

May 24, 1938.

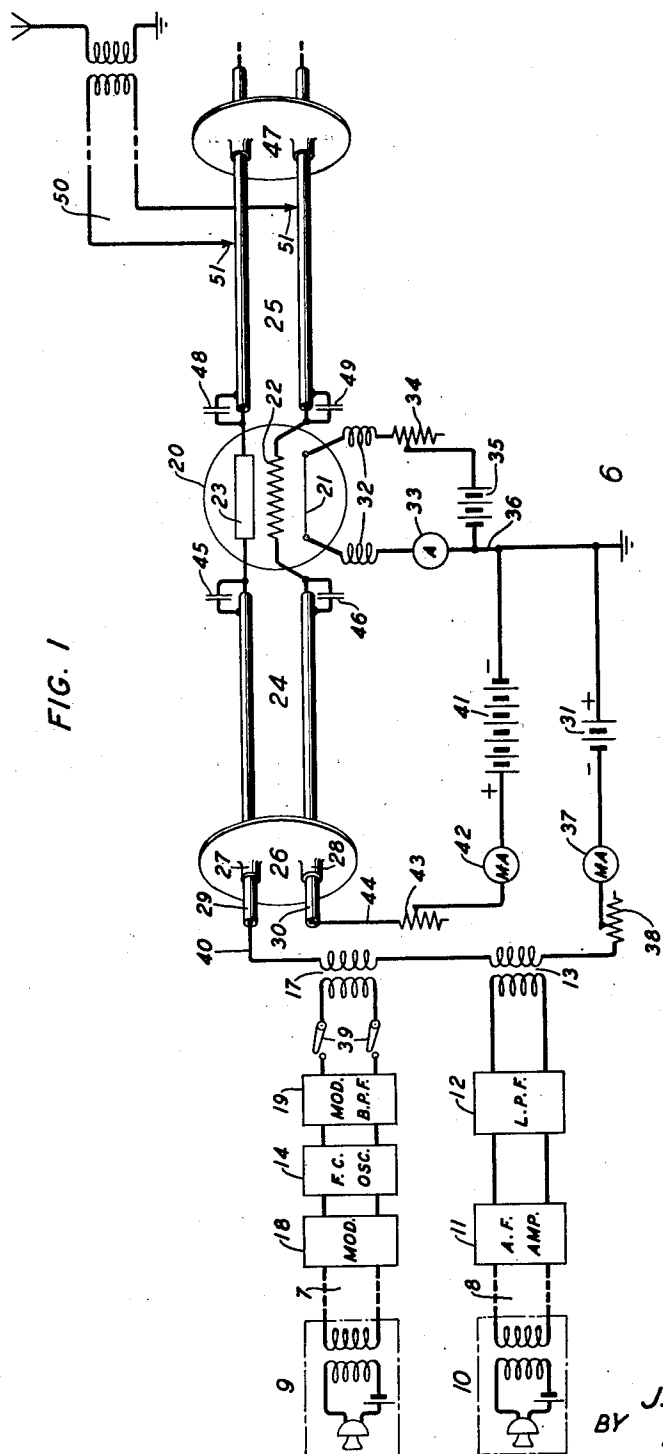
J. G. CHAFFEE

2,118,161

RECEIVING SYSTEM FOR FREQUENCY MODULATED WAVES

Filed Dec. 24, 1935

4 Sheets-Sheet 1



INVENTOR
J.G. CHAFFEE
BY *E.V. Briggs*
ATTORNEY

May 24, 1938.

J. G. CHAFFEE

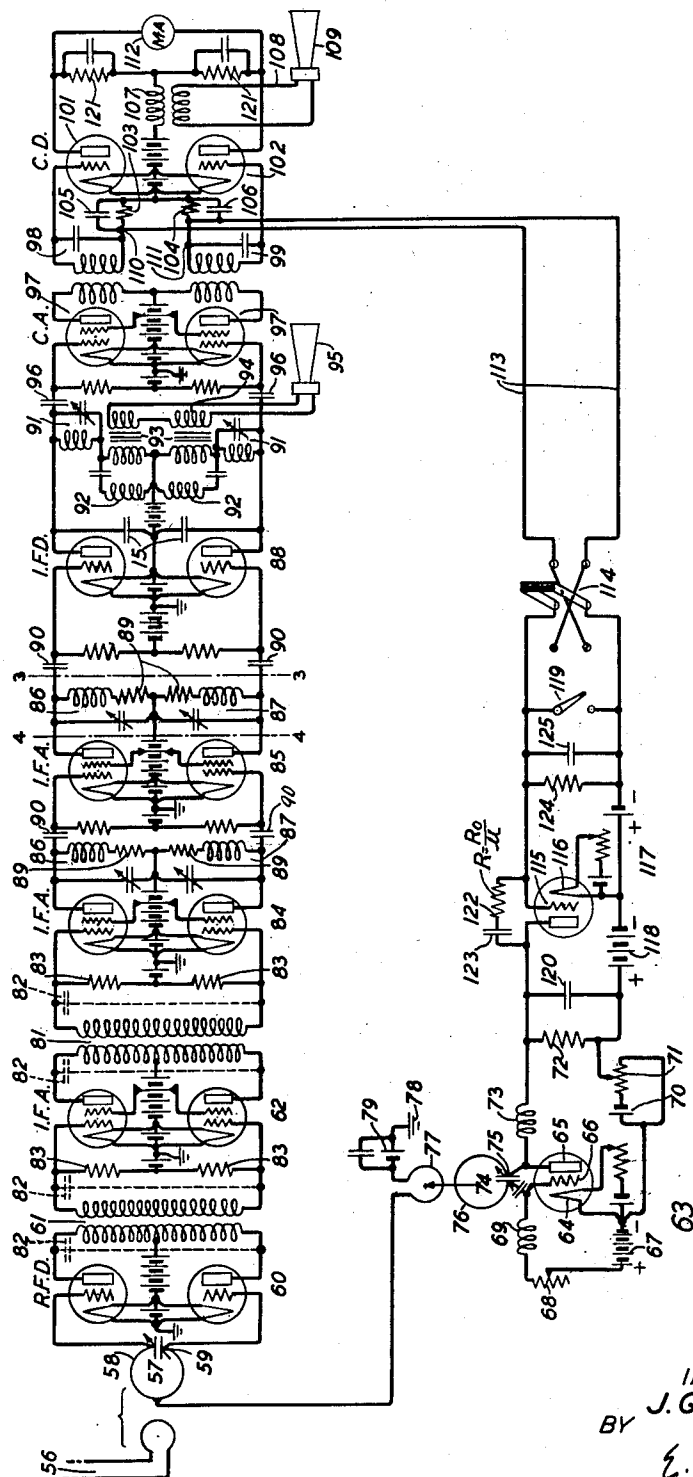
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RECEIVING SYSTEM FOR FREQUENCY MODULATED WAVES

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FIG. 2



INVENTOR
J. G. CHAFFEE
BY
E. V. Briggs
ATTORNEY

May 24, 1938.

J. G. CHAFFEE

2,118,161

RECEIVING SYSTEM FOR FREQUENCY MODULATED WAVES

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FIG. 3

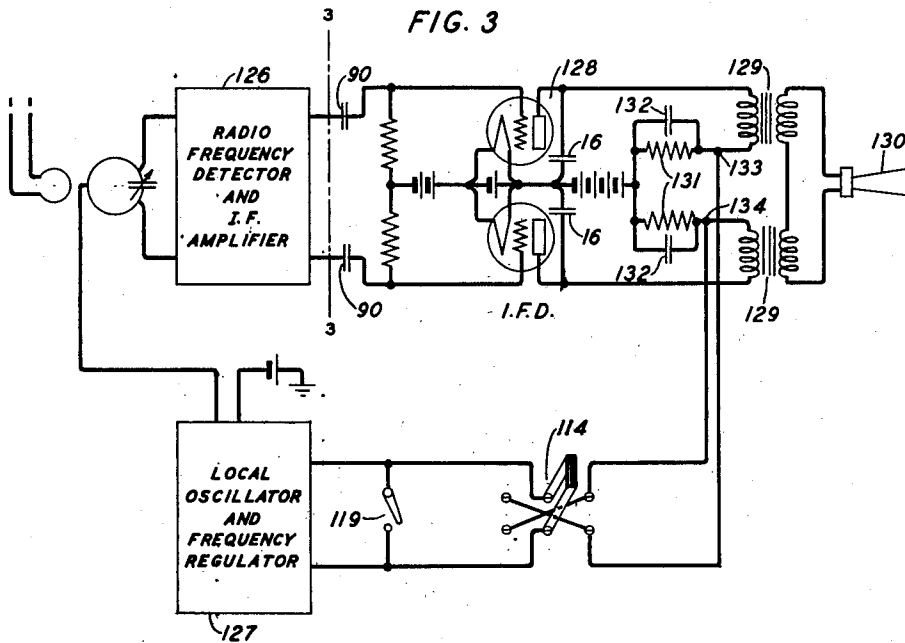
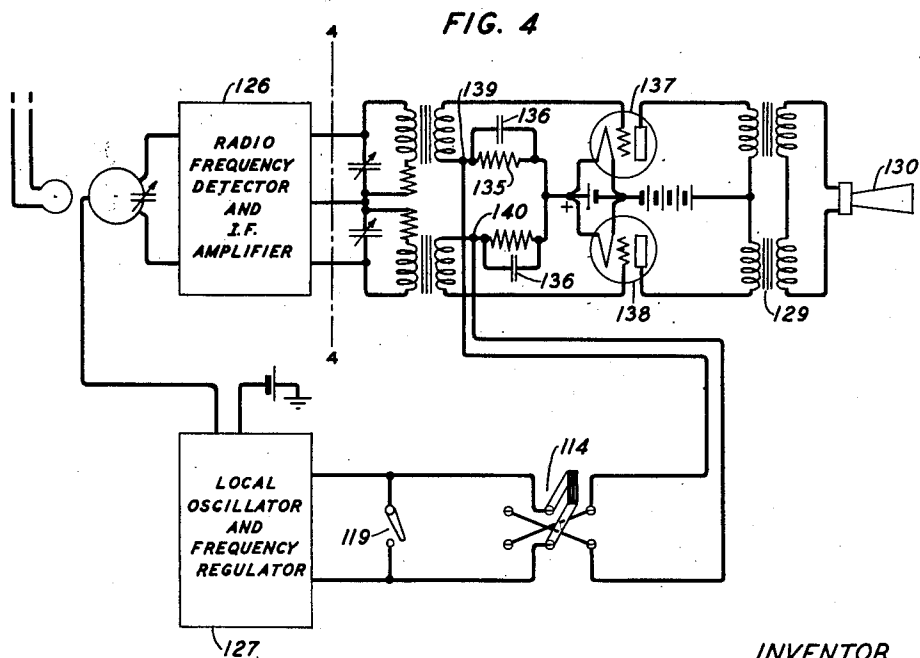


FIG. 4



INVENTOR
J. G. CHAFFEE
BY *E. V. Griggs*
ATTORNEY

May 24, 1938.

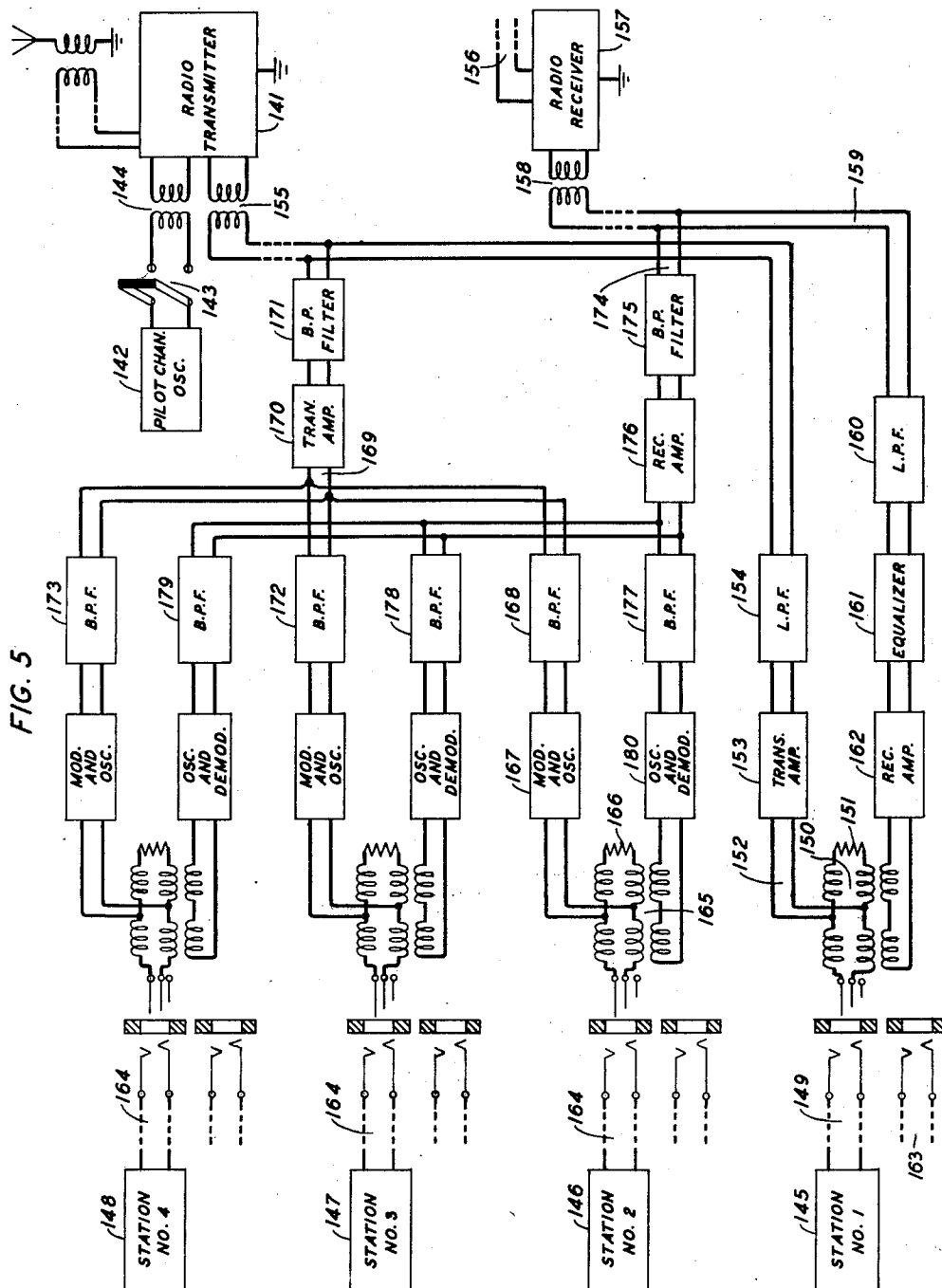
J. G. CHAFFEE

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4 Sheets-Sheet 4



INVENTOR
J. G. CHAFFEE
BY
E. V. Briggs
ATTORNEY

UNITED STATES PATENT OFFICE

2,118,161

RECEIVING SYSTEM FOR FREQUENCY
MODULATED WAVES

Joseph G. Chaffee, Hackensack, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application December 24, 1935, Serial No. 56,017

9 Claims. (Cl. 250—9)

This invention relates to receiving systems for frequency modulated waves and more particularly to means for varying the frequency of a local oscillator at a receiving station in accordance with changes in the mean frequency of received carrier waves.

The production of a fairly large degree of pure frequency modulation at ordinary commercial radio frequencies when using oscillators of conventional design is difficult without recourse to rather special means. In the region of wavelengths below about one meter the use of the so-called Barkhausen type of oscillator makes it possible to produce practically pure frequency modulation with comparative ease. This is described in detail in the application of J. G. Chaffee, Serial No. 702,443, filed December 15, 1933, Patent No. 2,038,992, dated April 28, 1936. Because of the relatively great dependence of the frequency of these oscillators upon all of their operating voltages, a considerable change in wave-length takes place from time to time due to variations in supply voltage and slow deterioration of the tube itself. While it is possible to overcome much of this by close regulation of the supply voltages, it is not feasible for economic reasons to secure, in this manner, the degree of frequency stability necessary in a system employing frequency modulation.

A considerable degree of frequency stability is necessary in a frequency modulation system for the following reasons. In receiving a frequency modulated wave the received ultra high frequency waves or intermediate frequency waves derived therefrom are passed through circuits which convert the variations in frequency which result from the modulation of the ultra high frequency transmitted wave, into variations of amplitude by virtue of the sloping response versus frequency characteristics of these elements. There is thus obtained the equivalent of an amplitude modulated wave which is then detected in the customary manner. Since the useful portion of the characteristics of the converting circuits is limited in extent it is essential, if the most efficient operation is to be obtained, that the frequency of the unmodulated wave correspond approximately to the center of the useful region of this characteristic. Modulation may then be applied up to the point where the entire useful region of the circuit characteristic is traversed by the frequency modulated carrier wave. Having thus defined the maximum degree of modulation which can be applied to the transmitter under the above conditions, it will be obvious that if the average

frequency of the transmitter changes for any reason, distortion will take place unless the degree of modulation is reduced. It is thus particularly desirable in a frequency modulation system that the average frequency of the transmitter be kept within rather close limits.

The well-known superheterodyne circuit has many advantages for receiving high frequency waves. Since it is based upon the production of intermediate or difference frequency oscillations by interaction between the received waves and locally generated oscillations, it follows that any variations in the mean frequency of either the received or the locally generated waves will be attended with equal variations in the mean frequency of the intermediate frequency waves. Hence it is also important that the frequency of the local oscillator be maintained substantially constant for the same reason that the mean frequency of the transmitter should not vary.

In practical systems, particularly those employing oscillators of the Barkhausen type for both transmitter and for local oscillator at the receiver, certain unavoidable drifting of the frequency of these oscillators takes place. It is difficult to maintain an adequate degree of stability even with oscillators of conventional type, when operating at extremely high frequencies, if a highly selective receiver is to be employed. If, for example, the normal carrier frequency of the modulated wave be of the order of 500 megacycles, a variation of $\frac{1}{2}$ of 1% in the mean frequency of either transmitter or local beating oscillator would produce a change of one megacycle in the intermediate or difference frequency wave produced in the receiver. If these intermediate frequency waves are of the order of five megacycles normally, a frequency variation of the order of one megacycle would be very large on a percentage basis. If, however, the frequencies of both the remote transmitter and the local receiver oscillator were to undergo a simultaneous change of say, +1 megacycle, the frequency of the intermediate frequency wave would remain as before, and no change in the performance of the system would be observed. According to one feature of the invention, the frequency of the local oscillator is made to vary in such a manner that when unavoidable changes in the mean frequency of the transmitter take place, the intermediate frequency wave is caused to remain at a constant average frequency best suited to the receiver characteristic. Furthermore, any tendency of the local oscillator to change in frequency is automatically corrected.

According to the invention, the ultra high frequency carrier wave is modulated as to frequency at the transmitting station both by messages to be transmitted and by control frequency oscillations. A local oscillator is provided for the superheterodyne system at the receiving station and after the demodulating operation, the control frequency oscillations are selected and rectified to produce a control electromotive force which may be applied to the local oscillator to cause its frequency to undergo a shift similar to that of the incoming carrier wave frequency so as to maintain a substantially constant difference between the two frequencies.

In a modification of the invention the control frequency oscillations are, themselves, modulated in amplitude by a message and thus serve the dual purpose of controlling the frequency of the local oscillator and increasing the message capacity of the system.

In another modification of the invention the control frequency wave is dispensed with altogether and in its stead the intermediate frequency waves produced by the superheterodyne action are utilized to perform the control function. The intermediate frequency detector yields a space current change which varies with the intensity of the intermediate frequency waves and from this space current a frequency controlling electromotive force for the local oscillator may be derived.

In the drawings, Fig. 1 discloses an ultra short wave transmitting system for frequency modulation of an ultra short wave oscillator by message waves and by control waves. Fig. 2 discloses a superheterodyne system for receiving the frequency modulated waves transmitted from the station of Fig. 1. Figs. 3 and 4 disclose modifications of the circuit of Fig. 2 which dispense with the control frequency, and Fig. 5 discloses a multiplex transmitting station in which the ultra short carrier oscillations are frequency modulated by the carrier waves of a three-channel carrier line system and, also, by ordinary speech frequency waves and control frequency waves.

Referring to Fig. 1, there is shown an ultra short wave transmitter 6 of the Barkhausen type. Associated with the transmitter by suitable lines 7 and 8 are stations 9 and 10 illustrated as telephone stations but which may be originating points for message waves of any desired type. Station 10 is connected by line 8, audio frequency amplifier 11, preferably of the usual electron discharge type, and low-pass filter 12 of any well-known type for transmitting speech currents or any desired message currents to the primary winding of transformer 13. A source 14 of frequency control oscillations of some frequency, as, for example, 40,000 cycles, considerably higher than the highest frequency currents transmitted from station 10, is connected so that its output current is modulated by modulator 18. The output terminals of the oscillator 14 are connected through modulator band-pass filter 19 and the contacts of switch 39 to the primary winding of transformer 17. Accordingly, the oscillator 14 at all times transmits unmodulated frequency control oscillations of 40,000 cycles to the primary winding of the transformer. Modulator 18, which is preferably of the well-known thermionic type, serves to amplify the speech currents received from station 9 and to control the output of the oscillator 14 in any well-known manner as, for example, by the constant current modulation method disclosed in R. A. Heising

Patent 1,442,147, January 16, 1923. It follows that whenever message currents are received from station 9 over line 7 by the modulator that the control frequency oscillations are modulated in accordance with the message currents and that the message modulated control frequency oscillations are transmitted along with the unmodulated control frequency oscillations to the primary winding of transformer 17. Filter 19 is preferably designed to have a frequency transmission range which includes the unmodulated control frequency and the two message side-bands but it may, if desired, transmit only the unmodulated control oscillations and one side-band or it may be omitted altogether.

The radio transmitter 6 comprises an electron discharge device 20 having a cathode 21, a grid 22 and an anode 23. Associated with the grid and anode are two Lecher circuits 24 and 25 each comprising a pair of coaxial conductor sections. Circuit 24 is tuned by a disc or plate 26 of conducting material having integral collars or sleeves 27 and 28 respectively in contact with outer conductors 29 and 30. The anode 23 is negatively polarized by a source 31 over a path which may be traced from cathode 21, radio frequency choke coils 32, current indicator 33, cathode heating current regulating resistance 34 and heating current source 35, grounded lead 36, source 31, current indicator 37, regulating resistance 38, the secondary windings of transformers 13 and 17 and the inner conductor 40 to anode 23. Similarly, the path for biasing the grid 22 to a relatively high positive potential with respect to the cathode may be traced from the cathode 21, the cathode heating circuit, lead 36, grid polarizing source 41, current indicator 42, regulating resistance 43 and inner conductor 44 to the grid 22. By-pass condensers 45 and 46 connect the outer and inner conductors of each coaxial pair of circuit 24 at their tube terminal ends for the ultra short wave oscillations. Disc 26 serves not only to tune the Lecher circuit including the tube terminals and elements associated therewith but, also, to shield it from those portions of the conductors to the left of the disc. Lecher circuit 25 is similar to circuit 24 and its short-circuiting tuning disc 47 and by-pass condensers 48 and 49 are similar to the corresponding elements of circuit 24. A transmission circuit 50 connected to the Lecher circuit 25 by variable positive taps 51 enables outgoing frequency modulated ultra short waves to be transmitted to the transmission line or antenna.

It will be understood that the frequency of the ultra high frequency oscillations produced by transmitter 6 is a function of a number of parameters including the bias or polarizing potential impressed upon the anode 23. The normal frequency of the ultra short waves produced in the absence of all modulation is dependent upon the normal biasing potential impressed by source 31 upon the anode. The tuning discs 26 and 47 of the two Lecher circuits are so adjusted that in addition to establishing resonance in the whole system including circuits 24, 25 and the tube elements 22 and 23, maximum potentials are developed upon these latter elements. The transmitter circuit is preferably so designed and the biasing potentials are so chosen that within the range of electromotive forces applied by transformers 13 and 17 substantially pure frequency modulation of the ultra short waves will take place. This is usually the case when the oscillator is adjusted for maximum output.

Accordingly, message waves originating at station 10 after amplification by amplifier 11 are impressed through filter 12 upon the primary winding of transformer 13 to induce a message wave electromotive force in the secondary winding which is superposed upon the normal anode bias provided by source 31 and, accordingly, produces frequency modulation of the oscillations generated by the oscillator. Whenever switch 39 is closed control frequency oscillations of 40,000 cycles frequency are also impressed upon the oscillator anode circuit by the secondary winding of transformer 17 to produce frequency modulation of the ultra short carrier wave oscillations. The method by which the control frequency oscillations are used at the remote radio receiver to control the frequency of its local oscillator will be described in connection with Fig. 2.

If desired, the control frequency oscillations may serve also as the subsidiary "carrier" for an additional message. Message waves from station 9 may be impressed upon the modulator 18 to cause amplitude modulation of the control frequency oscillations and these modulated control frequency oscillations will be transmitted to transformer 17 thus providing for simultaneous transmission of a second message wave over the ultra short wave transmitting channel.

Fig. 2 illustrates the circuits of an ultra short wave receiving station designed to cooperate with the transmitter of Fig. 1. As shown, the incoming circuit 56 leading from the incoming high frequency line or receiving antenna, not shown, is coupled to a tuned receiving circuit 57 comprising an inductance loop 58 and variable condenser 59. The circuit 57 is tuned to the ultra short wave to be received as, for example, to a wave-length of 58 centimeters. Connected to the tuned circuit 57 is the push-pull electron discharge detector 60, the output circuit of which is coupled by transformer 61 to the input circuit of the first stage 62 of a three-stage push-pull intermediate frequency amplifier. A local beat frequency oscillator 63, illustrated as of the Barkhausen type, supplies oscillations which differ in frequency from the incoming ultra short waves by a predetermined intermediate frequency as, for example, 5 megacycles. The oscillator comprises an electron discharge device having a cathode 64, anode 65 and grid 66, a current source 67 for biasing the grid to a high positive potential with respect to the cathode over a path through variable resistance 68 and radio frequency choke coil 69 and a current source 70 for biasing the anode slightly negative with respect to the cathode over a path including potentiometer 71, coupling resistance 72 and radio frequency choke coil 73. It will be apparent that the net bias on the anode 65 of oscillator 63 is the resultant of the drop in potential in resistance 72 in consequence of space current flow therethrough from tube 117 and the voltage delivered by potentiometer 71. It is quite possible that potentiometer 71 may be called upon to deliver a positive bias in the event that the drop in potential across the resistance 72 would impress an excessive bias upon the anode. A tuned circuit 74 for the oscillator comprises a variable condenser 75 and a loop 76 variably coupled to an inductance turn 77 in a path extending from ground 78 by way of grid biasing source 79 and its by-pass condenser and loop 77 to approximately the electrical mid-point of loop 58. It will be readily appreciated that locally generated oscillations will be impressed by oscillator 63 upon the input circuit of detector 60 in the same phase

on each of the grids. Detector 60 will yield an intermediate or difference frequency product in the manner of the well-known superheterodyne circuit.

The windings of intermediate frequency transformers 61 and 81 are each so designed that the distributed capacities thereof, represented by dotted lines at 82, will effectively tune the circuits of the windings to the intermediate frequency of 5 megacycles. Shunt resistances 83 serve to broaden the effective transmission band of the intermediate frequency amplifier and the coupling between the primary and secondary of each transformer is sufficient to produce a band-pass characteristic. The intermediate frequency amplifier tubes are preferably of the shield grid type, as illustrated.

Intermediate frequency amplifier stages 84 and 85 serve in addition to their amplifying function to convert the constant amplitude variable frequency intermediate frequency waves to variable amplitude intermediate frequency waves. For this purpose the output circuits 86 of one discharge device of each of these two stages are tuned to a frequency somewhat higher than the intermediate frequency while the output circuits 87 of the other tube of each stage are independently tuned to a frequency correspondingly lower than the intermediate frequency. Moreover, the output circuit 86 of each stage is made substantially free from coupling with the circuit 87 of the same stage. Accordingly, as the intermediate frequency wave in its excursion from the normal intermediate frequency approaches the resonance frequency of the tuned output circuit 86 of stage 84, the amplitude of the resulting intermediate frequency oscillations in that circuit will correspondingly increase with accentuation of the effect in the correspondingly tuned circuit 86 of the stage 85. At the same time, the intermediate frequency will recede from the resonance frequency of circuits 87 with a corresponding diminution in the response of circuits 87. Accordingly, the intermediate frequency amplifier will transmit to the intermediate frequency detector 88 an intermediate frequency electromotive force having amplitude variations as described in connection with Figs. 4 and 5 of the copending application of J. G. Chaffee, Serial No. 44,321 filed October 10, 1935. To increase the linearity of the selectivity curves of circuits 86 and 87 each is provided with a resistance 89.

The upper amplifiers of stages 84 and 85 connected with tuned circuits 86 in effect form one branch or transmission path and the lower amplifiers connected with tuned circuits 87 form a second branch or transmission path. The intermediate frequency current levels in these two branches are equal only when the tuning of the receiver oscillator 63 differs from the frequency center of the received band by precisely the fixed intermediate frequency at which the response of circuits 86 and 87 are alike, assuming that their characteristics have equal and opposite slopes at this frequency. Any excursion of the frequency of either transmitter or receiving beating oscillator increases the level in one branch at the expense of the other, the favored branch depending upon the direction of the frequency drift.

Coupling of the intermediate frequency amplifier to detector 88 is effected through low reactance coupling capacity elements 90. Intermediate frequency detector 88 is of the balanced or push-pull type and the plate circuits of its individual electron discharge devices each in-

clude resonant loops 91 and series tuned by-pass paths 92, all tuned to the control frequency oscillations which, in this case, are of 40 kilocycle frequency. Included in the space current paths and in shunt to the by-pass paths 92 are the primary windings of audio frequency transformers 93 which supply to circuit 94 and telephone receiver or loud-speaker 95 demodulated currents corresponding to the speech frequency waves from station 10 by which the incoming ultra short wave is modulated. As shown, the current delivered to receiver 95 is proportional to the difference between the speech frequency currents set up in the plate circuits of the two tubes comprising the detector 88. This connection is necessary since these currents are in phase opposition. This follows from the fact that the slopes of the transmission characteristics of the amplifiers preceding either of the detector tubes are opposite in sign to that which actuates the other detector. Obviously, a single output transformer having a center tapped primary and secondary winding could be used in place of the separate transformers 93.

If switch 39 at the transmitting station of Fig. 1 is closed and no message waves are generated at station 9 unmodulated control frequency oscillations will be transmitted and received as modulations of the incoming ultra short carrier wave. If, however, messages are initiated at station 9, modulator 18 will serve to correspondingly modulate the output oscillations of oscillator 14, in which case message modulations of the control frequency oscillations will also be applied to modulate the ultra short carrier wave. The effect of modulating the oscillator 14 is to produce variations in the degree to which this device frequency modulates the high frequency oscillator 6. No amplitude modulation of the high frequency transmitted wave is produced. However, when the wave is received and detected, the component of frequency corresponding to that of oscillator 14 will have an amplitude which varies in accordance with the modulation of that oscillator, and is hence amplitude modulated. Subsequent detection will recover the original signal supplied by station 9.

The control frequency oscillations appearing in the plate circuit of intermediate frequency detector 88 will be effectively by-passed about transformers 93 by the paths 92. Small capacity elements 15 serve to by-pass intermediate frequency components directly between the anode and cathode and improve the detecting efficiency. The potentials developed by the control oscillations and by the message modulation of the control oscillations in circuits 91 will be impressed through large capacity blocking condensers 96 upon the input circuit of control frequency amplifiers 97 preferably comprising two tubes of the screen grid type each connected to an individual one of the detector tubes 88. After amplification by amplifiers 97 the control frequency oscillations are impressed on the individual input circuits 98 and 99 of control frequency detectors 101 and 102. Circuits 98 and 99 are tuned broadly to the control frequency. Detectors 101 and 102 include in their grid cathode circuits series resistances 103 and 104, with shunting condensers 105 and 106, the magnitudes of which are so predetermined as to cause the detectors to operate according to the grid rectification method. There will, accordingly, appear in the common plate circuit path of the detectors demodulated currents corresponding to the signal currents originating at station 9.

These may be applied by transformer 107 to circuit 108, the terminals of which are connected to a telephone receiver or loud-speaker 109.

In order to maintain the central frequency of the intermediate frequency waves substantially constant, frequency control potentials are derived from the series resistances 103 and 104 in the grid circuits of the control frequency detector tubes. When the average frequency of the transmitter differs from the frequency of the local oscillator 63 by an intermediate frequency which corresponds exactly to the middle of the intermediate frequency band, the amplitudes of the control frequency voltages impressed upon the grids of the detectors 101 and 102 will be equal. As a result the rectified currents flowing through resistances 103 and 104 will be equal and hence the direct current potential difference between points 110 and 111 will be zero. If the average frequency of the short wave carrier sent out by the transmitter departs from its normal value, the rectified currents set up in resistances 103 and 104 will no longer be equal since the two branches of the intermediate frequency amplifier are tuned to slightly different frequencies. As a result a potential difference will be established between points 110 and 111. The sign of this potential difference will depend upon whether the frequency of the transmitter has increased or decreased and its magnitude will depend upon the extent of this frequency departure. It will also be evident that changes in the frequency of local oscillator 63 will have a similar effect upon this potential difference.

A circuit 113 connected to points 110 and 111 serves, when switch 114 is closed, to impress these potential variations on the grid 115 and cathode 116 of a control amplifier 117, the anode and cathode of which are connected through space current source 118 to the terminals of resistance 72. The proper effective voltage for the plate of the oscillator 63 is adjusted by means of the source 70 and potentiometer 71. It will be apparent that correcting potentials developed between points 110 and 111 will be amplified by control amplifier 117 and impressed in amplified form across resistance 72 thus changing the bias on the anode 65 of Barkhausen oscillator 63. Inasmuch as the frequency of oscillator 63 is a function of its anode bias potential the oscillations produced by oscillator 63 will undergo variations in frequency which are a function of the potential difference between points 110 and 111.

In making a preliminary adjustment, switch 119 will be closed to eliminate any effect of circuit 113 and the oscillator 63 will be adjusted to produce the normal intermediate frequency when ultra short waves of the normal incoming carrier frequency are applied to circuit 51. Opening switch 119 with switch 114 closed places the control system in operation. Should the local oscillator frequency drift it, too, will tend to be restored to the proper value by the control system. Proper speed of regulation is secured by the choice of suitable time constants for resistance 103, capacity 105, resistance 104, capacity 106, resistance 124 and capacity 125.

A sensitive current indicator 112 is connected directly between the anodes of rectifier tubes 101 and 102 and across capacity-shunted resistances 121. The pointer of indicator 112 is adjusted to rest at the middle of the scale when no current is flowing. The potential appearing across indicator 112 and hence the current flowing through it will follow the potential appearing between

points 110 and 111, being zero when the transmitter frequency has its proper value. Departure in the frequency of the transmitter from this value will result in deflections of the pointer of indicator 112 to one side or the other of its zero position. Thus, this arrangement affords a means of observing the degree of regulation provided by the frequency control system, and, with switch 114 open, is also useful in securing an approximately correct setting of the frequency of oscillator 63 before placing the control system in operation.

A by-pass path including resistance 122 and condenser 123 in series therewith is connected directly between the grid and anode of control frequency amplifier 117. The large capacity condenser 123 serves primarily to interrupt the unidirectional current path which would, otherwise, be formed between the grid and anode and interposes very little impedance for alternating impulses. Resistance 122 is given a value equal to

$$\frac{R_o}{\mu}$$

where R_o is the alternating current resistance of the internal plate circuit of the device and μ is its voltage amplifying factor. For sudden disturbances or clicks, or for control or message frequency potentials appearing in circuit 113, the voltage applied directly from circuit 113 to the plate circuit path of the device 117 by way of path 122, 123 is equal and opposite to that applied by the repeating action of the device.

In order to insure that the frequency corrections produced in oscillator 63 are in the same direction as those of the incoming ultra short waves reversing switch 114 is provided so that the correcting potential may be applied to the oscillator in the proper sense to make its frequency increase with increasing central incoming wave frequency. It will be seen that if the frequency of the local oscillator 63 is changed from a value greater than that of the transmitter by the amount of the intermediate frequency, to a value less than that of the transmitter by the same amount, it will be necessary to reverse phase of the control voltage by throwing switch 114 to its opposite position.

Fig. 3 discloses a modified form of radio receiving circuit in which the control frequency oscillations are dispensed with and instead the intermediate frequency waves produced by the superheterodyne action are utilized to regulate the frequency of the local oscillator at the receiver. The circuit is similar to that of Fig. 2 up to the line 3—3 of Figs. 2 and 3 which is just in advance of the point where the coupling capacities 90 are included in the input circuit of the intermediate frequency detector. Accordingly, element 126 will be understood to embody the same circuits as radio frequency detector element 60 and intermediate frequency amplifier elements 62, 84 and 85 of Fig. 2.

The local oscillator and its frequency regulating circuits indicated by element 127 correspond in every respect to the circuits of oscillator 63 and control amplifier 117 of Fig. 2. Intermediate frequency signal modulated oscillations having amplitude variations produced by the intermediate frequency amplifiers as has been described in connection with the operation of the system of Fig. 2, are impressed on the input circuit of intermediate frequency detector 128. The resulting demodulated audio frequency signal currents corresponding to the currents origi-

nating at station 10 of Fig. 1 are supplied by output transformers 129 to receiving device or loudspeaker 130. In series in the space current path of each detector tube are resistances 131 each shunted by an audio frequency by-pass capacity element 132. The resistances are normally traversed by equal currents so that there is no difference of potential between points 133 and 134. A departure from the normal frequency of the transmitter will produce potential differences between points 133 and 134 in the same fashion as at points 110 and 111 in Fig. 2. Small capacity elements 136 each serves as a by-pass for intermediate frequency currents and to increase the detecting efficiency of detector 128.

The use of resistance in the space current path of a detector tends to straighten the detector tube characteristic and reduces its rectifying efficiency. It is sometimes desirable to avoid that effect. This may be accomplished by the circuit of Fig. 4 which corresponds in general to that of Fig. 3 but is modified to include the control bias resistance elements in the grid cathode circuits of the detector tubes. In fact, the resistance elements 135 and capacity elements 136 are designed in accordance with well-known grid circuit detection practice so that the intermediate frequency detector tubes 137 and 138 serve to yield audio frequency signals in their output circuits and at the same time to provide a frequency-regulating control potential between points 139 and 140 in their grid circuits. The remainder of the circuit of Fig. 4 corresponds to that of Fig. 2 up to the dashed line 4—4 as indicated in Figs. 2 and 4. Corresponding elements are indicated in Fig. 4 by the same reference characters as in Fig. 3. In some instances it may be desirable to include an extra stage of direct current amplification in the element 127 of Fig. 4 since the rectified voltages developed across resistance 135 will be, in general, smaller than those developed across the resistance 131 in Fig. 3.

Fig. 5 illustrates the circuit of a multiplex two-way radio system. The transmitter 141 corresponds to the element 6 of Fig. 1. A pilot channel oscillator 142 similar to oscillator 14 of Fig. 1 is connected by way of switch 143 and transformer 144 to the anode circuit of the transmitter, the transformer corresponding in function and its circuit connections to the transformer 17 of Fig. 1. It will be understood that in lieu of the oscillator 142 and the switch 144 as illustrated in Fig. 5 there may be substituted a speech current modulating system comprising elements corresponding to elements 7, 9, 14, 18 and 19, and 39 of Fig. 1 whereby the frequency control or pilot channel may serve for both carrier frequency control and as a subsidiary carrier message channel as desired. Accordingly, the system of Fig. 5 is to be interpreted as including that apparatus which may all be diagrammatically represented by the element 142.

Four stations 145, 146, 147 and 148 are shown at each of which speech or other signals within the voice frequency range originate. Station 145 is connected by a line 149 leading to the remote radio transmitting station 141. Line 149 terminates in a hybrid coil 150 and a line balancing network 151 both of well-known type. A transmitting channel 152 including a transmitting amplifier 153 and a low-pass filter 154 leads to the primary winding of a transformer 155 associated with the anode circuit of the oscillator of transmitter 141 in the same manner as is transformer 13 of Fig. 1. However, transformer 155

serves not only to transfer speech frequency electromagnetic force but also for transfer of carrier frequency electromagnetic force and hence must be designed to have a relatively broad transmission band as will later become evident.

A radio receiving system for incoming carrier waves comprises an incoming circuit 156 to which any suitable type of receiving antenna or radiant energy collector may be connected. The radio receiver 157 may correspond to any of the three radio receiving systems of Figs. 2, 3 and 4. However, only the circuit of Fig. 2 is used if pilot channel waves are to be employed. An output transformer 158 for the receiver 157 corresponds to output transformers 93 and 129 of the circuits of Figs. 2, 3 and 4. When using a receiver of the type shown in Fig. 2, it has been found desirable to remove the 40-kilocycle current bypass circuits 92 from the plate circuits of detectors 88 since, while the impedance of these circuits is very low at 40 kilocycles and quite high at voice frequencies—a condition very desirable for the operation of Fig. 2 as originally described—these circuits 92 may still have a rather low impedance at frequencies corresponding to the higher frequency channels of the Type C system. Consequently, a certain amount of attenuation of these channels may result from the inclusion of these circuits. An incoming speech frequency channel 159 including low-pass filter 160, equalizer 161 and receiving amplifier 162 conducts return message currents to the hybrid coil 150. Equalizer 161 compensates for any unequal transmission of the voice frequency current range by transformer 158. It will accordingly be evident that a person at station 1 may carry on two-way telephone communication with a person located at a station similar to station 1 and associated with a two-way radio transmission terminal system like that of Fig. 5. The radio terminal systems will be similar except that for outgoing transmission an ultra short carrier wave of a frequency somewhat different from that of the incoming ultra short carrier wave will be used. The expedient of different carrier waves in the two directions may be relied upon to prevent "singing" from the radio transmitter 141 to its local receiver 157. It may, if desired, be supplemented by relatively wide separation of the transmitting and receiving antennae and by the use of highly directional antennae.

It is also to be understood that instead of leading directly from the message station to the radio transmitting and receiving stations the lines 149 from the subscribers' stations and the channels 152 and 159 leading respectively to the radio transmitter and radio receiver may terminate at a central office or message exchange station so that any one of various other stations similar to station 1 and having subscribers' circuits terminating at the same central office may be connected for two-way radio telephone communication. Terminals of the individual lines for such other stations are indicated at 163.

The stations 146, 147 and 148 are associated with lines 164 which are illustrated as connected with the three channels of a multiplex carrier wave system. The carrier wave apparatus is connected to radio transmitter 141 by transformer 155 and to radio receiver 157 by transformer 158 so that outgoing modulated carrier waves may modulate the ultra short waves produced by the transmitter and that incoming ultra short waves received by the receiver may be translated into

modulated carrier waves to be impressed on the carrier wave receiving circuits.

The three carrier wave channels differ only in the carrier frequencies allotted to them and in the corresponding variations made necessary in the oscillators and in the filters and selective circuits. They are substantially identical with the terminal channels of the Type C carrier system disclosed at Fig. 2 of the paper by Affel, Demarest and Green entitled "Carrier Systems on Long Distance Telephone Lines" published in the Bell System Technical Journal, Vol. VII, pp. 564-629, July, 1928. A brief description of one channel of this well-known system will suffice for all three channels. Voice frequency message currents originating at station 146 and which may be telephonic, telegraphic or of any other character falling within the discrete frequency band allotted to that particular channel are transmitted over line 164 to the hybrid coil 165 with which is connected the customary line balancing network 166. Outgoing message currents pass from the hybrid coil to the oscillator and modulator unit 167 which preferably includes a modulator of the well-known carrier suppression type so associated with an oscillator as to cause the message currents to modulate the amplitude of the oscillations and produce two side-bands. One of the side-bands is transmitted and the other suppressed by modulator band-pass filter 168 and the transmitted side-band together with the similar side-bands outgoing from the carrier wave channels associated with stations 147 and 148 pass by way of path 169 to transmitting amplifier 170 and transmitting band-pass filter 171 to the primary winding of transformer 155. It will, accordingly, be understood that when messages originate at stations 146, 147 and 148, their corresponding side-bands, each of its individual carrier frequency as determined by the frequency of its oscillator 167, will be impressed upon transformer 155 to bring about frequency modulation of the ultra short wave carrier waves produced at transmitter 141 for transmission to the outgoing transmission line or radiating antenna.

As an example of the range of frequencies of the currents employed filter 154 may pass currents of all frequencies up to approximately 2800 cycles, band-pass filter 168 may have a transmission range extending from 4850 cycles to 7350 cycles, filter 172 from 7850 cycles to 10350 cycles, filter 173 from 11150 cycles to 13650 cycles, filter 171 from 3500 cycles to 14,000 cycles, and the filter of pilot channel oscillator 142 corresponding to filter 19 of Fig. 1 may have a transmission band falling within the range of from 37,000 cycles to 43,000 cycles.

Incoming ultra short waves are impressed by circuit 156 upon radio receiver 157. After amplification and demodulation the resulting speech currents and single side-band carrier waves are supplied by transformer 158 to incoming speech frequency channel 159 and to incoming carrier wave path 174. The incoming carrier wave path includes a band-pass filter 175, the transmission frequency range of which, in accordance with the well-known frequency allocation practice of the Type C carrier telephone system, is higher than that of the local transmitting band-pass filter 171 and may extend from approximately 16,000 cycles to 28,000 cycles. The incoming carrier path also includes a carrier wave receiving amplifier 176 to the output terminals of which the input terminals of three band-pass filters 177, 178 and 179 are connected in parallel. The filter 75

177 may have a transmission range extending from 23,900 to 26,450 cycles, filter 178 from 16,350 to 18,850 cycles and filter 179 from 20,050 to 22,550 cycles. The filter 177 accordingly selects its individual carrier side-band and supplies it to an oscillator and demodulator 180 which yields voice frequency message currents and impresses them through hybrid coil 165 and line 164 upon the circuits of station 146. The operation of the other two carrier wave channels is similar and differs only in the carrier frequencies involved and the consequent differences in the tuning of the oscillator and other selective circuits employed.

Any drifting of the central transmitted or ultra short wave "carrier frequency" or of the frequency of the beating oscillator which may occur from time to time will be automatically compensated for by the frequency control mechanism operating to correct the local beating oscillator frequency.

It should also be noted that control of the local beating oscillator frequency may be effected in accordance with the principles of this invention with the conventional feed-back type of oscillator as well as with oscillators of the Barkhausen type. Conventional type oscillators when operating at very high frequencies can be made to vary in frequency by a change in plate voltage. This will also alter the electromotive force of the beating oscillations impressed upon the first detector but that will not have any serious effect upon the system.

What is claimed is:

1. The method of transmission by frequency modulated carrier waves which involves modulating the frequency of the carrier waves before transmission by a frequency control wave, transmitting the modulated waves to a remote receiving station, producing locally generated waves at the receiving station, causing the received carrier waves and the locally generated waves to interact, deriving from the resultant waves a component of the control wave frequency by which the received carrier wave was modulated and utilizing the derived control frequency component wave to control the frequency of the locally generated waves.

2. The method of deriving message indications from carrier waves, the frequency of which is modulated in accordance with both message waves and with a fixed frequency control wave which comprises receiving the frequency-modulated carrier waves, causing them to interact with local oscillations, demodulating the resulting frequency modulated intermediate frequency waves to reproduce the message wave and the control wave, rectifying the reproduced control wave and controlling the frequency of the local oscillations in accordance with the rectified reproduced control wave.

3. The method of receiving carrier waves which are frequency modulated by desired message waves and also by fixed frequency control waves which comprises causing the received waves to interact with locally generated waves to produce intermediate frequency waves, impressing the intermediate frequency waves upon two branches differentially tuned with respect to the normal intermediate frequency, demodulating the intermediate frequency waves to derive the desired message waves by which the received carrier waves are modulated and the fixed frequency control waves, and utilizing rectified control waves derived from the two branches to control

the frequency of the locally generated waves so as to cause it to follow the central frequency of the received waves.

4. A receiver for carrier waves which are frequency modulated both in accordance with signals and with fixed frequency control waves comprising a local source of oscillations, a demodulating device, means for causing the incoming frequency modulated carrier waves and the local oscillations to be simultaneously impressed upon said demodulating device to produce intermediate difference frequency oscillations, means connected thereto for demodulating the intermediate frequency oscillations to derive therefrom currents corresponding to the modulating signals and to the fixed frequency control waves, and means for rectifying the fixed frequency modulation component resulting from the demodulation of the intermediate frequency oscillations and for impressing the resulting rectified electromotive force on the local source of oscillations to maintain its frequency at substantially a fixed difference from the mean frequency of the incoming carrier waves.

5. A receiving system for waves which are frequency modulated in accordance with a fixed frequency control wave, comprising a receiving circuit upon which the received frequency modulated waves may be impressed, a local oscillator coupled thereto to supply locally produced oscillations to interact with the received waves, a combining device connected to the circuit to respond to the received waves and the locally produced oscillations and to yield resulting oscillations of a beat frequency, frequency detecting means connected to the combining device to derive from the beat frequency oscillations the control wave by which the received wave is frequency modulated, and means to apply the derived control wave to the local oscillator to control its frequency to maintain a definite relationship between the frequency of the local oscillator and the frequency of the received frequency modulated wave.

6. In combination, a source of ultra high frequency carrier waves, means for simultaneously modulating the frequency of the waves in accordance with messages and frequency control current, a receiver for receiving the frequency modulated carrier waves, a local oscillator associated with the receiver to produce oscillations to interact with received modulated carrier waves, and means whereby the control current modulation of the incoming waves is utilized to cause the frequency of the local oscillator to vary in a manner and magnitude corresponding approximately to that of the central frequency of the received frequency modulated carrier waves.

7. A receiving system for short waves which are frequency modulated in accordance with audio frequency message currents comprising a local oscillator, a high frequency detector, means for impressing the received modulated waves and oscillations from the local oscillator upon the detector, an intermediate frequency amplifier comprising two branches connected to the detector and tuned to frequencies at opposite sides of the normal intermediate frequency and having a characteristic of amplitude response with respect to frequency which is sloping in the range of intermediate frequencies employed whereby intermediate frequency modulated waves impressed thereon are converted to intermediate frequency amplitude modulated waves, a detector connected to each of said branches, means for

superposing audio message currents derived from the two detectors, a differential rectifier, means for impressing components of the two detector output currents of higher than audio frequencies upon the differential rectifier, and means for applying the resulting unidirectional electromotive force upon the local oscillator to cause its frequency to substantially follow the central frequency of the received modulated waves.

8. In a frequency-modulated carrier wave system, a transmitting station comprising means for modulating the frequency of a carrier wave simultaneously in accordance with frequency control waves and message waves, a remote receiving station for receiving the modulated waves comprising a local source of oscillations, means for causing the locally produced oscillations to interact with frequency-modulated carrier waves received from the transmitting station, means for deriving from the resultant interaction prod-

uct a frequency control wave component, and means responsive to the derived frequency control wave component for controlling the frequency of the locally produced oscillations.

9. The method of maintaining the frequency of a local oscillator at a receiving station for frequency modulated waves at a fixed numerical difference with respect to the central frequency of desired received frequency modulated waves which comprises imparting to the frequency modulated wave at the point of transmission a frequency modulation by control oscillations of a fixed frequency, receiving the frequency modulated waves at the receiving station, demodulating the received waves to reproduce the control frequency oscillations, and causing the reproduced control frequency oscillations to control the frequency of the local oscillator at the receiving station.

JOSEPH G. CHAFFER. 20