by the control means during those periods of fading in which the carrier wave of the desired signal is of insufficient magnitude to operate said control means; and means operable when tuning said receiver for reducing to a smaller order of magnitude the time delay provided by said delay means, thereby to facilitate the tuning of said receiver with the assistance of said control means and said indicating means.

20. The method of selective reception of signal-modulated carrier waves which includes: selecting the desired modulated signal wave; generating and combining therewith a wave of approximately constant but incidentally variable frequency separation from the carrier frequency thereof to produce a modulated carrier wave of first intermediate frequency; selecting the carrier wave of first intermediate frequency corresponding to said desired signal wave; generating and combining with said selected first intermediate-frequency carrier wave a second wave of substantially constant frequency to produce a modulated carrier wave of second intermediate frequency; modifying the frequency of said second generated wave within a range of a small per cent of its mean value in accordance with, and responsive to, deviations in frequency above a predetermined magnitude, of the carrier of said second intermediate-frequency wave from its normal frequency to restore it thereto; and thereafter converting and utilizing said modulated carrier wave of second intermediate frequency.

21. A tunable radio receiver comprising: a tunable first frequency changer for converting a selected signal wave into a first modulated intermediate-frequency carrier wave of approximately constant frequency; an untunable second frequency changer for converting said first intermediate-frequency carrier wave into a second modulated intermediate-frequency carrier wave subject to minor deviations from a given normal frequency; means responsive to said deviations in frequency, above a predetermined magnitude, for modifying the tuning of said second frequency changer to restore the frequency of said second intermediate-frequency carrier wave to said given frequency; and means for converting and utilizing said second modulated intermediate-frequency carrier wave.

22. In a tuned circuit having an inductive

arm and a capacitive arm effectively in parallel, means for controlling the resonant frequency of such circuit comprising a pair of conductive paths individually effectively connected, respectively, across at least a portion of said inductive arm and across at least a portion of said capacitive arm, and means for selectively adjusting the resistance of either of said paths in the same sense selectively to alter in opposite senses the effective inductance or capacitance of said circuit.

23. In combination; a tuned circuit containing at least two inductance and at least two capacitance elements disposed and proportioned so that said circuit is electrically symmetrical with respect to its points of maximum voltage difference, across which points the output of said circuit is derived; and means for controlling the resonant frequency of said circuit, comprising, two vacuum tubes having their space paths effectively connected respectively across only one inductance element and only one capacitance element of said resonant circuit, corresponding terminals of said one inductance and said one capacitance elements being electrically corresponding points of said arms, and means for selectively controlling the conductance of either of said tubes in the same sense selectively to alter in opposite senses the effective inductance or capacitance of said circuit.

24. In combination; a tuned circuit having two terminals of which one is effectively grounded, and containing, in parallel between said terminals, two series-connected inductance elements and two series-connected capacitance elements, the inductance and capacitance elements with one terminal thereof effectively grounded each having at the normal resonant frequency of said circuit a reactance which is substantially equal in magnitude to the reactance of the other and which is a minor fraction of the total reactance of like kind in said circuit; and means for controlling the resonant frequency of said circuit, comprising, two vacuum tubes having their space paths effectively connected respectively across said inductance element and said capacitance element that have one terminal thereof effectively grounded, and means for selectively controlling the conductance of either of said tubes in the same sense thereby selectively to alter in the opposite senses the effective inductance or capacitance of said circuit.

25. In combination; a tuned circuit having two terminals of which one is effectively grounded, and containing, in parallel between said terminals, two series-connected inductance elements and two series-connected capacitance elements, the inductance and capacitance elements with one terminal thereof effectively grounded each having at the normal resonant frequency of said circuit a reactance which is substantially equal in magnitude to the reactance of the other and which is a minor fraction of the total reactance of like kind in said circuit; and means for controlling the resonant frequency of said circuit, comprising, two vacuum tubes having their space paths effectively connected respectively across said inductance element and said capacitance element that have one terminal thereof effectively grounded, means for negatively biasing said tubes at least to approximately plate current cutoff, and means for selectively applying in a positive sense a variable control bias voltage to either of said tubes for controlling their conductances in the same sense thereby selectively to alter in the opposite senses the

effective inductance or capacitance of said circuit when said variable bias voltages exceed a predetermined value sufficient to overcome the cut-off effect of said fixed bias voltage.

- 5 26. In combination, an oscillation generator including a frequency-determining circuit having an inductive arm and a capacitive arm effectively in parallel, and means for controlling the oscillation frequency thereof comprising: a
10 pair of conductive paths individually connected, respectively, across at least a portion of said inductive arm and across at least a portion of said capacitive arm of said circuit; and means dependent on the oscillation frequency of said
15 generator for selectively controlling the resistance of either of said paths in the same senses thereby selectively to alter in the opposite senses the effective inductance or capacitance of said circuit.
- 20 27. In combination, an oscillation generator for generating oscillations, means for controlling the frequency of said oscillations comprising two vacuum tubes so connected in circuit with said generator that similar control of said tubes produces equal and opposite effects on the frequency
25 of said oscillations, and means for simultaneously controlling said tubes in equal and opposite

senses to produce a cumulative shift of the frequency of said oscillations.

28. In combination, an oscillation generator including a plurality of reactance elements for generating oscillations and means for controlling
5 the frequency of said oscillations comprising two vacuum tubes each individually connected in circuit with one of said reactance elements, the connections between each tube and its associated reactance element being such that similar
10 control of said tubes produces equal and opposite effects on the frequency of said oscillations, and means for simultaneously controlling said tubes in equal and opposite senses to produce a cumulative shift of the frequency of said oscillations.
15

29. In combination, an oscillation generator for generating oscillations, means for controlling the frequency of said oscillations comprising two vacuum tubes so connected in circuit with said generator that similar control of said tubes produces equal and opposite effects on the frequency
20 of said oscillations, and means for selectively controlling said tubes in the same sense, selectively to shift in opposite senses the frequency of said oscillations.
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DISCLAIMER

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Hereby enters this disclaimer to claims 1, 2, and 3 of said patent.
[*Official Gazette* October 11, 1938.]

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