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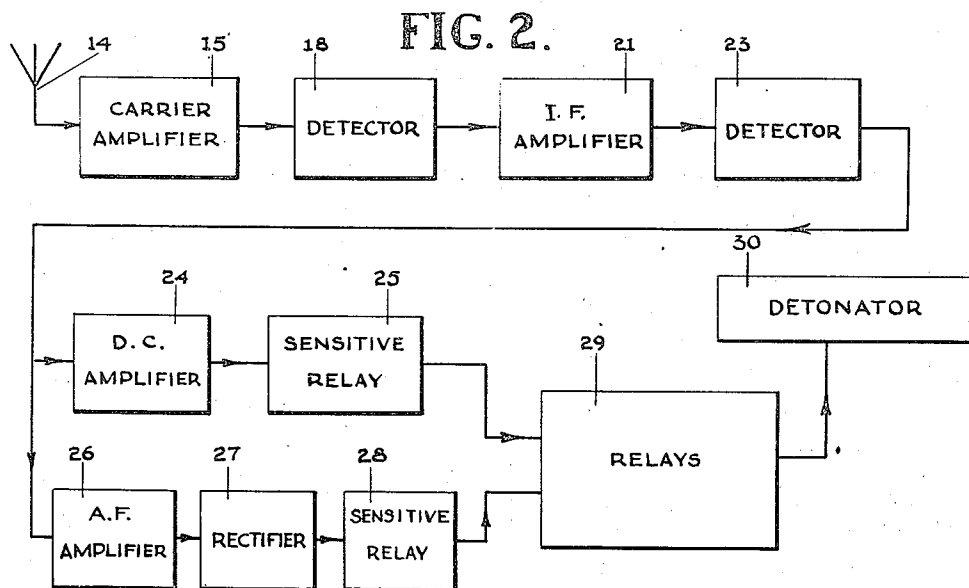
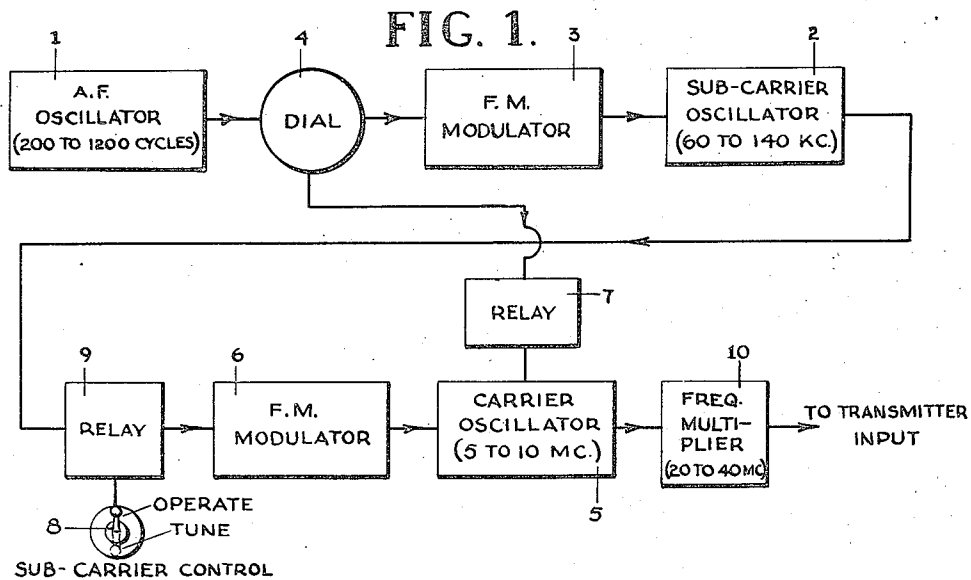
H. B. DEAL ET AL

2,413,296

RECEIVER SYSTEM

Filed Dec. 20, 1943

3 Sheets-Sheet 1



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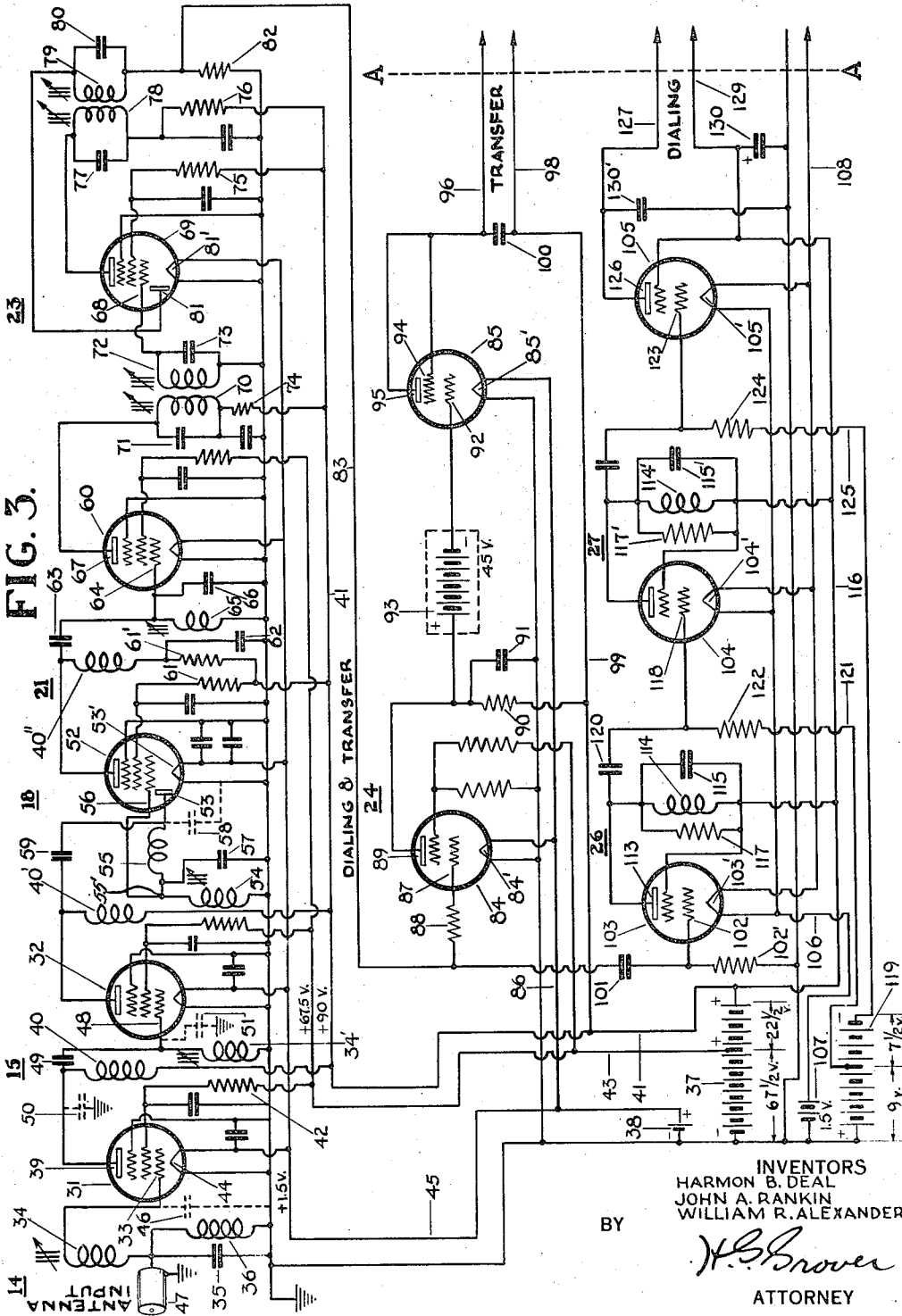
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RECEIVER SYSTEM

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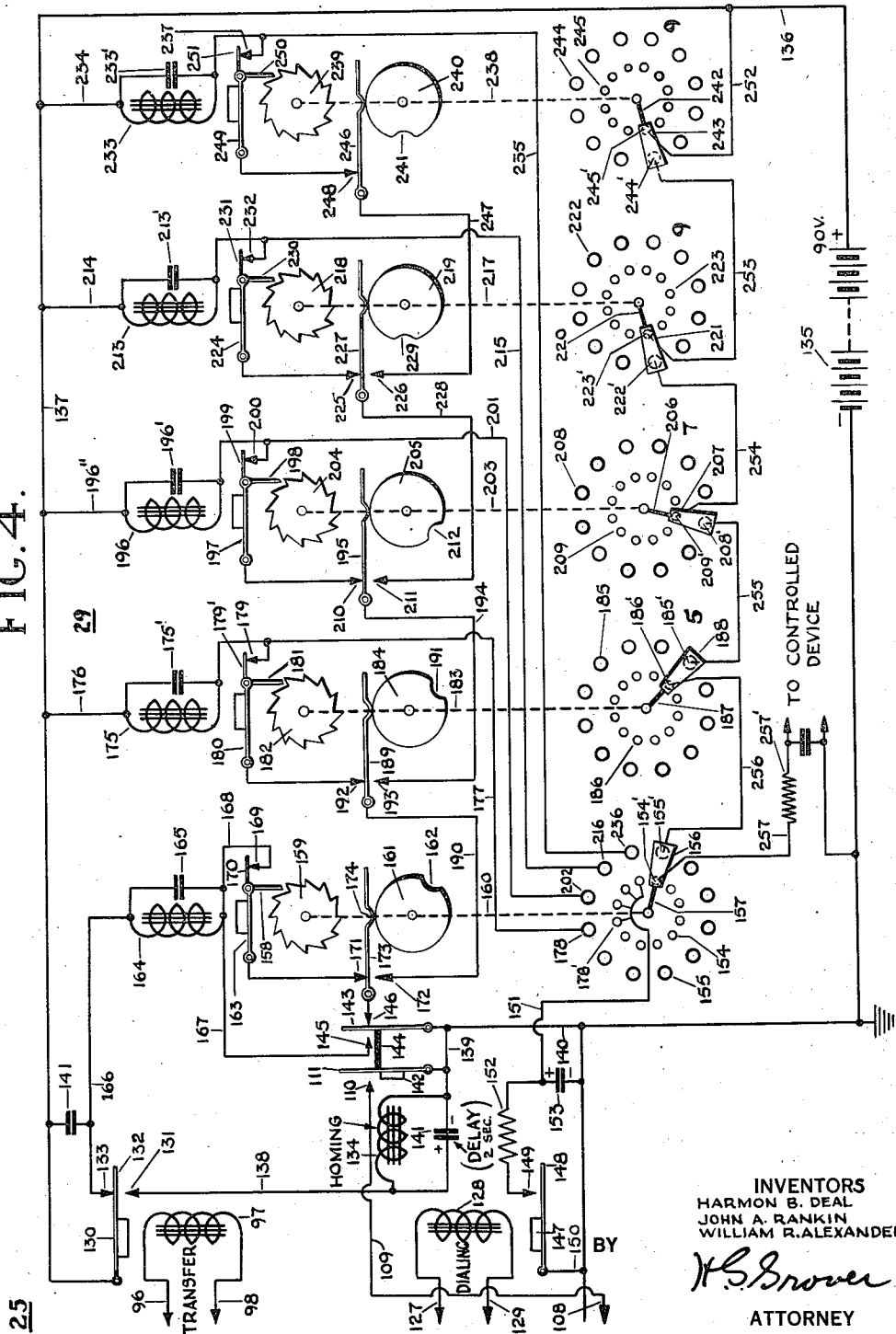
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FIG. 4.



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2,413,296

RECEIVER SYSTEM

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Application December 20, 1943, Serial No. 514,964

12 Claims. (Cl. 250—2)

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The invention covered herein may be manufactured and used by or for the Government of the United States for all governmental purposes without payment to us, or our assigns, of any royalty thereon.

Our present invention relates to receiving systems for angle modulated carrier waves, and more particularly to a frequency modulation receiver of novel construction and performance. The generic expression "angle modulated" is intended to cover frequency modulation, phase modulation and hybrids thereof.

There has been disclosed and claimed by S. W. Seeley, in his application Serial No. 509,232, filed November 6, 1943, a control system wherein a double frequency modulated carrier wave is radiated to one or more separate receivers. Each receiver is capable of responding solely to a wave having a predetermined combination of carrier, sub-carrier and modulation frequencies selected at the transmitter. Reception is accomplished in a unique manner, and without radiation from a receiver unit. Each receiver unit, upon proper energization, is capable of operating a controlled device, as for example a land mine. In our copending patent application Serial No. 497,000, filed August 2, 1943, we have disclosed and claimed a particular transmitter unit adapted for utilization in a system of the form shown in said Seeley application.

In our aforesaid copending application we have, in general, disclosed a transmitter unit wherein a selected carrier is frequency modulated ("FM" hereinafter for brevity) at a subcarrier frequency. The sub-carrier, in turn, is frequency modulated at a selected lower modulation frequency. The modulation current is pulsed at a repetition rate of approximately 10 pulses per second by means of a telephone dial, which permits the transmission of from 1 to 10 audio frequency pulses per dial operation. At the completion of each dialed number the carrier is interrupted for an interval of approximately one-tenth of a second. The secrecy of two million combinations is secured by using five carrier frequencies, five sub-carrier frequencies and eight modulation frequencies for a total of 200 combinations. At the receiver ratchet relays provide ten thousand combinations thereby providing a total of two million combinations.

At the receiver, as disclosed generally in the Seeley application, the complex multiple frequency modulated carrier wave is subjected to the discrimination action of highly selective tuned circuits. There is derived from the received FM

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wave an amplitude modulated carrier wave whose modulation frequency is the sub-carrier second harmonic. Detection of the derived energy yields an FM wave whose mean frequency is the said second harmonic and whose modulation frequency is the original modulation frequency applied at the transmitter. Further selective discrimination yields an amplitude modulated wave wherein the modulation is the second harmonic of the original modulating frequency. After demodulation, the resulting second harmonic modulation is passed through a selective network, and employed to operate relays in a predetermined sequence.

One of the main objects of our present invention is to provide a receiver unit which is capable of satisfactory operation in a system of the type shown by Seeley in his said application.

Another important object of our invention is to provide a reliable and efficient receiver unit adapted to be responsive to any one of a selected frequency combination of thousands of possible combinations radiated from a transmitter of the type disclosed in our aforesaid copending patent application.

In the particular embodiment of our receiver unit a novel detecting network and a novel relay arrangement are used. The received FM signal is amplified by a sharply tuned carrier amplifier resonant to the selected mean carrier frequency. Since the received signal is frequency modulated, the carrier may be thought of as varying in frequency above and below its quiescent frequency once each cycle of the modulating frequency. This process of modulation sweeps the carrier frequency back and forth across the single-peaked resonance characteristic of the carrier amplifier thereby imparting amplitude modulation to the carrier. The resulting amplitude modulation has two maxima and two minima for each cycle of frequency modulation. Hence, the modulation frequency is double, or the second harmonic of, the sub-carrier modulating frequency. Detection of the amplitude modulated carrier wave is followed by highly selective amplification in a so-called "intermediate frequency" network sharply tuned to the sub-carrier second harmonic frequency. As described previously, the result of this selective action is to provide an amplitude modulated wave wherein the audio modulation frequency is double the original audio frequency.

Both the direct current and alternating current components of the following detector output current are used. The direct current component is

amplified, and is used to operate a sensitive relay which performs three functions. First, the filaments of an audio amplifier are turned on in the presence of the intermediate frequency (I. F.) current. Secondly, in the absence of carrier transmission for long intervals of time, the dialing and transfer ratchet relays are connected so that they automatically "home." Thirdly, when carrier transmission is interrupted at the end of each dialed number the transfer ratchet relay is advanced one step.

The alternating current component of the detector is the second harmonic of the original audio modulation frequency. This component is amplified in a tuned amplifier, rectified and utilized to operate a second sensitive relay. This sensitive relay controls the dialing ratchet relays of which there are four. Each dialing relay may be dialed to any one of ten positions. When the four dialing relays are in the correct position a circuit is completed, and the latter action connects a land mine detonator to a battery of the receiver power supply.

It may be stated that it is a more specific object of our present invention to provide a highly efficient and reliable receiver unit for use in a secrecy radio control system, wherein the receiver unit operates with no local oscillator or other radiating signal to derive the benefits of selectivity and sensitivity of a superheterodyne circuit.

Still other features and objects of our invention will best be understood by reference to the following description, taken in connection with the drawings, in which we have indicated diagrammatically several circuit organizations whereby our invention may be carried into effect.

In the drawings:

Fig. 1 schematically shows the networks of a transmitter unit adapted to control a receiver of the present invention.

Fig. 2 schematically shows the networks of a receiver unit comprising the present invention.

Fig. 3 shows the circuit details of the receiver unit forming the subject matter of our present invention.

Fig. 4 shows the details of the relay circuits.

Before describing the circuit details of the receiving system shown in Fig. 3, the transmitter and receiver units will be generally described. In Fig. 1 we have depicted in purely schematic manner the general networks employed in our aforementioned transmitter application Serial No. 497,000. The numeral 1 designates a source of modulation signals. Specifically, the network 1 is an audio frequency oscillator of the resistance-capacity (RC) type arranged with switching means to generate oscillations at a plurality of different selected frequencies. In a particular example eight frequencies falling between 200 and 1200 cycles per second are employed. The sub-carrier oscillator 2 preferably generates oscillations in a range of 60 to 140 kc. A selector switch is provided in network 2 to permit the selection of any one of five sub-carrier frequencies. The selected sub-carrier frequency is deviated in accordance with a selected audio frequency. The FM modulator 3 is employed to provide the frequency modulation of the selected sub-carrier oscillations. Preferably the amplitude of the audio oscillations is adjusted to a level to provide the correct amplitude to drive the modulator tubes in network 3. Each selection of a desired sub-carrier frequency is, accordingly, accom-

panied by an appropriate selection of audio tone amplitude.

The numeral 4 denotes a manual dial through which during dialing operations the regulated output of audio source 1 is fed to the modulator tubes. The dialing mechanism is manually controlled, and pulses the audio frequency voltage at a repetition rate of approximately 10 pulses per second. This permits the transmission of from 1 to 10 pulses per dial operation, since the dial has 10 positions. The output of the dial 4 is fed to the modulator 3 to angle modulate the sub-carrier oscillations. In our aforesaid application we have shown the modulator as a pair of push-pull related reactance tubes to whose respective control electrodes is fed in differential manner the output of dialing device 4. The reactance tubes of modulator 3 act to reduce concurrently the effective capacity reactance and inductive reactance of the tank circuit of oscillator 2, and vice versa, thereby to change the frequency of the generated sub-carrier oscillations. The selected audio tone and amplitude causes the variation of the reactance tube effects.

The frequency modulated sub-carrier oscillations are now employed to modulate the carrier oscillations produced at network 5. The modulator 6, associated with carrier oscillator 5, is of the same construction as modulator 3. A pair of push-pull connected reactance tubes provide the modulation circuit for oscillator 5. The range of oscillator 5 is 5 to 10 mc., and any one of five carrier frequencies may be selected. Preferably, and as in the case of the sub-carrier frequency selection, we apply the modulated sub-carrier oscillations to modulator 6 in a balanced sense and of proper amplitude for constant deviation at the five different carrier frequencies. In both the frequency modulation steps at oscillators 2 and 5 the frequency of the generated wave will be deviated to an extent dependent upon the amplitude of the modulating signal, while the frequency of the modulating signal determines the number of times per second that the change or deviation in frequency of the wave takes place. It is assumed that the amplitude of each of sources 1, 2 and 5 is uniform, and that the waves are sinusoidal in character. These characteristics, however, are not restrictive.

After each dialing operation of dial device 4 the operation of carrier oscillator 5 is interrupted, for example, for approximately one-tenth of a second. This is done by employing for the control function a relay 7 which is energized for about one-tenth of a second after each dialing operation to render the oscillator 5 effectively inoperative. The numeral 8 denotes a control switch device for a relay 9, which when energized, acts to prevent the modulated output of oscillator 2 from reaching the modulator 6. Specifically, as shown in our aforesaid application, the switch 8 in "tune" position causes the relay 9 to be energized so that the grids of the reactance tubes of modulator 6 are grounded. When switch 8 is in "operate" position the relay 9 is in non-energized condition, and the connection from oscillator 2 to modulator 6 is normal. When the switch 8 is in "tune" position the frequency selection of oscillator 5 can readily be performed.

Remembering that the exciter output of oscillator 5 is one-quarter of the frequency at the final output after frequency multiplication, the frequency multiplier 10 is provided to quadruple the mean frequency of the frequency modulated

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carrier oscillations. Hence, there is passed on to remaining transmitter units wave energy having double frequency modulation and having a mean frequency in the 20 to 40 mc. band. The combinations of modulated excitation provide for 2,000,000 frequency combinations, or 400,000 combinations of any one selected carrier frequency. The secrecy of 2,000,000 combinations is obtained by using 5 carrier frequencies, 5 sub-carrier frequencies and 8 audio frequencies for a total of 200 combinations, which when multiplied by the 10,000 combinations provided by the ratchet relays at each receiver unit gives a total of 2,000,000.

When a certain receiver is to be dialed the tuning dials of the oscillator 1, oscillator 2 and carrier oscillator 5 are set, and the switch 8 is adjusted from "tune" to "operate." The proper numbers are then dialed by the dial mechanism 4 for a receiver control operation, following which the relay 9 is returned to "tune" position if the next succeeding receiver control operation requires a different carrier frequency. In order to allow other receiving equipment to "home," that is permit their relays to return to their original settings, a period of 5 seconds should elapse before dialing another receiver having the same sub-carrier and carrier frequencies. When one receiver is used to operate two or more detonators on different dialed numbers, this homing sequence must be carefully observed.

The receiving system of our present invention is schematically represented in Fig. 2. One of the factors of prime importance in the receiving system, as disclosed and claimed in the aforesaid Seeley application, is that the receiver is so constructed that it will produce amplification at the second harmonic of a predetermined modulation frequency of an incoming carrier. The second harmonic is produced by the action of simple narrow-band tuned circuits at the carrier frequency. It will be remembered that in the usual receiver of FM carrier waves the detector is customarily preceded by amplification of a broad band of frequencies at the carrier frequency followed by some type of discriminator. In the present receiver there is no discriminator network per se, since the discrimination is an inherent function of the sharp selectivity characteristic in each of the cascaded tuned circuits. The advantages of sensitivity and selectivity inherent in superheterodyne receivers are secured in this system, yet no local oscillator is employed with the result that no oscillatory energy is radiated from the receiver.

The received multiple frequency modulated carrier wave energy may be collected by any desired type of signal collector 14. Depending upon the installation of the receiver unit, the collector 14 could be a grounded antenna circuit, a dipole, or any other well known pick-up device capable of collecting wave energy whose mean carrier frequency is in the operating range of 20 to 40 mc. The carrier amplifier 15 may be of any well known construction, and it has an input circuit which is sharply tuned to the selected carrier frequency of the received wave. The amplifier 15 is followed by a detector 18 whose tuned input circuit will be sharply tuned to the selected carrier frequency. It is desired that the resonance curves of the input circuits of amplifier 15 and detector 18 be of the same type.

Since it has been fully disclosed in the aforesaid Seeley application how the selective input circuit of the amplifier derives amplitude modulated energy from the double FM carrier, it is

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not believed necessary to repeat the description of the derivation in as great detail. It is sufficient for the purposes of Fig. 2 to point out that since the received modulated carrier wave is frequency modulated, the carrier may be thought of as varying in frequency above and below its quiescent frequency once each cycle of the modulating frequency. This process of modulation sweeps the carrier frequency back and forth across the single-peaked resonance characteristic of the amplifier 15 thereby imparting amplitude modulation to the carrier. For each cycle of frequency modulation the resulting amplitude modulation has two maxima and two minima. Hence, there will be applied to the detector input circuit an amplitude modulated carrier wave whose mean frequency is the received carrier frequency, but whose modulation frequency is the second harmonic of the sub-carrier frequency.

The detector 18 acts to rectify the amplitude modulated carrier wave energy. The detected energy is frequency modulated wave energy whose mean frequency is double the sub-carrier frequency, and whose modulation is made up of a component provided originally by the audio frequency oscillator 1 of the transmitter unit. The frequency modulated wave energy of double the sub-carrier frequency is termed "intermediate frequency energy" (I. F. for brevity). The term should not be understood as implying the use of a local oscillator as is done in superheterodyne receiver practice. The expression "I. F." is used herein, because the second harmonic sub-carrier frequency is intermediate the received carrier frequency and the original audio modulation frequency.

The I. F. energy output of detector 18 is amplified by an I. F. amplifier 21 whose input circuit is highly selective, and is tuned sharply to the second harmonic of the sub-carrier frequency. The sharp selectivity characteristic of the input circuit of amplifier 21 acts in the same manner as do the sharp input circuits of amplifier 15 and detector 18. In other words, the FM wave energy applied to the input circuit of I. F. amplifier 21 is translated into amplitude modulated wave energy whose mean frequency is the second harmonic of the sub-carrier frequency, but whose modulation frequency is double the original selected audio frequency. This means that there will be applied to the sharply tuned input circuit of the following detector 23 an amplitude modulated wave whose mean frequency is the I. F. value, but whose modulation frequency is the second harmonic of the selected audio frequency.

Both the alternating current and direct current components of the detected output current of detector 23 are utilized. The direct current component is amplified by the direct current amplifier 24, and the amplified output of amplifier 24 operates a sensitive relay 25 which performs three functions. First, the filaments of an audio amplifier are connected in a complete heating circuit in the presence of I. F. energy. Secondly, in the absence of carrier transmission for long intervals of time, the dialing and transfer ratchet relays are connected so that they automatically "home." Third, when the operation of the transmitter is interrupted, at the end of each dialed number, the transfer ratchet relay is advanced one step.

The alternating current component of the detected output of detector 23 is amplified by the audio frequency amplifier 26. It is preferable to have amplifier 26 tuned to the second harmonic

of the selected audio frequency. The rectifier 27 rectifies the output of tuned audio amplifier 26. The output voltage of rectifier 27 operates a second sensitive relay 28. This relay 28 controls the dialing ratchet relays, of which there are four, located at 29. The detonator 30 is actuated in accordance with the operation of the relays located at 29.

It will now be seen that in general in the detecting system used at the receiver a form of double demodulation takes place, and at the I. F. amplifier 21 there is provided a doubling of the tone frequency. In other words, where the audio oscillator at the transmitter is adapted to operate at a selected one of eight frequencies running from 200 to 1200 cycles, at the output of detector 23 in Fig. 2 one may select a tone frequency from eight frequencies located in the range of 400 to 2400 cycles. The detected output of detector 23 includes, in addition to the selected double frequency tone, a direct current component which is derived from the rectified carrier. The selected tone frequency is used to step up one of a series of dialing sensitive digital relays, there being four in this embodiment. More may be employed, if desired. Absence of the direct current component is used to transfer operation of the tone frequency from one digital relay to the next.

Since in the operation at the receiver it is desired to interrupt the direct current component thereby to operate the relay 25, the relay 7 is provided at the transmitter unit in Fig. 1 for interrupting the carrier oscillator operation after each dialing operation. As stated previously, at the transmitter unit the audio frequency is pulsed by the dialing mechanism 4 at a repetition rate of about ten pulses per second, this permitting the transmission of one to ten audio pulses per dial operation. At the completion of each dialed number the operation of the carrier oscillator is interrupted approximately for one-tenth of a second. This interruption is used to operate the transfer switch at the receiver unit which conditions a second digital ratchet relay for operation, assuming that the first one was operated by the dialing described above. The digital relays, and other relays, at the receiver unit are frequency sensitive, and respond to one particular tone frequency only. When the four digital relays are in the correct position, which has been predetermined, a circuit is completed which connects the land mine detonator, or any controlled circuit, to an energizing source.

Attention is now directed to the detailed circuit diagram of Fig. 3 wherein is shown the specific circuit connections of one embodiment of a receiver unit. The carrier amplifier network 15 consists of a pair of cascaded tuned amplifier stages. Of course, more than two stages of carrier-tuned amplification may be employed. The first tube 31 and second tube 32 are illustratively represented as pentodes, although any other suitable type of tube may be used. The signal grid 33 of tube 31 is connected to one end of a tuner coil 34 which is of the adjustable iron core type. The lower end of coil 34 is connected to ground through condenser 35. The direct current return path for grid 33 consists of the choke coil 36. Energizing current sources 37 and 38, both shown as battery sources by way of illustration, are provided for the screen, plate and cathode electrodes.

The plate electrode 39 of tube 31 is connected to the positive terminal of direct current source 37 over a path comprising choke coil 40 and lead

41. The screen electrode is connected to an appropriate positive voltage point on battery 37 over a path consisting of voltage reducing resistor 42 and lead 43. The grounded suppressor grid and the positive screen electrode are appropriately bypassed to ground for high frequency currents. The filament 44 of tube 31 is connected across the heating current source 38 by virtue of its connection between ground and lead 45.

The coil 34, condenser 35 and the input capacitance of tube 31 (designated by the dotted condenser 46 between grid 33 and the grounded cathode or filament 44) provide a resonant input network for amplifier tube 31. The input network 34-35-46 is tuned to the desired carrier frequency of the collected double frequency modulated wave energy. The inductance of coil 34 may be chosen so as fixedly to tune the amplifier to any of the following five carrier frequencies: 21, 25.5, 30, 34.5 and 39 mc. These are, of course, purely illustrative values. These values will correspond to the carrier frequencies selectively radiated from the transmitter, it being understood that in the present example of our invention the radiated frequencies are four times those produced by the carrier oscillator 5 of Fig. 1.

The antenna input transmission line 47 may be connected to feed across condenser 35. The line 47 is preferably designed to operate out of a quarter wavelength antenna normally having a resistive output impedance of 35 ohms. The coupling between line 47 and the input network of the tube 31 is below critical to the extent that a reactive component in the antenna impedance equal to the antenna resistance does not detune the input network. Hence, the antenna connected to line 47 could vary considerably from a quarter wavelength without detuning the input network 34-35-46. The resonance curve of the latter network is sharply peaked by virtue of proper selection of the "Q" of coil 34.

The second carrier amplifier tube 32 has its electrodes energized in the same manner as tube 31. The filament of tube 32 is connected to the heating source 38. The screen and plate are connected to leads 43 and 41 respectively. The choke coil 40' is in circuit with the plate and lead 41. The control grid 48 of amplifier tube 32 is connected by direct current blocking condenser 49 to the plate end of coil 40. The coil 34' is an iron core tuner coil, similar to coil 34, and acts to tune the input circuit of tube 32 to the desired carrier frequency. The coil 34' also functions as a direct current return path for grid 48.

The iron core of coil 34' is adjusted so that the selected inductance thereof will resonate with the output capacitance of tube 31 and the input capacitance of tube 32 to the received carrier frequency. The output and input capacitances are shown in dotted lines, and are designated by reference numerals 50 and 51 respectively. The tuned network 34'-50-51 has a high "Q"; its resonance curve has a sharp peak at the selected carrier frequency. The plate circuit of amplifier tube 32 is impedance-coupled to the diode section of multiple function tube 52. The latter may be a diode-pentode tube, or it can be any other type of tube or two separate tubes providing a diode section and an amplifier section.

The filament 53' of tube 52 is heated from source 38. The diode anode 53 receives its electrons from a portion of the filament surface. Anode 53 is connected to the grounded leg of the filament through a series path consisting of coils 54 and 55. Both coils preferably have ad-

justable iron cores. The junction point 55' of the coils 54 and 55 is connected to the control grid 56 of the amplifier section of tube 52. Condenser 57 shunts coil 54, and tunes the latter to the second harmonic frequency of the sub-carrier frequency employed at the transmitter. Coil 55 and the inherent diode capacitance 58 provide a resonant input network for diode 53—53' sharply tuned to the carrier frequency. The capacitance 58 is shown dotted, since it is the inherent anode to filament capacity of the diode. The tuned circuit 54—57 acts as the diode load. At the same time it is the tuned input network of the amplifier section of tube 52. The anode 53 is connected by direct current blocking condenser 59 to the plate end of choke coil 40'.

The cascaded amplifiers up to the diode 53—53' act to provide simultaneous discrimination and amplification of the received double frequency modulated carrier wave. The effect of the cascaded sharply tuned circuits 34—35—46, 34'—51 and 55—58 is to translate substantially all the frequency modulated carrier wave energy into amplitude modulated carrier energy whose frequency of modulation is of double the sub-carrier frequency. The specific manner in which each of the cascaded highly selective circuits acts to provide such discrimination has been fully explained in the aforementioned Seeley application. Frequency modulated wave energy whose mean frequency is of double the sub-carrier frequency is derived by detection in the tuned diode circuit. The output voltage developed across tuned load 54—57 is the so-called "I. F." voltage, which is shown in Fig. 2 as amplified at 24.

The I. F. energy developed at tuned diode load circuit 54—57 is amplified in the cascaded I. F. amplifier tubes 52 and 60. The screen grid and plate of tube 52 are connected to lead 41 through separate voltage reducing resistors 61 and 61' of equal value. The shunt feed coil 40'' is in series with resistor 61', and the junction of the two elements is bypassed to ground for carrier currents by condenser 62. A parallel resonant circuit, consisting of coil 65 and condenser 66, functions as the sharply tuned input circuit of tube 60. The plate of tube 52 is coupled through direct current blocking condenser 63 to the high alternating potential side of tuned circuit 65—66 and to the control grid 64 of I. F. amplifier tube 60.

The tuned circuit 65—66 resonates at the I. F. and has a high "Q" so as to provide a sharply peaked resonance curve as in the case of tuned I. F. circuit 54—57. Similarly to the prior amplifier tube, the tube 60 has its screen grid connected through a properly bypassed voltage reducing resistor to lead 43. The plate of tube 60 is coupled to the control grid 68 of multiple function tube 69 by means of a pair of reactively coupled tuned circuits, each tuned to the I. F. The tuned circuit connected with plate 67 consists of iron core coil 70 shunted by condenser 71. The second tuned circuit consists of iron core coil 72 shunted by condenser 73. Coils 70 and 72 are magnetically coupled to provide a resonance curve sharply peaked at the operating I. F. value (second harmonic of transmitter sub-carrier frequency).

The lower end of coil 70 is connected through bypassed resistor 74 to supply lead 41. The lower end of coil 72 is returned to ground, and the filament of tube 69 is heated by source 38. As in the case of tube 52, the screen and plate of the amplifier section of tube 69 are connected

through bypassed voltage reducing resistors 75 and 76 to supply lead 41. The pentode section of tube 69 functions as an amplitude limiter. The resistors 75 and 76 are chosen in magnitude so that the pentode section of tube 69 readily saturates in response to excessive amplitude of signal voltage at grid 68.

In the plate circuit of the amplitude limiter section there is included a parallel resonant circuit 77—78 similar in construction to tuned circuit 71—70. The coil 78 is magnetically coupled to coil 79 of parallel resonant circuit 79—80, connected between diode anode 81 and the upper end of diode load resistor 82. The lower end of resistor 82 is connected to the grounded leg of the filament 81' of tube 69. It will be understood that circuit 79—80 is the tuned input circuit of diode 81—81', and is connected in series with the unbypassed load resistor 82. Magnetic coupling between coils 78 and 79 is chosen so as to provide sharp selectivity for the diode input circuit. The resonance curve of coupled circuits 77—78, 79—80 will have a sharp peak at the I. F. value.

It will be appreciated that detector diode 81—81' is preceded by a plurality of cascaded highly selective resonant networks 54—57, 65—66, 71—70—72—73 and 77—78—79—80. In each of these networks frequency modulated I. F. energy is converted into amplitude modulated I. F. energy whose audio modulation is double the selected audio modulation selected at network 1 of the transmitter unit (see Fig. 1). Thus, there will be a maximum of FM energy converted due to the large number of sharply tuned circuits preceding the detector. There will occur concurrent amplification of converted I. F. energy at tubes 52 and 60. However, at tube 69 amplitude limiting is accomplished so as to control the level of the audio output of detector 23, and hold it within usable limits. The plate circuit limiter 69 permits a variation of audio output of approximately 3:1. The I. F. amplifier should be sufficiently sensitive so as to provide an output at the detector 23 which is sufficient to operate the following networks 24, 26 and 27.

The diode 81—81' detects the limited modulated I. F. energy applied thereto from circuit 79—80. There will be developed across load resistor 82 a direct current voltage component and an audio frequency voltage component. The audio voltage component has a frequency which is double the original modulation frequency. The audio voltage and the direct current voltage are both applied over a common lead 83 to an audio amplifier 26 and a direct current amplifier 24 respectively. The lead 83 is designated as the "dialing and transfer" path since the direct current component controls the transfer relay, while the audio component controls the dialing relay. Both of these relays will be described in more detail in connection with Fig. 4.

Considering first the direct current amplifier 24, it consists of a tube 84 which is directly coupled to a following tube 85. The filaments 84' and 85' of tubes 84 and 85 respectively are heated by the heating current source 38, and the ungrounded leads of these two filaments are connected by a common lead 86 to the heating supply lead 45. The control grid 87 of tube 84 is connected by a resistor 88 to the common lead 83. It will, therefore, be seen that grid 87 returns to ground through a path consisting of resistor 88, lead 83 and diode load resistor 82. The screen grid of tube 84 derives its positive voltage from lead 43, while the plate 89 is connected by means

of the plate resistor 90 and lead 99 to the positive voltage supply lead 41. The plate end of resistor 90 is connected to ground by condenser 91 in order to bypass the audio component.

Tube 85 has its control grid 92 directly connected to the plate 89 through a negative biasing battery 93. This battery should be well insulated from the chassis, and preferably applies a negative bias of about -45 volts to grid 92. The screen grid 94 and the plate 95 of tube 85 are connected in common to the positive voltage supply lead 41. This connection is made over a path comprising lead 96, transfer relay winding 97 (Fig. 4), lead 98, lead 99 and lead 41. Condenser 100 shunts the winding 97.

In order to explain the operation of tubes 84 and 85, let it first be assumed that no carrier is being radiated from the transmitter unit shown in Fig. 1. This will happen, for example, when after a number is dialed the carrier oscillator is momentarily rendered ineffective. In this no-carrier state the tube 84 is conductive, and provides a voltage drop across the plate load resistor 90. This causes a reduction in the plate potential to a small positive value. This small positive voltage at the plate end of resistor 90 is not enough to prevent the high negative bias of battery 93 from cutting off the plate current flow of tube 85. Hence, there will be no current flow through the winding 97 in the absence of received carrier energy.

On the other hand, when carrier energy is being received, the direct current voltage developed across resistor 82 will be applied to the grid 87 in a negative polarity. This negative voltage applied to grid 87 considerably reduces the flow of plate current through resistor 90 with the result that the voltage drop across the resistor decreases. Hence, the plate potential of tube 84 effectively rises in a positive sense until it offsets the cut-off bias due to battery 93 to an extent such that current flows through the plate circuit of tube 85 and through the transfer relay winding 97.

The unit 24 is actuated by the momentary suppression of the carrier to effect transfer operations from one dialing relay to the next dialing relay. It will be noted that tube 84 operates at zero grid potential. Normally, and merely by way of illustration, the plate 89 could be allowed to be positive by only +20 volts in the absence of received carrier energy. This would provide a net bias for grid 92 of about -25 volts, which is double the negative voltage necessary to cut off the plate current of tube 85. If now carrier energy is received, and say for example one volt of negative voltage is applied to grid 87, the plate 89 would have a potential of about +82 volts. This would permit the application of +37 volts to grid 92 thereby permitting maximum plate current to flow through the sensitive transfer relay winding 97. Such maximum plate current would be some five times the current necessary to close the transfer relay.

To prevent the audio component, which is also applied to grid 87, from biasing the output tube, and also to prevent relay clicks and spark discharges from operating this relay, considerable time delay and bypassing is provided by condenser 91 and the shunt condenser 100. The total time delay produced by these two bypass condensers must be less than the time intervals between dialing the numbers 1-1-1-1 as rapidly as will ever be required. This is another way of saying that the delay must be short enough

to permit the most rapid transfer operation the system will ever have to handle. The amplifier 24 is quite sensitive and in the present example of our invention will operate its associated relay 97 when the input voltage on grid 87 is more negative than -0.6 volt (D. C.), which will occur for the minimum operable signal on the receiver antenna. Moreover, the sensitivity of the amplifier is not appreciably impaired toward the end of the life of the plate voltage supply source 37, because of the initial excess during reception of operable signals of positive grid potential on the grid 92 of tube 85.

Considering now the utilization of the audio component provided across load resistor 82, the audio voltage is supplied through the direct current blocking condenser 101 to the control grid 102 of tube 103. The tube 103 functions along with the following tube 104 as a selective audio frequency amplifier. The final tube 105 functions as a plate rectification type of detector. The filaments 103', 104' and 105' of the three tubes have one common lead 106 to the positive terminal of the heating current source 107, the negative terminal of source 107 being grounded. The remaining filament lead of each of tubes 103, 104 and 105 is connected to a common lead 108. The lead 108 returns to ground through a path (see Fig. 4) consisting of lead 109, contact point 110, contactor 111, armature 142, lead 139 and lead 140. It will, therefore, be seen that the filaments 103', 104' and 105' will not be heated unless the switch 110-111 is closed.

In the plate circuit of each of tubes 103 and 104 there is provided a parallel resonant circuit which is tuned to the second harmonic of the audio frequency selected at the network 1 of the transmitter unit in Fig. 1. The plate 113 of tube 103 is connected to the high alternating potential side of the first resonant circuit. The latter consists of a coil 114 shunted by condenser 115. The low potential end of coil 114 is connected to a lead 116, which, in turn, is connected to the positive terminal of the plate voltage supply source 37. A damping resistor 117 is connected in shunt with the parallel resonant 114-115, and the screen grid of tube 103 is connected to the lower end of coil 114. The control grid 102 is returned to ground through a resistor 102', but the control grid 118 of tube 104 has a negative bias of about -9 volts applied thereto from a negative biasing source 119. The direct current blocking condenser 120 couples grid 118 to the upper end of coil 114, and the biasing lead 121 includes the grid resistor 122 in circuit therewith.

The plate circuit of tube 104 similarly includes a parallel resonant circuit consisting of coil 114' shunted by condenser 115'. The damping resistor 117' is connected in shunt across the second resonant circuit, and the plate and screen grid of tube 104 are connected to the upper and lower ends of coil 114' respectively. The lower end of coil 114' is connected to the voltage supply lead 116. The detector tube 105 has its control grid 123 connected through the grid resistor 124 and lead 125 to the negative terminal of the biasing source 119, and a negative bias of about -16½ volts is normally applied to grid 123. The plate 126 of tube 105 is connected to the positive terminal of supply source 37 through a path which consists of lead 127, dialing relay winding 128, lead 129 and lead 116. The screen grid of tube 105 is connected directly to the lead 116, and condenser 130 bypasses the lower end of winding 128 to ground.

The unit 26—27 provides audio selectivity, and utilizes the audio dialing pulses to operate the dialing relay 128. Assuming by way of illustration that at the transmitter the selected audio frequency was 430 cycles; then each resonant circuit 114—115 and 114'—115' would be tuned to 860 cycles. The 860 cycle voltage developed across the second tuned circuit is sufficient to exceed the $-16\frac{1}{2}$ volt normal bias on the grid 123 of the plate circuit detector tube 105. This detector tube has sufficient current capacity so that no direct current voltage amplifier is required subsequent to rectification. The increase in grid voltage from beyond cut-off increases the plate current flow of tube 105 through the winding 128 from zero to approximately twice the current required to operate the relay. The large bypass condenser 130' across the detector plate circuit provides time delay, and also integrates the half waves of audio frequency that would otherwise appear across this circuit. The delay and integration is desirable short of the failure point of the fastest dialing operation which will ever be required. Such failure might result from too long a holdover for the sensitive dialing relay, precluding its release and recovery within the time between two dialing pulses. Short of this point, the delay and integration is desirable in that it makes the dialing operation relatively immune to interference resulting from relay clicks and other extraneous pulses from the transmitter, or from external sources such as ignition interference, unless it is strong and of long persistence.

Each of the tuned audio circuits is shunted with a resistor. The first tuned audio circuit 114—115 is shunted by a resistor 117, while the second tuned audio circuit 114'—115' is shunted by a resistor 117'. The function of these resistors is to prevent shock excitation of the tuned circuits. The damping of these circuits is a compromise between immunity from shock excitation and necessary selectivity. The resulting selectivity is sufficient to preclude operation by adjacent audio frequencies. As stated above, the filaments of the tubes of the dialing unit 26—27 are closed upon closure of switch 110—111. This switch is closed only when the "homing" relay is actuated to disconnect the homing circuits. That is, the audio amplifier heaters are not connected in circuit with source 107 until current flows through the transfer relay winding 97. This has the desirable features of diminishing the drain on both the plate and filament supply batteries, except preparatory to dialing.

Reference is now made to Fig. 4 for a detailed explanation of the manner in which the various relay functions are performed. It is to be understood that the circuit shown in Fig. 4 is a continuation of the circuit shown in Fig. 3 to the right of the vertical dotted line A—A. Upon flow of current through winding 97 of the transfer relay the armature 130 is pulled towards the position in which fixed contact 131 and movable contact 132 touch. This breaks the connection through movable contact 132 and fixed contact 133. Upon closing of switch 132—131 the winding 134 of the homing relay is placed in an electrical circuit with the relay battery 135 which has a potential relative to its grounded negative terminal of about +90 volts. The resulting electrical circuit through the homing relay may be traced over the following path: from the positive terminal of battery 135 by lead 136 to common relay lead 137, thence to armature 130 and switch 132—131 to lead 138, through winding 134 to lead 139, and

through lead 140 to the grounded negative terminal of battery 135.

A condenser 141 bypasses the switch 133—132 when the latter is closed. Condenser 141 shunts the homing relay winding 134 to provide a time delay of 2.0 seconds. Upon closing of the aforesaid electrical circuit through winding 134, the latter is energized and the armature 142 is pulled towards the electromagnet. This causes closing of switch 110—111. Armature 142 has associated therewith a second movable contact 143. Contacts 111 and 143 are spaced from each other by the insulation spacer 144, but are nevertheless connected in common by lead 139. The contact 143 cooperates with a pair of fixed contacts 145 and 146. Normally the switch consisting of contacts 143 and 146 is closed, while switch 145—143 is open. Upon closure of switch 110—111, as pointed out previously, the filaments of audio tubes 103, 104 and 105 are connected in circuit with heating source 107. The tubes become operative to energize the dialing relay winding 128.

Upon energization of winding 128, the armature 147 is attracted thereby closing the switch consisting of movable contact 148 and fixed contact 149. The armature 147 is connected at its pivoted end to ground by lead 150. The fixed contact 149 is connected to lead 151 by resistor 152. Condenser 153 connects the right hand end of resistor 152 to ground. The lead 151 is connected to predetermined ones of a circle of spaced contacts 154. A second circle of spaced contacts 155 is provided concentrically with the contacts 154. Corresponding contacts 154 and 155 are aligned radially so that a rotatable metallic connector 156 may electrically connect them in pairs. This connector may be of any desired shape; preferably it should be a metal plate whose inner end is secured to an insulation carrier bar 157.

The connector unit 157—156 is mechanically mounted for rotation about an axis or shaft assumed to be passing through the common center of the circles of contacts 154 and 155. Rotation of the contactor unit in a clockwise direction will then be seen to provide sequential electrical connection between the respective pairs of contacts 154 and 155. The connector unit is rotated in a clockwise direction by means of a pawl and ratchet designated by numerals 158 and 159 respectively. The dotted line 160 schematically represents a common mechanical coupling, such as a shaft, upon which is mounted the ratchet 159, the connector unit 157—156 and cam 161. The cam 161 generally has the shape of a disc, except that it is provided with a recess 162. The mechanical structure of the ratchet 159, cam 161, connector unit 157—156 and shaft 160 are schematically represented, but it is to be understood that those skilled in the art are fully aware of the manner of constructing these units. It is sufficient for the purposes of this application to point out that upon rotation of the ratchet 159 the cam 161 will concurrently be rotated, as will also the connector unit 157—156. It will, also be understood that when the ratchet 159 is rotated through an angular distance equal to one tooth, the connector 156 will be moved from one pair of aligned contacts to the immediately following pair of contacts in a clockwise sense.

The pawl 158 is pivotally secured to the armature 163 of a digital stepping relay. The numeral 164 denotes the winding of the electromagnet of that relay. This relay is the transfer step relay of a bank of five stepping relays. Condenser 165 shunts the winding 164, and the upper end of

the winding 164 is connected by lead 166 to the contact point 133. The lower end of winding 164 has one connection 167 to the fixed contact point 145, while a second connection 168 is connected to the fixed contact point 169. The mobile contact 170 is electrically associated with contact point 169, and the former is carried by the armature 163.

Hence, it will be seen that when winding 164 is unenergized, the armature 163 will be in its released position and switch 170—169 will be closed. Of course, the pawl 158 will be in its lowermost position. The pivoted end of armature 163 is connected to a fixed contact point 171 which has a spaced mate contact 172. Contact points 171 and 172 have electrically associated therewith a mobile contact 173, which actually is the pivoted spring follower of cam 161. The follower 173 is provided with a convex portion 174 adjacent its free end. This portion 174 rides along the cam periphery of disc 161 and is normally seated in the recess 162.

The pivoted end of cam follower 173 is electrically connected to the fixed contact point 146. Accordingly, when the homing relay winding 134 is energized to attract its armature 142, the switch 143—145 will be opened, while switch 145—143 will be closed. Furthermore, switch 171—173 will be closed, as shown in Fig. 4, during the time that the cam follower rides out of recess 162 and along the cam periphery. It follows, therefore, that when the convex portion 174 is seated in recess 162, switch 173—171 will be opened, while switch 173—172 is closed.

Each of the remaining members of the group of digital relays is constructed in the same manner as described in connection with the first stepping relay. Thus, the second stepping relay has a winding 175 whose upper end is connected by lead 176 to the common conductor 137. The lower end of winding 175 is connected by lead 177 to one contact of the circle of contacts 155. This one contact is designated by numeral 178, and it will be noted that the contact 178 and its mate 178' are in the twelve o'clock position of the connector unit. The lower end of winding 175 is, also, connected to the fixed contact point 179. The armature associated with winding 175 is designated by numeral 180. The pawl 181 is pivotally carried by armature 180, and ratchet 182 is provided adjacent the free end of pawl 181. The common mechanical coupling for ratchet 182 and cam disc 184 is denoted by dotted line 183. The concentric circles of contacts are designated by numerals 185 and 186. The mechanical driving means 183 is provided with the connector unit consisting of the insulation carrier bar 187 and the metallic connector plate 188. The cam follower 189 for the cam disc 184 has its pivoted end connected by lead 190 to the fixed contact point 172. The cam disc is provided with recess 191, and the cam follower has associated therewith the pair of fixed contacts 192 and 193. The fixed contact 192 is connected to the armature 180, while the fixed contact 193 is connected by lead 194 to the cam follower 195 of the third stepping relay unit. As in the case of winding 164, the winding 175 is bypassed by condenser 175'.

In the following stepping relay unit the relay winding 196, bypassed by condenser 196', is provided with an armature 197. The pawl 198 is pivotally secured to armature 197, and the free end of the armature functions as a mobile contact 199 for the fixed contact point 200. The lower end of winding 196 is connected by lead

201 to the second contact 202 of the circle of contacts 155. The upper end of winding 196 is connected by lead 196'' to the common conductor 137, while lead 201 is electrically connected to the fixed contact 200. The common mechanical coupling 203 is provided with the ratchet 204, a cam disc 205 and the connector unit. The latter consists of the insulation bar 206 provided with the metallic connector plate 207. The outer circle of contacts for this connector unit is designated by numeral 208, while the inner circle of contacts is designated by numeral 209. The cam follower 195 is associated with the spaced fixed contacts 210 and 211, while the cam disc 205 is provided with the recess 212.

The penultimate stepping relay unit comprises winding 213 whose upper end is connected by lead 214 to the common conductor 137. Bypass condenser 213' shunts winding 213. The lower end of winding 213 is connected by lead 215 to contact 216 following contact 202 in a clockwise sense. The common means 217 mechanically couples ratchet 218, cam disc 219 and connector unit 220—221. The outer circle of contacts is denoted by numeral 222, while the inner circle of contacts is designated by numeral 223. The armature 224 has its pivoted end connected to fixed contact 225; the opposite fixed contact is 226. The cam follower 227 has its pivoted end connected by lead 228 to the fixed contact 211. The recess 229 is provided in the cam periphery of disc 219. Armature 224 is provided with pawl 230 and mobile contact 231. The fixed contact 232 is connected to the lower end of winding 213.

The final relay unit comprises the winding 233, bypassed by condenser 233', whose upper end is connected by lead 234 to conductor 137. The lower end of winding 233 is connected by lead 235 to the outer contact 236 following contact 216 of the circular row of contacts 155. The fixed contact 237 is, also, connected to the lower end of winding 233. Common means 238 mechanically couples ratchet 239, cam disc 240 and connector unit 242—243. Recess 241 is provided in the periphery of disc 240. The connector unit cooperates with the concentric circles of spaced contacts 244 and 245. The cam disc 240 has associated therewith cam follower 246, and only one fixed contact 248 is provided here. The lead 247 connects the pivoted end of follower 246 to the fixed contact 226. Armature 249 of the relay has the pivoted end thereof connected to contact 248. The armature is, furthermore, provided with pawl 250 and mobile contact 251.

In order properly to understand the functioning of the various relay units it is necessary to appreciate that the ultimate circuit through the controlled device can be closed only when the connectors 156, 188, 207, 221 and 243 are in electrical contact with respective predetermined pairs of contacts. In Fig. 4 there is shown the finally adjusted positions of the connector units to close the controlled circuit. The closed circuit is traced as follows: from the positive terminal of battery 135 to lead 136, then through lead 252 to inner contact 245', then through connector 243 to outer contact 244' connected to lead 253, then through inner contact 223', plate 221 and outer contact 222' to lead 254, then through inner contact 209', plate 207 and outer contact 208' to lead 255, then through outer contact 185', plate 188 and inner contact 186' to lead 256, then to lead 257 through outer contact 155', plate 156 and inner contact 154', and then through the controlled device back to the grounded negative terminal of battery 135.

It will be seen that unless the connector plates are adjusted to their respective pairs of contacts, as shown in Fig. 4, the controlled circuit will be broken. The function of the stepping relays is selectively to adjust in a sequential manner the various connector units. The order of adjustment chosen for illustration in this application is the case where connector plate 188 is at the 5 o'clock position; plate 207 is at the 7 o'clock position; plates 221 and 243 are at the 9 o'clock positions; and plate 156 is at the 4 o'clock position. The adjustment of plate 156 to its ultimate position takes place after the dialing of 5—7—9—9 at the transmitter for control of the relays having windings 175, 196, 213 and 233 respectively.

In order to explain the operation of the entire system, let it be assumed that no carrier is being radiated from the transmitter. In that case (Fig. 3) there will be no direct current voltage developed across resistor 82, and tube 84 will have no effect on the normally inoperative detector tube 85. Hence, no current will flow through transfer relay winding 97. Consequently switch 131—132 will be open thereby causing the homing relay to be de-energized. As a result switch 110—111 will be open thereby breaking the filament heating circuit of the audio tubes 103 and 104 and rectifier tube 105. Let it, also, be assumed that ratchets 159, 182, 204, 218, 239 are in normal positions. This means that all connector units are at 12 o'clock positions on their respective concentric circles of contacts. Also, cam followers 173, 189, 195, 227 and 246 have their respective convex portions seated in their respective cam recesses 162, 191, 212, 229 and 241. Consequently switches 173—172, 189—193, 195—211 and 227—226 are closed.

Let us now assume that at the transmitter unit it is desired to dial the combination 5—7—9—9 so that the controlled circuit will be closed at a particular receiver of the many thousands of receivers which have been located at predetermined points in a given area. The particular receiver will, of course, have been wired for control by such dialing combination. It is additionally assumed that there has been selected for the particular receiver in question a combination of frequencies as follows: audio modulation frequency 200 cycles, sub-carrier frequency 60 kc. and carrier oscillator frequency 5 mc. If the transmitter unit shown in Fig. 1 had been previously adjusted at networks 1, 2 and 5 for a different combination of audio, sub-carrier and carrier frequencies, then it will be necessary to adjust the frequency selecting devices of the networks to select the new combination of frequencies.

Of course, in the case of the selection of a new carrier frequency switch 8 (Fig. 1) should be thrown to the "tune" position, thus effectively preventing the modulated sub-carrier oscillations from being applied to the modulator 6. This may be taken as the "standby" condition of the transmitter. In this position of switch 8 the selector of carrier oscillator 5 may be adjusted to the desired frequency. Generally speaking, when a certain receiver is to be dialed, the audio and sub-carrier selectors are set, and the transmitter is switched to "operate." The proper numbers are then dialed by the dialing device 4 for a receiver control operation, after which the transmitter is again returned to its "standby" condition. This means that the transmitter has been conditioned to radiate the carrier only without modulation. In order to allow other receiving equipment to "home," a period of five seconds is allowed to

elapse before dialing another receiver having the same sub-carrier and carrier frequency values. When one receiver is used to operate two or more detonators on definite dialed numbers, this homing sequence must be carefully observed. To provide the maximum secrecy of operation the transmitter should radiate only during the initial carrier tune; that is, without sub-carrier modulation and during actual dialing operations.

The transmitter now being assumed conditioned for the predetermined audio sub-carrier and carrier frequencies, the dialing mechanism 4 is actuated for the numeral "5." Before explaining what takes place at the receiver when the numeral "5" is dialed, it should be understood that the radiation of the double frequency modulated carrier wave conditions the receiver in the following manner. Referring to Fig. 3 the input circuits of tubes 31 and 32 act to convert the frequency modulated carrier wave energy into amplitude modulated carrier wave energy of the same carrier frequency as is radiated from the transmitter, which would be 20 mc. due to frequency multiplication at network 10 of Fig. 1, and whose modulation is the second harmonic of the sub-carrier frequency. Simultaneously, this amplitude modulated carrier wave energy is amplified by tubes 31 and 32. Detection occurs by virtue of diode 53—53', and across the resonant load circuit of the diode there appears frequency modulated wave energy whose mean frequency is the second harmonic of the sub-carrier frequency. In other words this is the so-called I. F. energy to be amplified by the I. F. amplifier 21 shown in Fig. 2.

The amplifier section of tube 52 and tube 60 provide amplification of the I. F. energy. In the resonant circuits up to diode 81—81' there occurs conversion of the frequency modulated I. F. energy into amplitude modulated I. F. energy, whose modulation is the second harmonic of the original 200 cycle audio modulation frequency. Tube 69 limits the amplitude of the energy fed to the diode 81—81'. The direct current voltage component of the rectified voltage developed across resistor 82 is applied over lead 83 to the grid 87 of tube 84. This causes less current to flow through the plate circuit of the tube and thereby permits the plate end of resistor 90 to assume an increased positive potential. This potential is sufficiently positive to overcome the normal cut-off bias due to battery 93. As a result tube 85 becomes conductive and permits current to flow through the transfer relay winding 97.

As a consequence of the energization of winding 97 the armature 130 is attracted and switch 132—131 is closed. It must be remembered that the application of the audio voltage component developed across resistor 82 to the grid 102 of audio amplifier 103 results in amplification of the 400 cycle voltage, this amplification being repeated by tube 104. The rectifier tube 105 provides current for the dialing relay winding 128. The tubes 103, 104 and 105 are capable of functioning, because as soon as the switch 132—131 is closed, the electrical circuit through the winding 134 of the homing relay was closed as heretofore explained in this application. Energization of the homing relay caused attraction of the armature 142 with the result that both switches 110—111 and 145—143 were closed. Closure of switch 110—111 completed the electrical circuit including the filaments 103', 104' and 105' and the heating current source 107, as has been previously described.

Returning now to the explanation of what happens as the numeral "5" is dialed at the transmitter, there will be five pulses of current flowing through the dialing relay winding 128 at the receiver. This results in a similar actuation of the armature 147 with the result that switch 148—149 will be closed five times. Since it has been assumed that the connector plate 156 is at its twelve o'clock position, this means that plate 156 electrically connects the contacts 178 and 178'. Hence, there will be established the following electrical circuit during the dialing of the numeral "5"; from switch 148—149 through resistor 152 and lead 151 to lead 177 through contact 178', connector plate 156 and contact 178, then through the relay winding 175 and lead 176 to common conductor 137, then through lead 136 and battery 135 back to the grounded side of switch 148—149.

As a result of the aforementioned circuit being closed the relay winding 175 will have five pulses of current flow therethrough, and will thereby step the ratchet 182, by virtue of the action of armature 180 and pawl 181, five times in a clockwise direction. This will cause the connector plate 183 to be adjusted to the five o'clock position shown in Fig. 4. At the same time that this adjustment is happening the cam disc 184 has been rotated in the clockwise direction. As a result the cam follower rides out of recess 191 and rides along the periphery of the cam disc to substantially the position shown in Fig. 4. Consequently the switch 193—189 is opened, while switch 192—189 is closed.

It was previously pointed out that the relay 7 at the transmitter unit (Fig. 1) is actuated at the end of each dialing operation. The function of relay 7 is momentarily to interrupt carrier radiation so as to permit the transfer function to take place at the receiver. The relay 7 in Fig. 1 is so connected that it is energized for $\frac{1}{10}$ of a second after each dialing operation. This relay, as fully disclosed in our aforementioned application, interrupts the production of carrier oscillations. Upon this momentary interruption of the carrier the direct current voltage component across resistor 82 of Fig. 3 vanishes. Consequently, the current flow in tube 84 will increase to a point such that the positive voltage at the plate end of resistor 90 is insufficient to prevent biasing source 93 from cutting off tube 85. This results in the transfer relay releasing armature 130 thereby opening switch 131—132 and closing switch 132—133. The homing relay will not release by virtue of the fact that it has a time delay of two seconds. If the transfer relay were released longer than the holding time of the homing relay (as would happen if the transmitter were shut off), the homing relay would delay about two seconds due to the charge leaking off the condenser 141 across this relay and then release with results which are further set forth below.

Since release of armature 130 has closed switch 133—132, and since switch 145—143 is closed due to the energization of the homing relay, there is completed an electrical circuit through the relay winding 164 which is traced as follows. From the positive terminal of battery 135 through leads 136 and 137 to switch 132—133, then through winding 164, lead 167, switch 145—143 to lead 146, and then back to the negative terminal of battery 135. Current flow through winding 164 causes armature 163 to be attracted towards the electromagnet, and the pawl 158 is therefore con-

ditioned to adjust ratchet 159 in step should the armature 163 be released. The release of armature 163 takes place, because the carrier radiation at the transmitter is resumed after having been interrupted for one-tenth of a second by relay 7 thus causing the resumption of current flow in winding 97 after this period of time and independently of the next dialing operation.

Upon release of armature 163 the cam disc 161 is rotated an angular distance equal to one tooth of the ratchet 159, and this is sufficient to shift the connector plate 156 to contact 202 and its mate contact. It will be noted that simultaneously the cam follower rides out of recess 162 thereby closing switch 173—171 and opening switch 172—173. The transfer to relay winding 196 has accordingly been accomplished, and the system is conditioned so that dialing of numeral "7" steps the connector plate 207 to its predetermined seven o'clock position. That this will take place is readily seen from the fact that the relay winding 196 is now in circuit with the battery 135 by virtue of the fact that the lead 201 connects back to the negative terminal of battery 135 through the same path described in connection with winding 175, except for the fact that the connector plate 156 now connects contact 202 and its mate to lead 151. As previously described in connection with the stepping of connector plate 183, the connector plate 207 will be adjusted to its desired position by virtue of the stepping of ratchet 204 an angular distance of seven teeth. The cam disc 205 will assume substantially the position shown in Fig. 4. The cam follower 195 will open switch 211—195 and close switch 195—219.

It will now be appreciated that connector plates 221 and 243 are adjusted in sequence in accordance with the same series of operations already described. It is not believed necessary to repeat the series of operations, since it has been previously pointed out that at the end of each dialing operation carrier radiation will be momentarily interrupted thereby closing switch 133—132 to permit flow of current from battery 135 through winding 164. This will result in the ratchet 159 being moved one tooth as soon as carrier radiation is resumed. Therefore, when numeral "9" is dialed the connector plate 156 has already been positioned over contact 216 and its mate contact.

Hence, the winding 213 is now in circuit with battery 135 by virtue of the lead 215 being connected to contact 216. As a result of dialing "9" the connector plate 221 will be adjustably positioned to contacts 222' and 223'. As soon as the carrier is interrupted after this dialing operation, the switch 133—132 is closed again and the pawl 158 is ready to move the ratchet another tooth. Before the dialing of the second numeral "9" the connector plate 156 has been moved to connect contact 236 and its mate contact thereby connecting lead 235 and winding 233 in circuit with battery 135. Thus dialing of the second numeral "9" will result in adjustment of connector plate 243 to the position where it connects contacts 244' and 245'. It will be noted that there is no companion contact associated with contact 248. Upon momentary interruption of the carrier and then resumption of carrier radiation after the passage of $\frac{1}{10}$ of a second, the connector plate 156 will be shifted into its final position where it electrically connects contacts 154' and 155'. Upon this latter connection taking place the controlled circuit which

sistance. If it is impossible to obtain the required time constant by this expedient, a simple relay might be used.

While we have indicated and described a preferred system for carrying our invention into effect, it will be apparent to one skilled in the art that our invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of our invention.

What we claim is:

1. A receiving system comprising at least one amplifier having an input circuit sharply tuned to a desired carrier wave, means for applying to said input circuit a double frequency modulated carrier wave, said input circuit deriving from said wave a corresponding amplitude modulated carrier wave wherein the modulation is in the form of a frequency modulated sub-carrier, a rectifier provided with an input connection to said amplifier for rectifying the amplitude modulated wave energy, a resonant load circuit connected to said rectifier and tuned to develop thereacross modulation voltage derived from said amplitude modulated wave energy, a second amplifier having at least one sharply tuned input circuit to which said modulation voltage is applied whereby there is produced an amplitude modulated wave whose modulation is the second harmonic of the original modulation on the carrier, means for rectifying the last mentioned amplitude modulated wave energy to produce an alternating current component and a direct current component, means for amplifying the alternating current component, and means responsive to said direct current component for controlling the effectiveness of the last mentioned amplifying means.

2. A receiving system comprising at least one amplifier having an input circuit sharply tuned to a desired carrier wave, means for applying to said input circuit a double angle modulated carrier wave, said input circuit deriving from said wave a corresponding amplitude modulated carrier wave, a rectifier provided with an input connection to said amplifier for rectifying the amplitude modulated wave energy, a resonant load circuit connected to said rectifier and tuned to develop thereacross modulation voltage derived from said amplitude modulated wave energy, a second sharply tuned input circuit to which said modulation voltage is applied whereby there is produced an amplitude modulated wave whose modulation is the second harmonic of the original modulation on the carrier, and means for rectifying the last mentioned amplitude modulated wave energy.

3. In a frequency modulated wave receiver, a selective network tuned to the mean frequency of the wave and being adapted to produce from said modulated wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for detecting said amplitude modulated wave to provide said double harmonic modulation, and a resonant modulation utilizing circuit tuned to said double harmonic frequency.

4. In a frequency modulated wave receiver, a selective network tuned to the mean frequency of the wave and being adapted to produce from said modulated wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for de-

tecting said amplitude modulated wave to provide said double harmonic modulation, a resonant modulation utilizing circuit tuned to said double harmonic frequency, and means responsive to the direct current voltage component of the detected wave voltage for rendering said utilizing circuit effective.

5. In a frequency modulated wave receiver, a selective network tuned to the mean frequency of the wave and being adapted to produce from said modulated wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for detecting said amplitude modulated wave to provide said double harmonic modulation, a resonant modulation utilizing circuit tuned to said double harmonic frequency, a normally-open controlled circuit, means for closing said controlled circuit, and means responsive to a predetermined number of pulses of current in said utilizing circuit for adjusting said closing means to circuit-closing position.

6. A frequency modulation receiver comprising a selective amplifier having at least one resonant circuit tuned to the mean frequency of received frequency modulated carrier waves, said resonant circuit having its constants chosen to render it operative to produce substantial translation of the wave energy into corresponding amplitude modulated wave energy of the same means frequency, means for rectifying said amplitude modulated wave energy, said rectifying means including a load impedance tuned to the frequency of the modulation on said translated wave energy, an amplifier for said modulation, said tuned impedance additionally being the input circuit of the last amplifier.

7. In a modulated carrier wave receiver, a selective network tuned to the frequency of the wave and being adapted to produce from said modulated wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for detecting said amplitude modulated wave to provide said double harmonic modulation, and a modulation utilizing circuit coupled to the detecting means.

8. In a frequency modulated wave receiver, a plurality of cascaded selective networks each tuned to the mean frequency of the wave and being adapted to derive from said modulated wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for detecting said amplitude modulated wave to provide said double harmonic modulation, a modulation utilizing circuit, and means responsive to the direct current voltage component of the detected wave voltage for controlling said utilizing circuit.

9. In an angle modulated carrier wave receiver, at least one selective network tuned to the mean frequency of the wave and being adapted to derive from said modulated carrier wave energy amplitude modulated wave energy whose modulation frequency is the double harmonic of the original modulation frequency applied to said wave, means for detecting said amplitude modulated wave to provide said double harmonic modulation, a modulation utilizing circuit, a normally-open controlled circuit, means for closing said controlled circuit, and means responsive to a predetermined number of pulses of current in

includes the leads 257 is completed, and the controlled device is actuated. In the instant case the controlled device is a detonator.

Provision is made to "home" the dialing relays for the various situations which may occur wherein receivers other than the desired receiver are partially actuated, or for the situation wherein the desired receiver is only partially actuated and the complete operation not carried out. It has been previously pointed out that if the transfer relay is released longer than the holding time of the homing relay, the latter will delay about two seconds and then release. If for any reason, therefore, the homing relay releases armature 142, it will be seen that switches 118—111 and 145—143 are opened. The filament circuits of the audio tubes are promptly opened. It is important to note that the transfer relay should be the first to home. Otherwise it is possible that in the process of homing, one of the dialing connectors might sweep over and momentarily establish a firing circuit.

Release of armature 142 establishes a circuit through the "buzzer contacts" 170—169 of the transfer ratchet relay. The complete circuit is traced as follows: current source 135, lead 136, lead 137, switch 133—132, lead 166, winding 164, lead 169, buzzer contacts 163—170, armature 163, contact 171, follower 173, switch 146—143, lead 140 and back to current source 135. Closing this circuit permits current flow through winding 164, and armature 163 is attracted. This breaks the contact between 169 and 170, and armature 163 falls thereby stepping ratchet 159. Closure of contacts 169—170 takes place again, and the ratchet 159 is stepped clockwise in this manner until the recess 162 of cam disc 161 receives convex portion 174 of follower 173. In this position the connector plate 156 is back to "home" or twelve o'clock position, i. e., its normal position. Further, the switch 171—173 is opened, while switch 173—172 is closed. Hence, the homing circuit through the transfer ratchet relay is broken, while a homing circuit has been established through winding 175 by virtue of the following circuit: battery 135, leads 136 and 137, winding 175, buzzer contacts 179—179', armature 180, switch 192—189, lead 190, switch 172—173, switch 143—146, lead 140 and back to battery 135.

The ratchet 182 is actuated as previously described for ratchet 159 until cam disc 184 reaches normal position, wherein cam follower 189 is seated and switch 192—189 is opened. In this position the connector unit is at its home or normal setting. Each of the following ratchets 204, 218 and 239 may be sequentially actuated in the same manner. In each case the homing of a given cam disc transfers the homing circuit to the following relay winding until all the relay cams are at home or normal positions. It will now be seen that by causing the transfer ratchet relay to home before the following relays, there can never be an inadvertent completion of the controlled circuit by virtue of only three proper numbers being dialed and the fourth being dialed during the homing operation.

The condenser 153 across the dialing relay contacts increases the reliability of the dialing operation for weak or short dialing pulses. Its function is to charge instantly when the dialing contacts 149 and 148 are first established, before the current through the winding 128 can build up due to its self-inductance. Once condenser 153 is charged, however, it will discharge through the

relay coils even though the dialing contacts have opened. The condenser is made as large as possible consistent with rapid dialing. The resistor 152 serves to limit the initial charging current to values that preclude freezing of the contacts, but does not greatly affect the charging time of the condenser. The shunt condensers, 165, 175', etc., associated with each of the dialing relay coils are spark absorbing capacitors to reduce reaction on the receiver circuits. In the absence of such condensers the tuned receiver circuits might pick up pulses which would operate relays to transmit new pulses that would thus sustain an oscillating or motorboating system. It will be obvious, of course, that several four-figure numbers may be set up to establish several firing circuits leading to different mine fields.

In the absence of a signal from the detonating transmitter severe noise may operate the transfer ratchet relay 164. For operation of a dialing ratchet relay the filaments of the audio amplifier tubes must be heated (due to closing of the transfer sensitive relay), and further the antenna noise input must be of the order of several volts. Even if the audio amplifier filaments are heated, any noise impulse sufficient to operate a dialing ratchet relay will be more than that required to operate the transfer ratchet relay 164. High amplitude noise of sufficient duration to actuate all of the dialing ratchet relays is unlikely. Completion of the firing circuit requires that each of the ratchets be advanced at least one position so that chance detonation due to noise is remote.

At the cessation of the noise the ratchets "home" to the "standby" position. During the operation of the receiver by a signal from the transmitter, noise impulses may cause the transfer relay ratchet to advance one or more steps in addition to those steps caused by the normal signals. The same impulses might also advance a dialing relay ratchet, but, in general, this requires more severe noise. If a single mine field contained 10,000 receivers with the same carrier, I. F., and audio frequencies, each receiver with a different dial combination, then any number dialed would fire the corresponding mine. If in the process of dialing, a single noise pulse of just sufficient amplitude to actuate the transfer ratchet relay occurred, a different or undesired combination would result and a different mine would be fired.

The inclusion of a resistance and condenser time constant means 257' in the firing circuit prevents noise or static, which occurs during the dialing operation, from firing any mine other than that desired. This, however, does not insure that the desired mine will be fired. If noise causes an extra transfer operation, then the total number of transfer operations will be five rather than the normal of four. At the completion of the dialing operation the transfer relay ratchet will be in a position one beyond that which completes the firing circuit. The time constant in the firing circuit must be longer than the time taken to dial a single zero. This prevents firing during the time the transfer relay ratchet passes through the firing position. Obviously if the noise had not occurred during the dialing operation, the desired mine would be detonated by merely waiting the time required for the firing circuit current to build up. The time constant necessary to perform this function is of the order of one second. It is possible that this time constant could be obtained by merely shunting the squib or detonator with a large capacity and adding series re-

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said utilizing circuit for adjusting said closing means to circuit-closing position.

10. In a system of radio control of the type wherein there is radiated a control wave in the form of a carrier wave modulated by a sub-carrier which is in turn modulated by a plurality of successive groups of sequential audio pulses, and wherein the carrier wave is momentarily interrupted at the end of each of said groups; a receiver for said control wave comprising means for deriving from the modulated carrier wave the said groups of modulation at the second harmonic frequency thereof, a controllable circuit including a plurality of circuit-closing devices arranged in series and which must be adjusted in a predetermined order corresponding to said group succession, means responsive to said carrier interruptions for determining said predetermined order, a plurality of actuating devices each respectively associated with a respective one of said circuit-closing devices, and means for energizing each of said actuating devices in accordance with a predetermined group of said audio pulses.

11. A frequency modulation receiver comprising a selective amplifier having at least one resonant circuit tuned to the mean frequency of received frequency modulated carrier waves, said resonant circuit having its constants chosen to render it operative to produce substantial translation of the wave energy into corresponding am-

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plified amplitude modulated wave energy of the same mean frequency, means for rectifying said amplitude modulated wave energy, said rectifying means including a load circuit tuned to the frequency of the modulation on said translated amplified wave energy.

12. In a system of control of the type wherein there is employed a control wave in the form of a carrier wave modulated by a sub-carrier which is in turn modulated by a plurality of successive groups of sequential audio pulses, and wherein the carrier wave is momentarily interrupted at the end of each of said groups, means for deriving from the modulated carrier wave the said groups of modulation at the second harmonic frequency thereof, a circuit including a plurality of circuit-closing devices arranged in series and which must be adjusted in a predetermined order corresponding to said group succession, means responsive to said carrier interruptions for determining said predetermined order, a plurality of actuating stepping devices each respectively associated with a respective one of said circuit-closing devices, and means for energizing each of said actuating devices in accordance with a predetermined group of said audio pulses.

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