June 22, 1937. W. A. MacDONALD 2,084,647

AUTOMATIC FREQUENCY CONTROL

Filed Sept. 4, 1936 2 Sheets-Sheet 1

FIG. 1.

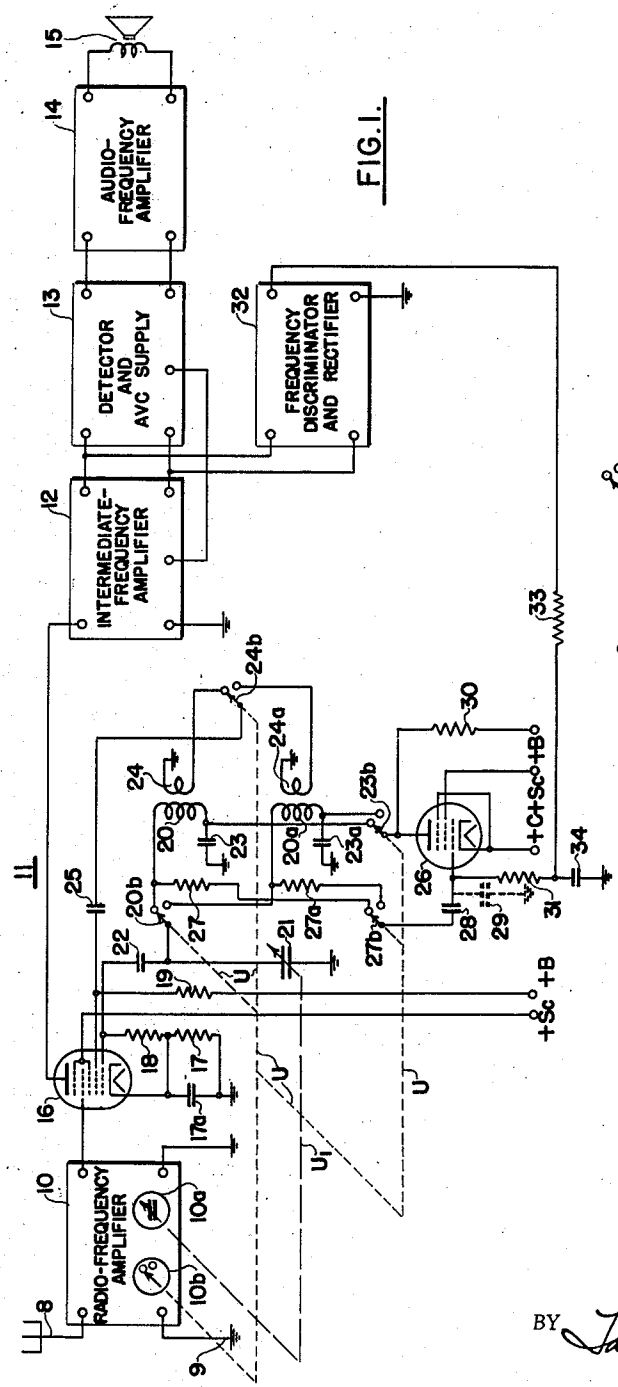
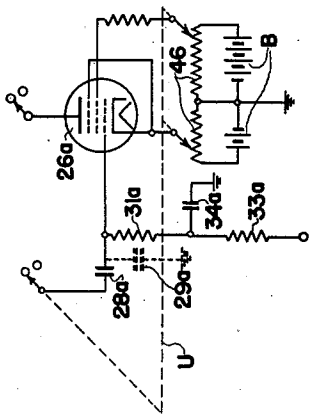


FIG. 5.



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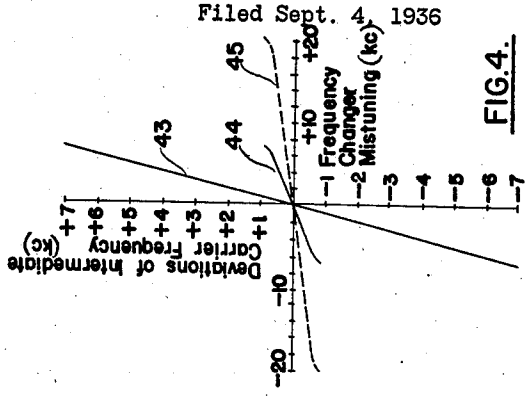


FIG.4.

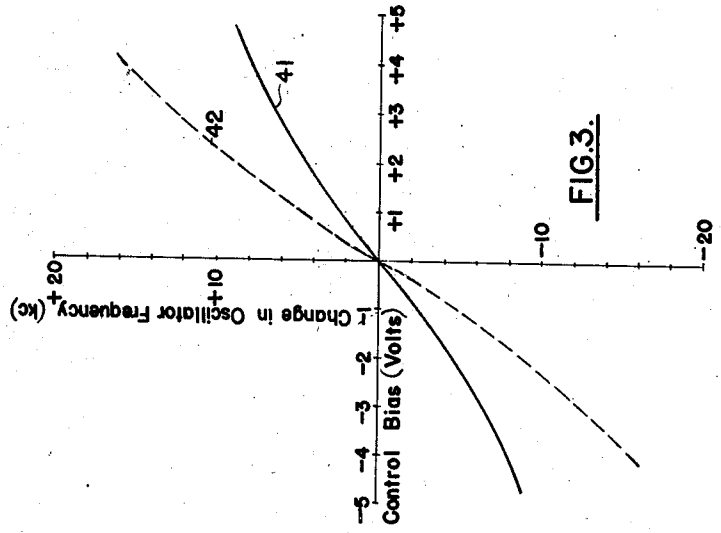


FIG.3.

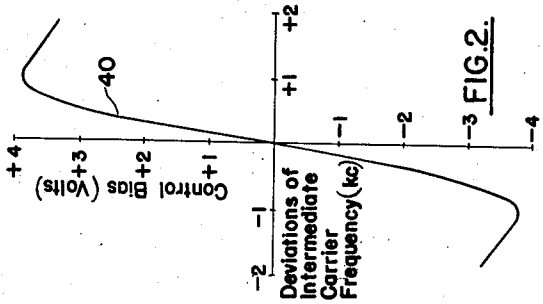


FIG.2.

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UNITED STATES PATENT OFFICE

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AUTOMATIC FREQUENCY CONTROL

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Application September 4, 1936, Serial No. 99,335

16 Claims. (Cl. 250—20)

This invention relates to multi-band modulated-carrier signal receivers of the superheterodyne type, and particularly to provisions for automatically controlling the frequency derived by the tunable frequency-changing means of such a receiver.

According to conventional radio broadcasting practice, each program is transmitted on a carrier frequency having sidebands of modulation usually extending five or more kilocycles on either side thereof, and the various broadcasting stations are allotted different carrier frequencies which are spaced, usually uniformly, throughout the different ranges or bands in the frequency spectrum. In a conventional superheterodyne receiver of the multi-band type, there is included as an element of the band-selecting means frequency-changing means adjustable to select any one of several bands of the frequency spectrum and tunable over each selected band to derive from any desired signal thereof an intermediate-frequency signal having a carrier which is normally of a predetermined frequency. An intermediate-frequency channel is provided at the output of the frequency-changing means and designed selectively to pass a band of frequencies including the intermediate-frequency signal carrier and its modulation sidebands, the normal or predetermined intermediate-carrier frequency being equal to the mean resonant frequency of the band passed by this channel.

For optimum selectivity and fidelity of reproduction the intermediate-frequency carrier should always be maintained at or near its normal or predetermined frequency, that is, it should be located near the center of the band of frequencies passed by the intermediate-frequency selector circuits. As is well understood in the art, however, the frequency-changing means is subject to mistuning, due to incorrect tuning adjustments by the operator, to drift in the frequency of the local oscillations produced in the frequency-changing means, or to other causes, and such mistuning causes deviations in the intermediate-frequency carrier from its normal or predetermined frequency, thereby impairing the fidelity of reproduction to the extent of the deviations. For various reasons, including the fact that the same percentage mistuning of the frequency-changing means constitutes a substantially greater actual deviation in frequency in kilocycles at higher frequencies than at lower frequencies, the extent of the mistuning is likely to be substantially greater at the higher than at the lower frequency bands. It is desirable, therefore, that the frequency-changing means be automatically controlled so as to reduce the intermediate-frequency carrier deviations above referred to, and further that the range of such control be varied in accordance with the frequency band selected to afford control over wider frequency ranges at the higher frequency bands. Heretofore, certain frequency control arrangements have been devised for automatically reducing the above-described frequency deviations. Such arrangements, however, have not been entirely satisfactory in that the desired ranges of frequency control for the several frequency bands selected could not be readily obtained, in general these ranges varying within such wide limits for the high-frequency bands as to render the frequency control practically inoperative.

It is a primary object, therefore, of the present invention to provide an improved automatic-frequency control for the frequency changer of a multi-band modulated-carrier signal receiver, whereby any preselected ranges of control may be obtained for the several frequency bands which may be received.

More particularly, it is an object of the present invention to provide, in a modulated-carrier signal receiver of the multi-band type, an improved system for controlling the resonant frequency of a tunable oscillation circuit of the frequency-changing means in such receiver, independently of the main tuning means of the circuit and in response to deviations from a predetermined normal frequency of the intermediate frequency developed by the frequency-changing means for minimizing such deviations and for providing ranges of control varying in accordance with the frequency band selected in a preselected manner.

In accordance with a preferred embodiment of the present invention, a multi-band modulated-carrier signal receiver of the superheterodyne type includes the usual frequency-changing means adjustable for selecting any one of a plurality of frequency bands and tunable over the selected band to derive from any desired signal thereof an intermediate-frequency signal having a carrier which is normally of a predetermined frequency. The intermediate-frequency signal is subject to deviations within narrow limits from its predetermined carrier frequency due to the factors discussed above. Control means, independent of the main tuning control of the frequency-changing means and responsive to the intermediate-frequency signal deviations within a predetermined range, are provided for so adjust-

ing the tuning of the frequency-changing means as to minimize these deviations. In order to procure the proper ranges of frequency control for the several frequency bands selected, means are provided for varying the effectiveness and the range of the frequency control means in accordance with, but at a lesser rate than directly proportional to, the mean frequency of the selected band. This rate of variation is preferably within the limits of the one-third power and the two-thirds power of the mean frequency of the band selected as, for example, at a rate of the order of the square root of the mean frequency of the band selected.

In a specific form of the invention hereinafter described, the receiver includes frequency discriminating means for developing a control bias voltage which corresponds in polarity and amplitude to frequency deviations of the intermediate-frequency carrier from its normal frequency within a predetermined range. This voltage is utilized to control the mutual conductance of a vacuum tube which is so connected in circuit with the oscillation circuit of the frequency-changing means and which has such characteristics relative to the constants of its associated circuit as to simulate a reactive impedance in this circuit, effective to cause substantially equal variations of the resonant frequency of the circuit for all frequencies of a given band for equal variations of its mutual conductance. The variation in bias voltage thus effects such adjustments of the intermediate frequency as to minimize the deviations thereof from its normal frequency. The constants of the tube circuits, however, are arranged to be so adjusted by unicontrol with the frequency band-selecting means of the receiver that the effectiveness or sensitivity of the control means is increased in accordance with the mean frequency of the selected band, providing wider ranges of frequency correction at the higher than at the lower frequency bands for any given maximum permissible deviation of the intermediate frequency.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings, Fig. 1 is a circuit diagram, partly schematic, of a complete superheterodyne radio receiver embodying the present invention; Figs. 2, 3, and 4 are graphs representing certain operating characteristics of the circuit shown in Fig. 1 to aid in the understanding of the invention; and Fig. 5 is a fragmentary circuit diagram illustrating a modified form of the invention.

Referring now more particularly to the drawings, there is shown schematically a superheterodyne receiver including a tunable radio-frequency amplifier **10** connected to an antenna **8** and ground **9**. Connected in cascade with the radio-frequency amplifier **10**, in the order named, are a tunable frequency changer indicated generally at **11**, an intermediate-frequency amplifier **12**, a detector and automatic amplification control or a-v-c supply **13**, an audio-frequency amplifier **14**, and a sound reproducer or loud-speaker **15**. The a-v-c supply may be connected by a suitable lead to the control grids of the tubes in the amplifier **12** in conventional manner. In accordance with the usual design of multi-band receivers, each of the tunable circuits of the radio-frequency amplifier **10** and frequency changer **11** includes a plurality of reactance elements of different values selectively connectible, by a frequency switch, in circuit with a tuning condenser to form a closed circuit for selecting any desired frequency band, each circuit being tunable by its respective tuning condenser over the selected band to receive any desired signal thereof. The switches and tuning condensers of the amplifier **10** and frequency changer **11** are ganged for unicontrol, as will be presently more fully described. The frequency changer **11**, including the tunable oscillation circuit and frequency band switch, is shown in detail and it, together with the parts of the system associated therewith comprising the essential features of the present invention, will be hereinafter described in detail. For the radio-frequency amplifier, however, the tuning condensers and the frequency band switches are simply indicated schematically at **10***a* and **10***b*, respectively. It will be understood that several parts of the system which are illustrated schematically may be conventional in their construction and operation, the details of which are well known in the art, rendering description thereof unnecessary herein.

Neglecting for the moment the particular operation of the frequency-control system embodying the present invention, the system above described includes all of the features of a conventional multi-band superheterodyne receiver. The operation of such a receiver being well understood in the art, detailed explanation thereof is deemed unnecessary. In brief, however, the tunable circuits of the radio-frequency amplifier **10** and frequency changer **11** are adjusted by the frequency band switches for selecting the desired band of frequencies and are tuned by their respective tuning condensers so that a desired modulated-carrier signal of the selected band intercepted by the antenna **9** is selected and amplified in the radio-frequency amplifier **10** and converted by the frequency changer **11** to an intermediate-frequency signal. This signal is selected and amplified by the intermediate-frequency amplifier **12** and translated therefrom to the detector **13**, wherein the audio frequencies of modulation are derived. The audio frequencies of modulation are amplified in the audio-frequency amplifier **14** and reproduced by the loud-speaker **15** in conventional manner. Biasing potentials, developed by the a-v-c supply in a well-understood manner and connected to control the amplification of one or more of the stages of the intermediate-frequency amplifier **12** and, if desired, also to control the amplification of the preceding stages of the receiver, are effective to maintain the amplitude of the signal input to the detector **13** within a relatively narrow range for a wide range of received signal amplitudes.

Referring now more particularly to the parts of the system comprising the present invention, the frequency changer **11** comprises a pentagrid oscillator-modulator tube **16** having its signal input grid coupled to the radio-frequency amplifier **10**, and an oscillation circuit including a tuning condenser **21** and inductances **20** and **20***a* of different inductance values adapted to be selectively connected in parallel therewith by means of a frequency band switch **20***b* for tuning to different frequency bands. The oscillation circuit is coupled to the first or oscillator grid of the tube **16** by way of the switch **20***b* and a suitable coupling condenser **22**, and to the second grid or oscillator anode through a feed-back path

comprising a coupling condenser 25, a band-selecting switch 24b and either an inductance 24 or an inductance 24a coupled to the inductances 20 and 20a, respectively. The switches 20b and 24b are connected for unicontrol with the frequency band switch 10b of the radio-frequency amplifier 10, as indicated by the broken lines U, while condenser 21 is connected for unicontrol in conventional manner with the tuning condensers 10a of the amplifier 10, as indicated by the broken lines U_1. Aligning condensers 23 and 23a are connected in series with the inductances 20 and 20a, respectively, and serve to align the oscillation circuit with the tuned circuits 10a of the radio-frequency amplifier 10 so that a substantially fixed intermediate frequency will be developed by the frequency changer as the tunable circuits are all simultaneously adjusted by the unicontrol means U_1 to tune the circuits over their respective ranges.

A suitable biasing resistor 17 and by-pass condenser 17a are included in the cathode circuit of the tube 16 and a leak resistor 18 is connected between the oscillator grid and the cathode. Proper operating potentials are supplied to the screen from a suitable source, indicated at +Sc, and to the oscillator anode from a suitable source, indicated at +B, by way of a high-frequency blocking resistor 19. The parts of the frequency changer thus far described are substantially of conventional design and the operation of the same is well known.

For the purpose of adjusting the frequency of the oscillation circuits 20—21 or 20a—21 independently of the main tuning condenser 21, there is provided a pentode tube 26 having its space current path adapted to be connected across either the series-aligning condenser 23 or the series-aligning condenser 23a by means of a frequency band switch 23b. The input circuit of the tube 26 is adapted to be selectively connected across the oscillation circuits 20—21 or 20a—21 through a switch 27b and a phase-shifting circuit comprising in series the inherent-grid-to-cathode capacitance of the tube indicated by the dotted line condenser 29, a blocking condenser 28 and either a resistor 27 or a resistor 27a, respectively. The blocking condenser 28 is sufficiently large as to have substantially no effect on characteristics of the input circuit at the oscillation frequencies, while the impedances of the resistors 27 and 27a are large relative to that of the grid-cathode capacitance 29 at the oscillation frequencies. The switches 23b and 27b are connected for unicontrol with the other frequency band switches of the receiver as indicated by the broken lines U. However, this feature of connecting the frequency control device across the series-aligning condenser of the frequency-determining circuit of the frequency changer, in order to procure a frequency correction that is approximately uniform over the tuning range of the receiver, per se, forms no part of the present invention, but is disclosed and claimed in a copending application of Nelson P. Case, Serial No. 91,864, filed July 22, 1936.

The cathode circuit of the tube 26 includes a suitable source of biasing voltage indicated at +C, through which its input and output circuits are completed by way of ground. The tube 26 is preferably of a high impedance type, such as a pentode, operating voltages being supplied to the screen from a suitable source indicated at +Sc, and to the anode from a source indicated at +B by way of a blocking resistor 30.

For the purpose of controlling the above-described frequency-adjusting means in accordance with deviations of the intermediate-frequency carrier from its normal value, due to oscillator drift, misadjustments of tuning, or other causes, so as to minimize such deviations and ensure optimum fidelity of reproduction at all times, means are provided for developing a control voltage which varies in amplitude and polarity in accordance with such deviations and for properly applying this voltage to the control grid of the tube 26 in order to effect the required frequency adjustments. These means preferably comprise a frequency discriminator and rectifier, indicated schematically at 32, coupled to the intermediate-frequency amplifier 12 and having its output circuit connected by way of a suitable filter including a series resistor 33 and a shunt condenser 34 and by way of a blocking resistor 31 to the control grid of the tube 26. The discriminator and rectifier 32 may be of any suitable type, various practical arrangements for this purpose being well known in the art. For example, the discriminator-rectifier may comprise a circuit arrangement such as is described in detail in British Patent No. 443,423, accepted February 25, 1936. Preferably, however, this arrangement for providing the frequency-control bias voltage will comprise a circuit arrangement similar to that disclosed in a copending application of Nelson P. Case, Serial No. 72,522, filed April 3, 1936.

Referring now more particularly to the operating characteristics of the frequency-control circuits, since the impedances of resistors 27 and 27a are high compared to that of the grid-to-cathode capacitance 29, the voltage across the capacitance 29 lags the voltage across the oscillation circuit. The circuit constants are so chosen that, at the high-frequency end of each frequency range, the voltage lag will be approximately 90 degrees. At the low-frequency end of each range the impedance of the capacitance 29 increases relative to that of the resistors 27, 27a so that the lag of the voltage across the capacitance 29 will be correspondingly less. The space current of the tube, being in phase with the tube input voltage, also lags the voltage across the oscillation circuit in corresponding degree. It is to be noted, however, that the voltage across the condenser 23 or 23a is in phase opposition to the voltage across its respective oscillation circuit, so that the space current of the tube leads the voltages across these condensers and the tube simulates an impedance having capacitance and resistance components only, the value and character of which impedance varies in accordance with the frequency of the oscillation circuit and the value of which varies also in accordance with the grid-bias voltage applied to the tube.

By proper adjustment of the various circuit constants, the variations of the amplitude and phase of the plate current of the tube 26 with respect to the oscillation voltage, as the oscillation circuit is tuned over a particular band of frequencies, are such that equal variations of the mutual conductance of the tube, resulting from adjustments of its grid-bias voltage, effect substantially equal adjustments of the resonant frequency of the circuit for all frequencies of such band.

This relation is possible because the tube 26 is connected across an aligning condenser 23 or 23a, which is connected in series with the tuning condenser 21. The effectiveness of each of these

aligning condensers is dependent upon the ratio of its impedance to that of the tuning condenser **21**, which varies in a predetermined manner as the oscillation circuit is tuned over its range. It will be understood that the word "effectiveness" as here employed is intended to mean the frequency adjustment of the oscillation circuit, in kilocycles. If condensers **23**, **23***a*, per se, were made adjustable for the purpose of effecting the auxiliary frequency adjustment, the percentage frequency adjustment effected by a given adjustment of the condensers would vary inversely in accordance with the frequency to which the circuit was tuned. Obviously, a given percentage frequency adjustment at a high frequency constitutes a substantially greater adjustment in kilocycles than the same percentage frequency adjustment at a low frequency. Although the above-mentioned variation in effectiveness of condensers **23** and **23***a* with frequency would be such that the percentage frequency adjustment would be less at the higher frequencies than at the lower frequencies for a given capacitance adjustment, which is a variation in the proper sense, the capacitances of condensers **23**, **23***a* are determined primarily by the alignment requirements and are not ordinarily of such size that their percentage frequency variation would be at the proper rate to result in equal effectiveness, that is, equal frequency adjustments in kilocycles for the same capacitance adjustment at different frequencies of a given frequency band. However, by utilizing as the auxiliary frequency-adjusting means the tube **26** and its associated circuits as described above, the percentage frequency variation thereof, with respect to the frequency to which the oscillation circuit is tuned, may be correlated with the circuit constants of the associated oscillation circuits so that any given increment of bias control voltage, while effecting different percentage frequency adjustments of the oscillation circuit at different points of the tuning range, effects the same frequency adjustment in kilocycles at all frequencies of any given frequency band. Furthermore, in the arrangement described having the space current path of the tube **26** connected across the relatively large aligning condenser **23** of the oscillation circuit, the tuning range of the circuit is not limited to an appreciable extent by the effective capacitance of the auxiliary frequency-adjusting means.

For the purpose of providing ranges of frequency control variable in accordance with the frequency band selected, the resistors **27** and **27***a* are so proportioned relative to the other constants of the circuits, particularly the value of the grid-cathode capacitance **29**, that the effectiveness of the tube **26** is greater for the higher frequency band, affording a wider range of correction in the higher frequency band for any given range of intermediate-frequency deviations. It will be apparent that the effectiveness of the tube **26** is dependent upon the various circuit constants of the system, which are, of course, different for the different frequency bands. If the circuit constants of the input excitation circuit and the oscillation circuit were the same for both frequency bands, the percentage frequency adjustment effected by a given adjustment of the mutual conductance of the tube **26** would be the same for both bands, but the effectiveness of the tube **26** (in kilocycles) would be greater for the higher frequency band and would vary directly in accordance with the mean frequency of the band. Such variation would, however, be too great to provide the proper range of control for the higher frequency band. The variation in the impedance of the grid-to-cathode capacity, with frequency, is in the proper sense to compensate for such excessive variation in effectiveness and, by proper selection of the resistance value of resistors **27** and **27***a* in series therewith, the input voltage to the tube, developed across the capacitance **29**, is so proportioned as to give the desired degrees of effectiveness to the tube **26** and the desired ranges of frequency adjustment for the different frequency ranges.

In considering the operation of the above-described automatic-frequency control system, it will be assumed that the frequency band switches are initially adjusted by the unicontrol U for receiving a desired signal in the lower frequency or broadcast band; the switches being in the positions shown in Fig. 1; the oscillation circuit comprising condenser **21**, inductance **20** and aligning condenser **23**; the input circuit of the tube **26** being connected across this oscillation circuit by way of resistor **27**; and the space current path of the tube being connected across the condenser **23**. It will further be assumed that the receiver is initially exactly tuned to the desired signal frequency of the selected band so that the normal intermediate-frequency carrier is being developed by the frequency changer **11**; so that no bias voltage is developed by the discriminator and rectifier **32**; and so that the resonant frequency of the oscillation circuit is of a proper value to give this normal intermediate frequency, taking into consideration the effect of the tube **26** with normal grid voltage applied. When, however, the intermediate-frequency carrier deviates from its normal frequency, due to mistuning of the oscillator with respect to the carrier wave of the desired signal or other causes, a bias voltage is developed by the discriminator and rectifier **32** having polarity and amplitude variable in accordance with the direction and amount of the deviation. This voltage is applied to the control grid of the tube **26** and effects a variation in the mutual conductance thereof, and hence a change in its apparent capacitance and resistance effectively in parallel with the condenser **23**, so as to adjust the oscillation frequency in the proper direction to minimize the frequency deviation of the intermediate-frequency carrier and ensure optimum fidelity of reproduction.

The operation of the frequency-control system as a whole can be better understood by reference to the curves of Figs. 2, 3, and 4. In Fig. 2, curve **40** represents generally the preferred operating characteristics of the frequency discriminator and rectifier **32**, these characteristics being the same for operation in both frequency bands. Deviations of the intermediate-frequency carrier from its normal predetermined frequency, in kilocycles, are indicated by the abscissae, and the ordinates represent control bias voltage developed by the circuit in question and applied to the tube **26**.

In Fig. 3, the curves **41** and **42** show the response of the tube **26** when the receiver is adjusted for receiving a signal in the lower frequency band and the higher frequency band, respectively, that is, the effectiveness of the tube in adjusting the resonant frequency of the oscillation circuit in accordance with grid-bias voltage applied thereto. The grid-bias voltages are indicated by the abscissae while the ordinates represent resultant frequency adjustments, in kilo-

cycles, of the oscillation circuit. It is apparent from the curves **41** and **42** that the effectiveness of the tube is substantially greater for the higher band than for the lower band. Further, the range of frequency adjustment varies directly with the effectiveness of the tube **26** for any given maximum control bias, which in this case is the same for both bands (±4 volts). Thus, for the lower frequency band a bias of ±4 volts is shown by the curve **41** to effect an oscillation frequency adjustment of approximately ±8 kilocycles, while for the higher band the same voltage is shown by the curve **42** to effect an oscillation frequency adjustment of ±16 kilocycles.

The ultimate effects of the frequency control are indicated in Fig. 4, where tuning misadjustments of the frequency changer, in kilocycles, are indicated by the abscissae, and the resultant frequency deviations of the intermediate-frequency carrier from its normal predetermined frequency are indicated by the ordinates. Curve **43** shows the frequency deviations of the intermediate-frequency carrier if no frequency control is employed, in such case being numerically equal to the oscillator frequency deviations. In this same figure, curves **44** and **45** show the results obtained, when the frequency control of the present invention is employed for the lower and higher frequency bands, respectively. It will be observed that frequency deviations of the intermediate-frequency carrier are maintained within relatively narrow limits, that is, within less than ±1 kilocycle for mistuning adjustments up to approximately ±8 kilocyles for the lower band, as shown by the curve **44**, and for mistuning adjustments up to approximately ±16 kilocycles for the upper band as shown by the curve **45**.

In Fig. 5, there is illustrated a modified form of the invention, whereby the variation in the effectiveness of the tube **26** and the range of frequency adjustment afforded by the frequency control for different frequency bands are obtained in a manner different from that illustrated by Fig. 1. The tube **26***a* of Fig. 5 and the elements connected thereto and designated by numerals with subscript "a" correspond to and may be substituted for the elements which are designated by the same numerals in the system of Fig. 1. In this modified arrangement, the effectiveness of the tube for the different frequency bands is varied by adjustments of the bias voltages applied to the control electrode and screen of the tube in accordance with the frequency band to which the system is adjusted. To this end, a voltage divider resistor **46** is connected across a source of potential, as indicated by the battery B, which is grounded at an intermediate point. Adjustable contacts on the voltage divider are connected one to the cathode and the other to the screen of the tube and are mechanically interconnected for adjustment by the unicontrol U to effect adjustments of the voltages applied to the cathode and screen in opposite senses and in the proper proportion simultaneously with the adjustment of the frequency band switches of the system. These operating voltage adjustments serve to vary the mutual conductance, and hence the effectiveness, of the tube so that the range frequency adjustment of the oscillation circuit for a given change in grid-bias voltage is greater, to the desired extent, for the higher frequency band than for the lower frequency band. The general operation of the system embodying the arrangement of Fig. 5 is substantially the same as that of Fig. 1, described above.

While the invention has been described above in connection with a system adapted to receive only two different frequency bands, obviously the invention is equally suitable for use in connection with multi-band receivers designed for the reception of any greater number of frequency bands, it being necessary only to provide additional frequency-control circuit elements and connections similar to those described above, so as to obtain the required different ranges of adjustment for the several bands. Thus, in a three-band receiver, the ranges of correction of mistuning of the oscillation circuit for the broadcast band, 450–1500 kilocycles, and for the police band, 1.5–6 megacycles, will preferably be ±8 kilocycles and ±16 kilocycles, respectively, as in the embodiments illustrated in the drawings, while for a higher frequency band of, for example, 6–18 megacycles, the range will preferably be ±30 kilocycles. In general, the variation in the range of correction of the frequency-control means is preferably within the limits of the one-third power and the two-thirds power of the mean frequency of the band selected; in the preferred embodiment illustrated this variation being at a rate of the order of the square root of the mean frequency of the selected band.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, and means responsive to operation of the band-adjusting means for varying said range of frequency adjustment in accordance with the mean frequency of the band selected.

2. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, and means for varying said range of frequency adjustment directly in accordance with, but at a rate substantially less than proportional to, the mean frequency of the band selected.

3. A multi-band modulated-carrier signal receiver comprising means including frequency-

changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, and means for varying said range of frequency adjustment at a rate of the order of the square root of the mean frequency of the selected band.

4. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, and means for varying said range of frequency adjustment at a rate within the limits of the one-third power and the two-thirds power of the mean frequency of the selected band.

5. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range, in accordance with said deviations, to minimize said deviations, and means simultaneously operable with operation of the band-adjusting means for varying said range of frequency adjustment directly in accordance with, but at a rate less than proportional to, the mean frequency of the band selected.

6. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and turnable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal, means for adjusting automatically the frequency derived by said frequency-changing means over a predetermined narrow range, in accordance with said deviations, to minimize said deviations, means for varying said range of frequency adjustment, and unicontrol means for simultaneously operating the band-adjusting means and the frequency-adjusting means to adjust said range variation directly in accordance with, but at a rate less than proportional to, the mean frequency of the band selected.

7. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal, means for adjusting automatically the frequency derived by said frequency-changing means over a predetermined narrow range, in accordance with said deviations, to minimize said deviations, means for varying said range of frequency adjustment, and unicontrol means for simultaneously operating the band-adjusting means and the frequency-adjusting means to adjust said range variation directly in accordance with, but at a rate of the order of the square root of, the mean frequency of the selected band.

8. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal, means for adjusting automatically the frequency derived by said frequency-changing means over a predetermined narrow range, in accordance with said deviations, to minimize said deviations, means for varying said range of frequency adjustment, and unicontrol means for simultaneously operating the band-adjusting means and the frequency-adjusting means to adjust said range variation directly in accordance with, but at a rate within the limits of the one-third power and the two-thirds power of, the mean frequency of the band selected.

9. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means having an oscillation circuit adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within a related frequency band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal and including a vacuum tube connected in circuit with said oscillation circuit to simulate an adjustable impedance and control means for said tube for adjusting the frequency derived by said oscillation circuit over a predetermined narrow range in accordance with said deviations thereby to minimze said deviations, and means for adjusting the effectiveness of said tube to vary said range of frequency adjustment directly in accordance with, but at a rate less than proportional to, the mean frequency of the band selected.

10. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means having an oscillation circuit adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within a related frequency band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal and comprising a vacuum tube connected

in circuit with said oscillation circuit to simulate an adjustable impedance, means responsive to said deviations for applying an adjustable bias voltage to said tube to adjust the frequency of said oscillation circuit over a predetermined narrow range, thereby so to adjust the frequency of said intermediate-frequency signal as to minimize said deviations, and means for so controlling the effectiveness of said tube as to vary said range of frequency adjustment directly in accordance with, but at a rate less than proportional to, the mean frequency of the band selected.

11. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, means for maintaining the effectiveness of said frequency-adjusting means substantially constant as the first said tunable means is tuned over a selected frequency band to select a desired signal thereof, and additional means for varying said range of frequency adjustment directly in accordance with, but at a rate less than proportional to, the mean frequency of the band selected.

12. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within said band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal for adjusting the frequency derived by said frequency-changing means over a predetermined narrow range to minimize said deviations, means for maintaining the effectiveness of said frequency-adjusting means substantially constant as the first said tunable means is tuned over a selected frequency band to select a desired signal thereof, and additional means for varying said range of frequency adjustment directly in accordance with, but at a rate within the limits of the one-third power and the two-thirds power of, the mean frequency of the band selected.

13. A multi-band modulated-carrier signal receiver comprising means including frequency-changing means having an oscillation circuit adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive, from any desired signal within a related frequency band, an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, means independent of the tuning of the first said means to select a desired signal and comprising a vacuum tube connected in circuit with said oscillation circuit to simulate an adjustable impedance and control means for said tube for adjusting the frequency of said oscillation circuit over a predetermined narrow range in accordance with said deviations, thereby so to adjust the frequency derived by said frequency-changing means as to minimize said deviations, means for controlling said tube so to modify the mutual conductance thereof as said oscillation circuit is tuned over a selected frequency band that equal increments of adjustment of said control means effect equal independent tuning adjustments, and additional control means for said tube for varying the effectiveness thereof thereby to vary said range of frequency adjustment in accordance with, but at a rate less than directly proportional to, the mean frequency of the band selected.

14. The method of operating a multi-band modulated-carrier signal receiver having means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive from any desired one of the signals of said band an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, which comprises adjusting the frequency derived by said frequency-changing means independently of the tuning adjustment and over a predetermined narrow range to minimize said deviations, and varying the range of said frequency adjustment directly in accordance with, but at a rate less than proportional to, the mean frequency of the selected band.

15. The method of operating a multi-band modulated-carrier signal receiver having means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive from any desired one of the signals of said band an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, which comprises adjusting the frequency derived by said changing means independently of the tuning adjustment and over a predetermined narrow range to minimize said deviations, and varying the range of said independent tuning adjustment simultaneously with adjustments of the frequency-changing means to select a desired frequency band and in accordance with the mean frequency of the band selected.

16. The method of operating a multi-band modulated-carrier signal receiver having means including frequency-changing means adjustable to select any one of a plurality of frequency bands and tunable over the selected band to derive from any desired one of the signals of said band an intermediate-frequency modulated-carrier signal normally of a predetermined frequency but subject to deviations within narrow limits, which comprises adjusting the frequency derived by said changing means independently of the tuning adjustment and over a predetermined narrow range to minimize said deviations, and varying the range of said independent tuning adjustment simultaneously with adjustments of the frequency-changing means to select a desired frequency band and at a rate within the limits of the one-third power and the two-thirds power of the mean frequency of the band selected.

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DISCLAIMER

2,084,647.—*William A. MacDonald*, Little Neck, N. Y. AUTOMATIC FREQUENCY CONTROL. Patent dated June 22, 1937. Disclaimer filed August 28, 1937, by the patentee; the assignee, *Hazeltine Corporation*, assenting.

Hereby enters this disclaimer to claims 1 and 15 of said patent.

[*Official Gazette September 21, 1937.*]