

Sept. 1, 1964

J. P. WHITE

3,147,334

DEVICE FOR ALTERING TONE QUALITY IN ELECTRONIC
MUSICAL INSTRUMENT OR THE LIKE

Original Filed Sept. 28, 1955

5 Sheets-Sheet 1

FIG. 1

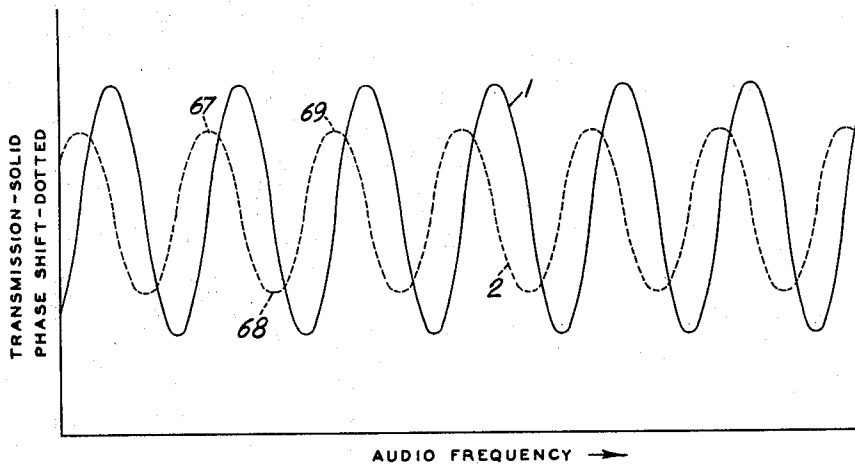


FIG. 2

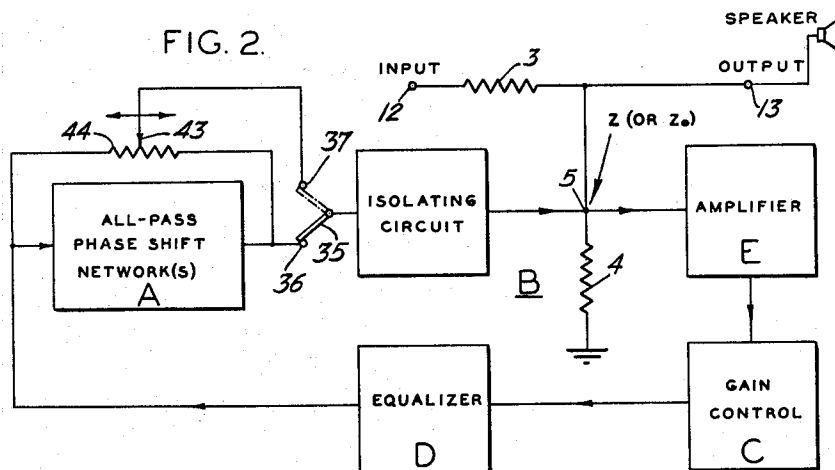
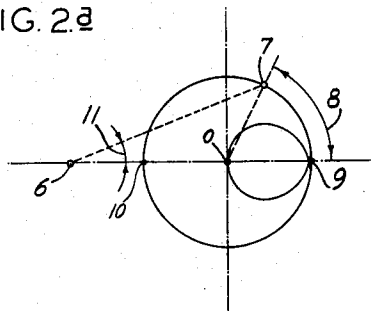


FIG. 2a



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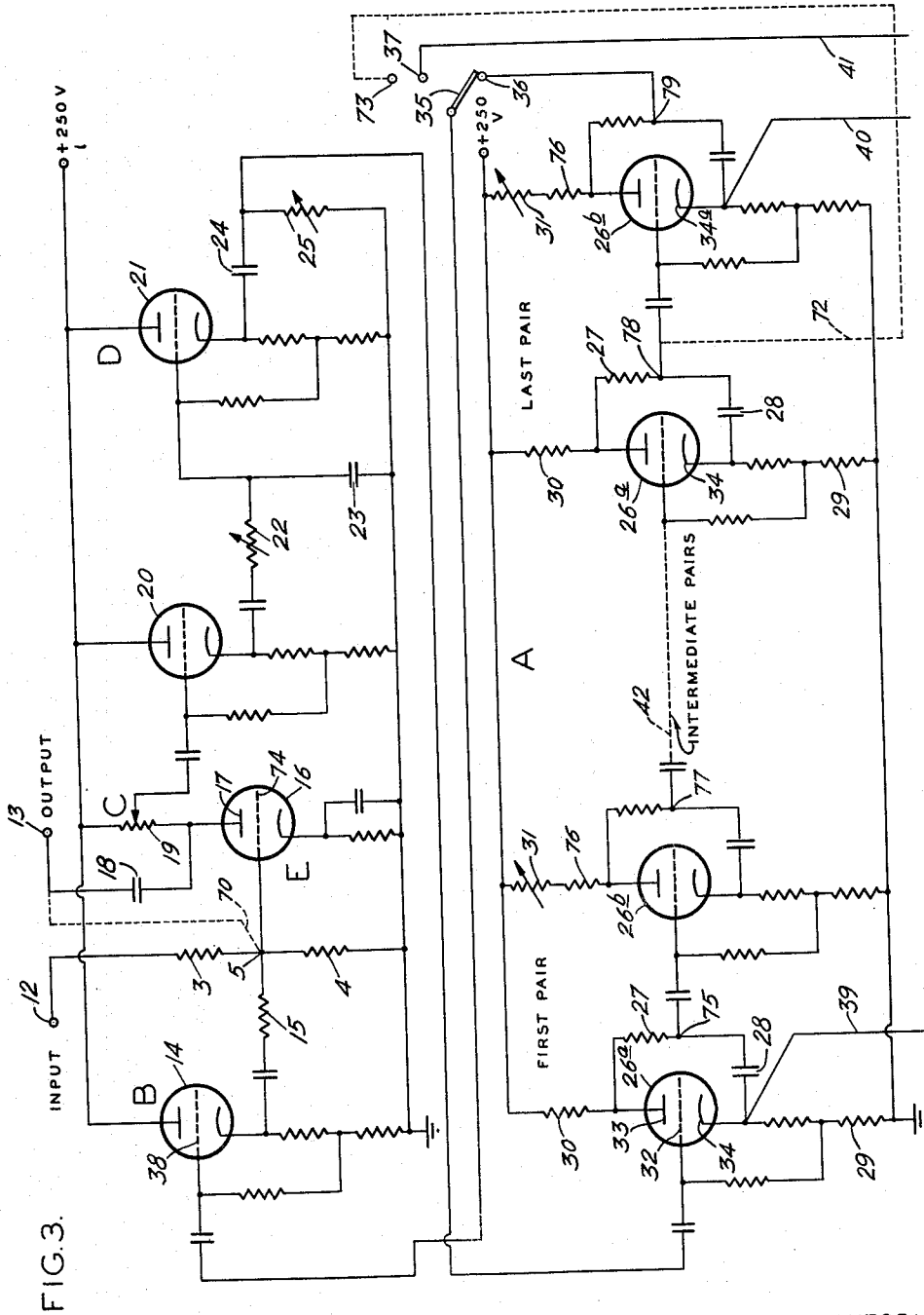
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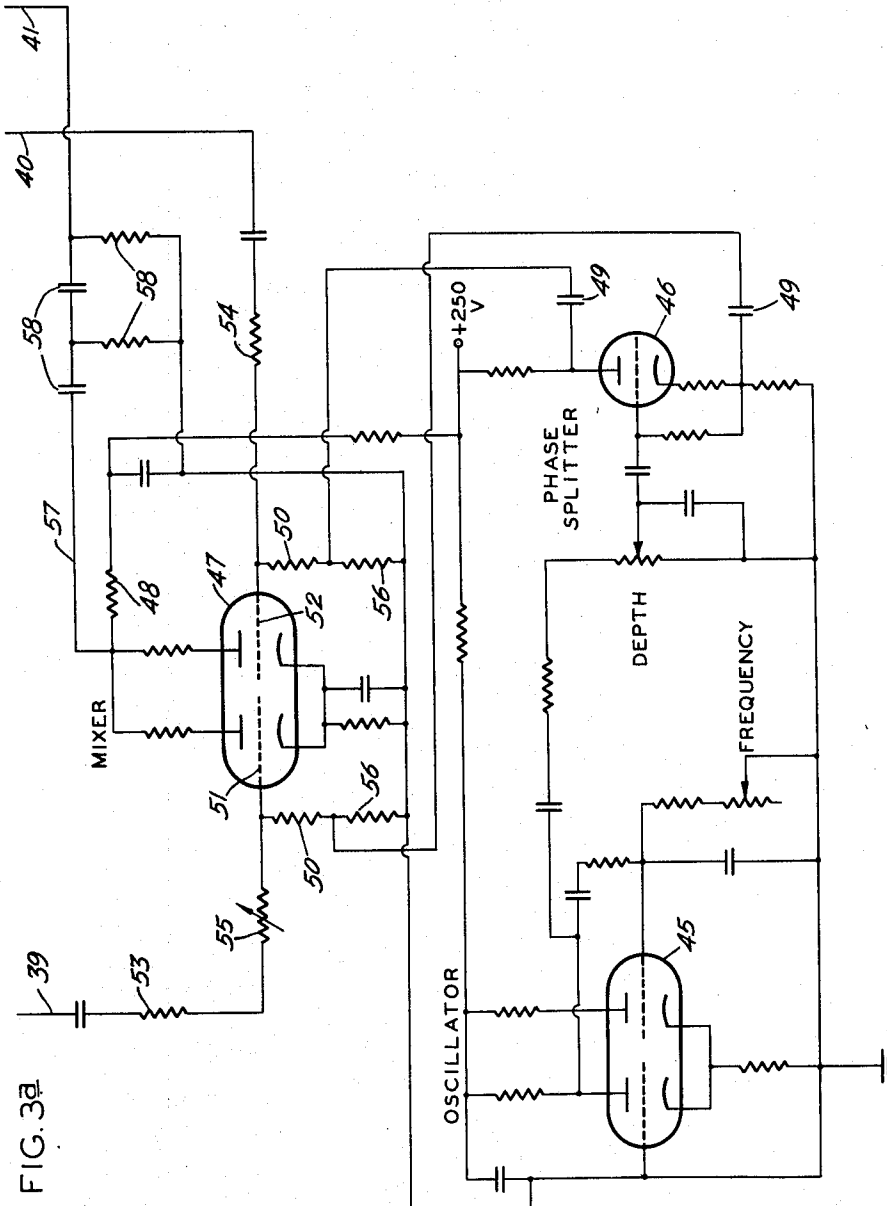


FIG. 3a

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FIG. 4.

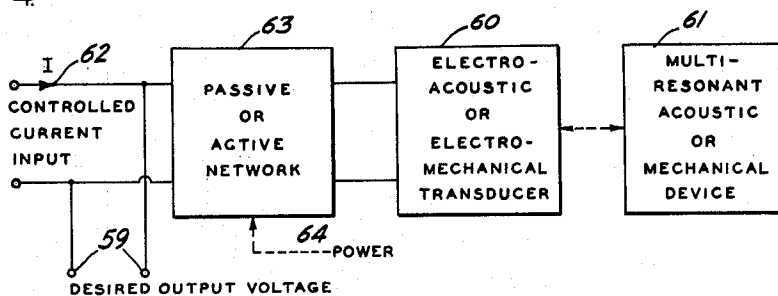


FIG. 4a

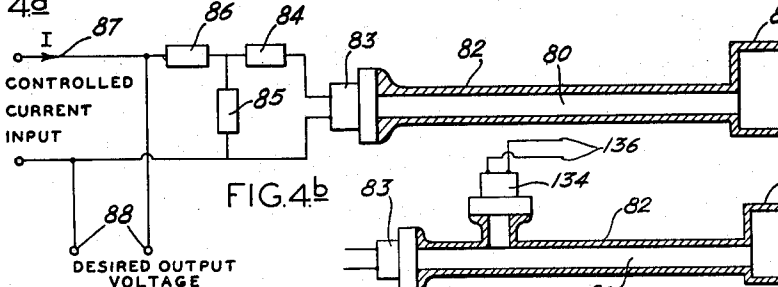


FIG. 4b

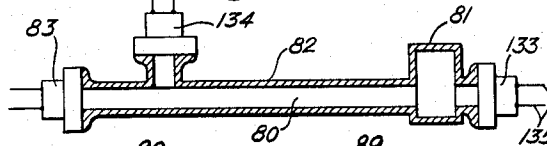


FIG. 5.

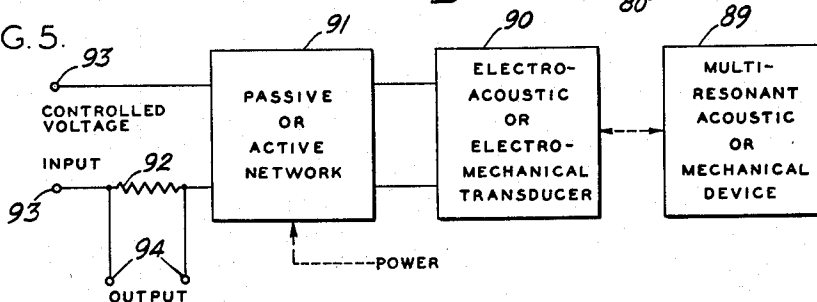
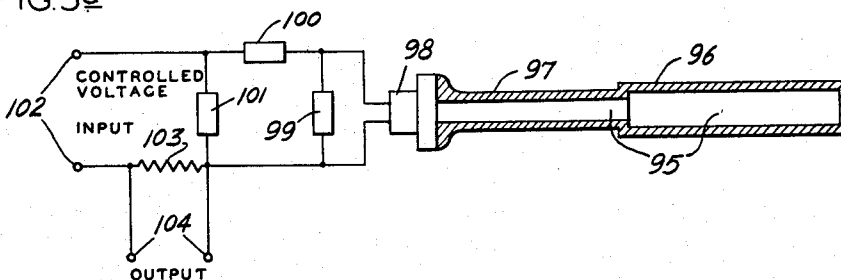


FIG. 5a



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FIG. 6

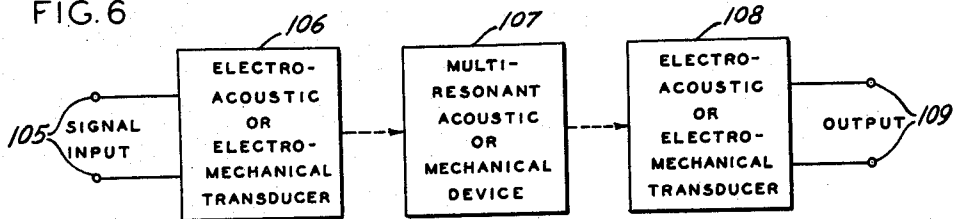


FIG. 6a

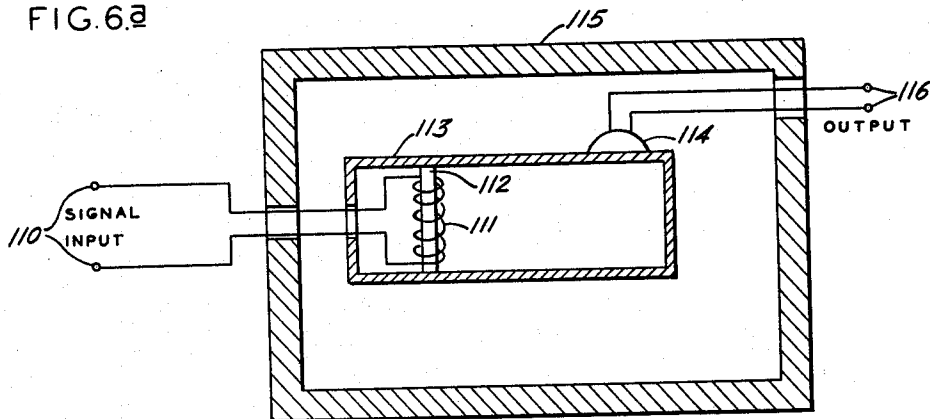


FIG. 7

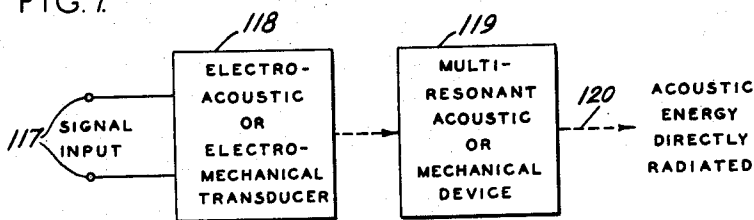
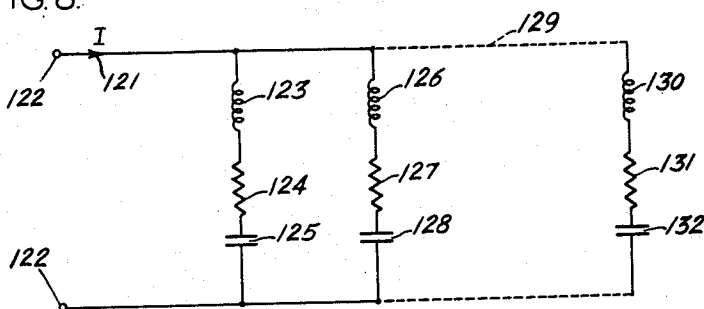


FIG. 8



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DEVICE FOR ALTERING TONE QUALITY IN ELECTRONIC MUSICAL INSTRUMENT OR THE LIKE

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Original application Sept. 28, 1955, Ser. No. 537,134, now Patent No. 3,031,909, dated May 1, 1962. Divided and this application Nov. 8, 1961, Ser. No. 150,916 21 Claims. (Cl. 84-1.25)

The present invention relates to electrical and electronic musical instruments, and more particularly to the improvement of the tone quality of such instruments.

It is frequently observed that in spite of the best efforts of the makers of electronic organs and associated musical instruments, there yet remains a certain lack in the tonal quality of these instruments which makes them inferior to the actual instruments of the orchestra. The present invention provides a novel method of overcoming this tonal deficiency of electronic and electrical musical instruments.

It is generally recognized that sound produced by several instruments playing in unison, known as chorus effect, is more pleasing than the sound of a single instrument. Likewise, the sound of a single instrument is more pleasing than the sound of an electronically generated tone. These effects are due to a preference by the ear for sounds producing a throbbing or "beating" sensation. The inequalities of pitch existing among several instruments playing in unison produce a strong beating sensation; the beating among the harmonics of a single instrument (to be described) produces a modest beating effect; and an electronically generated tone produces an almost negligible beating effect.

A single orchestral instrument produces a beating effect for two reasons: (1) The pitch is not absolutely stable, and (2) The phase shift between the primary source of vibration and the air is not constant, but is a function of frequency; that is, the phase shift through the instrument (for example, from mouthpiece to the air in the case of a trumpet) would be an undulating (up and down) curve when plotted against frequency.

These two facts cooperate to produce a beating effect as follows. All of the harmonics of the primary source of vibration are varying in frequency at once by reason of the first factor. As each harmonic so varies, its phase will change an additional amount dependent on the shape of the phase curve (second factor) in the vicinity of the harmonic frequency in question. Since this curve will have various positive and negative slopes at the different harmonic frequencies, the additional rate of change of phase of the various harmonics will in general be unequal so that (as is well known in the theory of frequency modulation) the frequencies of the harmonics will be shifted instantaneously with respect to the fundamental frequency in a somewhat random manner. Hence, the instantaneous frequencies of the audible harmonics will not be in exact (integral) harmonic relation, and hence will beat with each other and produce a sound having a much more pleasing musical effect than the sound produced by an instrument with all harmonics in exact harmonic relationship at all times, such as an electronically generated tone.

The principles as outlined above for non-electric musical instruments are applied in this invention to electric and electronic musical instruments, by providing an undulating phase shift vs. frequency characteristic (similar to that described) in the transmission path between the source of electrical vibrations and the ear of the listener.

It is a fundamental object of the present invention to provide a device for use with electrical and electronic

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musical instruments to improve the tone quality, and produce new and interesting tone qualities.

It is another object of the invention to provide a device for use with electrical and electronic musical instruments to alter the tonal character in a manner closely analogous to the manner in which the initial mechanical vibrations of most non-electronic musical instruments are altered before the principal acoustic radiation takes place.

Other and further objects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings; in which

FIG. 1 illustrates the type of characteristics desirable in a device to alter and/or improve the tonal quality of electrical and/or electronic musical instruments. FIG. 1 also illustrates the characteristics of most non-electric musical instruments with regard to the transmission and phase shift from the primary vibration generator to the surrounding air.

FIG. 2 is essentially a block diagram of an electronic filter embodying the principles of the present invention, and showing, symbolically, the action of the vibrator addition.

FIG. 2a is a "Nyquist" diagram of the electronic filter, and shows the locus of certain vectors useful in understanding the operation of the electronic filter.

FIG. 3 is a schematic wiring diagram of the electronic filter shown in block diagram in FIG. 2.

FIG. 3a is a schematic wiring diagram of a vibrator addition to the circuit of FIG. 3.

FIG. 4 is a block diagram of an electroacoustic or electromechanical embodiment of the principles of the present invention.

FIG. 4a is a combination schematic diagram and mechanical illustration of a representative physical embodiment of the block diagram of FIG. 4.

FIG. 4b shows a modification of the embodiment of FIG. 4a for the purpose of producing a vibrato.

FIG. 5 is a block diagram of an electroacoustic or electromechanical embodiment of the present invention in which means are provided to minimize the effects of reverberation due to the multiresonant acoustic or mechanical device.

FIG. 5a is a combination schematic diagram and mechanical illustration of a representative physical embodiment of the block diagram of FIG. 5.

FIG. 6 is a block diagram of another type of electroacoustic or electromechanical device embodying the principles of the present invention.

FIG. 6a is a combination schematic diagram and mechanical illustration of a representative physical embodiment of the block diagram of FIG. 6.

FIG. 7 is a block diagram of another embodiment of the present invention in which acoustic energy is directly radiated without the use of a conventional loudspeaker.

FIG. 8 is a schematic diagram of a representative "lumped constant" network embodying the principles of the present invention.

In FIG. 1 appears a diagram of the transmission curve 1 and phase shift curve 2 typical of the body of string-type orchestral instruments and of the air column of wind-type orchestral instruments and also of the various tone quality improvement devices herein disclosed. It has been shown that the phase shift curve 2 is responsible for the production of a more pleasing tone quality when a device producing an effect similar to that depicted by FIG. 1 is used in the transmission path between the initial source of signal and the listener, provided that there is some frequency instability in the signal applied to the device in question. The use of such devices in conjunction with an electrical or electronic musical instrument is set forth by the present disclosure.

The difference between the usual tonal control and "coloring" circuits found in all electronic or electric musical instruments and the tone coloring method discussed here may be summarized as follows. The tone color (timbre) circuits generally used in electronic organs have as their purpose the production of an output wave having the desired harmonic structure characteristic of each note of the scale for the stop in use. Such tone color circuits as used in electric or electronic organs will also have a phase shift vs. frequency characteristic, but the phase shift produced is very much less than that of the method proposed by the present invention. That is, the total phase change in the audio band is much greater for the proposed method than for any existing electronic musical instrument. By "total phase change" is meant the sum of the magnitudes of all phase changes in the audio range without regard to sign; that is, to obtain the total phase change in FIG. 1, we would add the magnitude of the phase change from maximum 67 to minimum 68 to the magnitude of the phase change from minimum 68 to maximum 69, and so on throughout the entire audio frequency range. The distinction between the present state of the art and the present invention is this: The tone color circuits of electronic organs and similar instruments are used to produce relatively gradual changes in transmission with respect to frequency for the purpose of producing an output wave of the desired harmonic structure, with only incidental changes in phase shift with frequency; on the other hand, the tone coloring system herein disclosed makes use of rapid changes in phase shift with respect to frequency for the purpose of ultimately producing beats in the auditory sensation (as described), with only incidental changes in transmission with frequency. In the case of the prior art, the incidental changes in phase shift with frequency are insignificant for the purpose of ultimately producing an auditory beating sensation, whereas with this invention such changes in phase shift with frequency are very significant. The phase and amplitude undulations shown in FIG. 1 are representative only of the type of characteristic desired, and not of the exact number of undulations proposed. In general, the more peaks there are in these curves, the better the effect. Even if it were desirable to limit the differences between adjacent maxima and minima of the transmission curve 1 of FIG. 1 to say 3 decibels, it would still be possible to obtain any desired amount of total phase change throughout the range by having a sufficiently large number of these relatively small transmission peaks.

An electronic device, which may be designated an "electronic filter," capable of producing the rapidly varying phase shift with frequency as desired, is shown in block diagram in FIG. 2, and the actual circuit in FIG. 3. The block diagram, FIG. 2, shows a voltage divider consisting of resistors 3 and 4. If the rest of the circuit were disconnected, this voltage divider would attenuate the input voltage at terminal 12 to produce the output voltage at terminal 13 by the same amount at all frequencies within the range of interest. When the rest of the circuit is connected as shown, the impedance from point 5 to ground is no longer always equal to the resistance 4 but may be either larger or smaller than resistor 4, depending on the circuit adjustments and the frequency. Hence, the voltage divider consisting of resistor 3 and the effective impedance between point 5 and ground will change its output as the frequency is varied, so that if the input voltage were constant at all frequencies, the output voltage would be found to vary in amplitude and phase as the frequency was varied throughout the frequency range of interest.

The block diagram of FIG. 2 consists of five parts (in addition to resistor 3). A is an "all-pass" phase shift network(s); B is an isolating circuit, and includes the resistor 4; C is a gain control; D is an equalizer; and E is an amplifier. Although all of these five parts are shown separately, it is nevertheless true that not all are

absolutely necessary for the operation of a circuit of this type. Parts B, C, and D could conceivably be omitted (except that the resistor 4 would still have to be physically or effectively incorporated into the remainder of the circuit), and part E could even be designed to be an integral part of part A. In addition, the relative order of these five parts need not be as shown in FIGS. 2 and 3, but may be in any convenient sequence as we proceed around the closed loop from point 5 until we return to point 5. Any such changes would not alter the basic operation of the circuit, even though they might make it slightly less flexible. For convenience and clarity, let us consider the operation in terms of the block diagram of FIG. 2. The five parts of this circuit mentioned constitute a feedback circuit in that the parts are connected together so as to form a complete closed loop, as shown by the connecting lines and arrows. It is well known to those skilled in the art that the impedance to ground looking into such a circuit at a convenient point such as point 5, is given by the following formula:

$$Z = \frac{Z_o}{1 - ABCDE}$$

In this formula Z_o represents the effective impedance to ground at point 5 with the feedback loop broken at some remote point; the other symbols represent the transfer function as noted. For example, A in the formula represents the mathematical expression giving the vector output voltage of the circuit part A, divided by the vector input voltage of circuit part A as a function of frequency, with the circuit part A actually connected to the rest of the circuit as shown. An examination of this formula for Z shows that when the quantity $-ABCDE$ in the denominator approaches minus one, the value of Z will become very large, so that the magnitude of the circuit output voltage at terminal 13 may approach that of the circuit input voltage at terminal 12. At other frequencies where the quantity $-ABCDE$ does not approach minus one, the value of Z will be smaller, so that the circuit output voltage may be much smaller than the circuit input voltage. Hence, if the quantity $-ABCDE$ can be made to approach and recede from the value minus one any desired number of times as the frequency is varied over the range of interest, the desired number of peaks will be introduced into the response vs. frequency curve of the electrical system to which this circuit is connected, and a large total phase change will be produced if sufficient peaks are introduced into the system.

A diagram showing one possible way in which the quantity $-ABCDE$ might vary with frequency is shown in FIG. 2a. This diagram is a "Nyquist" type of diagram, in which the magnitude and phase angle of the quantity $-ABCDE$ are plotted for all frequencies. The curved line is the locus of the tip of the vector extending from 0 to 7. The distance on the diagram from 0 to 6 represents unit distance, so that at some particular frequency the quantity $-ABCDE$ might be plotted to the same scale as point 7, where the distance from 0 to 7 represents the magnitude of this quantity, and the angle 8 represents its phase angle. As the frequency varies, the point 7 will move. The entire locus of point 7 may be described as follows: starting at zero frequency at the point 0, we follow the arrow clockwise to near the point 9, and continue clockwise on the approximately circular path through 10 and 9, going around the center point 0 as many complete revolutions of 360 degrees as we desire peaks in the response vs. frequency curve of the electrical system. It is obvious from the foregoing that each time the point 7 reaches position 10, a peak will occur, since the point 6 represents the position of minus one on the diagram. Similarly, each time the point 7 reaches position 9 a minimum of transmission through the device will occur. The ratio of this maximum to minimum output voltage will be the same as the ratio of the length of the straight line connecting points 6 and 9 to that connecting

points 6 and 10. After the last revolution, the point 7 will pass near the point 9 and follow the clockwise path to point 0 which will also correspond to infinite frequency. If the frequencies corresponding to the passage of point 7 through point 10 are chosen to be within the frequency band of interest, we have succeeded in introducing peaks as desired. It may be seen that the magnitude of the peaks may be controlled by C, the loop gain control, so that the point 10 may be made to fall anywhere on the line segment from 0 to 6. The peaks and the corresponding phase shift will be large when 10 falls near 6, and small when 10 is near 0.

The portions of the Nyquist diagram, FIG. 2a, from 0 to near 9 are due to residual circuit reactances, or they may be controlled by the equalizer, part D. In the description just given of FIG. 2a, the five parts of the circuit as shown in FIG. 2 were treated as having the magnitudes of their transfer functions substantially constant over the frequency range of interest, when the point 7 is travelling around the large circular path. The all-pass phase shift network(s), A, are designed, however, to have a constantly changing phase angle with frequency throughout the frequency band of interest. It is apparent that the Nyquist diagram of FIG. 2a could be varied considerably by adjustment of the Equalizer, D, to have the magnitude of the transfer function of part D vary with frequency. This would cause the contour traced by point 7 to differ from that shown, so that the point 7 on its successive revolutions around point 0, would approach the point 6 more or less closely; that is, there would be a multiplicity of points 10 where the locus intersects the horizontal axis between 0 and 6. Since the distance from point 6 to point 10 is proportional to the denominator of the expression for Z, it is seen that the impedance Z determining the magnitude of the peaks will vary from one revolution of the point 7 to the next, so that the peaks will have different and controllable heights. That is, each revolution of the point 7 will produce in this case a different minimum value of the denominator of Z, and so a variable maximum of Z, and hence a changing peak output as we go through the different peaks.

The gain control, C, of FIG. 2, will expand the entire diagram of FIG. 2a proportionally about the point 0, so that the point 10 can be made to approach the point 6 as closely as desired; conversely, the diagram can be made to contract as desired, until at minimum gain the entire diagram will coincide with point 0, and the output voltage of the circuit will be constant if the input voltage vs. frequency is constant, thereby eliminating all peaks and phase shift. Hence, if resistor 3 of FIG. 2 is large compared with the effective impedance at point 5, which is Z, the peaks may be varied from very large when the points 10 are very near point 6, to very small or vanishing peaks when the points 10 approach or coincide with the point 0. The phase shift curve will vary in a corresponding manner. To those skilled in the art, it will be obvious that the phase angle of the denominator of the expression for Z, is shown in FIG. 2a by the angle 11. Therefore, if we assume a zero phase angle for Z_0 , the phase angle of Z is merely the negative of the angle 11. The magnitude of the variations of the angle 11, formed by the straight line segments from point 0 to point 6 and from point 6 to point 7, will then be the same as the magnitude of the variations of the angle of the impedance Z, and the total phase change of the impedance Z will be equal to the total angular change of the angle 11. It should be noted that the total phase change of the output voltage at terminal 13 of FIG. 2, with respect to the input voltage at terminal 12, will be somewhat less than the total phase change of the impedance Z, due to the presence of resistor 3. The larger resistor 3 is made, the more nearly equal will these two total phase changes become; however, it is impractical to make resistor 3 too large, because this

would reduce the output voltage at terminal 13 to an undesirably small value. In FIG. 2a, it is readily seen that the maximum value of angle 11 will occur when the straight line segment from point 6 to point 7 is tangent to the circular path through point 10 in the second quadrant; and similarly, the minimum will occur when the point of tangency lies in the third quadrant. It is also obvious that the closer the points 10 are to point 6, the larger will be the variations in the angle 11, and the greater will be the total phase change in the output voltage. Thus, large variations in the total phase change may be produced by adjustment of the gain control, C, since this gain control will control the position of the points 10 between the limits of point 0 and point 6.

FIG. 3 shows an embodiment of the principles of FIGS. 2 and 2a. The letters A, B, C, D and E of FIG. 2 are repeated in FIG. 3, and are placed near the various circuits performing the specific functions shown in block diagram in FIG. 2. An audio signal voltage at terminal 12 causes a current to flow through resistor 3 to junction point 5, where a voltage is produced that is fed to grid 74 of vacuum tube 16. An amplified version of the same voltage appears at the plate 17 of tube 16, and is attenuated an adjustable amount by gain control 19 before being fed to the cathode follower tube 20. The output of tube 20 passes through an adjustable low-pass filter consisting of variable resistor 22 and capacitor 23, and is then fed to cathode follower tube 21. The output of tube 21 passes through an adjustable high-pass filter consisting of capacitor 24 and variable resistor 25, and is then fed to the grid 32 of the first phase shift tube 26a. A resistor 30 is the plate load resistor of tube 26a, and a resistor 29 which is nominally equal to resistor 30 is used as the principal part of the cathode load of tube 26a. Under these conditions, approximately equal voltages will appear at the plate 33 and at the cathode 34 of tube 26a; however, such voltages will differ by 180 degrees in phase. The circuitry mentioned above in connection with tube 26a is commonly known as a "split load phase inverter" in that equal but opposite voltages are produced at the plate and cathode of the tube in question. From plate 33 of tube 26a a resistor 27 and capacitor 28 are connected in series with the far end of the capacitor 28 connecting to cathode 34 of the same tube 26a.

It will now be apparent to those skilled in the art that the voltage (to ground) at junction point 75 of resistor 27 and capacitor 28 will have a magnitude approximately equal to the magnitude of the voltages at plate 33 and cathode 34 of tube 26a, and a phase angle which leads the voltage on grid 32 of tube 26a by an angle between zero and 180 degrees, depending on the frequency. At very low frequencies the voltage at point 75 will lead the voltage on grid 32 by almost 180 degrees, and at very high frequencies the voltage at point 75 will approach the voltage at grid 32 in phase angle. This voltage at point 75 is fed on to the second phase shift tube 26b, which is exactly the same in operation as the first phase shift tube 26a, with the exception that the plate load resistor 30 of first phase shift tube 26a is now replaced in the second phase shift tube 26b with a resistor 76 and a variable resistor 31 connected in series. The purpose of this arrangement is to provide a means by which the output voltages of the second phase shift tube 26b, which appear at point 77, may be adjusted for approximate equality of amplitude throughout the frequency range of interest. This adjustment is provided by variable resistor 31, which may be adjusted to compensate for inequalities in the plate and cathode loading of first phase shift tube 26a and also provides the proper plate load adjustment for second phase shift tube 26b. Resistor 76 is included in the circuit in order to allow variable resistor 31 to have a smaller total resistance and so be more easily adjusted. If desired, resistor 76 could be omitted and its resistance incorporated in variable resistor 31. In addition, if satis-

factory equality of voltage throughout the frequency range of interest can be obtained at points 75, 77, etc., it is unnecessary to have an adjustable plate load in every other phase shift tube's plate circuit, as shown by variable resistors 31, but such adjustment may be provided only if deemed necessary after the signal has passed through any convenient number of phase shift tube circuits.

These phase shift tubes constitute the all-pass phase shift network(s) A of FIG. 2. Two phase shift tubes with associated circuitry will produce one peak in the response of the entire unit, since each stage will shift the phase a maximum of 180 degrees, so that two stages are necessary to cause the point 7 of FIG. 2a to make one complete revolution around the large circular path. For this reason the first two stages of phase shift tubes of FIG. 3 are referred to as the "first pair"; succeeding similar cascaded pairs of phase shift tube stages are referred to as "intermediate pairs," and are indicated only by dotted line 42 of FIG. 3 in order to simplify the drawing. Such intermediate pairs may be visualized as a cascaded series of phase shift tube stages with each stage identical to the phase shift tube stages of the first pair, except that the adjustable plate load 31 may be used only as necessary, and where it is not used a fixed resistor 30 is used to replace resistor 76 and variable resistor 31. The "last pair" of phase shift stages is shown in FIG. 3, and is the same as the first and intermediate pairs. After the signal has traversed all of the phase shift stages, the output of the last pair of phase shift stages appears at point 79, and is connected to contact 36 of switch 35.

When the arm of switch 35 is on contact 36, the output of these all-pass phase shift networks is fed to grid 38 of isolation tube 14, and the output of tube 14 passes through resistor 15 to point 5. The original input signal applied to input terminal 12 produced a voltage at point 5, but the signal from tube 14 after passing through resistor 15 will now act to modify the voltage appearing at point 5 so as to produce a voltage at point 5 which is, in general, different from the voltage that would appear at point 5 due to the input signal alone. If we consider any given frequency in the input signal at terminal 12, it is apparent that the output of tube 14 will contain this frequency since such output is derived wholly from the input signal itself which contains this frequency. Hence, at this particular frequency, the voltage at point 5 derived from tube 14 will add vectorially to the voltage at point 5 derived from input 12. Therefore, the total voltage at point 5 at this particular frequency may be greater or smaller than the voltage that would appear at point 5 due to the input signal from terminal 12 alone. Likewise, the phase of the total voltage at point 5 may either lead or lag the phase of the voltage that would appear at point 5 due to the input signal from terminal 12 alone. If the input signal contains a multiplicity of frequencies, each component frequency voltage will be acted upon by the circuit of FIG. 3 in the manner just described for the input voltage of a particular frequency. Hence, it is evident that the device of FIG. 3 will have a transfer characteristic from input 12 to point 5 which is depicted by FIG. 1, because, with a constant input voltage at terminal 12, the vector sum of the two components of voltage at point 5 will vary with frequency because of the constantly changing phase shift with frequency in the all-pass phase shift networks A that the feedback signal from tube 14 has passed through before being combined with the input signal at point 5. Thus, the device of FIG. 3 produces the desired effect.

Certain variations in the circuit of FIG. 3 are possible. The output at terminal 13 is shown as taken from plate 17 of tube 16 through blocking capacitor 18 instead of being taken directly from point 5 via dotted connection 70. This is done in order to take advantage of the gain of tube 16, since the voltage at its plate 17 is an amplified version of the voltage at point 5 which is directly connected to grid 74 of this tube 16. Another variation would

consist of additional contacts similar to contact 73 on switch 35. Contact 73 is connected by dotted conductor 72 to circuit point 78, so that when the arm of switch 35 is on contact 73, the signal will traverse one less phase shift stage than when the arm of switch 35 is on contact 36 before said signal is fed to the grid 38 of tube 14. By providing a multiplicity of contact points on switch 35 similar to contact 73, and with each such similar contact point connected to a different circuit point similar to circuit points 79, 78, 77, 75, etc., it is possible by adjustment of switch 35 to cause the signal to pass through any desired number of phase shift stages before being fed on to tube 14. This will then provide an adjustment of the number of transmission peaks introduced by the device, as well as an adjustment of the total phase change throughout the audio frequency spectrum produced by the circuit between input terminal 12 and output terminal 13. It should be noted that the gain control 19 will also provide an adjustment of the total phase change produced by the device, but will not affect the number of transmission peaks, although it will provide an adjustment of the height of these peaks. In general, it would seem desirable to have as many pairs of phase shift stages included in the intermediate pairs at 42 as possible or economically practical. Experiments with the electronic filter of FIG. 3 have indicated that it is generally necessary to have more than eight peaks in the response vs. frequency curve if the beneficial effects of this basic method of tone quality improvement are to be achieved to any practical degree.

The foregoing discussion should now make apparent the fact that the device disclosed in FIGS. 2 and 3 will simulate substantially the action of the rigid parts of the violin, as described, or the air column in a wind instrument, etc. No attempt is made herein to simulate exactly the tonal quality of any particular orchestral instrument by the use of the subject device. That would require a selection of the proper number of intermediate pairs of phase shift circuits, and a selection of the proper values of the capacitors 28 and resistors 27 of FIG. 3, together with proper adjustment of the gain control and equalizer to approximate the variation of transmission with frequency which is characteristic of any specific orchestral instrument.

When the input signal to terminal 12 is derived from a tone generator having high frequency stability, as found in most electrical and electronic organs, it should be noted that it is necessary to use the vibrato built into the electronic organ in order to provide the necessary frequency instability to allow the production of the beats referred to, since the tone generators used in electronic organs are much too stable in frequency to allow the very phase shift vs. frequency characteristic of any device following the basic method of FIG. 1 to produce its beneficial effect. It should also be noted that the introduction of the large number of peaks in the response vs. frequency curve causes musical tones separated by as little as a semitone to have significantly different harmonic structures, and there will be considerable variety in the tonal quality of the different notes of the scale. This effect, when not overdone, is usually considered beneficial; in fact, many of the instruments of the orchestra exhibit the same changing tonal quality as they play the musical scale. Such effect is to be expected because of the action of the conventional musical instruments in altering the harmonic structure of the wave produced at the point of generation, such as the string of a violin or the mouthpiece of a trumpet, etc. This effect is one more indication of the fact that the overall action of any device following the basic method of FIG. 1 is the counterpart of the action of the body of the various orchestral instruments or of the air column of the wind instruments as applied to electric and electronic musical instruments. It is, however, possible to limit the differences in the harmonic structure of the different notes of the scale by limiting the ratio of each maximum transmission to the next adjacent minimum transmission while

retaining the desired total phase change throughout the audio range by having a sufficient number of transmission peaks in this audio range. It should be emphasized that, to produce the maximum beating effect, as described, it is advantageous to use as many transmission peaks as possible, since the total phase change will thereby increase proportionally so long as the peak to valley ratio is kept constant.

It would not be possible to use only the all-pass phase shift network(s) A of FIG. 2 as a device to produce the desirable beating effect that has been described, since such an attempt would result in the phase shifts of the various harmonics of a signal being all in the same direction, so that very little beating would result. However, the all-pass phase shift network(s) A could be used alone to produce considerable beating effect if the output were taken from a multiplicity of points instead of from a single point of the circuit. For example, the phase shift stages alone of FIG. 3 could be used in this manner if, with circuit parts B, C, D and E deleted, the input terminal 12 were to connect to grid 32 of first phase shift tube 26a, and the output terminal 13 were to be connected through suitable isolation resistors to two or more of, for example, the cathodes 34 of the phase shift tubes. Such an arrangement, however, would be difficult to adjust and control, and would, in general, produce an amplitude vs. frequency characteristic having apparently erratic maxima and minima, and a phase shift vs. frequency characteristic somewhat less desirable than that produced by the unmodified circuit of FIG. 3.

If the signal input to any device following the basic method of FIG. 1 has little or no instability in its frequency, the subject devices will produce little or no ultimate beating effect, as described. To overcome this difficulty in another manner, a vibrato may be built into the subject tone color devices. An embodiment of such a vibrato addition, suitable for use with the circuit of FIG. 3, is shown in FIG. 3a.

In FIG. 2 is also shown a symbolic representation of the effect of the circuit of FIG. 3a. The vibrato addition is added to the circuit of FIG. 3 when the moving arm of switch 35 shown in FIGS. 2 and 3 is thrown to position 37. In FIG. 2, this causes the input to B to come from the moving arm 43 of the symbolic potentiometer 44, the ends of which are connected to the input and output of all-pass phase shift network(s) A. As the vibrato addition causes the moving arm 43 of this symbolic potentiometer 44 to move from the one end to the other end, the input to B will alternately be derived principally from the input to A and the output of A. This action alternately removes and then reinserts the phase shift network(s) A in the system shown.

In FIG. 3a is shown a circuit including one tube 45 as vibrato frequency oscillator (frequency range approximately 4 to 10 cycles per second); a second tube 46 is used as a "phase splitter" to produce two voltages of equal amplitude but 180 degrees apart in phase; this phase splitter 46 is fed from the oscillator tube 45 and so produces an output of vibrato frequency. These two vibrato frequency signals 180 degrees apart in phase are then fed to the third tube 47 which is a double triode having a common plate load resistor 48 for both triodes. The two vibrato frequency signals are fed to the two grids 51 and 52 of this tube 47, one signal to each grid, via capacitors 49 and resistors 50. To these same two grids 51 and 52 are fed signals from cathodes 34 (of first phase shift tube 26a) and 34a (of last phase shift tube 26b) of FIG. 3. The signal to grid 51 comes from cathode 34 via conductor 39, and the signal to grid 52 comes from cathode 34a via conductor 40. Suitable resistive voltage dividers comprising resistors 50, 53, 54, 55 and 56 are used to equalize these two signal voltages on the two grids 51 and 52. This third tube 47 will now act as a mixer tube under the control of the vibrato frequency signals to produce in its plate circuit 57 a signal having a periodic variation in the ratio of the signal derived

from cathode 34 to the signal derived from cathode 34a. This effect is produced by the opposite changes of transconductance of the two halves of this mixer tube 47 produced by the variations in the grid voltages caused by the vibrato frequency signals. The "mixed" signal now appearing across the common plate load resistor 48 of the two triodes of this mixer tube 47 is now passed through a high-pass filter 58 to remove most of the vibrato frequency signal and its lower harmonics, and is then connected to contact 37 of the switch 35 of FIG. 3 via conductor 41, and (when the arm of the switch 35 is moved to contact point 37) is fed back to grid 38 of tube 14 in the circuit shown in FIG. 3.

The action of the three additional tubes 45, 46 and 47 may now be summarized as follows: The vibrato frequency oscillator 45, the phase splitter 46, and the mixer tube 47 result in a periodic variation in the effect of the phase shift circuits of FIG. 3 (A of FIG. 2) at a vibrato frequency rate; that is, the circuit of FIG. 3 is caused to act so that the signal appearing at the arm of switch 35 is derived mostly from the first phase shift tube cathode 34 when the vibrato oscillator 45 is producing an output of a certain polarity, and, when the vibrato oscillator 45 is producing an output of the opposite polarity, the signal appearing at the arm of switch 35 is derived mostly from cathode 34a. Since the phase shift of the entire instrument being described, from input to output (at any particular frequency), is a function of the number of phase shift stages (the "pairs" of FIG. 3) that the signal passes through before being fed back to the circuits connected to the arm of switch 35, it may be seen that the phase shift from input to output of the entire instrument will vary at the vibrato frequency rate, and the output of the instrument will then be frequency modulated, or, in common musical terminology, a vibrato has been introduced into the signal.

The use of a circuit such as shown in FIG. 3a in conjunction with the circuit of FIG. 3 is to enable the instrument to produce an output signal capable of exciting an auditory sensation of beating, as previously referred to, even when the input signal has no frequency variation whatever. Any given harmonic component of the input signal will then emerge from the output of the instrument with its frequency varying back and forth at the vibrato rate, as just described. However, since each harmonic is a different frequency, each will be affected in a different manner by the action just described. That is, the frequency variation of the different harmonics will be of varying amount, and, in general, of varying sign; some harmonics will be increasing in frequency at various rates at the same instant that other harmonics are decreasing in frequency at various rates. These harmonics will ultimately produce a pleasing auditory effect similar to that described. To produce a still greater effect of this type, it is possible to use this vibrato addition with the input signal already frequency modulated by a vibrato signal from some other source.

FIG. 4 is a block diagram of another embodiment of the basic method of FIG. 1. To obtain the Desired Output Voltage from terminals 59, an electroacoustic or electromechanical transducer 60 is coupled to an acoustic or mechanical device 61. The transducer 60 may be any of the common types such as the electrodynamic (moving conductor), electrostatic, magnetic, magnetostriction, or piezoelectric types. The acoustic or mechanical device 61 may have an almost infinite variety of forms; typical examples of acoustic devices would be the air or other gas or liquid column or cavity inside a tube or horn or other cavity of almost any conceivable shape, with or without openings to the outside air. Similar examples of mechanical devices would be rods, tubes, bells, boxes, solid resonators with or without internal cavities which may or may not be accessible from the outside, such resonators having almost any conceivable shape. These acoustic or mechanical devices 61 are designed to have a multiplicity of resonances within the audio frequency range,

such resonances being preferably not harmonically related. The effect of these resonances is "reflected" back into the electrical circuit to produce a variation in the electrical impedance of the transducer 60. If a Controlled Current as represented at 62 is passed through the circuit containing the transducer 60, the voltage appearing across the circuit at output terminals 59 may be made to exhibit as many or almost as many peaks in its responsive vs. frequency curve as there are minima of acoustic or mechanical impedance in the device 61 coupled to the transducer 60. This effect of transferring acoustic or mechanical impedances and variations of the same back into an electrical circuit is set forth very clearly in the book by F. V. Hunt, "Electroacoustics"—Chapter 2 in particular. The Controlled Current 62 (the input signal) may be controlled by controlling the source impedance from which it is derived, and/or by controlling its magnitude with respect to frequency. Network 63 is used to control and modify the overall effect of the entire device in producing response peaks and phase shifts; it could be omitted if the effect of the device were satisfactory without it. If network 63 is composed only of passive components, the power source 64 is not needed; however, if network 63 contains active components (vacuum tubes, transistors or other amplifying devices), then power source 64 will be needed to supply the required operating potentials of these active components. Although the descriptions of the diagrams showing some of the preferred embodiments of the present invention may mention the production of peaks in the response vs. frequency curve more frequently than the production of phase shift changes vs. frequency, it should be remembered that this is done only because of the convenience of visualizing the action of such devices from this standpoint; the phase shift changes which necessarily accompany these peaks in the response constitute the basic and primary reason for the use of these devices in connection with electronic or electric musical instruments.

FIG. 4a shows a possible embodiment of the block diagram of FIG. 4. The multi-resonant device is the air column 80 contained in tube 82 and cavity 81. The electroacoustic transducer is the electrodynamic earphone 83, which is tightly coupled to the air column 80 through the only opening in the tube and cavity assembly 82 and 81. The transducer 83 is connected to the active network composed of impedances 84, 85 and 86 arranged in a T configuration. This T configuration is particularly useful with transducers functioning by the action of magnetic fields, such as the magnetic, electrodynamic (moving conductor) and magnetostriction types. In the embodiment of FIG. 4a, the impedances 84 and 85 are active impedances, and impedance 86 passive. The active impedances are used in order to neutralize or partially neutralize the effect of the electrical and mechanical parameters of the transducer 83 which would otherwise tend to obscure the impedance changes of transducer 83. In particular, impedance 84 is the negative of the "blocked" impedance of the transducer 83, and impedance 85 is the negative of the impedance of the shunt portion of the equivalent electrical circuit of transducer 83, which shunt portion is representative of the reflected electrical effect of the entire moving coil assembly of transducer 83. Impedance 86 is a resistor which acts to limit the minimum values of impedance offered to the controlled current 87. If it were desirable to limit these minimum impedances more at the lower audio frequencies than at the higher frequencies, then impedance 86 could be in the form of a resistor shunted by a capacitor; if it were desirable to limit the minima of impedance more at the higher than at the lower audio frequencies, then impedance 86 could be in the form of a resistor in series with an inductance. Many variations in the impedances 84, 85 and 86 are possible, so that it is possible to satisfactorily control the impedance presented to the controlled current 87 at audio frequencies.

The general action of the device of FIG. 4a is as follows: The air column 80 will exhibit acoustic impedance variations at the opening to which transducer 83 is fastened. A minima of acoustic impedance will be presented to the transducer 83 at the lowest resonant frequency of the air column 80; as the frequency is increased, the acoustic impedance will increase until a maximum is reached, and, as the frequency is increased still more the acoustic impedance will fall again until a second minimum is reached. This process will repeat itself as the frequency is increased still further, so that successive maxima and minima of acoustic impedance will be presented to the transducer 83. Each minima of acoustic impedance will cause a maxima of electric impedance to appear at the terminals of transducer 83, and each maxima of acoustic impedance will cause a minima of electric impedance. These electrical impedance variations may, however, be rather small because of the obscuring effect of the electrical and mechanical parameters of transducer 83. Impedances 84 and 85 will act, as described, to increase these electrical impedance variations, and impedance 86 will modify them as desired. Since the impedance which is presented to the controlled current 87 has now been made to vary in the desired manner, it is obvious from the alternating current form of Ohm's Law that the voltage developed across this impedance and fed to output terminals 88 will be proportional to this impedance if the controlled current is derived from a very high impedance source. Hence as the impedance of the device goes through successive maxima and minima, the desired output voltage at terminals 88 will likewise go through successive maxima and minima, and a transfer function such as is shown in FIG. 1 is obtained, as desired. It is, of course, obvious that either or both of the active impedance elements 84 and 85 may be omitted or replaced with passive impedances if satisfactory results are obtained in this manner. The large variations that may be found in the types of air column 80 (length, diameter, etc.) and in the transducer 83 make it difficult to generalize concerning the exact characteristics of each of the impedances 84, 85 and 86; the most appropriate values must be determined in each individual case. Although transducer 83 was specified as being an electrodynamic earphone, it is obvious that any type of electro-acoustic transducer could also be used provided the other components associated with it were suitably chosen to operate in a satisfactory manner in conjunction with the various characteristics of the particular transducer used. The diameter of the air column 80 must be selected to provide a suitable load for the moving element of transducer 83; similarly, the length of air column 80 and the size of cavity 81 must be selected to provide the most suitable distribution of resonances throughout the audio frequency range. In order to conserve space, tubing 82 may be coiled as desired. The use of cavity 81 may be explained as follows: If the cavity 81 were omitted and the right hand end of tube 82 closed, the frequencies of minimum acoustic impedance presented to the transducer 83 would be proportional to the following integers: 1, 3, 5, 7, 9, 11, 13, etc. It may be seen that the number of these resonances in any given octave containing such resonances, will, in general, be more than the number of such resonances in the next lower octave. Since a signal containing all harmonics of the fundamental frequency also has more harmonics in any given octave than in the next lower octave, we see that the action of the air column tends to "fit" the signal, in that more phase undulations per octave are available in the upper octaves where the signal's harmonics are most numerous. However, it is not desirable that the action of the air column "fit" the signal exactly, even if it be at only one signal frequency. If this were to occur, then the fundamental frequency of the signal would occur at the lowest frequency of minimum acoustic impedance, the third harmonic of the signal would be at the next higher frequency of minimum

acoustic impedance, the fifth harmonic of the signal would be at the third minimum of acoustic impedance, and so on. Unless the amplitude peaks in the electrical response of the device were small, the occurrence of such a condition would produce a disproportionately large increase in the amplitude of the signal at this particular frequency. To prevent such an occurrence the cavity 81 has been used. The use of an acoustical capacity such as cavity 81 will prevent the minima of acoustic impedance from following the 1, 3, 5, etc. series given above, so that the condition would not occur where the fundamental frequency of the signal were the same as the lowest frequency of the series.

Devices of electroacoustic or electromechanical nature would possess both cost and weight advantages over the electronic filter of FIG. 3, and at the same time could be made to produce better results in that their resonances tend to "fit" the signal better than the resonances of the electronic filter of FIG. 3 could economically be made to do.

FIG. 5 is an embodiment of the present invention which is very similar to FIG. 4. Multi-resonant device 89 may be identical to 61; transducer 90 may be the same as 60; and network 91 performs the same function as 63. FIG. 5, however, instead of being fed from a high impedance current source is fed from a low impedance voltage source. The impedance undulations at the input to network 91 will cause corresponding changes in the current taken from the voltage source connected to input terminals 93. This changing current flows through resistor 92, which has a resistance value sufficiently low to not interfere greatly with the current changes produced by components 89, 90 and 91. An output voltage will therefore be produced across resistor 92 and appear at output terminals 94. This voltage will have the same undulating characteristic with respect to frequency as the output voltage of the system of FIG. 4. The system of FIG. 5 differs from that of FIG. 4, however, in that it is now possible to adjust the source impedance of the controlled input voltage to terminals 93 and the value of resistor 92, together with the components in network 91 so that all the electrical parameters together reflect an impedance into the mechano-acoustic system composed of the moving elements of transducer 90 and multi-resonant device 89 of such a magnitude that the multi-resonant device 89 is connected to its characteristic acoustic or mechanical impedance at the point where the transducer 90 is coupled to it. This arrangement has the advantage that a minimum of what is variously called "reverberation," "hangover," or "ringing" is transmitted to the output terminals 94 after the removal of a voltage applied to input terminals 93. The desirability of a device following FIG. 5 compared to that following FIG. 4 must be decided by the preference of the listener.

A possible embodiment of FIG. 5 is shown in FIG. 5a. An air column 95 is formed by the air in tubes 97 and 96, which two tubes have different internal diameters, and are securely joined together, with the right-hand end of tube 96 closed, and with the left-hand end of tube 97 tightly coupled to electrostatic transducer 98 as shown. The electrical connections to transducer 98 are connected to a "pi" network composed to impedances 99, 100 and 101. Such a pi network is useful with transducers depending on the electric field for their operation, such as the piezoelectric and electrostatic types. In the embodiment of FIG. 5a, the impedances 99 and 100 are active impedances, and impedance 101 passive. The active impedances are used in order to neutralize or partially neutralize the effects of the electrical and mechanical parameters of the transducer 98 which would otherwise tend to obscure the impedance changes of transducer 98. In particular, impedance 99 is the negative of the static electrical capacitance of electrostatic transducer 98, and impedance 100 is the negative of the impedance of the series portion of the equivalent electrical circuit of transducer 98, which

series portion is principally representative of the reflected electrical effect of the mechanical constants of the diaphragm of transducer 98. Impedance 101 is a resistor which acts to limit the maximum values of impedance inserted in the circuit by transducer 98 acting with active impedances 99 and 100. Many variations in the impedances 99, 100 and 101 are possible, so that it is possible to satisfactorily control the impedance inserted in the circuit throughout the audio frequency range. In general, the impedances 99, 100 and 101 have a function analogous to that of impedances 84, 85 and 86 of FIG. 4a, so that the same or equivalent comments apply to both sets of impedances.

The general action of the embodiment of FIG. 5a is analogous to that of FIG. 4a; however, in FIG. 5a the maxima of acoustic impedance will be reflected into the electrical circuit as maxima of electrical impedance, and vice versa. Since the impedance which has been introduced into the circuit by air column 95, electrostatic transducer 98, and impedances 99, 100 and 101 has been made, by suitable adjustment of these parameters, to exhibit a multiplicity of successive maxima and minima throughout the audio range, it is obvious that the current passing through resistor 103, and hence the output voltage appearing at terminals 104 will likewise exhibit a similar multiplicity of maxima and minima. With respect to the selection of air column 95, tubing 97 and transducer 98, the previous comments concerning the corresponding components of FIG. 4a are generally applicable. Tubing 96, having a different internal diameter than tubing 97, is used to accomplish the same purpose as is cavity 81 of FIG. 4a. For greatest efficiency, the input voltage source connected to terminals 102 should have as low an internal impedance as possible, so that the resistor 103 may be as large as possible in order to produce the maximum output signal at terminals 104. There will, however, in any given setup embodying the various components shown in FIG. 5a, be some one particular value of resistor 103 which will cause a minimum of reverberation as discussed in connection with FIG. 5.

FIG. 6 shows another block diagram embodiment of the basic method of FIG. 1. The signal is applied to input terminals 105 which are directly connected to electro-acoustic or electromechanical transducer 106, which is coupled to multi-resonant acoustic or mechanical device 107. Also coupled to resonant device 107 is another electroacoustic or electromechanical transducer 108, the electrical output of which is connected to output terminals 109. Transducers 106 and 108 and resonant device 107 may be the same as any of the corresponding devices mentioned in connection with FIG. 4. The mode of operation embodied in the block diagram of FIG. 6 does not depend upon the principle of reflected impedances, but is a type of operation similar to the action of the rigid parts of a violin (for example) or the open air column of a wind instrument in that the resonances are introduced by a transmission of the signal through the multi-resonant device 107 from input transducer 106 to output transducer 108.

A specific embodiment of the principle of FIG. 6 is shown in FIG. 6a, which illustrates one possible form such a device might take in which it is desired to imitate the resonance pattern of a hollow-bodied string instrument such as a violin. Signal input to terminals 110 is applied to coil 111 which is wound on nickel rod 112. Coil 111 and rod 112 comprise a magnetostrictive transducer which is tightly coupled to wooden shell 113. Microphone 114 picks up the vibrations in shell 113 and produces an output voltage which appears at terminals 116. As the signal input frequency is varied, the output from terminals 116 will exhibit various peaks in its response curve, depending on the various resonances of shell 113. Variations in the placement of nickel rod 112 and microphone 114 will cause considerable variety in the response pattern that is produced. Sound proof box 115 is used to prevent

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sound from being radiated directly from the shell 113, and also to prevent unwanted sound from being picked up by microphone 114. Frequency discrimination produced by either input or output transducer may be compensated for by any convenient means, which means are well known to those skilled in the art.

FIG. 7 is another block diagram embodiment of the basic method of FIG. 1. The signal is applied to input terminals 117 which are directly connected to transducer 118, which is coupled to multi-resonant device 119. These components may be of the same type as those described in connection with FIG. 6. In FIG. 7, however, resonant device 119 is allowed to radiate acoustic energy 120 directly to the surrounding air. The signal applied to input terminals 117 must have sufficient power capability to produce a useful acoustic signal. Since multi-resonant device 119 will radiate most efficiently at its resonant frequencies, an undulating response vs. frequency will be obtained as desired. FIG. 6a will serve to illustrate a specific embodiment of FIG. 7 if sound-proof box 115, microphone 114, and output terminals 116 are all omitted, so that resonant shell 113 may be allowed to radiate sound directly to the atmosphere. It is obvious that the method of FIG. 7 most closely simulates the effect of an actual instrument of the orchestra, the only difference being that the vibrations are transmitted to the multi-resonant device by the use of a transducer, whereas with an orchestral instrument the vibrations are a direct result of the physical effort of the musician.

FIG. 8 illustrates the use of lumped electrical constants to satisfy the basic method of FIG. 1. In this embodiment, a controlled current 121 is applied to terminals 122, which terminals serve both as current input terminals and voltage output terminals. Current 121 may flow through a multiplicity of series resonant circuits all connected in parallel. The first, which is composed of inductance 123, resistor 124 and capacitor 125, is tuned to some particular frequency; the second, which is composed of inductance 126, resistor 127 and capacitor 128, will be tuned to a different frequency; other similar circuits symbolized by dashed lines 129 will each be tuned to its own particular resonant frequency; and the final series circuit, which is composed of inductance 130, resistor 131 and capacitor 132, will be tuned to the last resonant frequency that we desire to include in this embodiment. Although resistors 124, 127 and 131 may be actual physical devices, it will more frequently be found that it is desirable to reduce the resistance of each series circuit to a minimum, so that these resistors will then be symbolic of the total effective residual resistance of each circuit. As is well known to those skilled in the art, in accordance with Foster's Reactance Theorem (Bell Sys. Tech. Journ., April 1924), the voltage appearing across the terminals 122 of FIG. 8, when fed from a suitable current source such as a constant current source, will exhibit characteristics such as illustrated in FIG. 1. It is possible to arrange the components of FIG. 8 in various ways to produce the same or equivalent results; several such rearrangements are shown in Chap. V of Ernest A. Guillemin's book "Communication Networks," vol. II. Still other modifications are possible, such as the use of one or more resonant circuits in the circuitry of each stage of successive stages of vacuum tube amplification. Each of such cascaded stages need not necessarily contain inductive elements, but may be of the resistance-capacitance feedback type, such as the parallel-T or bridged-T frequency-selective feedback amplifier or some modification or equivalent thereof.

All of the various embodiments of the present invention which have no internal vibrato (such as the vibrato addition of FIG. 3a supplies to the embodiment of FIG. 3) need some type of frequency instability present on the input signal if the effectiveness of the device is to be realized. However, if no such frequency instability is present or if it is desired to incorporate an internal vi-

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brato in any of the embodiments of the present invention, a suitable vibrato addition can generally be added to the various embodiments. Such a vibrato addition would consist of a device to periodically vary the resonant frequencies of the acoustic or mechanical device coupled to the transducer(s) at a vibrato frequency rate. For example, a vibrato addition could be added to the embodiment of FIG. 4a by the use of additional transducers, as shown in FIG. 4b, designed to operate in the vibrato frequency range (about 4 to 10 cycles per second). Transducer 133 is connected by wires 135 to a suitable source of vibrato-frequency voltage, and transducer 134 is connected by wires 136 to the same source of voltage, but in such manner that as the diaphragm of transducer 133 is driven to the left (in FIG. 4b), the diaphragm of transducer 134 is driven upward, and vice versa. Hence, if the transducers 133 and 134 have similar characteristics, the pressure in air column 80 will not be appreciably altered by the combined motions of their diaphragms. However, many of the resonant frequencies of air column 80 will be altered by the action of transducers 133 and 134 at the vibrato frequency rate, thus producing a vibrato-frequency variation of the impedance reflected into the electrical circuits of transducer 83, as desired. These additional transducers and associated circuitry would be designed to present a high acoustic impedance to normal audio frequencies, and would therefore not greatly interfere with the resonance pattern at any particular instant, even though they would be varying this pattern from instant to instant. Other devices to produce the same or equivalent results could readily be devised by those skilled in the art for all embodiments of the present invention.

It is, of course, to be understood that wherever thermionic vacuum tubes are mentioned in this disclosure, the same or equivalent results could be achieved by the use of transistors or other solid-state amplifying devices. I consider the alternate use of such devices to be entirely within the scope of the present invention.

The term feedback or coupling, as used in the claims, will be understood to include not only electronic feedback but also feedback or coupling through mechanical means as well, in accordance with this disclosure.

Since the present invention will probably find its greatest application to electric or electronic organs, it might be well to describe several ways in which it might be applied to such organs. The signal which normally went to the input of the power amplifier of the organ could be fed instead to the input of one of the embodiments of the present invention. The output of this embodiment could then be fed to the input of the power amplifier of the organ. However, it might be desirable to apply the present invention to only one manual of the organ at a time; in this case the output signal of the desired manual, after passing through all of the tone filters and couplers connected with that manual, would be fed to the input of an embodiment of this invention, the output of which would be fed to the mixer or to the separate power amplifier which might be associated with that particular manual. Again, it might be desirable to have one embodiment of this invention for each manual of the organ, with each of the various embodiments having different resonance patterns. Other methods of applying this invention to electrical organs or other electronic musical instruments will be readily apparent to those skilled in the art.

Although the present invention has been disclosed in connection with certain preferred embodiments thereof, it will be apparent to those skilled in the art that many modifications and variations thereof may be made without departing from the fundamental principles of the invention. I therefore desire by the following claims to include within the scope of my invention all such variations and modifications by which substantially the results

of the invention may be obtained by the use of substantially the same or equivalent means.

This is a divisional application of United States application Serial No. 537,134, filed September 28, 1955, for "Device for Altering Tone Quality in Electronic Musical Instrument or the Like."

I claim:

1. A device for producing a modified vibrato in an electronic musical instrument or the like comprising an input circuit, an output circuit, a multiresonant acoustic device, and transducer means including at least one transducer coupling said multiresonant device to said input and output circuits to produce more than eight peaks in the transfer response versus frequency of the signals in said output circuit with respect to the signals in said input circuit.

2. A device according to claim 1, wherein the multiresonant acoustic means propagates sound waves.

3. The device according to claim 1 in which the said input circuit has at least one input terminal to which signals having a vibrato frequency characteristic are applied, and in which the said output circuit has at least one output terminal at which a modified phase shifted signal is produced, and means coupled to said at least one output terminal to provide an audible output having the desired phase shift changes.

4. The device according to claim 1 in which said transducer means in combination with said multiresonant device produces an effective electrical impedance and phase angle which varies with frequency.

5. The device according to claim 4 in which a voltage is produced across the effective impedance of said transducer means and multiresonant device in combination in response to a controlled signal current in said input circuit, said voltage being applied in said output circuit to produce an output signal having the desired multiplicity of peaks in its response versus frequency.

6. The device according to claim 5 in which said multiresonant device is an acoustic pipe-like structure.

7. The device according to claim 4 in which the effective impedance of said transducer means and multiresonant device in combination modifies the current flow produced by a controlled signal voltage in said input circuit, said current acting in said output circuit to produce an output signal having the desired multiplicity of peaks in its response versus frequency.

8. The device according to claim 7 in which said multiresonant device is an acoustic pipe-like structure.

9. The device according to claim 1 in which the transducer means coupling said multiresonant device includes a first transducer coupled to said input circuit and a second transducer coupled to said output circuit.

10. The device according to claim 9 in which said multiresonant device is a hollow vibratory body.

11. The device according to claim 9 in which said multiresonant device is an acoustic structure.

12. Apparatus for producing a modified vibrato in an electronic musical instrument or the like comprising input terminals, output terminals, a multiresonant acoustic device, and transducer means including at least one transducer coupling said multiresonant device to said input and output terminals to produce more than eight peaks in the response versus frequency characteristics of the apparatus.

13. The device according to claim 12 in which signals having a vibrato frequency characteristic are applied to the said input terminals, and in which a modified phase shifted signal is produced at the said output terminals, and means coupled to said output terminals to provide an audible output having the desired phase shift changes.

14. The device according to claim 12 in which said transducer means in combination with said multiresonant device produces an effective electrical impedance and phase angle which varies with frequency.

15. The device according to claim 14 in which a voltage is produced across the effective impedance of said transducer means and multiresonant device in response to a controlled signal current applied to said input terminals, said voltage being coupled to said output terminals to produce an output signal having the desired multiplicity of peaks in its response versus frequency.

16. The device according to claim 15 in which said multiresonant device is an acoustic pipe-like structure.

17. The device according to claim 14 in which said transducer means and multiresonant device modifies the current flow produced by a controlled signal voltage applied to said input terminals, said current flow producing the desired modified version of the input signal voltage across said output terminals.

18. The device according to claim 17 in which said multiresonant device is an acoustic pipe-like structure.

19. The device according to claim 12 in which the transducer means coupling said multiresonant device includes a first transducer coupled to said input terminals, and a second transducer coupled to said output terminals.

20. The device according to claim 19 in which said multiresonant device is a hollow vibratory body.

21. The device according to claim 19 in which said multiresonant device is an acoustic structure.

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