Dec. 12, 1944. E. W. KELLOGG 2,364,723

F-M CONTROL TRACK OPERATION

Filed Nov. 11, 1943

Fig. 1.

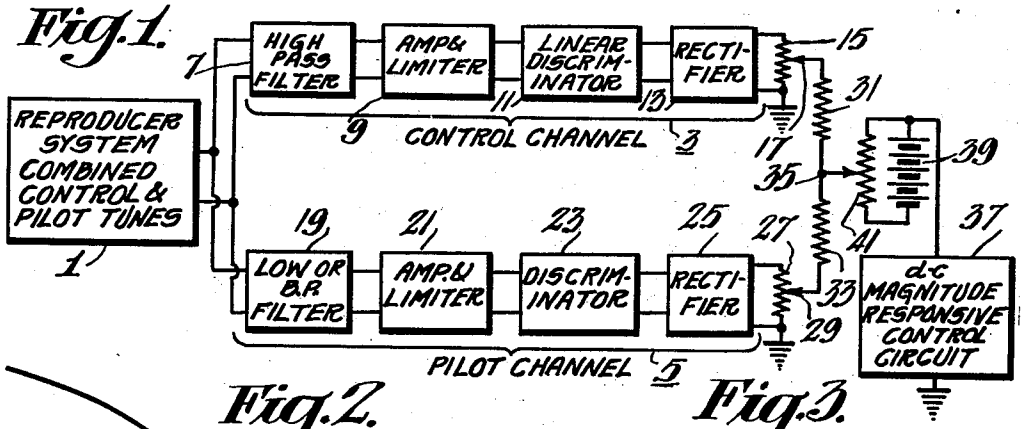


Fig. 2.

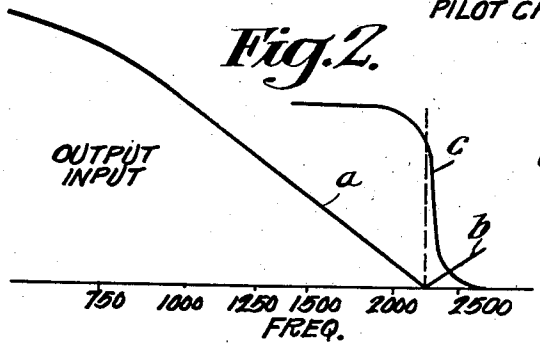


Fig. 3.

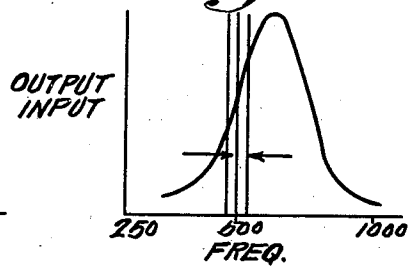


Fig. 4.

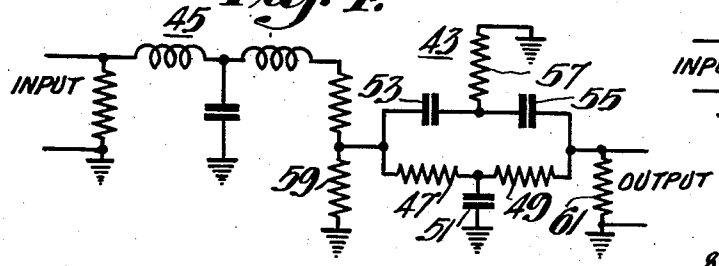


Fig. 5.

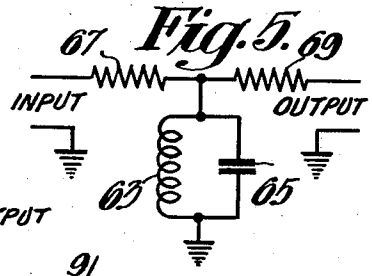
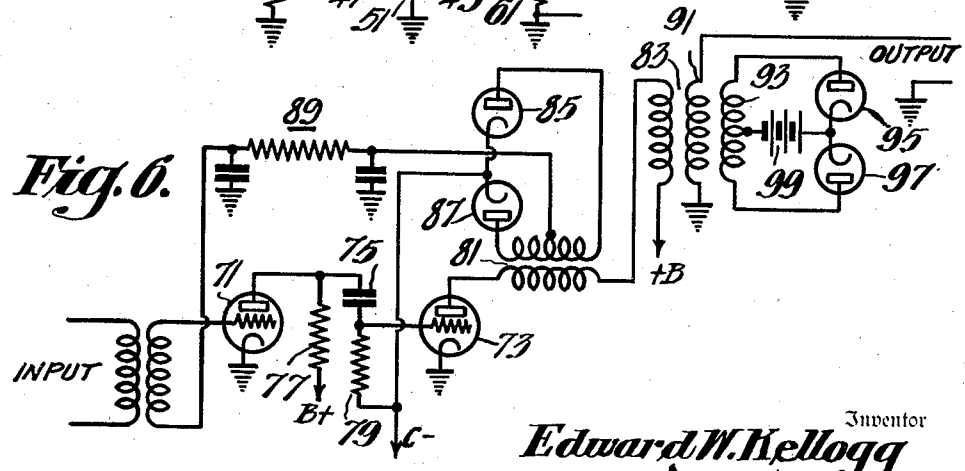


Fig. 6.



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2,364,723

F-M CONTROL TRACK OPERATION

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Application November 11, 1943, Serial No. 509,932

12 Claims. (Cl. 179—100.1)

This invention relates to record-responsive control systems, and more particularly to improvements in the art of automatically adjusting some factor, such as the gain of an amplifier, the physical position of a mechanical load device, or the like, in accordance with variations in frequency of a recorded control tone.

Numerous applications have been found for control of electrical or mechanical devices by means of a recorded alternating current which varies either in amplitude or frequency, according to the system chosen, the record being employed with a suitable reproducing device and a circuit which responds to the change in recorded amplitude or frequency. One of the best-known applications of this principle consists in utilization of such a recorded alternating current to vary the gain of amplifiers in a sound-reproducing system. A continuous alternating current or tone is recorded on the same record with the sound to be reproduced, and reproduced from the record by a separate reproducing device from that employed for converting the sound record into electrical currents. The recorded tone, usually designated as the "control tone," is rectified and thereby caused to provide a varying direct current voltage which alters the gain of the sound amplifier. The control tone system makes it possible to provide large changes in the level or loudness of the reproduced sound. With constant amplification, maximum and minimum limits are imposed by the characteristics of the sound record, usually a definite overload point on the one hand and on the other hand background noise which becomes conspicuous when the recorded levels are very low. With a control tone the sound may be so recorded that it is at all times safely below the overload point and well above ground noise level, and the control tone can provide large changes in amplification to afford the desired musical or other sound effects.

Control tones as just described are ordinarily of two types. In the first the frequency remains constant and the amplitude is varied, while in the second type the amplitude is constant and the frequency is varied. In the variable frequency system the reproduced tone is applied to a circuit or network, commonly called a "discriminator" circuit, which is composed of reactances or combinations of reactance and resistance, and which has the property of developing across its output terminals, a voltage which depends on the frequency of the input, although the input itself may be of constant magnitude. This varying voltage may then be rectified and caused to change the bias on a variable gain tube or other device for changing amplification in the sound channel.

The variable frequency control tone system is somewhat more complicated than the variable amplitude system, but it has the advantages that the control tone is all times recorded at a moderately high level and this makes the system less sensitive to disturbances due to imperfections in the record. Moreover, since it is a part of the system that the tone is to be maintained at constant amplitude up to the point of its application to the discriminator, it is common practice to employ an amplitude-limiting circuit, such as an amplifier tube which reaches a sharp overload point and is thus incapable of transmitting alternating voltages above a certain magnitude. Such a limiter still further reduces the danger of changes in the final output of the control tone system due to record imperfections. The imperfections to which I refer are the same things which cause noise in reproduced sound. They may be scratches, pits or dirt in the case of a groove record such as a phonograph disc, or dirt, scratches or other specks in the surface of a photographic record on film. Such accidentally produced effects may momentarily produce voltages higher than those of the recorded tones, and these might produce considerable disturbance or changes in amplifier gain. The limiter prevents the noise sources from ever producing an instantaneous voltage greater than that of the recorded tone.

Control tones can be applied to many devices other than variable gain amplifiers, for example, to accomplish any actions for which a cam might be used in a mechanical system. Suppose, for example, a robot is designed to execute a large variety of slow movements. It could be made to carry these out by constructing a suitably designed cam for each type movement such as nodding its head, lifting its arm, etc. In simple applications where the power requirements are small, the duration of the cycle moderately short, and the variety of actions not too large, the controls may be advantageously provided by mechanical cams; but where these limitations do not exist and greater freedom of performance is needed, the control tone system may be employed using servo electric motors or other devices which can be remotely controlled.

Although the variable frequency control tone system as described above has the advantages which I have pointed out, it is subject to one

serious disadvantage, since the discriminator responds to frequency, any deviation from correct operating speed, by the apparatus by which the tone is recorded or reproduced, results in a change of frequency from that which was intended. For example, it might be desired at a certain place on the record to record at 1000 cycles. We shall assume that the recordist correctly adjusts an oscillator to 1000 cycles, but if the recording machine is running 1% slow at the moment, the recorded waves will be slightly shortened, and if the reproducing machine runs at the correct speed the reproduced tone would be approximately 1010 cycles; and if the reproducing machine itself should run 1% fast, the reproduced tone might be as high as 1020 cycles. Experience with sound recording and reproducing machines indicates that random deviations of this magnitude are extremely likely to occur, as well as continuous or slowly drifting changes of speed. It is obvious that the discriminating circuit will respond to these incorrect frequencies just as if they were the correct or desired frequencies. For some applications there may be large enough tolerance for random variations in the final control voltage so that satisfactory performance can be obtained by using machines of reasonably good speed regulation and with no further insurance against impaired results due to speed changes. For other applications the small variations due to speed changes may interfere with the desired overall results.

The principal object of this invention is to provide an improved method of and means for recording and reproducing a variable frequency control tone.

Another object is to provide means for reducing or eliminating the effects of speed variations which may occur either in the recording or reproducing of a variable frequency control tone or in both.

These and other objects will become apparent to those skilled in the art upon consideration of the following description, with reference to the accompanying drawing, of which Figure 1 is a schematic block diagram of a control system embodying the instant invention, Figures 2 and 3 are graphs of the transmission characteristics of the discriminator circuits in the system of Figure 1, Figures 4 and 5 are schematic circuit diagrams of discriminators having the characteristics illustrated by Figures 2 and 3 respectively, and Figure 6 is a schematic circuit diagram of an amplifier and limiter of the type employed in the system of Figure 1.

The present invention contemplates the use of two tones recorded simultaneously on the same record carrier, one of constant amplitude but variable frequency, to perform the controlling operation, and the other constant in both frequency and amplitude for the purpose of neutralizing the effects of changes in the speed of operation of the recording or reproducing equipment. The variable frequency tone is applied to a frequency responsive circuit, or discriminator, similar in function to those used commercially in F-M radio application and the like, which cause a change in the frequency of the input tone to give rise to a change in the magnitude of a rectified voltage. The constant frequency tone is applied to a second discriminator having a frequency response characteristic which (in the preferred embodiment of my invention) slopes in the opposite direction to that of the first, and the rectified outputs of the two discriminators are combined in such proportions that the effects of speed changes are balanced against each other for minimum total response to speed variations.

Referring to Figure 1, a reproducer system 1 is provided for producing a combined output voltage which comprises a nominally constant frequency, constant amplitude component, herein referred to as a pilot tone, and a constnant amplitude control tone component which varies in frequency, having been recorded according to a predetermined schedule or time function, for the purpose of accomplishing some desired control. The reproducer 1 may comprise a film phonograph reproducing photographically recorded tones, or a disc phonograph, magnetic tape device, or any known mechanism capable of providing A. C. electrical output in response to and corresponding to a suitable record. Inasmuch as numerous such systems are well known to those skilled in the art, it is deemed unnecessary to describe the reproducer 1 in detail. For the purpose of describing the present invention, it is suffcient to state that the record elements to be employed with the reproducer 1 carry a composite wave comprising the control and pilot tones, or else two tones recorded side by side, so that each provides its respective input into the reproducing device 1.

The output circuit of the reproducer 1 is connected to a control tone channel 3 and to a pilot tone channel 5. The control channel 3 includes a high pass filter 7, through which the output of the reproducer 1 is applied to an amplifier and limiter 9. The output circuit of the amplifier 9 is connected to a discriminator 11, which is in turn connected to the input circuit of a rectifier 13. The output circuit of the rectifier 13 includes a voltage divider 15 provided with a manually adjustable tap 17. The filter 7 is designed to pass frequencies of, for example, 1000 cycles per second and higher, and the discriminator 11 is designed to provide, in response to constant amplitude input, an output having an amplitude which is a linear function of the logarithm of the input frequency. Such a characteristic is illustrated by the curve *a* of Figure 2, which for purposes of illustration is here shown as usable throughout the range 1000 to 2000 cycles.

The pilot channel 5 is similar to the control channel 3, but includes a low pass or band pass filter 19 instead of the high pass filter 7 of the control channel. The filter 19 is designed to pass, for example, 500 cycles per second, and to reject the control tone frequencies of 1000 cycles per second and higher. The amplifier and limiter 21 may be identical with the corresponding element 9 of the control channel, except that the gain controls of the two amplifiers are not necessarily set alike. The discriminator 23, while similar in function to the discriminator 11 of the control channel, is designed to have a transmission vs. frequency characteristic which slopes in the opposite direction from that of the control channel discriminator, in the neighborhood of the pilot tone frequency, i. e., 500 cycles per second. The characteristic of the discriminator 23 need not be linear, since it will be required to operate only over a narrow band width corresponding to the frequency variations due to the speed variation which will occur in the operation of the recording or reproducing system. A typical frequency response curve of a discriminator suitable for this purpose is illustrated by the curve of Figure 3. The rectifier 25 and the voltage divider 27 may be identical with the correspond-

ing elements 13 and 15 of the control channel. Both of the rectifiers 13 and 25 are provided with filter circuits preferably of the well-known choke input type, which provide output voltages more nearly the average values rather than the peak values of the respective inputs, the advantage of this being that such an average rectified voltage is less affected by accidental defects in the record such as scratches or dirt.

The adjustable taps 17 and 29 of the voltage dividers 15 and 27 are connected through resistors 31 and 33 to a junction point 35, which is connected to the input circuit of a D.-C. magnitude-responsive control device 37. Included in the connection between the point 35 and the device 37 is an adjustable D.-C. bias source, comprising a battery 39 and a voltage divider 41. The control device 37 may be an amplifier, a servomotor, or any device which is to be controlled in accordance with the record associated with the reproducer 1.

The operation of the above described system is as follows:

The taps 17 and 29 are adjusted on the voltage dividers 15 and 27 respectively to provide equal frequency discrimination sensitivities in the control and pilot channels, i. e., equal percentage frequency changes produce equal output voltage changes at the taps 17 and 29. For example, if a 1% increase in the frequency of the control tone, say from 1500 to 1515 cycles, causes a decrease of 2 volts in the rectified voltage applied to divider 15, and a 1% increase in the frequency of the pilot tone, or from 500 to 50 cycles produces an increase of 1.8 volts in the voltage impressed across divider 27, the sliding contacts 17 and 29 would be adjusted to equalize these two effects at junction 35 in which case a 1% increase in reproducing speed of the record would have no effect on the rectified voltage applied to control circuit 37, the one being neutralized by the other.

This adjustment may be accomplished in several ways; for example, a calibration record carrying 500 and 1400 cycle tones, synchronously frequency modulated at one cycle per second over a band width of, say, two percent, is placed in the reproducer 1. The adjustment for correct neutralization of the effect of a speed change may also readily be made using any good recording of pilot tone and a constant frequency tone within the control tone operating range, the speed of the reproducing machine being caused to execute a cyclic change, as by unbalancing a flywheel. A voltmeter is connected from the junction point 35 to ground. One or both of the taps 17 and 29 may be adjusted so that the voltmeter reading remains constant. It will be found that for substantially every position of the tap 17, there is a correct adjustment for the tap 29, and vice versa. Which pair of positions is selected will affect the overall sensitivity of the system, like a gain control in the circuit of the reproducer 1.

After said adjustment is properly made, a record bearing a consant frequency pilot tone and a variable frequency control tone is placed in the reproducer 1. The composite output voltage is divided into its pilot tone and control tone components by the filters 7 and 19. These components are amplified by the amplifiers 21 and 9, respectively. Any variations in amplitude are removed by limiting action in the amplifiers, as explained more fully herein below. The output of the amplifier 9 comprises a constant amplitude voltage, varying in frequency within the range of 1000–2000 cycles per second, in accordance with the record. Superimposed upon said frequency variation is a further frequency variation caused by substantially unavoidable changes in the speed of operation of the reproducer 1. The discriminator 11, being unable to distinguish between modulation on the record and modulation caused by variation in record speed, provides an output corresponding to the sum of these two modulations. This output is rectified by the rectifier 13, providing a D.-C. output having instantaneous magnitude proportional to the amplitude of the discriminator output.

The pilot channel 5 operates in the same manner as the control channel 3, with the exceptions that the input to the discriminator 23 is nominally of constant frequency, and therefore is modulated only by variations in record speed, and the frequency characteristic of the pilot discriminator 23 slopes oppositely to that of the discriminator 11. The output of the pilot channel rectifier 25 thus varies in magnitude in accordance with the record speed variations, but in the opposite sense from that of the control channel.

The two outputs are combined at the junction point 35. The resistors 31 and 33 are preferably each made of much higher resistance than the voltage dividers or potentiometers 15, 27, and also of high resistance compared with the input circuit resistance of the device 37 for these conditions give a wider range of voltage control and more uniform relation between slider position and voltage. The voltage at said input circuit is then substantially proportional to the sum of the voltages at the taps 17 and 29. Variations in record speed produce little or no effect on the utilization device 37, since such variations cause equal but opposite changes in the magnitudes of the outputs of the control and pilot channels.

The control sensitivity of the system, in volts per octave, may be regulated by simultaneous or coordinated adjustment of the voltage dividers 15 and 27, or better by means of a voltage divider (not shown) in the output circuit of the reproducer 1 or in the input circuit of the control circuit 37. The position of the range of operation, or zero setting, may be adjusted by means of the voltage divider 41 to control the D.-C. bias upon which the control voltage is superimposed. It is obvious that with the potentiometers 15 and 27 adjusted for correct neutralization of speed changes, the relative levels of the pilot and control tones must remain constant. The limiters can take care of some variations, and with the balancing adjustments at a given setting the limiters should also remain adjusted to control the tone levels at fixed relative values prior to their application to their respective discriminators. In order not to depend too much on the limiters the recordings should all be made with a standardized ratio of control tone to pilot tone amplitude.

Referring to Figure 4, the circuit of the discriminator 11 of the control channel includes a parallel-T network 43 and a conventional low-pass network 45 connected in cascade. The parallel T 43 comprises a low-pass section formed by series resistors 47 and 49 and a shunt capacitor 51, and a high-pass section in parallel therewith, comprising series capacitors 53 and 55, and a shunt resistor 57. The values of these elements are interrelated, in accordance with well known

practice, to cause cancellation of the outputs of the two parallel channels, and hence infinite attenuation, at a frequency of approximately 2200 cycles per second. It is characteristic of this type of circuit to provide transmission varying substantially linearly with respect to the logarithm of the frequency over a substantial range of frequencies below the null, or cancellation frequency, providing the input and load resistances properly selected. These conditions are met by determination of the values of resistors 59 and 61 respectively. The characteristic of the parallel T circuit has two limbs, *a* and *b* (Fig. 2). The transmission represented by limb *b* is undesirable, since harmonics generated by the limiting amplifier 9, if allowed to pass to the rectifier 13, would cause improper operation. Accordingly, the low pass section 45, designed to cut off slightly above 2200 cycles, is provided. The transmission characteristic of this section is illustrated by the curve *c* of Figure 2. The resultant transmission of sections 43 and 45 together is substantially the same as the line *a* of Figure 2. The design of the control tone discriminator to give a linear characteristic when plotted as voltage output vs. log. frequency, results in a uniform sensitivity to speed change such that the drop in voltage for a given percentage speed increase is constant, whether the tone being recorded at the moment is 1000 cycles, 1500 cycles, 2000 cycles or any intermediate frequency.

The design of the discriminator 23 of the pilot channel may be much simpler than that of the control discriminator 11, since it is required to operate only over a relatively narrow band width.

Refer to Figure 5. A parallel resonant circuit comprising an inductor 63 and a capacitor 65 is connected as a shunt element in a T network, wit hseries resistors 67 and 69. The LC product of the elements 63 and 65 is determined so that resonance occurs at some frequency above the pilot tone frequency, say at 600 cycles per second. The Q of this resonant circuit, and the values of the resistors 67 and 69 will affect the slope of the transmission characteristic. Since the overall response of the pilot channel is readily adjustable by means of the voltage divider 27, it is evident that there is considerable flexibility in the design of this discriminator circuit. It is in general desirable to tune it to such a frequency that the mean pilot tone frequency is on the straightest part, which is also approximately the steepest part of the characteristic, as shown in Figure 3. In view of the fact that the steepness of the characteristic of the pilot tone discriminator at this point can be made much greater than that of the control tone discriminator, the voltage of the pilot tone can be correspondingly less, and still neutralize the effect of speed fluctuations. Whence it would be permissible, and in general desirable, to record the pilot tone at lower level than the control tone, but to subject both tones to the action of limiters, each appropriately adjusted, apply them to their respective discriminators and rectifiers, and then combine the rectified voltages, as already described, in appropriate proportions to neutralize the effects of speed changes.

Referring to Figure 6, the limiting action is provided by two devices, each well known to the art, the one an automatic volume control which alters the gain of an amplifier stage as required to reduce variations, and the second a limiter of the overload type, which virtually short circuits all voltages in excess of a predetermined magnitude. These devices supplement each other, to give more nearly complete amplitude control. The amplitude control circuits 9 and 21 each include electron-discharge tubes 71 and 73, coupled in cascade in conventional manner by a capacitor 75 and resistors 77 and 79. The anode circuit of the tube 73 includes transformers 81 and 83. The transformer 81 is connected to a full wave rectifier comprising diodes 85 and 87 and a resistance-capacitance filter 89. The negative output terminal of this rectifier is connected to the grid return of the tube 71, and the positive rectifier terminal is connected to a source of fixed grid bias C—.

The transformer 83 is provided with two closely coupled secondary windings 91 and 93. The winding 91 comprises the output circuit of the limiter-amplifier. The winding 93 is connected to a full wave biassed rectifier type limiter comprising diodes 95 and 97 and a battery 99.

The automatic volume control portion of Figure 6 operates as follows:

The tubes 71 and 73 constitute and function as a conventional two stage amplifier, tube 71 being of the variagle gain type. A portion of the output voltage of the tube 73 is impressed through the transformer 81 on the rectifier 85, 87, providing a unidirectional output voltage substantially proportional to the output of the tube 73. The rectifier output is smoothed by the filter 89 and applied in series with the fixed bias C— to the grid return circuit of the tube 71. The polarity of this voltage is such as to aid the bias, so that as the output of the tube 73 increases, the negative bias on the grid of the tube 71 increases, decreasing the gain afforded by the tube 71 and thereby tending to maintain the output of the tube 73 at a more or less constant level in spite of variations in the amplitude of the input to the tube 71.

The output of the tube 73 is coupled to the output circuit of the amplifier through the transformer 83; however, the limiter diodes 95 and 97 are effectively shunted across this output circuit by virture of the close coupling between the secondaries 91 and 93. So long as the output voltage across the diodes 95 and 97 does not exceed the voltage of the battery 99, the diodes do not conduct. When the negative peaks tend to exceed the battery voltage, one diode, for example the diode 95, will conduct, effectively short circuiting the output and bringing the voltage down to a peak value substantially equal to the battery voltage. Similarly, when the positive output peaks tend to exceed the battery voltage, limiting is provided by the diode 97. Partial limiting is thus provided by the variable bias circuit including the rectifier 85, 87, and the limiting is completed by the diodes 95 and 97. As a simplification it would be possible to derive a bias-changing voltage from the currents flowing through the peak limiting diodes 95, 97. This arrangement is not illustrated, being only a variation of the general system described, wherein a separate rectifier 85, 87 furnishes the voltage for changing the grid bias of tube 71.

The invention has been described as a frequency responsive control system for use with a recorded variable frequency control tone. Undesired frequency variations, superimposed on the intentional variations, by changes in speed of the record element during recording and/or repro-

ducing, are neutralized by recording a constant frequency pilot tone simultaneously with the control tone. The reproduced tones are separated by filters, separately amplified and limited, and applied to discriminators having oppositely sloping frequency characteristics. The discriminator outputs are rectified and balanced against each other, providing a resultant D. C. output whose amplitude is a function substantially only of the ratio of frequencies of the reproduced control and pilot tones, rather than the absolute frequency of the reproduced pilot tone, over the range of speed variation which will occur in recording and reproducing. Since for small changes in speed, this ratio is independent of the actual frequencies involved, proportional variations in frequency caused by speed variations have no effect on the resultant ouput.

It is obvious that in order to secure the benefits of this invention with respect to imperfections in the speed constancy of the recording machine, it is necessary that the pilot tone and the control tone be recorded simultaneously, as will be the case if the recordist uses an oscillator of fixed frequency, say 500 cycles, and mixes its output with that of a variable frequency oscillator, say 1000 to 2000 cycles, the combined voltage being recorded through a single recording device. The desired result would not be obtained if the pilot tone and control tone were recorded side by side in two separate operations, or by two successive exposures, wherein the record is run twice through a recording machine.

The system has been described as calling for discriminator circuits which have operating characteristics with opposite slopes. The invention is not limited to this characteristic, for similar results might be obtained with discriminator circuits for the control tone and pilot tone having the same direction of slope but with the final rectified voltages so combined that the output of the controlling device is affected by the difference between the two rectified voltages instead of by their sum. It should be recognized that in a system arranged as just described, the slopes may still be described as "opposite," with reference to the final combined voltage, for an increase in the frequency of one tone will cause this final voltage to fall, while an increase in the frequency of the other tone will cause the combined voltage to rise. If the system is arranged to work on the difference between the two rectified voltages, provision must be made to prevent this from ever reaching zero, by designing and adjusting the system so that the normally smaller of the two voltages, is always smaller.

In this invention as hitherto described, a pilot tone of nominally constant frequency is employed. The principles of the invention, however, may be employed and the benefits obtained by employing two variable tones, the pitches of both of which are varied in the original recording in opposite directions and both of which contribute to the desired control. Both tones would be applied to discriminator networks and the rectified outputs combined to provide a voltage affected by the ratio of the recorded frequencies but wherein the effects of a simultaneous rise or fall in both frequencies by the same percentage will be neutralized.

Throughout this specification and in the claims the word "tone" is used to designate an alternating current since such control systems generally employ alternating currents whose frequencies are in the audible range, but the "tone" may never exist as audible sound. By "reproducer" device is meant a device which in cooperation with a moving record, produces an alternating electric current.

I claim as my invention:

1. In a record responsive control system including record reproducing means providing an output voltage which varies in frequency nominally in accordance with a control tone carried on a record cooperating with said reproducing means, and varies further in frequency owing to variations in the speed of operation of said reproducing means, means for producing a second voltage of nominally constant frequency which varies in frequency only in proportion to said variation in speed, two frequency discriminator circuits having oppositely sloping transmission characteristics, means for applying one of said voltages to one of said discriminator circuits and the other of said voltages to the other of said discriminator circuits, two rectifiers connected respectively to said discriminator circuits, and means for adding the outputs of said rectifiers.

2. The method of producing a D. C. voltage which varies in magnitude in proportion to the ratio of the frequencies of two components of a complex A. C. wave, said components lying within different frequency bands, comprising the steps of separating said components according to the frequency bands within which they lie, amplifying and limiting said components, varying the amplitude of one of said limited components as a linear function of the logarithm of the frequency of said component, varying the amplitude of the other of said limited components as a predetermined function of frequency, separately rectifying said amplitude-varied components, and combining the products of said separate rectifications.

3. The method of producing a D. C. voltage which varies in magnitude substantially in proportion to the ratio of the frequencies of two A. C. waves recorded on a single record carrier, comprising the steps of separating said waves, varying the amplitude of the first of said waves as a function of the frequency of said wave, varying the amplitude of the second of said components as a second function of frequency, rectifying said first and second components, and combining said first and second rectified components.

4. A limiting amplifier including electron discharge means having an input circuit and an output circuit, and connected to provide amplification of voltage applied to said input circuit, rectifier means coupled to said output circuit to rectify a portion of the output voltage of said electron discharge means, filter means connected to said rectifier means, means for applying the output of said filter means to said input circuit as bias whereby the amplification afforded by said electron discharge means is controlled inversely in accordance with said output voltage, second rectifier means coupled to said output circuit, and connected to a substantially constant potential D. C. source, whereby said output circuit is effectively short circuited with respect to output voltages exceeding a predetermined amplitude.

5. A record responsive control system including record reproducer means, filters providing mutually exclusive transmission characteristics connected to said reproducer means, limiting ampli-

fiers connected respectively to said filters, discriminators connected respectively to said limiting amplifiers, said discriminators providing oppositely sloping characteristics of transmission vs. frequency, rectifiers connected respectively to said discriminators, adjustable voltage dividers connected to said rectifiers, and a voltage combining circuit connected to said voltage dividers, whereby similar coincidental variations in the frequencies of the outputs of said filters caused by variations in the speed of operation of said reproducer means are neutralized.

6. In a control system wherein a recorded tone of variable frequency is employed to produce a varying rectified voltage, a record carrying two tones, means responsive to a change in the frequency of one of said tones for producing a rectified voltage, means responsive to a change in the frequency of the second of said tones for producing a second rectified voltage, and means for combining said voltages in such sense and in such relative magnitudes that when the frequencies both increase or both decrease by equal percentages, the net change in the combined voltage is substantially cancelled.

7. In a control system, a record carrying two tones, means for simultaneously reproducing both tones, a frequency responsive discriminator circuit to which the first of said tones is applied, a frequency responsive discriminator circuit to which the second of said tones is applied, and means for combining voltages derived from said two tones.

8. In a record responsive control system including record reproducing means providing an output voltage which varies in frequency nominally in accordance with a control tone carried on a record cooperating with said reproducing means, and varies further in frequency owing to variations in the speed of operation of said reproducing means, means for producing a second voltage of nominally constant frequency which varies in frequency only in proportion to said variations in speed, two frequency discriminator circuits, means for applying one of said voltages to one of said discriminator circuits and the other of said voltages to the other of said discriminator circuits, two rectifiers connected respectively to said discriminator circuits, and means for adding the outputs of said rectifiers.

9. The method of producing a D. C. voltage which varies in magnitude in proportion to the ratio of the frequencies of two A. C. voltages, comprised of varying frequencies and lying within different frequency bands, comprising the steps of separately amplifying and limiting said voltages, varying the amplitude of one of said limited voltages as a linear function of the logarithm of the frequency of said voltage, varying the amplitude of the other of said limited voltages as a predetermined function of frequency, separately rectifying said amplitude varying voltages, and combining the products of said separate rectification.

10. The method of producing D. C. voltage which varies in magnitude in proportion to the ratio of the frequencies of two components of a complex A. C. wave, said components lying within different frequency bands, comprising the steps of separating said components according to the frequency bands within which they lie, amplifying and limiting said components, varying the amplitude of one of said limited components as a linear function of the logarithm of the frequency of said component, said linear function being predetermined so that said amplitude is decreased with increase in frequency, varying the amplitude of the other of said limited components as a predetermined function of frequency so that said amplitude of said other component is increased with increase in frequency, separately rectifying said amplitude-varied components, and combining the products of said separate rectifications.

11. The method of producing a D. C. voltage which varies in magnitude substantially in proportion to the ratio of the frequencies of two A. C. waves recorded on a single record carrier, comprising the steps of separating said waves, varying the amplitude of the first of said waves as a function of the frequency of said wave, said function being predetermined so that said amplitude is decreased with increase in frequency, varying the amplitude of the second of said components as a second function of frequency, said second function being predetermined so that said amplitude of said second component is increased with increase in frequency, rectifying said first and second components, and combining said first and second rectified components.

12. A limiting amplifier including electron discharge means having an input circuit and an output circuit, and connected to provide amplification of voltage applied to said input circuit, unilaterally conductive means coupled to said output circuit through a D. C. source whereby output voltages in excess of a predetermined magnitude are short circuited, and means for varying said amplification in response to rectified output of said electron discharge means.

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