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AUTOMATIC CONTROL SYSTEM FOR CARRIER-WAVE SIGNAL RECEIVERS

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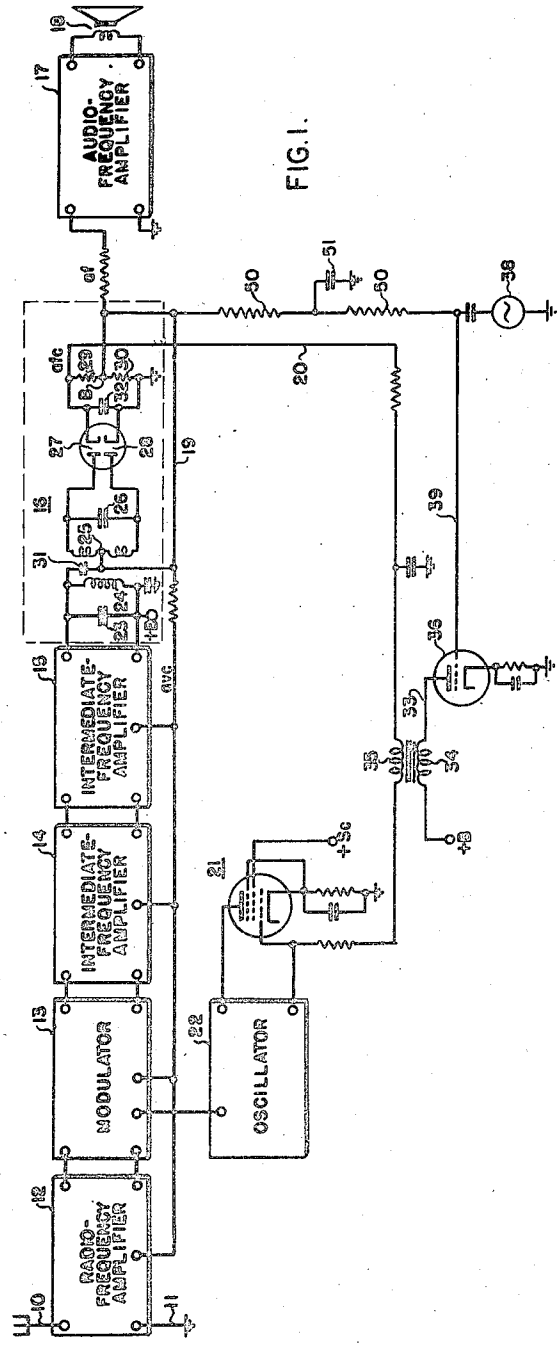

FIG. 1.

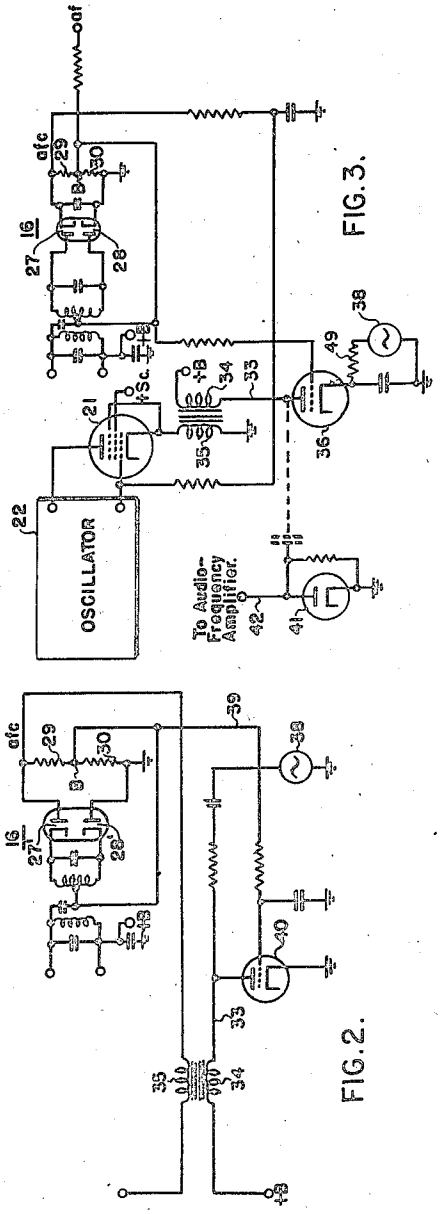

FIG. 3.

FIG. 2.

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AUTOMATIC CONTROL SYSTEM FOR CARRIER-WAVE SIGNAL RECEIVERS

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7 Claims. (Cl. 250—40)

The present invention relates to an automatic control system for a carrier-wave signal receiver and more particularly to an improved automatic frequency control system adapted to be utilized in such a receiver.

In the design of a superheterodyne receiver including an automatic frequency control system, the take-hold and release action of the system should occur at the same increment of frequency separation from the resonant frequency of the intermediate-frequency amplifier and the action should also be independent of signal strength. The frequency interval over which the action is effective should be chosen as a compromise between two limitations; the control action should be sufficient to correct for oscillator frequency instability caused by temperature and voltage changes and for mistuning caused by shortcomings in mechanical preset tuning devices; and in the other extreme, the control action should be less than that which would be operative by the carrier signal on an adjacent channel. In a broadcast receiver this compromise suggests a choice of automatic frequency control action over a frequency range of about 7 kilocycles on either side of the desired signal-carrier frequency. Thus, with conventional automatic frequency control, the sensitivity characteristic or S-curve of the discriminator must extend over a given frequency range of about 14 kilocycles. Attempts to obtain an S-curve of large slope sensitivity and consequently finer tuning correction generally are frustrated because any increase in the slope of such characteristic S-curve to a certain extent reduces the given frequency range to one smaller than the permissible 14 kilocycles.

As pointed out in the article entitled "Improvements in A. F. C. Circuits," pp. 20–23 of the November 1936 issue of "Electronics," the frequency separation of the S-curve peaks determines to some extent the amount of mistuning of a signal for which the automatic frequency control system will lock in. Once this locking has occurred, the control-tube sensitivity determines how much the local oscillator may be mistuned without losing the signal. For a satisfactory locking-in, the peak separation on the S-curve of the discriminator should not be much greater than the receiver over-all band width at twice resonant voltage input as otherwise the band width of the intermediate-frequency amplifiers preceding the discriminator network determines the amount of mistuning of a signal for which the automatic frequency control system will lock in. This limitation becomes severe and decreases the value of an automatic frequency control system whenever the deviation of the oscillator frequency from that which produces the correct intermediate frequency is larger than half the band width of the intermediate-frequency amplifier preceding the discriminator network. Such condition is sometimes present in highly-selective broadcast receivers using preset tuning mechanisms and is quite generally present in ultra-high-frequency receivers used for television reception or for frequency-modulated wave reception.

In the case of a television superheterodyne receiver, normal changes in temperature alone cause a frequency drift of the local oscillator of several hundred kilocycles. Because of certain advantages as to simplicity and economy, it is preferable to utilize the accompanying sound carrier to a television signal as the pilot signal to operate the automatic frequency control system. Thus, the discriminator network is placed in the intermediate-frequency amplifier channel which is responsive to the sound signal-carrier frequency. From the standpoint of reducing noise and interference it is desirable to make the band width of this sound amplifier channel no greater than necessary to accept the sound signal sidebands; in consideration of this, a band width of less than 50 kilocycles is desired. Such a choice is directly in conflict with the large band width required to give satisfactory automatic frequency control.

It is an object of the invention, therefore, to provide an improved automatic control system for a carrier-wave signal receiver which overcomes the above-mentioned disadvantages of such arrangements of the prior art.

It is a further object of the invention to provide an improved automatic frequency control system for superheterodyne receivers which has relatively high sensitivity and high tuning correction efficiency and which, at the same time, operates automatically from an amplifier channel having a relatively narrow frequency range without decreasing the permissible frequency tolerance for manual or automatic tuning or for oscillator frequency instability.

In accordance with the invention, there is provided an automatic control system for a carrier-wave signal receiver comprising a network the output of which varies in response to variation of the frequency or other given characteristic of a signal input thereto over a given range of variation of the frequency or other characteristic,

together with means responsive to the output of the network for maintaining the frequency or other characteristic of the signal input to the network approximately at a predetermined value, or within a desired small range, within the given range of variation when the frequency or other characteristic of the input signal has any value within such given range. The control system includes additional means for periodically sweeping the value of the frequency or other characteristic of the signal input to the network over a range which is wider than and which overlaps the given range. The system also includes means responsive to the resulting frequency or other characteristic of the signal input to the network for rendering the additional means inoperative when the resulting frequency or other characteristic has a value within the given range.

In a preferred embodiment of the invention as applied to a superheterodyne receiver, the intermediate-frequency signal is applied to the frequency discriminator, and the additional means varies the frequency of the intermediate-frequency signal input to the discriminator so that it sweeps over a frequency range wider than, but which overlaps, the given frequency range of the discriminator network. The additional means effectively applies to the oscillator control tube a relatively low-frequency sweeping or searching voltage whereby the receiver is tuned automatically to signals which initially are out of the given frequency-response range of the discriminator. Also, in accordance with a preferred embodiment of the invention, means are provided for rendering the additional means inoperative when the frequency of the signal input to the network is momentarily swept within said given frequency range, which means comprises a vacuum tube controlled by the output of the discriminator and controlling the application of the sweep voltage to the oscillator control tube.

The novel features which are believed to be characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects thereof, will be best understood by reference to the specification, taken in connection with the accompanying drawing, in which Fig. 1 is a circuit diagram, partly schematic, of a complete superheterodyne receiver including an automatic frequency control system embodying the present invention; and Figs. 2 and 3 are circuit diagrams of different embodiments of automatic frequency control systems constructed in accordance with the invention.

Referring to Fig. 1 of the drawing, there is shown a circuit diagram, partly schematic, of a complete modulated-carrier signal receiver of the superheterodyne type embodying the invention. This receiver comprises, in cascade, an antenna-ground circuit 10, 11, a radio-frequency amplifier 12, a modulator 13 and associated oscillator 22, intermediate-frequency amplifiers 14 and 15, a frequency-discriminator and detector network 16, an audio-frequency amplifier 17 of one or more stages, and a sound reproducer 18. Automatic amplification control, or A. V. C., is secured in a well-known manner by a unidirectional-bias voltage derived from the unit 16 and applied, over conductor 19, to the control electrodes of one or more of the vacuum tubes included in radio-frequency amplifier 12, modulator 13, and intermediate-frequency amplifiers 14 and 15.

Automatic frequency control, or A. F. C., is secured by applying a unidirectional voltage, derived from frequency-discriminator network 16, over conductor 20 to a frequency-control tube 21 which, in turn, is coupled to the oscillator 22 in any suitable manner well known in the art. All of the elements or assemblies illustrated in schematic form may be of suitable conventional construction and arrangement.

Neglecting for the moment the operation of that part of the system embodying the present invention, the circuit described constitutes, in general, a conventional superheterodyne receiver including automatic volume control and automatic frequency control systems, the operation of which, in general, is well understood by those skilled in the art. Any of a number of signals intercepted by antenna-ground circuit 10, 11 is selected and amplified in radio-frequency amplifier 12 and translated to oscillator-modulator 22, 13, wherein it is converted to an intermediate-frequency signal. The intermediate-frequency signal is selectively amplified in intermediate-frequency amplifiers 14 and 15 and delivered to the frequency-discriminator and detector network 16, wherein the audio-frequency signals and the automatic amplification control and automatic frequency control biasing potentials are derived. The audio-frequency signals, in turn, are amplified by audio-frequency amplifier 17 and supplied to sound reproducer 18 for reproduction. The automatic amplification control bias derived from unit 16 is effective to control the amplification of one or more of the units 12, 13, 14, and 15 to maintain the amplitude of the signal input to the unit 16 within a relatively narrow range for a wide range of received signal intensities, while the automatic frequency control bias derived from the unit 16 is effective to control the frequency-control tube 21 to maintain the frequency of the signal input to the network 16 at a substantially constant value.

The detector and frequency-discriminator network 16 comprises a primary circuit including an inductance 24 tuned by a condenser 23 and inductively coupled to an inductance 25 in a secondary circuit tuned by a condenser 26. Circuits 23, 24 and 25, 26 are tuned to the normal intermediate-carrier frequency of the receiver. Network 16 also includes diode rectifiers 27 and 28, to which are applied the sum and difference, respectively, of the voltages across the primary circuit 23, 24 and across half of the secondary circuit 25, 26. To this end, a coupling condenser 31 is connected between the high alternating-potential side of the circuit 23, 24 and a mid-tap on secondary inductance 25, while the mid-tap on inductance 25 is coupled by way of conductor 19 to a common terminal B of individual load resistors 29 and 30 of rectifiers 27 and 28, respectively. A by-pass condenser 32 is connected across load resistors 29 and 30 in series.

The value of condenser 31 has a very marked effect on the selectivity of the network 16 as to audio-frequency characteristics and also as to discriminator characteristics. When the capacitance of such condenser 31 approaches zero or is very small, the discriminator action of the network 16 disappears, but the audio-frequency fidelity is as good as conventional intermediate-frequency diode detector stages. However, a compromise value for the capacitance of the condenser 31 can be found which gives very good discriminator action as well as good audio-frequency fidelity. For an intermediate frequency

of 450 kilocycles and with a value of capacitance of condenser 31 in the range of 4 to 10 $\mu\mu f$, and with comparatively loose coupling of the inductances 24 and 25, an automatic frequency control characteristic having a peak separation of 2 to 4 kilocycles is obtainable with a slope sensitivity of 30 to 40 volts per kilocycle (per peak volt applied to the preceding amplifier tube grid) and with correspondingly high gain at the peaks. It will be appreciated that this is from 2 to 10 times the sensitivity ordinarily utilized in prior practice in which a peak separation of the order of 14 kilocycles is desired. However, if such a discriminator is used, it will not produce automatic frequency control action until the receiver is tuned almost to the frequency of the desired signal, that is to say, to within 4 to 5 kilocycles from resonance. Thus, it will be seen that network 16 has a unidirectional-voltage output which varies in response to variation of the frequency of the signal input to the network only over a given frequency range which is relatively small, preferably about 2 kilocycles. The attainment of such a narrow range of response of the discriminator is further facilitated by inserting a resistor in series with lead 19 in conformance with the ideas set forth in the applicant's copending application Serial No. 230,820, filed September 20, 1938, which issued as Patent No. 2,184,072, December 19, 1939.

The oscillator control tube 21 and the oscillator-modulator stage 22, 13 constitute means responsive to the output of the network 16 for adjusting the frequency of the signal input thereto to a frequency within a desired small range, or maintaining the frequency of the signal input thereto approximately at a predetermined value, within the given range of permissible frequency deviation when the frequency of the signal input is within the given frequency range. That is to say, the operation of the circuit described in detail up to this point, in general, is similar to a conventional automatic frequency control system except that an extremely sharp discriminator is used having a sensitivity from 2 to 10 times the sensitivity of the usual discriminator and a much smaller separation between peaks of the discriminator characteristic S-curve.

However, according to this invention, there is provided additional means for periodically sweeping the frequency of the signal input to the network 16 over a frequency range which is wider than and which overlaps the normal or given frequency range of the discriminator and at a sweep frequency lower than any frequency within such given frequency range, together with means for rendering the additional means inoperative, when the frequency of the signal input to the network 16 is within such given frequency. The additional means preferably comprises means for effectively applying a low-frequency alternating potential to the control tube for varying periodically the oscillator frequency; specifically, this means comprises a periodic searching potential circuit 33 inductively coupled by means of a transformer 34, 35 to the input circuit 20 of the oscillator control tube 21. The circuit 33 comprises the output circuit of a vacuum tube 36 to the control electrode of which is applied a periodic voltage from a suitable source, such as conventional 60-cycle alternating current supply circuit 38, over a conductor 39. A filter network, comprising series resistors 50, 50 and a shunt condenser 51, preferably is coupled between the supply circuit 38 and the discriminator network 16 to prevent the sweep voltage from getting back into the automatic amplification control and audio-frequency system.

The application of a periodic voltage to the control electrode of the oscillator control tube 21 causes the oscillator frequency to be swept through a range which is wider than but includes the normal frequency range of the discriminator 16 and thus provides means for augmenting the action of the sharp discriminator 16. When the receiver produces an intermediate-frequency signal of the proper frequency as it is tuned in the vicinity of the desired broadcast signal and the oscillator 22 is swept through a relatively wide range as described above, the sharp discriminator takes effect and locks in the signal in a conventional manner. As the discriminator action takes effect, the diode rectifier 28 develops a negative-bias voltage across its load resistor 30, regardless of the side from which resonance is approached, which operates to bias the control electrode of the vacuum tube 36 to cutoff which, in turn, renders inoperative the frequency sweep system of the oscillator 22. The diode 28 and its associated circuit comprises means responsive to the resulting frequency of the signal input to the discriminator network for rendering the additional or frequency sweeping means inoperative when the resulting frequency has a value within the given range of the discriminator. Such action alone provides limited automatic frequency control action and, with a very sharp discriminator, the range of the automatic frequency control action depends only on the amplitude of the periodic sweep voltage and not at all on signal strength for signals above a certain threshold level.

Summarizing the general features and operation of this system, an extremely sharp discriminator network is used; then, in order that signals may be automatically tuned in, which are initially out of the normal frequency-response range of the receiver discriminator circuit, an auxiliary periodic voltage effectively is added to the control tube bias in addition to any unidirectional-bias potential developed by the discriminator. Thus, for off-tune signals that would otherwise be ineffective to develop a discriminator bias, the system "pulls in" to them because the control tube is sweeping the signal input to the network through a relatively wide frequency range. If the off-tune signal is in this swept frequency range, discriminator voltages are developed each time the oscillator traverses the frequency that causes the correct intermediate frequency to be developed.

Referring to Fig. 2 of the drawing, there is shown an automatic frequency control system embodying a modified form of the invention which, in general, is similar to that described above in connection with Fig. 1, similar elements of the two circuits having identical reference numerals. In this system the diodes 27', 28' of the discriminator 16 are reversed so that a positive bias is developed at the common terminal B of the resistors 29 and 30 of the network for biasing the control electrode of a gaseous vacuum-tube relay, such as a "Thyratron," 40 coupled to the circuit 33. With no bias on the control electrode of the relay 40, the tube is nonconductive and a periodic sweep voltage appears at the transformer primary 34. When the control grid is made positive by the discriminator bias developed by a signal locked in, the relay 40 acts as a conductor and

thereby short-circuits the transformer primary 34. Othewise, the operation of the automatic frequency control system of Fig. 2 is similar to that described above in connection with Fig. 1.

Since the control tube 36, Fig. 1, is operative only with "no signal," the invention also may be made to provide a very efficient intercarrier noise suppressor by rectifying and utilizing the periodic sweep voltage in the output circuit 33 of tube 36. Such an arrangement is shown in Fig. 3, in which the sweep voltage output of tube 36 is rectified by a diode rectifier 41 and the resulting bias voltage applied negatively over conductor 42 to the control electrode of an audio-frequency stage tube to bias the latter to cutoff and thus suppress reproduction of interchannel noises. The diode 41 and its associated circuit thus comprises means responsive to the additional or frequency sweeping means for restricting the output of the receiver while the additional means is operative. When a signal is tuned in, this suppressor bias completely vanishes. In the circuit of Fig. 3, the transformer secondary 35 is coupled to the cathode of control tube 21 and the supply circuit 38 preferably is coupled in series with the cathode-biasing resistor 49 of vacuum tube 36. This arrangement eliminates the need of a filter network, such as that comprising resistors 50, 50 and condenser 51 of Fig. 1, for preventing the sweep voltage from affecting the automatic amplification control and audio-frequency channel of the receiver; otherwise, the systems are substantially similar.

It will be understood that other types of frequency-discriminator networks may be utilized in place of the discriminator network illustrated and described.

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. In a carrier-wave signal receiver, an automatic control system comprising, a network the output of which varies in response to variation of a given characteristic of a signal input thereto over a given range of variation of said characteristic, means responsive to the output of said network for maintaining said given characteristic of said signal input to said network approximately at a predetermined value within said given range of variation when said characteristic of said input wave has any value within said given range, additional means for periodically sweeping the value of said characteristic of said signal input over a range which is wider than and which overlaps said given range, and means responsive to the resulting characteristic of the signal input to said network for rendering said additional means inoperative when said resulting characteristic has a value within said given range.

2. An automatic frequency control system comprising, a discriminator network the output of which varies in response to variation of the frequency of a signal input thereto over a given frequency range, means responsive to the output of said network for maintaining the frequency of said signal input to said network approximately at a predetermined frequency within said given frequency range when said frequency of said signal input falls within said given frequency range, additional means for periodically varying the frequency of said signal input over a frequency range which is wider than and which overlaps said given frequency range, and means responsive to the resulting frequency of the signal input to said network for rendering said additional means inoperative when said resulting frequency has a value within said given frequency range.

3. An automatic frequency control system comprising, a discriminator network the output of which varies in response to variation of the frequency of a signal input thereto over a given frequency range, means responsive to the output of said network for adjusting the frequency of said signal input to said network to a frequency within a desired small frequency range within said given frequency range when said frequency of said signal input is within said given frequency range, additional means for periodically varying the frequency of said signal input so that it sweeps at a frequency lower than any frequency within said given frequency range and over a frequency range which is wider than and which overlaps said given frequency range, and means responsive to the resulting frequency of the signal input to said network for rendering said additional means inoperative when said resulting frequency has a value within said given frequency range.

4. An automatic frequency control system comprising, means including a discriminator network the output of which depends upon the frequency of a signal input thereto over a given frequency, control means responsive to said output for maintaining the frequency of said signal input approximately at a predetermined frequency range within said given frequency range when the frequency of said input wave falls within said given frequency range, additional means comprising a searching potential circuit for varying periodically the frequency of said signal input at a frequency lower than any frequency within said given frequency range and over a frequency range which is wider than and which overlaps said given frequency range, and means responsive to the output of said discriminator for rendering said additional means ineffective when the resulting frequency of said signal input falls within said given frequency range.

5. In a carrier-wave signal receiver of the superheterodyne type, an automatic frequency control system comprising, a discriminator network, an oscillator control tube, means including said discriminator network for developing a frequency-control bias and applying it to said tube, additional means for effectively applying a low-frequency alternating potential to said control tube for varying periodically the oscillator frequency, whereby automatically to tune the receiver to signals which initially are out of the frequency-response range of the discriminator, and means responsive to the resulting frequency of the signal input to said network for removing said low-frequency voltage from said control tube when said resulting frequency has any value within the frequency-response range of said discriminator.

6. In a carrier-wave signal receiver of the superheterodyne type, an automatic frequency control system comprising, an exceedingly sharp discriminator network the output of which varies in response to variation of the frequency of an intermediate-carrier signal input thereto over a given frequency range, an oscillator control

tube, means responsive to said output for controlling said control tube to adjust the frequency of said intermediate-carrier signal input to a frequency within a desired small frequency range when said frequency of said intermediate-carrier signal input has any value within said given frequency range, additional means for applying a low-frequency alternating potential to said oscillator control tube for varying periodically the oscillator frequency so that it sweeps at a frequency lower than the intermediate-carrier frequency of said receiver and over a frequency range which overlaps and is wider than said given frequency range, and means responsive to the output of said discriminator network for rendering said additional means inoperative when the resulting frequency of said intermediate-carrier signal input falls within said given frequency range.

7. In a modulated-carrier wave signal receiver, an automatic frequency control system comprising, a discriminator network the output of which varies in response to variation of the frequency of a signal input thereto over a given frequency range, means responsive to the output of said network for maintaining the frequency of said signal input to said network approximately at a predetermined frequency within said given frequency range when said frequency of said signal input falls within said given frequency range, additional means for varying the frequency of said signal input over a frequency range which is wider than and which overlaps said given frequency range, means for rendering said additional means inoperative when the resulting frequency of the signal input to said network falls within said given frequency range, and means responsive to said additional means for restricting the output of the receiver while said additional means is operative, whereby to suppress intercarrier noises when the receiver is not tuned to a carrier-wave signal.

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DISCLAIMER

2,261,800.—*Robert L. Freeman.* Flushing, N. Y. AUTOMATIC CONTROL SYSTEM FOR CARRIER-WAVE SIGNAL RECEIVERS. Patent dated November 4, 1941. Disclaimer filed September 2, 1943, by the inventor; assignee, *Hazeltine Corporation,* assenting.

Hereby enters this disclaimer to claims 4, 5, and 6 of said patent.

[*Official Gazette September 28, 1943.*]

DISCLAIMER

2,261,800.—*Robert L. Freeman*, Flushing, N. Y. AUTOMATIC CONTROL SYSTEM FOR CARRIER-WAVE SIGNAL RECEIVERS. Patent dated November 4, 1941. Disclaimer filed June 22, 1944, by the inventor; the assignee, *Hazeltine Corporation*, assenting.

Hereby enters this disclaimer to claims 1, 2, and 3 of said patent.

[*Official Gazette August 1, 1944.*]