Feb. 26, 1946. D. MITCHELL 2,395,575

SYSTEM FOR THE TRANSMISSION OF MOTION

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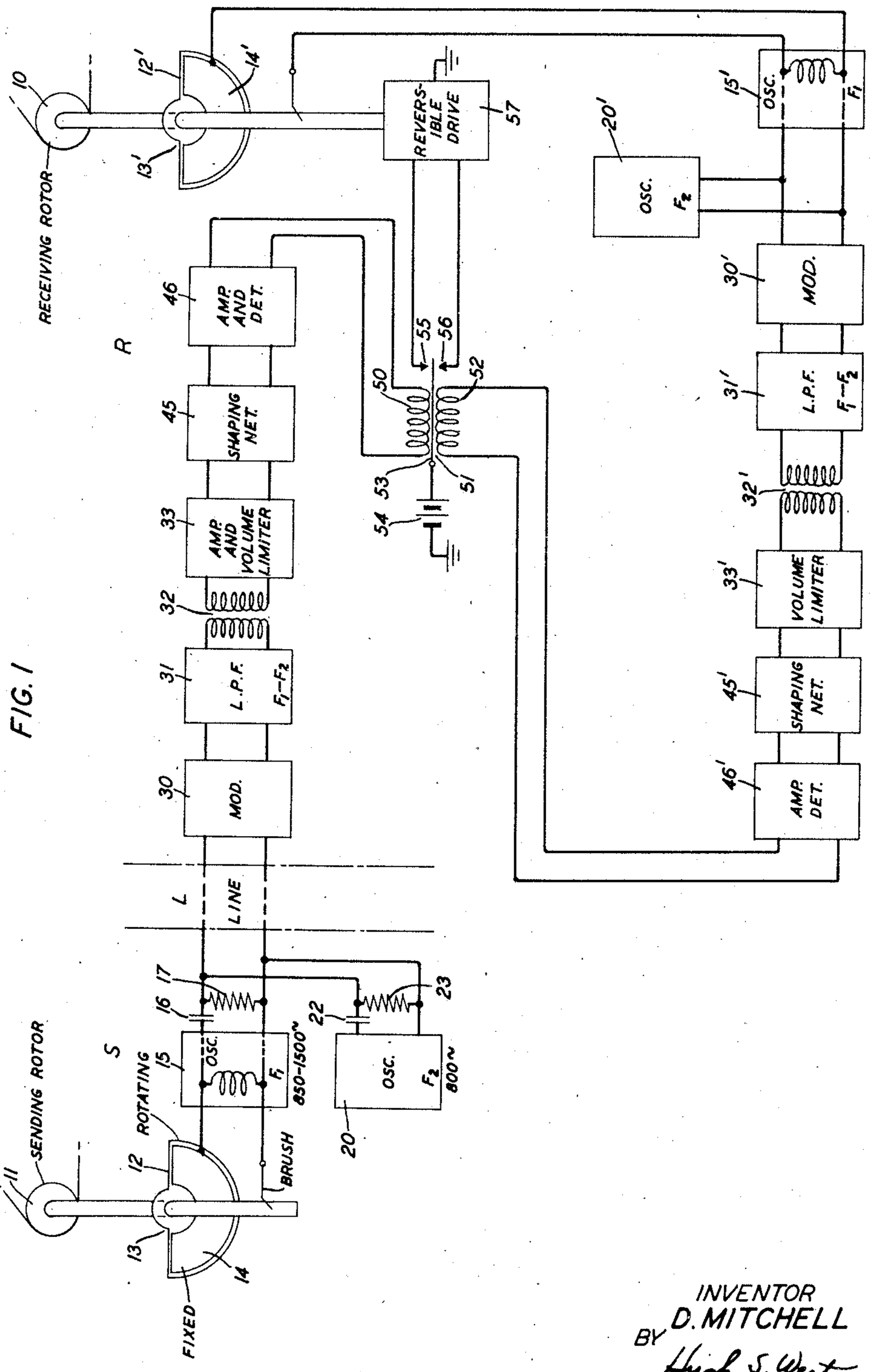

FIG. 1

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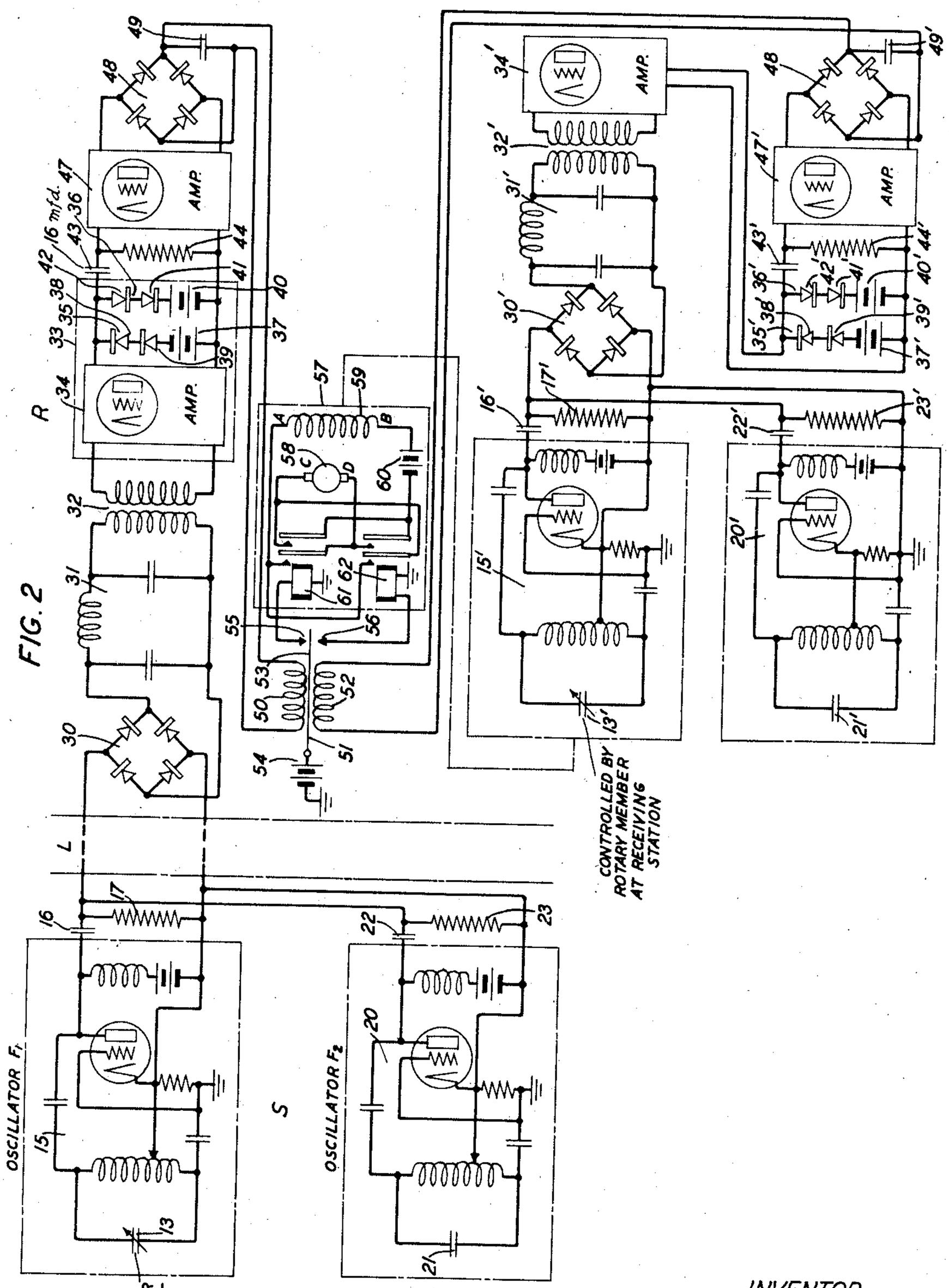
FIG. 2



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SYSTEM FOR THE TRANSMISSION OF MOTION

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This invention relates to electrical systems for the transmission of movements and more specifically to systems in which circular motion produced by turning a dial or other rotary member at one point is very accurately and automatically reproduced at a distant point.

Various methods are known for remote automatic reproduction of circular motion, such as that produced, for example, by turnir- a dial. Two very well known methods of producing this result respectively utilize direct current and Selsyn motors. The systems using these methods work very well over comparatively short distances but they are not very practical in operation over long lines. The need sometimes arises, as in the control of guns from distant points, for a highly accurate system for reproducing angular motion over comparatively long distances. The present invention has for its principal object the provision of such an electrical system.

In accordance with the invention, this object is attained by producing at the transmitting station two waves of different frequencies, obtaining therefrom a wave having a frequency which is the difference between the frequencies of the original waves, utilizing this derived wave to obtain a direct current signal the amplitude of which is proportional to the frequency of the derived wave, and opposing this direct current signal by a second direct current signal produced at the distant station which is representative of the difference in frequency between two waves of different frequency the frequency difference of which is dependent upon the position of the member whose position it is desired to make correspond with that of the member at the sending station, the position of said member being determined by the combined effect of the opposed direct current signals.

In the specific embodiment of the invention chosen by way of example for illustrative purposes, a motor drives the rotating member at the receiving station until the direct current signal representing the position of the rotating member at the receiving station equals that of the direct current signal representing the position of the rotating member at the sending station, at which point no further rotation of the member at the receiving station takes place. Since frequency difference (or the two frequencies themselves) is the only information which has to be transmitted, the effects of amplitude variation in any circuit or carrier system may be made negligible, in accordance with well known practice in the transmission of frequency modulated carrier waves, by amplitude limiting. By keeping the two frequencies produced at the sending station close together, and near the middle of the telephone band, for example, the effects of delay distortion are made so small as to be almost negligible. Due to the fact that a motor at the receiving station is used to drive the rotating member at that station, there is no practical limitation to the amount of torque that can be delivered at the distant point. For this reason the arrangement has a marked advantage in such remote-control operations as gun-pointing, telautography, etc.

In this embodiment of the invention, a variable condenser containing a fixed and a rotating element is provided at the sending station, the rotating element being mechanically connected to the dial or other rotary member whose circular motion it is desired to reproduce at a distant receiving station. The rotation of this portion of the condenser varies the condenser capacitance and as the condenser is included in the tuned circuit of an oscillator, the output frequency of the oscillator is varied. The output waves of this oscillator are preferably applied to a line, which may be either a telephone line or a radio channel, along with the output waves from a second oscillator, this one of fixed frequency. Preferably, the output waves of the second oscillator have a frequency which is within the audio range while the frequency of the output waves of the first oscillator varies from a value which is just greater than the frequency of the second oscillator to a value which is somewhat less than twice the frequency of the second oscillator. At the far end of the line, that is, at the receiving station, the waves from the first and second oscillators are applied to a modulator in the output circuit of which is connected a low-pass filter which passes frequencies corresponding to the difference between the waves of the first and second oscillators but which will cut off frequencies corresponding to those of the waves from these two oscillators. This "difference" frequency wave is then applied to a volume limiter which is arranged to produce a substantially flat-top wave whose amplitude is independent of the amplitude of the received wave. This wave is then passed through a shaping network which causes the amplitude of its output wave to vary in accordance with the frequency of the signal from the volume limiter. The output wave of the shaping network is then applied to a detector to produce an output signal which is applied to one winding of a differential relay, the other winding of which

is connected to the output of a circuit similar to that already described, which circuit is controlled by a condenser having a rotatable element driven by the movement of the rotary member at the receiving station whose angular movement is adapted to follow that of the dial or similar device of the sending station. The strength of the current in each winding of the differential relay is thus dependent only on the difference in frequency between the output waves of the fixed frequency oscillator and of the variable frequency oscillator in the circuit feeding the winding. The two circuits respectively feeding the windings of the differential relay are made equal within very close limits so that if the two "difference frequencies" are the same, the currents in the two windings of the differential relay are equal and hence the armature of the relay will not be operated in either direction to operate a motor driving the rotatable element at the receiving end of the line. If the difference frequency representing the position of the movable member at the transmitting station varies, however, the balance between the two windings of the relays is immediately upset and the motor will be operated in a direction to restore the balance. Obviously, either the two frequencies generated at the transmitting station or the difference between them may be transmitted to the receiving station.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a schematic circuit diagram of the arrangement according to this invention; and

Fig. 2 is a more detailed circuit diagram of the arrangement shown in Fig. 1.

Referring more specifically to the drawings, Figs. 1 and 2 are circuit diagrams of an electrical system for the transmission of angular movement which is shown by way of example to illustrate the principles of the present invention. Fig. 1 is a schematic circuit diagram showing certain of the elements of the circuit in block diagram form while Fig. 2 is a more detailed circuit diagram of the arrangement shown in Fig. 1. In accordance with the invention, it is desired to have the receiving rotor 10 follow the angular movement of the sending rotor 11. These two rotors may be, and in the usual case are, separated by a considerable distance and it is the purpose of the arrangement of this invention to have the receiving rotor 10 accurately follow the movement of the rotor 11.

Referring now to the sending station identified by the reference character S, the sending rotor 11 is connected by any suitable means to the rotating element 12 of the condenser 13, which condenser also has a fixed member 14. The condenser 13 is included in the tuned circuit of a Hartley oscillator 15 which is well known to those skilled in the art. For a description of the Hartley oscillator, reference may be made to page 51 of the Radio Amateur's Handbook, Special Defense edition, 1942. Variation of the capacitance of the condenser 13 by the rotation of the movable member 12 thereof varies the frequency of the output waves which, for example, are applied by means of the coupling condenser 16 and resistor 17 to a line or other channel L to the receiving station R.

A second oscillator 20, preferably of the same type as the oscillator 15 except that the condenser 21 in the tuned circuit thereof has a fixed capacity, is included at the sending station. The output waves of the oscillator 20 may be applied by means of the coupling condenser 22 and resistor 23 to the line or other channel L. By way of example, the oscillations from the oscillator 20 may have a frequency of about 800 cycles per second while those from the oscillator 15 may vary from a frequency of about 850 cycles per second to about 1,500 cycles per second. In the arrangement shown, both waves are applied to the line L without modulation but it is apparent that other arrangements are possible, as will be pointed out more fully below.

At the far end of the line, that is, at the receiving station R, one of the two waves is modulated by the other by any suitable modulator, such as the dry rectifier bridge circuit 30. The modulation products are then conducted to a low-pass filter 31 which passes the component corresponding in frequency to the difference between the frequency produced by the oscillations from the oscillator 15 (F_1) and those from the oscillator 20 (F_2) but which will not pass frequencies corresponding to F_1, F_2 or any harmonics thereof. Thus it will be seen that preferably the output waves of the first oscillator 15 should have a frequency which varies from a value which is greater than the frequency of the second oscillator 20 to a value which is somewhat less than twice the frequency of the oscillator 20. It will thus be understood that the output of the low-pass filter 31 is a wave the frequency of which is the difference between the frequencies of the oscillators 15 and 20, or, in other words, is F_1-F_2.

The output wave of the filter 31 is applied by any suitable means such as the transformer 32 to the amplifier and volume limiter circuit 33 comprising any suitable amplifier 34 and two parallel circuits 35 and 36. The circuit 35 comprises in series arrangement a source of potential 37 and two rectifiers 38 and 39. The circuit 36 comprises in series arrangement a source of potential 40 and two rectifiers 41 and 42. The sources of potential 37 and 40, which are oppositely polarized with respect to the output wave in the amplifier 34, are adapted to bias the circuits 35 and 36 so that no current flows therethrough until the output wave of the amplifier 34 exceeds a certain predetermined value, in which case the parallel circuits 35 and 36 become conducting to pass current, thus limiting any waves above said certain amplitude from being applied to the condenser 43, which is of relatively small capacity, for example, 0.16 microfarad, and the resistor 44 of the order of about 1,000 ohms. The resistor 44 and the capacitor 43 form a shaping network 45 which causes, in a manner well known to those acquainted with frequency modulation practice, the amplitude of its output to vary in a predetermined manner according to the frequency of the signals from the limiter circuits 35 and 36.

The output wave from the shaping network is then applied to an amplifier and detector 46 comprising any suitable amplifier 47 and a balanced detector comprising the bridge circuit 48. The detector produces a pulsating direct current at its output which is smoothed out by condenser 49 and then applied to winding 50 of relay 51. The amplitude of this direct current is dependent upon the amplitude of the wave applied to the input of the amplifier 47 which in turn is proportional to the frequency of the wave applied to the amplifier and volume limiter circuit 33. Direct current is also applied to a second

coil 52 of relay 51 from a circuit, similar to that already described, which is controlled by the position of the receiving rotor 10. For convenience, each of those elements of the second circuit similar to a corresponding element of the first circuit has been given the same reference character as the corresponding element of the first circuit except that a prime has been added to the reference character.

The relay 51 has an armature 53 which is adapted to be connected through a source of potential 54 to ground and which is energized to make contact with one or the other of two contacts 55 and 56 depending on whether the current in coil 50 is stronger than that in coil 52 or vice versa. When no current is flowing in the coils 50 and 52 or when the currents in these two coils are equal, the armature 53 assumes a neutral position between the contacts 55 and 56. When the armature makes contact with either of contact elements 55, 56, the reversible drive mechanism 57 is energized in one direction or the other to rotate (either directly or through appropriate gearing) the rotating element 12' of the condenser 13' in the proper direction to cause the output frequency of the oscillator 15' to change until the direct currents in the windings 50 and 52 are once again equal. The reversible drive mechanism 57 may be of any suitable form such as that shown in Fig. 2. The arrangement in this figure comprises a motor armature 58, a series field 59, a source of potential 60 and two relays 61 and 62, the contacts of which are normally open when the corresponding armature is not energized. As will be pointed out more fully below, when the relay 61 is energized the series field winding 59 is connected in one direction to the armature 58 which causes the motor to rotate in one direction while if the relay 62 is energized the series field winding is connected in the reverse direction to the armature 58 and causes the motor to rotate in the opposite direction.

The operation of the circuit shown in Figs. 1 and 2 is as follows: Let it be assumed that the rotor of the condenser 13 is in such a position that the frequency of the oscillator 15 is 1,000 cycles and the position of the rotor 12' of the condenser 13' is such that the frequency of the oscillator 15' is also 1,000 cycles, the frequency of the oscillators 20 and 20' being constant at 800 cycles. Then the frequency passed by each of the filters 31 and 31' is the difference frequency between the output waves of the oscillators 15 and 20 and 15' and 20' respectively, or 200 cycles. The tops of the 200-cycle waves are cut off by the volume limiters 33 and 33' making a series of flat top waves of both positive and negative amplitudes. These flat top waves are shaped in the shaping networks 45 and 45' to produce signals the amplitude of which varies with the frequency of the output waves of the filters 31 and 31'. If this frequency is high, the impedance of the condenser 43 (or 43') is small and the transmitted signal is large while if this frequency is small, the reverse is true. The output waves of the shaping networks 45 and 45' are amplified and detected by the apparatus 46 and 46' to produce two equal direct current signals applied respectively to the coils 50 and 52 of the relay 51. Since these two currents are equal the armature 53 is held in its intermediate position, that is, in a position intermediate the contacts 55 and 56 and not contacting either of them. In this position, the motor forming part of the reversible drive 57 is not energized to move the rotor 12' of the condenser 13'.

Now let it be assumed that the sending rotor 11 is suddenly rotated in such a direction that the capacity of the condenser 13 is varied by an amount sufficient to cause the output wave of the oscillator 15 to be increased to 1,200 cycles per second. The output wave of the filter 31 is then 400 cycles. After this wave is passed through the volume limiter and the shaping network the output wave of the network 45 has a larger amplitude than it had previously when frequency F_1 was 1,000 cycles. The current in the coil 50 is therefore larger than that in the coil 52 and the armature 53 is attracted towards the contact 55 thus energizing the relay 61 and causing its contacts to close and complete a circuit through which current flows from the source of direct potential 60 through series winding 59 from terminal B to terminal A, the first contact of relay 61, the armature 58 in the direction from D to C and the second contact of the relay 61 back to the source 60. This causes the motor to turn the rotor 12' of condenser 13' in such a direction as to increase the frequency of the oscillator 15' which increase will tend to increase the current in the coil 52 until a balance has been obtained again between the currents in the coils 50 and 52. When this balance is obtained the receiving rotor 10 is in a position once again corresponding to the position of the sending rotor 11.

Now if the sending rotor 11 is turned in a direction opposite to that assumed in the preceding paragraph the frequency of the oscillator 15 is reduced, for example to 900 cycles; the frequency passed by the low-pass filter 31 becomes 100 cycles which when acted upon by the apparatus 33, 45 and 46 produces a smaller current in the coil 50 than in the coil 52. This causes the armature 51 to contact the contact element 56 closing the circuit to energize the relay 62. This completes a circuit through which current flows from source 60 through the series winding 59 in a direction from B to A, the first set of contacts of the relay 62, the armature 58 in the direction from terminal C to terminal D and the second set of contacts of the relay 62 back to the source 60. The motor is therefore energized in the direction opposite to that described in the preceding paragraph and the rotor 12' is driven in the direction which tends to reduce the frequency of the output of oscillator 15', thereby decreasing the current in the coil 52 until it becomes equal again to the coil 50, at which time the armature 53 is returned to its intermediate position and the receiving rotor 10 is in a position corresponding to that of the sending rotor 11. Thus, regardless of the direction of rotation of the member 11, the member 10 will tend to follow it with no appreciable lag.

In a modification, certain of the apparatus shown in Figs. 1 and 2 at the receiving station may be located at the sending station as, for example, the modulator 30 and the filter 31 in which case the difference frequency passed by the filter 31 will be transmitted over the line 11 instead of the two frequencies produced by the oscillators 15 and 20. Moreover, the two members whose movements it is desired to synchronize need not be rotor members but may instead be any members having movement in opposite directions as, for example, a linear movement on one side or the other of a reference position. Moreover, the movement of the member at the sending

station may vary the inductance or resistance in a suitable oscillator instead of causing variation of capacity as in the circuit arrangement shown.

The arrangement of this invention may be used in any situation where it is desired to reproduce at one position the movement of a member at another, such as in a telautograph, metering, or gun-pointing.

Various other modifications may be made in the apparatus disclosed without departing from the spirit of the invention, the scope of which is indicated in the appended claims.

What is claimed is:

1. Apparatus for accurately producing by the movement of a member at a sending station a desired predetermined movement of a member at a receiving station, comprising motor means for driving said member at the receiving station, circuit means for producing a signal controlled by, and corresponding to the position of, said sending station member, a second circuit means for producing a signal controlled by, and corresponding to the position of, said receiving station member, and means simultaneously differentially responsive to the magnitude of said two signals for actuating said motor means, each of said circuit means comprising means for deriving a periodically varying voltage the frequency of variation of which is dependent at each instant upon the position of the one of said members controlling that circuit means, and means responsive to the frequency of said periodically varying voltage in that circuit for determining the magnitude of the signal in that circuit and controlling said differentially responsive means.

2. The combination of elements as in claim 1 in which the movement of each of said members is rotary.

3. Apparatus for accurately producing by the movement of a member at a sending station a desired predetermined movement of a member at a receiving station, comprising motor means for driving said member at the receiving station, circuit means for producing a signal controlled by, and corresponding to the position of, said sending station member, a second circuit means for producing a signal controlled by, and corresponding to the position of, said receiving station member, and means simultaneously differentially responsive to the magnitude of said two signals for actuating said motor means, each of said circuit means comprising means for deriving a voltage wave of fixed frequency, means for deriving a periodically varying voltage wave the frequency of variation of which is dependent at each instant upon the position of the one of said members controlling that circuit means, means for modulating the wave of said first frequency with the wave of said second frequency, means for filtering the resultant modulated wave to produce a wave the frequency of which is equal to the difference between said two frequencies, and means responsive to said last-mentioned wave for determining the magnitude of the signal in that circuit and controlling said differentially responsive means.

4. The combination of elements as in claim 3 in which the frequency of said variable voltage wave is adapted to vary between a frequency which is slightly greater than the frequency of said fixed frequency voltage wave and a frequency which is less than twice the frequency of said fixed frequency wave.

5. Apparatus for accurately producing by the movement of a member at a sending station a desired predetermined movement of a member at a receiving station, comprising motor means for driving said member at the receiving station, circuit means for producing a signal controlled by, and corresponding to the position of, said sending station member, a second circuit means for producing a signal controlled by, and corresponding to the position of, said receiving station member, and means simultaneously differentially responsive to the magnitude of said two signals for actuating said motor means, each of said circuit means comprising means for deriving a voltage wave of fixed frequency, means for deriving a periodically varying voltage wave the frequency of variation of which is dependent at each instant upon the position of the one of said members controlling that circuit means, means for modulating the wave of said first frequency with the wave of said second frequency, means for filtering the resultant modulated wave to produce a third wave the frequency of which is equal to the difference between said two frequencies, means for limiting the volume of said last-mentioned wave, means for shaping said volume limited wave whereby the amplitude of said shaped wave is dependent upon the frequency of said third wave, and means for rectifying said shaped wave to produce a signal the magnitude of which is also representative of the frequency of said third wave.

6. The combination of elements as in claim 1 in which said motor means comprises an armature, a first relay, a second relay, a series field winding, a source of direct potential, means including the contacts of one of said relays for connecting said series winding in one direction to said armature, and means including the contacts of said second relay for connecting said series winding in the opposite direction to said armature.

7. Apparatus for accurately producing by the movement of a member at a sending station a desired predetermined movement of a member at a receiving station, comprising motor means for driving said member at the receiving station, circuit means for producing a signal controlled by, and corresponding to the position of, said sending station member, a second circuit means for producing a signal controlled by, and corresponding to the position of, said receiving station member, and means simultaneously differentially responsive to the magnitude of said two signals for actuating said motor means, each of said circuit means comprising means for deriving a voltage wave of fixed frequency, means for deriving a periodically varying voltage wave the frequency of variation of which is dependent at each instant upon the position of the one of said members controlling that circuit means, means for producing a wave the frequency of which is equal to the difference between said two frequencies, and means responsive to said last-mentioned wave for determining the magnitude of the signal produced in that circuit and controlling said differentially responsive means.

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