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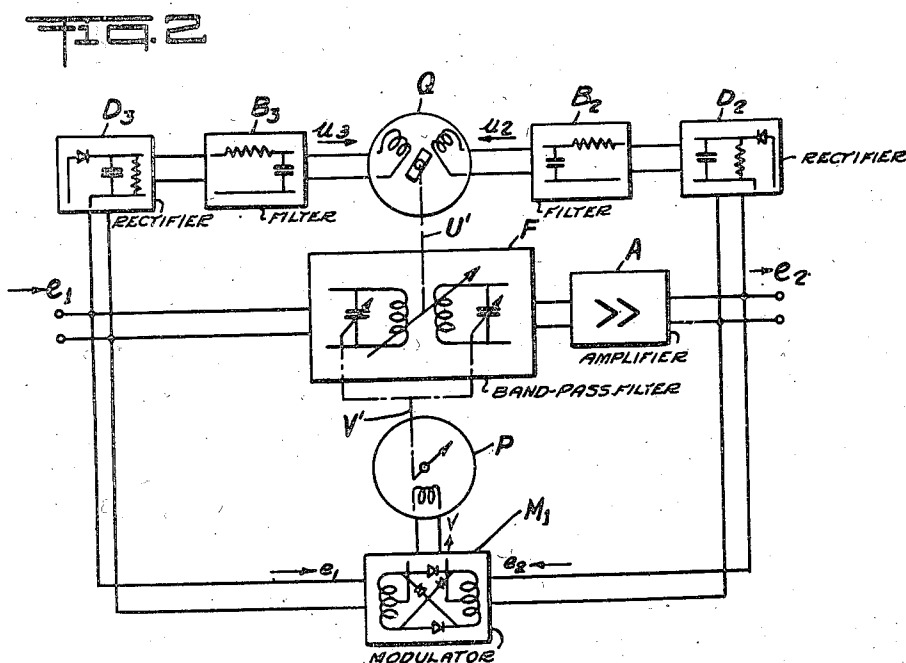
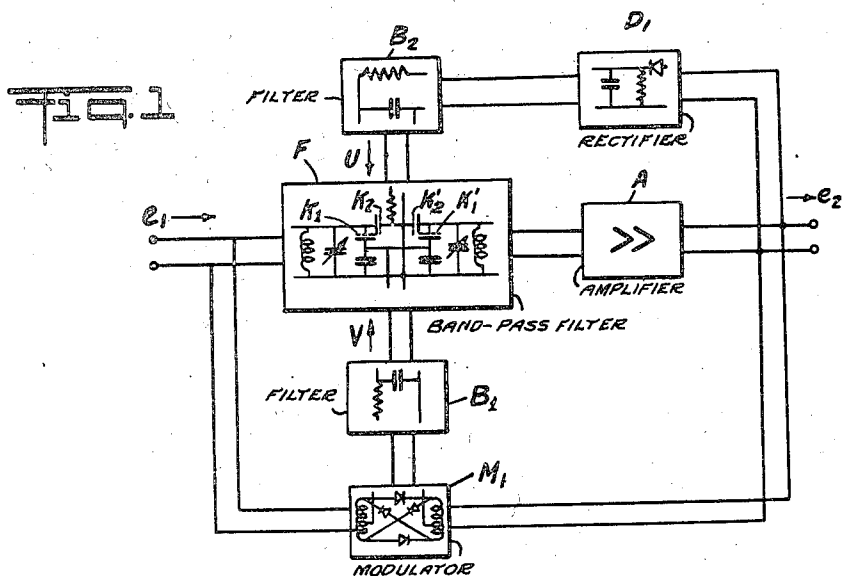
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2,453,988

AUTOMATIC FREQUENCY CONTROL

Filed Feb. 26, 1944

3 Sheets-Sheet 1



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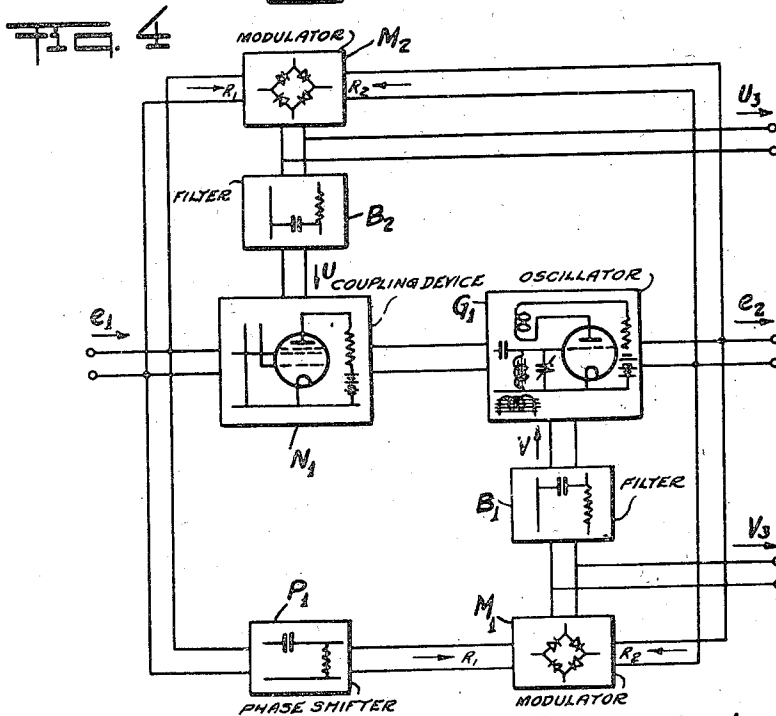
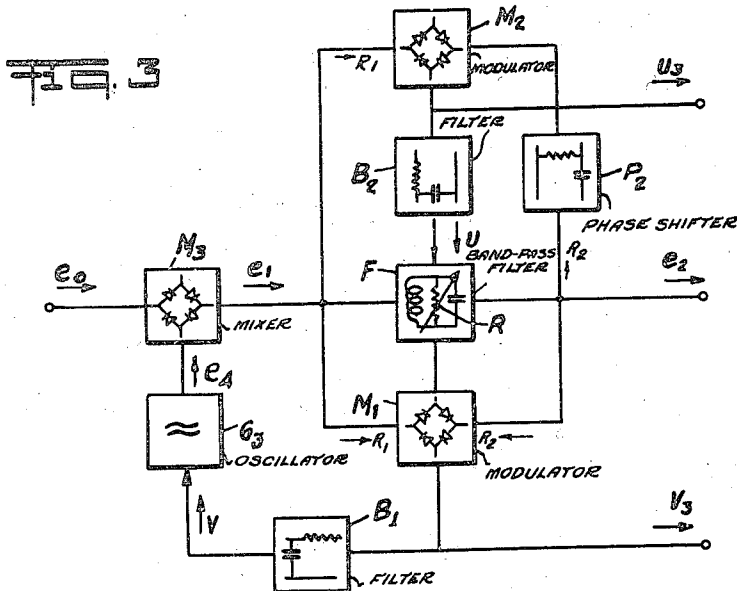
Nov. 16, 1948.

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AUTOMATIC FREQUENCY CONTROL

2,453,988

Filed Feb. 26, 1944

3 Sheets-Sheet 2



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Nov. 16, 1948.

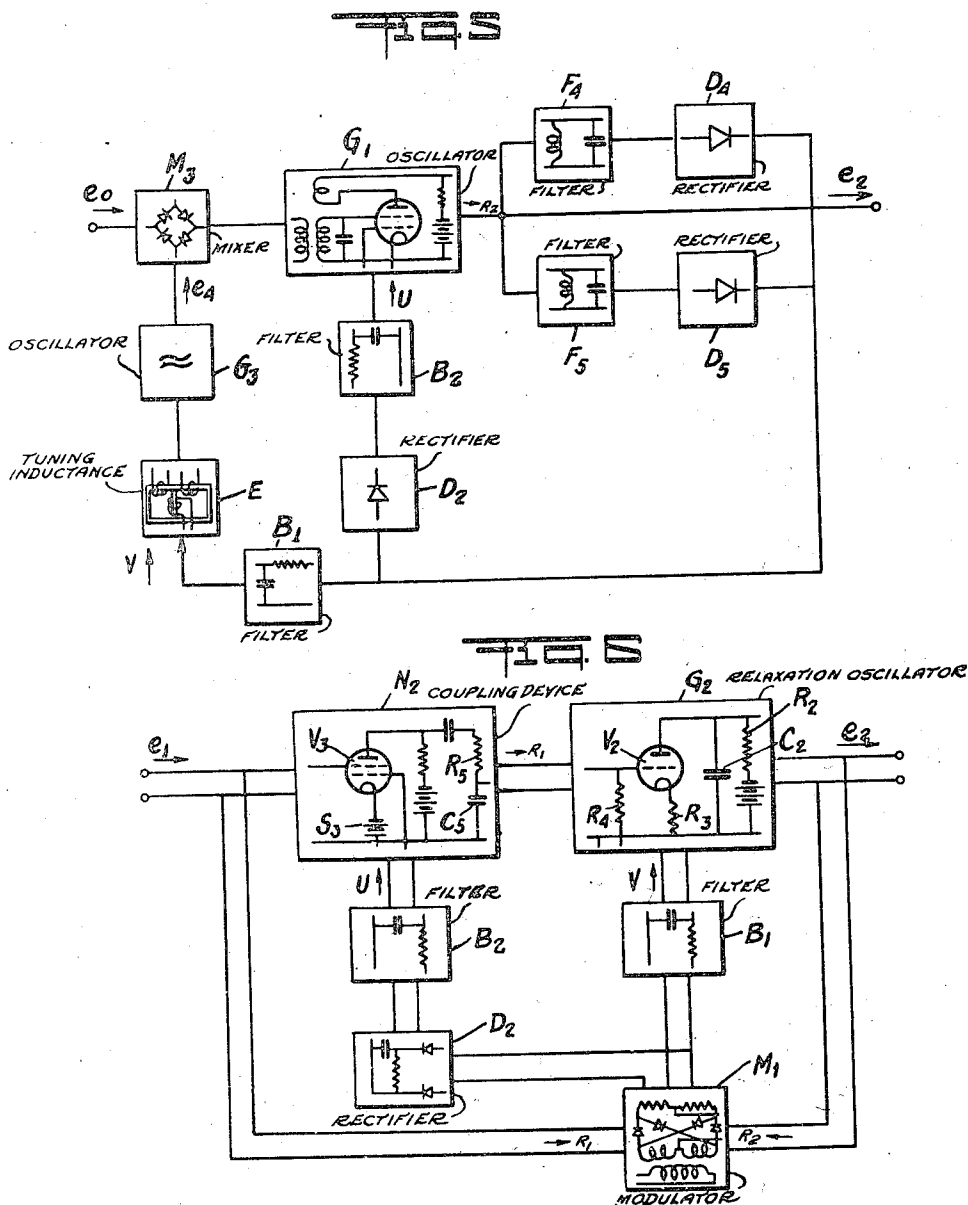
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2,453,988

AUTOMATIC FREQUENCY CONTROL

Filed Feb. 26, 1944

3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,453,988

AUTOMATIC FREQUENCY CONTROL

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Application February 26, 1944, Serial No. 524,080
In Switzerland July 10, 1942

Section 1, Public Law 690, August 8, 1946
Patent expires July 10, 1962

18 Claims. (Cl. 250—20)

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The present invention relates to a method of and means for controlling the frequency of an electrical oscillator or the resonant frequency of a tuned circuit or network, more particularly to automatic tuning or frequency control to maintain the frequency at a desired or assigned value.

According to a known method for the automatic sharp tuning of oscillation circuits, the tuning control is influenced by a regulating voltage depending on the deviation from resonance in such a manner that the resonant frequency of the circuit to be tuned, such as a band pass filter, is adjusted to coincide with the frequency of a controlling oscillation. The disadvantage of this method is the fact that if the initial deviation from resonance of such an oscillation circuit is large, practically no oscillations are transmitted by it, so that no regulation is possible. In order to be able to initiate the regulating process if there is a difference between the controlling and the resonance frequency it is necessary that the frequency passing range of the oscillation circuit should not be too small. After the regulation is completed, all frequencies within a larger range will then, however, be transmitted, such as the side bands of a modulated carrier as well as neighbouring disturbing frequencies. The suppression of these frequencies which are very often undesirable causes considerable difficulty in arrangements featuring automatic sharp tuning or frequency control.

According to other known methods, oscillation generators are synchronized with an incoming oscillation by means of a regulating voltage formed by comparing the phase of the generated oscillation with that of the incoming oscillation, the resulting regulating voltage depending, as regards both magnitude and sign, upon the phase difference between both oscillations and serving to influence the generator tuning adjustment so that a definite phase relationship is maintained between both oscillations. Such a regulation is only possible after synchronism has been achieved between both said oscillations.

Oscillation generators may also be synchronized with external oscillations by applying the external alternating voltage to the generator so that the generator frequency, even if the generator is slightly detuned, coincides with the external frequency due to the so-called lock-in effect. In this case, the generated oscillation may, however, also be influenced in an undesirable manner by disturbing voltages which differ only slightly from the generator tuning frequency.

The disadvantages of these known methods are

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avoided according to the present invention by reducing the difference between the resonance frequency of a tunable circuit and the frequency of a controlling voltage by means of a first regulating voltage the sign and magnitude of which are a function of the deviation from resonance, the dependence of the output voltage of said circuit on the controlling voltage being influenced by a second regulating voltage which depends on the absolute value of the deviation from resonance and which decreases when the deviation from resonance decreases. This second regulating voltage is thus large during a large initial deviation from resonance so that, despite such deviation, sufficient output amplitudes are available to enable the automatic tuning correction to be initiated. As soon as the deviation from resonance is reduced by the action of the first regulating voltage, the dependence of the output alternating voltage on the input voltage also decreases on account of the effect of the second regulating voltage, whereby to eliminate or reduce the effect of interfering signals on the frequency control.

The tunable circuit may for instance be a band pass filter. The change of the dependence or relation between the input and output voltage may be effected by altering the coupling of individual filter elements, by varying the tuning adjustment of such elements, by influencing the filter damping or in any other known manner. Alternatively, a vacuum tube generator in regenerative feedback connection or any other form of oscillation generator may be used wherein the dependence of the input voltage on the output voltage is influenced by varying the degree of feedback.

Constructional examples of the invention are illustrated diagrammatically in Figures 1-6 of the accompanying drawings, wherein:

Fig. 1 is a block diagram illustrating a basic system embodying the principles of the invention for automatically maintaining a resonant circuit or network in tune with a high frequency current or signal;

Fig. 2 shows a modification of Fig. 1;

Fig. 3 is a block diagram illustrating a system according to the invention for maintaining the frequency of an incoming signal in tune with the resonating frequency of a resonant circuit or network;

Fig. 4 shows a system according to the invention for automatically maintaining the frequency of an oscillator in tune or synchronism with an incoming or controlling frequency; and

Figs. 5 and 6 are systems similar to Fig. 4 illus-

trating further modifications and improvements of the invention.

Like reference characters identify like parts throughout the different views of the drawings.

In the arrangement shown in Fig. 1, the circuit to be tuned has the form of a band pass filter F comprising two capacitively coupled parallel-tuned oscillation circuits. The average passing frequency is influenced by the direct current regulating voltage v , for instance in such a manner that this voltage is applied to both the parallel capacities K_1 and K_1' whose capacity value depends on a direct current polarisation voltage. A simple form of such condenser is described in my U. S. Patent No. 2,191,315. In order to produce the regulating voltage v , the modulation product is formed from the input alternating voltage e_1 and the output alternating voltage e_2 of the filter with the aid of a modulator M_1 of any suitable type such as of the dry rectifier type, as indicated. If the circuit F is out of tune with the controlling voltage e_1 , the phase angle between e_1 and e_2 differs from the 90° angle prevailing when the filter is in resonance with the frequency of e_1 , this variation being either positive or negative depending upon the sense of deviation of the resonant frequency from the controlling frequency. The modulation product therefore includes a positive or negative direct current component. This direct current is separated from the alternating components by the filtering device B_1 and serves to influence in the form of the regulating voltage v the filter tuning adjustment, until the phase angle between voltages e_1 and e_2 approaches the value 90° , in which case the deviation from resonance tends to disappear. The amplitude of the output oscillation voltage e_2 increases as the deviation from resonance decreases. The band width of the filter circuit F is therefore decreased simultaneously. A band width regulating voltage u which corresponds to the amplitude of voltage e_2 may be used for this purpose. This regulating voltage may be obtained by rectifying a portion of output energy in the rectifier D_1 and subsequently filtering it in by means of the low-pass filter B_2 . The regulation of the band width as a function of voltage may be effected by controlling the coupling capacities K_2 which upon being reduced by an increasing polarisation voltage will affect the band width. Other means are known for controlling the tuning adjustment and band width in dependence upon a regulating voltage or current, such as inductances with variable premagnetisation, vacuum tube arrangements with controllable grid or anode reactances, and the like. The amplifier A which is located after the band filter F and serves to decrease the filter loading may be located in another branch of the circuit or may be omitted.

A disadvantage of the arrangement according to Fig. 1 is the fact that the regulating voltage u not only depends on the deviation from resonance but also on the amplitude of the input voltage e_1 . In order to reduce this dependence on the amplitude, the regulating voltage u may be derived from the difference of the rectified voltages e_1 and e_2 . The regulating voltage thus produced decreases if the deviation from resonance decreases and should be supplied to the filter in such a way that the coupling also decreases simultaneously.

The regulating voltage u may be completely independent of the input amplitude by deriving it from the quotient of the rectified input and output voltage e_1 and e_2 respectively. For this pur-

pose, components of the voltages e_1 and e_2 which as shown in Fig. 2 are rectified by means of rectifiers D_2 and D_3 , respectively, are passed through the filtering circuits B_2 and B_3 to a quotient meter Q. The regulating voltage u then appears for instance in the form of a torque or a rotation of an axis corresponding to the quotient

$$\frac{U_2}{U_1}$$

The rotation or torque of the device Q in the example illustrated serves to directly mechanically vary the coupling between the resonant circuits of the filter F, as indicated schematically by the coupling connection U' . Similarly, the output of the modulator M_1 may serve to mechanically control the tuning adjustment of the filter F by means of a direct current instrument P having its movable member coupled with the adjustable filter condensers, as indicated schematically at V' in the drawing.

The resonance deviation of the filter may also be reduced by a corresponding alteration of the filter input frequency with the filter being tuned to a constant frequency. In the arrangement shown in Fig. 3, the input voltage e_1 is produced by forming the sum or difference frequencies from an incoming alternating voltage e_0 and an auxiliary alternating voltage e_4 produced by a generator G_3 with the aid of the modulator M_3 . The tuning adjustment of generator G_3 and in turn the frequency of voltages e_1 and e_4 are controlled by the frequency regulating voltage v . This regulating voltage is again obtained by forming the modulation product of voltages e_1 and e_2 in modulator M_1 and subsequently filtering it in filter B_1 . A second regulating voltage u is obtained by mutually intermodulating in the modulator M_2 the filter input voltage e_1 with a portion of the output voltage e_2 which latter is displaced in phase by 90° in the phase rotating circuit P_2 . Thus, when the deviation from resonance disappears, the phase angle between voltages e_1 and e_2 to be intermodulated will be 0° , that is to say the direct current component of the modulation product will be a maximum. Filter B_2 is provided for the suppression of the sum frequencies occurring in modulator M_2 and of any temporary disturbances of the regulating voltage u . The control of the filter F by the regulating voltage u may be achieved by controlling the damping resistance R whose magnitude determines the frequency passing range and which should have a minimum when the voltage u reaches its maximum value.

In the arrangement shown in Fig. 4, the tuned circuit forms a part of a vacuum tube generator G_1 . The input alternating voltage e_1 is applied to this generator by way of a variable coupling element N_1 whose gain or amplification varies in direct proportion to the degree of deviation of the frequency generated by the generator G_1 from the frequency of the controlling signal voltage e_1 . The phase difference between the generated oscillation e_2 and the controlling oscillation e_1 is again a measure of the deviation from synchronism. When this deviation disappears, both oscillations are in phase. By modulating in the modulator M_1 , the controlling oscillation e_1 , after phase shifting by 90° in the phase-shift circuit P_2 , with a portion of the output oscillation e_2 , a modulation product is obtained which, after the alternating voltage components have been suppressed in filter B_1 , yields a direct voltage v corresponding to the phase difference between voltages e_1 and e_2 and

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thus to the deviation from synchronism of the generator both in magnitude and sign from the frequency of the input voltage e_1 . This direct voltage v is applied as a frequency regulating voltage to the generator G_1 whose tuning adjustment, as indicated, is influenced by varying the pre-magnetisation of an iron-core coil so as to reduce the deviation from synchronism. Simultaneously, the coupling of the generator to the input voltage e_1 by the coupling tube N_1 is reduced, whereby the generator tuning adjustment is maintained despite the reduced deviation from synchronism. For this purpose, the modulation product of voltages e_1 and e_2 is formed in modulator M_2 which, with both oscillations being in phase, that is to say, with a minimum deviation from synchronism, and after filtering in B_2 yields a control voltage u attaining a maximum value and thus reducing the coupling through N_1 to a minimum. The effect of any disturbing input voltage on the generator oscillation e_2 is thus correspondingly reduced. If the frequency of voltage e_1 is sufficiently constant, the coupling in N_1 may be reduced to zero by a maximum regulating voltage u so that the influence of any disturbing frequencies on the generator disappears entirely. The frequency and phase equality between voltages e_1 and e_2 is then maintained continuously by the regulating voltage v which depends on the relative phase between e_1 and e_2 . If for any reason the generator should fall out of step the direct current component of the modulation product formed in M_2 will disappear. This causes the coupling in N_1 to increase again and the generator to be affected once more by the incoming signal voltage e_1 so that a renewed tuning regulation will be initiated until the duration from synchronism disappears again. The coupling may be varied by regulating the amplification of the coupling tube N_1 in accordance with the regulating voltage u . Other means for varying the coupling may consist in controlling a coupling inductance or capacity, in a manner well known and understood.

In the arrangement according to Fig. 5, the deviation from synchronism is reduced similarly as in Fig. 3 by the frequency control action of an auxiliary generator G_3 , whose alternating voltage e_4 is superimposed in the modulator M_3 on the incoming or control oscillation e_3 . The tuning adjustment of the generator G_1 may then remain constant. For controlling the frequency, the generator oscillation e_2 is transmitted over the oscillatory circuits F_4 and F_5 , one of which is tuned slightly above and the other is tuned slightly below the generator frequency, and which circuits are followed by rectifiers D_4 and D_5 , respectively. The difference of the rectified voltages which is filtered in B_1 corresponds both in magnitude and sign to the frequency deviation between the generator oscillation and the generator tuning adjustment and is applied to the auxiliary generator G_3 as a regulating voltage v so as to effect a reduction of the frequency deviation. For the purpose of the frequency control a tuning coil having a ferro-magnetic core is shown provided at E , the saturation of this coil being varied by the regulating voltage v . With a relatively large original deviation of the oscillator G_1 from the desired frequency only a very small feed-back is necessary in order to maintain the oscillation. This feed-back may be increased as soon as the oscillator frequency decreases so that undesirable effects due to the appearance of disturbing oscilla-

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tions are suppressed. Instead of varying the feed-back it is also possible to vary the amplification of the tube. In order to produce an amplification control voltage u , a portion of the output of the frequency discriminator F_4 , F_5 , D_4 , D_5 is rectified in rectifier D_2 and filtered in a filter B_2 . The regulating voltage thus obtained is zero when the tuning deviation is at a minimum and causes a reduction in the amplification and therefore an increase in the limits of synchronism according to whether the tuning deviation is positive or negative.

In the arrangements which have been described it has been assumed that the input and output alternating voltages are sinusoidal. There are, however, cases where at least one of these voltages is not sinusoidal but follows some other periodic law. Thus, the voltages in question may be in the form of impulse or saw-tooth voltages. If the input voltage is not sinusoidal, the voltage may be filtered to give it a sinusoidal shape, whereupon it is applied in the manner already described to the tuned circuits and compared with the output voltage. Non-sinusoidal output voltages may be obtained from sinusoidal filter or generator voltages by non-linear transmission elements or in any other known manner. There are, however, also arrangements wherein the generator voltage itself is not sinusoidal.

Thus in the arrangement shown in Fig. 6, G_2 represents a saw-tooth oscillation generator comprising a gas-filled discharge tube V_2 whose anode condenser C_2 is slowly charged through a resistance R_2 until the ignition voltage of tube V_2 is reached and a rapid discharge occurs through the tube so that an oscillation of saw-tooth shape occurs. Due to the voltage drop through the cathode resistance R_3 during each discharge, negative grid voltages are produced which favour the extinction of the tube. The frequency of the oscillations depends on the average grid voltage which is supplied through resistance R_4 . In order to synchronize the generator, periodic impulses may be transmitted by way of the variable coupling device N_2 or serve as input or controlling voltage e_1 for the generator G_2 . Whenever the impulse amplitude is adequate, each impulse causes an oscillation process so that the oscillation is carried along by the impulse, even if the natural frequency of the generator determined by C_2 , R_2 and the grid bias voltage do not coincide with the impulse frequency. The modulation product formed in modulator M_1 from the oscillation and impulse voltages depends on the phase difference between the two voltages. The direct current component obtained by filtering in filter B_1 corresponds in magnitude and sign to small phase differences between these voltages, being zero if the middle of the saw-tooth voltage flank coincides with the centre of the impulse. This direct current component is supplied through the grid resistance R_4 to the oscillation generator as a regulating voltage v so that the natural frequency which the generator would have without any impressed control voltage, approaches the impulse frequency. At the same time the amplitude of the impressed impulse voltage may be reduced without risk of disturbing the synchronism, because on account of the reduced deviation the generator is certain to be kept in synchronism. By this means, any disturbing effects on the oscillation are reduced. The electron tube V_3 in the coupling circuit N_2 whose amplification decreases when the regulating voltage u becomes more negative may be provided to reduce the amplitude

of the impressed voltage. This regulating voltage may be formed by rectifying and filtering in the circuits D_2 and B_2 respectively, a portion of the modulation product obtained in M_1 , so that voltage u becomes positive both with a positive and negative generator deviation from synchronism and decreases as the detuning disappears. With a suitable value for the cathode bias battery S_3 or a corresponding grid bias source, an amplification by the tube is obtained which varies between a maximum and minimum according to the generator deviation from synchronism. At the end of the regulating operation, the saw-tooth voltage e_2 coincides with the impulse voltage e_1 as regards both frequency and phase, whereby the coupling through N_2 is very small or zero. The saw-tooth oscillation generator is then maintained in synchronism primarily by means of the frequency regulating voltage v which depends on the relative phase between C_1 and C_2 , and the regulating process is then analogous to the mechanism described in U. S. Patent 2,231,998, issued February 18, 1941, entitled "Synchronizing system." When there is a close coupling through N_2 , the oscillation of generator G_2 has the tendency to begin with each impulse. The phase changes of the saw-tooth oscillations depending on the detuning are thus only small. It is therefore advisable to produce from the impulse voltage, with the aid of the capacity C_5 and the relatively large series resistance R_5 , a saw-tooth voltage which is impressed on the generator G_2 . The phase difference between this saw-tooth voltage and saw-tooth output voltage e_2 depends to a large extent on the generator synchronism, so that correspondingly large positive or negative frequency regulating voltages v will result. In order to improve the regulating process, special filter or retarding circuits may be placed in the transmission path of the input voltage e_1 either in front of the coupling circuit N_2 or the modulator M_1 .

The examples illustrated in the drawings represent only a few of the many possible modifications by which the invention can be carried out in practice. Thus, both regulating voltages or currents may be converted into corresponding mechanical forces or movements. In this case, the modulation circuits represented by M_1 and M_2 may be replaced by wattmeter-like devices producing a force corresponding to the average product of the applied currents or voltages. Known means may be employed to prevent the regulation from hunting. Thus, integrating or differentiating means may be provided in the transmission path which according to prevailing conditions produce either a very accurate or very rapid regulation.

The arrangements according to the invention may be put to various uses and applications. In the arrangements shown in Fig. 3 or Fig. 4, oscillations with amplitude or phase modulation may for instance be supplied as input alternating voltages e_0 or e_1 , respectively. The modulation side bands of these oscillations, after the regulating process is ended, are practically completely suppressed by the progressive decrease by the damping of filter F or by the decoupling effect of the generator G_1 , so that the output oscillation e_2 coincides with the unmodulated and phase-rotated carrier. It is known that the modulation product of this carrier with the modulated oscillation produces the low frequency signal transmitted by amplitude or phase modulation. This signal may thus be derived from the outputs of the modulators M_2 or M_1 as the output voltage u_3 or u_2 , respectively. The difficulties hitherto en-

countered with known homodyne reception methods of this type as regards an extremely exact tuning of the filters or generators for obtaining the unmodulated carrier, are thus avoided.

The method according to the invention may also be used to eliminate disturbing oscillations from alternating voltages of variable frequency. In this way, it is possible for instance to eliminate all disturbances from the received oscillations in remote measuring transmitting devices having a frequency depending on the measuring value.

The arrangement shown in Fig. 6 is suitable for producing synchronized picture or line deflection voltages in television receiving apparatus. In this case, the effects of unavoidable transmission disturbances on the deflection voltage are avoided, so that an automatic synchronisation within a large frequency range of the picture or line variation is obtained.

If the automatic tuning influence should also follow very rapid frequency variations of the added alternating voltage, the time constants of the automatic regulation circuits must be selected so as to be correspondingly small. The deviation from synchronism may thus be kept continuously at a low value even if this alternating voltage is frequency-modulated according to speech or audio frequencies. The disturbances which occur at the reception of such frequency-modulated oscillations are thus reduced to a minimum, since all disturbing frequencies which differ from the momentary frequency of the carrier will have no effect on the output alternating voltage.

I claim:

1. In a system for maintaining resonance between the natural frequency of a resonant network and the frequency of an alternating current wave, means comprising discriminating means for producing a control voltage varying in sense and magnitude according to the relative departure between the frequencies of said network and said wave, frequency control means operated by said control voltage and effective in restoring and maintaining resonance between the frequency of said network and said wave, means for producing a further control voltage varying in direct proportion to the absolute value of said frequency departure, and means for varying the effectiveness of said discriminating means in accordance with said further control voltage.

2. In a system for maintaining the frequency of an electrical resonant network in tune with the frequency of a controlling oscillation, means comprising discriminating means for producing a control voltage varying in sense and magnitude according to the relative departure between the frequencies of said network and said oscillation, frequency control means for said network operated by said control voltage to restore and maintain the resonance between said network and oscillation, means for producing a further control voltage varying in direct proportion to said frequency departure, and further means for varying the effectiveness of said discriminating means in accordance with said further control voltage.

3. In a system for maintaining the frequency of a resonant network in tune with the frequency of a controlling oscillation, means comprising discriminating means for producing a control voltage varying in sense and magnitude according to the relative departure between the frequencies of said network and said oscillation, frequency control means for said network operated by said control voltage to restore and maintain

resonance between said network and said oscillation, band width control means for said network, means to produce a further voltage in response to and being proportional to the absolute value of said frequency departure, and means to operate said band width control means by said further control voltage to increase the band width of said network in proportion to said frequency departure.

4. In a system for maintaining the frequency of a resonant network in tune with the frequency of a controlling oscillation, means comprising discriminating means for producing a control voltage varying in sense and magnitude according to the relative departure between the frequencies of said network and said oscillation, frequency control means for said network operated by said control voltage to restore and maintain resonance between said network and said oscillation, means for controlling the input-output amplitude transmission ratio of said network, means for producing a further control voltage in response and being proportional to the absolute value of said frequency departure, and means for operating said transmission control means in accordance with said further voltage to increase the transmission ratio of said network in proportion to said frequency departure.

5. In a system for maintaining the frequency of a resonant network in tune with the frequency of a controlling oscillation, means to apply said oscillation to the input of said network and to derive oscillatory energy from the output of said network, modulating means energized by input and output oscillatory energy of said network to produce a first control voltage proportional in sense and magnitude to the relative departure between the frequencies of said network and said oscillation, frequency control means for said network operated by said control voltage to restore and maintain resonance between said network and said oscillation, further means for producing a second control voltage proportional to the absolute value of said frequency departure, input-output amplitude ratio control means for said network, and means to operate said last control means by said second control voltage to vary said first control voltage in proportion to said frequency departure.

6. In a superheterodyne system comprising a network having a fixed resonant frequency, heterodyning means comprising an auxiliary oscillator for converting the frequency of an incoming oscillation to an intermediate frequency equal to the resonant frequency of said network, means for applying the intermediate frequency oscillation to said network, means comprising discriminating means for producing a control voltage varying in sense and magnitude according to the relative frequency departure between said intermediate frequency oscillation and said network, frequency control means for said oscillator operated by said control voltage to restore and maintain resonance between said network to said intermediate frequency oscillation, means for controlling the input-output amplitude transmission ratio of said network, means for producing a further control voltage in response and being proportional to the absolute value of said frequency departure, and means for operating said amplitude transmission control means by said further control voltage to increase the effectiveness of said discriminating means in proportion to said frequency departure.

7. In a superheterodyne system comprising a network having a fixed resonant frequency, het-

erodyning means comprising an auxiliary oscillator for converting the frequency of an incoming oscillation to an intermediate frequency equal to the resonant frequency of said network, means for applying the oscillations of intermediate frequency to said network, modulating means energized by input and output oscillatory energy of said network to derive a first control voltage varying in sense and magnitude according to the relative frequency departure between said network and the intermediate frequency, frequency control means for said oscillator operated by said control voltage to restore and maintain said network in resonance with said intermediate frequency, further means for producing a second control voltage proportional to the absolute value of said frequency departure, input-output amplitude transmission control means for said network, and means to operate said last control means by said second control voltage to vary said first control voltage in direct proportion to said frequency departure.

8. In a system for maintaining the frequency of a self-excited electron tube oscillator in synchronism with a wave of control frequency, variable coupling means for applying said wave to said oscillator to synchronize the oscillating frequency, discriminating means producing a first control voltage varying in sense and magnitude according to the departure of the frequency of said oscillator from the frequency of said wave, frequency control means for said oscillator operated by said control voltage to restore and maintain said oscillator in synchronism with said wave, means for producing a second control voltage proportional to the absolute value of said frequency departure, and means for controlling said coupling means by said second control voltage to vary the coupling in direct proportion to said frequency departure.

9. In a system for maintaining the frequency of a self-excited electron tube oscillator in synchronism with a wave of control frequency, a coupling tube having an amplification control electrode for applying said wave to said oscillator to synchronize the frequency of the generated oscillation, discriminating means for producing a first control voltage varying in sense and magnitude according to the departure of the frequency of said oscillator from the frequency of said wave, frequency control means for said oscillator operated by said first control voltage to restore and maintain synchronism of said oscillator with said wave, means for producing a further control voltage proportional to the absolute value of said frequency departure, and means for applying said further control voltage to said control electrode to vary the amplitude of the control wave applied to said oscillator in proportion to said frequency departure.

10. In combination with a vacuum tube oscillator having regeneratively coupled input and output circuits including at least one frequency determining resonant circuit, means for maintaining the frequency of said oscillator in synchronism with a wave of control frequency comprising a coupling tube having an amplification control electrode for applying said control wave to said oscillator to synchronize therewith the oscillating frequency, discriminating means for producing a first control voltage varying in sense and magnitude according to the departure of the frequency of said oscillator from the frequency of said wave, frequency control means for said oscillator operated by said control voltage to re-

store and maintain the synchronism of said oscillator with said wave, rectifying means energized by said oscillator to produce a further control voltage proportional to the absolute value of said frequency departure, and means for applying said second control voltage to said amplification control electrode to vary the amplitude of the controlling wave applied to said oscillator in proportion to the degree of said frequency departure.

11. In a system for maintaining the natural frequency of an electric network in synchronism with a wave of control frequency, means responsive to the departure from and effective to restore the synchronism between said network and said wave, means for producing a control voltage proportional to the absolute value of said departure, and means for varying the effectiveness of said first named means in proportion to said control voltage.

12. In a system for maintaining the frequency of a self-excited oscillator in synchronism with a wave of control frequency, a coupling tube having an amplification control electrode for applying said wave to said oscillator to synchronize the frequency of the generated oscillations, means for producing a control voltage proportional to the absolute value of the degree of departure of the oscillator frequency from synchronism with the frequency of said control wave, and means for applying said voltage to said control electrode to vary the amplitude of the control wave upon said oscillator in proportion to said departure.

13. In a system for maintaining the frequency of a self-excited oscillator in synchronism with a wave of control frequency, variable coupling means for applying said control wave to said oscillator to synchronize the frequency of the generated oscillations, means for producing a control voltage proportional to the absolute value of the degree of departure of the oscillator frequency from synchronism with the frequency of said control wave, and further means for controlling said coupling means by said control voltage to vary the coupling thereof in proportion to said departure.

14. In an electric system, a self-excited oscillator, controllable coupling means for applying a wave of control frequency to said oscillator to synchronize the oscillator frequency with said control frequency, phase shifting means to produce quadrature input signal energy, a first modulator for combining said quadrature energy with output energy of said oscillator to produce a first control voltage varying in sense and magnitude according to the degree of departure of the oscillator frequency from synchronism with said wave, frequency control means for said oscillator operated by said control voltage to restore and maintain the synchronism of said oscillator with said control wave, a second modulator for combining normal input signal energy with output signal energy of said oscillator to produce a second control voltage varying according to the absolute value of said frequency departure, and means for controlling said coupling means by said second control voltage to reduce the coupling thereof in direct proportion to said frequency departure.

15. In an electric system, a self-excited oscillator, a coupling electron tube having an amplification control electrode for applying a wave

of control frequency to said oscillator to synchronize the oscillator frequency with the frequency of said wave, phase shifting means to produce quadrature signal input energy, a first modulator for combining said quadrature energy with output energy of said oscillator to produce a first control voltage varying in sense and magnitude according to the degree of departure of the oscillator frequency from synchronism with said wave, frequency control means for said oscillator operated by said control voltage to restore and maintain the synchronism of said oscillator with said wave, a second modulator for combining normal input signal energy with output energy of said oscillator to produce a further control voltage varying in proportion to the absolute value of said frequency departure, and means for applying said further control voltage to said amplification control electrode to vary the amplitude of the control wave applied to said oscillator in proportion to said frequency departure.

16. In an electric system, an oscillator, controllable coupling means for applying input energy of control frequency to said oscillator to synchronize the oscillating frequency with said control frequency, modulating means for combining input signal energy with output energy of said oscillator to derive a control voltage varying in proportion to the degree of departure of the oscillator frequency from synchronism with the control frequency, and means for controlling said coupling means by said control voltage to vary the applied input energy upon said oscillator in proportion to said frequency departure.

17. In a method of maintaining the natural frequency of an electrical network in synchronism with a wave of control frequency, the steps of producing a control voltage responsive to an initial relative departure of the network frequency from the frequency of said wave and being effective in counteracting said departure, and varying said control voltage in direct proportion to said departure.

18. In a method of maintaining the frequency of an electrical oscillator in synchronism with a wave of control frequency, the steps of producing a control voltage in response to an initial departure of said oscillator from synchronism with said wave and effective to counteract said departure, and varying said control voltage in direct proportion to said departure.

GUSTAV GUANELLA.

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