

June 28, 1949.

G. GUANELLA

2,474,354

AUTOMATIC FREQUENCY CONTROL CIRCUITS

Filed June 4, 1943

2 Sheets-Sheet 1

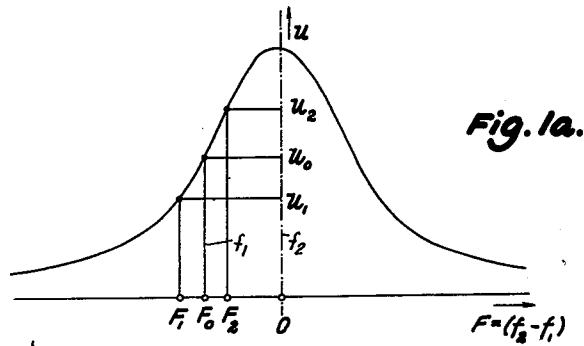


Fig. 1a.

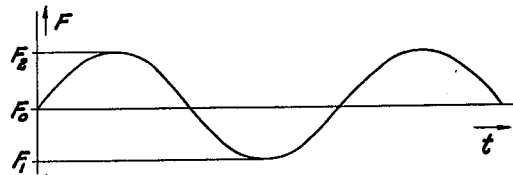


Fig. 1b.

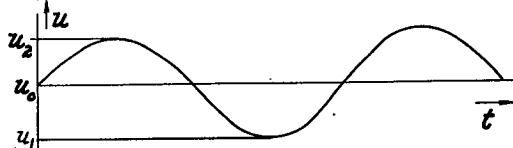


Fig. 1c.

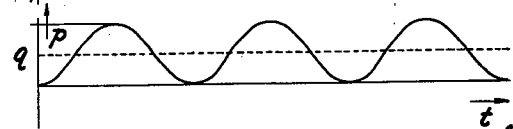


Fig. 1d.

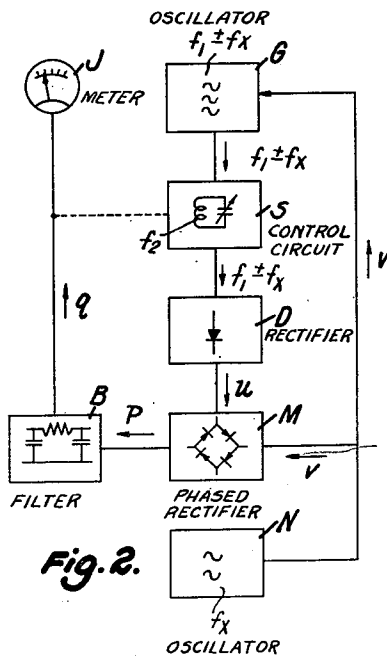


Fig. 2.

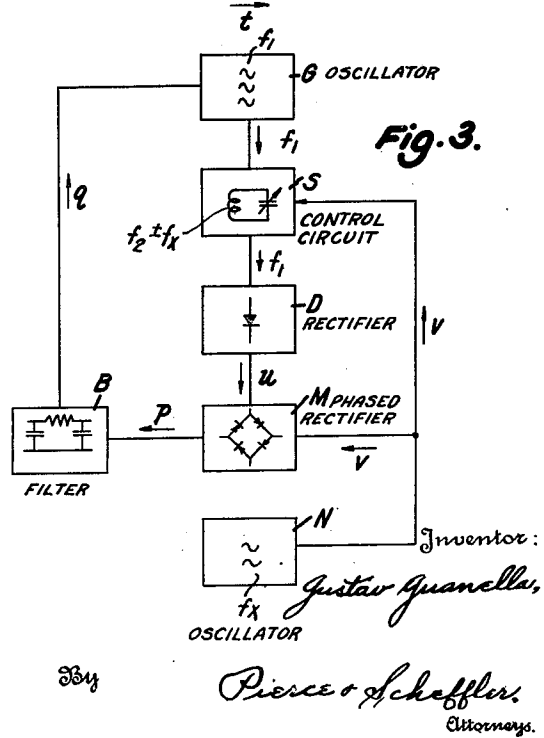


Fig. 3.

Inventor:
Gustav Guanella,
Pierce & Scheffler,
Attorneys.

June 28, 1949.

G. GUANELLA

2,474,354

AUTOMATIC FREQUENCY CONTROL CIRCUITS

Filed June 4, 1943

2 Sheets-Sheet 2

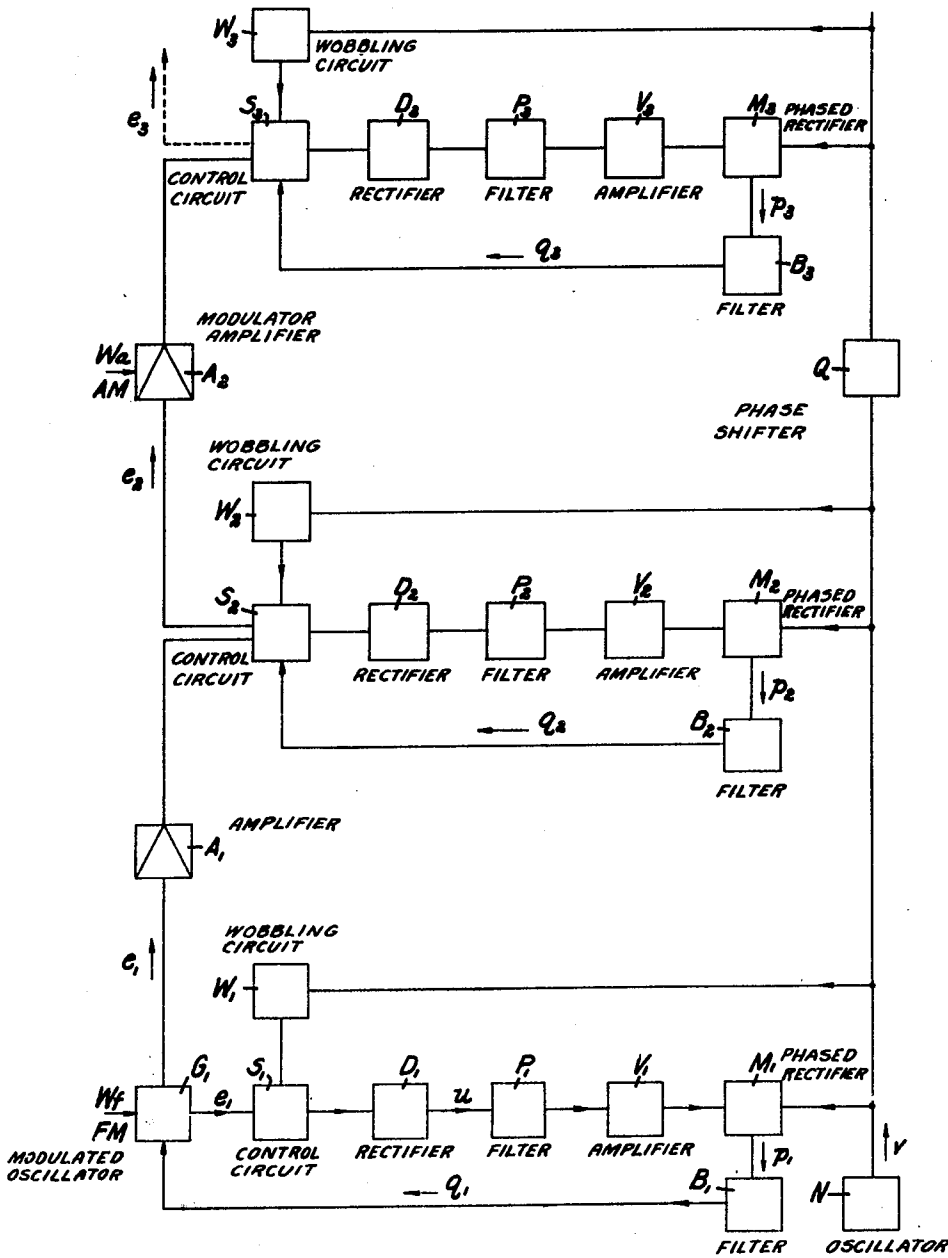


Fig. 4.

Inventor:
Gustav Guanella,

334

Pierce & Shreffler,
Attorneys.

UNITED STATES PATENT OFFICE

2,474,354

AUTOMATIC FREQUENCY CONTROL
CIRCUITSGustav Guanella, Zurich, Switzerland, assignor to
"Patelhold" Patentverwertungs- & Electro-
Holding A.-G., Glarus, SwitzerlandApplication June 4, 1943, Serial No. 489,679
In Switzerland May 19, 1942Section 1, Public Law 690, August 8, 1946
Patent expires May 19, 1962

13 Claims. (Cl. 250—40)

1

With radio transmitting and receiving apparatus, particularly for very high frequencies, certain difficulties are encountered as regards the tuning and the avoidance of uncontrollable frequency deviations. The employment of extremely frequency-constant control elements, such as for instance oscillation crystals with a very small natural damping, certainly enables the frequency to be stabilized. Besides the frequency multiplying arrangements especially necessary with short waves such a solution, however, involves very complicated measures if the frequency of the radio apparatus has to be varied over a more or less wide range.

The present invention concerns methods of and circuit arrangements for producing a control voltage by which it is always possible to maintain the tuning error of transmitting and receiving equipment at a minimum. The new methods and circuits have the advantage that they do not detrimentally affect the quality of the transmission, either of an unmodulated signal or of a signal carrying an amplitude or a frequency modulation.

The control voltage for automatic tuning is obtained by periodically varying the tuning of an oscillator or of an oscillatory circuit working out of the oscillator, rectifying the output voltage of the oscillatory circuit to develop an alternating voltage that varies in amplitude with the instantaneous detuning of the circuit, and phase-rectifying the alternating voltage of varying amplitude to develop a pulsating voltage having a mean value of an algebraic sign that corresponds to the sense of the prevailing average detuning. The frequency of the applied detuning voltage should be outside of the range of transmission of the radio apparatus in which the oscillatory circuit is incorporated, and may be subsonic or supersonic. When the oscillatory circuit is accurately tuned to the desired signal frequency, the developed control voltage is of course zero.

Objects of the invention are to provide methods of and circuit arrangements for automatic tuning that are characterized by a high fidelity transmission over a wide tuning range. Objects are to provide automatic tuning methods and circuit arrangements that are applicable both to amplitude and to frequency modulated transmission and reception. More specifically, objects are to provide methods of and circuit arrangements for cyclically varying the detuning of an oscillatory circuit by superposing an alternating current upon a voltage-variant reactance of the circuit, and developing from the resultant

2

amplitude-varying output a pulsating current that varies in magnitude and in algebraic sign with the average detuning of the circuit.

These and other objects and advantages of the invention will be apparent from the following specification when taken with the accompanying drawings in which:

Fig. 1a is a resonance curve of an oscillatory circuit of the apparatus to be controlled;

Fig. 1b is a curve sheet showing on a time basis the cyclic detuning that arises when an oscillatory current or voltage input to the circuit is continuously varied over a small frequency range;

Fig. 1c is a curve sheet showing on a time basis the amplitude variation of the voltage output which results from the cyclic detuning;

Fig. 1d is a curve sheet showing on a time basis the magnitude and algebraic sign of the pulsating control voltage developed from the amplitude-varying output voltage;

Figs. 2 and 3 are schematic diagrams of circuit arrangements for developing control voltages that vary in amplitude and in sign with the extent and the sense of the average detuning of an oscillatory circuit; and

Fig. 4 is a circuit diagram of a radio transmitter that includes electrical devices for developing the desired control voltages for automatic tuning.

The resonance curve of a frequency-stabilized control circuit such as contemplated by the invention is shown in Fig. 1a, the abscissae F of the curve being the magnitude of the detuning $(f_2 - f_1)$ between the frequency f_1 of the transmitted oscillations and the resonant frequency f_2 of the control circuit. The ordinates of the curve indicate the relative amplitudes of the current or voltage output of the circuit for signals of different frequencies below and above the resonant frequency f_2 of the control circuit. As illustrated, the frequency f_2 of the transmitted oscillations differs from the resonant frequency f_1 of the circuit by a value F_0 and, in accordance with the invention, the tuning error is varied between values F_1 and F_2 by imposing a periodic variation upon the frequency f_1 of the transmitted oscillations, see Fig. 1b. A voltage output from the control circuit may be rectified to develop an alternating current u of the frequency of the applied detuning, see Fig. 1c, which varies in amplitude between values u_1 and u_2 with respect to a value u_0 corresponding to the average detuning F_0 . By rectifying this alternating voltage u , a pulsating control voltage p is obtained

3

which has a mean value q dependent upon the average detuning F_0 , see Fig. 1d, and which has an algebraic sign corresponding to the sense of the detuning when the rectification is effected by a phase-sensitive rectifier. This average value q of the control voltage becomes zero as soon as the average detuning disappears.

An arrangement for performing the method according to the invention is illustrated schematically in Fig. 2 as including an oscillator G which supplies a radio frequency voltage to the oscillatory circuit S which is tuned to resonance at a frequency f_2 , the basic frequency f_1 of the oscillator being varied at a low frequency f_x by an alternating current voltage v developed by a source N . The specific details of the circuit element or elements by which the frequency of the oscillator is varied between $f_1 - f_x$ and $f_2 + f_x$ by the applied voltage v are not an important feature of the invention. Any of the known arrangements, for example a saturating core inductance, a condenser having an electrode vibrated by an electromagnet on which the voltage v is impressed, or a variable reactance tube may be employed. The frequency $f_1 \pm f_x$ of the radio frequency signal transmitted by the control circuit S is not affected by the mistuning of that circuit to frequency f_2 but the amplitude of the signal at the output side of the circuit S varies at the applied mistuning frequency f_x . A rectifier D is connected to the oscillatory circuit S and develops a low frequency alternating voltage u which varies in amplitude with the instantaneous detuning as shown in Fig. 1c. This alternating voltage u is of the same frequency f_x as the applied detuning voltage v , and is imposed upon a phase-sensitive rectifier M , which is shown schematically as a ring modulator upon which the alternating voltage v is also impressed. The voltage output p from the ring modulator M is a pulsating direct current voltage which varies in magnitude and also as to algebraic sign, with the periodic detuning of the generator G . The pulsating voltage p is transmitted through a low pass filter B to develop an average control voltage q which is impressed upon the control oscillatory circuit S_1 , as indicated by the dotted line connection, to adjust the resonant frequency thereof towards the mean frequency f_1 of the signal voltage output from the generator G . The value of the control voltage q may be indicated on a measuring instrument J .

In an alternative arrangement, as shown schematically in Fig. 3, the periodic detuning by the voltage v is imposed upon the tuned oscillatory circuit S , and the control voltage q , which is developed by the same circuit elements and process steps as in the Fig. 2 circuit, is applied to generator G to reduce the divergence between the frequency f_1 of the generator output and the resonant frequency f_2 of the tuned circuit S .

The periodic influence of the tuning of the generator G or the oscillation circuit S by the control voltage v is for instance achieved with controllable reactances such as variable reactance tubes, inductances with variable saturation of the iron core, and the like. Purely mechanical tuning controls for the oscillator or the oscillation control circuit are also possible if, for instance, small additional capacities are provided the magnitude of which is varied by electromagnetic devices responsive to the regulating voltage. The same also applied to the tuning influences which the control voltage q has to exert.

Fig. 4 shows the application of the invention to a frequency or amplitude modulated transmitter.

4

The controlled oscillator G_1 of the transmitter can for the purpose of frequency modulation (FM) be influenced by the low frequency signal W_1 . The tuning of the frequency-control circuit S_1 is varied periodically in synchronism with the low frequency voltage v by means of a wobbling circuit W_1 , so that the output amplitude of this circuit is varied periodically by known frequency-variant reactances such as just described. The voltage output of the control circuit S_1 is rectified, as previously described, in a rectifier D_1 to develop a voltage u of the same frequency as the detuning voltage v . With a frequency modulation of the generator G_1 , the low frequency voltage u contains a considerable number of undesirable components whose frequency differs from the constant frequency of the regulating voltage v . A band-pass filter P_1 is provided for the suppression of these disturbing components. After amplification in amplifier V_1 the voltage u which depends on the detuning is passed to the phase-sensitive rectifier circuit M_1 at the output of which the voltage p_1 occurs in the manner described. The control voltage q_1 obtained by smoothing p_1 in the low-pass filter B_1 acts on a tuning element of the oscillator G_1 in such a manner that its average detuning compared with the control circuit S_1 always remains as small as possible.

By this means a frequency modulated high frequency voltage e_1 can be obtained whose average frequency always corresponds to the mean resonant-frequency f_2 of the circuit S_1 . The tuning variations of the oscillator G_1 due to voltage and temperature changes, which are difficult to avoid, are thus always immediately corrected. The control circuit S_1 can be constructed with a very small damping and can also easily be maintained at a constant temperature so that the frequency of the generator G_1 remains to a great extent independent of external influences. The tuning of the control circuit S_1 and if necessary at the same time also the rough tuning of the generator G_1 are varied for the purpose of selecting a desired frequency.

The same method is also used for a tuning control of the coupling circuit S_2 . For this purpose the tuning of this circuit is varied periodically by the wobbling device W_2 . With the aid of the intermediate circuits D_2 , P_2 , V_2 , M_2 , B_2 whose construction and method of operation correspond with that of the circuits already mentioned, a control voltage q_2 is obtained which maintains the detuning of the coupling circuit S_2 continuously at a minimum. The same method can also be applied to the further coupling circuit S_3 . Between the controlled circuits are the individual amplifier stages A_1 , A_2 whose amplification can be controlled by a low frequency signal W_a for the purpose of amplitude modulation (AM), as is indicated at A_2 .

Due to the periodic tuning variations of the control and coupling circuit S_2 small periodic variations occur in the amplitude of the high frequency output voltage e_2 . These variations affect the automatic tuning control of the oscillation circuit S_3 if its wobbling occurs in the same or opposite phase as the tuning variation of S_2 . This influence can, however, be avoided by shifting the phase of the low frequency voltage v by 90° in the phase-shifting circuit Q . Another means of avoiding this disturbance is to use different frequencies for the voltages v which serve to alter periodically the tuning of the coupling circuits S_2 and S_3 .

The same method can of course also be applied to numerous other arrangements, particularly with radio receivers. Where superheterodyne receivers are concerned it is advisable to influence the auxiliary or local oscillator by means of both the control voltage q as well as the periodically varying regulating voltage v , so that the detuning of the intermediate frequency signal compared with the tuned intermediate frequency circuits is maintained at a minimum.

I claim:

1. In radio receiving or transmitting apparatus, a pair of serially arranged oscillatory circuits comprising a tunable carrier frequency oscillator working into a tunable control circuit normally resonant at the desired frequency of carrier wave generation, said oscillator including a voltage-variant reactance to control the resonant frequency thereof, means for cyclically varying the resonant frequency of said control circuit about its normal value of the desired frequency of carrier wave generation, whereby the output voltage of said circuits varies periodically in amplitude with the cyclic detuning of said control circuit, means for rectifying said amplitude-variant voltage to develop an alternating voltage of the frequency of the periodic detuning, means for phase-rectifying such alternating voltage to develop a pulsating voltage having a mean value dependent in magnitude and sign upon the degree and sense of the average detuning of said circuits with respect to each other, and means for impressing said pulsating voltage upon the voltage-variant reactance in said oscillator circuit to reduce the average detuning.

2. In radio receiving and transmitting apparatus, the invention as recited in claim 1, wherein said means for cyclically varying the tuning of said control circuit includes a variable reactance in said circuit, electro-mechanical means for controlling the effective value of said variable reactance, and a source of cyclically varying voltage energizing said electromechanical means.

3. In radio receiving and transmitting apparatus, the invention as recited in claim 1, wherein said means for phase-rectifying such alternating voltage comprises a ring modulator.

4. In radio receiving or transmitting apparatus, a source of oscillatory current, a plurality of cascaded transmission stages working out of said source and each including an oscillatory circuit having a voltage-variant reactance, means for imposing different periodic detunings upon said oscillatory circuits to develop voltages fluctuating in amplitude with said detunings, and means including phased rectifiers for developing from said fluctuating-amplitude voltages a plurality of control voltages for application to the voltage-variant reactances of the associated oscillatory circuits to reduce the average detuning thereof with respect to the frequency of said oscillatory current source.

5. In radio receiving or transmitting apparatus, the invention as recited in claim 4, wherein said means for detuning said oscillatory circuits impose detunings thereon of different frequencies.

6. In radio receiving or transmitting apparatus, the invention as recited in claim 4, wherein said means for detuning said oscillatory circuits impose detunings thereon of the same frequency but of different phase.

7. In radio receiving or transmitting apparatus, the invention as recited in claim 4, wherein said means for detuning said oscillatory circuits impose upon two of said oscillatory circuits detun-

ings of the same frequency and phase-shifted by 90° .

8. In the operation of radio transmitting and receiver apparatus including a tunable carrier frequency oscillator working into a tunable oscillatory circuit, said oscillator including a voltage-variant reactance for controlling the resonant frequency thereof, the process of reducing any tuning deviation between the resonant frequency of said circuit and the frequency of the oscillator which comprises the steps of periodically and progressively varying a frequency-controlling voltage applied to the voltage-variant reactance of said oscillatory circuit to effect a cyclic tuning deviation at a frequency outside the signal transmission range of the apparatus, thereby to vary the amplitude of the voltage output of said circuit at the frequency of tuning deviation, rectifying such amplitude-varying voltage to develop an alternating current voltage of the frequency of tuning deviation, phase-rectifying the alternating current voltage to develop a direct current voltage which varies in algebraic sign with the sense of the average detuning, and impressing said direct current voltage upon the voltage-variant reactance of said oscillator.

9. In the operation of radio transmitting and receiving apparatus of the type including a pair of cascaded tunable circuits, each of said circuits including a voltage-variant reactance to control the tuning thereof, the process of reducing deviations between the resonant frequencies of said circuits with respect to the frequency of a carrier wave transmitted by said circuits, said process comprising the steps of periodically and progressively varying the tuning of said circuits at a frequency outside the audio frequency range, thereby to vary the amplitudes of the output voltages of said cascaded circuits at the frequency of the imposed detuning, rectifying such amplitude-varying voltages to develop alternating voltages of the frequency of the applied detuning, phase-rectifying such alternating voltages to develop direct current voltages which vary in algebraic sign with the sense of the average detunings of the respective circuits, and imposing such direct current voltages upon said voltage-variant reactances of the respective circuits from which they were derived to reduce the average detuning thereof.

10. In the operation of radio transmitting and receiver apparatus of the type including a plurality of tunable circuits in series in a line of signal transmission, each of said circuits including voltage-variant reactances for controlling the resonant frequency thereof; the process of controlling the tuning of said circuits which comprises periodically varying the resonant frequencies of said tunable circuits at different frequencies which are each outside the range of audio frequencies, rectifying the output voltages of said circuits to develop alternating current voltages of the said different frequencies, phase-rectifying said alternating current voltages to develop direct current voltages which vary in algebraic sign with the sense of the average detuning of the several circuits, and impressing said direct current voltages upon the voltage-variant reactances of the individual circuits from which the respective direct current voltages were derived.

11. In the operation of radio transmitting and receiver apparatus of the type including a plurality of tunable circuits in series in a line of signal transmission, each of said circuits includ-

ing voltage-variant reactances for controlling the resonant frequency thereof; the process of controlling the tuning of said circuits which comprises periodically detuning said circuits at the same frequency but out of phase, rectifying the output voltages of said circuits to develop alternating current voltages, phase-rectifying said alternating current voltages to develop direct current voltages which vary in algebraic sign with the sense of the average detuning of the several circuits, and impressing said direct current voltages upon the voltage-variant reactances of the individual circuits from which the respective direct current voltages were derived.

12. In the operation of radio transmitting apparatus of the type including a tunable carrier frequency oscillator working into an amplifier stage and a control circuit having a resonant frequency corresponding to the desired frequency of carrier wave transmission, said oscillator including a voltage-variant reactance for controlling the resonant frequency thereof, means for impressing a modulation upon the carrier frequency output of said oscillator, and a tunable circuit including a voltage-variant reactance coupling said oscillator and said amplifier stage; the process of maintaining a substantially constant frequency transmission which comprises periodically varying the resonant frequency of said control circuit and said coupling circuit at a frequency outside the modulation range to develop alternating voltage outputs therefrom which vary in magnitude at the frequency of the detuning, phase-rectifying such alternating current voltages to develop pulsating direct current voltages which vary in magnitude and in algebraic sign with the extent of and the sense of, respectively, the detuning of the oscillator and the coupling circuit, impressing the direct current voltage derived from said control circuit upon the voltage-variant reactance of said oscillator, and impressing the other direct current voltage

upon the voltage-variant reactance of said coupling circuit, whereby said oscillator and coupling circuit may be retuned to the desired transmission frequency.

13. In the operation of radio transmitting and receiving apparatus including a plurality of cascaded amplifier stages upon which a carrier wave of substantially fixed frequency is impressed, and coupling circuits including voltage-variant reactances working into said amplifier stages; the process of reducing detuning of said coupling circuits which comprises periodically detuning said coupling circuits, thereby to develop alternating output voltages therefrom of the frequency of the detuning, phase-rectifying such alternating output voltages to develop direct current voltages which vary in magnitude and sense with the average detuning of the coupling circuits, and impressing such direct current voltages upon the voltage-variant reactances of the individual coupling circuits to reduce the average detuning thereof.

GUSTAV GUANELLA.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,819,904	Love	Aug. 18, 1931
1,907,965	Hansell	May 9, 1933
2,231,996	Guanella et al.	Feb. 18, 1941
2,245,685	Koch	June 17, 1941
2,261,800	Freeman	Nov. 4, 1941
2,287,925	White	June 30, 1942
2,296,100	Foster et al.	Sept. 15, 1942
2,354,510	Earp	July 25, 1944

OTHER REFERENCES

363,862	Dolle et al.	Pub. May 25, 1943
---------	-------------------	-------------------