

Nov. 16, 1943.

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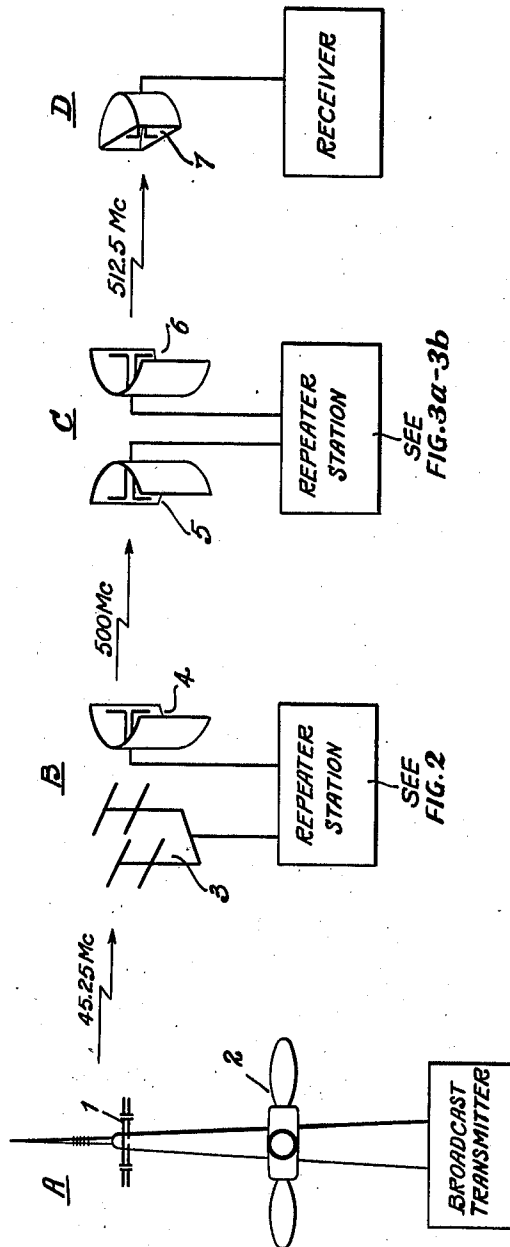
2,334,189

RELAY SYSTEM AND ASSOCIATED CIRCUIT THEREFOR

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6 Sheets-Sheet 1

Fig. 1.



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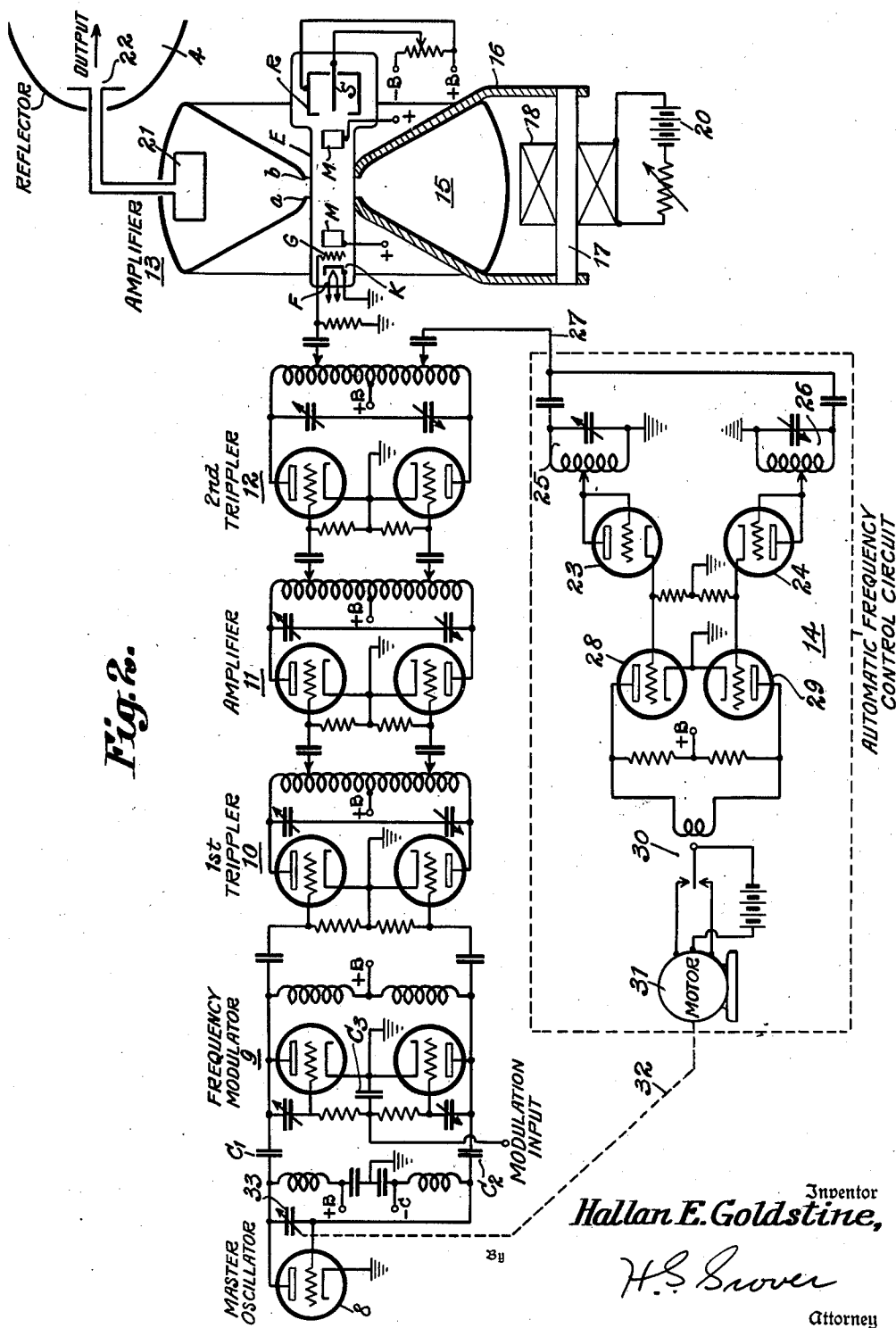
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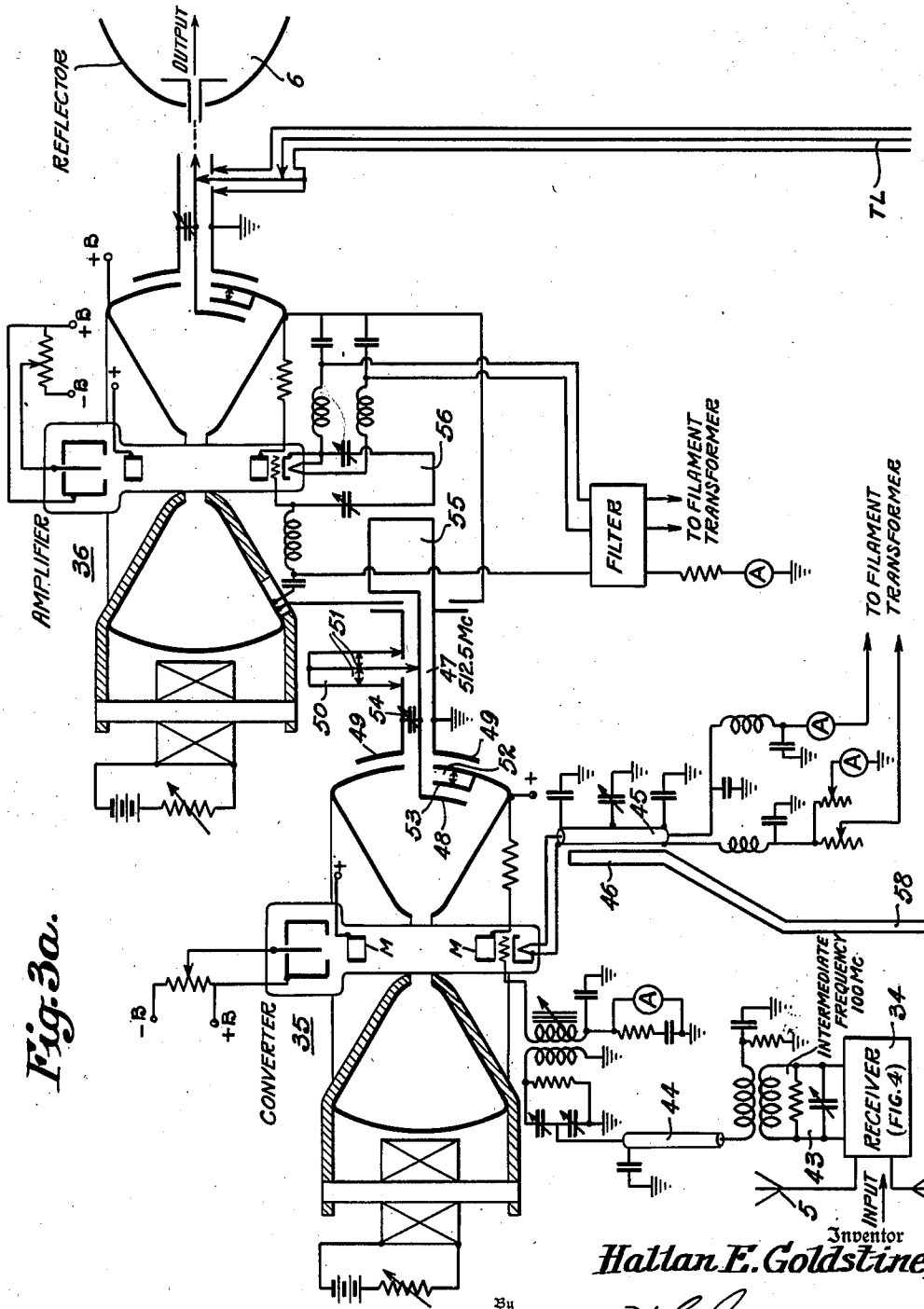


Fig. 3a.

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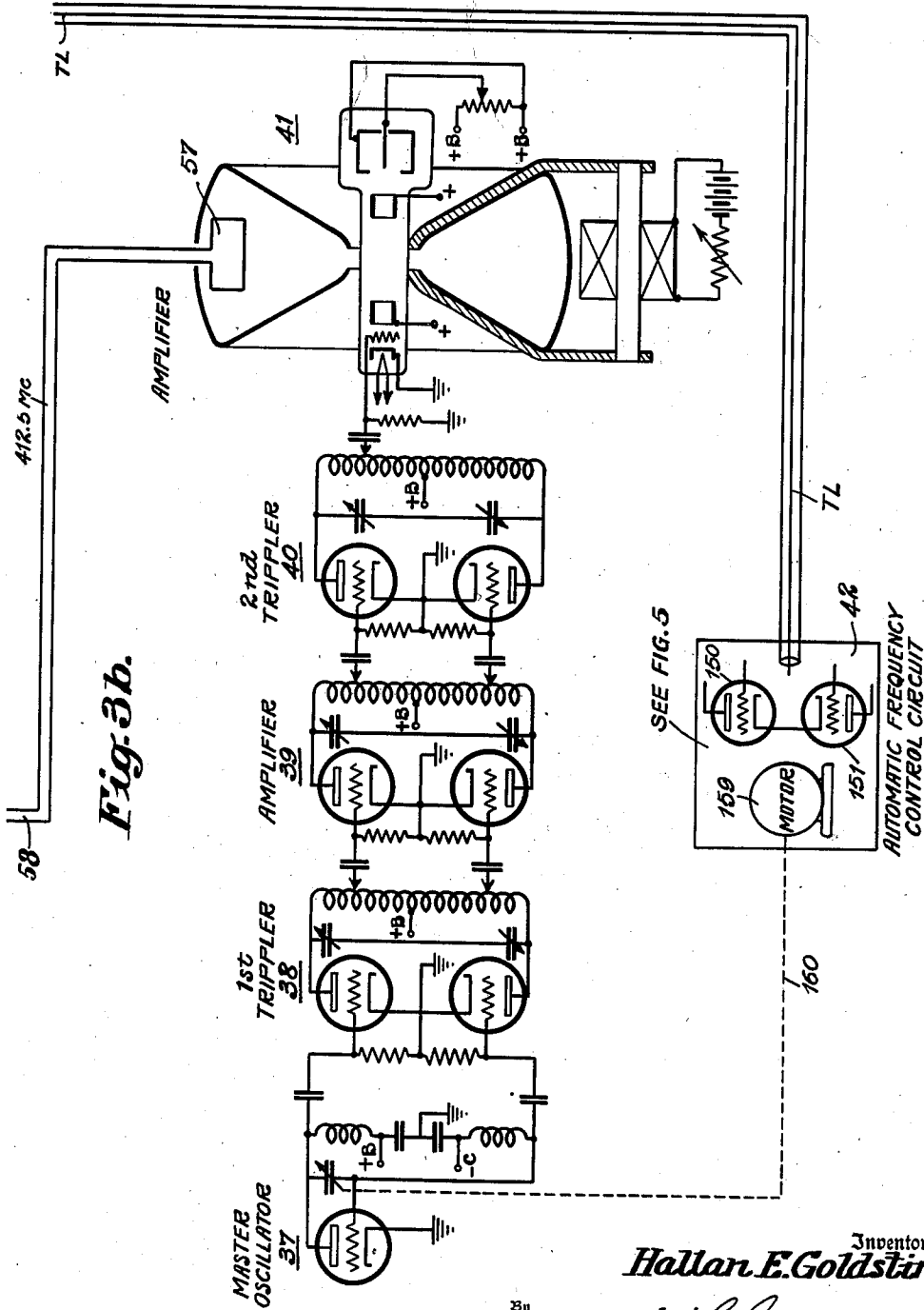
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RELAY SYSTEM AND ASSOCIATED CIRCUIT THEREFOR

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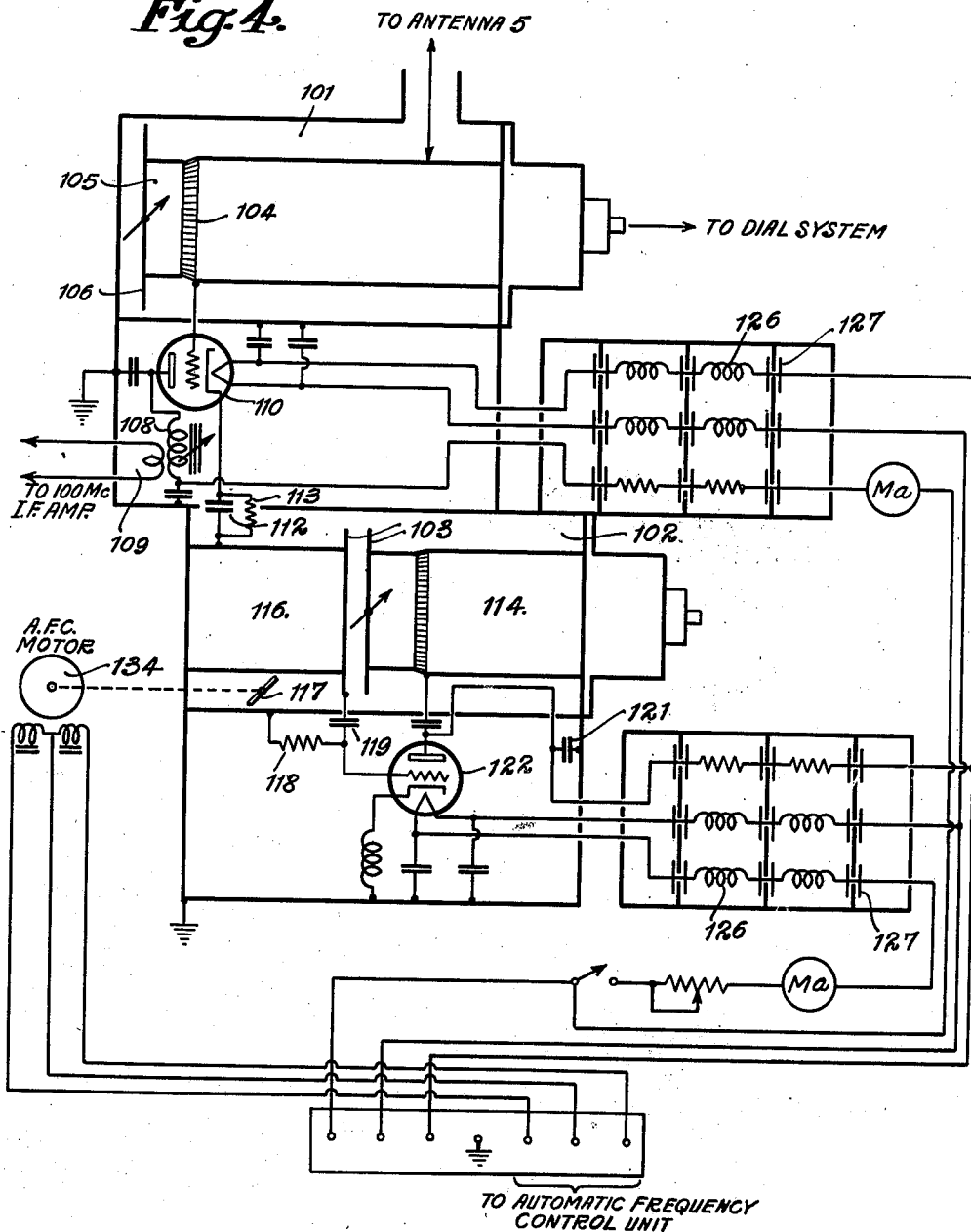
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RELAY SYSTEM AND ASSOCIATED CIRCUIT THEREFOR

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Fig. 4.



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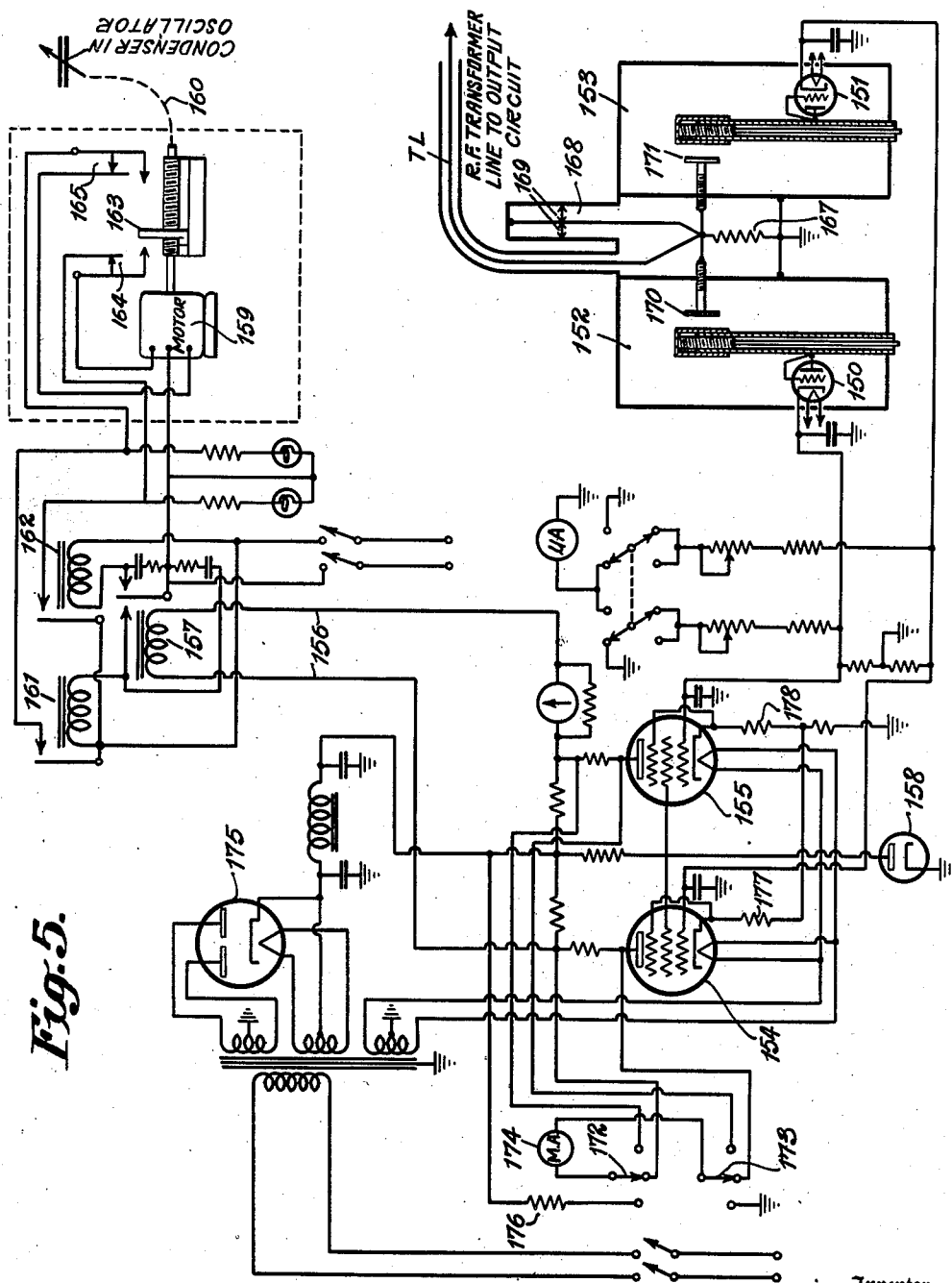
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RELAY SYSTEM AND ASSOCIATED CIRCUIT THEREFOR

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UNITED STATES PATENT OFFICE

2,334,189

RELAY SYSTEM AND ASSOCIATED
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Application June 5, 1940, Serial No. 338,862

11 Claims. (Cl. 250-15)

This invention relates generally to a radio relaying system. More particularly, the invention relates to such features as (1) the frequency modulator circuit, (2) the repeater station for receiving a frequency modulated signal on one carrier frequency and relaying or retransmitting this frequency modulator signal on another carrier frequency, and (3) the automatic frequency control circuit employing cavity or concentric line resonators.

The following is a detailed discussion of the invention accompanied by drawings, wherein Fig. 1 shows very generally a complete radio relay system in which the present invention may be employed; Fig. 2 shows the frequency modulator system of the invention employed in a repeater station of the system of Fig. 1 for converting video signals into frequency modulated high frequency signals; Figs. 3a and 3b taken together show apparatus employed at one of the repeater or relay stations of the system of Fig. 1 for changing the carrier frequency of a received frequency modulated signals to another carrier frequency; Fig. 4 illustrates one type of ultra high frequency converter unit which may be used in the receiver of Fig. 3a for changing the received signal to a lower intermediate frequency signal; and Fig. 5 illustrates an automatic frequency control circuit which is employed in the circuit of Fig. 3b for stabilizing the frequency of an oscillator.

The radio relaying system of Fig. 1 is designed for use particularly with ultra short wave radio signals of the order of six meters and less, and may be used for the transmission of television signals, although it will be understood that it may also be used to transmit telegraph signals or any other type of radio signal. The system includes a transmitting station A, a plurality of intermediate repeater or relay stations B and C, and a receiving station D, suitably spaced apart along the line of transmission. Repeater stations B and C are designed to repeat the signals from station A to station D. The arrows indicate the directions of the signals between the respective stations. Although only two repeater stations have been shown, it should be understood that this number is illustrative of any number of repeater stations which may be located at frequent intervals along the line of transmission, for relaying and amplifying signals.

The antenna system indicated at the transmitting station A of Fig. 1 is shown to be of the omnidirectional type, having constant characteristics over a frequency band sufficiently wide to

accommodate the full band spectrum of high definition television. This antenna consists of two separate and independent radiator systems, 1 and 2, the former for sound and the latter for vision transmission, both radiators being supported on a common column located an appreciable distance above ground, usually on the top of a tall building.

The antenna system of the transmitter station A is of the type installed at the top of the Empire State Building in New York, New York, and is described quite adequately in the copending application of Nils E. Lindenblad, Serial No. 208,573, filed May 18, 1938, now United States Patent 2,239,724, granted April 29, 1941. The antennas on stations B, C and D are of the unidirectional type, there being used a pair of antennas at the intermediate stations B and C, one for receiving the signals from the nearest transmitting antenna and the other for repeating and reradiating the signals to the next repeater or relay station along the line of transmission. Since the transmission range of the ultra short waves at which this system is designed to function depends substantially upon the air line or visual distance, a factor proportional to the height above the earth's surface, it is proposed to locate all stations at points having as great height as possible, such as on mountains, tall buildings, radio masts, etc. The receiving antenna 3 at repeater station B consists of a pair of dipole arrays placed one behind the other and suitably phased relative to each other for providing a unidirectional effect. This antenna is designed to receive the signals transmitted from station A. Reference is hereby made to P. S. Carter, United States Patent No. 2,183,784, granted December 19, 1939, for a suitable description of antenna 3. The reradiating or transmitting antenna 4 of station B is of the metal parabolic type which has at its focus a dipole or a plurality of dipole antennas arranged in the same straight line. These dipole antennas may be of the folded type which has been found to be more effective than the single dipole and is preferably of the general form described in the copending application of Philip S. Carter, Serial No. 155,385, filed July 24, 1937, now United States Patent 2,283,914, granted May 26, 1942. At repeater station C there are shown a receiving antenna 5, and a reradiating or transmitting antenna 6, both of the parabolic type employing folded dipole antennas as described in connection with antenna 4 of station B. Antennas 5 and 6 are of course effective in different direc-

tions, the receiving antenna 5 being positioned to receive the signals from station B while the transmitting antenna 6 is positioned to transmit the signals in the direction of the next adjacent station D. Antennas 5 and 6, as well as all the equipment at station C, are preferably mounted high above the earth's surface, such as on a steel tower. The antenna 7 at receiving station D comprises a parabolic reflector having at its focus one or more dipoles, preferably folded up dipoles, this antenna being, of course, directed to receive the signals from antenna 6 of the adjacent repeater station. The antennas of stations A to D, inclusive, have been described as being of particular types, mainly by way of example, since it is apparent that other types of antennas can be used to achieve the desired results.

In the operation of the system of Fig. 1, television signals emanating from broadcasting station A are amplitude modulated and radiated at a frequency of 45.25 megacycles and received on an antenna 3 at station B, from which the signals pass to a television receiver thereat to provide a video component, the band width of which may be substantially of the order of 4 megacycles. The video output of this television receiver at station B is used to control a transmitter with multi stages of frequency tripling, described more in detail later in connection with Fig. 2. The output of station B radiated from antenna 4 is a frequency modulated wave of the order of 500 megacycles; (in one particular embodiment tried out in practice the output was about 474 megacycles with a band frequency deviation of plus and minus about 3.5 megacycles). At repeater station C the receiving antenna 5 receives the 500 megacycle frequency modulated signal radiated by antenna 4 of station B, and converts the signal by means of apparatus described later in more detail in connection with Figs. 3a and 3b to a 100 megacycle signal for more efficient amplification. This 100 megacycle signal is then amplified and converted to an output frequency modulated signal having a mean frequency different than the incoming frequency, let us say a frequency of 512.6 megacycles, which is then transmitted by antenna 6 toward the next adjacent station, in this case receiver station D. At the final receiving station D in the radio link, the frequency modulated signal of 512.5 megacycles is received on antenna 7 and converted to a lower frequency signal which is then amplified and amplitude limited before it is passed on to a detector which transforms the frequency modulated signals to amplitude modulated signals. From the foregoing, it will be seen that the amplitude modulated signal transmitted by the broadcasting transmitter at station A at one frequency is received at station B and converted to a frequency modulated signal of a different frequency which is then radiated to station C where this frequency modulated signal is changed to a frequency modulated signal having another and different carrier frequency, after which the last converted signal is transmitted to station D where it may be converted to an amplitude modulated signal for local use or for use in affecting another broadcasting station to send out the television signals over one or more additional stations.

Fig. 2 illustrates the frequency modulated circuit employed at station B for producing a desired frequency modulated signal from the amplitude modulated waves received at this station. The system of Fig. 2 comprises a master

oscillator 8, a frequency modulator circuit 9, a first tripler stage 10 for tripling the frequency impressed thereon, an amplifier stage 11 for amplifying the output of the first tripler stage, and a second tripler stage 12 for tripling the frequency in the output of amplifier 11, also a final amplifier stage 13 of the inductive output electron discharge device type, and an automatic frequency control circuit 14 for stabilizing the frequency of the master oscillator 8. Although stages 9, 10, 11 and 12 are each shown as comprising a pair of electron discharge devices arranged in push-pull, it should be understood that if desired the two vacuum tube electrode structures of each of these stages may be included within a single evacuated envelope. As an illustration, the push-pull electrode structures of stages 9 and 10 may each be constituted by a single electron discharge device tube of the RCA 832 type, while the amplifier stage 11 may be constituted by a single electron discharge device of the RCA 829 type. The second tripler stage 12 may be constructed in accordance with the teaching described in the copending application of Orville E. Dow; (Serial No. 302,655, filed November 3, 1939, now United States Patent 2,253,849, granted Aug. 26, 1941, while the amplifier stage 13 may be of the type described in the copending application of Fred H. Kroger, Serial No. 296,045, filed September 22, 1939. In the operation of the circuit of Fig. 2, the video component of the signal received at station B is applied in parallel to the two control grids of the electrode structures of the frequency modulator 9, which functions to modulate the output of the master oscillator 8. The master oscillator, as an example, may generate oscillations of a frequency of the order of 52.67 megacycles. The output from the master oscillator is passed on to the frequency modulator stage 9 and the frequency modulated waves then impressed upon the first tripler stage 10, which provides an output of, let us say, 158 megacycles, this last output being amplified in stage 11 and then passed on to the second tripler stage 12 from which there is obtained, let us say, an output of 474 megacycles with a band frequency deviation of approximately plus and minus four megacycles, which last output is passed on to the amplifier stage 13 from which energy is derived for radiation by the antenna 4. It should be noted that the frequency modulator is capacity coupled to the master oscillator 8 by means of condensers C₁ and C₂, although it should be understood that, if desired, inductive coupling may be employed by the use of suitable transformers between the master oscillator and the frequency modulator. The condenser C₃ in the frequency modulator stage 9 is of very small value compared to the modulation but fairly large compared to the radio frequency.

The amplifier stage 13 consists of an electron discharge device circuit comprising a vacuum tube structure, generally of the so-called inductive output type consisting of an evacuated glass envelope E containing within it an indirectly heated cathode K, a filament or heater F, a grid G, ring-like accelerator electrodes M, M, a collector electrode R, and a suppressor S. The heater F may be supplied with energy from a suitable alternating current source through choke coils (not shown). Connected to the grid G is a connection extending to the output of the tripler stage 12. The collector electrode R for gathering the electrons traversing the length of the glass envelope

E is shown to be cup-shaped in form although, if desired, it may be hemispherical, conical or of other suitable shape. Centrally located within the interior of collector R there is provided a rod-like suppressor electrode S for gathering secondary electrons which may emanate from R. The suppressor S may take any suitable form according to the design of the collector R. Accelerator electrodes M, M are narrow in width and are maintained at a suitable positive potential relative to the cathode. Surrounding the exterior of the glass envelope E and located intermediate the two accelerator electrodes M, M there is provided a tank circuit 15 (hour-glass type) in the form of a surface of revolution whose central surface is perpendicular to the electron beam emanating from cathode K. This tank circuit is symmetrically arranged around the glass envelope E and is provided with a gap *a, b*. The configuration of this tank circuit 15, as shown in the drawings, is the cross section of a surface of revolution through the axis of revolution in the plane of the drawings and approximates two equal sectors with their vertices toward the glass envelope E. The dimension of the tank circuit 15, as measured from the center of the glass envelope to the arc of the sector, is approximately one-quarter of the length of the communication wave corresponding to the resonant frequency, provided that the gap *a, b* is not supplied with capacitor discs to change the frequency to a value less than the natural frequency of the resonator. This tank circuit is a high Q, low loss circuit and is preferably made of a high electrically conducting material such as copper. For focusing the electron beam there are provided a plurality of magnetic lenses (not shown) in series relation and surrounding the glass envelope, the magnetic field being provided by a strap of iron 16 which is placed adjacent the sides of one of the sectors of the tank 15 and then completed through an iron core 17, in turn surrounded by an electromagnetic field coil or solenoid 18 excited by a direct current source of supply 20. A suitable output coupling coil 21 derives energy from the tank circuit and supplies this energy to the dipole antenna 22 of the antenna system 4. The manner in which the amplifier circuit 13 functions is now well understood and is described quite adequately in the Kroger copending application Serial No. 296,045, supra, to which reference is herein made.

In order to stabilize the frequency of the master oscillator 8, there is provided an automatic frequency control (AFC) circuit 14 which is coupled between the master oscillator 8 and the output of the second tripler stage 12. AFC circuit 14 comprises a pair of rectifier tubes 23 and 24 supplied with radio frequency energy from the tuned circuits 25 and 26, the latter in turn being coupled to the tripler stage 12 by means of connection 27. The tuned circuits 25 and 26 have intersecting resonance curves at the mean or assigned carrier frequency of the output of the second tripler stage 12, with maxima at frequencies lying either side of the output frequency of the tripler 12, these tuned circuits applying the potential fluctuations to the anodes of the two detector tubes 23 and 24 so that output current varies differentially with frequency change. The rectified energies from the two detector tubes 23 and 24 respond differentially with frequency (due to the resonant curves being located above and below the mean frequency causing one diode current to go up and the other down with variation in frequency) and are applied to the grids of the

balanced amplifier circuit comprising vacuum tubes 28 and 29 in whose anode circuits is connected a polar relay 30, the latter in turn controlling the direction of rotation of the reversible motor 31 whose shaft 32 is shown in dotted lines connected to the condenser 33 for controlling the frequency of the master oscillator 8. It should be noted that the outputs of tubes 28 and 29 are in opposition to each other and it will thus be obvious that with equal current flow through both tubes 28 and 29 the polar relay 30 will have its armature in mid position, without causing the motor to rotate one way or the other. Any frequency change in the output of the tripler 12, produced let us say by the change in the frequency of the master oscillator 8, will cause one of the two resonant circuits 25, 26 to become more strongly energized than the other, as a consequence of which there will be a greater flow of current through one of the tubes 28 or 29, depending upon which of the tubes 23 and 24 is more strongly excited with departure of frequency from the assigned carrier frequency. The net response in the polar relay 30 will be proportional to the difference between the assigned carrier wave in the output of the tripler stage 12 and the wave impressed by the tripler 12 upon the tuned circuits 25 and 26. A departure from the desired mid band frequency will thus unbalance the direct current voltages in the outputs of tubes 28 and 29, and will cause the polar relay 30 to affect the motor 31 to rotate in one direction or the other, depending upon whether the frequency is higher or lower than the desired mid band frequency in the output of the tripler stage. The rotation of the motor 31 will be in such direction as to cause the condenser 33 to change its value such that the master oscillator 8 returns to a frequency where the signal in the output of the second tripler 12 is again at mid band assigned frequency.

Figs. 3a and 3b considered together, illustrate the apparatus at the repeater station C of Fig. 1, and includes a receiving antenna 5, a receiver 34 for converting the received incoming signal which is of the order of 500 megacycles to an intermediate frequency of 100 megacycles, a frequency converter inductive output electron discharge device 35, an amplifier 36 also of the inductive output electron discharge device type, a local oscillator circuit consisting very generally of a master oscillator 37, a first frequency tripler stage 38, an amplifier stage 39, a second frequency tripler stage 40, and an amplifier of the inductive output electron discharge device type 41. There is also provided an automatic frequency control (AFC) circuit 42 for stabilizing the frequency of the master oscillator 37. The receiver 34, which is shown conventionally in box form, includes an ultra high frequency converter unit for converting the incoming signal waves of the order of 500 megacycles to an intermediate frequency of about 100 megacycles, and also intermediate frequency amplifier apparatus for this 100 megacycle band. The ultra high frequency converter unit of the receiver 34 is shown in Fig. 4, which will be described later. The automatic frequency control circuit 42 is shown in more detail in Fig. 5, which is also to be described in greater detail later.

In the operation of Figs. 3a and 3b, the incoming signals received on antenna 5 are converted to an intermediate frequency of about 100 megacycles by the receiver of Fig. 4 and passed on to the output circuit 43 which is designed to

pass a wide band of frequencies on both sides of the mid band intermediate frequency. Output circuit 43 is shown coupled through a concentric line connecting circuit 44 to the grid of the inductive output vacuum tube converter 35 to whose cathode circuit there is inductively coupled the amplified output of the local oscillator. Converter tube 35 is generally of the type described above in connection with the amplifier 13 of Fig. 2, and a more detailed description thereof is to be found in the copending Kroger application, supra. The cathode circuit for the converter tube 35 includes a coaxial line 45, the inner conductor of which is coupled to one leg of the heater while the outer conductor is coupled to the other leg of the heater. By means of the arrangement shown, the cathode circuit comprises, in effect, a parallel tuned circuit tuned to the 412 megacycle frequency and to which is coupled the loop 46 extending to the output of the inductive output vacuum tube 41 of the local oscillator circuit. Since the amplifier 41 is designed to amplify oscillations of the order of 412.5 megacycles, in the manner described in more detail hereinafter, the converter functions to provide in its output circuit a mid band frequency of the order of 512.5 megacycles, which is then passed on through a coaxial line affair 47 to an inductive output type of amplifier 36 where the signal having a mid band frequency of 512.5 megacycles is amplified and then passed on to the antenna system 6 for radiation to the next adjacent station.

It should be noted that energy is derived from the output of the converter circuit by inductive coupling to the coaxial line 47 over a metallic strip 48 which extends within the tank circuit of the converter tube 35 but is insulated therefrom. The outer conductor of the coaxial line 47 is grounded, insulated from the tank circuit of converter 35, and has its ends adjacent this tank circuit provided with flange-like metallic strips 49 which extend on opposite sides of the aperture in the tank circuit. It should be noted that the tank circuit is here maintained at a positive potential relative to ground and that one or more accelerator electrodes of the electron discharge device is coupled to the tank circuit through a resistor. This arrangement is merely for simplicity of design, since it will be obvious that if desired the ring-like accelerator electrodes can be provided with a positive potential while the tank circuit is left free or grounded. In view of the fact that the outer conductor of the coaxial line 47 is grounded, and the tank circuit maintained at a positive potential, it is necessary to isolate the inner and outer conductors of the coaxial line 47 from the tank circuit and this is done in the manner shown in the drawing by means of the flanges 48 and 49. The auxiliary pot or coaxial line 50 is, in effect, a tunable inductance arrangement which tunes the output circuit for the converter and is provided with a slidable connection 51 movable along the inner and outer conductors of the coaxial line 50 for adjusting the inductance of the circuit. In effect, that portion of the tank circuit of the converter which is labeled 52 constitutes a loop made up of a metallic flange 53 and connected at one end to the arc of the tank. The tank circuit comprises the primary of a transformer whose secondary circuit consists of the loop 52, the flange 48, the coaxial line 47 and the coaxial line tuning inductance 50. The coaxial line 50 then serves to tune the secondary since it is

movable along the length of the coaxial line 47 and connects to the inner conductor of the coaxial line 47 through a slot in the outer conductor of the line 47. The coarse tuning of the output circuit of the converter is first effected by moving the position of the coaxial line inductance 50 such that the secondary circuit is tuned to the mid frequency of the band pass. The variable condenser 54 serves as a micrometer adjustment to tune the secondary. The area of the loop 52, of course, must be adjusted to first obtain the desired band pass and then for uniform response in the band pass the output circuit of the converter is adjusted by means of the slider 51 while maintaining constant the position of the line 50. One advantage of the particular output arrangement just described is that the feed line to the next adjacent stage is maintained fixed at all times and need not be moved. In this connection, attention is invited to copending application Serial No. 346,106, filed July 18, 1940, jointly by myself and Orville E. Dow, for a description of a similar coupling circuit.

The amplifier 36 is energized from the coaxial line 47 over the loop 55 which is inductively coupled to the loop 56 comprising suitable connections between the grid and the cathode of this amplifier stage. Here again it will be noted that the tank of the amplifier 36 is shown maintained at a positive potential while the output circuit for the amplifier 36 is substantially similar to the output circuit for the converter 35, and possesses the same relative advantages. The grid of the amplifier 36 as well as the grid of the converter tube 35 are maintained at suitable negative values relative to the cathode.

Stages 37, 38, 39 and 40 of the local oscillator circuit are similar in arrangement to stages 8, 10, 11 and 12, respectively, of Fig. 2, and are designated in the same manner. The master oscillator 37 is designed to generate oscillations of the order of 45.83 megacycles, these oscillations in turn being tripled in frequency by the stage 38 to 137.5 megacycles. The output of stage 38 is then amplified in stage 39 and the frequency again tripled by stage 40 to 412.5 megacycles, this last frequency being impressed upon the grid of the inductive output amplifier 41 and the amplified oscillations derived therefrom by loop 57 applied over line 58 and coupling loop 46 to the tuned cathode circuit of the converter tube 35, where the oscillations from the local oscillator are beat with the intermediate frequency of 100 megacycles to provide a sum frequency, the latter being passed on from the converter to the amplifier 36 in the manner described hereinabove. Amplifier 41 is also of the type previously described above in connection with the amplifier 13 of Fig. 2, and is described in greater detail in the copending Kroger application, supra.

From the foregoing, it will be seen that an incoming frequency modulated signal of one carrier frequency is received by the repeater station of Figs. 3a and 3b and changed at this station to a frequency modulated signal of another carrier frequency. The incoming received frequency is first changed from the order of 500 megacycles to 100 megacycles for most efficient amplification and then the frequency of 100 megacycle component increased to a different frequency, for example 512.5 megacycles, which is then radiated.

The ultra high frequency converter unit employed in the receiver 34 of Fig. 3a for changing the incoming frequency of the order of 500 mega-

cycles to an intermediate frequency of 100 megacycles is illustrated in more detail in Fig. 4. This figure illustrates a system very generally of the type described in copending application Serial No. 222,104, filed July 30, 1938, by K. G. McLean, now United States Patent 2,236,004, granted March 25, 1941, and, if desired, may comprise the identical converter unit arrangement shown in this copending application. Referring to Fig. 4 in more detail, there is shown, conventionally, a detector 110 to whose grid is fed the incoming signal energy arriving from the antenna 5 and to whose cathode is supplied oscillatory energy from a local high frequency oscillator 122. Both the detector 110 and the oscillator 122 have, respectively associated therewith, concentric line resonator circuits 101, 102, each having an outer conductor and an inner conductor. The inner conductor of resonator 101 carries a multi-fingered contact section 104 which provides contact to movable piston 105 on which is mounted the tuning capacitor plate 106. The concentric line 102 has for its inner conductor a pair of tubular conductors 116 and 114 placed end to end and coaxially arranged with respect to the outer conductor. The tubular conductors 114 and 116 have their adjacent ends spaced apart and provided with capacity plates 103 which are adjustable with respect to one another for tuning purposes. The tubular conductor 114 is also provided with a multi-fingered contact section as shown, and a movable piston on which is mounted one of the capacitor plates 103. The output 109 of the detector 110 receives the beat frequency (100 megacycles) of the incoming signal wave and the local oscillator frequency and extends to an intermediate frequency amplifier circuit, not shown. The intermediate frequency coil 108 is tuned by a copper slug which is adjustable in position inside the coil form. An inspection of the detector unit 110 will show that there is included in each leg of the filament or heater thereof a filter unit comprising choke coils 126 and low pass filter condensers 127. The filament and the anode circuit of oscillator 122 are also similarly provided with filter elements 126 and 127, generally of the same type shown in connection with the detector unit. The filter elements of the detector unit 110 and the oscillator unit 122 are divided into shielded compartments and the vacuum tubes per se are also shielded both from the shielded elements and the filter units and from the associated concentric line tuned circuits. The cathode of the detector 110 is connected to the oscillator concentric line through a bias resistor and condenser combination 113 and 112. The oscillator 122, it should be observed, comprises a vacuum tube whose anode is grounded to the shield or outer conductor of the concentric line through a by-pass condenser 121, and whose grid electrode is coupled through a coupling condenser 119 to the plate 103 of the inner conductor 116 of the associated concentric line resonator 102, the latter functioning as a frequency controlling element. A resistor 118 connects the grid of the oscillator to ground.

In order to compensate for drifting either of the oscillator 122 of Fig. 4 or the signal frequency received over the antenna 5, there is provided an automatic tuning device comprising a reversible telechron motor 134 which drives a metal vane 117 located below the inner conductor 116 of the concentric line 102. Control voltage for the automatic frequency control motor 134 is obtained from a discriminator circuit in the

output of the ultra high frequency converter unit. This discriminator circuit may comprise the usual pair of rectifier or diode tubes coupled to off-tuned circuits whose resonant characteristics intersect at the assigned mid band intermediate frequency. When metal vane 117 is rotated in response to an unbalance in the discriminator circuit caused by the departure of frequency from the desired frequency, such that the vane is parallel with the axis of the inner conductors 116 and 114, it will be seen that considerable flux about the tube 114 is interrupted, and the inductance of 114 is reduced, thus raising the oscillator frequency. One the other hand, when vane 117 is rotated 90° from this position relatively little flux is interrupted and the frequency is lowered. A friction clutch is preferably used between the motor 134 and the vane 117, so that the vane may be set at the center of its tuning range by a suitable panel control knob, the latter also serving to indicate the position of the vane.

Fig. 5 illustrates the preferred form of automatic frequency control circuit designated by box 42 in Fig. 3b, and comprises a pair of vacuum tube detectors 150 and 151 associated respectively with concentric line resonator circuits 152 and 153. Resonator circuits 152 and 153 have intersecting resonance curves with maxima at frequencies lying either side of the assigned operating frequency of 512.5 megacycles in the output of the amplifier 36 of Fig. 3a. Energy from the output of the amplifier 36 of Fig. 3a is fed through transmission line TL which is capacitively coupled to both concentric line resonators 152 and 153, and the rectified outputs on the cathodes of the rectifier tubes 150 and 151 are applied in push-pull to the balanced vacuum tube amplifiers 154 and 155. The anodes of both amplifier tubes are connected through leads 156 to the opposite terminals of the winding of sensitive polar relay 157. Tubes 154 and 155 are provided with screen grids supplied with a positive potential through a voltage regulator tube 158, and with suppressor grids which are connected to their cathodes, as shown. A reversible motor 159 controlled by the polar relay 157 functions to vary the position of the condenser in the master oscillator circuit over a flexible shaft 160. In view of the sensitive nature of polar relay 157 there are provided two rugged auxiliary motor relays 161 and 162 between the motor 159 and the polar relay 157 in order to protect this polar relay. The circuit for operating the motor either in one direction or the other will be obvious from a mere inspection of the contact arrangement shown in the drawings, it being understood, of course, that the polar relay 157 will move its armature one way or the other depending upon whether amplifier tube 154 or 155 draws more current than the other. Normally, when there is no drift from the assigned mid band frequency, the outputs of both amplifiers 154 and 155 will be the same and balanced, as a consequence of which the polar relay 157 will be in the position shown in the drawing with the armature midway between its opposed contacts. Whenever a drift in the frequency occurs, the rectifiers 150 and 151 will draw different currents and influence their respective amplifier tubes 155 and 154, respectively, to operate the polar relay 157 such that the motor 159 will rotate its shaft 160 to vary the tuning of master oscillator in a manner to restore the frequency to the desired value.

The reversible motor 159 and its shaft 160 are provided with limit switches 164 and 165 cooperating with a tongue or button 163 on the shaft 160. The tongue or button 163 serves to open the contacts 164 and 165 at the two extremes of travel or adjustment of the oscillator condenser setting associated with the shaft 160; so that if the oscillator or carrier frequency is so far off the assigned frequency that the adjustment of the condenser by means of shaft 160 will not bring the frequency of the oscillator back to the assigned value, then one or the other of the limit switches will be opened by the tongue 163 in order to open the motor circuit, thus preventing the motor from overrunning.

Returning now to the concentric line resonator circuits 152 and 153 of Fig. 5 and the manner in which they are coupled to the transmission line TL, it should be observed that there is provided a resistance 167 for matching the termination of the radio frequency line TL. A tuning inductance in the form of an adjustable coaxial line 168 tunes out the capacity across the resistor 167, so that in effect there is provided a pure resistance of a value equivalent to the characteristic impedance of the line TL for terminating this line. This tuning inductance 168 includes an adjustable slider or disc 169 contacting both the inner and outer conductors of the line 168. The transmission line TL is capacitively coupled to the two concentric lines 152 and 153 one being tuned above and the other being tuned below the assigned carrier or output frequency impressed on TL in the manner described above. It should be noted that the capacitor coupling from the line TL to the inner conductors of the two concentric lines is achieved through the sides of the concentric lines by means of adjustable capacity plate arrangements 170 and 171.

The automatic frequency control circuit of Fig. 5 is also provided with a pair of switches 172 and 173 for enabling the milliammeter 174 to measure the current in any one of the amplifier tubes 154 or 155, depending upon the position of these switches. In still a third position of the switches 172 and 173 the attendant is able to measure the voltage of the rectifier 175 which supplies potentials to the anodes of the amplifier. Resistor 176 is a multiplier resistor which enables the amplifier to function as a voltage meter. In the cathode circuits of the amplifiers 154 and 155, the resistors 177 and 178 are degeneration resistors for enabling the amplifier tubes to give a more linear response in their operation.

Although the relay system of Fig. 1 has been described as starting out with an amplitude modulated signal at the transmitter station A, it will be obvious that in such a system, if desired, station A could be a frequency modulated transmitter radiating a much higher frequency than 45.25 megacycles; for example, a signal having a carrier frequency on or about 500 megacycles, which signal would be fed through a series of repeater stations as described hereinbefore in connection with Fig. 1.

Further, although the automatic frequency control circuit of Figs. 2 and 5 illustrate motors for controlling the condenser of the local oscillator, it will be obvious that this motor can easily be replaced by a relay or other type of movable coil arrangement for varying a small condenser.

In view of the foregoing, it should be understood that the invention is not limited to the precise circuit arrangements illustrated in the

drawings but that various modifications can be made without departing from the spirit and scope of the invention. If desired, the resonant frequency of both of the off-tuned resonant control lines of the AFC circuit of Fig. 5 can be controlled simultaneously, at the same time providing a means for tuning each individual concentric line above and below the mid-band frequency. Such an arrangement enables the peak of the resonant frequencies of the two diodes 150, 151 to be set a fixed frequency apart, say 10 megacycles, and still enables the center or mid frequency to be shifted while maintaining this fixed separation. Thus, if the carrier or mid band frequency changed slightly, it would only be necessary for the attendant to tune the control knob which would shift the frequency of both lines simultaneously.

What is claimed is:

1. In combination, means for producing frequency modulated waves including an oscillator having a frequency controlling element, a frequency stabilizing circuit comprising two concentric line resonators having intersecting resonance curves with maxima lying either side of the mean operating frequency, means for supplying frequency modulated energy of said mean operating frequency to said two resonators in cophasal relation, a rectifier connected to each resonator for obtaining a direct current component therefrom, a first relay of relatively sensitive character, a balanced amplifier circuit coupled to said rectifiers and responsive to an unbalance in the outputs of said rectifiers to operate said relay, a pair of contacts on said relay, second and third relays of more rugged character than said first relay connected to said contacts and alternatively operable in response to the closures of said contacts, a reversible motor connected to said second and third relays and responsive to the operation thereof for varying said frequency controlling element in a direction to lessen said unbalance.

2. A system in accordance with claim 1, including a shaft for said motor and means linked to said shaft for opening the operating circuit of said motor at the two extremes of travel of said shaft corresponding to the maximum and minimum settings of said frequency controlling element.

3. In a radio system in which a transmitter radiates energy which is frequency modulated, two resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a feeder for supplying said two resonator circuits cophasally with said frequency modulated energy, rectifiers for said two resonator circuits, the outputs of said rectifiers being coupled to a circuit responsive to the difference voltage, a resistor connected to said feeder at the termination thereof nearest said resonator circuits for matching the impedance of said feeder, and means for tuning out the capacity across said resistor.

4. In a radio system, means for producing energy which is frequency modulated including an oscillator, an automatic frequency control circuit for said oscillator comprising two concentric line resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a feeder for supplying said two resonator circuits cophasally with said frequency modulated energy, rectifiers for said two resonator circuits, the outputs of said rectifiers being coupled to a circuit responsive to the difference voltage, a resistor connected to said feeder

at the termination thereof nearest said resonator circuits for matching the impedance of said feeder, and means for tuning out the capacity across said resistor.

5. In a radio system, means for producing energy which is frequency modulated including an oscillator, an automatic frequency control circuit for said oscillator comprising two concentric line resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a coaxial line feeder having its inner conductor capacitively coupled to the inner conductors of said two resonator circuits in electrically parallel relation for supplying said two resonator circuits with said frequency modulated energy, means for connecting the outer conductors of concentric line resonator circuits and said coaxial line together and to ground, a resistor connected between ground and the termination of said feeder nearest said resonator circuits, and a variable inductance element in parallel to said resistor for turning out the capacity across said resistor.

6. A system in accordance with claim 5, characterized in this that said variable inductance element is a coaxial line, the inner conductor of which is connected at one end to that terminal of the resistor which is connected to said feeder, the other end of said last inner conductor being directly connected to the outer conductor.

7. In combination, an oscillator having a frequency controlling element, a frequency stabilizing circuit comprising two concentric line resonators having intersecting resonance curves with maxima lying either side of the mean operating frequency, means for supplying frequency modulated energy of said mean operating frequency to said two resonators in cophasal relation, a rectifier connected to each resonator for obtaining a direct current component therefrom, a first relay, a balanced amplifier circuit coupled to said rectifiers and responsive to an unbalance in the outputs of said rectifiers to operate said relay, a pair of contacts on said relay, second and third relays connected to said contacts and alternatively operable in response to the closures of said contacts, a reversible motor connected to said second and third relays and responsive to the operation thereof for varying said frequency controlling element in a direction to lessen said unbalance.

8. A frequency stabilizing system comprising two resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a feeder for supplying said two resonator circuits

cophasally with said frequency modulated energy, rectifiers for said two resonator circuits, the outputs of said rectifiers being coupled to a circuit responsive to the difference voltage, a resistor connected to said feeder at the termination thereof nearest said resonator circuits for matching the impedance of said feeder, and means for turning out the capacity across said resistor.

9. A frequency stabilizing system comprising two resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a feeder for supplying said two resonator circuits cophasally with said frequency modulated energy, rectifiers for said two resonator circuits, the outputs of said rectifiers being coupled to a circuit responsive to the difference voltage, a resistor connected to said feeder at the termination thereof nearest said resonator circuits for matching the impedance of said feeder, and a variable inductance element in parallel to said resistor for tuning out the capacity thereacross.

10. A frequency stabilizing system comprising two resonator circuits having intersecting resonance curves with maxima lying either side of the mean operating frequency, a feeder for supplying said two resonator circuits cophasally with said frequency modulated energy, rectifiers for said two resonator circuits, the outputs of said rectifiers being coupled to a circuit responsive to the difference voltage, and a resistor connected to said feeder at the termination thereof nearest said resonator circuits for matching the impedance of said feeder.

11. In combination, an oscillator having a frequency controlling element, a frequency stabilizing circuit comprising a pair of resonators having intersecting resonance curves with maxima lying either side of the mean operating frequency, means for supplying frequency modulated energy of said mean operating frequency to said two resonators in cophasal relation, a rectifier connected to each resonator for obtaining a direct current component therefrom, a first relay, a balanced amplifier circuit coupled to said rectifiers and responsive to an unbalance in the outputs of said rectifiers to operate said relay, a pair of contacts on said relay, second and third relays connected to said contacts and alternatively operable in response to the closures of said contacts, a reversible motor connected to said second and third relays and responsive to the operation thereof for varying said frequency controlling element in a direction to lessen said unbalance.

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