

June 21, 1966

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3,257,510

FEEDBACK CONTROL APPARATUS

Filed Oct 15, 1962

3 Sheets-Sheet 1

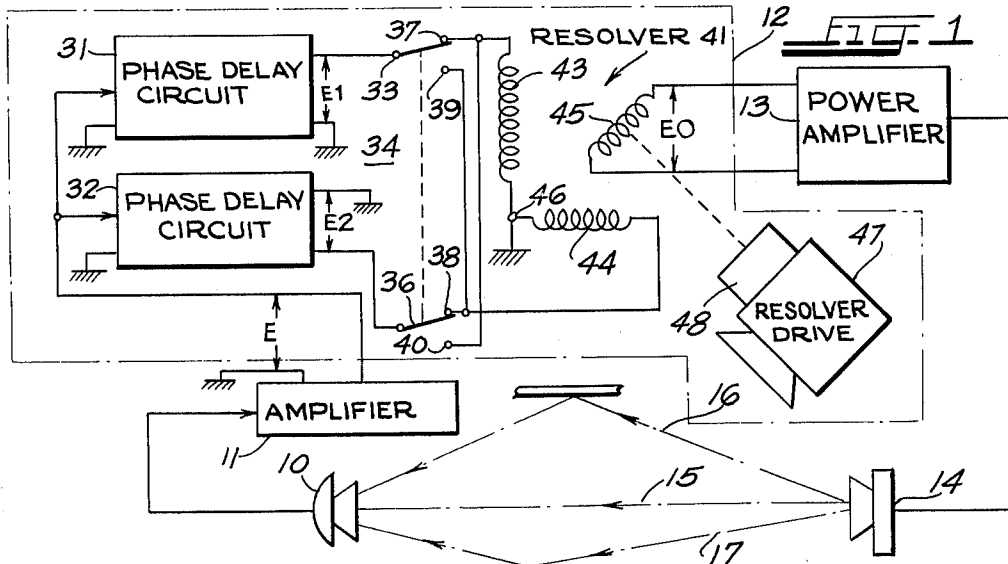


FIG. 2

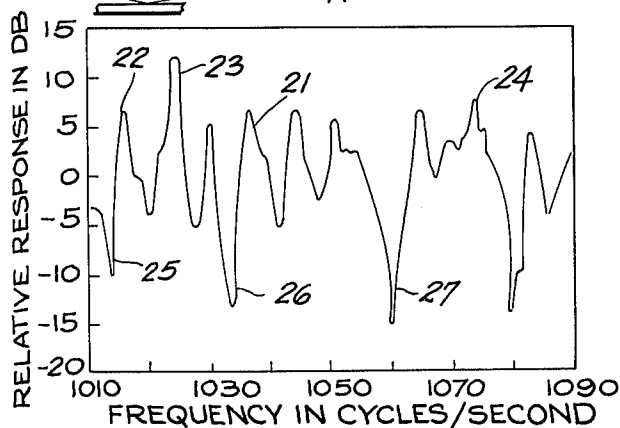
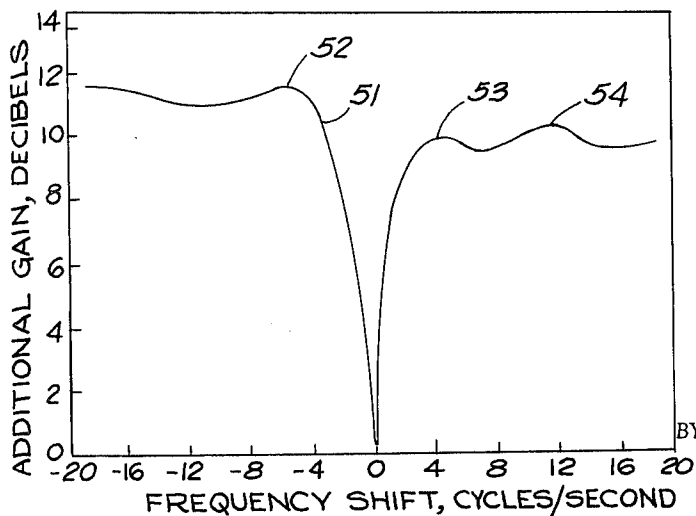


FIG. 3



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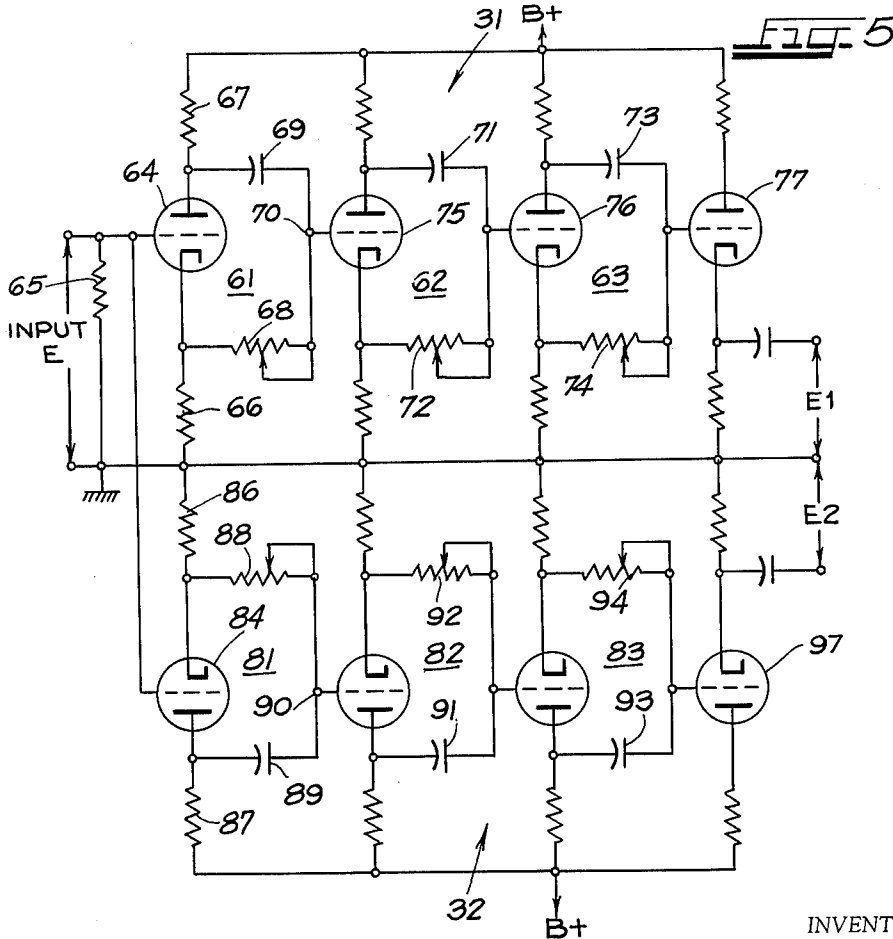
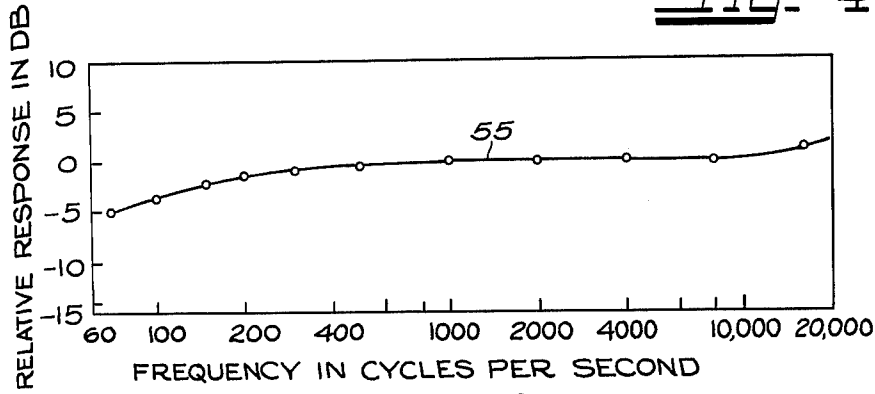
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3 Sheets-Sheet 2



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FEEDBACK CONTROL APPARATUS

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3 Sheets-Sheet 3

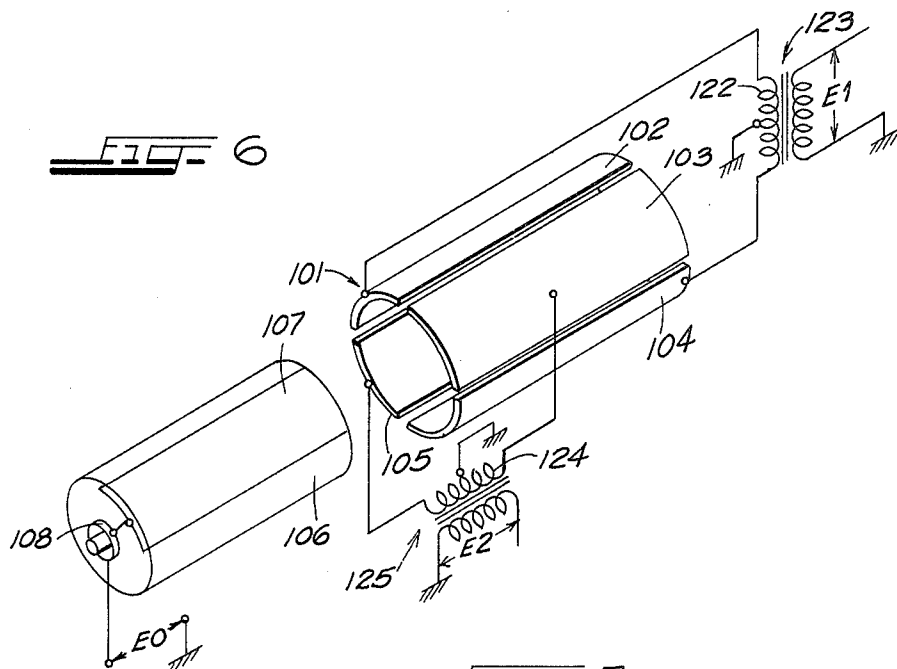


FIG. 7

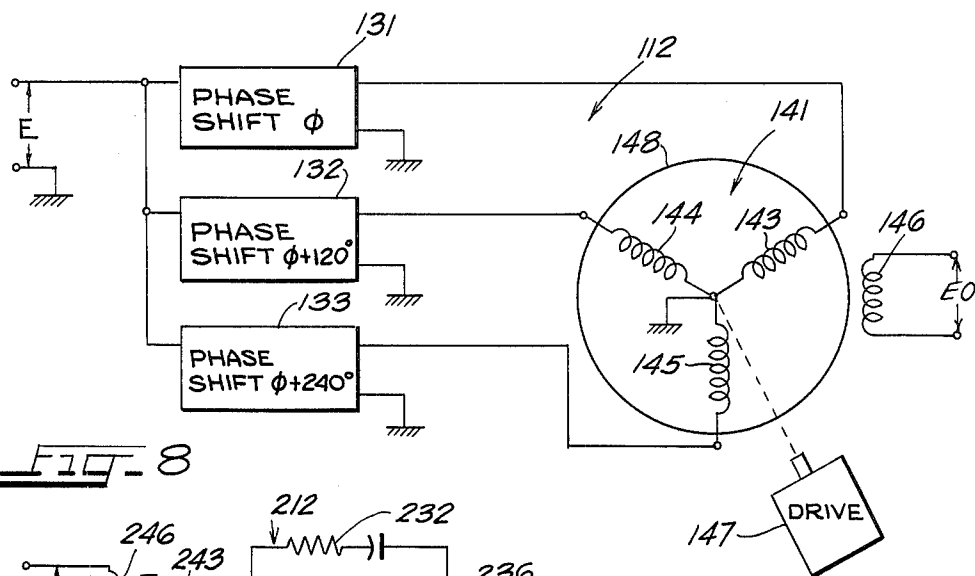
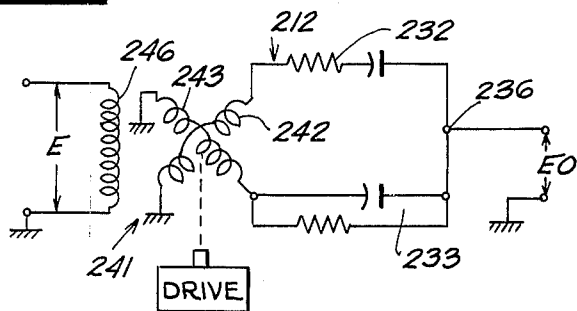


Fig. 8



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3,257,510

FEEDBACK CONTROL APPARATUS

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5 Claims. (Cl. 179—1)

This invention relates to a new and improved feedback control apparatus. More particularly, the invention relates to a feedback control apparatus that is effective to prevent oscillation in a system comprising an output device that is coupled back to its input device through a feedback medium producing irregular gain at different frequencies. The invention is particularly advantageous as applied to a public address or similar sound system, and is described in that connection, but may also be applied to other applications presenting similar oscillation problems.

System oscillation, resulting in "howling" or "squealing," is a familiar phenomenon in the operation of public address and similar sound systems. The oscillation results from acoustical feedback from the loudspeaker of the system to the microphone. Some of the feedback can be minimized by employing electrical filters to minimize response peaks in the system, particularly in the speakers. Direct acoustical feedback from the speakers to the microphone can also be reduced by proper placement of these devices and, on occasion, by the use of directional microphones and speakers. These expedients, however, are not effective with respect to acoustical energy that is reflected from the walls of the room, when the system is located indoors, or from other encompassing structures.

The reflected sound, sometimes known as reverberant sound, is not of constant amplitude at all frequencies within the range of operation of the system. Rather, there are marked variations in the amplitude of the sound impinging upon the microphone, depending upon frequency. The distribution of the acoustical feedback peak frequencies over the frequency range of the system may vary substantially, depending upon the location of the microphone and the speakers within a given structure. Thus, although individual peak frequencies might be reduced by fixed filters, effective results could not be achieved if the microphone were moved during the course of operation of the system, as frequently occurs. Furthermore, the peak frequencies are so numerous as to make individual filtering an economically prohibitive procedure.

Reverberant-sound oscillation can be avoided by incorporating a frequency shifting circuit between the microphone and the loudspeaker of the public address system to shift all frequency components of the signal supplied to the speaker by a constant amount. Optimum operation of a system of this kind is achieved with a frequency shift generally corresponding to the spacing between the peak response frequencies of the location in which the system is employed. The actual amount of frequency shift is not extremely critical. On the other hand, the frequency shift utilized in systems of this kind cannot be at too high a frequency without appreciably distorting the output of the system.

Frequency shifting apparatus as heretofore proposed for the correction of feedback difficulties in public address and similar systems has been relatively complex and expensive. In one proposed system, the initial signal,

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after amplification, is first modulated with a high frequency carrier signal from a crystal controlled oscillator. The signal is subsequently demodulated with a carrier signal from a second crystal controlled oscillator, the two carrier signals being very close in frequency. A system of this kind is dependent upon the maintenance of a constant frequency differential between the two frequency oscillators and requires relatively complex and expensive operating circuits.

It is a principal object of the present invention, therefore, to provide a new and improved feedback control apparatus that is effective to minimize instability and oscillation in a public address or similar system of the kind entailing substantial feedback, with different amplitudes at varying frequencies, over a given frequency band. A related object of the invention is to overcome the difficulties and disadvantages of previously known feedback control apparatus.

A more specific object of the present invention is to provide a continuously varying phase shift affording an effective frequency shift between the input and output devices of a public address system or the like, minimizing the tendency of the system to oscillate, without requiring the use of critical frequency elements such as crystal controlled oscillators and modulators.

Another object of the invention is to afford a means for quickly and conveniently varying the rate of phase shift in a continuous phase-shift feedback control apparatus for a public address or similar system entailing feedback at varying amplitudes for different frequencies over a relatively broad frequency band, thereby making the feedback control apparatus of the invention readily adaptable to afford optimum performance in different environments.

A specific object of the invention is to provide an inexpensive and simple mechanical system for controlling frequency shift in a feedback control apparatus for a public address or similar system.

Thus, the present invention is directed to feedback control apparatus suitable for use in a public address or like system that includes input means for developing an initial signal, a signal channel comprising an amplifier and utilization means, such as a loudspeaker, for utilizing the amplified signal. In particular, the feedback control apparatus is applicable to a system of the kind in which the utilization means is coupled back to the input means through a feedback medium producing varying gain at different frequencies within a given frequency band. Feedback control apparatus constructed in accordance with the invention comprises a rotary resolver interposed in the signal channel between the input and utilization means of the system; the rotary resolver includes at least two input stages and an output stage with the output stage being rotatable relative to the input stages to vary the interstage coupling of the resolver. The control apparatus further includes phase shifting means for developing two intermediate signals each corresponding to the initial signal developed by the input means of the system but shifted in phase, relative to each other, by a predetermined amount. In addition, the apparatus includes drive means for rotating the resolver at a predetermined frequency, preferably below the frequency range over which the system operates. As a result of rotation, the output stage of the resolver produces a utilization signal that corresponds to the initial signal from the input means of the system but is of continuously varying phase, and hence shifted in frequency, relative thereto. Switch-

ing means or other appropriate means are provided for reversing the effective direction of rotation of the resolver to change the sign of the frequency shift.

Other and further objects of the present invention will be apparent from the following description and claims and are illustrated in the accompanying drawings which, by way of illustration, show preferred embodiments of the present invention and the principles thereof and what is now considered to be the best mode contemplated for applying these principles. Other embodiments of the invention embodying the same or equivalent principles may be made as desired by those skilled in the art without departing from the present invention and the purview of the appended claims.

In the drawings:

FIG. 1 is a block diagram, partly schematic, of feedback control apparatus constructed in accordance with a preferred embodiment of the present invention, shown in connection with a conventional public address system;

FIG. 2 illustrates a typical variation in sound pressure amplitude, relative to frequency, at a given location in a room;

FIG. 3 is a chart illustrating the additional gain that can be employed safely in a public address system in which the present invention is incorporated;

FIG. 4 illustrates the overall frequency response to the feedback control apparatus illustrated in FIG. 1;

FIG. 5 is a detailed schematic diagram of a phase splitting circuit used in the feedback control apparatus of FIG. 1;

FIG. 6 illustrates an alternate form of rotary resolver for the feedback control apparatus of FIG. 1;

FIG. 7 illustrates a feedback control apparatus comprising another embodiment of the present invention; and

FIG. 8 illustrates yet another embodiment of the invention.

FIG. 1 illustrates a public address system comprising a microphone or other suitable input device 10 connected to a conventional audio amplifier 11. Amplifier 11 is provided with an output circuit that is coupled through a feedback control apparatus 12, constructed in accordance with the present invention, to a suitable power amplifier 13. The power amplifier 13, in turn, is connected to utilization means which in this instance comprises one or more loudspeakers 14. It is thus seen that the system illustrated in FIG. 1 is conventional in form except for the incorporation of the feedback control apparatus 12 in the signal channel coupling the input device 10 of the system to the output device 14.

As shown in FIG. 1, some of the output from speaker 14 may be acoustically coupled directly back to microphone 10 along a path 15. Direct acoustical feedback coupling of this kind can be minimized by proper placement and orientation of the speaker and the microphone relative to each other. Additional feedback is produced, however, by reflection of the sound from speaker 14 to microphone 10 along a variety of different paths which may be of varying length. This aspect of the system is generally illustrated by the reflection feedback paths 16 and 17. In an actual system, of course, the total number of different acoustical feedback paths between speaker 14 and microphone 10 is very large in number and the lengths of these paths vary so substantially that there are marked differences in the gain, or amplitude, of different frequency components of the reverberant sound impinging upon microphone 10.

FIG. 2 is a graphic representation of the relative acoustical response or sound pressure level in a typical room, over a range of frequencies in the neighborhood of 1 kilocycle. The average value of the sound pressure level is taken as the zero point on the response scale in FIG. 2; superimposed upon this average level is the contribution of the sound reflected from the walls of the room or other objects in the room, as represented by the curve 21. As can be seen from FIG.

2, at some frequencies the reverberant sound provides increased sound pressure (for example peaks 22, 23, 24). At other frequencies, the reverberant sound reduces the sound pressure level, at the same location, as evidenced by the valleys 25, 26, 27 and others in curve 21.

Feedback control apparatus 12 (FIG. 1) takes advantage of this irregularity in frequency response by reducing the sound pressure peaks to lower values, thereby decreasing the tendency for the public address system to oscillate. The lower limiting value, of course, is the average sound level in the room, the zero level of the response scale in FIG. 2. At the same time, feedback control apparatus 12 effectively raises the minimal points or valleys in the room frequency response characteristic toward the average sound pressure.

Feedback oscillation, in a public address system or the like, occurs at frequencies for which the phase of the feedback signal is such as to aid in synchronism with other signals entering the microphone. If this synchronism is disrupted by phase shifting or frequency shifting, the tendency toward system oscillation is minimized. A finite time is required for the build-up of oscillation. If the phase of the feedback signal is changed during a period less than the build-up time required for oscillation, then it is necessary for build-up toward oscillation to begin anew. Consequently, if the phase of the signal is changed continuously, producing an effective frequency shift, there is an effective increase in the sound level required to initiate oscillation in the system. Control apparatus 12 effectively interrupts the phase coherence of the acoustically fed back signal from speaker 14 to microphone 10, making it possible to increase the overall gain of the system and thereby permitting a substantial increase in the effective signal sound level in the room.

Although the foregoing discussion is based upon considerations pertaining to the use of a public address system in an enclosed space such as a room, control apparatus 12 is equally effective in any similar application in which acoustical or mechanical feedback is present and in which the frequency response over the feedback path is of irregular nature.

As shown in FIG. 1, feedback control apparatus 12 comprises phase shifting means including a first phase delay circuit 31 and a second phase delay circuit 32, both of which are coupled to the output of amplifier 11. The phase shifting means represented by circuits 31 and 32 may constitute any of a number of conventional phase splitting devices. In a convenient and preferred arrangement, circuit 31 comprises a first series of resistance-capacitance phase shift elements and circuit 32 constitutes a similar series of RC phase shift elements. A specific circuit of this kind is described hereinafter in connection with FIG. 5. Each series of phase shift circuits provides a continuous and approximately constant change of phase over a relatively broad frequency range determined by the number of stages in the series. In the present instance, the two phase delay circuits are adjusted to afford different phase shift characteristics, the phase difference at the outputs being established at approximately 90°.

It is necessary that the phase difference between the output signals of circuits 31 and 32 be approximately constant over a frequency range corresponding to at least a substantial portion of the operating frequency range of the public address system. The preferred circuit illustrated in FIG. 5 may be replaced by any phase shifting apparatus effective to achieve this end.

The output of phase delay circuit 31 is connected to a movable contact 33 in the first section of a double-pole double-throw switch 34. Similarly, the output terminal of circuit 32 is connected to a second movable contact 36 of the switch. The first movable contact 33 of switch 34 is engageable with fixed contacts 37 and 39; the other movable contact 36 engages either of two fixed contacts 38 and 40.

Feedback control apparatus 12 further includes a rotary resolver 41 which in this instance is a rotary transformer. Resolver 41 includes a pair of input stages comprising primary windings 43 and 44, and an output stage comprising a secondary winding 45. Input windings 43 and 44 are disposed in quadrature relation to each other and terminate at a common terminal 46 which is grounded. The secondary winding 45 of the resolver is rotatable relative to the two primary windings 43 and 44, rotation of winding 45 being effective to vary the coupling between the output winding and each of the two input windings. It is the output winding 45 of the resolver that is connected to power amplifier 13 of the public address system.

The output stage of rotary resolver 41, winding 45, is mechanically connected to a resolver drive means 47. Drive means 47 may comprise a conventional electrical motor and may be a constant speed device. On the other hand, it is frequently desirable to provide some means for varying the speed of rotation of resolver winding 45; to this end, it may be desirable to utilize a variable speed electrical motor or to provide a variable drive ratio device 48 as a part of the drive means 47 for rotatable winding 45.

In considering operation of feedback control apparatus 12, it is seen that the signal E from amplifier 11 is applied to both of the phase delay circuits 31 and 32. As noted above, the output signals from the phase delay circuits are displaced by a phase angle of 90° relative to each other. Accordingly, the output signal E_1 from circuit 31 may be represented by the expression

$$(1) \quad E_1 = E \sin wt$$

and the output signal E_2 from circuit 32 may be represented by the expression

$$(2) \quad E_2 = E \cos wt = E \sin (wt + 90^\circ)$$

The first intermediate signal E_1 is supplied to input winding 43 of resolver 41 and the other intermediate signal E_2 is applied to the second input winding 44 of the resolver. Since the secondary winding 45 of the resolver is inductively coupled to both of primary windings 43 and 44, the signal E_0 developed in the secondary or output winding of the resolver is a function of both of the input signals E_1 and E_2 . Thus, the output or utilization signal E_0 from the resolver that is applied to power amplifier 13 may be represented by the equation

$$(3) \quad E_0 = E_1 \sin \theta + E_2 \cos \theta = E \sin (wt + \theta)$$

in which θ is the instantaneous angle of resolver secondary 45 relative to the reference axis of the primary windings 43 and 44 of the resolver.

The output winding 45 of resolver 41, however, is rotated continuously by resolver drive 47, and the rate of phase change in the output signal E_0 from the resolver is $d\theta/dt$. Accordingly, the utilization signal E_0 may also be represented by the expression

$$(4) \quad E_0 = E \sin \left(w + \frac{d\theta}{dt} \right) t$$

From FIG. 2, it can be seen that the spacing between response peaks for the location in which the public address system is used is of the order of five to ten cycles per second. Consequently, a frequency shift of the order of five cycles per second should be effective to break up the otherwise potentially coherent feedback pattern of the system and effectively minimize the tendency of the system to oscillate at peaks such as the peak 23.

To accomplish this, with resolver 41, drive means 47 is adjusted to afford a rate of rotation for resolver secondary 45 of five revolutions per second. Each revolution of secondary 45 accomplishes a complete 360° phase shift and thus constitutes a frequency change of one cycle per second. Accordingly, if drive means 47 rotates secondary winding 45 at 300 r.p.m., five revolutions per

second, the resulting rotation of the secondary produces a total frequency shift in signal E_0 , as compared with the initial input signal E , of five cycles per second. A frequency shift of six cycles per second can be accomplished by operating drive 47 at a speed of 360 r.p.m., and corresponding changes in the drive speed may be accomplished to afford other frequency shift values, depending upon the spacing between the peaks and valleys in the response curve, FIG. 2.

From the foregoing description, it can be seen that feedback control apparatus 12 may be considered in terms of either a frequency shifting device or a phase changing device. The apparatus affords a frequency shift of a given value, as for example, five cycles per second, each time a signal passes through it. Thus, an acoustical signal applied to microphone 10 is shifted five cycles per second in frequency before it is emitted into the room by loudspeaker 14. The sound fed back acoustically to microphone 10, along paths 15-17, is again shifted in frequency by the same amount as it is passed through the signal channel of the public address system and back to speaker 14.

As the signal returns repeatedly for reamplification by the public address system, it is shifted in frequency by a total of $5n$ cycles per second, where n is the number of times the signal passes through the system. As a consequence, the loop gain of the system is maintained at less than unity as long as the sound being fed back at relatively high levels, corresponding to the peaks of the response curve (FIG. 2), is shifted into regions of the response curve having low response levels. If the sound level in the room were uniform and independent of frequency, the frequency-shifted signal would still be fed back at a level that could lead to oscillation, but a room construction affording such characteristics is virtually unknown.

An inductively coupled resolver, such as resolver 41, provides substantial latitude in selection of turns ratios and other performance characteristics. Consequently, a wide choice of design parameters, particularly with respect to the output impedance of the resolver, is available. On the other hand, capacitive or resistive resolvers can be employed, a capacitive device being discussed hereinafter in connection with FIG. 6.

One advantageous feature of the feedback control apparatus 12 is the ease and convenience of changing the amount of frequency shift (the rate of phase change) by the simple expedient of varying the speed of resolver drive 47. As noted above, the rate of rotation can be modified by utilizing a variable speed motor as the resolver drive or by employing a mechanical linkage 48 of variable drive ratio between the resolver drive and resolver secondary 45. This aspect of the invention enables a simple and expedient adjustment of the operating characteristics of the resolver to meet the conditions of the auditorium or other environment in which the public address system is used.

Another feature of feedback control apparatus 12 is that it provides for quick and convenient reversal of the direction or sign of the frequency shift without the addition of circuit elements other than switch 34. If switch 34 is actuated from the illustrated position to the alternate position, it is seen that the signals E_1 and E_2 are reversed in their connections to the primary windings 43 and 44 of resolver 41. Thus, with switch 34 thrown to its alternate position, signal E_1 is supplied to input winding 44 and signal E_2 is applied to input winding 43. It can be shown that, under these conditions, the resultant signal E_0 developed across secondary winding 45 is of the form

$$E_0 = E \sin \left(w - \frac{d\theta}{dt} \right) t$$

Thus, the reversal of the input connections to resolver 41 effected by switch 34 is equivalent to reversing the direction of rotation of secondary winding 45 relative to primary windings 43 and 44 and reverses the sign or direc-

tion of the frequency shift, a reversal that is difficult and costly with previously known frequency-shift feedback control apparatus.

Of course, the sign of the frequency shift or phase change effected by apparatus 12 can also be reversed by reversing the direction of rotation of resolver drive 47. This can be accomplished by utilizing an electric drive motor that may be reversed in its direction of rotation, as by changing the polarity of the input to the motor or by changing the connections to the field and armature of the motor, in accordance with conventional practice. The feature of reversal of the sign of frequency shift, whether accomplished by means of a reversible drive or by means of a switch such as switch 34, is desirable to compensate for variations among auditoria in which the apparatus may be employed.

FIG. 3 is a graphical representation of the additional gain available, short of oscillation, in the public address system of FIG. 1 with the feedback control apparatus 12 incorporated therein, as compared with a similar system not employing comparable feedback control apparatus. The additional gain is plotted as a function 51 of the frequency shift effected by apparatus 12.

From curve 51 of FIG. 3, it can be seen that, as would be expected, no additional gain can be realized if the frequency shift afforded by apparatus 12 is equal to zero. Furthermore, very small frequency shifts of the order of one or two cycles do not have sufficient effect in breaking up feedback coherence in the overall public address system and permit only relatively small increases in total gain of the system. A frequency shift of as much as four cycles, either advancing or retreating, makes it possible to achieve quite substantial amplitude increases without engendering oscillation in the system. Furthermore, as will be apparent from FIG. 3, there are definite optimum frequencies permitting maximum gain as indicated by points 52, 53 and 54 in FIG. 3. It should be understood that the curve 51 is applicable only to a given reverberant room or other specific environment and that this curve can be substantially different in other environments, thereby establishing different optimum conditions for the amount of frequency shift that will afford the maximum opportunity for advancing the gain of the system.

FIG. 4 is a graphical representation of the relative response of feedback control apparatus 12, plotted as a function 55 of signal frequency in cycles per second. As can be seen from curve 55, the frequency response of the feedback control apparatus is virtually flat from about 500 cycles per second to over 10,000 cycles per second. The initial portion of curve 55 (60 to 500 cycles) shows some low-frequency loss, due primarily to a somewhat reduced low-frequency response in the particular phase splitter circuits 31 and 32 employed in the specific apparatus for which the curve was taken. But this slight low-frequency loss is not sufficient to cause noticeable distortion in operation of the public address system. The rise in relative response above about 15,000 cycles is due to the fact that resolver 41 exhibits a resonant peak. In this instance the resonant frequency would be of the order of fifty kilocycles.

FIG. 5 illustrates a specific phase splitter circuit that may be utilized for the phase delay circuits 31 and 32 in frequency control apparatus 12 of FIG. 1. Circuits 31 and 32, as shown in FIG. 5, each constitute an iterated circuit of the general type described in National Bureau of Standards Report No. 1470 dated February 29, 1952.

Phase delay circuit 31 comprises three individual phase shift circuits 61, 62 and 63; circuits 61-63 are substantially identical to each other except for circuit parameters. Thus, the initial phase shift circuit 61 in series 31 includes a triode 64 having a control electrode connected to a suitable input stage as by means of an input resistor 65. The cathode of triode 64 is returned to ground through a load resistor 66 and the anode is connected to a suitable B+ supply by means of a load resistor 67.

The cathode of the triode is connected through a potentiometer 68 to the control electrode of the next stage 62 in the chain. The capacitor of triode 64 is connected by a coupling capacitor 69 to the control electrode of the succeeding triode.

The next stage of circuit 31 is essentially similar to stage 61. A coupling capacitor 71 connects the anode of triode 75 in this stage to the control electrode of tube 76 in the next stage. A potentiometer 72 connects the cathode of tube 75 to the control electrode of the triode 76. Circuit 63 includes a coupling capacitor 73 that couples the anode of tube 76 to the control electrode of an output triode 77. A potentiometer 74 connects the cathode of tube 76 to the control electrode of triode 77.

Phase delay circuit 32 includes 3 stages 81, 82 and 83 paired with stages 61, 62 and 63, respectively, of circuit 31. Stage 31 is similar in construction to circuit 61 and includes a triode 84 having a cathode returned to ground through a resistor 86 and an anode connected to the B+ supply through a resistor 87. The control electrode of tube 84 is connected back to resistor 65 to receive the same input signal as applied to triode 64. The output circuit of stage 81 includes a potentiometer 88 that connects the cathode of tube 84 to the triode for stage 82. A capacitor 89 couples the anode of triode 84 to the control electrode in the next stage.

Circuits 82 and 83 are of similar construction. The output circuit of stage 82 includes a coupling capacitor 91 and a potentiometer 92. The corresponding elements in stage 83 are the coupling capacitor 93 and the potentiometer 94. The latter two impedances are coupled to the control electrode of an output triode 97.

Circuits 61 and 81 may be considered as a pair. These two circuits each produce an output signal that is shifted in phase as a function of frequency, the maximum phase shift being at a frequency determined by the circuit parameters selected for elements 68, 69, 88 and 89. Similarly, circuits 62 and 82 function as a pair to afford a further phase shift, the frequency of maximum shift being selected to broaden the overall operating frequency band of the circuit. The third circuit pair 63, 83 represents a continuation of this process, again broadening the frequency range. It can be demonstrated that the illustrated circuits may be constructed to afford a frequency shift of approximately 90°, in the output signals E₁ and E₂ over a range of 100 to 10,000 cycles per second.

If desired, a fourth phase splitter circuit pair could be added to increase the frequency range and to narrow the tolerance of the system with respect to deviations from the desired 90° phase shift. On the other hand, a less expensive system could be constructed with only two sets of phase splitter circuits. Such a two-stage phase splitter circuit, if otherwise similar to the circuit of FIG. 5, would ordinarily have a narrower frequency range and would not be able to maintain as close tolerances with respect to deviations from the desired 90° phase shift. By replacing each of the coupling capacitors (e.g. capacitors 69 and 89 in the first stage of FIG. 5) with a series RC circuit and replacing each related coupling resistor (e.g. resistors 68 and 88) with a parallel RC circuit, however, the overall performance of a two-stage circuit of this general type can be improved to a level comparable to and even better than the three-stage circuit illustrated.

Triodes 77 and 97 serve only as output stages and do not contribute to the overall phase shift of the system. The illustrated circuit affords the necessary 90° phase shift between signals E₁ and E₂; with modification, as noted above, virtually any desired frequency range can be achieved for the system.

In order to afford a more complete illustration of the present invention, circuit parameters for a substantial portion of the circuit illustrated in FIG. 5 are set forth in detail hereinafter. It should be understood that these data are furnished merely by way of illustration and in no sense as a limitation on the invention.

Plate load resistors 67, 87, etc.	kilohms--	12
Cathode load resistors 66, 86, etc.	do-----	12
Vacuum tubes (all)	Type 12AT7	
Resistor 65	do-----	500
Resistor 68	do-----	330
Resistor 72	do-----	390
Resistor 74	do-----	240
Resistor 88	do-----	180
Resistor 92	do-----	220
Resistor 94	do-----	47
Capacitor 69	microfarad--	0.005
Capacitor 71	do-----	500.0
Capacitor 73	do-----	200.0
Capacitor 89	do-----	0.002
Capacitor 91	do-----	500.0
Capacitor 93	do-----	200.0
B+, volts D.C.	-----	+150

The embodiment of FIG. 1, utilizing the specific circuit shown in FIG. 5, affords substantial improvement in the operation of the public address system as evidenced by the increased permissible amplification, FIG. 3, and the essentially flat response, FIG. 4. There is little or no evidence of modulation distortion in the audio output of the system. The system does not require the use of crystal controlled oscillators or other critical frequency determining elements; nevertheless, it affords substantially greater versatility than previously known systems with respect to changing the frequency shift to suit individual room conditions.

FIG. 6 illustrates a simple rotary resolver 101 that may be incorporated in feedback control apparatus 12 (FIG. 1) in place of the resolver 41 illustrated therein. Resolver 101 includes four capacitor plates 102, 103, 104 and 105 each shaped to afford a quadrant section of a composite cylindrical structure. Plates 102 and 104 are electrically connected to the opposite ends of a center-tapped secondary winding 122 of an input transformer 123, the tap on winding 122 being grounded. Similarly, plates 103 and 105 are connected to the opposite ends of a center-tapped secondary winding 124 of a second input transformer 125.

Resolver 101 further includes a rotor 106 upon which a single capacitor plate 107 is mounted. Plate 107 covers approximately 90° of the surface of rotor 106 and is electrically connected to a slip ring 108 to afford a means for coupling an output circuit to the plate. In FIG. 6, the rotor 106 is shown displaced from the stationary capacitor plates 102-105; in actual use, the rotor would be located within the cylindrical configuration afforded by the stationary capacitor plates.

In operation, capacitor plates 102 and 104 afford the first input stage for the rotary resolver 101 and capacitor plates 103 and 105 constitute the second input stage for this resolver structure. Signal E_1 is applied to plates 102 and 104 in push-pull relation, through transformer 122, and signal E_2 is applied in phase opposition to plates 103 and 105, through transformer 124. Rotor 106 is mechanically connected to resolver drive 47 (FIG. 1) and is rotated at a rate commensurate with the desired frequency shift to be imparted to the utilization signal E_0 derived from the slip ring 108 upon the rotor.

Operation of rotary resolver 101 is essentially similar to the resolver described in connection with FIG. 1 except that output plate 107 is capacitively coupled to the input stages rather than being inductively coupled as in resolver 41. Again, to achieve a five cycle per second frequency shift with resolver 101, the rotor must be rotated at a speed of 300 revolutions per minute, since each complete cycle of rotor 106 is equivalent to a total phase shift of 360°.

FIG. 7 illustrates a feedback control apparatus 112 that is generally similar to the previously described apparatus 12 of FIG. 1 but which uses a three phase resolver instead of the quadrature resolver of the initial embodiments, and in which the rotor and stator are reversed with regard to

input and output functions. Thus, apparatus 112 includes three phase shift circuits 131, 132 and 133 with input circuit means for applying the same signal E to all three of the circuits. Circuits 131 and 132 produce output signals that are shifted 120° in phase relative to each other. Circuits 132 and 133 afford a phase shift of 120° with respect to each other, the phase shift between the output signals of circuits 131 and 133 being 240°.

The resolver 141 of feedback control apparatus 112 is again a rotary transformer having three input windings 143, 144 and 145. Windings 143-145 are disposed in 120° alignment with respect to each other; in this instance the input windings are mounted on the rotor 148 of the resolver rather than on the stator. The three input windings are all terminated at a common ground connection. Winding 143 is connected to the output of phase shift circuit 131, winding 144 is connected to phase shift circuit 132, and winding 145 is coupled to phase shift circuit 133. Rotor 148 is connected to a suitable drive apparatus 147.

Again, the resolver is provided with an output winding 146 that performs the same function as the winding 45 of resolver 41. Output winding 146, however, is a stator winding in the rotary transformer 141.

With the apparatus 112 illustrated in FIG. 7 the output signal E_0 can again be demonstrated to conform to the expression given above in Equation 4; that is, the frequency shift of the feedback control apparatus is again determined directly by the speed of rotation of the rotor 148 of the rotary resolver, the signal induced in output stage 146 being a composite signal having a phase determined by the instantaneous angular orientation of this winding with respect to the input stage windings 143-145.

In FIG. 7, the positions of the rotor and stator of the resolver in the signal channel coupling the microphone or other input device to the utilization device, such as the loudspeaker, are reversed as compared with the construction shown in FIG. 1. It is also possible to reverse the relative positions of the resolver and the phase-shift circuits in the signal channel, as shown in FIG. 8.

Thus, FIG. 8 illustrates a feedback control apparatus 212 comprising an inductive rotary resolver 241 having a single input winding 246 and a pair of output windings 242 and 243. Input winding 246 is a stator winding and is coupled to a suitable signal source, not shown, the signal E being applied thereto. Output windings 242 and 243 are mounted on a rotor in quadrature orientation to each other. One terminal of winding 242 is grounded and the other terminal is connected to a series RC phase shift circuit 232. One terminal of winding 243 is grounded and the other terminal is connected to a parallel RC phase shift circuit 233. The two phase shift circuits are connected together at a common terminal 236.

As before, the rotor of resolver 241 is connected to a suitable drive means 247 that operates to rotate the rotor continuously during operation of the apparatus 212. In this form of the invention the input signal E is split into two components that are shifted in phase, relative to each other, by 90° plus a continuously varying factor determined by the rotational speed of the resolver. These two components are recombined, by means of phase shift circuits 232 and 233, to produce an output signal E_0 having the same attributes, relative to the input signal E , as in the previous embodiments. Of course, the apparatus 212 would have a relatively narrow frequency range, as illustrated, but this can be broadened where necessary by replacing the simple phase shift circuits 232 and 233 with broad band circuits such as shown in FIG. 5.

By considering the basic functional attributes of each of the various embodiments of the invention described above, their essential similarity is made readily apparent. In each form of the feedback control apparatus, the signal channel between the input device and the utilization device is split into two or more sub-channels. The signals in the sub-channels are first subjected to a substantially

constant phase modification that is preferably a function of the number of sub-channels used; 90° is preferred with two channels and 120° with three channels. Subsequently, the signals in the sub-channels are subjected to a complementary fixed phase modification and the channels are recombined to again afford a single channel. In addition, a continuously varying phase shift is effected, with respect to the signals translated through the sub-channels, resulting in a frequency shift in the output signal from the apparatus.

In each embodiment, the rotary resolver performs two of the basic functions described above. Thus, the resolver simultaneously carries out the varying phase shift operation and one of the two substantially constant phase modification operations. The other fixed phase modification is effected by conventional circuit means located either ahead of or after the resolver in the signal channel.

Hence, while preferred embodiments of the invention have been described and illustrated, it is to be understood that they are capable of variation and modification, and I therefore do not wish to be limited to the precise details set forth, but desire to avail myself of such changes and alterations as fall within the purview of the following claims.

I claim:

1. Feedback control apparatus for minimizing oscillation tendencies in a public address or like system including input means for developing an initial signal varying over a wide frequency range, a signal channel comprising amplifier means for amplifying that signal, and utilization means for utilizing the amplified signal, and in which the utilization means is coupled back to the input means through a feedback medium producing varying irregular gain at different frequencies within said frequency range, said feedback control apparatus comprising:

a rotary resolver, incorporated in said signal channel, including three input stages disposed in 120° relation to each other and an output stage, coupled to all of said input stages, said resolver output stage being rotatable relative to said input stages progressively to vary the coupling of the output stage to the input stages in balanced three-phase relation;

phase-shifting means, incorporated in said signal channel ahead of said resolver and coupled to said input means, for developing and applying to said input stages three intermediate signals each corresponding to said initial signal but mutually differing in phase, relative to each other, by phase angles of 120° over at least a substantial portion of said frequency range;

drive means for rotating said output stage of said resolver at a frequency below said frequency range to produce, in the output stage of said resolver, a utilization signal corresponding to said initial signal but of continuously varying phase relative thereto; and means for reversing the effective direction of rotation of said resolver to change the direction of phase variation in said utilization signal.

2. Feedback control apparatus for minimizing oscillation tendencies in a public address or like system including input means for developing an initial signal varying over a wide frequency range, a signal channel comprising amplifier means for amplifying that signal, and utilization means for utilizing the amplified signal, and in which the utilization means is coupled back to the input means through a feedback medium producing irregular gain at different frequencies within said frequency range, said feedback control apparatus comprising:

a rotary resolver capacitor incorporated in said signal channel and including a plurality of input stages each comprising a capacitor plate, and an output stage comprising a capacitor plate, further including rotatable means for varying the capacitive coupling between said capacitor plate of said output stage and

said capacitor plates of said input stages of said resolver;

phase-shifting means, incorporated in said signal channel ahead of said resolver, for developing and applying to said resolver input stages a corresponding plurality of intermediate signals each corresponding to said initial signal but shifted in phase, relative to each other, by a predetermined amount;

drive means for continuously rotating said rotatable means in said resolver at a constant frequency below said frequency range to produce, in the output stage of said resolver, a utilization signal corresponding to said initial signal but shifted in frequency by an amount directly proportional to the rotational frequency of said rotary means of said resolver;

and means for reversing the effective direction of rotation of said resolver to change the sign of said frequency shifted.

3. Feedback control apparatus for minimizing oscillation tendencies in a public address or like system including input means for developing an initial signal varying over a wide frequency range, a signal channel comprising amplifier means for amplifying that signal, and utilization means for utilizing the amplified signal, and in which the utilization means is coupled back to the input means through a feedback medium producing irregular gain at different frequencies within said frequency range, said feedback control apparatus comprising:

a rotary resolver incorporated in said signal channel and including a plurality of input stages, an output stage, and a rotor, said rotor being rotatable relative to said input stages to vary the coupling of the resolver output stage to each of said input stages in predetermined ratio;

phase-shifting means, incorporated in said signal channel ahead of said resolver, for developing and applying to said input stages a corresponding plurality of intermediate signals each corresponding to said initial signal but shifted in phase, relative to each other, by a predetermined amount;

drive means for continuously rotating said resolver rotor at a constant frequency below said frequency range to produce, in the output stage of said resolver, a utilization signal corresponding to said initial signal but of continuously varying phase relative thereto, the rate of phase change being a direct function of the rotational speed of said rotor;

means for adjusting the operating speed of said drive means to modify the rate of phase change to suit the environment of said system;

and means for reversing the effective direction of rotation of said resolver to change the direction of phase variation in said utilization signal.

4. Feedback control apparatus for minimizing oscillation tendencies in a public address or like system including input means for developing an initial signal varying over a wide frequency range, a signal channel comprising amplifier means for amplifying that signal, and utilization means for utilizing the amplified signal, and in which the utilization means is coupled back to the input means through a feedback medium producing irregular gain at different frequencies within said frequency range, said feedback control apparatus comprising:

a rotary resolver incorporated in said signal channel and including two input stages and an output stage, said resolver output stage being rotatable relative to said input stages to vary the interstage coupling of the resolver;

phase-shifting means, incorporated in said signal channel ahead of said resolver, for developing two intermediate signals each corresponding to said initial signal but shifted in phase, relative to each other, by a predetermined amount, and for applying each of said intermediate signals to a respective one of said resolver input stages;

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drive means for continuously rotating said resolver at a constant frequency below said frequency range to produce, in the output stage of said resolver, a utilization signal corresponding to said initial signal but of continuously varying phase relative thereto; 5
and switching means for reversing the connections of said phase-shifting means to said resolver input stages to reverse the direction of phase change effected by said resolver.

5. Feedback control apparatus for minimizing oscillation tendencies in a public address or like system including input means for developing an initial signal varying over a wide frequency range, a signal channel comprising amplifier means for amplifying that signal, and utilization means for utilizing the amplified signal, and in which the utilization means is coupled back to the input means through a feedback medium producing irregular gain at different frequencies within said frequency range, said feedback control apparatus comprising: 10 15

a rotary resolver incorporated in said signal channel and including an input stage and an output stage, one of said stages comprising a plurality of sub-stages, said resolver output and input stages being rotatable relative to each other to vary the interstage coupling of the resolver; 20

phase-shifting means, comprising a corresponding plurality of sub-channels individually incorporated in said signal channel in series with the sub-stages of said resolver, for shifting the signals traversing said sub-channels in phase, relative to each other, by a predetermined amount; 25 30

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drive means for continuously rotating said resolver at a constant frequency substantially smaller than the principal portion of said frequency range to produce, in the output of said signal channel, a utilization signal corresponding to said initial signal but shifted in frequency with respect thereto, the net frequency shift being directly proportional to the rotational velocity of said resolver and of a sign determined by the direction of rotation; and means for reversing the effective direction of rotation of said resolver to change the sign of said frequency shift.

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