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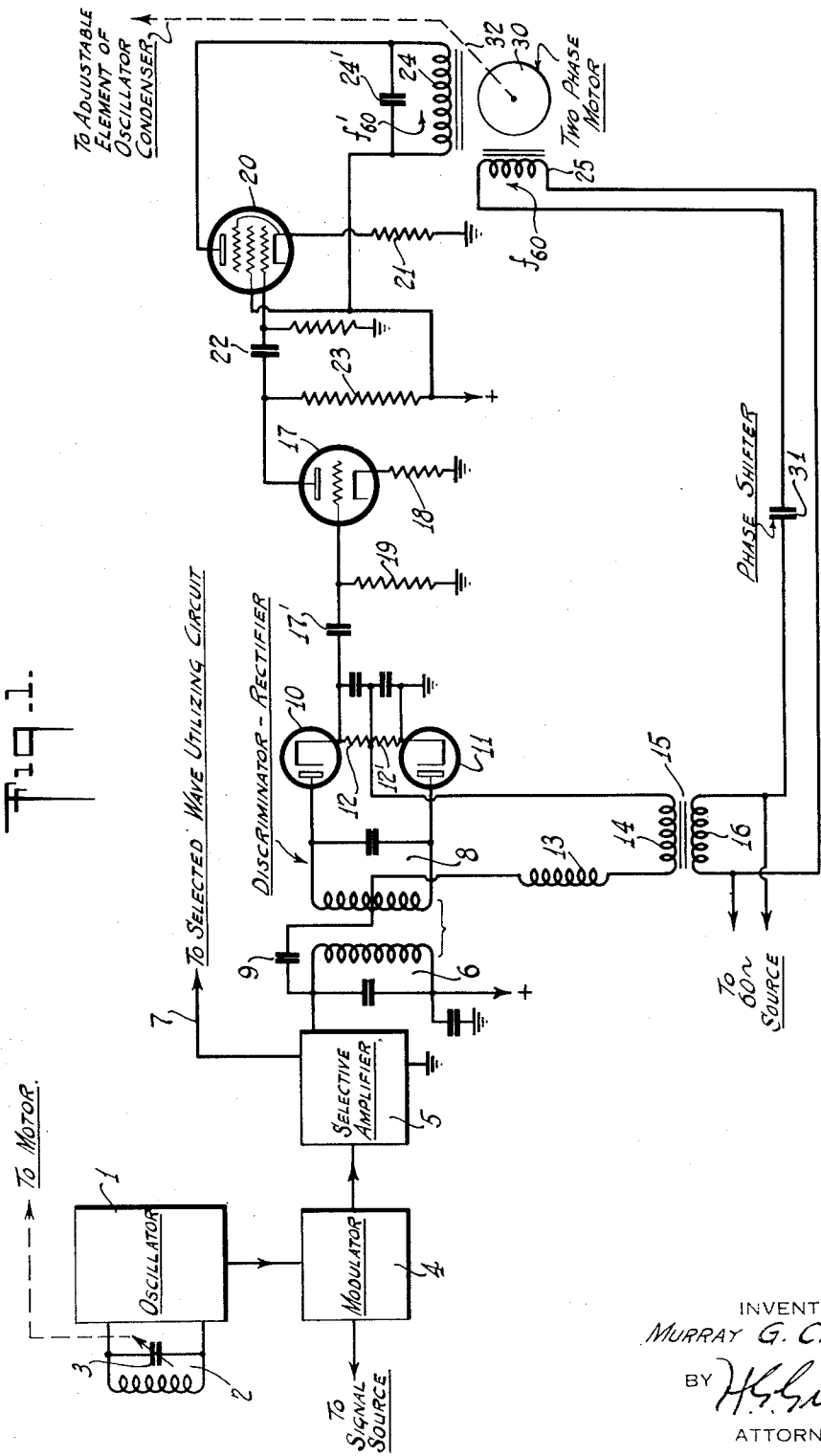
M. G. CROSBY

2,379,689

FREQUENCY CONTROL CIRCUIT

Filed Jan. 27, 1943

2 Sheets-Sheet 1



INVENTOR
MURRAY G. CROSBY.

BY *H. G. Brown*
ATTORNEY

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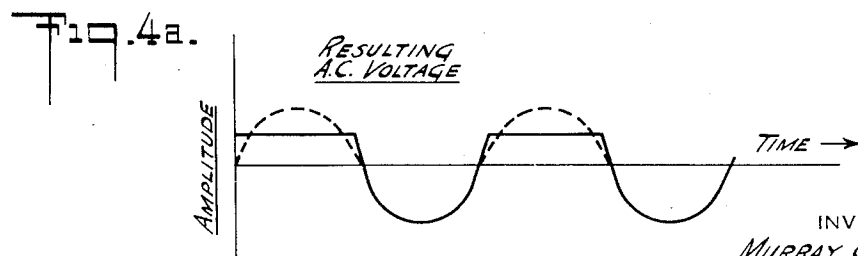
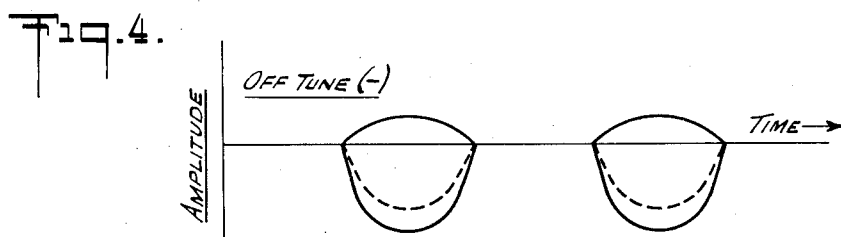
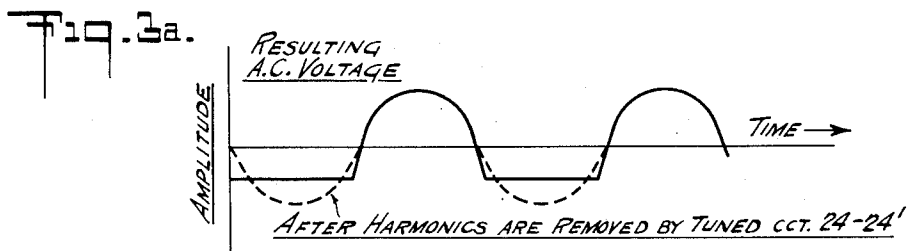
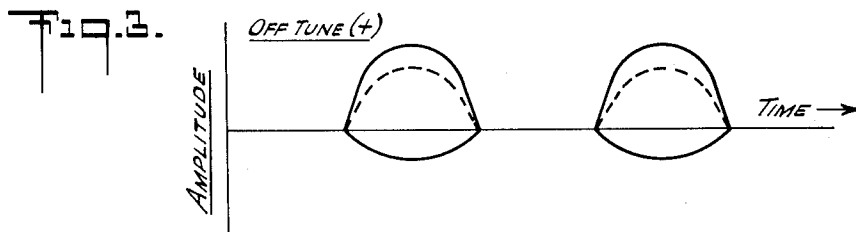
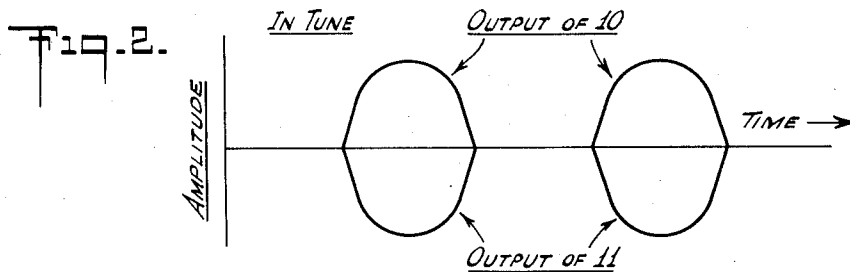
M. G. CROSBY

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FREQUENCY CONTROL CIRCUIT

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2 Sheets-Sheet 2



INVENTOR
MURRAY G. CROSBY
BY *H. B. Snover*
ATTORNEY

UNITED STATES PATENT OFFICE

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FREQUENCY CONTROL CIRCUIT

Murray G. Crosby, Riverhead, N. Y., assignor to
Radio Corporation of America, a corporation
of Delaware

Application January 27, 1943, Serial No. 473,681

1 Claim. (Cl. 250—36)

My present invention relates to frequency control circuits, and more particularly to automatic frequency control (AFC) circuits of the type responsive to shifts in carrier frequency from a predetermined frequency value.

One of the main objects of my present invention is to improve the gain of, and simplify, automatic frequency control systems of the type disclosed in my copending application Serial No. 393,339, filed May 14, 1941.

Another important object of this invention is the provision of a frequency discriminator circuit upon which is applied modulated high frequency energy of a predetermined mean frequency, there being provided a two phase motor device for maintaining the magnitude of the mean frequency of the modulated energy, a low frequency motor-energizing current source being provided to feed current to said discriminator and said motor device in quadrature phase relation, and said motor device being energized as a function of the extent and sense of frequency shift of the modulated energy from said mean frequency by virtue of the low frequency current appearing at the discriminator output.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claim; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description, taken in connection with the drawings, in which I have indicated diagrammatically a circuit organization whereby my invention may be carried into effect. Fig. 1 shows a system of AFC employing the invention.

Fig. 2 illustrates the rectifier outputs in the in-tune state,

Fig. 3 shows the rectifier outputs for off-tune state, and Fig. 3a shows the resulting current flow through coil 24,

Figs. 4 and 4a show similar relations to Figs. 3 and 3a respectively for off-tune state in the opposite sense.

Referring, now, to the accompanying drawings, I have shown my present invention applied generally to an AFC system of a well known form. Generically, there are shown an oscillator 1 having a resonant tank circuit 2. The latter has a tuning, or frequency selecting, instrumentality 3. The oscillator, which may be considered as operative in any desired frequency band, feeds its oscillations to a network 4 indicated as a "Modulator." The latter is to be construed as generic to a transmitter modulator or a superheterodyne

receiver converter. The input electrode of the modulator will be connected to a source of signals. The modulator output energy, in the form of signal-modulated oscillations whose mean frequency is that of the frequency of tank circuit 2, is applied to a selective amplifier having input and output circuits each tuned to the aforesaid mean frequency. The numeral 6 designates the tuned output circuit of amplifier 5.

The numeral 7 denotes a transmission path feeding a utilizing circuit with the output energy of the selective amplifier 5. Where the system is a superheterodyne receiver, the oscillator 1 will be the usual local oscillator which is tunable, by tuning condenser 3, over a range of frequencies. The modulator 4 will, therefore, be the conventional first detector whose tunable input circuit is adjustable over a range of carrier frequencies. The modulator output circuit will, accordingly, be fixedly resonated to the intermediate frequency (I. F.) value. Amplifier 5 will be tuned to the operating I. F. value, as will the resonant output circuit 6. The path 7 may then feed the I. F. energy to additional I. F. amplifiers and to a second detector followed by audio frequency amplifiers and audio reproducer.

If the system is a transmitter, then the modulator 4 would be fed with audio signals, and with carrier oscillations of a predetermined frequency from a master oscillator 1. The output energy of modulator 4 will be at the frequency of the oscillator 1, but modulated in accordance with the signals fed to modulator 4. The amplifier 5 will then feed the modulated oscillatory energy to a radiating system over path 7.

It will now be seen that in either system there is developed at circuit 6 modulated carrier frequency energy. The carrier frequency may be in the kilocycle (kc.) range, or in the megacycle (mc.) range. As is well known in present-day super-heterodyne receivers, a change in oscillator frequency is accompanied concurrently by a change in the signal frequency of the converter input circuit. The resulting I. F. signal output energy is not accurately tuned in unless its mean frequency is equal to the resonant frequency of circuit 6. An AFC circuit responds to a frequency difference between the I. F. signal energy and the predetermined I. F. value to vary the oscillator tuning in a sense, and to an extent, such as to cause the frequency difference to be reduced. Similarly, in the case of a transmitter, a change in constants of the oscillator 1 may create a frequency difference to exist between the predetermined frequency value of amplifier 5 and the

mean frequency of the modulated carrier energy output of the amplifier.

A well known form of discriminator-rectifier network is shown coupled to circuit 6. The function of the network is to provide a control voltage, for AFC purposes, in response to a predetermined frequency shift of the carrier of the modulated wave energy applied to circuit 6. The specific form of circuit is that disclosed, and claimed, by S. W. Seeley in his U. S. Patent No. 2,121,103, granted June 21, 1938. Accordingly, the action of the discriminator-rectifier will not be described in detail, reference being made to that patent. It will be sufficient for the purposes of this application to explain that a resonant circuit 8, tuned to the same frequency as circuit 6, is magnetically coupled thereto. A direct current blocking condenser 9 is connected directly from the high potential side of circuit 6 to the midpoint of the coil of circuit 8.

The diode rectifiers 10 and 11, which may be provided by a 6H6 type tube, are arranged in polarity opposition. The anodes of the diodes are connected to respectively opposite sides of common input circuit 8. The cathodes are connected by a center-tapped resistor which is thereby divided into series load resistors 12 and 12'. Each of load resistors 12 and 12' is bypassed for carrier frequency currents by a respective shunt condenser. The cathode end of resistor 12' is grounded. The junction of load resistors 12 and 12' is connected to the midpoint of the coil of circuit 8 through a path consisting of coils 13 and 14 in series. Coil 14 is the secondary of a power input transformer 15. The primary winding 16 of the transformer is connected across a source of low frequency current. For example, the latter may be the usual 60 cycle line current employed to energize the various tubes of the system. The invention is not limited to the use of 60 cycle current, and it is to be clearly understood that any other value of low frequency may be used in place of the specific 60 cycle value.

The cathode end of resistor 12 is connected to the control grid of tube 17, shown as a triode merely by way of illustration, by a direct current blocking condenser 17'. The cathode of tube 17 may be connected to ground by the bias resistor 18, and the control grid returned to ground by the resistor 19. A further amplifier, as for example a pentode, is designated by numeral 20. The bias resistor is 21, and the input grid of tube 20 is coupled by direct current blocking condenser 22 to the plate end of the plate load resistor 23. The screen and plate of tube 20 may be connected to the lower end of resistor 23, the winding 24 of the two phase motor device being included in the plate circuit. The condenser 24' shunts winding 24, and tunes the winding to resonance with the 60 cycle current.

The numeral 30 designates the rotor of the two phase motor. The latter is schematically represented, since its construction is well known in the electrical art. The energizing windings of the motor rotor 30 are represented by numerals 24 and 25. These windings are wound on a common iron core, and will each carry 60 cycle current derived from the 60 cycle source. The winding 25 has one end thereof connected through phase shifter condenser 31 to one end of primary winding 16 of transformer 15. The opposite end of coil 25 is connected to the opposite end of winding 16. In other words, the coil 25 is arranged in a closed series circuit with the primary winding 16 and phase shifter 31.

The rotatable element of the two phase motor is indicated as being arranged for mechanical coupling with the adjustable, or rotor, element of variable condenser 3. The numeral 32 indicates a dotted line which is to be understood as schematically representing any desired type of mechanical coupling between the rotatable element of the two phase motor and the adjustable element of the tuning mechanism of oscillator 1. The motor need not adjust the rotor of the tuning condenser 3, since it can operate an auxiliary padder condenser arranged in shunt with condenser 3. This use of an auxiliary adjusting condenser will be desirable in most cases, and especially where frequency control is desired for small ranges on either side of the operating oscillator frequency.

In explaining the operation of the system which has been described, it is first pointed out that 60 cycle current will flow through windings 25 and 24. Furthermore, these currents must be in phase quadrature in order to energize the rotor 30. The currents through the windings 24 and 25 have been indicated by arrows designated respectively as i_{50} and i'_{50} . The 60 cycle current flowing through winding 24 is derived directly from the discriminator-rectifier network by virtue of the 60 cycle current injected into the common input circuit 8. The 60 cycle current flowing through winding 25 is derived directly from the 60 cycle source, but the phase shifter condenser 31 creates a 90 degree phase shift in the 60 cycle current flowing to the winding 25. Hence, in order to energize the motor it is merely necessary for 60 cycle current to appear in the winding 24.

However, the 60 cycle current will not appear in winding 24 unless the modulated carrier energy appearing at the circuit 6 has a mean frequency which is not equal to the predetermined frequency of circuits 6 and 8. In other words, for modulated carrier energy whose mean frequency is equal to the predetermined frequency of input circuit 8 the discriminator-rectifier network has no output with a 60 cycle current component. However, if the modulated carrier energy developed across circuit 6 has its mean frequency shifted from the aforementioned predetermined frequency of circuits 6 and 8, that is for off-tune condition, then a 60 cycle voltage component will appear across load 12-12' and be transmitted through tubes 17 and 20 thereby to flow through winding 24.

The tubes 17 and 20 function as 60 cycle current amplifiers. When the mean frequency of the applied modulated carrier energy is equal to the predetermined frequency of each of circuits 6-8, the radio frequency voltages applied to the rectifiers 10 and 11 will be of equal magnitude. This arises in virtue of the construction of the discriminator network, and has been explained in detail in the aforesaid Seeley patent. The equal radio frequency voltages applied to rectifiers 10 and 11 are rectified into direct current voltages developed across each of resistors 12 and 12'. These direct current voltages are of equal magnitude. Hence, both diodes are biased equally, and, since both are fed equal amounts of the 60 cycle voltage from 14, the differential output of 60 cycles appearing across 12 and 12' will be zero. The diode output resistors are connected in phase opposition. Consequently, there will be zero 60 cycle voltage in this case. This is equivalent to showing that there will be zero 60 cycle current flow through winding 24.

On the other hand, if the mean frequency of

the applied modulated carrier energy departs from the predetermined frequency in one direction, one of the rectifiers will receive more radio frequency voltage than the other. This places unequal biases on the diodes so that their output of 60 cycle component will be unequal. The differential output will then no longer cancel so that 60 cycle voltage will be developed at the cathode end of resistor 12, and the magnitude and polarity of the voltage will depend upon the extent and direction of shift of the aforesaid mean frequency. Hence, 60 cycle current flow through winding 24 will have a magnitude and direction dependent upon the extent and direction of shift of the mean frequency of the applied modulated carrier energy from the predetermined frequency of circuits 6 and 8. In this way, there is provided a method of operating the two-phase motor at variable speed and in alternative directions. This permits an accurate control over adjustments of the tuning instrumentality of circuit 2 of oscillator 1.

In Figs. 2, 3, 3a, 4 and 4a there is graphically presented the functioning of the circuit embodying my invention. In Fig. 2 there is shown the "in-tune" voltage outputs of rectifiers 10 and 11 so far as 60 cycle current is concerned. Since both diodes are equally biased, each acts as a half wave rectifier. The outputs are equal and cancel. Fig. 3 shows the "off-tune" state, when the mean frequency of applied carrier energy has shifted to one side of the predetermined reference frequency. The output of rectifier 10 exceeds that of rectifier 11, and the resultant output is shown in dotted curves in Fig. 3. Fig. 3a shows the resulting voltage in full line curve, and the dotted curve in that figure shows the effect of tuned circuit 24—24' in removing harmonics. The 60 cycle current through winding 24 has been reduced in intensity.

Figs. 4 and 4a show the manner in which the

phase of the 60 cycle current is changed when the "off-tune" is in the opposite sense. Figs. 4 and 4a correspond respectively to Figs. 3 and 3a.

While I have indicated and described one system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention as set forth in the appended claim.

What I claim is:

In combination with a high frequency oscillator having means for adjusting the frequency thereof, a two phase motor provided with a pair of energizing windings, a source of alternating current, means for applying current from said source to one of said windings, a discriminator-rectifier network comprising a pair of diodes each having an anode and cathode, an input circuit coupled between the anodes of said diodes, a resistor connected between the cathodes of the diodes, a second input circuit connected between a point on the first input circuit and a point on said resistor, means for impressing oscillatory energy derived from said oscillator upon the first input circuit whereby said diodes develop across said resistor rectified voltages which bias the diodes equally in response to the frequency of the oscillatory energy being equal to a predetermined reference frequency, means to apply current from the alternating current source to said second input circuit, and connections from said resistor to the second of said windings for providing alternating current through the latter in response to said rectified voltages becoming unequal due to a frequency difference between the oscillatory energy frequency and said reference frequency, and means causing said alternating currents to flow through said windings in phase quadrature.

MURRAY G. CROSBY.