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AUTOMATIC FREQUENCY CONTROL CIRCUITS

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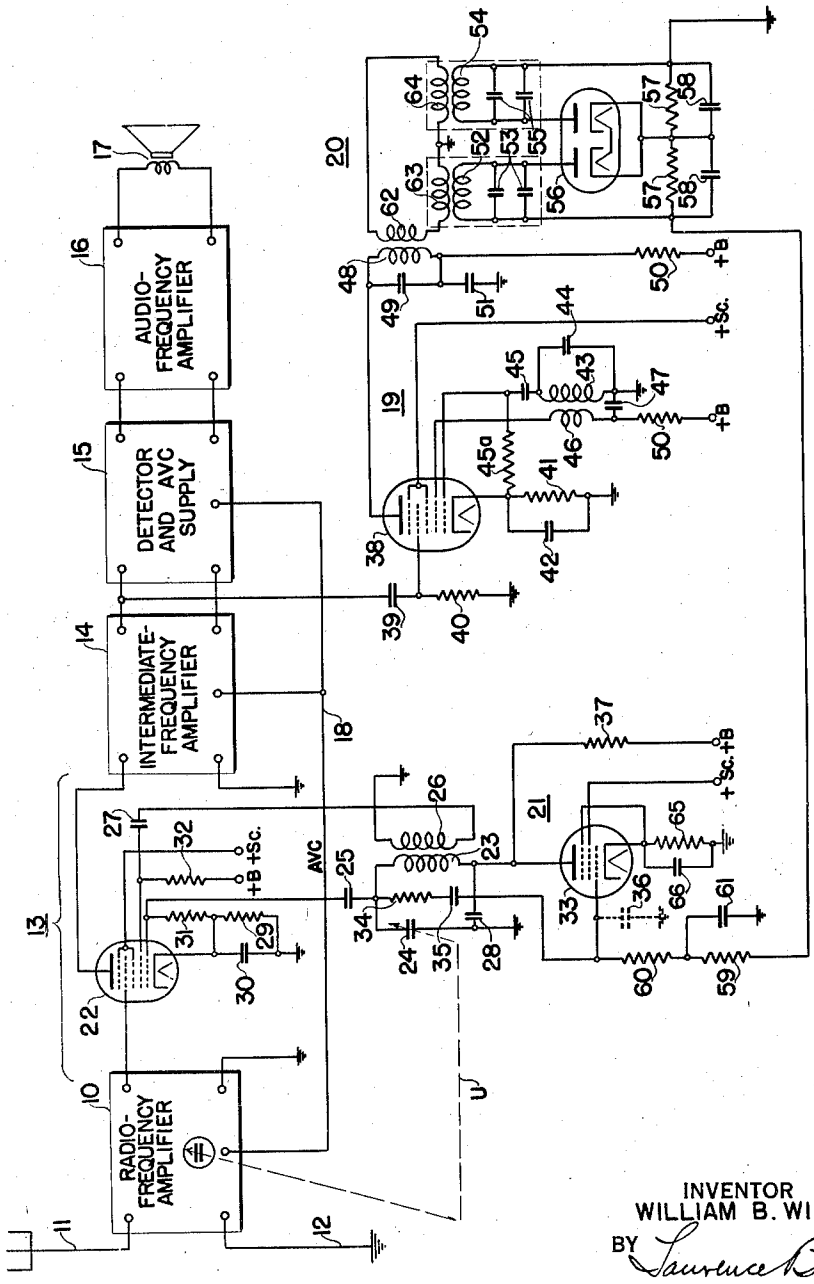

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AUTOMATIC FREQUENCY CONTROL CIRCUITS

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This invention relates to modulated-carrier signal-receiving systems, and more particularly to the automatic control of the resonant frequency of the local oscillation circuit of a superheterodyne receiver to maintain the intermediate-frequency carrier at a predetermined frequency for all tuning adjustments of the receiver.

In a conventional superheterodyne receiver, there is included a frequency changer tunable over a wide range of frequencies for deriving from any desired modulated-carrier signal, within an equal, related frequency range, a modulated-carrier signal normally having a predetermined carrier frequency. A signal-translating channel is coupled to the frequency-changing means and includes a band-pass selector for passing the predetermined carrier frequency and its sidebands of modulation, together with a signal-reproducing means, as, for example, the usual detector, audio-frequency amplifier, and loudspeaker. For optimum selectivity and fidelity of reproduction, the frequency of the modulated carrier developed by the frequency changer should be maintained substantially at the center frequency of the band-pass selector, that is, it should always be maintained at its normal predetermined frequency. As is well understood in the art, however, any mistuning of the frequency-changing means, due to incorrect tuning adjustments by the operator, drift in the frequency of the oscillations produced in the frequency changer, or to other causes, produces deviations in the carrier frequency developed by the frequency changer from its normal predetermined frequency, thereby impairing the selectivity and fidelity of reproduction to the extent of such deviations.

Certain arrangements have heretofore been devised for controlling the carrier frequency of the signal derived by the frequency changer automatically to reduce its deviations. Satisfactory automatic frequency control, however, has various operating characteristics which have been found difficult to procure. Among these characteristics are the following:

The intermediate-carrier frequency, when under control, should be held within relatively narrow limits of deviation; the automatic control action should be effective for mistuning of the frequency changer to an extent of the order of, but less than, the frequency separation of signals in the broadcast range, ordinarily 10 kilocycles, and should be relaxed, or preferably reversed, in action for greater extents of mistuning, in order that the frequency changer may thereupon immediately be adjusted to receive the next adjacent signal in the range. Further, the frequency control should be independent of the signal strength of any usable received signal. Various other characteristics must be achieved in order that the system shall be satisfactory from the standpoint of stability of operation and shall be commercially feasible in its construction, as will be more apparent hereinafter.

It is an object of the present invention to provide an improved modulated-carrier signaling system embodying a frequency changer and an automatic frequency control therefor having one or more of the desirable characteristics set forth above.

More particularly, it is an object of the present invention to provide an improved system of the character described, characterized by simplicity of construction and stability of operation.

In accordance with the embodiment of the present invention described herein, the improved system comprises a modulated-carrier signaling system, such as a superheterodyne receiver, including a tunable first frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a first predetermined frequency. A main signal-translating channel is coupled to the first frequency-changing means and includes signal-reproducing means. An auxiliary signal-translating channel is coupled to the first frequency-changing means and includes a second frequency-changing means for deriving from the second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency. The second and third carriers are subject to frequency deviations within narrow limits upon mistuning of the first frequency-changing means and means are coupled to the second frequency-changing means, responsive to the frequency deviations of the third signal carrier, for adjusting the first frequency-changing means to reduce the frequency deviations of said second and third carriers.

In accordance with a feature of the invention, means are provided for so coupling the output circuit of the first frequency-changing means to the second frequency-changing means that, for any normal operating conditions of the system, the amplitude of the input voltage to the second

frequency-changing means exceeds the overload level of the latter. As a result, the output voltage of the second frequency-changing means is substantially independent of variations in the amplitude of usable received signals, and the frequency-responsive means coupled thereto is supplied with an input voltage which is constant under operating conditions.

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 drawing, and its scope will be pointed out in the appended claims. The single figure of the accompanying drawing is a circuit diagram, partially schematic, of a complete superheterodyne receiver including an automatic control system according to the invention.

Referring now more particularly to the drawing, there is shown a superheterodyne receiver including a tunable radio-frequency amplifier **10** connected to an antenna **11** and ground **12**. Connected in cascade with the radio-frequency amplifier **10**, in the order named, are a frequency changer, indicated generally at **13**, an intermediate-frequency amplifier **14**, a detector and A. V. C. supply **15**, an audio-frequency amplifier **16**, and a signal reproducer or loudspeaker **17**.

Automatic amplification control bias voltage developed at the A. V. C. supply **15** may be applied by way of a suitable lead **18**, as shown, to one or more of the tubes of the radio-frequency amplifier **10**, the intermediate-frequency amplifier **14**, and the frequency changer **13**, in accordance with established practice. The frequency changer **13** together with other parts of the system associated therewith and involving the present invention are shown in detail and will be hereinafter further described. It will be understood that the 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 parts of the system involving the present invention, the system described above includes the features of a conventional superheterodyne receiver. The operation of such a receiver being well understood in the art, detailed explanation thereof is deemed unnecessary. Briefly, however, a desired modulated-carrier signal intercepted by the antenna **11** is selectively amplified in the radio-frequency amplifier **10** and converted by the frequency changer **13** to an intermediate-frequency modulated-carrier signal. This signal is selectively amplified by the intermediate-frequency amplifier **14** and translated therefrom to the detector and A. V. C. supply **15** wherein the audio frequencies of modulation are derived. The audio frequencies of modulation are amplified in the audio-frequency amplifier **16** and reproduced by the loud-speaker **17** in conventional manner.

Biasing potentials developed by the A. V. C. supply **15** are supplied to control the gain of one or more of the tubes of the radio-frequency amplifier **10** and intermediate-frequency amplifier **14**, and, if desired, also to control the gain of the frequency changer **13**, to maintain the amplitude of the signal output of the amplifier **14** within a relatively narrow range for a wide range of received signal amplitudes.

Coming now to the parts of the system involved in the present invention, there is included in the system means for controlling the intermediate-carrier frequency developed by the frequency changer **13** in accordance with deviations of the frequency of such carrier from its normal value, so as to minimize such deviations and insure optimum fidelity of reproduction at all times. These means comprise an auxiliary signal-translating channel coupled to the frequency changer **13** by way of the intermediate-frequency amplifier **14** and including a second frequency changer, indicated generally at **19**, a frequency discriminator and rectifier network, indicated generally at **20**, and control means, indicated generally at **21**, for adjusting the local oscillation frequency of the first frequency changer **13**.

The frequency changer **13** comprises a pentagrid oscillator-modulator tube **22**, having a signal-input grid coupled to the radio-frequency amplifier **10**, an output circuit coupled to the amplifier **14**, and an oscillation circuit including an inductance **23**, a tuning condenser **24**, and a series-aligning condenser **28**. The oscillation circuit is coupled to the first or oscillator grid of the tube **22** by way of a suitable grid condenser **25** and to the second grid or oscillator anode through a feed-back path comprising an inductance **26** coupled to the inductance **23** and a blocking condenser **27**. The condenser **24** is connected for uni-control with the tuning condensers of the radio-frequency amplifier **10** in a conventional manner, as indicated by the broken lines U. An aligning condenser **28** is connected in series in the oscillation circuit to align it with the tuned circuits of the radio-frequency amplifier **10**, so that a substantially fixed intermediate frequency will be developed by the frequency changer **13** as the tunable circuits are simultaneously adjusted by the unicontrol means U to tune the circuits over their respective ranges. A suitable biasing resistor **29** and by-pass condenser **30** are included in the cathode circuit of the tube **22** and a grid-leak resistor **31** is connected between the oscillator grid and the cathode. Proper operating potentials are applied to the screen from a suitable source, indicated at +SC, and to the oscillator anode by way of a resistor **32** from a suitable source, indicated at +B.

For the purpose of adjusting the resonant frequency of the oscillation circuit **23**, **24**, **28** independently of the main tuning condenser **24**, there is provided a vacuum tube **33** having an input circuit, which is excited from the high-potential side of the oscillation circuit through a series resistor **34** and blocking condenser **35**. The blocking condenser **35** is sufficiently large to have substantially no effect on the characteristics of the circuit at the oscillation frequency, while the resistance of the resistor **34** is large relative to the reactance at the oscillation frequency of the inherent grid-cathode capacitance of the tube, indicated by the dotted-line condenser **36**. The output circuit of the tube **33** is connected across the series-aligning condenser **28**; the cathode circuit of the tube **33** includes a suitable biasing resistor **65** and by-pass condenser **66**. The tube **33** is preferably of a high-impedance type, such as a pentode, operating voltages being supplied to its screen from a suitable source indicated at +Sc and to the anode from a source indicated at +B, by way of a resistor **37**.

The auxiliary signal-translating channel comprises a frequency changer **19** somewhat similar to the frequency changer **13** and comprising a pentagrid oscillator-modulator tube **38** having its

signal-input control grid coupled to the output circuit of the intermediate-frequency amplifier 14 by way of a coupling condenser 39 and a resistor 40 of high resistance. A suitable biasing resistor 41 and by-pass condenser 42 are included in the cathode circuit of this tube. An oscillation circuit including an inductance 43 and condenser 44, in parallel, is connected between the first, or oscillator, grid of the tube 38 and the cathode thereof, by way of a grid condenser 45, a leak resistor 45a being connected between the oscillator grid and cathode. A feed-back inductance 46 is inductively coupled to the inductance 43 and connected between the second grid, or oscillator anode, of the tube 38 and the cathode thereof, by way of a by-pass condenser 47. Included in the plate circuit of the tube 38 is a high-impedance circuit comprising an inductance 48 tuned by a condenser 49 to the second predetermined frequency, developed by the frequency changer 19. Suitable operating voltages are supplied to the screen of the tube 38 from a source indicated at +Sc and to the oscillator anode and the plate from sources indicated at +B by way of filter resistors 50, a by-pass condenser 51 being included in the plate circuit, as shown.

For the purpose of developing a control-bias voltage from the frequency deviations of the second intermediate-frequency signal derived by the frequency changer 19, a frequency discriminator and rectifier network 20 is coupled to the output circuit 48, 49 of the frequency changer 19. The discriminator portion of this network comprises a pair of resonant circuits 52, 53 and 54, 55 tuned to frequencies close to and below and above the second predetermined carrier frequency, developed by the frequency changer 19. The two discriminator circuits are coupled to the output circuit 48, 49 by means of a link circuit including in series a high-impedance winding 62 relatively closely coupled to the winding 48 and low-impedance windings 63 and 64 relatively closely coupled to the windings 52 and 54, respectively, and grounded at their junction. The tuned circuits 52, 53 and 54, 55 and their respective coupling windings are individually shielded, as indicated by the dotted lines. The two discriminator circuits are individually connected to a pair of rectifiers included in a double-diode tube 56, provided with suitable load circuits comprised of resistors 57 and by-pass condensers 58, as shown, the load circuits being connected in series with their unidirectional voltages opposing. One terminal of this series circuit is grounded and the other is connected to the control grid of the tube 33 by way of a filter including series resistors 59 and 60 and shunt condenser 61, providing a proper time constant for the control circuit.

Referring now to the operation of the system, the manner of the adjustment of the first frequency changer 13 and its control circuit including the tube 33 will first be considered. Since the resistance of the resistor 34 is high compared to that of the grid-to-cathode capacitance 36, the voltage across the capacitance 36 lags the voltage across the oscillation circuit, the circuit constants being so chosen that, at the high-frequency end of the tuning range, the lag is approximately 90 degrees. At the low-frequency end of the range the reactance of the capacitance 36 increases relative to the resistance of the resistor 34, so that the lag of the voltage across the capacitance 36 is correspondingly less. The space current of the tube 33, being in phase with the tube input voltage, also lags the voltage across the oscillation circuit in corresponding degree. The oscillation voltage across the condenser 28, however, is in phase opposition to the voltage across the oscillation circuit, referred to ground, so that the space current of the tube 33 leads the voltage across the condenser 28 and the tube simulates an impedance having capacitive and resistive 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 33. By proper adjustment of the various circuit constants, the variations of the amplitude and phase of the plate current of the tube 33 with respect to the oscillation voltage across condenser 28, as the oscillation circuit is tuned over its range, 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 oscillation circuit for all frequencies of its range.

Referring now more particularly to the second frequency changer 19, when any signal above the sensitivity limit of the receiver is being received, voltage of approximately the first predetermined frequency is supplied from the output circuit of the intermediate-frequency amplifier 14 to the input circuit of the tube 38. Oscillations developed in the resonant circuit 43, 44 are heterodyned with the input signal and a third modulated-carrier signal at approximately the second predetermined frequency is developed in the output circuit 48, 49 of the frequency changer 19. In accordance with this invention, the tube 38 of the frequency changer 19 has upper and lower cutoff characteristics so related to the circuit constants of the system that, for any normal operating conditions of the receiver, the amplitude of the input voltage to the tube 38 effects operation thereof beyond both cutoff limits. This is accomplished by virtue of the coupling of the tube 38 to the first frequency changer 13, by way of the intermediate-frequency amplifier 14, whereby the signal applied to the control grid of this tube is always sufficiently strong to drive the grid negative during each cycle beyond its lower cutoff limit. By virtue of the grid-leak resistor 40 and condenser 39, the tube also overloads or operates beyond its upper cutoff limit. The resonant circuit 48, 49 is tuned to the second predetermined frequency and designed to have a high antiresonant impedance at this and adjacent frequencies, resulting in a high gain from the tube 38. Thus, when a useful signal is being received, a substantially constant voltage is obtained across the circuit 48, 49, regardless of the variations in the amplitude of the signal, and this voltage is applied by way of the link circuit 62, 63, 64, to the selective circuits 52, 53 and 54, 55.

The selective circuits 52, 53 and 54, 55 are preferably tuned within two kilocycles of each other, for example, ±700 cycles from the second predetermined carrier frequency. The two circuits in question are maintained substantially uncoupled with respect to each other by virtue of being properly shielded and by proportioning the impedances of the windings of the link circuit so that the impedance of the winding 62 is large relative to that of the windings 63 and 64. The third modulated-carrier signal impressed upon the two selective circuits 52, 53 and 54, 55 develops unidirectional voltages across the resistors 57 included in the load circuits of the rectifier 56. These voltages are of opposite polar-

ity so that there difference varies positively or negatively in accordance with deviations of the second intermediate-frequency carrier from its normal value and toward the resonant frequency of one or the other of the circuits **52**, **53** and **54**, **55** and this voltage is applied to the control grid of the tube **33**, as mentioned above, to control the mutual conductance of the tube **33** and, hence, its apparent capacitance in parallel with condenser **28**. Due to the limiting action of the frequency changer **19**, the control behaves substantially uniformly for all signals of useful intensities.

Thus, the resonant frequency of the oscillation circuit of the first frequency changer is varied in acordance with the frequency deviations of the carrier frequencies of the first and second intermediate-frequency signals from their normal predetermined values. Since the frequency of the first intermediate-frequency signal is equal to the sum or difference of the received modulated-carrier frequency and the oscillation frequency of the frequency changer **13**, adjustments of the latter frequency in the proper sense operate substantially to reduce frequency deviations of the first intermediate-frequency signal carrier and accordingly of the second intermediate-frequency signal carrier, with respect to their respective predetermined normal carrier frequencies and in a predetermined ratio with respect to mistuning adjustments. This ratio is dependent upon the relative proportioning of the various elements of the frequency control arrangement.

In one illustrative embodiment of the invention, the proportioning of the control circuit constants is such that the ratio of control, or reduction in frequency deviation, is of the order of 10:1. In other words, mistuning adjustments of the first frequency changer which would tend to result in deviations of the second and third signal-carrier frequencies to an extent equal to such mistuning are substantially compensated, the deviations of the second and third signal-carrier frequencies being reduced to approximately $\frac{1}{10}$ this amount.

It is desirable that the control system shall be effective to maintain the receiver accurately adjusted for the reception of any desired signal only so long as the mistuning does not equal or exceed the frequency separation of adjacent signals, so that it will not be possible to skip over an adjacent signal. To this end, it is necessary that, while the control action shall be effective for all deviations of the second signal carrier within predetermined limits, for example, ±700 cycles, resulting from a mistuning adjustment of the first frequency changer of approximately ±7 kilocycles, the control action shall be ineffective or relaxed, or preferably reversed, for deviations beyond these limits. These relations are obtained by virtue of the selection of the resonant frequencies of the selective circuits **52**, **53** and **54**, **55** closely adjacent to and below and above the second predetermined carrier frequency, for example, 700 cycles below and above the second predetermined frequency.

Thus, when mistuning of the first frequency changer results in a deviation of the frequency of the third signal carrier to one side or the other of its normal predetermined frequency, one or the other of the selective circuits is increasingly favored until this deviation exceeds 700 cycles. That is, the control action is effective to reduce the deviations in large ratio, as long as they are within the limits represented by the resonant frequencies of the selective circuits **52**, **53** and **54**, **55**. When, however, the mistuning is to such an extent as to cause deviations of the third signal carrier beyond the limits mentioned, the control action in effect reverses, that is, both selective circuits become increasingly less responsive. This latter condition, of course, results in a decrease in the correction of the oscillation frequency of the frequency changer **13**, thereby causing still greater deviations of the third signal-carrier frequency and these greater deviations result in still less responsiveness of the selective circuits. Beyond the limits in question, therefore, due to the effective reversal of the normal control action, the control system causes a readjustment of the frequency of the oscillation circuit of the first frequency changer toward its normal value and the frequency changer is, therefore, adjusted to receive the next adjacent signal carrier to derive therefrom an intermediate-frequency signal at approximately its normal frequency.

In order that the required close spacing of the resonant frequencies of the circuits **52**, **53** and **54**, **55** may be readily obtained, it is essential that the frequency-control means **20** operate at a relatively low frequency, since a given percentage error in the tuning of the two selector circuits will result in a substantially smaller absolute error in the resonant frequencies of these circuits with respect to the third signal-carrier frequency when the latter frequency is relatively low. In the preferred embodiment of the present invention, therefore, the oscillation frequency of the second frequency changer **19** is such as to develop a relatively low third signal-carrier frequency, for example, 35 kilocycles. For various reasons this frequency would not be a satisfactory one for the main signal channel which supplies the signal to the detector of the system for reproductin and it is, therefore, a distinct advantage of the present arrangement that the second frequency-changing means and the control circuits associated therewith are included in an auxiliary channel which is independent of the main signal-translating channel which includes the signal-reproducing means.

While there has been described what is at present considered the preferred embodiment of the 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 modulated-carrier signal-receiving system comprising tunable frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a predetermined frequency, a second frequency-changing means for deriving from said second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency, said second frequency-changing means having upper and lower signal-amplitude cutoff limits, means so coupling said first frequency-changing means to said second frequency-changing means that, for any normal operating conditions of said system, the amplitude of the input voltage to said second frequency-changing means effects operation thereof beyond both cutoff limits, said second and third

signal carriers being subject to frequency deviations within narrow limits upon mistuning of said first frequency-changing means, and means coupled to said second frequency-changing means and responsive to the frequency deviations of said third signal carrier for adjusting said first frequency changing means to reduce said frequency deviations of the second and third carriers.

2. A modulated-carrier signal-receiving system comprising tunable frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a predetermined frequency, a second frequency-changing means including an oscillator-modulator tube and oscillation and feed-back circuits, means coupling said second frequency-changing means to said first frequency-changing means for deriving from said second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency, said tube having upper and lower cutoff characteristics, and said coupling means being so proportioned that, for any normal operating conditions of said system, the amplitude of the input voltage to said tube effects operation thereof beyond both cutoff limits, said second and third signal carriers being subject to frequency deviations within narrow limits upon mistuning of said first frequency-changing means, and means coupled to said second frequency-changing means and responsive to the frequency deviations of said third signal carrier for adjusting said first frequency-changing means to reduce said frequency deviations of the second and third carriers.

3. A modulated-carrier signal-receiving system comprising a tunable first frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a first predetermined frequency, a main signal-translating channel coupled to said first frequency-changing means and including signal-reproducing means, an auxiliary signal-translating channel coupled to said first frequency-changing means and including a second frequency-changing means for deriving from said second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency, said second frequency-changing means having upper and lower cutoff characteristics and being so coupled to said first frequency-changing means that, for any normal operating conditions of said system, the amplitude of the input voltage to the second frequency-changing means effects operation thereof beyond both cutoff limits, said second and third signal carriers being subject to frequency deviations within narrow limits upon mistuning of said first frequency-changing means, and means coupled to said second frequency-changing means and responsive to frequency deviations of said third signal carrier for adjusting said first frequency-changing means to reduce said frequency deviations of the second and third carriers.

4. A modulated-carrier signal-receiving system comprising a tunable first frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a first predetermined frequency, a main signal-translating channel coupled to said first frequency-changing means and including signal-reproducing means, an auxiliary signal-translating channel coupled to said first frequency-changing means and including a second frequency-changing means for deriving from said second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency, said second frequency-changing means including an oscillator-modulator tube and oscillation and feed-back circuits, said tube having upper and lower cutoff characteristics so related to its coupling with said first frequency-changing means that, for any normal operating conditions of said system, the amplitude of the input voltage to said tube effects operation thereof beyond both cutoff limits, said second and third signal carriers being subject to frequency deviations within narrow limits upon mistuning of said first frequency-changing means, and means coupled to said second frequency-changing means and responsive to the frequency deviations of said third signal carrier for adjusting said first frequency-changing means to reduce said frequency deviations of the second and third carriers.

5. A modulated-carrier signal-receiving system comprising tunable frequency-changing means for deriving from a selected modulated-carrier signal a second modulated-carrier signal having a carrier normally of a predetermined frequency, a second frequency-changing means for deriving from said second signal a third modulated-carrier signal having a carrier normally of a second predetermined frequency, said second frequency-changing means having upper and lower signal-amplitude cutoff limits, means so coupling said first frequency-changing means to said second frequency-changing means that, for any normal operating conditions of said system, the amplitude of the input voltage to said second frequency-changing means effects operation thereof beyond both cutoff limits, said second and third signal carriers being subject to frequency deviations within narrow limits upon mistuning of said first frequency-changing means, and control means coupled to said second frequency-changing means and responsive to the frequency deviations of said third signal carrier for modifying the transmission characteristic of the receiving system.

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